7/17/19 F. Kabat Planning Board Letter

List of Exhibits

Exhibit A –SRF Associates' Trip Generation/Crash Analysis Letter

Exhibit B—Letter from Jim Redmond to Planning Board, dated November 20, 2018. Planning Board Meeting Minutes, November 7, 2018, p. 17 and June 5, 2019, P. 7.

Exhibit C— County Road 28 at Shortsville Road Intersection Improvement Draft Design Report

Exhibit D—North Country Ecological Services Wetlands Delineation Report

Exhibit E—Foundation Design Geotechnical Study

Exhibit F— New York State Stormwater Design Manual, Chapter 2

Exhibit G— "Contributions of Heavy Metals from Material Exposures to Stormwater," Pitt, R. and Ogburn, O. University of Alabama (2013).

Exhibit H—"Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review" Eisler, Ronald. U.S. Fish and Wildlife Contaminant Hazard Reviews, Report 26. Biological Report 10. April 1993.

Exhibit I— September 12, 2018 Ontario County Planning Board Draft Meeting Minutes

Exhibit J—April 17, 2019 and May 15th 2019 Planning Board Meeting Minutes

Exhibit K— DRS Solar Panel Toxicity Report

Exhibit L—"If Solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste?" Shellenberger, Michael. Forbes, May 23, 2018.

Exhibit M—"Long-term leaching of photovoltaic modules," Nover, Jessica, et al. Japanese Journal of Applied Physics, 56 08MDO2 (2017).

Exhibit N— DRS Solar Decommissioning Plan

Exhibit O—"Innovation is Making Solar Panels Harder to Recycle," McMahon, Jeffery. Forbes, Sept. 4, 2018.

EXHIBIT A

SRF ASSOCIATES
www.srfa.net
Transportation Planning / Engineering / Design

3495 Winton Place
Building E, Suite 110
Rochester, NY 14623

phone 585.272.4660

May 31, 2019

Town of Farmington
1000 County Road 8
Farmington, New York 14425
Attn: Mr. Peter Ingalsbe

RE: Solar Farm Development, Fox & Yellow Mills Road, Town of Farmington, NY
Trip Generation Letter/Intersection Crash Analysis Letter

Dear Mr. Ingalsbe:

The purpose of this Technical Letter is to provide a trip generation assessment and crash analysis for the proposed Solar Farm Development in the Town of Farmington, NY, as outlined in the attached site materials. This letter details projected trip generation volume estimates, existing roadway conditions, crash history, and discusses the thresholds for completing a Traffic Impact Study (TIS). The following outlines the results of the assessment.

EXISTING HIGHWAY SYSTEM

A. Existing Traffic Volume Data

Figure 2 illustrates the lane geometry at the study intersection and the Average Daily Traffic (ADT) volumes on the study roadways. The following information outlined in **Table I** provides a description of the existing roadway network within the project study area.

TABLE I: EXISTING HIGHWAY SYSTEM

ROADWAY	ROUTE[1]	FUNC. CLASS[2]	JURIS.[3]	SPEED LIMIT[4]	# OF TRAVEL LANES[5]	TRAVEL PATTERN/ DIRECTION	EST. AADT[6]	AADT SOURCE[7]
Fox Road	-	Local	OCDPW	Not Posted	2	Two-way/ East-West	1,517	OCDPW (2019)
Yellow Mills Road	-	Local	OCDPW	Not Posted	2	Two-way/ North-South	933	OCDPW (2019)

Notes:
1. "NYS Rte" = New York State Route
2. State Functional Classification of Roadway: All are Rural.
3. Jurisdiction: "OCDPW" = Ontario County Department of Public Works.
4. Posted or Statewide Limit in Miles per Hour (MPH).
5. Excludes turning/auxiliary lanes developed at intersections.
6. Estimated Annual Average Daily Traffic (AADT) in Vehicles per Day (vpd).
7. Source (Year). Obtained volumes represent the most recent available data.

Detailed ADT counts collected along both Fox Road and Yellow Mills Road on April 6, 2019 were provided by OCDPW. Based upon these volumes, the peak hours for the intersection were determined to be 7:00-8:00AM and 4:00-5:00PM. The existing peak hour volumes are shown in **Figure 3**.

B. Existing Crash Investigation

A crash investigation was completed to assess the safety history at the existing study intersection of Fox Road and Yellow Mills Road. Crash data was compiled during the five (5) year period from January 2014 through April 2019. This data was provided by the Ontario County Department of Public Works (OCDPW).

The purpose of this crash analysis is to identify safety issues by studying and quantifying crashes at the study intersections and identifying abnormal patterns and clusters. A crash cluster is defined as an abnormal occurrence of similar crash types occurring at approximately the same location or involving the same geometric features. The severity of the crashes should also be considered. A history of crashes is an indication that further analysis is required to determine the cause(s) of the crash(es) and to identify what actions, if any, could be taken to mitigate the crashes.

A total of 7 crashes were documented at the study intersection during the five-year investigation period. The severity of the documented crashes is as follows:

- 3 – Reportable – Injury
- 3 – Reportable – Non-Injury
- 1 – Non-Reportable/Unknown

Reportable (non-injury, injury, and fatal injury) type crashes are defined as damage to one person's property in the amount of $1,001 or more. The Non-Reportable type crashes result in property damage of $1,000 or less.

Crash rates were computed for the project study intersection and compared with the NYSDOT average accident rates for similar intersections, as summarized in the following table. Intersection rates are listed as accidents per million entering vehicles (Acc/MEV).

TABLE II: INTERSECTION CRASH RATES

INTERSECTION	NUMBER OF CRASHES	ACTUAL PROJECT RATE	STATEWIDE AVERAGE RATE
Fox Road/Yellow Mills Road	7	1.52	0.15

As shown in **Table II**, the intersection had a crash rate over ten times greater than the statewide average. The accident types that occurred over the investigation period were right angle (3 – northbound, 2 – southbound), left turn (1 – southbound), and other (1 – northbound). It is noted that all crashes occurred in the northbound and southbound directions. Upon further investigation there is a pattern of northbound and southbound drivers failing to yield the right of way to eastbound and westbound drivers. However, the number of collisions occurring during the five-year investigation period does not warrant corrective action. STOP Ahead signs (MUTCD W3-1) are located along Yellow Mills Road approximately 825' in advance of both the northbound and southbound stop signs. Additionally, Intersection Warning signs with 45 MPH advisory speed plaques are located along Fox

Road in both the eastbound and westbound directions approximately 825' in advance of the Yellow Mills Road intersection. If the number and/or severity of collisions increases, OCDPW may consider additional warning measures.

The solar farm site should not have any equipment or plantings within the sight lines of the Fox Road/Yellow Mills Road intersection.

PROPOSED DEVELOPMENT

The proposed project will construct a 35-acre solar panel facility. Access is provided via a new full access driveway along Fox Road about 835' west of Yellow Mills Road.

Trip generation for this site was developed based upon its expected operation and maintenance plans. The Solar Facility will operate 7 days per week, generating electricity during the daylight hours. Preventative maintenance activities will occur during normal working hours generally twice per year with the occasional need to conduct corrective maintenance to certain equipment or facilities during non-scheduled or weekend hours. **Table III** summarizes the volume of projected site trips during the weekday AM and PM peak hours.

TABLE III: SITE GENERATED TRIPS

DESCRIPTION	SIZE/ UNITS	AM PEAK HOUR		PM PEAK HOUR	
		ENTER	EXIT	ENTER	EXIT
Solar Panel Facility	35 acres	1	0	0	1

The trip generation above assumes that the maintenance crew will be traveling in a single maintenance vehicle entering the site during the AM Peak (7:00-8:00AM) and exiting during the PM Peak (4:00-5:00PM). This trip generation is *only* projected for the two maintenance days per year that is anticipated for the proposed project.

THRESHOLDS FOR THE REQUIREMENT OF A TRAFFIC IMPACT STUDY

Reviewing agencies, including the New York State Department of Transportation (NYSDOT), use a guideline in determining whether a project warrants the preparation of a TIS. The applicable guideline is that if a proposed project is projected to add 100 site generated vehicles per hour (vph) on any one intersection approach, then that intersection should be studied for potential traffic impacts. The guideline was developed as a tool to identify locations where the magnitude of traffic generated has the potential to impact operations at off-site intersections and screen locations from requiring detailed analysis as they are unlikely to result in the need for mitigation.

Given that the proposed project is anticipated to generate an increase of one (1) vph or fewer entering and exiting the project site during the peak hours of study for any one approach, two times per year, the adjacent intersections and surrounding roadway network are very unlikely to experience any significant adverse traffic impacts and will not warrant a TIS.

CONCLUSIONS & RECOMMENDATIONS

Given the low volume of projected site generated traffic one (1) VPH or fewer entering and exiting the project site during the peak hours of study for any one approach) and the low ADT volumes of the existing roadways, it is our firm's professional opinion that the proposed project will not have any potentially significant adverse impact on traffic operations within the greater study area. The solar farm site should not have any equipment or plantings within the sight lines of the Fox Road/Yellow Mills Road intersection. No further study is warranted or recommended.

If you have any questions or require additional information, please do not hesitate to contact our office.

Very truly yours,
SRF Associates, D.P.C.

Amy C. Dake

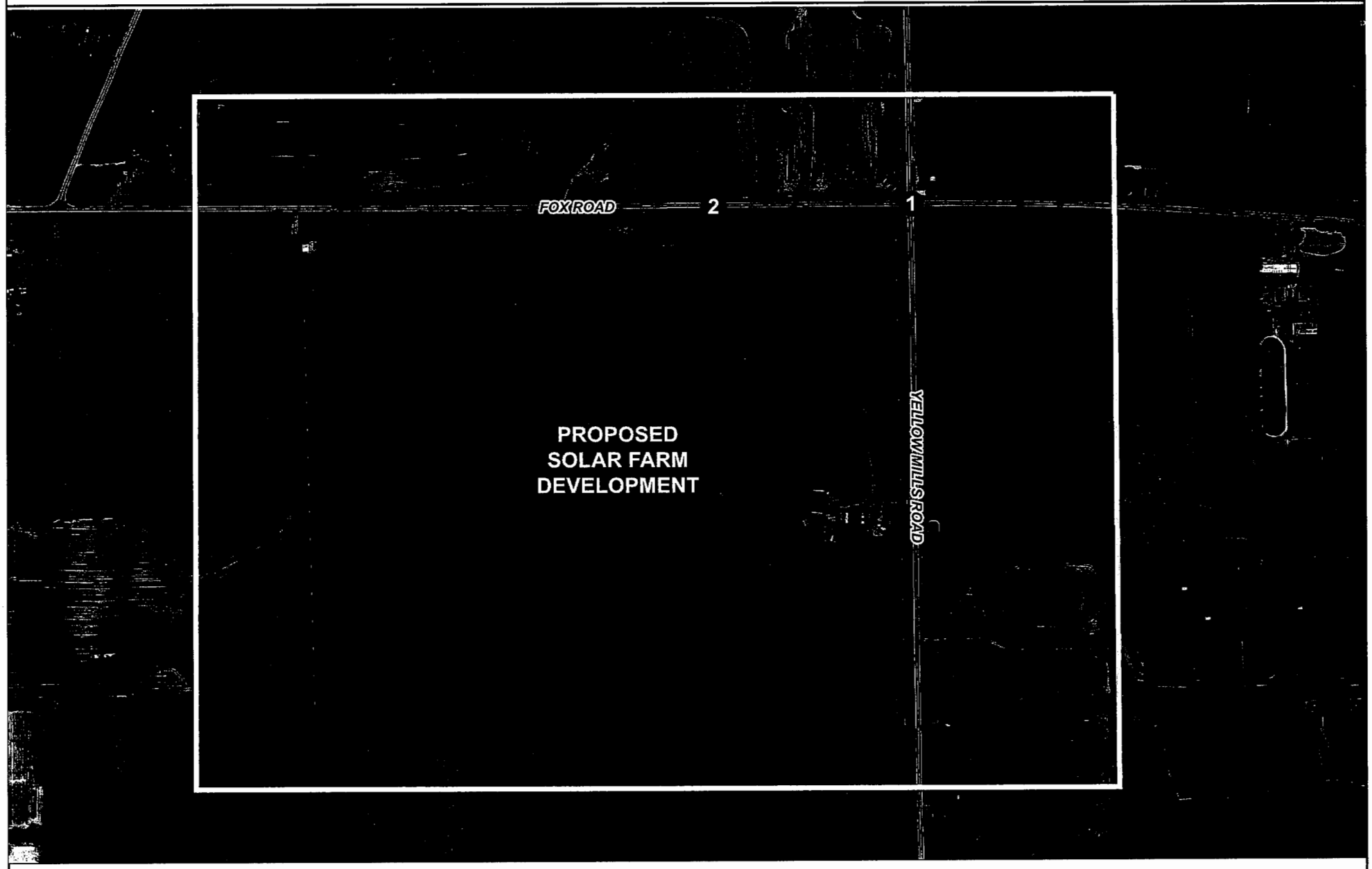
Amy C. Dake P.E., PTOE
Senior Managing Traffic Engineer

Attachments: Figures
Overall Site Plan
Trip Generation Estimates
Crash History Analysis

AD/pv

S:\Projects\2019\39036 Farmington Solar Farm\Report\Farmington Solar Farm - Traffic Analysis Letter.docx

FIGURE 1 - SITE LOCATION AND STUDY AREA



Study Intersection
Proposed Intersection
Site Location
Study Area

PROPOSED SOLAR FARM DEVELOPMENT

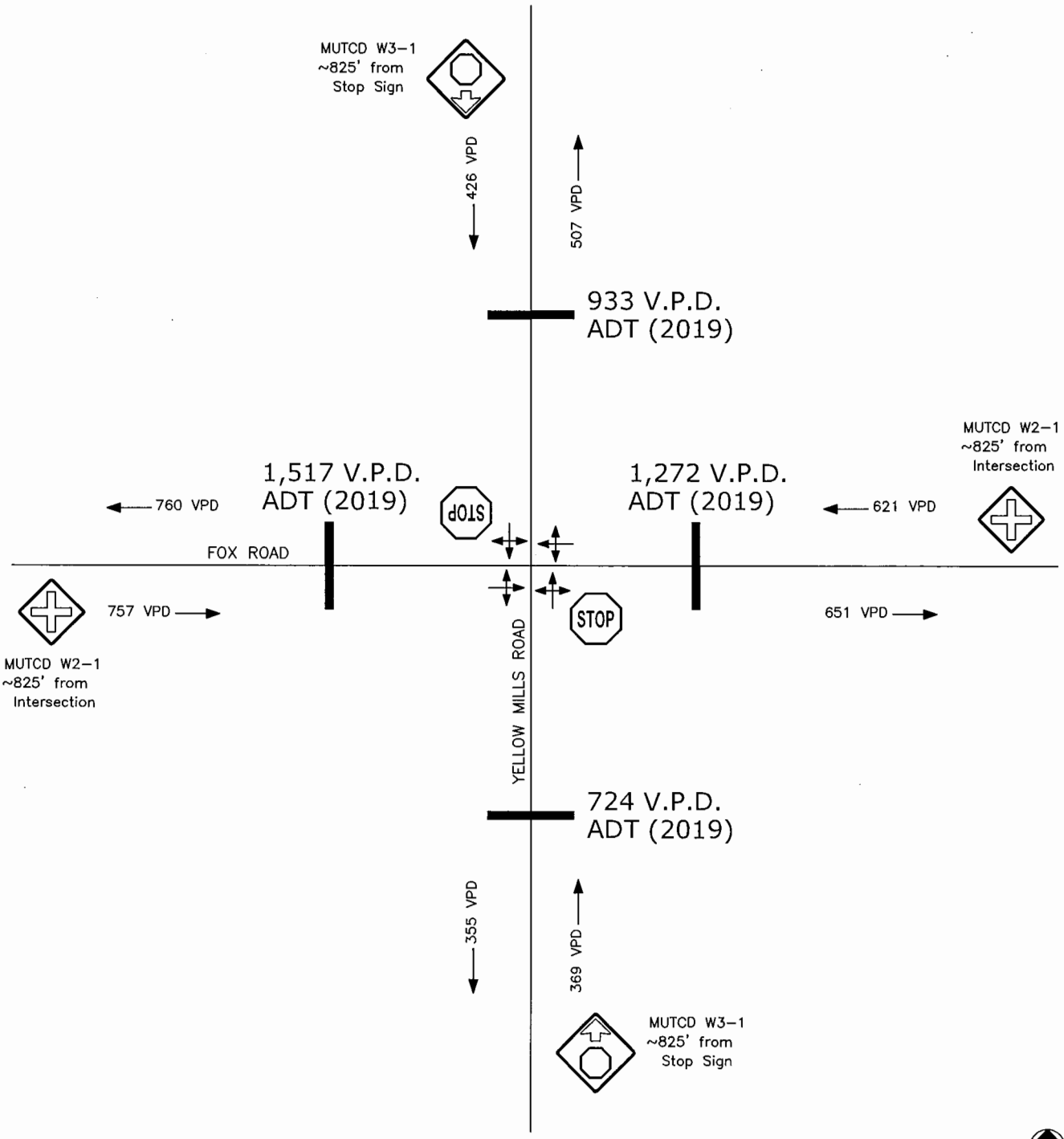
TOWN OF FARMINGTON, NY

0 300 600 1200
Feet

N

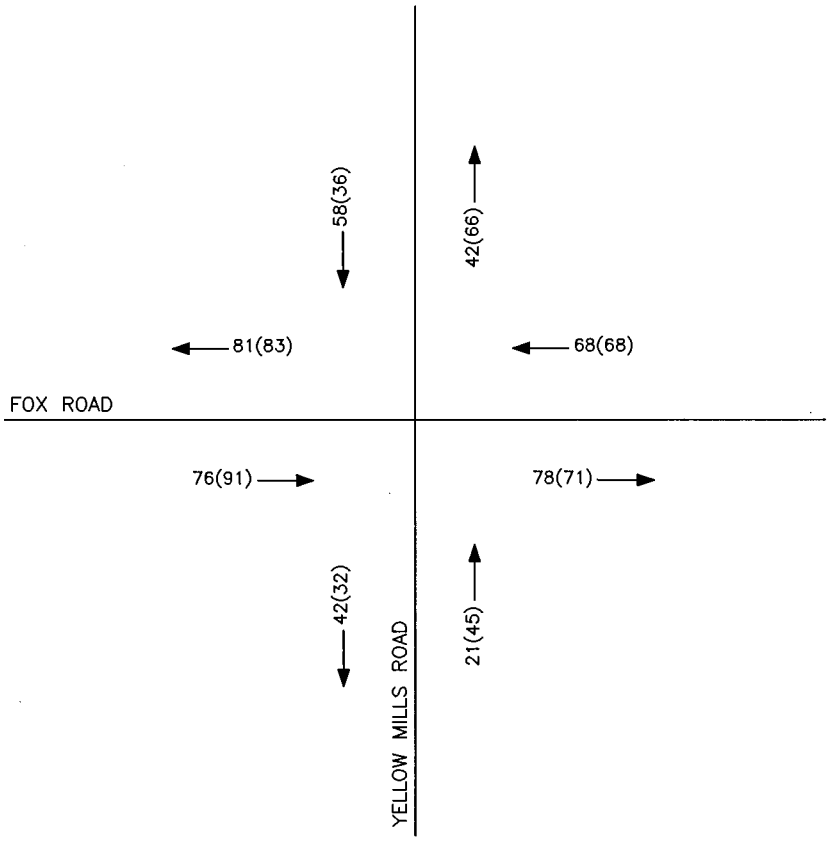
SRF ASSOCIATES
www.srfa.net
Transportation Planning / Engineering / Design

Notes:
1. All counts provided by Ontario County Department of Public Works (OCDPW).
2. V.P.D. = Vehicles per Day



N
NOT TO SCALE

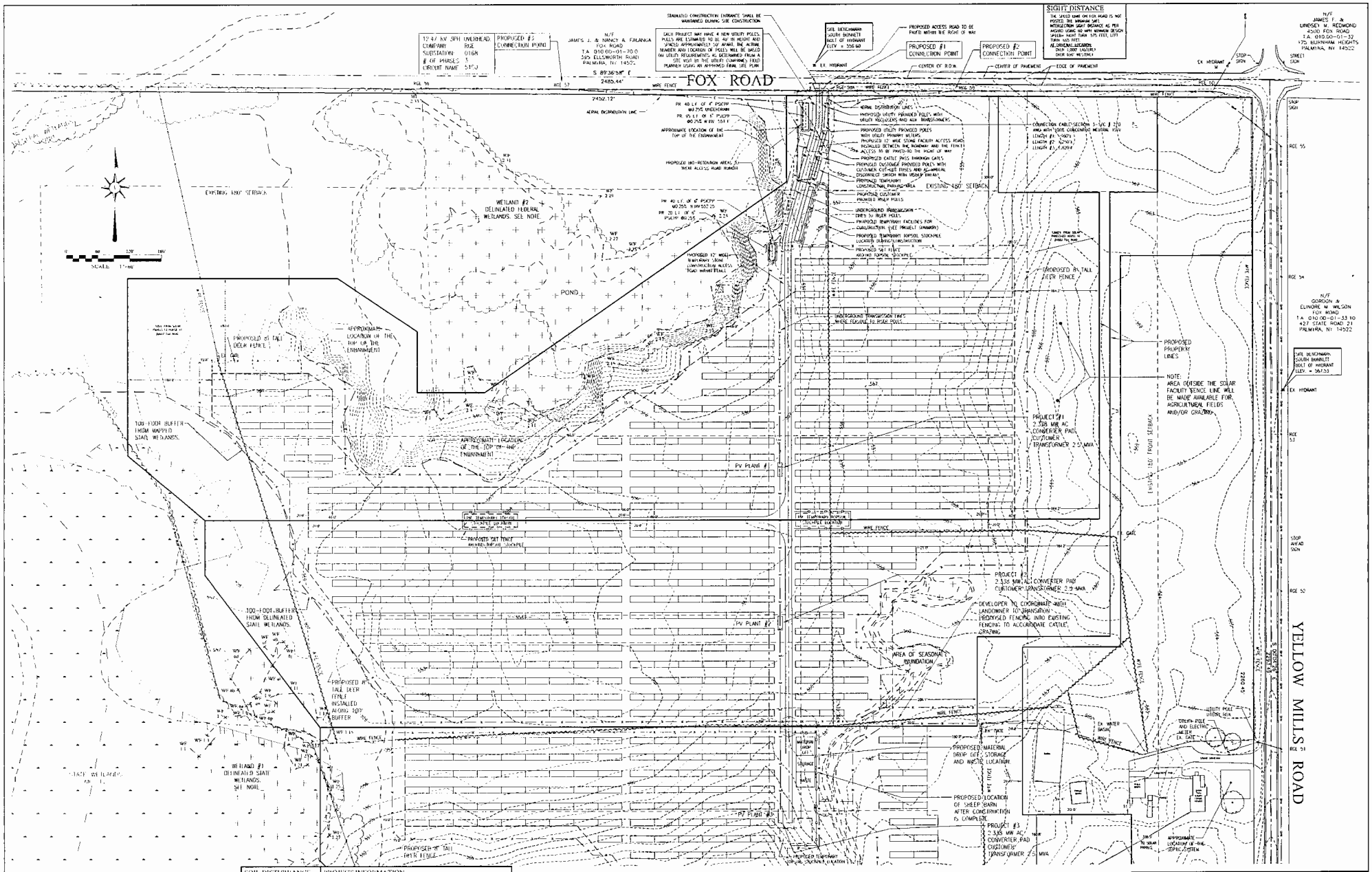
KEY	FIGURE 2	SRF ASSOCIATES
	LANE GEOMETRY & AVERAGE DAILY TRAFFIC	Transportation Planning / Engineering / Design www.srfa.net / (585) 272-4660
PROJECT NO: 39036	PROPOSED SOLAR FARM DEVELOPMENT TOWN OF FARMINGTON, N.Y.	



AM PEAK: 7:00–8:00AM
PM PEAK: 4:00–5:00PM

N
NOT TO SCALE

KEY	FIGURE 3	SRF ASSOCIATES
00(00) = AM(PM)	PEAK HOUR VOLUMES 2019 EXISTING CONDITIONS	Transportation Planning / Engineering / Design www.srfa.net / (585) 272-4660
PROJECT NO: 39036	PROPOSED SOLAR FARM DEVELOPMENT TOWN OF FARMINGTON, N.Y.	



SOIL DISTURBANCE

COMPONENT	SQ. FT.
WALK PADS	1,375
FENCE POSTS	175
DARK WOOD	35,175
TEMP. LOW DRIVES	2,042
TEMP. LOW FACILITY	400
MATERIAL STORAGE	5,000
INVERTER PADS	315
TEMP. LOW GRAVEL PADS	1,500
DEL. RETAINING AREA	5,475
TOTAL DISTURBANCE	44,000

PROJECT INFORMATION

PV PLANT	1	2	3	
NUMBER OF RACKS	250	250	250	
SOLAR PANELS PER RACK	28	28	28	
NUMBER OF SOLAR PANELS	7,000	7,000	7,000	21,000
AREA OF S.E.C. EQUIPMENT	2,142 AC	2,142 AC	2,142 AC	6,426 AC
AREA OF TEMP. DRIVE	0.226 AC	0.114 AC	0.050 AC	0.390 AC
AREA OF PERMANENT DRIVE	0.096 AC	0.096 AC	0.000 AC	0.192 AC
AREA OF TEMP. FACILITIES	0.000 AC	0.000 AC	0.478 AC	0.478 AC
LOT AREA	21.999 AC	15.275 AC	25.999 AC	63.273 AC
PERCENT COVERAGE	15.6%	22.1%	12.6%	15.5%

THE SOLAR PANELS ARE ATTACHED TO RACKS, EACH ROW IS 49.4' LONG, 19.7'10" WIDE AND ARE 20' ROW SPACES. THERE WILL BE 10' CLEAR ZONE BETWEEN EACH ROW (4 ROWS).

WETLAND DELINEATION

1. PORTIONS OF THE WETLANDS DEPICTED ON THIS MAP WERE DELINEATED BY NORTH COUNTRY ECOLOGICAL SERVICES, INC. ON APRIL 10, 2018 (25 WEST MAIN STREET, CLARKSVILLE, NY 12041)
2. THE MAPPED BOUNDARY OF THE ABOVE STATE WETLANDS WERE LOCATED BASED ON THE DRAFT MAPS PROVIDED BY THE NYSDEC ENVIRONMENTAL RESOURCE MAPPER.
3. THE MAPPED BOUNDARY OF THE FEDERAL WETLANDS WERE LOCATED BASED ON THE DRAFT MAPS PROVIDED BY THE U.S. FISH AND WILDLIFE NATIONAL WETLANDS INVENTORY MAPPER.

MAPS OF REFERENCE

1. MAP OWNERS: JAMES J. & NANCY A. FALANGA ESTATE BY MICHAEL JOS. ITS DATED JULY 1989 AND FILED IN THE ONTARIO COUNTY CLERK'S OFFICE AS MAP NUMBER 17679

NOTICE OF PROJECT NEAR FARM OPERATIONS

IT IS THE POLICY OF THE TOWN OF FARMINGTON TO CONSERVE, PROTECT AND ENCOURAGE THE DEVELOPMENT AND IMPROVEMENT OF AGRICULTURAL LAND FOR THE PRODUCTION OF FOOD AND OTHER PRODUCTS, AND ALSO FOR ITS NATURAL ECOLOGICAL VALUE. THIS NOTICE IS TO INFORM THE PROSPECTIVE LANDOWNER THAT THE PROPERTY THEY ARE MOVING TO ADJACENT TO FARMLANDS, WHICHEVER MAY FOR A VARIETY OF FARM OPERATIONS. PLEASE BE PREPARED TO ACCEPT THE INCONVENIENCE AND ACCOMMODATIONS THAT MAY BE NECESSARY DURING THE NORMAL COURSE OF FARMING OPERATIONS. FARMING OPERATIONS MAY PRODUCE NOISE, ODOR, DUST, AND VIBRATION AS A NORMAL PART OF THE FARMING OPERATION. THE FARMER MAY ALSO BE PERFORMING FARM OPERATIONS AT ANY TIME OF THE DAY OR NIGHT. IF YOU HAVE ANY QUESTIONS, PLEASE CONTACT THE TOWN OF FARMINGTON OFFICE AT (585) 924-9848.

SITE DEVELOPMENT STATISTICS

ZONING: A (AGRICULTURE DISTRICT)
TAX ACCOUNT NO.: 010.00-01-03.2 (1)
CURRENT ADDRESS: 4466 YELLOW MILLS ROAD
PARCEL AREA: 125.42 ACRES (TO ROW)

LANDOWNER OWNER:
WOODER & CHRISTA SMITH
4466 FOX ROAD
PALMYRA, NY 14522

DEVELOPER:
DELAWARE RIVER SOLAR, LLC
CHRISTOPHER DONTANES
1 GRAVINE PLACE
HOLLEY, NY 14380
(585) 548-6495

A-RC AGRICULTURAL DISTRICT SETBACK REQUIREMENTS:
FRONT 150'
SIDE 50'
REAR 50'

LOT REQUIREMENTS:
WIDTH: 300'
DEPTH: 250'
AREA: 80,000 SQ.FT.

TOWN CODE 185-40.3.6
AREA, BULK, AND DENSITY REQUIREMENTS FOR SOLAR ENERGY SYSTEMS
SETBACK REQUIREMENTS:
FRONT 60'+120'=180'
SIDE 60'+120'=180'
REAR 60'+120'=180'

LOT REQUIREMENTS:
WIDTH: 300'
DEPTH: 250'
AREA: 80,000 SQ.FT.
LOT COVERAGE: 25%

REVISIONS

No.	DATE	DISTRIBUTION	BY
1	08-06-18	REVISED FARMLAND PROTECTION PLAN FOR SOIL DESIGNATIONS	DSM
2	08-15-18	REVISED PER TOWN OF FARMINGTON COMMENTS	DSM
3	02-21-19	REVISED PROJECT PROPOSED LOCATIONS FOR NEW UTILITY POLES	DSM

CERTIFICATION

WE, SCHULTZ ASSOCIATES, ENGINEERS, AND LAND SURVEYORS, P.C. HEREBY CERTIFY THIS MAP WAS COMPLETED ON JULY 3, 2018 FROM AN INSTRUMENT SURVEY COMPLETED MAY 23, 2018. IN ACCORDANCE WITH THE PROVISIONS OF SECTION 7209 OF THE NEW YORK STATE EDUCATION LAW ANY ALTERATIONS AND A VIOLATION OF ARTICLE 145 SECTION 7209 OF THE NEW YORK STATE EDUCATION LAW.

MRS. S. SCHULTZ, L.S. NO. 049842
JAMES A. MASON, L.S. NO. 50196
ROBERT W. HATCH, L.S. NO. 50643

A MAP SHOWING

DELAWARE RIVER SOLAR, LLC SOLAR ENERGY FACILITY

~ YELLOW MILLS ROAD ~

SITUATE IN:
PART OF TOWN LOTS 118 & 119, TOWN OF FARMINGTON,
COUNTY OF ONTARIO, STATE OF NEW YORK

SCHULTZ ASSOCIATES
ENGINEERS & LAND SURVEYORS, P.C.
129 SOUTH UNION STREET, P.O. BOX 89
SPENCERPORT, NEW YORK 14559
585-349-3750
www.schultzassocpc.com

PRELIMINARY SITE PLAN

DRAWN BY	DSM	PROJECT NO.	18-023
CHECKED BY	KJS	SHEET No.	2 OF 1
SCALE	1" = 60'	DWG. NO.	S-1
DATE	JULY 3, 2018		

LOCATION MAP

LEGEND

2.9. Operation and Maintenance

During operation, maintenance activities will focus on the scheduled preventive maintenance and repairs of the solar generating equipment. The maintenance and repair of Project components is expected to be coordinated through monitoring, on-site inspections and technical support from the various warranty services of the original equipment manufacturers.

The Solar Facility will operate 7 days per week, generating electricity during the daylight hours. Preventive maintenance activities will occur during normal working hours generally twice per year with the occasional need to conduct corrective maintenance to certain equipment or facilities during non-scheduled or weekend hours.

The solar generating equipment will be continuously monitored and controlled from the central control room during normal working hours with 24 hour monitoring from a remote source. The generation units, auxiliary systems and balance of the Solar Facility will be connected to the SCADA system.

Standard maintenance for the Solar Facility will be as follows:

- **Modules Cleaning**: Module cleaning will be performed during preventive maintenance hours or extraordinary snow storms.
- **Scheduled Project Maintenance**: There will be the need to periodically inspect the modules (removal snow, ice, grass, vegetation) and make necessary alignment adjustments (i.e. tighten fasteners) or replace damaged modules to prevent breakdowns and production losses. Project components will go through maintenance checklist once or twice per year. The checklist shall include such items as:
    - Checking wire connections
    - Testing voltage/current at any part
    - Inspecting components for moisture
    - Confirming settings on the inverter
    - Transformer maintenance
    - Resealing of system components

- **Corrective Maintenance**: Corrective maintenance will occasionally be required due to uncontrollable circumstances such as severe weather or premature failure of components. These unscheduled repairs will be undertaken in a manner to minimize impacts to the continued operation of the Solar Facility.
- **Monitoring Management:** uses real-time data to oversee Project parameters.

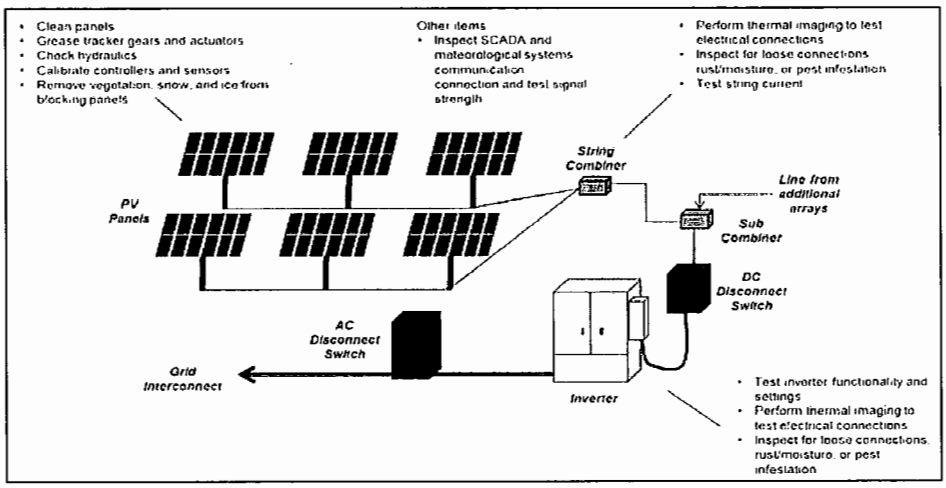


Figure 11. Highlights of the Solar Facility Maintenance

Typical equipment required to support operation and maintenance of the Solar Facility includes:

- Cleaning systems
- Standard electrical tools
- Building support systems
- Transport vehicles (pick-up truck, ATV, etc.)
- Standard machinist tools

2.10. Site Security

Limiting access to the Project Site to non-authorized personnel is necessary both to ensure the safety of the public and to protect equipment from potential theft and vandalism. Both, Project Owner and operator can be reached on a 24-hour basis. Phone numbers will appear on a sign placed at the entrance of the Solar Facility.

Some or all of the perimeter of the overall Solar Facility may be fenced with an approximately eight-foot-high chain-link fence to facilitate Project and equipment security. Surveillance methods such as security cameras or motion detector may be installed at locations along the Project Site

INTERSECTION CRASH RATE CALCULATIONS

$$\text{Rate per MEV} = \frac{\text{\# of Crashes} \times 1{,}000{,}000}{\text{Total No. of Entering Vehicles}} =$$

$$\text{Rate} = \frac{\text{\# of Crashes} \times 1{,}000{,}000}{\text{Veh./Day} \times \text{Duration of Study}} =$$

Crashes per million entering vehicles (Crash / MEV)

---

1 Fox Road/Yellow Mills Road

ADT = Peak hour entering volume / k factor

ADT = 240 VPH / 0.10 = 2526 VPD

$$\text{Rate} = \frac{7 \text{ Acc.} \times 1{,}000{,}000}{2526.3 \text{ VPD} \times 365 \text{ Days} \times 5.000 \text{ Yrs.}} = 1.52 \text{ Crash / MEV}$$

0.28 NYSDOT

SRF ASSOCIATES

Int #	Left turn	Rear-end	Overtaking	Right Angle	Right Turn	Head On	Side-swipe	Fixed Object	Backing	Other	Animal	Bike/Ped	Total	Injury	Non Injury	Non-Repo	Sum
1 Fox Road/Yellow Mills Road	1			5						1			7	3	3	1	7
TOTALS	1	0	0	5	0	0	0	0	0	1	0	0		3	3	1	

1. Fox Road/Yellow Mills Road

	Northbound	Southbound	Eastbound	Westbound	Unknown	Totals
Left turn		1				1
Rear-end						0
Overtaking						0
Right Angle	3	2				5
Right Turn						0
Head On						0
Side-swipe						0
Fixed Object						0
Backing						0
Other	1					1
Bike/Ped						0
Animal						0
Totals	4	3	0	0	0	7

EXHIBIT B

#36

November 20, 2018

Mr. Ronald L. Brand
Director of Development
Town of Farmington
1000 County Road 8
Farmington, NY 14425

Cc: All Committee Members

Dear Ron,
I am writing because I will be out of town for the next meeting with regard to the Delaware River Solar application for a special use permit and change in zoning and set-back laws for 466 Yellow Mills Road.

I am again stating my objection to subject application. My concerns are major and sincere.

1) Devaluation of adjacent properties. I own property a few feet away. I can stand in the front yard of 4500 Fox Road and look at most of the total 135 acres of the subject property. Any future residential development on adjacent properties would be severely compromised.

2) The land is zoned agricultural. Please read the 5th paragraph of the "NYSERDA" Redesign of NY – Sun's Megawatt Block Program. (Preserving New York's Valuable Agricultural Land are priorities of Governor Cuomo.) Let's help our Governor reach his 2030 goal by following his wishes and preserving our FARM LAND.

3) This subject POWER PLANT will make a very dangerous intersection much more dangerous. The intersection of Yellow Mills Road and Fox Road should not be dangerous, however we the people make it that way.
   a) Cars and trucks run the two stop signs every day and night. Mostly local residents who live in the area.
   b) I have seen tractor trailers run those stop signs.
   c) When the corn is high, some cars will turn their lights off on Yellow Mills heading south to see if lights are heading towards the intersection on Fox Road and then make a decision to stop or not.

d) I lost my 20 year old niece at that intersection. Anette was a junior at Geneseo State, studying to become an Elementary School Teacher, like her sister, her grandmother, and her aunt. She was travelling east on Fox Road heading back to her summer job after having lunch with her grandmother. She was hit by a large pickup truck, hauling a loaded trailer and doing an estimated 55 MPH that hit her driver's side door at the Yellow Mills intersection.
   The door was pushed almost half way into the Buick Station Wagon. This man had no intention of stopping and had been running those stop signs for years.
e) A few weeks ago one of my employees was heading home after work going west on Fox Road. He hit a car that ran the stop sign at the Yellow Mills intersection. His car was totaled; the other driver ended up in a ditch, the car on its roof. Luckily no one was killed.
f) The size of this Power Plant will be a huge added distraction. Everyone driving beside subject Power Plant will have to gawk at it. Taking their attention away from the intersection and road.

4) At one of the meetings, I believe the President of Delaware River Solar, LLC made a statement that the transformers would be 8-12 feet tall. He did not elaborate. I asked Brian Venton of Paradise Energy Solutions how wide and thick they might be. His company installed our 666 roof mounted solar panels. His answer was 4-6 feet wide and 1-2 feet thick. I assume there would be three of them. Where would they be located?

Ron, I hope the Committee Members understand our concerns and frustrations. How would they like to own our properties?

Best Regards,

Jim

Jim Redmond

JRLON, INC.
P.O. Box 244 • 4344 Fox Rd.
Palmyra, New York 14522

ROCHESTER NY 144

23 NOV 2018 PM 1 L

Mr. Ronald Brand
Director of Development
Town of Farmington
1000 County Road 8
Farmington, NY 14425

14425-9565

Town of Farmington

1000 County Road 8
Farmington, New York 14425

PLANNING BOARD
Wednesday, November 7, 2018, 2018, 7:00 p.m.

MINUTES—APPROVED

The following minutes are written as a summary of the main points that were made and are the official and permanent record of the actions taken by the Town of Farmington Planning Board. Remarks delivered during discussions are summarized and are not intended to be verbatim transcriptions. An audio recording of the meeting is made in accordance with the Planning Board adopted Rules of Procedure. The audio recording is retained for 12 months.

Clerk's Note 1: The Planning Board meeting of October 17, 2018, was cancelled due to having no applications or board business on the agenda.

Board Members Present: Edward Hemminger, *Chairperson*
Adrian Bellis
Shauncy Maloy
Mary Neale
Douglas Viets

Staff Present:
Lance S. Brabant, CPESC, Town of Farmington Engineer, MRB Group, D.P.C.
Ronald L. Brand, Town of Farmington Director of Development and Planning
David Degear, Town of Farmington Water and Sewer Superintendent
Dan Delpriore, Town of Farmington Code Enforcement Officer
Don Giroux, Town of Farmington Highway and Parks Superintendent
James Morse, Town of Farmington Code Enforcement Officer
John Weidenborner, Assistant Chief, Farmington Volunteer Fire Association

Applicants Present:
Daniel Compitello, Solar Project Developer, Delware River Solar, 130 North Winton Road, #10526, Rochester, N.Y. 14610
Melissa Kiefer, Oldcastle Lawn & Garden Inc., Environmental Director, Oldcastle Lawn and Garden, 900 Ashwood Parkway, Suite 600, Atlanta, Georgia 30338
Patrick S. Laber, P.E., Schultz Associates Engineers and Land Surveyors PC, 129 South Union Streert, P.O. Box 89, Spencerport, N.Y. 14559
Graham Marcus, Maddie's Motor Sports, 6226 State Route 96, Farmington, N.Y. 14425
David Matt, Project Engineer, Schultz Associates Engineers and Land Surveyors PC, 129 S. Union Street, Spencerport, N.Y. 14559

Jack Melsom, GreenRenewable Inc., 28 Taylor Avenue, P.O. Box 248, Berlin, N.Y. 12022
Roger and Carol Smith, 4790 Fox Road, Palmyra, N.Y. 14522
Rocco and Pat Venezia, 5120 Laura Lane, Canandaigua, N.Y. 14424
Cliff Weitzel, 6190 Fisher Hill Road, Canandaigua, N.Y. 14424
Rich Winter, Chief Executive Officer, Delaware River Solar LLC, 3 Bridge Street, P.O. Box 384, Callicoon, N.Y. 12723

Residents Present:
Hal Adams, 4650 Kyte Road, Shortsville, N.Y. 14548
Madeline Allen, Daniel [?], 4392 Fox Road, Palmyra, N.Y. 14522
Steve Austin, 220 [?] Street, Palmyra, N.Y. 14522
Robert and Linda Bailey, 5163 Fox Road, Palmyra, N.Y. 14522
Stefanie and Matthew Barnes, 4936 Fox Road, Palmyra, N.Y. 14522
Jennifer Baxter, 266 Yellow Mills Road, Palmyra, N.Y. 14522
Nancy Berger, 4971 Wiborn Road, Shortsville, N.Y. 14548
Terry Bieck, 358 Stafford Road, Palmyra, N.Y. 14522
[?] Blazey, 5075 Rushmore Road, Palmyra, N.Y. 14522
Gerald A. Bloss, 81 Gannett Road, Farmington, N.Y. 14425
John Boonstra, 5059 Maxwell Road, Farmington, N.Y. 14425
Charles and Karen Broersma, 5076 Maxwell Road, Farmington, N.Y. 14425
Barbara and Nelson Case, 169 Ellsworth Road, Palmyra, N.Y. 14522
Eric and Edie Chapman, 230 Ellsworth Road, Palmyra, N.Y. 14522
Kim and Mark Clement, 330 Ellsworth Road, Palmyra, N.Y. 14522
G[?] Consul, 5765 Limestone Lane, Farmington, N.Y. 14425
Gary, Kathleen and Steven Cook, 4973 Fox Road, Palmyra, N.Y. 14522
Robert and Allen Cooper, 222 Yellow Mills Road, Palmyra, N.Y. 14522
Roger and Sharon Cramer, 5022 Fox Road, Palmyra, N.Y. 14522
Ron Cramer, 5132 Fox Road, Palmyra, N.Y. 14522
James Dennie, 595 Yellow Mills Road, Palmyra, N.Y. 14522
John Depoint, 271 County Road 28, Palmyra, N.Y. 14522
Barbara and George Eckhardt, 357 County Road 28, Palmyra, N.Y. 14522
Marilyn and Jon Fair, 984 Stafford Road, Shortsville, N.Y. 14548
Nancy and Jim Falanga, 395 Ellsworth Road, Palmyra, N.Y. 14522
Ann and Jim Foley, 373 Ellsworth Road, Palmyra, N.Y. 14522
Daniel Geer, 6947 Proximity Lane, Victor, N.Y. 14564 (568 Yellow Mills Road)
Noah Giunta, 1445 Creek Pointe, Farmington, N.Y. 14425
Christopher Godly, 140 Galvin Court, Farmington, N.Y. 14425
Randy and Ann Marie Greco, 218 Ellsworth Road, Palmyra, N.Y. 14522
Caroline Heberle, 53 Mildorf Street, Rochester, N.Y. 14609 (531 Yellow Mills Road)
Linda Heberle, 531 Yellow Mills Road, Palmyra, N.Y. 14522
Ryan J. Heberle, 768 Yellow Mills Road, Shortsville, N.Y. 14548
Nancy and William Hood, 5023 Maxwell Road, Farmington, N.Y. 14425
Paolo Hu, 5765 Limestone Lane, Farmington, N.Y. 14425
Tammy and Edward Johnson, 126 Yellow Mills Road, Palmyra, N.Y. 14522
Dale Kratzenberg, 630 Sheldon Road, Palmyra, N.Y. 14522
Edward Lawrenz, 320 Yellow Mills Road, Palmyra, N.Y. 14522

Ms. Clement (330 Ellsworth Road) said that she owns just under six acres and that she cannot imagine a solar farm that big. She said it would be a monstrosity of 40 acres.

Mr. Falanga (395 Ellsworth Road) said that he and Gordon Wilson attended the October meeting of the Town Agriculture Advisory Committee meeting and that the Committee was against the solar proposal. He said that he also attended the October meeting of the Town Conservation Board. He read the names of the Committee and Board members from the minutes. He said that the Conservation Board agreed with the Agriculture Advisory Committee and said thumbs down on the large scale solar project. Mr. Falanga said that this is not a good project; that good neighbors help neighbors; that good neighbors lend their power equipment; and that good neighbors do not lie, distort or mislead. He said that there are no buffers [around this property] and that one must listen and read carefully. He said that DRS is only presenting what they want, as far as the Code. He said that Mr. Compitello appears online on how to develop solar codes, and low and behold, he gets to sell it on a later date.

Mr. Falanga said that the intersection of Yellow Mills Road and Fox Road is a horrible intersection for accidents and fatalities. He expressed concern about increased traffic.

Mr. Falanga said that the main aquifer for the Town of Farmington is under this land. He encouraged everyone to attend the next meeting of the Planning Board on December 5, 2018. He said that his research group is aware of 300 solar projects across the State and that less than 10 percent are approved. He said that this is a power plant and that it does not belong in the Town of Farmington.

Mr. Dennie (595 Yellow Mills Road) said that he purchased his cobblestone house about three years ago and that if he knew about this terrible project on this corner he never would have bought it. He said that he wants to live in the country and does not want to live anywhere near this.

Mr. Bieck (358 Stafford Road) asked if the eight-foot-high fence is a security fence to keep people and animals out, or if it will be a visibility fence so people cannot see on the other side. She asked if the fence is to block the visibility of the panels, and if so, it will need to be higher because the road is higher. Mr. Hemminger said that the fence will be a standard chain-link fence. Mr. Matt said that it will be more rectangular, eight feet in height, see-through, and will have no barbed wire.

Mr. Paul (4922 Maxwell Road) asked who will determine the amount of the bond to reclaim the site if the company goes bankrupt or if it abandons the property. Mr. Brabant said that a licensed professional engineer will be required to determine the appropriate quantities and value of the bond which will be submitted to the Town. The Town staff and the Town Engineer will review the bond which will then be approved by the Town Board following a recommendation from the Planninig Board. The bond will run with the project. It must be submitted as part of the initial work and would be under the control of the Town. Mr. Hemminger said that the amount of the bond would be reviewed at various periods of time during the duration of the project during which the Town Engineer will

review the reclamation process and costs to assure that an adequate bond is in place. He said that the amount of the bond is not a stagnant number and that there is a review process for this.

Mr. Paul asked if the solar panels are made in the United States and if it is a Union job. Mr. Hemminger requested the applicant to provide a written response to this.

Mr. Paul asked about maintenance and if the solar panels would be inspected once a month or every six months if a fence is down or for broken panels. Mr. Morse said that Town staff inspects projects and notifies property owners if violations are discovered. He said that the Town has the ability to use the applicant's Letter of Credit to pay for the cost of correcting the violations if the violations are not corrected by the applicant. Mr. Brabant said that this project would also be subject to conditions of the Special Use Permit and that the site would be inspected once a year following construction to assure continued compliance with the conditions of approval. Mr. Hemminger said that these conditions would be established by the Planning Board.

Mr. Kratzenberg (630 Sheldon Road) asked about wildlife on the property and if the New York State Department of Environmental Conservation (DEC) would inspect the site. Mr. Brabant said that the DEC would not inspect the site but that the applicant has provided a determination to the U.S. Army Corps of Engineers and the DEC as part of the environmental record regarding the delineation of the wetlands.

Mr. Hemminger then asked if anyone in the outer hallway who could not be seated in the room had any questions. Residents switched places with those from the hallway who wanted to speak.

A resident asked if DRS will purchase the property from the landowners. Mr. Compitello said that DRS will lease the land from the landowners. The resident asked if the Town knows the terms of the lease and if the financial information will be made public. Mr. Hemminger said that this is question to be answered in writing by the applicant. He said that the landowner and DRS may discuss this and he was not sure if this level of detail would be released to the Town or to the public.

Mr. Greco (218 Ellsworth Road) asked how often the site will be tested for any type of chemical spill or pollution. He said that all it takes is a few chemicals to be released into the water and that they are talking a lot of acres and a lot of panels He said that many people are still on well water and that he did not know that the main aquifer is under this property. He asked how is the Town going to protect the people of Farmington. Mr. Hemminger said that this question is exactly the type of information to be acquired during the SEQR process. He said that the Planning Board has the ability to place a number of conditions on the Special Use Permit and that best-practice inspections could be among them, assuming this application reaches that point. He again noted that the decision on this project is not a foregone conclusion and that this is not a done deal.

Town of Farmington

1000 County Road 8
Farmington, New York 14425

PLANNING BOARD
Wednesday, June 5, 2019, 7:00 p.m.

MINUTES—APPROVED

The following minutes are written as a summary of the main points that were made and are the official and permanent record of the actions taken by the Town of Farmington Planning Board. Remarks delivered during discussions are summarized and are not intended to be verbatim transcriptions. An audio recording of the meeting is made in accordance with the Planning Board adopted Rules of Procedure. The audio recording is retained for 12 months.

Clerk's Note: This meeting was held at the Farmington Highway Garage, 985 Hook Road, in anticipation of a large number of attendees.

Board Members Present: Edward Hemminger, *Chairperson*
Adrian Bellis
Mary Neale
Douglas Viets

Board Member Excused: Shauncy Maloy

Staff Present:
Lance S. Brabant, CPESC, Town of Farmington Engineer, MRB Group D.P.C.
David Degear, Town of Farmington Water and Sewer Superintendent
Dan Delpriore, Town of Farmington Code Enforcement Officer
Don Giroux, Town of Farmington Highway and Parks Superintendent
August Gordner, Town of Farmington Code Enforcement Officer

Applicants Present:
Daniel Bieck and Madeline Allen, 4392 Fox Road, Palmyra, N.Y. 14522
Karen Brake, 1840 Magog Road, Macedon, N.Y. 14502
Daniel Compitello, Solar Project Developer, Delware River Solar, 130 North Winton Road, #10526, Rochester, N.Y. 14610
Primo DiFelice, DiFelice Development Corporation, 91 Victor Heights Parkway, Victor, N.Y. 14564
Cindy Ingalsbe, 151 Galvin Court, Farmington, N.Y. 14425
David Matt, Project Engineer, Schultz Associates Engineers and Land Surveyors PC, 129 S. Union Street, Spencerport, N.Y. 14559
Robert F. Morris III, PLS, 104 Sherman Parkway, Newark, N.Y. 14513

Edward G. Parrone, P.E., Parrone Engineering, 349 W. Commercial Street, Suite 3200, East Rochester, N.Y. 14445
Terence Robinson, Esq., Boylan Code LLP, 28 South Main Street, Canandaigua, N.Y. 14424
Kyle Sadler, 5654 Allen Padgham Road, Farmington, N.Y. 14425
Roger and Carol Smith, 4790 Fox Road, Palmyra, N.Y. 14522
Mike Yaeger, Parrone Engineering, 349 W. Commercial Street, Suite 3200, East Rochester, N.Y. 14445

Residents Present:
Linda Bailey, 5163 Fox Road, Palmyra, N.Y. 14522
Terrence C. Bieck, 358 Stafford Road, P.O. Box 355, Palmyra, N.Y. 14522
Gerald A. Bloss, 81 Gannett Road, Farmington, N.Y. 14425
Edith and Eric Chapman, 230 Ellsworth Road, Palmyra, N.Y. 14522
Ruth DeBrock, 129 W. Main Street, Shortsville, N.Y. 14548
Nancy and Jim Falanga, 395 Ellsworth Road, Palmyra, N.Y. 14522
Jim and Ann Foley, 373 Ellsworth Road, Palmyra, N.Y. 14522
Caroline Heberle, for 531 Yellow Mills Road, c/o 53 Mildorf Street, Rochester, N.Y. 14609
Linda Heberle, for 531 Yellow Mills Road, c/o 53 Mildorf Street, Rochester, N.Y. 14609
Frances Kabat, Esq., The Zoghlin Group PLLC, 300 State Street, Suite 502, Rochester, N.Y. 14614
Sharon and Earl Maltman, 179 County Road 28, Palmyra, N.Y. 14522
Pat Murphy, 4995 Rushmore Road, Palmyra, N.Y. 14522

1. MEETING OPENING

The meeting was called to order at 7:00 p.m. After the Pledge of Allegiance was recited, Mr. Hemminger explained the emergency evacuation procedures. He asked everyone to please sign in and requested that cell phones and other devices be set on silent mode.

Mr. Hemminger said the meeting would be conducted according to the Rules of Procedure approved by the Planning Board on February 6, 2019.

2. APPROVAL OF MINUTES OF MAY 15, 2019

■ A motion was made by MS. NEALE, seconded by MR. BELLIS, that the minutes of the May 15, 2019, meeting be approved.

Motion carried by voice vote.

3a. PUBLIC HEARING: CONTINUED PRELIMINARY FOUR-LOT SUBDIVISION

PB #1003-18 Continued Preliminary Four-Lot Subdivision Application

Mr. Hemminger asked if anyone wished to comment or ask questions on the project.

Linda Heberle (531 Yellow Mills Road) said that she thought that the traffic study focused on the maintenance of the solar plant after construction and having one or two cars entering and leaving the site during maintenance. She asked about the number of vehicles and traffic that would be using the site during construction. Ms. Heberle said that it would be more relevant to ask for a traffic study on the impact of vehicles that would be using the site during construction. Mr. Hemminger said that the traffic study took a long-term picture of the project rather than the short-term construction phase.

Ms. Heberle said that here we are again on another Wednesday night. She said that we [many of the residents] are all here on Wednesday nights because they all really care about the situation and are opposed to it. She said that she wanted to thank the Planning Board and Mr. Hemminger for advocating for year 'round screening if the project does get approved. She said that this was the first time that they have heard about year 'round screening after your [the Planning Board's] intervention and that this is heading in the right direction. But Mrs. Heberle said that she still thinks that more screening is needed, especially on the southern two arrays. She said that although a neighboring property owner has some trees on his land in this area, the company should not really count on the neighbor to screen the project.

Ms. Heberle asked about the height of the arrays. Mr. Compitello said that the arrays would be about a total height of eight to nine feet.

Ms. Heberele asked about the height of the arbor vitaes proposed to be planted. Mr. Compitello said that the arbor vitaes would be about five to six feet high at the time of planting. Ms. Heberle said that it may take them about five years to reach the height of the arrays. Mr. Hemminger said that these details would be part of the board's Site Plan consideration. Ms. Heberle said that if it is going to take five years for the plantings to reach the height to buffer the arrays, then they [DRS] should plant the trees and let them [DRS] wait five years [before installing the arrays].

Ms. Heberle discussed the character of the neighborhood. She said that several people at a previous meeting said that there are rooftop solar arrays in the neighborhood. Ms. Heberle said that there is a huge difference between solar panels for individuals and a for-profit power plant from which power will be sold throughout the country. She said that they [solar arrays] are not the same at all.

Ms. Heberle said that the DRS responses [to the Planning Board's questions] mentioned a power plant in Geneva, N.Y. She asked how one can compare Yellow Mills Road to Geneva and call it comparable character.

Mr. Falanga (395 Ellsworth Road) asked who commissioned the traffic study. Mr. Hemminger said that he commissioned it. Mr. Falanga asked who commissioned the report by SRF Associates. Mr. Hemminger said that the Town commissioned it.

Mr. Falanga said that he did not see in the study how many cars actually drove through [the intersection]. He referred to that portion of the study which indicates that the crash rate is 10 times greater than the State average, as follows:

Table II: Intersection Crash Rates

Intersection	Number of Crashes	Actual Project Rate	Statewide Average Rate
Fox Road/ Yellow Mills Road	7	1.52	0.15

As shown in **Table II,** the intersection had a crash rate over ten times greater than the statewide average. The accident types that occurred over the investigation period were right angle (3—northbound, 2—southbound), left turn (1—southbound, and other (1—northbound). It is noted that all crashes occurred in the northbound and southbound directions. Upon further investigation there is a pattern of northbound and southbound drivers failing to yield the right of way to eastbound and westbound drivers. However, the number of collisions occurring during the five-year investigation period does not warrant corrective action. STOP Ahead signs (MUTCD W3-1) are located along Yellow Mills Road approximately 825 feet in advance of both the northbound and southbound stop signs. Additionally, Intersection Warning signs with 45 MPH advisory speed plaques are located along Fox Road in both the eastbound and westbound directions approximately 825 feet in advance of the Yellow Mills Road intersection. if the number and/or severity of collisions increasesm OCDPW may consider additional warning measures.

The solar farm site should not have any equipment or plantings within the sight lines of the Fox Road/Yellow Mills Road intersection.

—SRF Associates, May 31, 2019, Pages 2 and 3 of 4

Mr. Falanga said that he found the study lacking in how many cars went by and lacking in comparison of the Statewide average to our Town and County.

Mr. Falanga said that he met with Scott Allen, P.E., the Town of Macedon engineer. He said that Mr. Allen is very much aware of the solar power plant proposal in Farmington and that Mr. Allen said that a number of towns are watching to see what goes down [with this application] here.

Mr. Falanga said that Mr. Allen reported that Town of Macedon Special Use Permits are given consideration only on the site, and that the sites are chosen only after careful review of fencing and tree buffers to screen as much as possible.

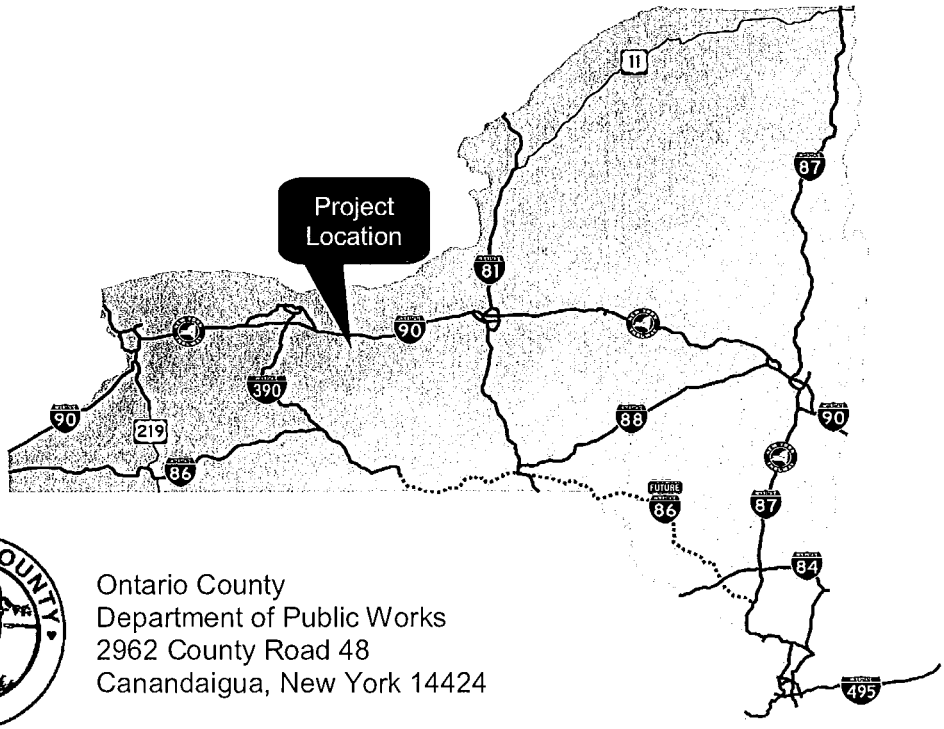
EXHIBIT C

Transportation Project Report

DRAFT Design Report

March 2019

County Road 28 at Shortsville Road Intersection Improvement
PIN 4ON0.03
Town of Farmington
Ontario County



Ontario County
Department of Public Works
2962 County Road 48
Canandaigua, New York 14424

NEW YORK STATE OF OPPORTUNITY. Department of Transportation

ANDREW M. CUOMO
Governor

PAUL A. KARAS
Acting Commissioner

U.S. Department of Transportation
Federal Highway Administration

Prepared by:
BERGMANN
ARCHITECTS ENGINEERS PLANNERS
280 East Broad Street, Suite 200
Rochester, NY 14604
585.232.5135
www.bergmannpc.com

Project Approval Sheet

Milestones	Signatures	Date
A. IPP Approval:	The project is ready to be added to the Regional Capital Program and project scoping can begin. The IPP was approved by:	
	Kevin C. Bush	11/16/17
	Kevin C. Bush, Regional Director	Date
B. Scope Approval:	The project cost and schedule are consistent with the Regional Capital Program. The scope was approved by:	
	Kevin C. Bush, Regional Director	Date
C. Categorical Exclusion Determination on Behalf of FHWA	This project qualifies as a Categorical Exclusion under the National Environmental Policy Act per the NYSDOT/FHWA Programmatic Agreement Regarding Categorical Exclusions.	
	Kevin C. Bush, Regional Director	Date
D. Recommendation for Scope, Design, and Nonstandard Feature Approval:	All requirements requisite to these actions and approvals have been met, the required independent quality control reviews separate from the functional group reviews have been accomplished, and the work is consistent with established standards, policies, regulations and procedures, except as otherwise noted and explained. The nonstandard features have been adequately justified and it is not prudent to eliminate them as part of this project.	
	Michael T. Croce, P.E Senior Project Manager, Bergmann Associates	Date
D. Public Hearing Certification (23 USC 128):	A public hearing was not required. A public information meeting will be held in March 2019.	
Local Project Nonstandard Feature Approval	No nonstandard features are proposed on Non-NHS local roadways.	
Local Project Scope and Design Approval	The required environmental determinations have been made, and the preferred alternative for this project is ready for final design.	
	William C. Wright, P.E. Commissioner, Ontario County Department of Public Works	Date

List of Preparers

Consultant Project Manager Responsible for Production of the Design Approval Document:

Michael T. Croce, P.E., Senior Project Manager, Bergmann Associates

Description of Work Performed by Firm: Directed the preparation of the Design Approval Document in accordance with established standards, policies, regulations and procedures, except as otherwise explained in this document.

Note: *It is a violation of law for any person, unless they are acting under the direction of a licensed professional engineer, architect, landscape architect, or land surveyor, to alter an item in any way. If an item bearing the stamp of a licensed professional is altered, the altering engineer, architect, landscape architect, or land surveyor shall stamp the document and include the notation "altered by" followed by their signature, the date of such alteration, and a specific description of the alteration.*

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CHAPTER 1 – PROJECT DEVELOPMENT

This report identifies the purpose and need for work at the intersection of County Road (CR) 28 and Shortsville Road along with its objectives and how they will be addressed. It also provides an assessment of the social, economic, and environmental impacts of the proposed action. The proposed project is located in the Town of Farmington, Ontario County, New York. The Project Identification Number (PIN) is 4ON0.03. This is a locally administered federal aid project.

1.1. Introduction

This report was prepared in accordance with the NYSDOT Project Development Manual, 17 NYCRR (New York Codes, Rules and Regulations) Part 15, and 23 CFR (Code of Federal Regulations) 771. Transportation needs have been identified (section 1.2.2), objectives established (1.2.3) to address the needs, and cost-effective alternatives developed (1.3). This project is federally funded.

1.1.1. Project Location

A Project Location Map is included as **Exhibit 1.2.1, Appendix A**. The following is a project location summary.

(1) Route number: County Road (CR) 28
(2) Route name(s): CR 28 and Shortsville Road
(3) Municipality: Town of Farmington
(4) County: Ontario
(5) Limits: 750 feet east, 1,000 feet west, 750 feet south, and 1,250 north of the intersection.

1.2. Purpose and Need and Objectives

1.2.1. Project Need

CR 28 meets Shortsville Road at a skewed, 60° angle. All four approaches fall on tangent alignments and the intersection is elevated slightly above the surrounding terrain. Plantings in an agricultural field (southwest corner) and a residential home (southeast corner) prevent northbound drivers on CR 28 from seeing vehicles approaching on Shortsville Road. Similarly, an embankment and trees in Meeting House Park (northwest corner) and another residential house (northeast corner) make it difficult to see vehicles approaching on Shortsville Road from southbound CR 28. Intersection warning signs provide some notice on CR 28, but it can be difficult to locate the intersection on approach, particularly in the southbound direction. The intersection serves passenger cars, agricultural traffic, and a substantial number of heavy trucks. These factors are compounded by approach speeds near or in excess of the 55 mile per hour speed limit.

The intersection of CR 28 and Shortsville Road has experienced a high frequency of accidents. The accident rate is roughly 6 times the statewide average for rural a two-way, stop controlled, intersection. Accident severity is also a concern, with 11 of 22 accidents recorded during a 7-year study period involving injuries. The intersection has also been the site of two fatal accidents during that time. The predominant accident patterns involve right angle collisions. Typical causative factors include failure to yield the right of way. Contributing factors typically include failure to yield the right of way and failure to stop. As a result, this intersection presents a substantial ongoing safety concern.

1.2.2. Project Purpose

The purpose of this project is to enhance safety performance at the intersection of CR 28 and Shortsville Road.

1.2.3. Project Objectives

The objectives of the project are as follows:

(1) Develop a design that incorporates effective crash reduction measures capable of addressing identified collision patterns and reducing the average annual accident rate to a level at or below the expected rate for similar locations throughout Ontario County and New York State.

(2) Develop a treatment that encourages motorists to lower their travel speed on approach to the intersection, thereby decreasing the potential for a high severity crash.

1.3. Project Alternatives

The following alternatives were considered:

Alternative 1: No Action/Maintenance
Alternative 2: Incremental Signing and Pavement Marking Enhancements
Alternative 3: Multi-Way Stop Intersection Control
Alternative 4: Signalized Intersection Control
Alternative 5: Modern Roundabout

Alternative 1, The No Action / Maintenance Alternative or "null", would retain two-way stop control at the intersection of CR 28 and Shortsville Road. No activities other than routine maintenance would be carried out. This alternative would not improve safety at the intersection. The null is retained only as a baseline for comparison and will not be discarded until a final decision is made regarding the selection of a build alternative.

Alternatives 2 through 4 were considered but eliminated from further study because they would not fully satisfy the project's purpose and need nor meet the project objectives. Refer to **Section 3.1** for a discussion of these alternatives.

The feasible alternative is Alternative 5, which would convert the existing, four-legged, two-way stop-controlled intersection of CR 28 and Shortsville Road into a modern roundabout. The roundabout would feature an 18-foot wide circulatory roadway (striped to 16 feet wide) with an inscribed circle diameter of 140 feet. The roundabout would also feature a truck apron (for off-tracking by the rear wheels of turning tractor trailers) and a landscaped central island. All approaches would feature an elongated splitter island with a set of curves, each successively smaller as one approaches the circle. The purpose of the curvature would be to reduce vehicle speeds as they approach the roundabout from free flow conditions (higher than 55 miles per hour) to approximately 20 miles per hour or less by the time they reach circle.

The roundabout would physically eliminate left turns and crossing maneuvers, therefore mitigating documented accident patterns. A reduction in intersection approach speeds would also reduce the severity of any collisions that do occur. The design would provide adequate capacity to meet projected traffic demand throughout the year 2040 while also accommodating tractor trailer movements, buses, passenger cars, bicyclists, and the occasional pedestrian.

Drainage patterns around the intersection would remain consistent with those found today; however, improvements would be made to encourage more efficient flow and to prevent salt laden runoff from entering nearby agricultural parcels. All pavement within the project limits would be fully reconstructed. All

signs and markings would be upgraded to meet current standards. Several temporary and permanent easements would be required to construct and maintain the new intersection.

Refer to **Section 1.6** of this document for additional information on the anticipated cost and schedule. For a more in-depth discussion of the proposed improvements and detailed design criteria see **Section 3.2.** See Section **3.3.3.2 (1)** for a summary of critical design elements that would not meet standards.

1.4 Project Effects

1.4.1 Environmental Classification

Exhibit 1.4.1
Environmental Classification Summary

NEPA Classification	Type II Categorical Exclusion	BY	NYSDOT
SEQR Type:	Type II	BY	Ontario County

NEPA: National Environmental Policy Act
FHWA: Federal Highway Administration
SEQR: State Environmental Quality Review

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1.4.2 Comparison of Considered Alternatives

Exhibit 1.4.2 Comparison of Alternatives		
Category	**Alternatives Evaluated**	
	Null	**Alternative 5: Modern Roundabout**
Environmental Impacts		
Wetlands	None	0.049 acres
Cultural Resources (Section 106)	None	TBD
Section 4(f)	None	TBD
Endangered/ Threatened Species	None	Not Likely to Adversely Affect the northern long eared bat
Noise	None	None
Social Impacts		
Property/Relocations	None	1.203 Acres PE 0.133 Acres TE
Visual	None	Negligible
Mobility (Pedestrian, bicycle, transit, etc.)	No Effect	Improved pedestrian and bicycle mobility
Environmental Justice	No Effect	No disproportionate high and adverse effects to minority or low-income populations
General Social Groups	No Effect	Beneficial impacts for elderly population and children's access to park
Crash Costs	High	Low
Economic and/or Operational Impacts		
Economic Impacts	No Effect	No change to vehicular access to businesses
Temporary Detours	No Effect	Travelers affected for 3 months
Intersection Control	Two-Way Stop	Modern Roundabout
Operation at ETC+20	LOS C or Better	LOS A (all approaches)
Pavement Condition	No Change	20 Year Surface Life 50 Year Overall Life
Drainage	No Change	Improved Flow
Utilities	None	Relocation required $0.29M (Water)
Safety – Benefit / Cost Ratio	0	8.13
Construction Cost	None	$2.339M

There are no mitigation measures proposed for this project (see **Chapter 4, Section 4.2.1.4**).

1.4.3 Anticipated Permits/Certifications/Coordination

Exhibit 1.4.3 Anticipated Permits/Certifications/Coordination
Permits
NYS Department of Environmental Conservation (NYSDEC):
• State Pollutant Discharge Elimination System (SPDES) General Permit
• Blanket Water Quality Certification (Section 401) of the FWPCA
Army Corps of Engineers (USACE):
• Nationwide Permit #14 – Linear Transportation Projects
New York State Department of Transportation (NYSDOT):
• Highway Work Permit
New York State Department of Health (NYSDOH):
• Application for Approval of Plans for Public Water Supply Improvement (DOH 348)
Coordination
Federal Highway Administration (via NYSDOT)
New York State Historic Preservation Officer (SHPO) (via NYSDOT)
US Fish and Wildlife Service
New York Natural Heritage Program
NYS Department of Agriculture & Markets
Municipality(ies) – Town of Farmington
Metropolitan Planning Organization – Genesee Transportation Council
Utilities – Town of Farmington Water, RG&E, Windstream, Charter Communications

1.5. Preferred Alternative

The reasonable and prudent alternative that best meets the project objectives is Alternative 5: Modern Roundabout. The decision to enter final design will not be made until after the environmental determination is finalized and a thorough evaluation of public and agency comments on the draft design approval document has been completed. See **Section 3.2.2** for a discussion of this alternative.

Design Approval is scheduled for April of 2019 with construction scheduled to last 9 months beginning in April of 2020.

For more detail on costs for each alternative refer to **Section 3.2.1**.

1.6. Project Schedule and Cost

Exhibit 1.6 - 1 Project Schedule	
Activity	**Date Occurred/Tentative**
Scoping Approval	November 2017
Public Information Meeting	April 2019
Design Approval	April 2019
Property Acquisition	Summer 2019
Letting (Bid Opening)	February 2020
Construction Start	April 2020
Construction Complete	October 2020

Exhibit 1.6 - 2 Project Costs – Design Bid Build		
Potential Alternative		**Alternative 5: Modern Roundabout[1]**
Highway		
Earthwork		$139,200
Pavement and Subbase		$972,222
Drainage		$376,000
Landscape		$80,000
Lighting		$52,800
Water Main		$286,565
Signs & Pavement Markings		$34,530
Work Zone Traffic Control		$50,000
Survey & Miscellaneous		$53,000
Subtotal		$2,044,317.00
Incidentals	0%	$0
Contingency	10%[2]	$204,431.70
Subtotal		$2,248,748.70
Field Change	0%[3]	$0
Subtotal		$2,248,748.70
Mobilization	4%	$89,949.95
Subtotal		$2,338,698.65
Inflation/Escalation to Midpoint of Construction	0%	$0
CONSTRUCTION COST[4,5]		**$2,338,698.65**
Final Design[6]		$112,000
QC & Administration of Final Design and Contract[6]		
Construction Inspection[7]		$262,000
Right-of-Way[8]		$19,000
TOTAL PROJECT COST		**$2,731,698.65**
ROUNDED TO NEAREST $10,000		**$2,730,000**

Notes:

1. Unit prices are in 2019 dollars.
2. For unforeseen and untabulated items like restoration sawcutting, milling, joint adhesive, test pits, erosion & sediment control, stormwater treatment, shoulder backup, subbase daylighting, detectable warning units, miscellaneous landscaping, roadside ditching outside of cut/fill, guide rail, mailboxes, and asphalt/fuel price adjustments.
3. Field Change Order would be 5% per the HDM Chapter 21 Section 21.4.3.3. Assume Field Change Order is included in the contingencies.
4. Costs do not include any private utility relocations including overhead electric and telephone relocations. Reimbursable utility costs not anticipated for this project.
5. Construction funding programmed in 2019-2022 GTC TIP at $1,870,000. Ontario County is requesting additional funding or will be expected to cover project construction costs in excess of the GTC TIP value.
6. Final design budget in the GTC TIP is $112,000. Actual cost to be negotiated during scoping for final design phase service agreement.
7. Construction inspection and support budget given in the GTC TIP is $262,000. Actual cost to be negotiated during scoping for construction phase services agreement.
8. ROW acquisition budget given in the GTC TIP is $19,000. Actual cost pending appraisals.

1.7. Public Involvement

The intersection CR 28 and Shortsville road has been the site of numerous right-angle accidents resulting in personal injury. Two accidents within the last 7 years resulted in fatalities.

With the intent to improve safety at the intersection, an Initial Project Proposal (IPP) was drafted and approved in November 2017. The project was subsequently added to the Genesee Transportation Council (GTC) Transportation Improvement Program (TIP). Ontario County then began coordination with the Town of Farmington, who participated in the selection of a design team. Preliminary design began in the late spring of 2018. Utility coordination also began at that time and will continue throughout design. Coordination with the NYSDOT and other agencies is ongoing.

A series of one-on-one stakeholder meetings were held by Ontario County in early 2019. Ontario County representatives specifically reached out to local elected officials and affected property owners. A public information meeting is tentatively scheduled for March 2019. Project information will be made available for inspection by the public, a brief presentation will be given, and project representatives will be present to listen to comments and record additional input. A public comment period will follow. Comments received at the meeting and during the public comment period will be considered and addressed. Information from the public meeting and a summary of all comments received will be made available in **Appendix G**.

Exhibit 1.7
Public Involvement Plan Schedule of Milestone Dates

Activity	Date Occurred/Tentative
Meetings with Stakeholders	January 2019 to April 2019
Meeting with Town of Farmington	January 2019
Public Information Meeting	April 2019
Current Project Letting	February 2020 (tentative)

For additional information or to provide comments, please contact:

Mailing Address: Mr. Timothy McElligott, P.E.
Professional Engineer
Ontario County Department of Public Works
2962 County Road 48
Canandaigua, New York 14424

Email Address: Timothy.McElligott@co.ontario.ny.us

Telephone: (585) 396-4000

Please include the six-digit Project Identification Number (PIN) 4ON0.03 in any correspondence.

The deadline for submitting comments on this report circulation is April 12, 2019.

The remainder of this report is a detailed technical evaluation of existing conditions, anticipated impacts of the one reasonable/preferred alternative and comparison to the null alternative, copies of technical reports and plans and other supporting information.

CHAPTER 2 - PROJECT CONTEXT: HISTORY, TRANSPORTATION PLANS, CONDITIONS AND NEEDS

This chapter addresses the history and existing context of the project site, including the existing conditions, deficiencies, and needs at the intersection of CR 28 and Shortsville Road.

2.1. Project History

In 2014, Ontario County Public Works updated its network screening of unsignalized, two-way stop-controlled intersections using the methods described in the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (HSM). Data utilized covered a period from January 2010 to December 2014. At that time, the accident experience at the intersection of CR 28 and Shortsville Road was flagged as significant in comparison to other locations countywide.

A subsequent safety benefit evaluation completed for the period from January 2011 through March 2016 per New York State Department of Transportation (NYSDOT) procedures also suggested a significant accident experience. The calculated accident rate of 1.95 accidents per million entering vehicles (acc/mev) was 6 times higher than the average accident rate for similar locations statewide. Just over 75% of the accidents involved a right-angle collision. There were two fatal accidents and 6 injury accidents.

These accidents came despite tangent approaches, signs, and markings. Drivers reportedly fail to yield the right of way at the skewed, four-way intersection. The existing geometry includes a small hill just north of the intersection and trees, houses, and planted agricultural fields that limit available intersection sight distance on CR 28. Whether stopped motorists are misjudging the relatively high speed of approaching traffic or the length of available gaps, the result is often a serious injury crash. The intersection has also been the site of two fatal accidents.

With a desire to improve safety at the CR 28 and Shortsville Road intersection by reducing the number and severity of crashes, Ontario County sought and secured Highway Safety Improvement Program (HSIP) funding in 2016. The project was approved and added to the Genesee Transportation Council (GTC) 2017-2020 Transportation Improvement Plan (TIP). Design Phase Authorization was issued in November 2017 and preliminary design activities began in 2018.

Ontario County completed interim signing and striping improvements in summer 2018 using county forces and funding. This was done to satisfy public concerns and enhance short-term safety at the intersection while waiting for the larger project to be approved, designed, and constructed.

2.2. Transportation Plans and Land Use

2.2.1. Local Plans for the Project Area

2.2.1.1. Local Comprehensive Plans ("Master Plan")

This project is consistent with the Town of Farmington's local comprehensive plan as amended in 2011.

2.2.1.2. Local Private Development Plans

There are no planned or approved developments within the project area that would impact traffic operations at the intersection of CR 28 and Shortsville Road.

The South Farmington Cemetery Association has plans to renovate the existing, on-site chapel building. The goal is to make the building into usable meeting space for the cemetery association and to rent it out to community groups, families of those being buried, and the public. The Cemetery Association also purchased additional land to the east and south of the existing parcel and will be developing a plan for the allocation of future grave sites.

2.2.2. Transportation Corridor

2.2.2.1. Importance of the Project Route Segment

CR 28 travels north and south, connecting NY Route 332 in the City of Canandaigua with NY Route 31 in Wayne County, just east of the Village of Macedon. Shortsville Road travels east and west, connecting NY Route 332 (via a portion of CR 41) in the Town of Farmington's developing business center with NY Route 21 in the Village of Shortsville. CR 28 and Shortsville Road collect traffic from intersecting local roads and adjoining private properties and feed it to the connecting network of arterial roadways. Both roadways also accommodate commuter, residential, recreational, and agricultural traffic.

2.2.2.2. Alternate Routes

CR 8 (2.1 miles to the west) and NY Route 21 (2.4 miles to the east) are potential alternate routes for CR 28. Both connect NY Route 332 and NY Route 31.

A combination of Canandaigua-Farmington Townline Road, CR 28, Schoolhouse Road, Sand Hill Road, and Latting Road (0.8 miles to the south) could serve as a southern alternative to Shortsville Road. NY Route 96 (0.8 miles to the north) could serve as a northern alternative. Both routes connect NY Route 332 and NY Route 21.

2.2.2.3. Corridor Deficiencies and Needs

There are no elements within the corridor that limit mobility through the area. Intersection safety improvements are necessary to reduce the number and severity of crashes as outlined in **Section 2.3.1.8**.

2.2.2.4. Transportation Plans

This project is on the approved GTC TIP under PIN 4ON0.03. It is described as the CR 28 at Shortsville Road Intersection Improvement. Highway Safety Improvement Program (HSIP) funds have been programmed for design, construction, and property acquisition activities.

2.2.2.5. Abutting Highway Segments and Future Plans for Abutting Highway Segments

CR 28 is owned by Ontario County. It extends from NY Route 332 in the south to CR 312 (Alderman Road) at the Wayne County line. It is a two-way, two-lane rural minor collector roadway. The New York State statutory speed limit of 55 miles per hour applies. Travel lane and paved shoulder widths are typically 11 feet and 5 feet, respectively.

Shortsville Road is owned by the Town of Farmington. It begins at the intersection of CR 8 and CR 41 to the west and extends east to the Village of Shortsville. It is a two-way, two-lane rural local roadway with a combination of asphalt and gravel shoulders. The New York State statutory speed limit of 55 miles per hour applies. Lane and paved shoulder widths are typically 11 feet and 2 feet, respectively.

It's interesting to note that the intersection of CR 28 and Shortsville Road is the only location where Shortsville Road traffic must stop along the entire length of the roadway. Vehicles can start traveling on Shortsville Road at a roundabout located 2.2 miles west of the subject intersection, must stop at CR 28, and need not stop again until reaching a traffic signal at NY Route 21 in the Village of Shortsville.

Ontario County Public Works and the Town of Farmington Highway Department have each confirmed that there are no plans to reconstruct or widen these roadways within the next 20 years.

2.3. Transportation Conditions, Deficiencies and Engineering Considerations

2.3.1. Operations (Traffic and Safety) & Maintenance

2.3.1.1. Functional Classification and National Highway System (NHS)

Classification data for the roadways approaching the subject intersection are summarized in **Exhibit 2.3.1.1**.

Exhibit 2.3.1.1
CR 28 and Shortsville Road Classification Data

Street Name	CR 28	Shortsville Road
Functional Classification	Rural Minor Collector	Rural Local Road
National Highway System (NHS)	No	No
Designated Truck Access Route	Yes	No
Qualifying Highway	No	No
Within 1 mile of a Qualifying Highway	No	No
Within the 16-foot vertical clearance network	No	No

2.3.1.2. Control of Access

There is no control of access along any approach roadways. Refer to **Section 2.3.3.1 (6)** for information on driveways within the project limits.

2.3.1.3. Traffic Control Devices

The intersection of CR 28 and Shortsville Road operates as a two-way stop. Stop signs (R1-1) are posted on both the eastbound and westbound (Shortsville Road) approaches. A stop sign is present on either side of the road on both approaches. Ontario County upgraded the stop signs with right-side, solar-powered, red, dual-flashing beacon assemblies and left-side, standard signs with red retro-reflective strips on the posts to enhance visibility in 2018 using county forces and funds. Additionally, stop ahead (W3-1) signs were upgraded on the eastbound and westbound approaches with right-side, solar-powered, amber, dual-flashing beacons and left side standard signs with yellow retro-reflective strips on the posts. There are advance intersection warning signs (W2-1) on the left and right sides of both the northbound and southbound (CR 28) approaches to the intersection. These were dual posted as part of the interim safety improvements. The existing 45 mile per hour advisory speed panels (W13-1P) were removed at that time. The warning sign posts include yellow retro-reflective strips to enhance visibility. There are street name signs (D3-1) for CR 28 and Shortsville Road in the southwest corner of the intersection.

Signs and sign posts within the project limits are in good condition based upon field inspection. Signs are also generally compliant with the National Manual on Uniform Traffic Control Devices, New York State

Supplement, and applicable revisions (MUTCD), except as follows: The street name signs have legends written in all capital letters. The stop ahead signs on Shortsville Road are located approximately 800 feet in advance of the stop line which exceeds the guidelines presented in the New York State Supplement. The advance intersection warning signs on CR 28 are located between 770 and 800 feet upstream of the intersection, also exceeding the guidelines presented in the New York State Supplement.

Pavement markings on CR 28 are in good condition based on field inspection. A double yellow (full barrier) line (prohibiting passing) separates traffic south of the intersection for approximately 645 feet. Passing is allowed in the southbound direction just south of the double yellow line. A double yellow line also prohibits passing in both directions for approximately 135 feet north of the intersection. Passing is allowed in the northbound direction just north of the double yellow line.

Pavement markings on Shortsville Road are in good condition based on field inspection. A yellow partial barrier line allows passing as one travels away from the intersection in both directions. There are also white stop lines on each Shortsville Road approach to CR 28. 24" stop bars were recently installed as part of the County's interim safety improvements.

2.3.1.4. Intelligent Transportation Systems (ITS)

There are no ITS systems in operation or planned for the project area.

2.3.1.5. Speeds and Delay

There are no speed limit signs within the project limits; therefore, New York State's statutory speed limit of 55 mph applies to all approach roadways as shown in **Exhibit 2.3.1.5**. Speed studies were conducted by Ontario County on all intersection approaches in May 2018. Speed data summaries are available in **Appendix C**. The 85th percentile speed is that speed at which or below 85 percent of all vehicles travel. The measured 85th percentile speed is higher than the posted speed limit of 55 mph on all approach roadways except westbound Shortsville Road. The results are summarized in **Exhibit 2.3.1.5**.

Exhibit 2.3.1.5
Speed Data

Roadway (Approach)	CR 28 (South)	CR 28 (North)	Shortsville Road (West)	Shortsville Road (East)
Existing Speed Limit	55 mph	55 mph	55 mph	55 mph
85th Percentile Speed	58 mph	63 mph	56 mph	53 mph

Note: Speed information given in the direction of travel approaching the intersection

2.3.1.6. Traffic Volumes

2.3.1.6. (1) Existing traffic volumes – Continuous 24-hour traffic volume counts were collected by Ontario County in May 2018. Two-way Average Daily Traffic (ADT) volumes for an average weekday (Tuesday through Thursday) were calculated from the data. Existing ADT volumes appear in **Exhibit 2.3.1.6 (1)-1**. Additional statistics are provided in **Exhibit 2.3.1.6 (1)-2**. Based upon field observation, no significant delays are currently experienced within the project limits; therefore, travel delay studies were not performed.

Exhibit 2.3.1.6 (1)-1 CR 28 and Shortsville Road Existing and Future Traffic Volumes				
Roadway (Approach)	**CR 28 (South)**	**CR 28 (North)**	**Shortsville Road (West)**	**Shortsville Road (East)**
Year	**ADT**	**ADT**	**ADT**	**ADT**
Existing (2018)	3660	3840	2140	2170
ETC (2020)	3740	3920	2190	2220
ETC+20 (2040)	4560	4780	2670	2710

Notes: 1. Refer to **Section 2.3.1.6. (2)** for growth rates.
2. ETC is the Estimated Time of Completion

Exhibit 2.3.1.6 (1)-2 Traffic Composition Data				
Roadway (Approach)	**CR 28 (South)**	**CR 28 (North)**	**Shortsville Road (West)**	**Shortsville Road (East)**
Directional Split	50/50	51/49	53/47	59/41
% Trucks	8	15	8	8

Notes: 1. Splits and percentages are based on daily traffic
2. Order of splits = EB/WB, SB/NB

Additionally, Ontario County conducted manual turning movement counts at the intersection of CR 28 and Shortsville Road. The traffic counts were collected on Thursday May 17, 2018 from 7:00 AM to 9:00 AM and 4:00 PM to 6:00 PM. The weekday AM and PM peak hours at the intersection occurred from 7:00 AM to 8:00 AM and 4:30 PM to 5:30 PM, respectively. Count data and peak hour volume diagrams are contained in **Appendix C, Exhibit 2.3.1.6 (1)-3** through **Exhibit 2.3.1.6 (1)-5**.

2.3.1.6. (2) Future no-build design year traffic volume forecasts – The Estimated Time of Completion (ETC) is 2020. A design year of 2040 (ETC+20) was selected per Appendix 5 of the NYSDOT Project Development Manual. Traffic volume projections were completed for ETC (2020) and the design year ETC+20 (2040). A growth rate of 1.0% was calculated based on historic count information. This growth factor (annually compounded) was used to forecast ADT volumes for the years 2020 and 2040 which appear in **Exhibit 2.3.1.6 (1)-1**. ETC+30 projections were not required as this project does not involve a bridge or large culvert.

The growth rate described above was also applied to the weekday morning and evening peak hour volumes for ETC (2020) and ETC+20 (2040). Peak hour volume diagrams illustrating the ETC and ETC+20 projections are contained in **Appendix C**.

2.3.1.7. Level of Service and Mobility

2.3.1.7. (1) Existing level of service and capacity analysis – Level of Service (LOS) is a qualitative measure describing traveler satisfaction with various factors influencing the degree of traffic congestion including travel time, speed, maneuverability, and delay. The methodology for performing capacity analyses and determining level of service is documented in the Highway Capacity Manual, Sixth Edition: A Guide of Multimodal Mobility Analysis (HCM) (Transportation Research Board, 2016). Levels of service range from A to F. LOS A describes traffic operations with little or no delay while LOS F describes highly congested conditions with substantial delays. LOS D or better is generally considered acceptable for vehicular operations during peak traffic hours in urban areas. LOS C or better is desirable within Ontario County. Analyses (motor vehicle mode of travel) were completed using the Highway Capacity Software (HCS) for the unsignalized intersection of CR 28 and Shortsville Road. Copies of the analysis reports are provided in **Appendix C**.

Results of the level of service analyses for existing conditions during the weekday morning and evening peak hour periods are summarized in **Exhibit 2.3.1.7 (1)-1** and **Exhibit 2.3.1.7 (1)-2**. As shown, all stop controlled and critical movements (moves that must yield to oncoming traffic) currently operate at LOS B or better. The intersection is currently operating acceptably and has adequate capacity to serve all peak hour motor vehicle demand.

Exhibit 2.3.1.7 (1)-1
Morning Peak Hour Level of Service and Delay
Existing and No Build Conditions

Intersection	Approach	Movement	Control	2018 Existing		2020 No-Build		2040 No-Build	
				Delay (sec/veh)	LOS	Delay (sec/veh)	LOS	Delay (sec/veh)	LOS
CR 28 / Shortsville Road	Northbound	Left	YIELD*	7.7	A	7.7	A	7.9	A
	Southbound	Left	YIELD*	7.5	A	7.5	A	7.6	A
	Eastbound	Left/Thru/Right	STOP	14.6	B	14.8	B	17.9	C
	Westbound	Left/Thru/Right	STOP	13.7	B	13.8	B	16.4	C

* - Movement has no sign control, however, left turns must yield to oncoming traffic when present.

Exhibit 2.3.1.7 (1)-2
Evening Peak Hour Level of Service and Delay
Existing and No Build Conditions

Intersection	Approach	Movement	Control	2018 Existing		2020 No-Build		2040 No-Build	
				Delay (sec/veh)	LOS	Delay (sec/veh)	LOS	Delay (sec/veh)	LOS
CR 28 / Shortsville Road	Northbound	Left	YIELD*	7.5	A	7.5	A	7.6	A
	Southbound	Left	YIELD*	7.7	A	7.7	A	7.8	A
	Eastbound	Left/Thru/Right	STOP	13.6	B	13.7	B	16.3	C
	Westbound	Left/Thru/Right	STOP	13.2	B	13.3	B	15.7	C

* - Movement has no sign control, however, left turns must yield to oncoming traffic when present.

2.3.1.7. (2) Future no-build design year level of service – Level of service analyses were also completed for future no-build conditions at ETC (2020) and ETC+20 (2040). They are summarized in **Exhibit 2.3.1.7 (1)-1** and **Exhibit 2.3.1.7 (1)-2.** According to the projected future no-action analyses, all intersection approaches would experience negligible, if any, increases in delay. Both intersections are projected to have adequate capacity to meet the anticipated demand with acceptable levels of service throughout the design year (2040).

2.3.1.8. Safety Considerations, Accident History and Analysis

An accident analysis was performed in accordance with the NYSDOT Highway Design Manual Chapter 5, Section 5.3.

For this project, accident reports were compiled from New York State Accident Location Information System (ALIS) data. New York State Department of Motor Vehicles (NYSDMV) Police Accident Reports (MV-104A forms) were also obtained by Ontario County covering a five-year and two-month period from January 1, 2011 to March 31, 2016. There are no high accident locations (HALs), no Priority Investigation Locations (PILs), Safety Deficient Locations (SDLs), or Priority Investigation Intersections (PIIs) within the study area as those designations are made by the NYSDOT for state highways.

A total of 17 intersection-related collisions occurred over the five-year and two-month period from January 2011 to March 2016. Injuries resulted from 7 of the 17 accidents. Two resulted in a fatality. The predominant collision pattern (13 of 17) involved right angle crashes. The calculated average annual accident rate per million entering vehicles (ACC/MEV) is 1.95 ACC/MEV, which is 6 times higher than the regional 0.33 ACC/MEV threshold. Non-reportable accidents were not included in the accident rate calculation.

As stated above, 76% of the accidents were right angle collisions. Contributing factors typically included failure to yield the right of way and failure to stop. Several accident reports suggested that drivers on Shortsville Road stopped but then failed to notice an approaching vehicle and pulled into the intersection to generate the conflict. Time of day and roadway surface conditions did not appear to be contributing factors. Field observations confirm sight restrictions, resulting from a roadside embankment, mature trees, and adjacent residential homes. The intersection also appears hidden from the perspective of southbound drivers on CR 28 approximately 700 to 800 feet north of Shortsville Road. Relatively high northbound and southbound approach speeds may be complicating gap selection for eastbound and westbound drivers and contributing to the documented accident pattern.

More recent accident data covering a two-year period from April 1, 2016 to December 31, 2017 were also obtained by Ontario County. During this period, a total of 5 reportable intersection-related collisions occurred with 4 resulting in injury. All 5 accidents were right angle crashes with failure to yield the right of way as a contributing factor. This validates the earlier study and suggests there has been no change to the accident pattern or contributing factors.

A table summarizing the 22 intersection accidents is included in **Appendix C**. A collision diagram is also included in **Appendix C**.

2.3.1.9. Existing Police, Fire Protection and Ambulance Access

The Ontario County Sheriff's Office routinely passes through the project area. Their headquarters is in Canandaigua, which is approximately 3.7 miles south of the intersection. New York State Police, Troop E, also uses roadways within the project area. Their headquarters is located approximately 4.3 miles away on NY Route 332, north of Canandaigua.

Shortsville Fire and Ambulance provide primary coverage to properties at the subject intersection. Their facility is located on Sheldon Street approximately 3 miles east of the intersection in the Village of Shortsville. Victor-Farmington Ambulance, which is on East Victor Road approximately 6 miles west of the site, also passes through the intersection.

2.3.1.10. Parking Regulations and Parking Related Conditions

There are no areas regulated by parking restrictions within the project limits.

2.3.1.11. Lighting

There is no street lighting within the project limits.

2.3.1.12. Ownership and Maintenance Jurisdiction

Ontario County owns and maintains CR 28. The County has a contract with the Town of Farmington for snow and ice control services. Basic services provided under the contract include: snow watch and dispatching; purchase, storage and application of salt and abrasives from Town stockpiles; snow plowing and wingback work; field supervision of salting and plowing activities; and observance of customary practice for correction of snow plow damage. Shortsville Road is owned and maintained by the Town of Farmington. The existing maintenance jurisdiction within the project limits is summarized in **Exhibit 2.3.1.12**.

Exhibit 2.3.1.12 Existing Maintenance Jurisdiction							
Part No.	Highway	Limits	Feature(s) being Maintained	Centerline (mile)	Lane (mile)	Agency	Authority
1	CR 28	750 feet south of Shortsville Road	Pavement, drainage, landscaping, signs, and pavement markings	0.14	0.28	Ontario County	Highway Law Section 129
2	CR 28	1200 feet north of Shortsville Road	Pavement, drainage, landscaping, signs, and pavement markings	0.23	0.46	Ontario County	Highway Law Section 129
3	Shortsville Road	1000 feet west of CR 28	Pavement, drainage, landscaping, signs, and pavement markings	0.19	0.38	Town of Farmington	Highway Law Section 10 Subdivision 25
4	Shortsville Road	750 feet east of CR 28	Pavement, drainage, landscaping, signs, and pavement markings	0.14	0.28	Town of Farmington	Highway Law Section 10 Subdivision 25

2.3.2. Multimodal

2.3.2.1. Pedestrians

There are no separate pedestrian facilities or provisions within the project limits and no signs of frequent pedestrian activity. There is low-density residential development in the project area that generates infrequent pedestrian travel. Pedestrian trips that do exist are anticipated to be primarily recreational trips without a specific destination along with some residence to residence travel. There are no plans for substantial generators of pedestrian traffic within or adjacent to the project limits. The occasional pedestrian may legally use the paved shoulder per the provisions of NYS Vehicle and Traffic Law Section 1156(b). A Capital Projects Complete Streets Checklist is contained in **Appendix C.**

2.3.2.2. Bicyclists

There are no separate provisions for bicyclists along any of the roadways within the project limits. Bicyclists share the road with motor vehicles or may legally use the paved shoulder where available. The existing level of and potential for bicycling is characterized as low due to the rural nature of the project area. There are generators of infrequent bicycle traffic within and near the project limits, such as residential homes. The route is not a designated bicycle route.

2.3.2.3. Transit

There are no transit providers operating within the project limits.

2.3.2.4. Airports, Railroad Stations, and Ports

There are no airports, railroad stations or port entrances within or in the vicinity of the project limits. No conflicts exist with the flight paths of aircraft.

2.3.2.5. Access to Recreation Areas (Parks, Trails, Waterways, State Lands)

There is a vehicular entrance to Meeting House Park located within 60 feet of the western edge of CR 28. The entrance is approximately 40 feet wide and paved with gravel. The Town of Farmington Highway Department had considered paving the entrance in the past to create a more hospitable parking area; however, that action has been postponed allowing for coordination with this project.

2.3.3. Infrastructure

2.3.3.1. Existing Highway Section

Existing features within the project corridor appear on the typical sections, plan, and profile sheets contained in **Appendix A**.

2.3.3.1.(1) Lane and Shoulder Widths -

Travel lane and shoulder widths along CR 28 and Shortsville Road are summarized in **Exhibit 2.3.3.1 (1).** Shoulders are paved with asphalt. The presence, condition, and width of stabilized shoulder backup material (e.g. crushed stone or compacted millings) varies throughout the project limits and in some areas, is missing. Shoulder edge drop-offs exist along portions of CR 28. Shoulders are generally flush with the backup material along Shortsville Road adjacent to the intersection.

Exhibit 2.3.3.1 (1)
Lane and Shoulder Widths

Street Name	CR 28	Shortsville Road
Travel Lane Width	11 feet typical, 12 feet (see Note 1)	11 feet
Shoulder Width	5 feet typical, 6 feet (see Note 1)	2 feet

Notes: 1. Within limits of 2006 Reconstruction. Wider shoulders and travel lanes extend approximately 500 feet north of CR 28's intersection with Shortsville Road.

2.3.3.1.(2) Horizontal Alignment -

Intersection approach roadways are generally straight (on a tangent alignment) within the project limits. There is a horizontal curve on CR 28 approximately 0.6 miles south of the intersection. There are horizontal curves on Shortsville Road approximately 0.5 miles west and 0.3 miles east of the intersection.

2.3.3.1.(3) Vertical Profiles -

All approach roadway profiles generally follow the level terrain found throughout the project limits. There is a 200-foot long vertical crest curve on CR 28 located approximately 900 feet south of the intersection with a 1.18% grade up from the south and a 0.94% grade down to the north. Heading from south to north, there is a short sag vertical curve just south of the intersection with Shortsville Road, leading into a 0.31% upgrade. From there, a 700-foot long crest vertical curve located approximately 323 feet north of the intersection. There is a 1.90% downgrade from that point north. The final sag vertical curve on CR 28 within the project limits is approximately 600-feet long and is located approximately 900 feet north of the intersection. The exit grade is 0.92%.

On Shortsville Road, starting at the western project limits, there is a crest vertical curve with an approximate 1.0% downgrade leading into the intersection with CR 28. Immediately east of the intersection, there is a small sag vertical curve prior to heading into a long ~0.5% upgrade to the eastern project limits.

2.3.3.1.(4) Intersection Geometry -

CR 28 and Shortsville Road intersect at a skewed (approximately 60°) angle. All intersection approaches consist of a single inbound lane and a single departure lane. There are no exclusive turn lanes. Relatively wide pavement aprons exist in the northwest and southeast corners of the intersection to accommodate turning trucks and buses.

2.3.3.1.(5) Roadside Elements -

Roadside elements include wooden utility poles, traversable granite curb, drainage ditches, and roadside embankments. The existing clearance from the edge of the travel lane to the face of utility poles is generally 12 feet or more. The locations of utility poles are shown on the plans in **Appendix A.** Other notable roadside elements include:

- A large, mature willow tree located immediately behind the southern ditch line of Shortsville Road approximately 130 feet east of the intersection;
- A stand of mature pine trees at the top of the western embankment along CR 28 in Meeting House Park between approximately 100 and 300 feet north of the intersection;
- Traversable granite curb along both the east and west sides of CR 28 for 750 feet north of the intersection;
- A 65-foot long segmental block retaining wall in front of the house at 1561 CR 28 located approximately 130 feet north of the intersection; and
- An existing Town of Farmington Water Department vault located approximately 75 feet south of the intersection along the west side of CR 28.

Other roadside areas are typically bordered by agricultural fields that are planted and rotated seasonally. The accident analysis summarized in **Section 2.3.1.8** revealed no patterns of accidents involving fixed objects along the roadside.

2.3.3.1.(6) Driveways -

Driveways within the project limits include the following:

Exhibit 2.3.3.1 (6)
Driveway Summary

Address / Location	Side	Apron Material	Function	Comments
1593 CR 28	East	Asphalt	Residential	
1561 CR 28	East	Asphalt	Residential	
1561 CR 28	East	Asphalt	Residential	
CR 28	East	Asphalt	Agricultural Access	
Shortsville Road	North	Gravel	Recreational Access	Meeting House Park
4899 Shortsville Road	South	Gravel	Cemetery Access	South Farmington Cemetery

Most of the driveways are generally in conformance with the written requirements specified in the NYSDOT Policy and Standards for the Design of Entrances to State Highways. The access to Meeting

House Park in the northwest corner of the intersection is approximately 35 feet wide and its closest edge is approximately 58 away from the edge of the southbound travel lane on CR 28. This access is closer to CR 28 than recommended by the NYSDOT Policy and Standards for the Design of Entrances to State Highways. Based on field observations, local farmers also access properties north and south of Shortsville Road, east and west of CR 28, directly from the shoulder without a formal access drive.

2.3.3.2. Geometric Design Elements Not Meeting Minimum Standards

Existing geometric elements were compared with the minimum standards used by the NYSDOT to make capital infrastructure improvements. This review helps ensure that project objectives and feasible alternatives consider key deficiencies. The relationship of features not meeting standards to the accident history is noted in **Section 2.3.3.2 (1)**.

2.3.3.2.(1) Critical Design Elements – Critical design elements are compared with the minimum design criteria for capital improvements. Any critical design element that fails to meet the minimum design standards is considered a "non-standard" feature and should be evaluated for remediation and mitigation. Non-standard features were identified based on the maximum allowable design speed for the roadway's functional class and are summarized in **Exhibit 2.3.3.2 (1)**. This is supported by studies summarized in **Section 2.3.1.5**, which show that current operating speeds exceed the speed limit.

Exhibit 2.3.3.2 (1)
Existing Nonstandard Features

Critical Design Element	Operating Speed(s)[2]	Standard[1]	Existing Condition	Adverse Accident History? (Yes/No)	Remarks
Lane Width: CR 28	58 to 63 mph	12 ft	11 ft	No	Accident rate is greater than state wide average. Lane width is not related to the accident experience.
Shoulder Width: CR 28	58 to 63 mph	6 ft	4 ft min. 5 ft max.	No	
Shoulder Width: Shortsville Road	53 to 56 mph	6 ft	4 ft	No	
Lane Cross Slope: CR 28	58 to 63 mph	1.5 min. / 3% max.	Varies from 2% to 4.5% max	No	
Lane Cross Slope: Shortsville Road	53 to 56 mph	1.5 min. / 3% max.	Varies from 1.5% to 5.0% max	No	

Notes: 1. Minimum standards based on NYSDOT HDM Chapter 7, Rural, Non-Freeway 3R standards.
2. Design speed of 60 miles per hour (mph) for CR 28 and 55 mph for Shortsville Road was selected for determination of non-standard features based on operating speeds / 85th percentile speed. Refer to **Section 2.3.1.5**.

2.3.3.2.(2) Other Design Parameters - Design parameters that are not critical design elements but depart from typical design practice are identified as non-conforming features. These features can have a considerable effect on operational efficiency and safety. Existing non-conforming features within the project limits are described below.

Crest Vertical Curve Length – Based upon record plans, the crest vertical curve at the southern project limit has a length less than the recommended minimum stopping sight distance. Reviewing the stopping sight distance in the field, it is adequate. The minimum stopping sight distance is desired for appearance and comfort, however not meeting this guidance is not atypical for rural roads.

Intersection Sight Distance – Based on visual inspection, eastbound intersection sight distance is limited to the north by the roadside embankment and mature trees in and adjacent to Meeting House Park. Additionally, during the summer months, sight distance is often further limited to the north by roadside vegetation. Westbound intersection sight distance is limited to the north by the adjacent residential home.

Guide Rail – Existing box beam guide rail in the southwest corner has end sections that are no longer approved for use.

Clear Zone – Based upon a field review, utility pole offsets from the edge of traveled way vary throughout the project limits and define the operational clear zone. Utility pole offsets from the edge of the traveled way are as follows:

- CR 28 - Approximately 15 feet
- Shortsville Road – Approximately 12 feet

The clear zone at the intersection of CR 28 and Shortsville Road is limited by the box beam guide rail in the southwest corner, which is approximately 6 feet from edge of the traveled way.

Centerline Audible Roadway Delineators (CARDS) – CR 28 and Shortsville Road do not have CARDS installed along the roadway centerline. CR 28 is of sufficient width and traffic volume per the guidance provided in NYSDOT Engineering Instruction EI 13-021 to have CARDS installed. It is not standard practice for Ontario County to install CARDS along its roadways.

2.3.3.3. Pavement and Shoulder

CR 28, along with the intersection at Shortsville Road, was originally constructed in its current form in 1967. The pavement was last chip sealed in June 2018 and at periodic intervals before that according to Ontario County's pavement history maintenance reports. Prior to the chip seal treatment, the pavement surface appeared in good condition based on field observation, showing some signs of longitudinal cracking along the shoulder and minor rutting in the travel lanes. Signs of shoulder pavement repairs (asphalt shimming) were also visible. In 2006 Ontario County completed a project to lower the profile of CR 28 within 750 feet of Shortsville Road to improve sight distance. That project involved full depth reconstruction of the asphalt pavement and resurfacing of the remaining intersection approaches.

Shortsville Road's pavement surface is also in good condition based on field observation, showing signs of periodic oil and stone surface treatments.

A series of 17 test borings were taken by Ontario County at the intersection of CR 28 and Shortsville Road in 2005, in preparation for the 2006 reconstruction project. Fifteen of the 17 borings included roadway cores to examine the existing pavement structure.

Pavement thicknesses in CR 28's travel lanes range from 4.5 inches to 6.5 inches. Shoulder thicknesses range from 1.25 to 4.5 inches. Record plans for the 2006 reconstruction of CR 28, north of Shortsville Road, indicate a 9.5-inch pavement section was constructed on 6 inches of subbase. Cores taken from Shortsville Road, east and west of CR 28, revealed 3 to 5 inches of asphalt pavement. All core samples showed the existing pavement structure to be in relatively good condition, with adequate bonding between the individual asphalt layers.

A Pavement Evaluation and Treatment Selection Report (PETSR) is included in **Appendix D**. Pavement core logs are included in **Appendix E**.

2.3.3.4. Drainage Systems

The existing drainage system primarily involves sheet flow that drains into open roadside ditches and underground cross culverts of varying sizes and materials. Based upon visual inspection, the existing ditches and pipes are in fair to good condition. Flow in open ditches is typically impeded by relatively flat grades.

South of the intersection, sheet flow from CR 28 drains toward a cross culvert just south of Shortsville Road. North of the intersection, CR 28 sheet flow is collected by drainage ditches on either side of the road that flow north to an unnamed tributary creek. Shortsville Road runoff, west of the intersection,

travels in shallow roadside ditches toward the intersection. In some cases, sheet flow can also be deposited directly into the adjacent agricultural properties. East of the intersection, Shortsville Road sheet flow is collected in roadside ditches and travels west toward the intersection.

Sheet flow captured in roadside ditches along the south, west, and east approaches is conveyed around the intersection by a combination of closed and open systems to the northeast quadrant. Aerial photography suggests flow is then carried to the northeast, though a meandering swale across adjacent farmland, eventually reaching the same unnamed tributary creek that crosses CR 28 at the project area's northern limit. Water often ponds in the low points and roadside ditches, particularly during the spring and fall, in the southwest, southeast, and north east quadrants. Ponding also occurs in the adjacent agricultural fields.

The closed system mentioned above consists of an existing 3-foot by 3-foot square drainage inlet that captures runoff in the northwest corner of the intersection. Water in that structure, and from the driveway culvert beneath the Meeting House Park driveway, drains south across Shortsville Road in an 18-inch reinforced concrete pipe (RCP) to the southwest corner. From there, flow is carried across CR 28 in another 18-inch RCP which outlets to a ditch in the southeast corner of the intersection. Flow is then carried east in a roadside ditch to an 18-inch HDPE pipe cross culvert located approximately 120 feet east of the intersection, conveying the flow to the northeast quadrant.

2.3.3.5. Geotechnical

A series of 17 test borings were taken by Ontario County at the intersection of CR 28 and Shortsville Road in 2005 in preparation for the 2006 reconstruction project. The geotechnical evaluation report and boring logs are included in **Appendix E.** Subgrade soils generally consisted of brown to reddish-brown silt, silt and sand, and silt and clay/clayey silt. The soils were generally found to be moist. Ground water was not encountered within the boring depths of 6 to 10 feet, although it was anticipated that it could be encountered at depths beyond 10 feet and be subject to seasonal variation. No bedrock was encountered; however, Ontario County and the Town of Farmington have anecdotally noted the presence of shallow bedrock along the northern approach. Ontario County plans additional borings to assess the potential for encountering bedrock in the spring of 2019. No special geotechnical concerns were noted within the project area and the underlying soils were deemed suitable for roadway construction.

2.3.3.6. Structure

There are no bridges within the project limits.

2.3.3.7. Hydraulics of Bridges and Culverts

There are no bridges or culverts over waterways within the project limits. There are no dams in the vicinity of the project that would be adversely affected.

2.3.3.8. Guide Railing, Median Barriers and Impact Attenuators

A summary of the existing guide railing within the project limits is provided in **Exhibit 2.3.3.8.**

Exhibit 2.3.3.8
Existing Guide Railing

Type	Location/Side	Length	Condition
Box Beam	Southwest corner of the CR 28 and Shortsville Road intersection	190 ft	Good condition overall. Run includes a Type I end section at either end. These are no longer approved for use in new construction projects in New York State. Protects a 4-foot high 1:3 slope and existing pressure reducing valve vault.

2.3.3.9. Utilities

Utilities within the project limits include underground water mains. There are also overhead electric, telephone, and cable suspended from utility poles. The existing utilities within the vicinity of the project limits are described in **Exhibit 2.3.3.9**.

Exhibit 2.3.3.9
Existing Utilities

Owner	Type	Location/Side
Town of Farmington	Water	West side of CR 28 throughout the project limits. North side of Shortsville Road, west of CR 28. Crossing of CR 28 along the north side of Shortsville Road, dead ends on east side. Existing pressure reducing valve vault along the west side of CR 28, south of Shortsville Rd.
RG&E	Electric	Overhead – West side of CR 28 for 300 ft north and south of Shortsville Road. East side of CR 28 from there to the project limits. North side of Shortsville Road throughout the project limits.
Windstream	Telephone	Overhead – West side of CR 28 for 300 ft north and south of Shortsville Road. East side of CR 28 from there to the project limits. North side of Shortsville Road throughout the project limits.
Charter Communications	Fiber Optic	Proposed Overhead – West side of CR 28 for 300 ft north and south of Shortsville Road. East side of CR 28 from there to the northern project limits. North side of Shortsville Road, west of CR 28.

2.3.3.10. Railroad Facilities

There are no railroads within the project limits and no at-grade crossings within ½ mile that could impact traffic conditions.

2.3.4. Potential Enhancement Opportunities

This section focuses on the existing areas to identify potential enhancement opportunities related to the project and to help avoid and minimize impacts. Chapter 4 focuses on the impacts, enhancements, and mitigation.

2.3.4.1. Landscape

2.3.4.1. (1) Terrain - The terrain within the project limits is classified as level per Section 2.5.2 of the NYSDOT Highway Design Manual.

2.3.4.1. (2) Unusual Weather Conditions - There are no unusual weather conditions within the project area that would affect the design and construction of this project. Snow and ice events experienced within the project limits during the winter months are typical of New York State. The Town of Farmington noted drifting snow can hinder sight lines to the north for vehicles stopped on Shortsville Road.

2.3.4.1. (3) Visual Resources - Land uses within and around the project limits are residential, agricultural, and recreational. There is one residential structure located along the east side of CR 28, north of the intersection. There is another residential structure located along the east side of CR 28, south of the intersection. Both homes generally have large, mature trees located alongside and behind the houses. Meeting House Park is located in the northwest corner of the intersection and is home to a stand

of large, mature pine trees. South Farmington Cemetery is located approximately 650 feet west of the intersection on Shortsville Road. The remaining properties within and around the project limits are open fields for agricultural use. The surrounding terrain can be characterized as primarily level to rolling, therefore sight lines are generally open between all surrounding land uses except as blocked by trees.

2.3.4.2. Opportunities for Environmental Enhancements

Practical opportunities for environmental initiative actions that could be considered in conjunction with this project include enhanced landscaping and the construction of a new entrance and parking area for Meeting House Park.

2.3.5. Miscellaneous

None.

CHAPTER 3 – ALTERNATIVES

This chapter discusses the alternatives considered for the CR 28 and Shortsville Road Intersection Improvement project (hereafter "the project") and examines the engineering aspects for alternatives that were determined to be feasible and practical to address the project objectives in **Chapter 1** of this report.

3.1. Alternatives Considered and Eliminated from Further Study

Alternative 1: No Action/Maintenance

The No Action/Maintenance or "null" alternative would retain the existing conditions at the intersection of CR 28 and Shortsville Road with no improvements other than routine maintenance activities. This would not improve vehicular safety at the intersection. This alternative does not satisfy the purpose and need of the project; however, it has been retained as a baseline for comparison to the feasible alternative(s).

Alternative 2: Incremental Signing and Pavement Marking Enhancements

A set of incremental signing and pavement marking enhancements (described below) were considered for the intersection of CR 28 and Shortsville Road. The intent of this progression would be to enhance the conspicuity of existing traffic control devices, highlight the intersection's location, and reinforce the message to drivers on Shortsville Road that traffic on CR 28 is not required to stop.

A. Add supplementary panels to the Shortsville Road stop signs with the text "Cross Traffic Does Not Stop". One sign would be placed below the near right stop sign and the other on the far left;

B. Add yellow flashing beacons to the right-side advance intersection warning signs on CR 28; and

C. Install a lane narrowing treatment on CR 28 at Shortsville Road consistent with guidance contained in the Federal Highway Administration (FHWA) report Two Low-Cost Safety Concepts for Two-Way Stop-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways. This would consist of a painted yellow median on the CR 28 approaches preceded by a no passing zone, centerline rumble strips within the painted median, and rumble strips on the outside shoulders. Smaller painted islands could also be added to each Shortsville Road approach. Refer to **Appendix A** for a graphic illustrating this concept.

As described in **Section 2.3.1.8**, most accidents at the intersection involve a right-angle collision. Many vehicles stop on Shortsville Road but fail to perceive and/or react to an approaching vehicle, ultimately pulling out into the intersection and causing a crash. Simply highlighting the need to stop on Shortsville Road is therefore unlikely to lead to a substantial reduction in accidents. Incremental treatments along CR 28 would improve the intersection's conspicuity. While initial studies of the FHWA concept have demonstrated some ability to reduce approach speeds and overall crash rates, long-term effectiveness remains unproven and further analysis is needed. While milled in audible roadway delineator strips (MIARDS) within the median and along the shoulders of CR 28 would encourage drivers to remain within the narrower lanes, they could also result in nuisance noise and vibration concerns for adjacent residents, Meeting House Park, and South Farmington Cemetery. This would be of concern given the substantial volume of heavy truck traffic on CR 28. In either case, vehicles on Shortsville Road would still need to select adequate gaps in CR 28 traffic to complete a crossing or turning maneuver. Sight distance limitations between intersection approaches would not be addressed.

While incremental signing and pavement marking enhancements may improve intersection safety performance in the near term, they may also lose their effectiveness over time, particularly at an intersection that is frequented by familiar, local drivers. More importantly, these features do not have the potential to physically prevent high-speed, right-angle collisions from occurring. Ontario County is committed to implementing a proven long-term safety improvement that will address the pattern of right-

angle collisions and maximize use of the available Highway Safety Improvement Program (HSIP) funding. This alternative would not accomplish either of those goals; therefore, it was dismissed from further consideration.

Alternative 3: Multi-Way Stop Intersection Control

Multi-way stop control was evaluated as a potential alternative for the intersection of CR 28 and Shortsville Road. This alternative would add stop signs on the CR 28 (northbound and southbound) approaches resulting in a four way stop. All vehicles approaching the intersection would be directed to stop by the regulatory signs. Detailed calculations and a summary document related to the evaluation of this alternative are included in **Appendix C**.

Assuming vehicles would obey the new regulations, this treatment would have the potential to reduce the frequency of right-angle accidents and mitigate the effects of poor intersection sight distance. It would also eliminate the need for drivers at the stop signs on Shortsville Road to identify adequate gaps to complete a crossing or turning maneuver. The relatively low anticipated initial cost of this alternative (estimated at $18,000) would yield an anticipated safety cost-benefit ratio of 102.65. In comparison, this exceeds the projected safety cost-benefit ratio for the roundabout alternative (8.13 – **Appendix C**), although that number also represents a positive net benefit. The multi-way stop alternative would require no easement acquisitions as opposed to 1.336 acres of easements for the proposed roundabout.

The FHWA offers guidance in the MUTCD to assess the applicability of multi-way stops (refer to Section 2B.07 of the MUTCD). Based upon an engineering study (see **Appendix C**), 3 of the 5 criteria contained in the MUTCD would not be satisfied at the intersection of CR 28 and Shortsville Road throughout the design year, 2040. Only the accident experience and major street volume warrant would be met. Companion minor street volume and intersection delay warrants would not be met.

The multi-way stop alternative would involve placing warning signs, regulatory signs, and markings on the relatively high-speed CR 28 (northbound and southbound) approaches. In comparison, the roundabout alternative would change the geometry of these approaches to encourage motorists to lower their travel speed, thereby decreasing the potential for an injury or fatal accident. The "geometric intervention" proposed under Alternative 5 would have greater potential to result in lower approach speeds in comparison to the signs and markings of Alternative 3.

The FHWA, in their document Toolbox of Countermeasures and Their Potential Effectiveness for Intersection Crashes, suggests that converting a rural two-way stop-controlled intersection could result in up to a 48% reduction in total accidents. The potential for high-speed, rear-end accidents would be of concern at the new stop signs on CR 28 particularly during the adjustment period (immediately after the new regulation is put into effect). By way of comparison, the same FHWA document suggests that converting the two-way stop to a modern roundabout could result in up to an 72% reduction in total accidents, making it superior in that regard. The potential for high-speed rear-end accidents would be mitigated under Alterative 5 by the curvilinear approach geometry. The potential for high-speed, right angle accidents would also be eliminated under Alternative 5 by design.

All vehicles would be required to stop under Alternative 3, including trucks. Potential negative effects from the installation of a multi-way stop could include additional air pollution, noise impacts, and fuel consumption associated with vehicles stopping, idling, and accelerating. In comparison, Alternative 5 (roundabout) would not require vehicles to fully stop when conflicting traffic is absent. Furthermore, capacity analyses suggest that multi-way stop control at the CR 28 and Shortsville Road intersection would result in at least 4 seconds more delay per vehicle in comparison to the roundabout alternative.

While the multi-way stop would initially be less costly and require less property, it does not surpass the roundabout alternative with respect to its potential to reduce the frequency of accidents or meet the objective of encouraging motorists to lower their travel speed on approach to the intersection, thereby decreasing the potential for an injury or fatal accident. This coupled with the fact that 3 of 5 MUTCD warrant criteria for the multi-way stop would not be satisfied, and the fact that all vehicles, including

trucks, must stop at a multi-way stop intersection even in the absence of conflicting traffic, led to the multi-way stop alternative being dismissed from further consideration.

Alternative 4: Signalized Intersection Control

The Signalized Intersection Control alternative would install an actuated, two-phase traffic signal at the intersection of CR 28 and Shortsville Road. Applicable traffic signal warrants in accordance with the MUTCD were analyzed. Copies of the analyses are included in **Appendix C.** The criteria of Warrant 7, Crash Experience, is met, however criteria related to volumes (Warrants 1 thru 3, and the volume criteria of Warrant 7) would not be satisfied throughout the design year, 2040. The installation of a traffic signal would present similar safety and environmental concerns to Alternative 3. An increase in the probability of rear end accidents would also be expected. This would be of concern on the high-speed CR 28 approaches; therefore, this alternative was dismissed from further consideration.

3.2. Reasonable Build Alternatives

Based on the project purpose, objectives, needs and a comparison of all alternatives considered, a single reasonable (feasible and practical) alternative was identified and developed for further study in this Draft Design Report.

3.2.1. Description of Reasonable Alternatives

Alternative 5: Modern Roundabout

This alternative would reconstruct the intersection of CR 28 and Shortsville Road as a modern roundabout. A roundabout would physically eliminate the potential for high-speed, right angle collisions by prohibiting left turns and crossing movements. Crashes at modern roundabouts are less likely to result in a serious injury as they typically involve low speeds and low angles of impact. A roundabout at this location would also be consistent with changes made at the nearby intersection of CR 8, CR 41, and Shortsville Road in 2015. Key elements of Alternative 5 are as follows:

Geometry	• Reconfigure the existing four-legged, two-way stop-controlled intersection of CR 28 and Shortsville Road into a modern roundabout. • Construct extended splitter islands with successive entry curves on each approach to "step down" vehicular speeds prior to reaching the yield line.
Operational	• Require entering vehicles to yield to traffic within the circulating roadway as typical of modern roundabout control. • Provide adequate capacity to meet the projected traffic demand throughout the design year, 2040.
Pavement	• Full-depth pavement reconstruction at the intersection of CR 28 with Shortsville Road and on all immediate approaches.
Curb	• Install mountable and/or traversable curb, where appropriate, along the proposed roundabout's central island, truck apron, and splitter islands. • Install traversable curb along the shoulders of the circulatory roadway and approaches immediately adjacent to the roundabout to facilitate drainage, maintain a stable roadside, and encourage drivers to remain on the pavement. Shoulders outside of the circulatory roadway and the immediate roundabout approaches would remain uncurbed.

Pedestrian & Bicyclist	• Continue to accommodate occasional pedestrians on paved shoulders. • Construct 10-foot wide crossings through the splitter island on each approach to accommodate the occasional crossing pedestrian. • Continue shared accommodation for bicyclists within the travel lanes. Bicyclists may also choose to dismount and walk their bicycle across the roundabout using the accessible crossings.
Drainage	• Replace existing storm sewer pipe crossings and driveway pipes where in poor condition or alterations are needed to drain the proposed design. • Install toe ditches to prevent roadway runoff from sheeting into adjacent agricultural properties. • Redirect the intersection's primary drainage outlet from a path through agricultural fields to the northeast of the intersection to a path along the east side of CR 28. Both the existing and proposed drainage paths would end at the same unnamed tributary.
Signing and Pavement Marking	• Install new signage and pavement markings in accordance with MUTCD standards.
Landscaping and Enhancements	• Reestablish turf beyond the shoulders. • Install new roadway lighting at the modern roundabout • Install appropriately scaled landscaping in the modern roundabout's central island and strategically placed landscaping at its edges to promote proper sight lines and improve aesthetics. • Install strategically placed landscaping where curvature is introduced on Shortsville Road to reinforce the new alignment.
Right of Way	• Seven property acquisitions (7 permanent easements (PE) and 3 temporary easements) to accommodate construction of the modern roundabout; approach roadway realignment; and associated drainage improvements.
Construction Cost and Phasing	• The opinion of probable construction cost for Alternative 5 is $2.339 million (M).
Project Goals	• These improvements satisfy the purpose, need, and objectives stated in Chapter 1 of this document.

3.2.2 Preferred Alternative

Alternative 5 has been identified as the preferred alternative because it best satisfies the project's purpose and need and objectives. Selection of the preferred alternative will not be finalized until the alternatives' impacts, comments on the draft design approval document, and comments from the public have been fully evaluated.

3.2.3. Design Criteria for Reasonable Alternative(s)

3.2.3.1. Design Standards

The following design standards and resources were consulted to develop the critical design element and other design element parameters for this project:

- NYSDOT *Highway Design Manual* (HDM)
- *National Manual on Uniform Traffic Control Devices for Streets and Highways*, Current Edition (MUTCD)
- *New York State Supplement to the National Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 Edition* (2011)
- AASHTO *A Policy on Geometric Design of Highways and Streets* (Green Book) 2011
- NCHRP Report 672 *Roundabouts: An Informational Guide*, Second Edition

3.2.3.2. Critical Design Elements

The design criteria applicable to this project consist of critical elements as described in the NYSDOT HDM (Chapter 2). Other design parameters, such as design vehicle, are found either in the NYSDOT HDM, the AASHTO Green Book, or other references. A list of the typical critical design elements that apply to this project is included in **Exhibit 3.2.3.2-1**.

Exhibit 3.2.3.2-1
Critical Design Elements Summary

1. Design Speed	9. Vertical Clearance
2. Lane Width	10. Structural Capacity
3. Shoulder Width	11. ADA Compliance
4. Horizontal Curve Radius	
5. Superelevation	
6. Stopping Sight Distance	
7. Maximum Grade	
8. Cross Slope	

Notes:
1. Rollover is the change of grade between the cross slope of adjacent lanes or between travel lanes and the shoulder.

Exhibit 3.2.3.2-2 and **Exhibit 3.2.3.2-3** summarize the critical design elements for CR 28 and Shortsville Road beyond the approaches to the proposed roundabout. Refer to **Section 3.2.3.3** for the Design Parameters associated with the proposed modern roundabout.

Exhibit 3.2.3.2-2
Critical Design Elements for CR 28

PIN:	4ON0.03	NHS (Y/N):	No
Route No. & Name:	CR 28	Functional Classification:	Rural Minor Collector
Project Type:	Safety Improvement	Design Classification:	Rural Collector
% Trucks (Max)[1]:	15%	Terrain:	Level
ADT (2040)[1]:	4,780	Truck Access/Qualifying Hwy.	Yes / No

	Element	Standard	Existing Condition	Proposed Condition
1	Design Speed	60 mph[2] *HDM Section 2.7.3.1.A.*	60 mph	60 mph
2	Lane Width	11 ft *HDM Section 2.7.3.1.B. Exhibit 2-5*	Varies 11 ft to 12 ft	11 ft
3	Shoulder Width	4 ft Minimum, 5 ft Desirable *HDM Section 2.7.3.1.C. Exhibit 2-5, Note 7*	Varies 4 ft to 6 ft	4 ft
4	Horizontal Curve Radius	800 ft Minimum (at e_{max}=8%) *HDM Section 2.7.3.1.D. Exhibit 2-5*	None	None
5	Superelevation	8% Maximum *HDM Section 2.7.3.1.E.*	Normal Crown	Normal Crown
6	Stopping Sight Distance (Horizontal and Vertical)	522 ft Minimum *HDM Section 2.7.3.1.F. Exhibit 2-5*	>522 ft	>522 ft
7	Maximum Grade	5% *HDM Section 2.7.3.1.G. Exhibit 2-5*	1.9% Maximum	3.58% Maximum
8	Cross Slope	1.5% Min. to 3% Max. *HDM Section 2.7.3.1.H.*	4.5% Maximum	2% Maximum
9	Vertical Clearance	14 ft Minimum 14 ft – 6 in Desirable *HDM Section 2.7.3.1.I. &* *BM Section 2.4.1. Table 2-2*	14 ft Minimum (to utilities)	14 ft Minimum (to utilities)
10	Design Loading Structural Capacity	New and Replacement Bridges NYSDOT LRFD Specifications AASHTO HL-93 Live Load and NYSDOT Design Permit Vehicle Buried Structures (Box Culverts, 3-sided Frames and Pipes) NYSDOT LRFD Specifications AASHTO HL-93 Live Load and NYSDOT Design Permit Vehicle *BM Section 2.6, HDM 19.5.3*	NA	NA
11	ADA Compliance	Shoulder *HDM Section 2.7.4.1.K., HDM Chapter 18, and PROWAG*	Shoulder[3]	Shoulder[3]

(1) Conditions for the critical segment of CR 28 shown. All design elements based upon this critical segment.
(2) Ontario County has concurred that the use of a Design Speed of 60 mph is consistent with the anticipated off-peak 85th percentile speed within the range of functional class speeds for the terrain and volume.
(3) Given the project's surrounding area has a low population and there are no significant pedestrian generators, the occasional pedestrian may legally use the shoulder. See **Section 3.3.2.1** for more information.
**Denotes non-standard feature.
NA – Not Applicable

Exhibit 3.2.3.2-3
Critical Design Elements for Shortsville Road

PIN:	4ON0.03	NHS (Y/N):	No
Route No. & Name:	Shortsville Road	Functional Classification:	Rural Local
Project Type:	Safety Improvement	Design Classification:	Rural Local
% Trucks (Max)[1]:	8%	Terrain:	Level
ADT (2049)[1]:	2,710	Truck Access/Qualifying Hwy.	No / No

	Element	Standard	Existing Condition	Proposed Condition
1	Design Speed	55 mph[2] *HDM Section 2.7.4.1.A.*	55 mph	55 mph
2	Lane Width	11 ft *HDM Section 2.7.4.1.B. Exhibit 2-7*	11 ft	11 ft
3	Shoulder Width	4 ft Minimum, 5 ft Desirable *HDM Section 2.7.4.1.C. Exhibit 2-7, Note 6*	2 ft	4 ft
4	Horizontal Curve Radius	651 ft Minimum (at e_{max}=8%) *HDM Section 2.7.4.1.D. Exhibit 2-7*	None	None
5	Superelevation	8% Maximum *HDM Section 2.7.4.1.E.*	Normal Crown	Normal Crown
6	Stopping Sight Distance (Horizontal and Vertical)	452 ft Minimum *HDM Section 2.7.4.1.F. Exhibit 2-7*	>452 ft	>452 ft
7	Maximum Grade	6% *HDM Section 2.7.4.1.G. Exhibit 2-7*	1.0%	2%
8	Cross Slope	1.5% Min. to 3% Max. *HDM Section 2.7.4.1.H.*	5% Maximum	2% Maximum
9	Vertical Clearance	14 ft Minimum 14 ft – 6 in Desirable *HDM Section 2.7.3.1.I. &* *BM Section 2.4.1. Table 2-2*	14 ft Minimum (to utilities)	14 ft Minimum (to utilities)
10	Design Loading Structural Capacity	New and Replacement Bridges NYSDOT LRFD Specifications AASHTO HL-93 Live Load and NYSDOT Design Permit Vehicle Buried Structures (Box Culverts, 3-sided Frames and Pipes) NYSDOT LRFD Specifications AASHTO HL-93 Live Load and NYSDOT Design Permit Vehicle *BM Section 2.6, HDM 19.5.3*	NA	NA
11	ADA Compliance	Shoulder *HDM Section 2.7.4.1.K., HDM Chapter 18, and PROWAG*	Shoulder[3]	Shoulder[3]

(1) Conditions for the critical segment of Shortsville Road shown. All design elements based upon this critical segment.
(2) Ontario County has concurred that the use of a Design Speed of 55 mph is consistent with the anticipated off-peak 85th percentile speed within the range of functional class speeds for the terrain and volume.
(3) Given the project's surrounding area has a low population there are no significant pedestrian generators, the occasional pedestrian may legally use the shoulder. See the Complete Streets Checklist, **Appendix C**, for more information.
**Denotes non-standard feature.
NA – Not Applicable

3.2.3.3. Other Design Parameters

In addition to the critical design elements described in **Section 3.2.3.2**, other design parameters established by the NYSDOT and AASHTO that are typically used to design roadway projects include guidelines for roundabouts, design vehicles, rainfall amounts for drainage facilities, and others. **Exhibit 3.2.3.3-1** provides the design parameters for roundabouts.

Exhibit 3.2.3.3-1
Roundabout Controlling Features

	Element	Parameter[1]	Proposed Condition			
			North Leg	West Leg	South Leg	East Leg
1	Design Vehicle	Largest Expected Vehicle	Refer to **Exhibit 3.2.3.3-3**			
2	Maximum Entry Speed	30 mph NYSDOT EI 00-021 3.1.2.a	21 mph	23 mph	23 mph	22 mph
3	Entry Width	10 ft Minimum NYSDOT EI 00-021 3.1.2.d 14 ft to 18 ft typical Maximum 35 ft Single Lane Approach NCHRP 672 6.4.2 & NYSDOT EI 00-021 3.1.2.e	16.5 ft	15.9 ft	16.5 ft	16.2 ft
4	Entry Radius	33 ft minimum, 328 ft maximum 65 ft desirable NYSDOT EI 00-021 3.1.2.f and NYSDOT Intersection Design Unit Guidance 90'-110' typ.	100 ft	100 ft	100 ft	100 ft
5	Entry Angle	20° minimum, 60° maximum 30° to 40° desirable NYSDOT EI 00-021 3.1.2.g	23.6°	25.5°	24.5°	25.5°
6	Entry Angle of Visibility	≥75° NCHRP 672 6.7.4	~130°	~120°	~140°	~120°
7	Splitter Island Length	≥ 50 ft minimum, ≥ 100' desirable	170 ft	280 ft	160 ft	195 ft
8	Approach Stopping Sight Distance	112.4 ft @ 20 mph 197.8 ft @ 30 mph 362.5 ft @ 45 mph 496.7 ft @ 55 mph NCHRP 672 6.2.6 & 6.7.3.1	>112.4 ft >197.8 ft >362.5 ft >496.7 ft	>112.4 ft >197.8 ft >362.5 ft >496.7 ft	>112.4 ft >197.8 ft >362.5 ft >496.7 ft	>112.4 ft >197.8 ft >362.5 ft >496.7 ft
9	Circulating Roadway Sight Distance	77.0 ft @ 15 mph NCHRP 672 6.2.6 & 6.7.3.1	77.0 ft minimum	77.0 ft minimum	77.0 ft minimum	77.0 ft minimum
10	Intersection Sight Distance	146.8 ft @ 20 mph Conflicting Approach Speed NCHRP 672 6.2.6 & 6.7.3.4	146.8 ft minimum	146.8 ft minimum	146.8 ft minimum	146.8 ft minimum
11	Sight Distance to Crosswalk	146.8 ft @ 20 mph Conflicting Approach Speed NCHRP 672 6.2.6 & 6.7.3.4	146.8 ft minimum	146.8 ft minimum	146.8 ft minimum	146.8 ft minimum
12	Inscribed Circle Diameter	50 ft minimum, 328 ft maximum 130 ft to 150 ft typ, single lane, WB-67 NYSDOT EI 00-021 3.1.2.k & NCHRP 672	140 ft			
13	Circulatory Roadway Width	16 ft to 20 ft desirable ≥ Maximum Entry Width ≤ Maximum Entry Width x 1.2 Design Vehicle + 3 ft Horizontal Clearance NYSDOT EI 00-021 3.1.2.m	18 ft			

Exhibit 3.2.3.3-1
Roundabout Controlling Features

Element		Parameter[1]	Proposed Condition			
			North Leg	West Leg	South Leg	East Leg
14	Minimum Exit Radius	65 ft minimum, 328 ft to 394 ft typical 656 ft desirable NYSDOT EI 00-021 3.1.2.p and NYSDOT Intersection Design Unit Guidance	300 ft	200 ft	300 ft	200 ft
15	Pedestrian Accommodations	Meet PROWAG NYSDOT EI 00-021 3.1.2.q, NYSDOT HDM Chapter 18, and PROWAG	Shoulder			
16	Control of Access	No Access within 80 ft of Yield Line Desirable NYSDOT EI 00-021 3.1.2.n	80 ft minimum			
17	Circulating Roadway Cross Slope	0.5% minimum, 2.5% maximum NYSDOT EI 00-021 3.1.2.l	2%			
18	Maximum Circulating Speed	25 mph NYSDOT EI 00-021 3.1.2.a & NCHRP 672	16 mph			
19	Maximum Entry Superelevation	5% NYSDOT EI 00-021 3.1.2.b	Normal Crown, 2%			
20	Horizontal Clearance - From Edge of Traveled Way (Splitter Islands)	Left (curbed): 0 ft minimum 1 ft to 2 ft desirable Right (uncurbed): 10 ft. without rail Along rail, use larger of 4 ft. or actual shoulder width *HDM Chapter 5*	1 ft (left) 4 ft (right, curbed)			
21	Approach Alignment	Radial Acceptable, Offset Left Desirable NYSDOT Intersection Design Unit Guidance	Offset Left			

1. Parameters per NCHRP Report 672, "Roundabouts: An Informational Guide (Second Edition)" and/or Main Office Intersection Design Squad, as applicable.
2. [ ] Not typical, desired or preferred, but within the general range of acceptance.
3. [ ] Not typical, desired, or preferred and outside the general range of acceptance. These are nonconforming features.

Exhibit 3.2.3.3-2
Other Design Parameters: General

	Element	Standard Criteria	Proposed Condition
1	Level of Service	LOS D Minimum LOS C Desirable	LOS A
2	Drainage Design Storm	10 Year Storm	10 Year Storm

Vehicle Turning Paths at Intersections (i.e. Design Vehicle) - Vehicle turning paths were analyzed for the proposed modern roundabout based on the ability of the design vehicle to complete various movements. All turning movements would accommodate the design turning paths as indicated in **Exhibit 3.2.3.3-3.**

Exhibit 3.2.3.3-3
Other Controlling Parameters: Design Vehicle

Location	Turning Movement	Design Vehicle	Vehicle Accommodated
Roundabout	Northbound right	WB-40	WB-40/WB-50[1]
	Northbound through	WB-67	WB-67
	Northbound left	WB-40	WB-67
	Southbound right	WB-40	WB-40/WB-50[1]
	Southbound through	WB-67	WB-67
	Southbound left	WB-40	WB-67
	Eastbound right	WB-40	WB-50[2]
	Eastbound through	WB-67	WB-67
	Eastbound left	WB-40	WB-67
	Westbound right	WB-40	WB-50[2]
	Westbound through	WB-67	WB-67
	Westbound left	WB-40	WB-67

Notes:

1. WB-67/62 vehicles do not typically make a northbound / southbound right turn. The existing intersection accommodates a single unit truck within the travel lanes and shoulder. Ontario County has elected to provide accommodation up to a WB-40 design vehicle within the proposed concrete pavement, and an infrequent WB-50 on the asphalt apron beyond the proposed traversable curb (utilized for rear wheel tracking during the movement). The WB-50 is representative of the typical "crop hauler" used for agricultural activity around the intersection. Should an infrequent WB-67/62 approach the intersection and need to make a northbound / southbound right turn, it would need to circle the roundabout and then exit appropriately to complete its movement.

2. WB-67/62 vehicles do not typically make the eastbound / westbound right turn. The existing intersection accommodates a WB-40 within the travel lanes and shoulder. Ontario County has elected to provide accommodation for a WB-50 design vehicle. This is representative of the typical "crop hauler" used for agricultural activity around the intersection. Should an infrequent WB-67/62 approach the intersection and need to make a northbound / southbound right turn, it would need to circle the roundabout and then exit appropriately to complete its movement.

3.3. Engineering Considerations

3.3.1. Operations (Traffic and Safety) & Maintenance

3.3.1.1. Functional Classification and National Highway System

This project will not change the functional classification of any approach roadways.

3.3.1.2. Control of Access

All highway boundaries will remain "with access".

3.3.1.3. Traffic Control Devices

3.3.1.3. (1) Traffic Signals - No new traffic signals are proposed.

3.3.1.3. (2) Signs - Existing signs including but not limited to stop, regulatory, warning, and street name signs would be removed and replaced with new signs meeting current MUTCD and New York State Supplement standards. All entries into the modern roundabout would be signed with yield signs. Appropriate signage would be installed on each approach to and within the modern roundabout.

3.3.1.3. (2) Pavement Markings - New pavement markings would be installed throughout the project limits in accordance with current MUTCD and New York State Supplement. Applicable NYSDOT standard details would be followed.

3.3.1.4. Intelligent Transportation Systems (ITS)

No ITS measures are proposed.

3.3.1.5. Speeds and Delay

3.3.1.5. (1) Proposed Speed Limit - The existing (statutory) speed limit of 55 mph would be retained on CR 28 and Shortsville Road upon completion of the project. An advisory speed for negotiating the roundabout would be posted in advance of the reconfigured intersection.

3.3.1.5. (2) Travel Time Estimates – The feasible alternative would not significantly impact travel distances or capacity, therefore travel time estimates were not calculated.

3.3.1.6. Traffic Volumes

There would be no modifications to overall traffic patterns (i.e. movements allowed or travel routes at the intersection) under Alternative 5; therefore, the projected average daily traffic (ADT) volumes for Alternative 5 would be the same as those experienced under no-build conditions. Refer to **Section 2.3.1.6 (1)** for information on the design year and development of ADT and volumes. Turning movement diagrams are presented in **Appendix C**.

3.3.1.7. Level of Service and Mobility

Refer to **Section 2.3.1.7 (1)** for a discussion of Level of Service (LOS).

3.3.1.7 (1) At Project Completion & Design Year – Level of service analyses were completed using SIDRA software (HCM 6 roundabout capacity model) for future build conditions at ETC (2020) and the design year ETC+20 (2040). **Exhibit 3.3.1.7 (1)-1** and **Exhibit 3.3.1.7 (1)-2** summarize the results of morning and evening peak hour analyses, respectively. Detailed reports are contained in **Appendix C**. As shown, all approaches are projected to operate at LOS A throughout the design year. Overall, the modern roundabout would have adequate capacity to meet the projected demand with an acceptable level of service throughout the design year, ETC+20 (2040).

On average, the roundabout would result in 4 to 5 seconds less delay per vehicle on CR 28 and approximately 12 to 14 seconds less delay per vehicle on Shortsville Road in comparison to the no-build (two-way stop control) alternative. It also represents about 7 to 9 seconds less delay per vehicle on CR 28 and 5 to 6 seconds less delay per vehicle in comparison to the all-way stop control scenario (Alternative 3).

Exhibit 3.3.1.7 (1)-1
Morning Peak Hour Level of Service and Delay
Proposed Roundabout

Intersection	Approach	Movement	Control	2020 Build		2040 Build	
				Delay (sec/veh)	LOS	Delay (sec/veh)	LOS
CR 28 and Shortsville Road	Eastbound	Left/Thru/Right	YIELD	3.4	A	3.8	A
	Westbound	Left/Thru/Right	YIELD	2.9	A	3.1	A
	Northbound	Left/Thru/Right	YIELD	2.2	A	2.3	A
	Southbound	Left/Thru/Right	YIELD	2.2	A	2.4	A
			Overall	**2.5**	**A**	**2.7**	**A**

Exhibit 3.3.1.7 (1)-2 Evening Peak Hour Level of Service and Delay Proposed Roundabout							
Intersection	Approach	Movement	Control	2020 Build		2040 Build	
				Delay (sec/veh)	LOS	Delay (sec/veh)	LOS
CR 28 and Shortsville Road	Eastbound	Left/Thru/Right	YIELD	2.8	A	3.0	A
	Westbound	Left/Thru/Right	YIELD	3.1	A	3.4	A
	Northbound	Left/Thru/Right	YIELD	2.3	A	2.5	A
	Southbound	Left/Thru/Right	YIELD	2.4	A	2.6	A
			Overall	**2.6**	**A**	**2.8**	**A**

3.3.1.7 (2) – Work Zone Safety & Mobility –

A. Work Zone Traffic Control Plan - All work zones and detours would be set up in conformance with the MUTCD and New York State Supplement. A clearly marked travel way would be delineated with temporary pavement markings, traffic signage, barricades, drums, cones, etc. as applicable while traffic is maintained through the project area. Flaggers would be utilized to direct traffic where required.

Conceptual work zone traffic control schemes would allow the contractor to initially utilize one-way alternating traffic with flagging control while maintaining vehicular traffic through the project area to accomplish underground utility and drainage work along with the initial stages of approach reconstruction. Following the underground and approach work, the intersection of CR 28 and Shortsville Road would be fully closed to all traffic allowing for construction of the modern roundabout. This plan would minimize the overall construction schedule (reducing the duration of disturbance to the traveling public) and improve the quality of the finished product. The following offsite detours would be posted and maintained for up to 3 months:

- CR 28: Canandaigua-Farmington Town Line Road, CR 8, and NY Route 96 (6.2 miles)
- Shortsville Road: CR 8, NY Route 96, Sandhill Road (3.6 miles)

This would allow traffic to get from one side of the closed intersection to the other. Refer to detour routing diagrams in **Appendix C**. The detours have the necessary geometry, width, and condition (based upon field inspection) to safely accommodate detoured traffic.

Upon completion of the roundabout, its truck apron, and approaches up to the asphalt top course, the intersection would be reopened to traffic. The contractor would be required to have pavement markings, signing, and lighting (permanent or temporary) in place prior to opening. Remaining finish activities including any remaining signing, final grading, landscaping, and turf establishment would be completed using short term temporary shoulder closures.

There are no significant generators of pedestrian traffic within the project limits, therefore, special accommodations would not be necessary during construction. Through bicyclists would be expected to use the posted detour routes.

B. Special Provisions – Nighttime construction is not anticipated. Work zone traffic control would be coordinated with local officials, residents, utility owners, school districts, police, and local emergency service providers. Access to affected residential properties would be maintained throughout construction or alternate accommodations provided. Access to South Farmington Cemetery and Meeting House Park would also be maintained. Ontario County would coordinate with local farmers to accommodate their operations during construction to the greatest reasonable extent.

C. Significant Projects (per 23 CFR 630.1010) - This project is not classified as a Significant Project, therefore its Transportation Management Plan (TMP) would consist of a Temporary Traffic Control (TTC) plan consistent with 23 CFR 630.1012. To satisfy this requirement, the construction documents would include Work Zone Traffic Control notes, plans, and details. The requirements of Section 619 of the New York State Standard Specifications would apply to the contract.

3.3.1.8. Safety Considerations, Accident History and Analysis

The proposed modern roundabout at the intersection of CR 28 and Shortsville Road would improve safety by reducing the number of possible conflict points from 32 to 8 and eliminating the potential for high speed, right-angle collisions. The use of successive curvature on entry would also mitigate the potential for high speed, rear-end collisions at the yield line. Roundabouts are proven to reduce the rate of all accidents, but particularly injuries and fatalities. As documented in NCHRP Report 672, experience in the United States has shown that where modern roundabouts have replaced a rural two-way stop-controlled intersection, the rate of all accidents has declined by 72%. The combined rate of injury and fatal accidents has declined by 87%. The roundabout would be of particular benefit at this intersection given the frequency of injury accidents and two fatal crashes.

3.3.1.9. Impacts on Police, Fire Protection and Ambulance Access

Refer to **Section 3.3.1.7 (2)** for a discussion of anticipated impacts during construction. Alternative 5 would have no significant long-term impacts on police, fire protection, or ambulance access. Any full-size (40-foot) buses or fire protection equipment (40-foot) passing through the roundabout would be accommodated on the circulatory roadway (i.e. they would not need to mount the truck apron).

3.3.1.10. Parking Regulations and Parking Related Issues

No changes are proposed.

3.3.1.11. Lighting

New lighting would be installed at the proposed modern roundabout. At this time, it is anticipated that overhead lighting would be supported on arms mounted to poles located around the perimeter of the circle; however, final locations would be determined during detailed design. Poles and lights would be chosen considering Ontario County's preferences. Lighting levels would be consistent with guidelines from the illuminating Engineering Society's (IES) *Design Guide for Roundabout Lighting* and/or current best practices for roundabout design. The up-lighting landscape features within the central island would also be considered during detailed design.

3.3.1.12. Ownership and Maintenance Jurisdiction

Ownership and Maintenance Jurisdiction would not be altered by Alternative 5. Refer to **Section 2.3.1.12** for discussion of Ownership and Maintenance Jurisdiction. Ontario County would assume maintenance jurisdiction for the proposed modern roundabout to the limit of each splitter island.

3.3.1.13. Constructability Review

There are no unique circumstances or design features that would negatively impact the constructability of Alternative 5. Overall the anticipated level of construction complexity would be considered routine. The anticipated use of Portland Cement Concrete (PCC) pavement for the roundabout would add an element of specialty work to the project; however, the local contracting community is capable of the work based on past construction experience at the adjacent intersection of CR 8, CR 41, and Shortsville Road. Closing the intersection to all traffic during construction of the roundabout would accelerate that portion of the schedule (given a lack of interference with the contractor's operations). The lack of interference with construction activities is also anticipated to enhance the quality of the final product.

3.3.2. Multimodal Considerations

3.3.2.1. Pedestrians

No separate pedestrian facilities are planned or warranted based upon the low-density residential development and infrequent pedestrian travel. This is consistent with the NYSDOT Highway Design Manual Chapter 18 and the Capital Projects Complete Streets Checklist in **Appendix C**. The occasional pedestrian may legally use the shoulder per the provisions of NYS Vehicle and Traffic Law Section 1156(b). Accessible crossings, compliant with ADA standards, would be constructed at each splitter island to accommodate the occasional pedestrian. Each crossing would be longer than 6 feet to act as a pedestrian refuge.

3.3.2.2. Bicyclists

No special provisions are proposed to accommodate bicyclists. Given the rural nature of the roadway, the shoulder is the primary location for accommodating bicyclists. Bicyclists would share the travel lanes with motor vehicles and should ride along the outer edge of the circulatory roadway. Bicyclists may legally use the paved shoulder and roadway, which is consistent with the NYS Vehicle and Traffic Law Section 1234. Typical on-road bicycle speeds are between 12 and 20 mph. The geometry of the proposed roundabout would constrain motor vehicle speeds to 15 to 20 mph, therefore relative speed differences would be kept to a minimum which would thereby improve safety and usability for bicyclists.

3.3.2.3. Transit

There are no transit providers operating within the project limits; therefore, the proposed alternative would not affect their operations.

3.3.2.4. Airports, Railroad Stations, and Ports

No changes are proposed that would affect airports, railroad stations, or port entrances.

3.3.2.5. Access to Recreation Areas (Parks, Trails, Waterways, and State Lands) –

A new driveway would be constructed to connect Meeting House Park with Shortsville Road as shown on the plans in **Appendix A**. This would move the park's entrance away from the existing intersection, west of the proposed roundabout. A segment of the splitter island on Shortsville Road would be depressed in the vicinity of the driveway to permit two-way access. Ontario County prefers this treatment to the alternative of a dedicated turn lane (which would require additional width) or a full break in the extended splitter island (which would detract from positive guidance to through vehicles on Shortsville Road). It is anticipated that park patrons will quickly familiarize themselves with the proper use of the flush treatment. A new parking area would also be constructed, replacing the existing gravel pad in the park. The planned enhancements have been reviewed by and are acceptable to the Town of Farmington. Collectively these changes would enhance park patron access and accommodation.

3.3.3. Infrastructure

3.3.3.1. Proposed Highway Section

Refer to **Appendix A** for a plans, profiles, and typical sections illustrating the approach roadways, circulatory roadway, and all other roadways within the project limits. Additional details regarding **Alternative 5** are summarized in the following sections.

3.3.3.1. (1) Right of Way - Anticipated property acquisitions are summarized in **Exhibit 3.3.3.1 (1).** They are also shown on the plans in **Appendix A**. In summary, the project would require seven (7) permanent easements and three (3) temporary easements. All takings would be de minimis.

Exhibit 3.3.3.1 (1) Anticipated Right-of-Way Acquisitions					
Number	**Address**	**Reputed Owner Tax Map No.**	**Type of Take**	**Estimated Acquisition Area (SF / Acres)**	**Remarks**
TE01	County Road 28	Town of Farmington 43.00-1-50.000	Temporary Easement	3492.60 / 0.080	Grading / Access Improvements
PE01	1561 County Road 28	Debra Ann Miller 43.00-1-38.000	Permanent Easement	1673.02 / 0.038	Roadway Realignment / Grading / Drainage
TE02			Temporary Easement	770.20 / 0.018	Grading / Drainage
PE02	Shortsville Road	John L & Georgiana Gerlock 43.00-1-41.210	Permanent Easement	5051.31 / 0.116	Roadway Realignment / Grading / Drainage
PE03	Shortsville Road	Robert C Gerlock 43.00-1-41.100	Permanent Easement	2574.54 / 0.059	Roadway Realignment / Grading / Drainage
PE04			Permanent Easement	1022.12 / 0.024	Roadway Realignment / Grading / Drainage
PE05	1593 County Road 28	Nicole L Moyer 43.00-1-40.000	Permanent Easement	1863.88 / 0.043	Roadway Realignment / Grading / Drainage
PE06			Permanent Easement	112.29 / 0.003	Roadway Realignment / Grading / Drainage
TE03			Temporary Easement	1508.31 / 0.035	Grading / Drainage
PE07	1702 County Road 28	Robert C & June B Gerlock 43.00-1-35.120	Permanent Easement	40086.71 / 0.920	Roadway Realignment / Grading / Drainage

3.3.3.1. (2) Curb – Granite barrier curb would be installed around the central island of the modern roundabout. Cast in place concrete truck apron curb would be installed at the inside edge of the circulatory roadway. Sloped granite curb would be installed along each splitter island. Additionally, sloped granite curb would be installed along the shoulders of the circulatory roadway and portions of the approaches immediately adjacent to the roundabout to facilitate drainage and maintain a stable roadside. Sloped granite curb would be extended along the southern approach, east side, and northern approach, east and west sides, to facilitate tying into the existing and proposed cut slopes. This curb would also provide a "traffic calming" effect, encouraging slower vehicle entry speeds and preventing the distribution of shoulder backup across the pavement as experienced at other rural roundabouts. Shoulders outside the circulatory roadway, immediate roundabout approaches, and outside the limits above would remain uncurbed.

3.3.3.1. (3) Grades – All maximum grades throughout the project limits would be in accordance with the standards contained in **Section 3.2.3.2.** Refer to the profiles in **Appendix A** for detailed grade information.

3.3.3.1. (4) Intersection Geometry and Conditions – Refer to plans in **Appendix A** for an illustration of the project's proposed intersection geometry.

Under Alternative 5, the 4-legged two-way stop-controlled intersection of CR 28 and Shortsville Road would be replaced with a modern roundabout. The roundabout would have an inscribed circle diameter of 140 feet, elongated splitter islands, a truck apron, and a landscaped central island. The roundabout would have a single approach lane in each direction, single departure lane in each direction, and a single circulating lane. Refer to **Exhibit 3.2.3.3-3** for a list of design vehicle turns that would be accommodated at the roundabout. Refer to the plans contained in **Appendix A** for the proposed intersection geometry.

As noted, all four approaches to the proposed roundabout would feature an elongated, raised splitter island. Each of these approaches would also feature a set of curves, each successively smaller in radius. The purpose of this feature, designed in accordance with guidance in NCHRP Report 672, would be to reduce vehicle speeds as they approach the roundabout from free flow (higher than 55 mph) to approximately 20 mph or less by the time they reach the roundabout's entry.

3.3.3.1. (5) Roadside Elements:

A. Sidewalks – There are no proposed sidewalks or shared use paths within the project limits.

B. Bikeways – There are no proposed bikeways or shared use paths within the project limits.

C. Snow Storage – Snow storage would be accommodated beyond the paved shoulders on all approach roadways. A 2-foot wide, relatively flat "bench" would be constructed along the back edge of curb along the east side of the southern approach and the west side of the northern approach. This would facilitate snow storage and reduce the chance of melting snow refreezing on pavement surface. Consideration was also given to winter conditions along to roadside slopes, particularly in cut sections, where it is desirable to minimize the potential for drifting snow to the greatest extent feasible. The proposed treatment includes flatter back slopes on ditches (1:4 instead of 1:3) in select locations.

D. Utility Strips – No new utility strips are anticipated within the project limits.

E. Bus Stops – There are no bus stops within the project limits.

F. Driveways – All driveways within the project limits would be replaced in kind, extended, or relocated as necessary to tie into the proposed work. This includes the existing asphalt and gravel driveways to the residential properties on the east side of CR 28, north and south of Shortsville Road, and all field access drives. The first residential driveway on CR 28, north of Shortsville Road would have a segment of the splitter island depressed in the vicinity of the driveway to permit two-way access. Though flush, the same median treatment would be carried through that area. This would provide full driveway access to the affected property owner while discouraging others from utilizing the physical break in the raised median.

Refer to **Section 3.3.2.5**. for a discussion on the relocated access to Meeting House Park. A new access drive to the relocated water vault would be installed along the west side of CR 28, south of Shortsville Road. This paved access would allow the Town's maintenance vehicles to safely park off the roadway and turn around when completing weekly maintenance work.

Additional field access drives may be added during detailed design subsequent to discussion with individual property owners. Refer to the plans in **Appendix A** for proposed driveway locations and layout. Driveway culverts would be installed where necessary to facilitate drainage patterns.

G. Clear Zone – The target clear zone for all roadways within the project limits is 30 feet maximum from the edge of travel lane and varies depending on the design speed and fore slope. Existing horizontal clearances from the edge of travel lane to the line of fixed objects is generally set by the line of utility poles along the roadway. The utility poles along the north side of Shortsville Road and west side of CR 28 would be relocated as a result of the project. Ontario County would work with affected utility owners to ensure utility poles are located outside the desired clear zone for the roadway, considering the design

speed of the adjacent curve, fore slope, and location on the curve. Horizontal clearances would remain or be increased as part of the project. Existing (typical) horizontal clearances to utility poles on the approach roadways are listed below for reference.

- CR 28 - Approximately 15 feet
- Shortsville Road – Approximately 12 feet

3.3.3.2. Special Geometric Design Elements

3.3.3.2. (1) Nonstandard Features – No critical design elements that would not comply with the geometric features and cross section elements listed in **Section 3.2.3.2** are proposed within the study limits. For the purposes of this project, modern roundabout design parameters apply from the tips of the splitter islands through the central island on each approach.

3.3.3.2. (2) Non-Conforming Features – Other design features were taken into consideration in addition to the critical design elements contained in Chapter 2 of the NYSDOT HDM during the development of Alternative 5. Non-critical design elements with the project limits are presented in **Section 3.2.3.3**. Non-conforming features are design elements that depart from typical design practice but are not related to designated design criteria. No non-conforming features are proposed within the project limits. Refer to the Non-Conforming Features Checklist in **Appendix F**.

3.3.3.3. Pavement and Shoulder

A full depth pavement section is recommended given the proposed intersection improvements and roadway realignments as discussed in the Pavement Evaluation and Treatment Selection Report (PETSR) in **Appendix D**. A Portland Cement Concrete (PCC) pavement section was developed for the circulatory roadway and approaches to the modern roundabout under Alternative 5. It was generated per the Equivalent Single Axle Loading (ESAL) pavement design procedure as outlined in the NYSDOT Comprehensive Pavement Design Manual. The expected pavement service life would be 50 years. The recommended full depth PCC pavement reconstruction section for the CR 28 and Shortsville Road roundabout is as follows:

- 9-inch Portland Cement Concrete Pavement
- 12.0-inch Granular Subbase Course

A hot mix asphalt (HMA) pavement section was developed for Alternative 5, generated per the Equivalent Single Axle Loading (ESAL) pavement design procedure as outlined in the NYSDOT Comprehensive Pavement Design Manual, for approaches to the roundabout, outside the limits of the splitter islands, and other reconstruction segments throughout the project limits. The expected pavement surface life would be 20 years with an expected total pavement service life of 50 years. The recommended full depth asphalt pavement reconstruction section for CR 28 and Shortsville Road is as follows:

- 1.5-inch HMA Top Course
- 2.5-inch HMA Binder Course
- 5.0-inch HMA Base Course
- 12.0-inch Granular Subbase Course

All shoulders would be constructed to full depth and edges supported with a minimum of 2 ft of shoulder backup material or traversable curb. Asphalt backup material would be placed, as necessary, to accommodate occasional WB-50 tracking in the southeast and northwest quadrant of the proposed roundabout.

3.3.3.4. Drainage Systems

The overall drainage pattern throughout the project limits would be changed with the proposed roundabout. Curbing along the outside of the circulatory roadway and on its immediate approaches would

direct runoff to adjacent roadside ditches or the proposed closed drainage system. Similar to existing, curbing along the northern approach would direct runoff to a closed drainage system. Curb would be introduced along the east side cut section on the southern approach to facilitate drainage. New low-points on the roundabout approaches would be located at just outside the limits of the proposed curbing. Proposed grading would establish toe ditches at the bottom of roadway embankments to collect roadway runoff, preventing sheet flow from entering adjacent residential and agricultural properties. This would help limit crop damage due to salty winter and spring runoff as well as flooding of fields during heavy rain events.

Where possible, the roadway subbase would be day lighted to drain the roadbed. Underdrain would be installed in locations where the adjacent ditch bottom could not be made low enough to daylight the subbase. Each underdrain would be designed to outlet at a low point in the approach profile. The truck apron and circulating roadway would both be banked outward toward the edge of the roundabout. The proposed drainage design is summarized in **Exhibit 3.3.3.4** and also shown on the plans in **Appendix A**.

All existing pipes under the road would be replaced. The proposed closed drainage system would capture ditch flow and roadway surface flow at low points and consist of a series of end sections, drainage structures, pipes, and manholes. Proposed drainage pipes beneath the road would be appropriately sized reinforced concrete pipe (RCP). Additionally, new pipes outside the roadway would be smooth interior corrugated plastic pipe made of high-density polyethylene (SICPP, HDPE), all with appropriately sized drainage structures or manholes. All existing driveway pipes in poor condition would be replaced as part of the project. The proposed closed drainage system would be installed throughout the project limits as summarized in **Exhibit 3.3.3.4**. The system would outlet at the northeast corner of the proposed intersection, along the east side of CR 28, to its end point approximately ~1,100 feet north of the intersection at an unnamed tributary of Padelford Brook. This would eliminate the roadway runoff from heading north through a meandering swale, across adjacent farmland, to the same unnamed tributary.

Exhibit 3.3.3.4
Proposed Drainage Design Summary

Leg / Roadway	Side	Ditch Section Slopes	Comments
West (Shortsville)	North	1:4 Fore 1:3 or Flatter Back 2 ft Bottom	Ditch would carry flow from the project limits to the approach low point and be picked up by the closed drainage system, outletting to the closed drainage system headed north.
	South	1:4 Fore 1:3 Back 2 ft Bottom	Ditch would carry flow from the project limits to the approach low point and be picked up by the closed drainage system, outletting to the closed drainage system headed north.
South (CR 28)	West	1:4 Fore 1:4 Back 2 ft Bottom	Ditch would carry flow from the project limits to the approach low point and be picked up by the closed drainage system, outletting to the closed drainage system headed north.
	East	1:5 Fore 1:4 Back 2 ft Bottom	Ditch would drain to the north / proposed catch basin adjacent to a residential driveway and outlet to the north into the trunk line. North of the driveway, a catch basin would be placed in the shoulder at the approach low point and outlet into the closed drainage system headed north.
East (Shortsville)	North	1:4 Fore 1:3 Back 2 ft Bottom	Ditch would carry flow from the project limits to the approach low point and be picked up by the closed drainage system, outletting to the closed drainage system headed north.

Exhibit 3.3.3.4 Proposed Drainage Design Summary			
Leg / Roadway	**Side**	**Ditch Section Slopes**	**Comments**
	South	1:4 Fore 1:3 Back 2 ft Bottom	Ditch would carry flow from the project limits to the approach low point and be picked up by the closed drainage system, outletting to the closed drainage system headed north.
North (CR 28)	West	NA	A catch basin would be placed in the shoulder at the approach low point and outlet into the closed drainage system headed north.
	East	NA	A catch basin would be placed in the shoulder at the approach low point and outlet into the closed drainage system headed north.

3.3.3.5. Geotechnical

Ontario County will be completing additional soil borings along the northern approach to determine the depth of existing bedrock in Spring 2019. This will be used to determine the feasibility of installing the proposed drainage outlet to the north along CR 28. No other special geotechnical considerations exist, and no special geotechnical construction techniques are anticipated within the project limits that would affect design or construction. A geotextile separation product would be installed between the prepared subgrade and new granular subbase in accordance with Ontario County design standards.

3.3.3.6. Structures

There are no proposed bridges within the project limits.

3.3.3.7. Hydraulics of Bridges and Culverts

There are no proposed bridges or culverts within the project limits. There are no dams in the vicinity of the project that would be adversely affected.

3.3.3.8. Guide Railing, Median Barriers and Impact Attenuators

Existing box beam guide rail in the southwest corner of CR 28 and Shortsville Road intersection would be removed. It would not require replacement in conjunction with the proposed intersection improvements and roadside grading.

3.3.3.9. Utilities

Public utility relocations would be required in order to complete the proposed construction. Potential utility impacts are summarized in **Exhibit 3.3.3.9**.

Exhibit 3.3.3.9 Location of Potential Utility Impacts			
Owner	**Type**	**Location/Side**	**Proposed Modifications**
Town of Farmington	Water	West side of CR 28 throughout the project limits. North side of Shortsville Road, west of CR 28. Crossing of CR 28 along the north side of Shortsville Road dead ends on east side. Existing pressure reducing valve vault along the west side of CR 28, south of Shortsville Rd.	Relocate / replace water main and vault in conflict with the proposed roundabout and approach roadways.
RG&E	Electric	Overhead – West side of CR 28 for 300 ft north and south of Shortsville Road. East side of CR 28 from there to the project limits. North side of Shortsville Road throughout the project limits.	Relocate (5) utility poles and overhead wires in conflict with the proposed roundabout and approach roadways and to accommodate clear zone requirements.
Windstream	Telephone	Overhead – West side of CR 28 for 300 ft north and south of Shortsville Road. East side of CR 28 from there to the project limits. North side of Shortsville Road throughout the project limits.	Relocate (5) utility poles and overhead wires in conflict with the proposed roundabout and approach roadways and to accommodate clear zone requirements.
Charter Communications	Fiber Optic	Proposed Overhead – West side of CR 28 for 300 ft north and south of Shortsville Road. East side of CR 28 from there to the northern project limits. North side of Shortsville Road, west of CR 28.	Relocate (3) utility poles and overhead wires in conflict with the proposed roundabout and approach roadways and to accommodate clear zone requirements.

3.3.3.10. Railroad Facilities

There are no railroad facilities within the project limits.

3.3.4. Landscape and Environmental Enhancements

Refer to Chapter 4 for complete discussion of environmental considerations.

3.3.4.1. Landscape Development and Other Aesthetics Improvements

Low maintenance, salt tolerant landscaping would be provided in the central island of the proposed roundabout to enhance its conspicuity, control sight lines, and enhance aesthetics. Ontario County has recently begun specifying stone mulch for the interior of its roundabouts. A small vegetated berm would be constructed on the eastbound Shortsville Road approach to the roundabout as the approach roadway curves to the south. The berm and landscaping would be placed in the "ghost" alignment of the existing roadway to help guide vehicles toward the reconfigured approach and intersections. The berm would be planted with trees to enhance its visual prominence and reduce the need for long-term maintenance (mowing).

All plantings would be of a self-sufficient and of a low maintenance variety. Although plantings would be considered low-maintenance, some maintenance would need to be performed, particularly in the roundabout's central island, 1 to 2 times a year beyond the period of establishment.

A limited number of tree removals (4 inches or more in diameter at breast height) would be included in the project. These would take place in the along the south side of Shortsville Road and east side of CR 28, in the southeast quadrant of the intersection. The intent of the proposed design is to avoid impacts to mature trees located within the Meeting House Park. Temporary vegetation protection fencing would be installed during construction to protect the existing plantings in this corner. Any other plantings disturbed by the project would be replaced in-kind. Turf would also be reestablished upon completion of the project.

The surfaces of the splitter islands would be standard, colored concrete. The surface of the truck apron would also have an aesthetic treatment to visually offset it from the circulatory roadway pavement. This would both enhance aesthetics and discourage motorists from improperly using the splitter islands and apron.

3.3.4.2. Environmental Enhancements

The entrance to Meeting House Park in the northwest corner of CR 28 and Shortsville Road would be moved away from the intersection along with the construction of a paved parking area. This would enhance access and visitor accommodation.

3.3.5. Miscellaneous

NYS Smart Growth Public Infrastructure Policy Act (SGPIPA)

Pursuant to ECL Article 6, this project is compliant with the New York State Smart Growth Public Infrastructure Policy Act (SGPIPA).

To the extent practicable this project has met the relevant criteria as described in ECL § 6-0107. The Smart Growth Screening Tool was used to assess the project's consistency and alignment with relevant Smart Growth criteria and reflects the current project scope. A copy of the Smart Growth Screening Checklist is provided in **Appendix I**.

Other Miscellaneous Information

None.

CHAPTER 4 - SOCIAL, ECONOMIC and ENVIRONMENTAL CONDITIONS and CONSEQUENCES

4.1 Introduction

4.1.1 Environmental Classification

4.1.1.1 NEPA Classification

This project is being progressed as a Class II action (Categorical Exclusion) because it does not individually or cumulatively have a significant environmental impact and is excluded from the requirement to prepare an Environmental Impact Statement (EIS) or an Environmental Assessment (EA) as documented in the Federal Environmental Approvals Worksheet (FEAW) and following discussion in this chapter.

Specifically, in accordance with the Federal Highway Administration's regulations in 23 CFR 771.117c(23), this project is one of the project types described in the 'C' list as primarily a "Federally-funded project that would receive less than $5,000,000; or with total estimated cost of not more than $30,000,000 and Federal Funds comprising less than 15% of total estimated project cost" and does not significantly impact the environment. Refer to **Appendix B** for the FEAW and the Environmental Checklist.

4.1.1.2 SEQR Classification

Ontario County is the SEQR Lead Agency. In accordance with 6 NYSCRR, Part 617.5, "State Environmental Quality Review," Ontario County has determined that this project is a SEQR Type II Action. No further SEQR processing is required.

4.1.2 Coordination with Agencies

4.1.2.1 NEPA Cooperating and Participating Agencies

The following agencies are Cooperating Agencies in accordance with 23 CFR 771.111(d):

- US Army Corps of Engineers
- New York State Department of Environmental Conservation (NYSDEC)

4.2 Social

The proposed alternative is not anticipated to change or impact the land use, neighborhoods, community cohesion, elderly or disabled persons or environmental justice populations, in the vicinity of the project. This project involves the improvement of the intersection of CR 28 and Shortsville Road in a rural, lightly developed, section of the Town of Farmington. This project will not result in a residential relocation.

4.3 Economic

4.3.1 Regional and Local Economies

The project would improve safety for all persons who travel through the intersection and is therefore anticipated to benefit the regional and local economies.

4.4 Environmental

4.4.1 Wetlands

4.4.1.1 State Freshwater Wetlands

There are no NYSDEC regulated freshwater wetlands or regulated adjacent areas (100 feet) within the project area per the NYSDEC Environmental Resources Mapper as shown in **Appendix B**. A site visit was performed to verify this. No further investigation is required and Environmental Conservation Law, Article 24 is satisfied.

4.4.1.2 State Tidal Wetlands

A review of the NYSDEC GIS wetland data files indicates that there are no NYSDEC jurisdictional tidal wetlands or regulated adjacent areas within or near the project limits, and ECL Article 25 does not apply.

4.4.1.3 Federal Jurisdiction Wetlands

Federal jurisdictional wetlands exist within the project limits as shown in the wetland delineation report in **Appendix B**. It is anticipated that the proposed project will involve impacts to wetlands as noted in **Exhibit 4.4.1.3**. There is no alternative to construction in wetlands and avoidance is not practicable; however, all practicable measures to minimize impacts to wetlands will be utilized. Efforts to minimize and avoid wetland impacts were made during the design of the proposed roundabout, but the requirement to meet current design standards would result in minor impacts to wetlands. Impacts to delineated wetlands were minimized, as one delineated wetland would be completely avoided and another would only be partially impacted. Mitigation for these impacts is not anticipated, as the total wetland impact area is less than 0.10 acre. It is expected that work will be authorized under Nationwide Permit # 14 - Linear Transportation Projects. Work will not commence until the permit is acquired and work will adhere to all permit conditions.

A Blanket Section 401 Water Quality Certification (WQC) will likely apply to this project, since the work required would meet the requirements of Nationwide Permit # 14 - Linear Transportation Projects and it would comply with the NYSDEC General WQC Conditions. Permits will be obtained once the location and extent of the impacts are finalized.

Exhibit 4.4.1.3
Wetland Impacts

Wetland		Identified Functional Values	Total Size (acre)	Impacts (acre)	
ID	Type			Temporary	Permanent
1	Emergent Swale	• Highway & Roadside drainage/filtering • Storm water drainage/storage	0.003	0	0.003

Exhibit 4.4.1.3 Wetland Impacts					
Wetland		Identified Functional Values	Total Size (acre)	Impacts (acre)	
ID	Type			Temporary	Permanent
2	Emergent Ditch	• Highway & Roadside drainage/filtering • Storm water drainage/storage	0.016	0	0.016
3	Emergent Ditch	• Highway & Roadside drainage/filtering • Storm water drainage/storage	0.039	0	0.030
4	Emergent Ditch	• Highway & Roadside drainage/filtering • Storm water drainage/storage	0.006	0	0
Total Impacts				0	0.049

4.4.1.4 Executive Order 11990

A programmatic Executive Order 11990 applies to this project, based on its classification as a Categorical Exclusion under 23 CFR 771.117 and its qualification for a U.S. Army Corps of Engineers Section 404 Nationwide Permit. Minor impacts to federal jurisdictional wetlands are proposed; however, there is no practicable alternative to construction in the wetlands and all practicable measures to minimize harm to the wetlands would be incorporated. The project satisfies the requirements of EO 11990. No further approval from FHWA is required.

4.4.1.5 Mitigation Summary

Impacts to wetlands are 1/10 of an acre or less and a Nationwide Permit applies to the proposed activities; therefore, no wetland mitigation/monitoring plan is required for this project.

4.4.2 Surface Waterbodies and Watercourses

4.4.2.1 Surface Waters

One tributary was identified within the project area: an unnamed tributary to Padelford Brook. The Ordinary High-Water Mark (OHWM) of this tributary was delineated during the Wetland Delineation and is included on the wetland mapping for the project. Project design will not require the placement of fill below the OHWM of the tributary and impacts to this tributary are not anticipated.

4.4.2.2 Surface Water Classification and Standards

The unnamed tributary is rated Class C and is not a 303(d) segment based upon a review of the NYSDEC GIS data maps for regulated streams.

The best usage for Class/Standard "C" waters is fishing. Water quality is suitable for fish propagation and survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes.

4.4.2.3 Stream Bed and Bank Protection

Based upon a review of the NYSDEC GIS database, and as verified by a site visit, there are no protected streams, nor 50-foot regulated stream banks (on either side of a regulated stream), in the project area.

4.4.3 Wild, Scenic, and Recreational Rivers

4.4.3.1 State Wild, Scenic and Recreational Rivers

There are no NYSDEC Designated, Study or Inventory State Wild, Scenic or Recreational Rivers within or adjacent to the proposed project site. No further review is required.

4.4.3.2 National Wild and Scenic Rivers

The project does not involve a National Wild and Scenic River as shown by the Nationwide Rivers Inventory List of National Wild and Scenic Rivers. No further review is required.

4.4.3.3 Section 4(f) Involvement

The proposed project does not involve work in or adjacent to a wildlife or waterfowl refuge. No further consideration is required.

4.4.4 Navigable Waters

There are no state or federally regulated navigable waters located within the project area.

4.4.5 Floodplains

The project is not located within a regulated floodplain as shown on the GIS data base for 100-year floodplains. No work is proposed within floodplain areas.

4.4.6 Coastal Resources

The proposed project is not located in or near a Coastal Erosion Hazard Area.

According to the NYS DOS website of approved Local Waterfront Revitalization Programs, updated May 2017, the project is not located in a Local Waterfront Revitalization Area. No further action is required.

The project is not located in, or near a coastal area under the jurisdiction of the Coastal Barrier Resources Act (CBRA) or the Coastal Barrier Improvement Act (CBIA).

4.4.7 Groundwater Resources, Aquifers, and Reservoirs

NYSDEC aquifer GIS data files have been reviewed and it has been determined that the proposed project is not located in an identified Primary Water Supply or Principal Aquifer Area. No further investigation for NYSDEC designated aquifers is required.

A review of the EPA-designated Sole Source Aquifer Areas Federal Register Notices, Maps, and Fact Sheets indicates that the project is not located in a Sole Source Aquifer Project Review Area. No federal review and/or approvals are required pursuant to Section 1424(e) of the Safe Drinking Water Act. Refer to **Appendix B** for the documentation.

4.4.8 Stormwater Management

A SPDES General Permit for Stormwater Discharges from Construction Activity GP-0-15-002 would be required because the project has more than one acre of soil disturbance. Based on the preliminary design, it is anticipated that permanent stormwater features would be required to treat the water quality volume for the project site. The project is a redevelopment project that proposes an increase in impervious area, resulting in 0.073 acre-feet of water quality volume required for treatment. The project plans to meet this requirement through the construction of dry swales within the project corridor. While the project would result in a small increase in impervious area, downstream analyses show there would be no increase in discharge at the confluence with the nearest stream; therefore, no water quantity treatment is required.

A Stormwater Pollution Prevention Plan (SWPPP) with the appropriate sediment and erosion control measures would be developed. Based on the SWPPP, permanent stormwater management practices would be developed during detailed design.

4.4.9 General Ecology and Wildlife Resources

4.4.9.1 Fish, Wildlife, and Waterfowl

A cursory review of the project's area of potential effect indicates that there is not a special habitat or breeding area. Potential impacts to federal listed species are discussed below.

4.4.9.2 Habitat Areas, Wildlife Refuges, and Wildfowl Refuges

The proposed project does not involve work in, or adjacent to, a wildlife or waterfowl refuge. No further consideration is required.

4.4.9.3 Endangered and Threatened Species

According to the NYSDEC GIS information database, there is potential for a Federally-protected, threatened, or endangered species to be located within the proposed project area.

Tree removal is proposed as part of the project. A review of the U.S. Fish and Wildlife Service (USFWS) Information for Planning and Consultation (IPaC) system revealed that there is potential for the Northern Long Eared Bat (*Myotis septentrionalis*) to be present at the project site. The FHWA New York Division Environmental Procedures for Section 7 of the Endangered Species Act dated December 2018 were followed to determine potential impacts to this species.

As a result, it was determined that the project will conform to the USFWS/FHWA Programmatic Consultation for Transportation Projects affecting the Northern Long Eared Bat. A preliminary determination of May Affect, Not Likely to Adversely Affect (MA NLAA) for the species was reached. This is still pending finalization by NYSDOT staff and requires USFWA/FHWA concurrence. The USFWS Species list for the project, and Section 7 documentation, is included in **Appendix B**.

4.4.9.4 Invasive Species

A review of the existing corridor did not indicate any significant presence of known invasive species within the right-of-way.

4.4.9.5 Roadside Vegetation Management

Existing roadside vegetation consists primarily of maintained lawn areas, farmland, and wetland areas. Efforts would be made to replace wildlife-supporting vegetation that is removed during the course of construction.

4.4.10 Critical Environmental Areas

4.4.10.1 State Critical Environmental Areas

According to information obtained from NYSDEC, the proposed project does not involve work in or near a Critical Environmental Area.

4.4.11 Historic and Cultural Resources

A Project Submittal Package (PSP) was submitted to the NYSDOT Regional Cultural Resources Coordinator, who uploaded the information to CRIS for SHPO for review. A Phase 1 Archaeological Survey was prepared for the project Area of Potential Effect. The SHPO staff completed a resource eligibility evaluation which determined the South Farmington Cemetery and Chapel to be eligible for the National Register of Historic Places. A Finding Documentation is being prepared for submission to the SHPO.

4.4.12 Parks and Recreational Resources

The proposed project would not impact areas identified as State or National Heritage Areas. The Town of Farmington's Meeting House Park is located in the northwest quadrant of the intersection. The park offers passive recreation and includes a parking area, a grassed area in a stand of evergreen trees, and a stone monument bearing a metal plate with the words:

> "IN MEMORY OF THE FRIENDS MEETING HOUSE ERECTED ON THIS SITE IN 1823. THE LAND WAS GIVEN BY WELCOME HERENDEEN BEING ON THE ORIGINAL FARM OF HIS FATHER NATHAN HERENDEEN WHO SETTLED HERE IN 1790. THIS MEMORIAL PLACED BY THE HERENDEEN ASSOCIATION 1928."

The property was conveyed to the Town of Farmington in a document dated June 26, 1976 (Liber 757, Page 46 of the Ontario County Clerk) from the Religious Society of Friends, containing a restriction that the Town of Farmington shall improve and maintain said lands for recreational purposes and maintain a monument containing the inscription above.

The proposed project would avoid taking any permanent easements from the park property. A temporary easement covering approximately 0.08 acres would be required to construct the project and some minor grading would occur around the south and east boundaries of the park. The project would also require the relocation of water main owned by the Town of Farmington. It is proposed that the relocated water main would cut across the southeast corner of the park property. The water main would be completely below ground and would not alter the character or use of any land above it.

4.4.12.4 Section 4(f) Involvement

Section 4(f) of the USDOT Act of 1966 (49 USC § 303; 23 CFR §774) prohibits the Secretary of Transportation from approving any program or project that requires the "use" of (1) any publicly owned parkland, recreation area, or wildlife and waterfowl refuge of national, state, or local significance; or (2) any land from a historic site of national, state, or local significance (collectively, "Section 4(f) properties"), unless there is no feasible and prudent alternative to the use of such land and such program or project

includes all possible planning to minimize harm to the park, recreation area, wildlife refuge, or historic site.

A project uses a Section 4(f) property when:

- It permanently incorporates land from the property into a transportation facility;
- It temporarily but adversely occupies land that is part of the property; or
- It "constructively" uses the property, which occurs "when the transportation project does not incorporate land from a Section 4(f) property, but the proximity impacts are so severe that the protected activities, features, or attributes that qualify property for protection under Section 4(f) are substantially impaired."

The Meeting House Park may be considered to be a Section 4(f) resource.

As discussed above, construction of the project would require temporary use of Meeting House Park. Per above, this might be considered a Section 4(f) use; however, there are exceptions to this in the regulations (23 CFR Part 774.13) which include, "Temporary occupancies of land that are so minimal as to not constitute a use within the meaning of Section 4(f). The following conditions must be satisfied:

(1) Duration must be temporary, *i.e.*, less than the time needed for construction of the project, and there should be no change in ownership of the land;
(2) Scope of the work must be minor, *i.e.*, both the nature and the magnitude of the changes to the Section 4(f) property are minimal;
(3) There are no anticipated permanent adverse physical impacts, nor will there be interference with the protected activities, features, or attributes of the property, on either a temporary or permanent basis;
(4) The land being used must be fully restored, *i.e.*, the property must be returned to a condition which is at least as good as that which existed prior to the project; and
(5) There must be documented agreement of the official(s) with jurisdiction over the Section 4(f) resource regarding the above conditions."

The construction use of the proposed project at the Meeting House Park would require only a portion of the total project construction duration for grading operations and construction of an enhanced parking area, desired by the Town of Farmington. There would be no permanent adverse physical impacts and any damage to the park as a result of construction activity would be repaired.

4.4.12.5 Section 6(f) Involvement

The project would not impact parklands or facilities that have been partially or fully federally funded through the Land and Water Conservation Act. No further consideration under Section 6(f) is required.

4.4.12.6 Section 1010 Involvement

This project would not involve the use of land from a park to which Urban Park and Recreation Recovery Program funds have been applied.

4.4.13 Visual Resources

The project, which would involve intersection reconstruction converting a four-legged, two-way stop-controlled intersection to a roundabout, is adjacent to and surrounded by rural agricultural and residential properties as well as a local park, cemetery, and chapel. There are three primary viewer groups of the proposed project: roadway traffic users, residential occupants, and pedestrians.

The streetscape is rural in nature with no street trees, sidewalks, or other man-made visual elements typical of a developed roadside. The view shed consists almost entirely of flat agricultural fields with isolated hedgerows delineating fields and residential areas. There are two residential properties within the

project limits. Both of the properties, one located at the northeast corner of the intersection of CR 28 and Shortsville Road and one in the southeast corner, are single family residences.

The project is expected to have minimal impact to the existing view shed. While the alignment of the intersection approaches would be slightly altered, the overall result of the alterations would not change the function or the large-scale appearance of the project area to the residential users. Vehicular users would find the intersection easier to maneuver with appropriate signage directing motorists through the roundabout. Additional signage and lighting may considered be a negative impact on the visual corridor but will substantially increase overall safety during both daytime and nighttime hours.

4.4.14 Farmlands

4.4.14.1 State Farmland and Agricultural Districts -

The proposed project is located within NYS Agricultural District 1 for Ontario County based on a review of NYS Agricultural District Maps. Since the proposed project will not acquire more than one acre from an actively operated farm within the Agricultural District, or more than ten acres within the Agricultural District, the notification requirements of the NYS Agriculture and Markets Law do not apply.

4.4.14.2 Federal Prime and Unique Farmland

Acquisition of prime or unique farmland, or farmland of state or local significance will be required for this project. It has been determined that this project will qualify for a 'small acreage exemption' and is exempt from the requirements of the Federal Farmland Protection Act, as the project proposes to convert less than 3-acres of land classified as United States Farmland. Completion of the US Department of Agriculture Farmland Conversion Rating (Form AD 1006) will not be required.

4.4.15 Air Quality

This project is located in Ontario County which is considered an ozone attainment area. The project is considered an exempt project as per Table 2 in Section 93.126 of 40 CFR. In addition, this project is also exempt from Regional Emissions Analysis as per Table 3 in Section 93.127 of 40 CFR. No additional analysis is required for this project.

4.4.16 Energy

An energy assessment is not required for the proposed project since it is not expected to:

a. Increase or decrease VMT;
b. Generate additional vehicle trips;
c. Significantly affect land use development patterns;
d. Result in a shift in travel patterns; or
e. Significantly increase or decrease vehicle operating speeds.

The project would not significantly affect energy consumption.

4.4.17 Noise

The project would not decrease the distance between the roadway and the closest receptors by more than 50%. The project would not significantly change either the horizontal or vertical alignment or increase the number of through-traffic lanes; therefore, this project is not a Type I project and does not require a traffic noise analysis as per 23 CFR 772.

4.4.18 Asbestos

An asbestos screening has been performed for this project and it has been determined that there are no areas of potential asbestos material present. The results of the full screening are included in **Appendix B**.

4.4.19 Hazardous Waste and Contaminated Materials

A Hazardous Waste/Contaminated Materials Site Screening was conducted in accordance with NYSDOT The Environmental Manual, Section 4.4.20, in order to document the likely presence or absence of hazardous/contaminated environmental conditions. A hazardous/contaminated environmental condition is the presence or likely presence of any hazardous substances or petroleum products (including products currently in compliance with applicable regulations) on a property under conditions that indicate an existing release, a past release, or a material threat of a release of any hazardous substances or petroleum products into structures on the property or into the ground, ground water, or surface water of the property.

The Hazardous Waste/Contaminated Materials Site Screening included a review of NYSDEC regulatory data files and a site 'walkover' completed on July 5, 2018.

No hazardous waste/contaminated materials were identified within or adjacent to the project area during the course of the Hazardous Waste/Contaminated Materials Site Screening. The potential risk for involvement with documented or undocumented inactive hazardous waste/contaminated materials is low.

The results of the full screening are included in **Appendix B**.

EXHIBIT D

Final

DELINEATION OF WATERS OF THE UNITED STATES

INCLUDING

FRESHWATER WETLANDS

Yellow Mills Road Solar Farm

Town of Farmington
Ontario County, New York

Prepared For:

Delaware River Solar, LLC
c/o Mr. Peter Dolgos
33 Irving Place
New York, New York 10003

Prepared By:

NORTH COUNTRY ECOLOGICAL SERVICES, INC.

July 24, 2018

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Appendix D – Supplemental Jurisdictional Information and Soil Survey Data

1.0 INTRODUCTION

At the request of Delaware River Solar, LLC (DRS), North Country Ecological Services, Inc. (NCES) completed an on-site delineation of Waters of the United States that include freshwater wetlands on a portion of a 135.36± acre property known as "Lands of Smith - Yellow Mills Road" (the "Site"). The Site is currently owned by Rodger and Carol Smith of 4790 Fox Road, Palmyra, New York 14522 (the "Owners"). the property is an active cattle farm. At this time, DRS is under contract to acquire a portion of the property from the Owners for the purposes of establishing a solar farm.

At the further request of DRS, the delineation was limited to 84.75± acres of the Site (the "Review Area"). The Review Area encompasses the lands that will be converted from agricultural use into the solar farm. The formal delineation was warranted to identify potential environmental constraints and assist in defining unrestricted land in conjunction with anticipated future development/usage of the property.

After a review of the Ontario County Soil Survey, the USGS 7.5' topographic map (Macedon Quadrangle), aerial photographs, and other technical information for the Site, NCES identified and delineated the limits of wetlands and other Waters of the United States that fall under the jurisdiction of the U.S. Army Corps of Engineers (USACE) pursuant to Section 404 of the Clean Water Act (CWA). NCES also reviewed the property for wetlands that would be subject to regulation by the New York State Department of Environmental Conservation (DEC) pursuant to Article 24 of the Environmental Conservation Law (ECL). The formal field delineation was completed by NCES on April 30, 2018.

As a result of the delineation, a total of 6.89± acres of vegetated wetland and 1,605± linear feet of stream channels (Seasonal Relatively Permanent Waterways – RPW's) were identified. The delineated wetland boundaries were subsequently field located by NCES utilizing GPS technology and were formally mapped by the firm of Schultz Associates, of 129 South Union Street, Spencerport, New York 14559 (Schultz).

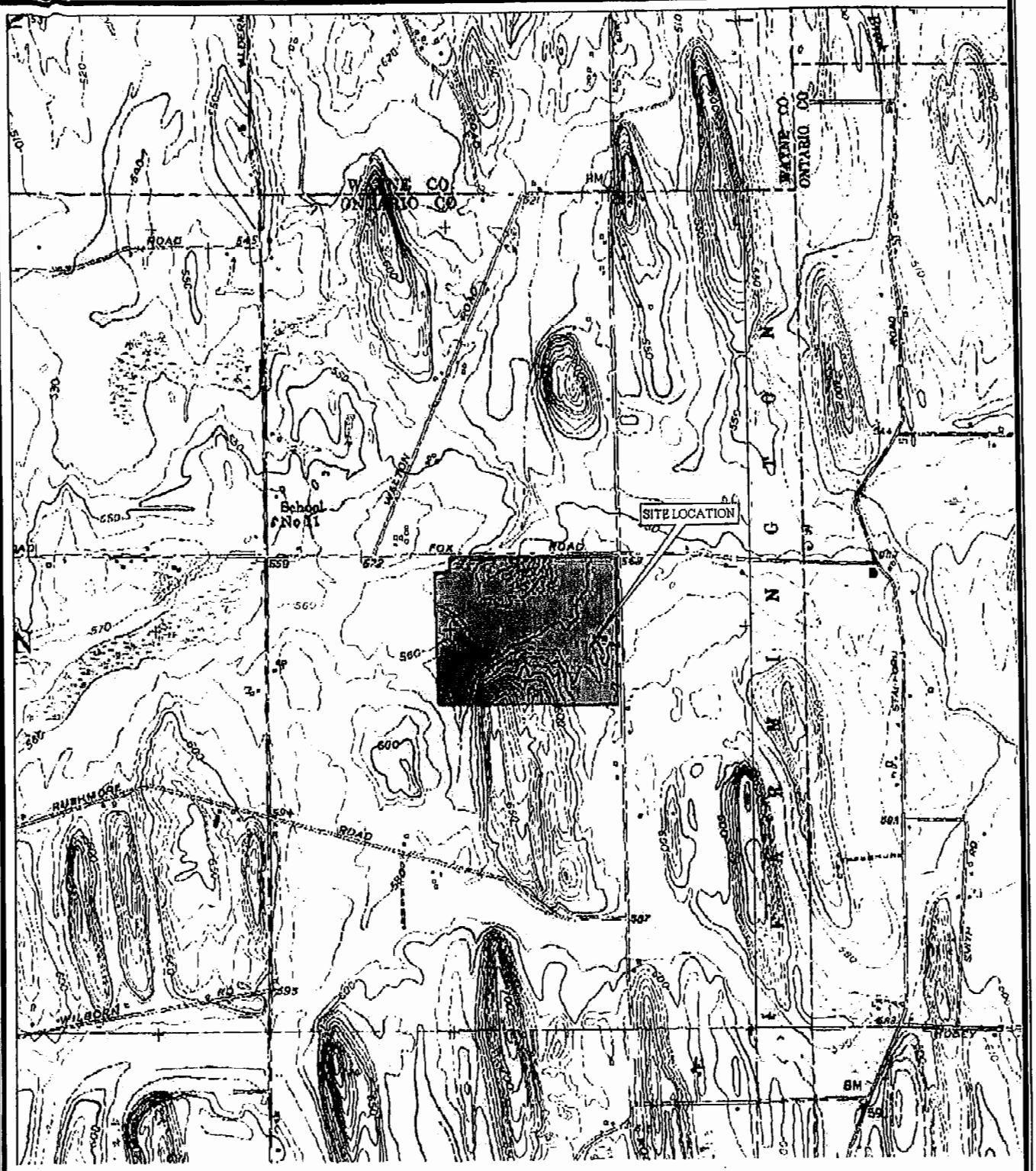
2.0 SITE LOCATION & DESCRIPTION

The Site is located at the southwest intersection of Yellow Mills Road and Fox Road in the Town of Farmington, Ontario County, New York (Figure 1). The Review Area basically encompassed the eastern two-thirds of the property. The centralized coordinates of the Review Area are 43° 00' 59.27" N Latitude and 77° 15' 38.19" W Longitude. The general topography of the Review Area is generally flat. However, a large upland ridge exists within the southwest corner of the property. Elevations within the Review Area range from 630 feet above mean sea level (msl), found along the aforementioned upland ridge, to 543 feet above msl, located at the edge of a pond found along Fox Road, resulting in an elevation difference of 87± feet.

The Site can be characterized as an active cattle farm. The majority of the land within the Review Area exists as pasture for cattle. Other fields on the farm utilized for hay and field crops to support the cattle operation. A large upland ridge is located in the southwest corner of the Site. This upland ridge is predominantly wooded. The northwest corner of the Review Area appears to have been mined for sand & gravel. Large, deep, pits and open water ponds are present in this portion of the Site.

With the exception of the upland ridge, all other portions of the Review Area have been historically utilized for farming or mining activities. It was apparent that portions of the ridge have been logged by the Owners. A large forested wetland complex is located along the western boundary of the Review Area. This portion of the Site has probably been historically too wet to have been actively farmed. Several large barns, garages, and a single-family home are also situated on the property along Yellow Mills Road. Areas immediately surrounding the house and barns exists as mowed lawn.

Based upon the definitions presented in the *Ecological Communities of New York State* (Edinger, 2014) and the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin, 1979), the following ecological communities have been identified within the Review Area:



Base Map: USGS Macedon 7.5' Quadrangle, Ontario County, N.Y.

Scale: 1" = 2000'

NCES

North Country Environmental Services, Inc.

FIGURE 1- SITE LOCATION MAP

- Pastureland (Edinger)
- Cropland - field crops (Edinger)
- Successional northern hardwood forest (Edinger)
- Quarry pond (Edinger)
- Red maple hardwood swamp (Edinger)**
- Palustrine forested wetland (Cowardin)**
- Palustrine emergent wetland (Cowardin)

** The Red maple hardwood swamp community identified by Edinger is the same as the Palustrine forested community described by Cowardin.

Land use surrounding the Site include single-family residential homes, active agriculture, and undeveloped forested land. The parcel is bordered to the north by Fox Road, on the east Yellow Mills Road Road, and to the south and west by undeveloped woodlands. Active agricultural fields are located to the north and east of the Site, on opposites sides of the road that border the property. Photographs of the Review Area that were taken by NCES to show the condition of the property at the time of the delineation are contained in Appendix A.

3.0 DELINEATION METHODOLOGY

Wetland boundaries were delineated using the three-parameter methodology as outlined in the *Corps of Engineers Wetland Delineation Manual,* 1987 (1987 manual). The 1987 manual was used in accordance with the Corps of Engineers Appropriation Bill and the Johnson Amendment of August 17, 1991, which states that until revisions to the January 1989 *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (1989 manual) are finalized, the Corps of Engineers will apply the 1987 manual to identify and delineate wetlands potentially subject to regulation under Section 404 of the CWA. In order for an area to be classified as a wetland, it must exhibit the following characteristics: hydrophytic vegetation, hydric soils, and wetland hydrology.

NCES also used information presented within the *Regional supplement to the Corps of Engineers Wetland Delineation Manual – Northcentral and Northeast Region* (January 2012) as further guidance for assessing and defining wetland boundaries. According to the 1987 Manual and Interim Regional Supplement, in order for an area to be classified as a wetland, it must exhibit hydrophytic vegetation; hydric soils; and wetland hydrology.

The routine on-site determination method was used to determine the wetland boundaries on the Site. Vegetative, soils, and hydrologic data were examined and collected along the upland/wetland transitions. Vegetation was sampled using the quadrant sampling procedure. Transects were established perpendicular to the wetland boundaries in order to document the vegetation, soils, and hydrology of the on-site wetlands and uplands.
The USACE has also issued the *National List of Plant Species That Occur in Wetlands*, which lists species of vascular plants that are likely to occur in a wetland. The list separates the plants into five categories that determine the "wetland indicator status." A species indicator status is based upon its frequency of occurrence in wetlands:

- *Obligate wetland* plants (OBL) occur almost always (estimated probability >99%) in wetlands under natural conditions;
- *facultative wetland* plants (FACW) usually occur in wetlands (estimated probability 67-99%), but are occasionally found in upland;
- *facultative* plants (FAC) are equally likely to occur in wetlands or uplands (estimated probability 34-66%);
- *facultative upland* plants (FACU) are those species that normally occur in uplands but occasionally occur in wetlands (estimated probability 67-99%); and,
- *upland* (UPL) species occur almost always in uplands (estimated probability >99%) under natural conditions (Federal Interagency Committee for Wetland Delineation, 1989).

Dominant plant species were determined for each vegetative stratum by estimating aerial cover. Dominant plant species are defined as those species in each stratum that, when ranked in decreasing order of abundance and when cumulatively totaled, exceed 50% of the total dominance measure for each stratum, plus any additional species that comprise 20% or more of the total dominance measure.

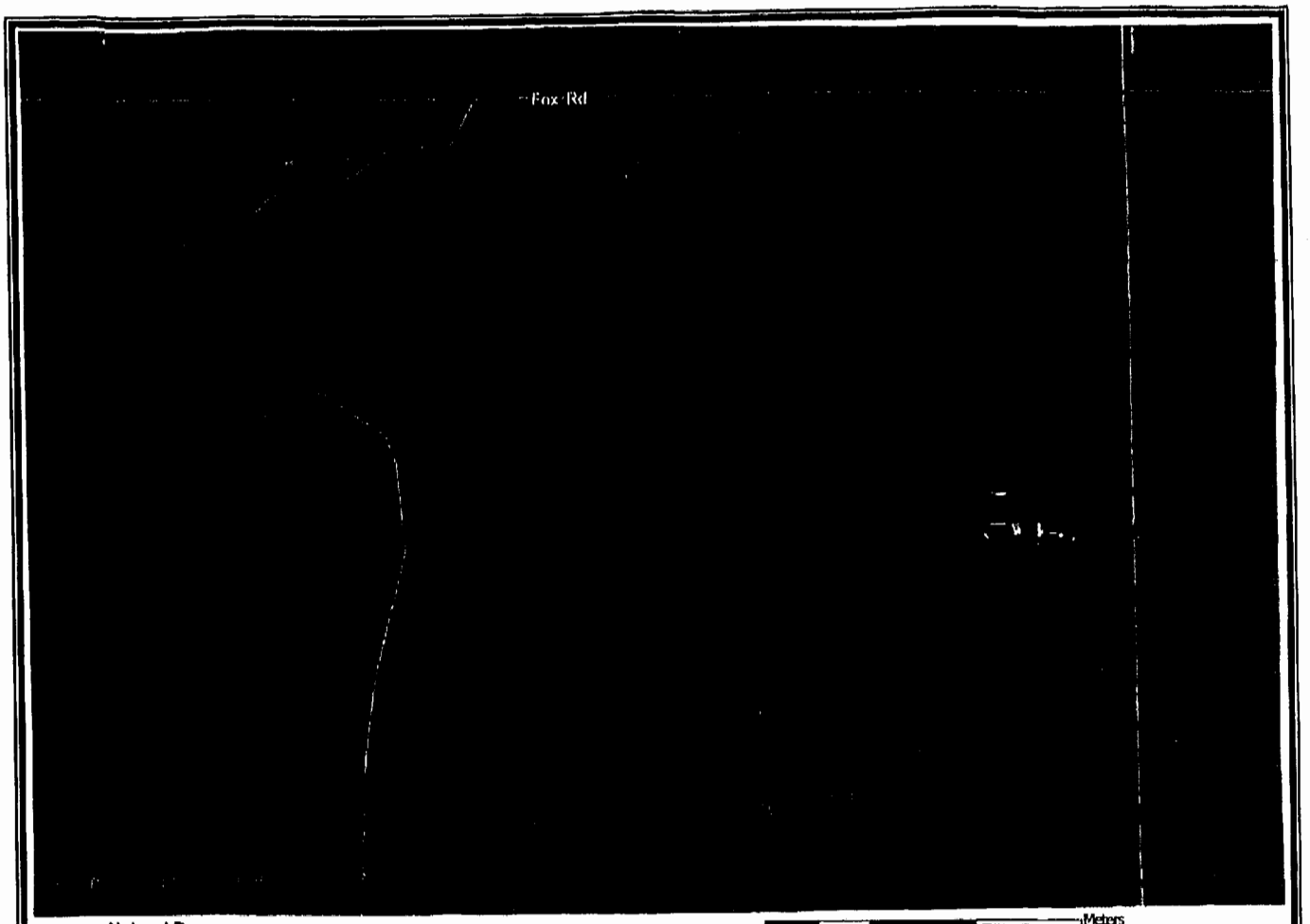
Soils were analyzed to depths below the A-horizon. Samples were taken in conjunction with the procedures outlined within the Regional Supplement. Soil samples were checked to determine Munsell Soil Color Chart designation and hydric soils were identified by color. Indicators of hydrology were noted on the field data sheets. Vegetation, soils, and hydrology were analyzed to determine the wetland boundary.

Perennial and Intermittent streams were identified by the formation of banks, apparent streambeds, and high water marks where extended hydrologic input has formed deep channels in the soils and formed hydric soils. Copies of the field data sheets used to document the vegetation, soils, and hydrology are contained in Appendix B.

4.0 EXISTING CONDITIONS

4.1 Soils

According to the USDA Natural Resources Conservation Service Web Soil Survey 3.2 for Ontario County, New York (the "Soil Survey"), a total of ten (10) different soil series were identified within the boundaries of the Site. The soil types identified include: Fine-loamy, mixed, active Typic Argiaquolls (19A); Canandaigua mucky silt loam, with 0-3% slopes (44A); Ontario fine sandy loam, with 8-35% slopes (112C & 112E); Ontario loam, with 3-25% slopes (116B, 116C & 116D); Palmyra cobbly loam, with 0-3% slopes (122A and 122B); Palmyra gravelly loam, with 3-15% slopes (126B and 126C); Phelps gravelly silt loam, with 0-3% slopes (210A); Kendaia loam, with 0-3% slopes (304A); and, Pits, gravel and sand (PG), (Figure 2).



USDA **Natural Resources Conservation Service**
Web Soil Survey
National Cooperative Soil Survey

Meters: 0 50 100 200 300
Feet: 0 250 500 1000 1500

Soils Legend

19A	– Fine-loamy, mixed, active Typic Argiaquolls	122A	– Palmyra cobbly loam, 0-3% slopes
44A	– Canandaigua mucky silt loam, 0-3% slopes	122B	– Palmyra cobbly loam, 3-8% slopes
112C	– Ontario fine sandy loam, 8-25% slopes	126B	– Palmyra gravelly loam, 3-8% slopes
112E	– Ontario fine sandy loam, 25-35% slopes	126C	– Palmyra gravelly loam, 8-15% slopes
116B	– Ontario loam, 3-8% slopes	210A	– Phelps gravelly silt loam, 0-3% slopes
116C	– Ontario loam, 8-15% slopes	304A	– Kendaia loam, 0-3% slopes
116D	– Ontario loam, 15-25% slopes	PG	– Pits, gravel and sand

Base Map: Web Soil Survey 3.2 – Ontario County Soil Survey, N.Y.

Scale: As Noted

NCES
North Country Ecological Services, Inc.

FIGURE 2 - SOIL SURVEY

4.2 Vegetation

During the review, NCES identified six (6) different ecological communities within the boundaries of the Review Area. These ecological communities include: Pastureland, Cropland - field crops, Successional northern hardwood forest, Quarry pond, Palustrine forested wetland, and Palustrine emergent wetland. Each of these vegetative communities, with the exception of the Quarry pond, possess different and distinct species of vegetation that assist in defining them. The Quarry pond community was simply an open body of water that did not possess any significant vegetation within it. The dominant species of vegetation observed in each ecological community are listed below:

Some of the dominant species of vegetation observed within the Pastureland and Cropland - field crops ecological communities included; but are not limited to: alfalfa (*Medicago sativa*), timothy (*Phleum pratense*), orchard grass (*Dactylis glomerata*), reed canary grass (*Phalaris arundinacea*), wild carrot (*Daucus carota*), birdsfoot trefoil (*Lotus corniculatus*), red clover (*Trifolium pratense*), common plantain (*Plantago major*), English plantain (*Plantago lanceolata*), wild madder (*Galium mollugo*), Canada goldenrod (*Solidago canadensis*), spotted knapweed (*Centaurea maculosa*), dandelion (*Taraxacum officinale*), common milkweed (*Asclepias syraca*), common mugwort (*Artemisia vulgaris*), ragweed (*Ambrosia artemisifolia*), daisy (*Chrysanthemum leucanthemum*), wild madder (*Galium mollugo*), and cow vetch (*Vicia cracca*).

Some of the dominant species of vegetation observed within the Successional northern hardwood forest ecological community included; but are not limited to: red oak (*Quercus rubra*), shagbark hickory (*Carya ovata*), white ash (*Fraxinus americana*), (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), quaking aspen (*Populus tremuloides*), honeysuckle (*Lonicera tatarica*), buckthorn (*Rhamnus cathartica*), poison ivy (*Toxicodendron radicans*), garlic mustard (*Alliaria officinalis*), and common blue violet (*Viola sororia*).

Some of the dominant species of vegetation observed within the Palustrine forested wetlands included, but are not limited to, red maple, green ash (*Fraxinus pennsylvanicum*), American elm (*Ulmus americana*), pussy willow (*Salix discolor*), witch hazel (*Hamamelis virginiana*), tussock sedge (*Carex stricta*), skunk cabbage (*Symplocarpus foetidus*), fowl manna grass (*Glyceria striata*), jewelweed (*Impatiens capensis*), cinnamon fern (*Osmunda cinnamomea*), royal fern (*Osmunda regalis*), and sensitive fern (*Onoclea sensibilis*).

Some of the dominant species of vegetation observed within the Palustrine emergent wetlands included; but are not limited to: purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*), moneywort (*Lysimachia nummularia*), soft rush (*Juncus effusus*) slender goldenrod (*Solidago tenuifolia*), sensitive fern, late goldenrod (*Solidago gigantea*), fox sedge (*Carex vulpinoidea*), dark green bulrush (*Scirpus atrovirens*), and jewelweed.

4.3 Hydrology

The main sources of hydrology that influence the wetlands identified on the Site appear to originate from ground water discharge, surface water runoff, and direct precipitation. The stream that bisects the field dissipates into natural sand and gravel in the center of the field. There is no physical outlet to this watercourse as the water simply dissipates into the ground.

The forested wetland located along the western boundary of the Review Area receives runoff from the adjacent upland ridge as well as retains surface water. Ground water seeps were noted along the toe-of-slope of the ridge and wetland boundary. This wetland naturally drains to the northwest and is hydrologically contiguous with a larger wetland complex found to the west of the Site. This off-site wetland physically abuts a perennial stream channel that flows to the north and into other wetlands that are located to the north of Fox Road. The open water ponds and adjacent wetland communities are primarily ground water induced, as surrounding lands were mined for sand and gravel and the land

was excavated to the groundwater elevation. These ponded areas fluctuate in depth as the ground water table rises and lowers in conjunction with the natural hydrologic cycle. These ponds, hydrologically connect with the off-site wetlands that drain into the aforementioned perennial stream channel found to the northwest of the Site.

The un-named stream continues to the north and eventually converges with Ganargua Creek. This stream is a third-order perennial tributary that flows east and into the Erie Canal. The Erie Canal is classified as a Traditional Navigable Waterway (TNW).

As previously stated, the drainage that extends into the center of the property is reliant upon direct precipitation and surface water runoff for hydrologic input. The linear drainage extends flows to the center of the property. Natural flow is northward from the southern property boundary to the center of the Site. Once in the center of the Site, the drainage dissipates into the soil. No surface connection between this drainage and the open water ponds found to the north were observed.

5.0 WETLAND FINDINGS

During the delineation, three (3) individual wetland areas were identified on the Site. The wetlands have been designated by NCES as Wetland Areas 1, 2, and 3. The location and configuration of these wetlands is shown on the drawing prepared by Shultz Associates that is titled "Existing Conditions - Delaware River Solar, LLC - Yellow Mills Road" dated May 30, 2108 and last revised June 28, 2018. A copy of this wetland delineation map is contained in Appendix C.

6.0 JURISDICTIONAL DETERMINATION

In light of the Supreme Court rulings regarding the potential restriction of authority of the USACE to assert jurisdiction over isolated, non-adjacent, non-navigable waters of the United States based on the Solid Waste Agency of Northern Cook County vs. United

States (SWANCC) and Rapanos vs. USACE (Rapanos), it is required that environmental consultants identify, describe, and segregate each wetland area into jurisdictional and non-jurisdictional categories. This is required to assist the USACE in determining which wetlands are jurisdictional. Consultants must also provide project specific information relative to "post Rapanos" guidelines. A copy of the supplemental information is contained in Appendix D.

According to the Supreme Court, if a wetland can be deemed "isolated," "non-adjacent," and/or "non-navigable" and it is not physically hydrologically connected with a tributary system of a Traditional Navigable Waterway (TNW), the USACE does not have authority to assert jurisdiction over these wetland areas without a "Significant Nexus" review to determine the significance of the wetland in relation to adjacent jurisdictional waters. If it is subsequently determined during a joint review between the USACE and the Environmental Protection Agency (EPA) that no significant nexus exists, and if the wetlands are not regulated by any other governmental agency, such as the DEC or the United States Fish and Wildlife Service (USFWS), then these wetlands are not regulated.

6.1 Army Corps of Engineers Jurisdictional Wetlands

The observations made by NCES during the wetland delineation process revealed that a direct hydrological connection with a tributary system of a navigable waterway was identified between some of the wetlands and off-site waters of the United States. Therefore, the wetlands identified in Table 1 fall under the regulatory jurisdiction of the USACE pursuant to Section 404 of the Clean Water Act.

TABLE 1
USACE Jurisdictional Wetlands

Area	Size	Stream Length	Vegetative Cover Types
1	1.52± Acres	0± linear feet	Palustrine Emergent and Forested
2	4.26± Acres	0± linear feet	Open Water Pond
Totals	**5.78± Acres**	**± linear feet**	

6.2 Potential Non - Jurisdictional Wetlands

Based on the observations made by NCES during the delineation process, one of the wetlands identified has the potential to be deemed "isolated" and thus "non-jurisdictional" as it does not possess a physical, surface connection with any other wetlands identified; it is not adjacent to, nor does it abut a wetland that is physically connected with off-site waters. Consequently, the wetland identified in Table 2 my not fall under the regulatory jurisdiction of the USACE.

TABLE 2
Potential Non- Jurisdictional Wetlands

Area	Size	Stream Length	Vegetative Cover Types
3	1.11± Acres	1,605± linear feet	Linear Palustrine Emergent

6.3 DEC Regulated Wetlands

Based on the review of the Article 24 Freshwater Wetland mapping that was obtained from the DEC's Environmental Resource Mapper (ERM), a portion of a currently mapped Article 24 regulated wetlands is found within the boundaries of the Site (Figure 3). Specifically, portions of Freshwater Wetland (FWW) MC-12 are contained within the property boundaries. Portions of the 100 foot Adjacent Area (buffer zone) of Freshwater Wetland MC-12 are also contained within the boundaries of the Review Area as well.

The DEC mapped wetland correlates with Wetland Area 1 as identified and delineated by NCES. The extent of the DEC regulated areas are shown on the delineation map contained in Appendix C and are outlined in Table 3 below:

TABLE 3
DEC Regulated Areas

Area	Size	Stream Length	Vegetative Cover Types
FWW MC-12	1.52± Acres	0± linear feet	Palustrine Emergent and Forested
100' A.A.	2.49± Acres	0± linear feet	Active Pasture
Totals	**4.01± Acres**	**0± linear feet**	

NEW YORK STATE - DEPARTMENT OF
ENVIRONMENTAL CONSERVATION

Map Layers & Legend

- Classified Water Bodies
- Classified Water Bodies
- State-Regulated Freshwater Wetlands
- Wetland Check-zone

Base Map: DEC Environmental Resource Mapper - Ontario County, NY

Scale: None

NCES

FIGURE 3 - DEC Regulated Areas

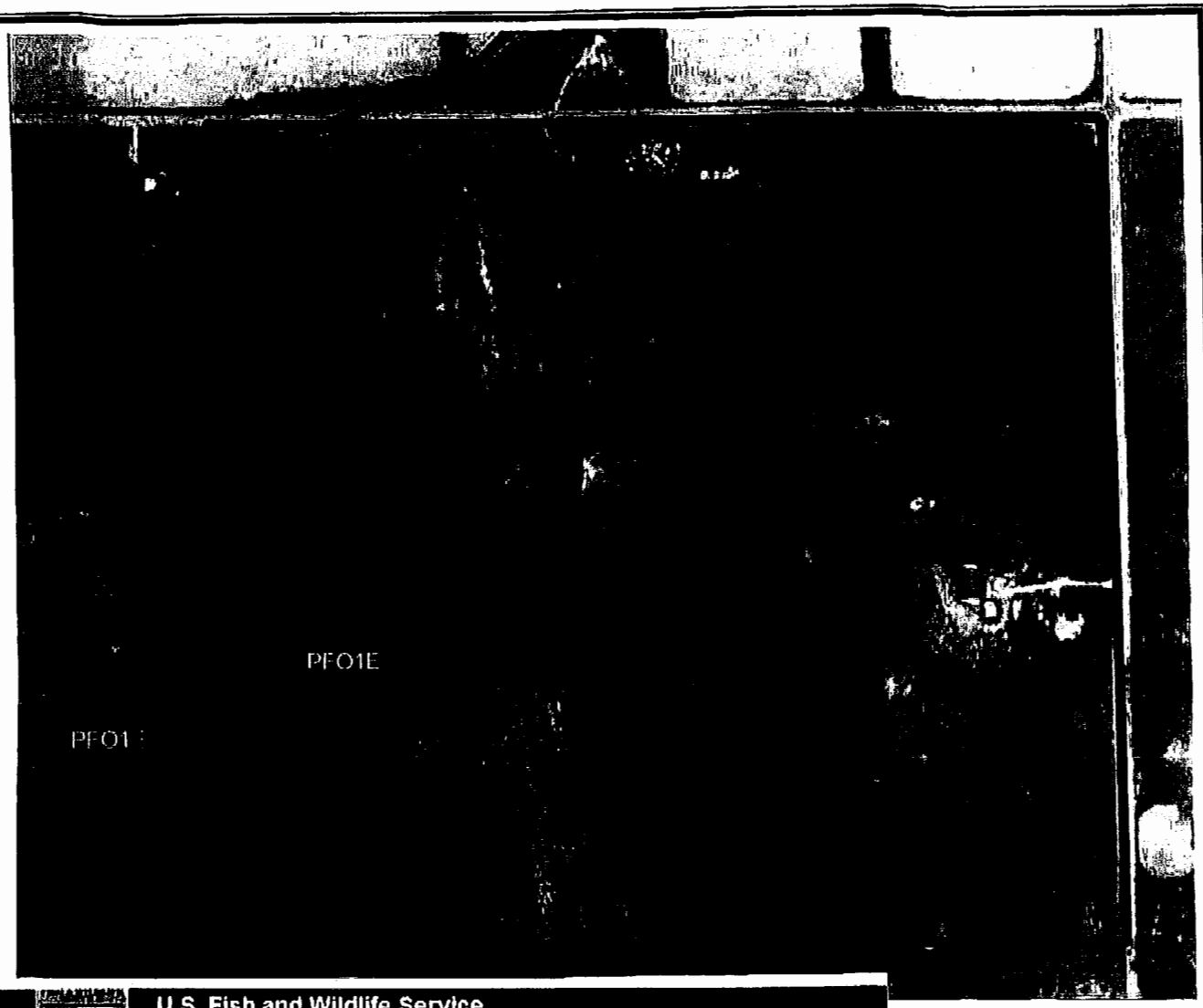
Based on the review of the Article 15 Protected Stream information obtained from the ERM, no Article 15 regulated streams exist on the Site. Therefore, no Article 15 Protection of Waters Permit will be required for this project.

6.4 National Wetland Inventory (NWI) Wetland Information

As is required by the USACE Buffalo District wetland reporting guidelines, NCES reviewed the U.S. Fish and Wildlife Service (USFWS) website and reviewed the National Wetland Inventory Mapper to determine if wetlands identified by the USFWS are present on the Site. Based on the information obtained from the National Wetland Inventory Mapper, it was determined by NCES that a portion of a NWI mapped wetland is present within the boundaries of the Site (Figure 4). The mapped wetland correlates with Wetland Area 1 as delineated by NCES and the wetland designated as FWW MC-12 by the DEC. The USFWS does not regulate wetlands and the NWI maps were generated to assist in identifying aquatic resources. No further consultation with the USFWS relative to wetlands is required.

7.0 CONCLUSION

As a result of the delineation, it has been determined that there are three (3) separate vegetated wetlands that total 6.89± acres within the Review Area. Within the confines of Wetland Area 3, a total of 1,605± linear feet of stream channel (Seasonal RPW) are present. Wetland Area 3 could not be field delineated since it was located within an active cattle pasture. While onsite, NCES was advised against entering the pasture with the cattle by the Owners. The herd contained several large bulls that, according to the Owners, are highly protective and aggressive. The edge of the drainage was well defined by topography and vegetation, and the boundaries of Wetland Area 3 were established using aerial photography and detailed topographic data.



U.S. Fish and Wildlife Service

National Wetlands Inventory

Wetlands

- Estuarine and Marine Deepwater
- Estuarine and Marine Wetland
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Freshwater Pond
- Lake
- Other
- Riverine

Base Map: USFWS NWI Wetlands Map, Ontario County, N.Y.

Scale: As Noted

NCES

North Country Ecological Services, Inc.

FIGURE 4 - NWI WETLANDS

While there are no DEC regulated streams found on the property, Wetland Area 1 is a portion of DEC regulated wetland MC-12. In addition to the wetland itself, the DEC regulates 100' from the boundary of the wetland and any disturbances to the wetland or within 100' of it, may require an Article 24 permit from the DEC. The remainder of the property is actively farmed and the fields appeared to be well drained and maintained for cattle.

8.0 REFERENCES

- Cowardin, L.M., V. Carter, F.C. Gocet and E.T. Laroe. December 1979.Classification of Wetlands and Deepwater Habitats of the United States. USFWS Office of Biological Service, FWS/IOBL-79/31.

- Edinger, Gregory. 2014. Ecological Communities of New York State. New York Natural Heritage Program. 96 pgs.

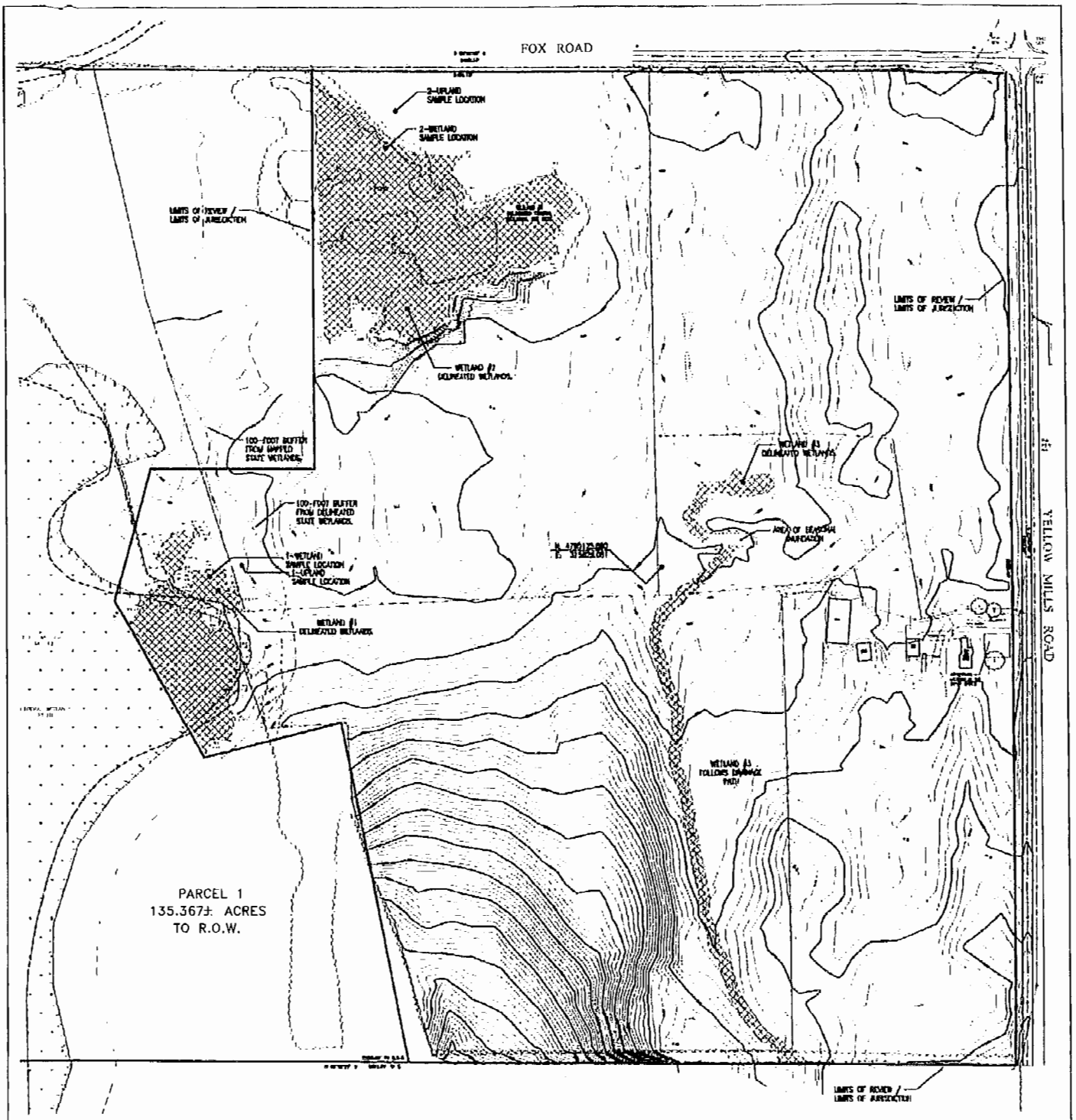
- Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1, US Army Engineer Waterway Experiment Station, Vicksburg, Mississippi.

- New York State Department of Environmental Conservation. Environmental Resource Mapper. Article 24 and Article 15 Regulated Resources of Ontario County, New York. On-line Resource Guide. www.state.ny.us

- U. S. Department of Agriculture, Natural Resource Conservation Service. Web Soil Survey 3.2. Soil Survey of Ontario County, New York.

Appendix C

Wetland Delineation Map



WETLAND INFORMATION

AREA OF REVIEW / LIMIT OF JURISDICTION: 61.21 ± ACRES

WETLAND TABLE:

AREA #1: 1.521 ACRES
AREA #2: 4.261 ACRES
AREA #3: 1.116 ACRES / 1,005 LINEAR FEET
TOTAL: 6.391 ACRES / [illegible] LINEAR FEET

WETLAND DELINEATION

1. PORTIONS OF THE WETLANDS DEPICTED ON THIS MAP WERE DELINEATED BY NORTH COUNTRY ECOLOGICAL SERVICES INC. ON APRIL 30, 2018 (25 WEST FULTON STREET, GLOVERSVILLE, NY 12078).
2. THE MAPPED BOUNDARY OF THE NYSDEC STATE WETLAND WERE LOCATED BASED ON THE DIGITAL MAPS PROVIDED BY THE NYSDEC ENVIRONMENTAL RESOURCE MAPPER.
3. THE MAPPED BOUNDARY OF THE FEDERAL WETLAND WERE LOCATED BASED ON THE DIGITAL MAPS PROVIDED BY THE U.S. FISH AND WILDLIFE NATIONAL WETLAND INVENTORY MAPPER.

LEGEND

LOCATION MAP

ZONING: A-80
TAX ACCOUNT No.: 010.000-0[illegible]-037.1[illegible]
CURRENT ADDRESS: 468 YELLOW MILLS RD
PARCEL AREA: 135.41 ACRES

LAND OWNER:
RODGER & CAROL SMITH
7296 FOX ROAD
PALMYRA, NY 14522

APPLICANT:
DELAWARE RIVER SOLAR, LLC
CONTACT: PETER DOLGOS
33 FRANK PLACE
NEW YORK, NY 10003
(646) 998-6495

A MAP SHOWING

DELAWARE RIVER SOLAR, LLC
SOLAR ENERGY FACILITY
~ YELLOW MILLS ROAD ~

SITUATE IN:
PART OF TOWN LOTS 118 & 119, TOWN OF FARMINGTON,
COUNTY OF ONTARIO, STATE OF NEW YORK

SCHULTZ ASSOCIATES
Engineers & Land Surveyors, P.C.
129 South Union Street, PO Box 89
Spencerport, New York 14559
585.349.3750

EXISTING CONDITIONS

DRAWN BY	BHL/JS/DSM	PROJECT NO.	18,023
CHECKED BY	CJA	SHEET No.	1 OF 1
DATE	MAY 30, 2018	DWG NO.	EX-1

Appendix D

Supplemental Jurisdictional Information

Supplemental Information for Jurisdictional Determination
Yellow Mills Road Solar

USACE Application #:	*Not Yet Assigned*
Project Name:	Yellow Mills Road Solar Farm
Current Property Owners:	Rodger and Carol Smith 4790 Fox Road Palmyra, New York 14522
Project Applicant:	Delaware River Solar, LLC c/o Mr. Peter Dolgos 33 Irving Place New York, N.Y. 10003
Environmental Consultants Wetland Delineators:	North Country Ecological Services, Inc. 25 West Fulton Street Gloversville, New York 12078 (518) 725-1007
Total Property Acreage:	135.36± acres
Limits of Jurisdiction:	84.75± acres
Site Coordinates:	43° 00' 59.27" N Latitude and 77° 15' 38.19" W Longitude
Historic Land Use:	Active Agricultural
Current Land Use:	Active Agricultural
Average Annual Rainfall:	34.0 Inches
Average Annual Snowfall:	66.0 Inches
Watershed Area:	582.4± acres
Site Location Map:	See Figure 1 in the Delineation Report – The Site is located at the southwest intersection of Yellow Mills Road and Fox Road, in the Town of Farmington, Ontario County, New York.

Soil Survey Map:	See Figure 2 in the Delineation Report - According to the USDA Natural Resources Conservation Service Web Soil Survey 3.2 for Ontario County, New York (the "Soil Survey"), a total of ten (10) different soil series were identified within the boundaries of the Site. The soil types identified include: Fine-loamy, mixed, active Typic Argiaquolls (19A); Canandaigua mucky silt loam, with 0-3% slopes (44A); Ontario fine sandy loam, with 8-35% slopes (112C & 112E); Ontario loam, with 3-25% slopes (116B, 116C & 116D); Palmyra cobbly loam, with 0-3% slopes (122A and 122B); Palmyra gravelly loam, with 3-15% slopes (126B and 126C); Phelps gravelly silt loam, with 0-3% slopes (210A); Kendaia loam, with 0-3% slopes (304A); and, Pits, gravel and sand (PG).
DEC Wetlands Map:	See Figure 3 in the Delineation Report – Based on the review of the Article 24 Freshwater Wetland mapping that was obtained from the DEC's Environmental Resource Mapper (ERM), a portion of a currently mapped Article 24 regulated wetlands is found within the boundaries of the Site. Specifically, portions of Fresh Water Wetland (FWW) MC-12 are contained within the property boundaries. In addition, portions of the 100 foot Adjacent Area of Freshwater Wetland MC-12 is also contained within the boundaries of the Review Area as well. The DEC mapped wetland correlates with Wetland Area 1 as identified and delineated by NCES.
Total Aquatic Resources:	6.89± acres

Jurisdictional Areas:	Acreage	Central Coordinates
	Area 1 = 1.52± acres	(43° 00' 56.95" N 77° 15' 50.20"W)
	Area 2 = 4.26± acres	(43° 01' 07.46" N 77° 15' 45.81"W)
Potential Non-Jurisdictional Wetlands:	Area 3 = 1.11± acres	(43° 00' 55.36" N 77° 15' 36.05"W)

Total On-Site Streams:	1,605± linear feet
Traditional Navigable Waterways:	0.0± linear feet

Perennial Relatively Permanent Waterways:	0.0± linear feet
Seasonal Relatively Permanent Waterways:	1,605± linear feet (within Wetland Area 3)
Non-Relatively Permanent Waterways:	0.0± linear feet

Wetland Connectivity with RPW's and TNW's:

The main sources of hydrology that influence the wetlands identified on the Site appear to originate from ground water discharge, surface water runoff, and direct precipitation. Wetland Area 3 does not connect with other waters of the U.S. It flows to a natural sand and gravel deposit and the water dissipates into the ground.

The forested wetland located along the western boundary of the Review Area receives runoff from the adjacent upland ridge and from ground water seeps were noted along the toe-of-slope of the ridge. This wetland naturally drains to the northwest and is hydrologically contiguous with a larger wetland complex found to the west of the Site. This off-site wetland physically abuts a perennial stream channel that flows to the north and into other wetlands that are located to the north of Fox Road.

The open water ponds and adjacent wetland communities are primarily ground water induced as they were mined for sand and gravel and the land was excavated to the groundwater elevation. These ponded areas fluctuate in depth as the ground water table rises and lowers in conjunction with the natural hydrologic cycle. These ponds, hydrologically connect with the off-site wetlands.

The un-named stream continues to the north and eventually converges with Ganargua Creek. This stream is a third-order perennial tributary that flows east and into the Erie Canal. The Erie Canal is classified as a Traditional Navigable Waterway (TNW).

The drainage that extends through the center of the property is reliant upon direct precipitation and surface water for hydrologic input. The linear wetland extends north to south into the center of the property. Natural flow is northward from the southern property boundary to the center of the Site. Once in the center of the Site, the drainage dissipates into the soil. No surface connection between this drainage and the open water ponds found to the north were observed.

Potential Pollutants:

During the field review NCES did not identify any contaminants or visible point sources of pollution on the property.

Habitat For Species:

During the site assessments, NCES documented only a few wildlife species on the Site. The species observed are extremely common and included white-tailed deer, raccoon, wild turkey, woodchuck, coyote, cottontail rabbit, chipmunk, and various early successional field associated birds. During the delineation, no endangered, threatened or rare species of flora or fauna were observed by NCES.

EXHIBIT E

Foundation Design, P.C.
SOIL • BEDROCK • GROUNDWATER

July 9, 2019

Delaware River Solar
33 Irving Place
New York, New York 10003

Attention: Mr. Peter Dolgos

Reference: Yellow Mills Road Solar Farm
466 Yellow Mills Road, Farmington, New York
Geotechnical Evaluation, 4618.0 (Revised)

Dear Mr. Dolgos:

This letter report summarizes our geotechnical evaluation for the referenced project. The 7mW Yellow Mills Road Solar Farm will cover 30± acres west of Yellow Mills Road in Palmyra, New York. The racking system, likely to be supported by driven piles, will be located in the open field. We base this report on our review of U.S.G.S. topographic mapping, National Resource Conservation Service mapping, test boring exploration; field and laboratory testing; and consultation with the design team. Delaware River Solar, LLC. retained Foundation Design, P.C. to perform the services outlined in our May 17, 2019 *Geotechnical Services Proposal, P4264.0.* We intend this report for exclusive use on this project.

The Yellow Mills Road Solar Farm will be located at 466 Yellow Mills Road in Farmington, New York. Fox Road lies to the north. A *General Location Plan*, on 2016 U.S.G.S. topographic mapping, is attached to this report. The parcel is pasture farmland located on the north face of a knoll. The ground surface rises gradually from approximately elevation 555 at the north end of the site to 570 to the south. A large hill lies south of the development area.

46A Sager Drive, Rochester, NY 14607 • Tel: 585 458-0824 • Fax: 585 458-3323 • foundationdesignpc.com

We completed soil borings P-1 though P-24 between June 13 and June 18, 2018. Target Drilling provided a CME-75 truck-mounted drill rig for the soil sampling. They advanced the test borings using hollow stem auger casings, recovering SPT split spoon soil samples continuously to 10 feet and at five foot intervals after that to completion; several borings terminated at auger refusal on cobbles/boulders within the soil matrix. The test borings terminated 12.5 to 20.0 feet below grade. A *Boring Location Plan* and the test boring logs are enclosed.

On June 21, 2019, we performed four, 4-point Wenner soil resistivity test (ASTM G-57) and eight soil thermal conductivity tests (ANSI/IEEE 442). These tests were performed in/adjacent to borings P-6, P-7, P-19, and P-23. For the 4-point Wenner soil resistivity tests, we used an AEMC Instruments 4630 digital ground resistance meter. Pins were spaced at 10 foot intervals and inserted six inches below grade. We measured in-place soil resistances as shown in Table No. 1 below. The field test reports are attached.

Table No. 1 – Field Resistivity Test Results

Location	Resistivity (ohm-cm)
P-6	10,176
P-7	9,858
P-19	38,641
P-23	18,246

For the soil thermal conductivity tests, we used a Decagon Devices KD-2 Pro thermal conductivity meter for the testing. Macedon Excavating and Paving provided a Cat 307 excavator to extend the holes to a 36-inch depth; testing at P-6 was performed at a 30-inch depth due to heavy water flow. CME Associates, Inc. performed in-place density tests (ASTM D-6938), documenting the in-place wet and dry density and the moisture content of the soil at that depth. We measured in-place soil thermal conductivity and thermal resistance values as shown in Table No. 2 below. The field test reports are attached.

Table No. 2 – Soil Thermal Conductivity Test Results						
Location	Wet Density (pcf)	Dry Density (pcf)	Moisture Content (%)	Thermal Conductivity (W/(m*K))	Thermal Resistivity (°C*(cm/W))	Initial Temp. (°C)
P-4	107.5	94.1	13.4	2.436	41.0	15.96
P-5	124.5	111.0	13.4	1.694	59.0	16.65
P-6	125.0	105.8	19.1	2.760	36.2	17.09
P-7	122.8	108.1	14.7	1.075	93.0	15.80
P-10	115.7	92.5	23.2	1.998	50.1	14.80
P-11	150.4	139.9	15.1	3.861	25.9	12.96
P-19	152.4	140.9	8.2	0.889	122.5	16.98
P-23	114.4	99.4	15.1	1.665	60.1	15.99

Upon completion of the fieldwork, we selected representative soil samples for laboratory testing. The testing program consisted of three pH determination, three lab resistivity test, two soluble chlorides tests, two soluble sulfates tests, seven sieve analysis, one liquid/plastic limits tests, and eleven moisture content tests. The test results are discussed below. The laboratory report is enclosed.

We encountered a subsurface profile consisting of surface topsoil over glacial outwash sand/gravel, then glacial till. The surface topsoil ranges from 6 to 30 inches thick at the sampled locations. The glacial outwash is a highly variable deposit. It consists primarily of sand and gravel with trace to some silt (SM or GM). The sand/gravel formation contains thinner layers of silty sand (SP-SM), clayey silt with sand (ML) and silt clay (CL). The outwash is loose to very dense. Numerous cobbles and boulders were noted during the augering. The glacial till formation consists of firm to very dense silt with sand, gravel and clay (ML in the Unified Soil Classification System). The till surfaces along the southern edge of the site; we believe the hill to the south is comprised of the till deposit.

Bedrock was not encountered in the test borings and is estimated to lie over 30 feet below grade. Geologic mapping indicates that the bedrock is the Akron and Bertie Formations. The Akron Formation consists of dolomites; the Bertie Formation consist of black shales.

We noted three water surfaces on the parcel. In general, the depth to groundwater drops from south to north across the parcel. We believe that the ponded water around elevation 545 north of the site (along Fox Road) is more representative of the true groundwater table.

Surface water appears to be travelling on top of the topsoil where the 'intermitten stream' is present southeast of the development; the stream appears to flow into the pond northwest of the barnyard and infiltrate. The surface gradient allows for water flow over the well compacted topsoil faster than infiltrating. Note that the groundwater in the borings adjacent to the stream (borings P-5 and P-7) did not encounter water until a depth of seven feet below ground surface. Test pits excavated adjacent to the 'stream' for in-place density testing and soil thermal conductivity tests were dry to a three foot depth.

Shallow, 'perched' groundwater conditions (wet/saturated soil samples within four feet of the surface) were noted at borings P-2, P-6, P-8, P-12, P-14, P-15, and P-22. Groundwater was not encountered at soil borings P-13, P-19, and P-21 located along the north edge of the proposed development. Heavy water flow occurred into the test pit excavated adjacent to P-6 below 2.5 feet after heavy rains the day before; soil samples at a similar depth were wet (not saturated) when boring P-6 was performed a week prior. While we believe this 'perched water condition' is due to water travelling on top of the dense glacial till formation, it may intersect with the groundwater that surfaces near Fox Road. The high permeability of the upper sand/gravel formation overlying the dense soil likely results in large fluctuations in the water levels over short periods.

As part of this evaluation, we performed laboratory testing to assess the corrosive environment on-site. This testing consisted of soluble chloride concentrations, soluble sulfates concentrations, pH determinations and lab resistivity testing. Chloride and sulfate levels were very low, below the detectable limits. Table No. 3 below summarizes the test results. Although the soil resistivity values

are somewhat low, the pH values are near neutral. Based on these results, we do not anticipate a corrosive environment on this parcel.

Table No. 3 - Corrosion Test Results

Boring Location	Lab Resistivity (ohm-cm)	pH	Soluble Chlorides (mg/L)	Soluble Sulfates (mg/L)
P-9 S-1/S-2	---	---	34	34
S-3/S-4	5,200	7.4	---	---
P-17 S-1/S-2	---	---	33	33
S-3/S-4	4,200	7.3	---	---
P-19 S-3/S-4	21,000	7.7	---	---

Criteria for Potential Corrosive Environment:

pH	< 5.5
Resistivity	< 2,000 ohm-cm
Chlorides	> 500 mg/L
Sulfates	>2,000 mg/L

Based on the above, we make the following specific recommendations:

1. Clear and grub the solar array area. If re-grading is required, remove the surface topsoil prior to starting major site grading operations. The contractor should provide a loaded ten-wheel truck or similar heavy construction equipment for the proof-rolling. Rework or replace as directed areas that rut, weave, quake, or are otherwise deemed unsuitable prior to starting the filling operations.

2. It is our opinion that the on-site sand/gravel soil is suitable for use as structural fill during re-grading operations (if required). However, the near surface on-site soils are silty/clayey, will tend to be moisture sensitive, and are frost susceptible. If planning to reuse the on-site soil as structural fill, plan for the earthwork/utility backfilling to be performed during the drier summer months. Place and moisture condition structural fill to within two percent of optimum moisture. Compact structural fill to at least 95 percent of maximum dry density as determined by the Standard Proctor method, ASTM D-698. Place fill in loose lifts not exceeding twelve inches thick. Maintain good surface drainage.

3. We understand that the preferred foundation system would consist of the light-weight steel I-beams or C-channel. While it is our opinion that this type of system is viable for the soil conditions expected, pre-augering of each hole should be expected due to cobbles, boulders,

and very dense soil conditions that will limit the penetration depths. The racking system design should account for frost impact and potential heaving of the racks. For preliminary estimating of the pile performance, assume the soil properties outlined in Table No. 4 below. We recommend performing uplift and lateral load tests to confirm that the required design resistance is developed and that production piles be installed using equipment and methods similar as those used during the test pile installation process.

Table No. 4 – Soil Properties		
Soil Property	**Upper Four Feet**	**Deeper Soil Conditions**
Unit Weight (Moist)	120 pcf	140 pcf
Friction Angle	28°	34°
Cohesion	0 psf	0 psf
Vertical Subgrade Modulus	20 psi/in	60 psi/in

4. The corrosion testing performed leads us to believe that a corrosive environment is not present on this parcel.

5. Based on values from the nearby Canandaigua Station, we recommend designing the solar array based on mean annual temperature of 48°F, and the Air Freezing Index Return Periods (°F-Days) tabulated below:

Table No. 5 – Air Freezing Index Return Periods (°F-Days)		
5-Year	**10-Year**	**20-Year**
870	965	1,045

Based on these Air Freeze values and assuming a clear, turf surface condition, we recommend using a site specific frost depth of 30 inches below the surface. For the on-site soils, we recommend using an ad-freeze value of 25 psi for the sand/gravel soil within the frost zone.

6. Construct the transformer pad and other support equipment on mat foundations. Remove all surface topsoil from under the new equipment. We recommend placing at least 12-inches of granular material under the mat slabs. N.Y.S.D.O.T. Item 304.12 (No. 2 crusher-run stone) meets this criterion. Rework and re-compact the underlying native soil to structural fill standards outlined in Paragraph No. 2 above prior to installing the stone base course. Design the mat foundations based on a uncorrected Modulus of Subgrade Reaction, K_{vi}, of 250 psi/in at the bottom of slab/top of stone; the structural engineer should adjust this subgrade value for the size of the mat.

Frost may heave the pad, potentially separating pipe conduit at joints. To protect the pad, we suggest 1.) undercutting the pad to a 48-inch depth and backfilling with a non-frost susceptible material such as No. 2 crusher-run stone subbase (NYSDOT Item 304.12) or 2.) installing a high density insulation board under the pad. Under the insultation approach, extend the board horizontally 48-inches in each direction beyond the edge of the pad. Cover the board with a minimum of six inches of soil. If insulation board is used, we suggest using a 2-inch thick, Type IV, V, VI or VII XPS board.

7. The measured in-place soil thermal resistivity values (Rho) documented at a 36-inch depth ranged from 25.0 to 122.5°C*(cm/W), representative of the highly variable soil conditions in the upper portion of the soil profile. As part of this design, we have not developed dry-out curves (plots of Rho versus density and Rho versus moisture) to assess further variability of these values.

   Due to the highly variable test result, we do not recommend backfilling the electric trenches using the on-site soil. We are concerned that localized hot spots may develop that burn out the wiring. We recommend backfilling with an imported processed, uniform material that would allow for more consistent design values to be used.

8. The NYS Building Code identifies various seismic design criteria for this project. We identify the site as having a Site Classification of D (Stiff Soil Profile). Based on ASCE 7-10 guidelines and using a Risk Category IV, we recommend using the following seismic design parameters.

Table No. 6 – Seismic Design Parameters

Spectral Response Acceleration		Soil Factors		Design Spectral Response Acceleration	
S_S	S_1	S_{MS}	S_{M1}	SD_S	SD_1
0.150g	0.059g	0.240g	0.141g	0.160g	0.094g

9. Perform the trenching and excavating work in accordance with NYS Building Code and OSHA safety standards. The contractor is responsible for determining what measures are required to meet these standards. Under no circumstances should slopes be steeper than 1 horizontal on 1 vertical. While it is our opinion that the foundation and utility excavation work can be achieved with 'normal' excavating equipment capable of achieving the desired depths, cobbles and boulders should be expected. Remove water that accumulates in open excavations using sumps and pumps.

10. Due to the on-site soil conditions, we suggest budgeting for the following minimum pavement sections for your access roadway. Be sure to completely remove all topsoil from under the new roadway; make up undercuts to remove thick topsoil areas using extra subbase material. Thicken this section as needed if used as the construction haul road for the material deliveries expected.

Table No. 7 –Pavement Section		
9.0"	No. 2 Crusher-run Stone Subbase	NYSDOT Item 304.12
	Geogrid	Tensar T-130
	Subgrade	Approved Proof Roll

11. Establish site drainage to keep water from ponding. Ponding water will result in more significant frost heave developing during the winter months and may impact rack performance in areas nearby.

Attached is a Geoprofessional Business Council paper entitled *Important Information about your Geotechnical Engineering Report*. It describes how we intend this report to be used. We will continue to work cooperatively with you, other project principals, and interested parties to achieve win/win solutions that benefit all.

This concludes our geotechnical consultation services; call if you have questions or if you require additional design information. Forward a copy of the near final plans and specifications for our review and comment. It has been a pleasure to work with you on this project and we look forward to hearing from you again in the near future.

Very truly yours,
FOUNDATION DESIGN, P.C.

Jeffrey D. Netzband, P.E., P.G.
Vice President
Enc.

STATE OF NEW YORK
JEFFREY D. NETZBAND
074888
LICENSED PROFESSIONAL ENGINEER

Important Information about This

Geotechnical-Engineering Report

Subsurface problems are a principal cause of construction delays, cost overruns, claims, and disputes.

While you cannot eliminate all such risks, you can manage them. The following information is provided to help.

The Geoprofessional Business Association (GBA) has prepared this advisory to help you – assumedly a client representative – interpret and apply this geotechnical-engineering report as effectively as possible. In that way, clients can benefit from a lowered exposure to the subsurface problems that, for decades, have been a principal cause of construction delays, cost overruns, claims, and disputes. If you have questions or want more information about any of the issues discussed below, contact your GBA-member geotechnical engineer. Active involvement in the Geoprofessional Business Association exposes geotechnical engineers to a wide array of risk-confrontation techniques that can be of genuine benefit for everyone involved with a construction project.

Geotechnical-Engineering Services Are Performed for Specific Purposes, Persons, and Projects

Geotechnical engineers structure their services to meet the specific needs of their clients. A geotechnical-engineering study conducted for a given civil engineer will not likely meet the needs of a civil-works constructor or even a different civil engineer. Because each geotechnical-engineering study is unique, each geotechnical-engineering report is unique, prepared *solely* for the client. *Those who rely on a geotechnical-engineering report prepared for a different client can be seriously misled.* No one except authorized client representatives should rely on this geotechnical-engineering report without first conferring with the geotechnical engineer who prepared it. *And no one – not even you – should apply this report for any purpose or project except the one originally contemplated.*

Read this Report in Full

Costly problems have occurred because those relying on a geotechnical-engineering report did not read it *in its entirety*. Do not rely on an executive summary. Do not read selected elements only. *Read this report in full.*

You Need to Inform Your Geotechnical Engineer about Change

Your geotechnical engineer considered unique, project-specific factors when designing the study behind this report and developing the confirmation-dependent recommendations the report conveys. A few typical factors include:

- the client's goals, objectives, budget, schedule, and risk-management preferences;
- the general nature of the structure involved, its size, configuration, and performance criteria;
- the structure's location and orientation on the site; and
- other planned or existing site improvements, such as retaining walls, access roads, parking lots, and underground utilities.

Typical changes that could erode the reliability of this report include those that affect:

- the site's size or shape;
- the function of the proposed structure, as when it's changed from a parking garage to an office building, or from a light-industrial plant to a refrigerated warehouse;
- the elevation, configuration, location, orientation, or weight of the proposed structure;
- the composition of the design team; or
- project ownership.

As a general rule, *always* inform your geotechnical engineer of project changes – even minor ones – and request an assessment of their impact. *The geotechnical engineer who prepared this report cannot accept responsibility or liability for problems that arise because the geotechnical engineer was not informed about developments the engineer otherwise would have considered.*

This Report May Not Be Reliable

Do not rely on this report if your geotechnical engineer prepared it:

- for a different client;
- for a different project;
- for a different site (that may or may not include all or a portion of the original site); or
- before important events occurred at the site or adjacent to it; e.g., man-made events like construction or environmental remediation, or natural events like floods, droughts, earthquakes, or groundwater fluctuations.

Note, too, that it could be unwise to rely on a geotechnical-engineering report whose reliability may have been affected by the passage of time, because of factors like changed subsurface conditions; new or modified codes, standards, or regulations; or new techniques or tools. *If your geotechnical engineer has not indicated an "apply-by" date on the report, ask what it should be*, and, in general, *if you are the least bit uncertain* about the continued reliability of this report, contact your geotechnical engineer before applying it. A minor amount of additional testing or analysis – if any is required at all – could prevent major problems.

Most of the "Findings" Related in This Report Are Professional Opinions

Before construction begins, geotechnical engineers explore a site's subsurface through various sampling and testing procedures. *Geotechnical engineers can observe actual subsurface conditions only at those specific locations where sampling and testing were performed.* The data derived from that sampling and testing were reviewed by your geotechnical engineer, who then applied professional judgment to form opinions about subsurface conditions throughout the site. Actual sitewide-subsurface conditions may differ – maybe significantly – from those indicated in this report. Confront that risk by retaining your geotechnical engineer to serve on the design team from project start to project finish, so the individual can provide informed guidance quickly, whenever needed.

This Report's Recommendations Are Confirmation-Dependent

The recommendations included in this report – including any options or alternatives – are confirmation-dependent. In other words, *they are not final*, because the geotechnical engineer who developed them relied heavily on judgment and opinion to do so. Your geotechnical engineer can finalize the recommendations *only after observing actual subsurface conditions* revealed during construction. If through observation your geotechnical engineer confirms that the conditions assumed to exist actually do exist, the recommendations can be relied upon, assuming no other changes have occurred. *The geotechnical engineer who prepared this report cannot assume responsibility or liability for confirmation-dependent recommendations if you fail to retain that engineer to perform construction observation.*

This Report Could Be Misinterpreted

Other design professionals' misinterpretation of geotechnical-engineering reports has resulted in costly problems. Confront that risk by having your geotechnical engineer serve as a full-time member of the design team, to:

- confer with other design-team members,
- help develop specifications,
- review pertinent elements of other design professionals' plans and specifications, and
- be on hand quickly whenever geotechnical-engineering guidance is needed.

You should also confront the risk of constructors misinterpreting this report. Do so by retaining your geotechnical engineer to participate in prebid and preconstruction conferences and to perform construction observation.

Give Constructors a Complete Report and Guidance

Some owners and design professionals mistakenly believe they can shift unanticipated-subsurface-conditions liability to constructors by limiting the information they provide for bid preparation. To help prevent the costly, contentious problems this practice has caused, include the complete geotechnical-engineering report, along with any attachments or appendices, with your contract documents, *but be certain to note conspicuously that you've included the material for informational purposes only.* To avoid misunderstanding, you may also want to note that "informational purposes" means constructors have no right to rely on the interpretations, opinions, conclusions, or recommendations in the report, but they may rely on the factual data relative to the specific times, locations, and depths/elevations referenced. Be certain that constructors know they may learn about specific project requirements, including options selected from the report, *only* from the design drawings and specifications. Remind constructors that they may perform their own studies if they want to, and *be sure to allow enough time* to permit them to do so. Only then might you be in a position to give constructors the information available to you, while requiring them to at least share some of the financial responsibilities stemming from unanticipated conditions. Conducting prebid and preconstruction conferences can also be valuable in this respect.

Read Responsibility Provisions Closely

Some client representatives, design professionals, and constructors do not realize that geotechnical engineering is far less exact than other engineering disciplines. That lack of understanding has nurtured unrealistic expectations that have resulted in disappointments, delays, cost overruns, claims, and disputes. To confront that risk, geotechnical engineers commonly include explanatory provisions in their reports. Sometimes labeled "limitations," many of these provisions indicate where geotechnical engineers' responsibilities begin and end, to help others recognize their own responsibilities and risks. *Read these provisions closely.* Ask questions. Your geotechnical engineer should respond fully and frankly.

Geoenvironmental Concerns Are Not Covered

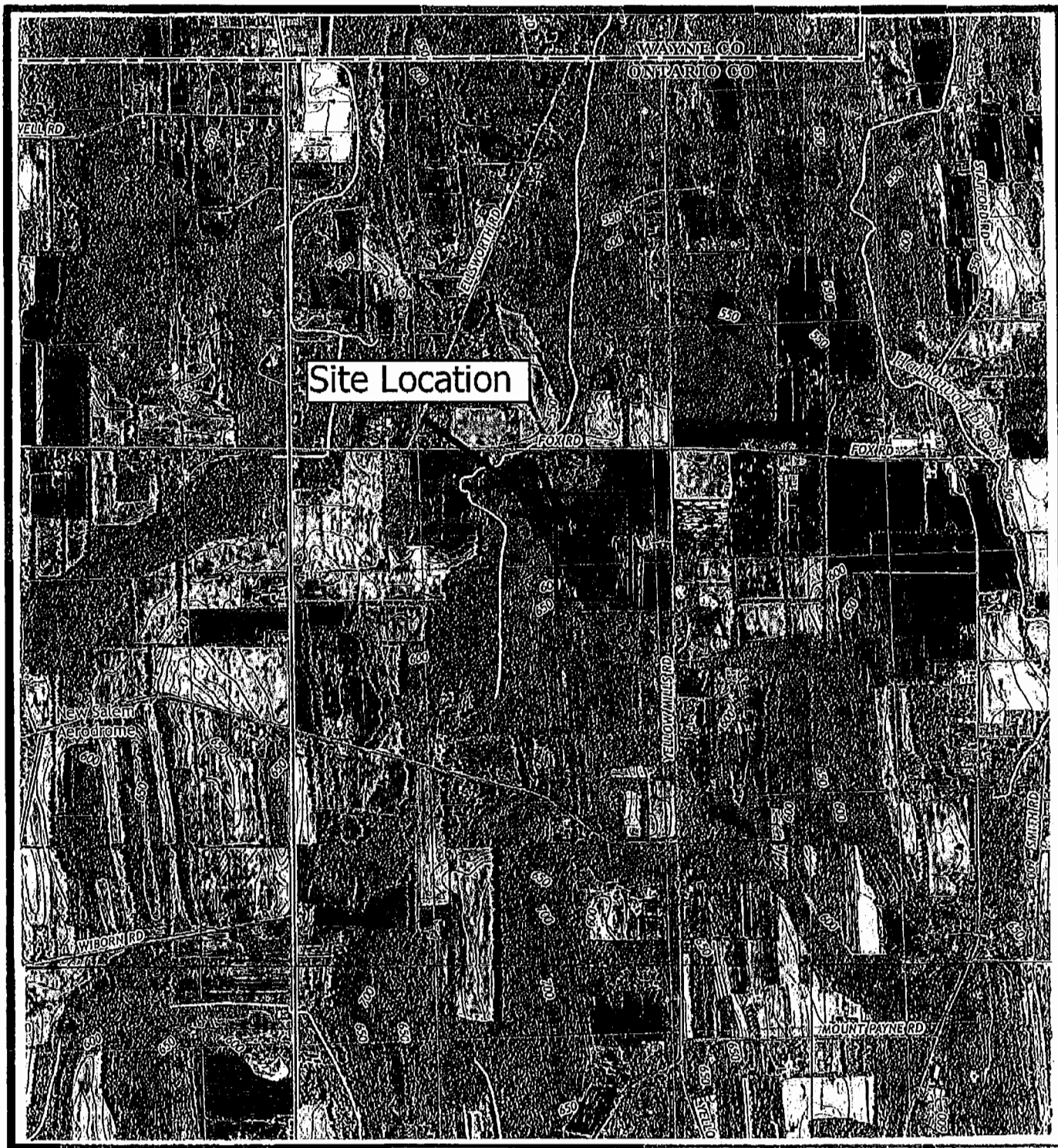
The personnel, equipment, and techniques used to perform an environmental study – e.g., a "phase-one" or "phase-two" environmental site assessment – differ significantly from those used to perform a geotechnical-engineering study. For that reason, a geotechnical-engineering report does not usually relate any environmental findings, conclusions, or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. *Unanticipated subsurface environmental problems have led to project failures.* If you have not yet obtained your own environmental information, ask your geotechnical consultant for risk-management guidance. As a general rule, *do not rely on an environmental report prepared for a different client, site, or project, or that is more than six months old.*

Obtain Professional Assistance to Deal with Moisture Infiltration and Mold

While your geotechnical engineer may have addressed groundwater, water infiltration, or similar issues in this report, none of the engineer's services were designed, conducted, or intended to prevent uncontrolled migration of moisture – including water vapor – from the soil through building slabs and walls and into the building interior, where it can cause mold growth and material-performance deficiencies. Accordingly, ***proper implementation of the geotechnical engineer's recommendations will not of itself be sufficient to prevent moisture infiltration.*** Confront the risk of moisture infiltration by including building-envelope or mold specialists on the design team. ***Geotechnical engineers are not building-envelope or mold specialists.***

GEOPROFESSIONAL BUSINESS ASSOCIATION

Telephone: 301/565-2733
e-mail: info@geoprofessional.org www.geoprofessional.org

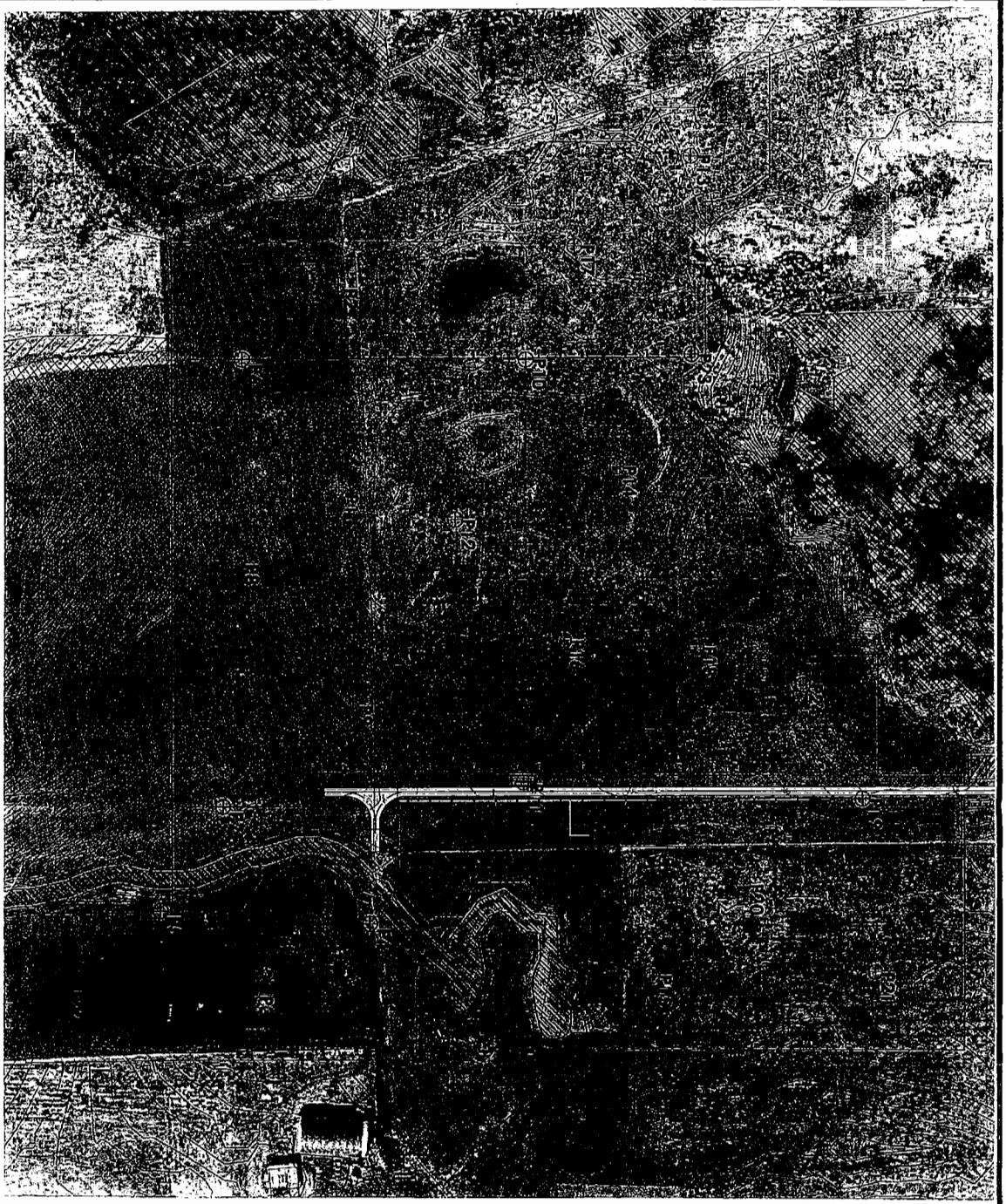


Foundation Design, P.C.

46A Sager Drive
Rochester, New York 14607
Phone (585) 458-0824
FAX (585) 458-3323

Yellow Mills Road Solar
466 Yellow Mills Road, Farmington, NY
General Location Plan
Adapted from: USGS topographic mapping *Macedon, Palmyra, Canandaigua, and Clifton Springs* Quadrangles dated 2016

CHECKED BY:	JDN	Scale 1"= 2,000'	DATE: 06-24-19
DRAWN BY:	JAG		JOB NO.:4618.0



Foundation Design, P.C.

46A Sager Drive
Rochester, New York 14607
Phone (585) 458-0824
FAX (585) 458-3323

Yellow Mills Road Solar
466 Yellow Mills Road, Farmington, NY
Boring Location Plan
Adapted from: Delaware River Solar
Boring Location Layout reviewed and modified 08/22/18

CHECKED BY: JDN	Scale 1" = 150'	DATE: 07-9-19
DRAWN BY: JAG		JOB NO.: 4618.0

Foundation Design, P.C.

SOIL • BEDROCK • GROUNDWATER

SOIL DESCRIPTIONS

COHESIVE SOIL

Very fine grained soils. Plastic soils that can be rolled into a thin thread if moist. Clays and silty clays show cohesion.

DESCRIPTION	STP –BLOWS/FOOT
Very Soft	0-2
Soft	3-5
Medium	6-15
Stiff	16-25
Hard	26 or more

NON-COHESIVE SOIL

Soils composed of silt, sand and gravel, showing no cohesion or very slight cohesion

DESCRIPTION	STP –BLOWS/FOOT
Loose	0-10
Firm	11-25
Compact	26-40
Dense	41-50
Very Dense	51 or more

SOIL COMPOSITION

DESCRIPTION	ESTIMATED PERCENTAGE
and	50
some	30-49
little	11-29
trace	0-10

MOISTURE CONDITIONS Dry, Damp, Moist, Wet, Saturated
Groundwater measured in the boring or test pit may not have reached equilibrium

SOIL STRATA:

TERM	DESCRIPTION
layer	Soil deposit more than 6" thick
seam	Soil deposit less than 6" thick
parting	Soil deposit less than 1/8" thick
varved	Horizontal uniform layers or seams of soil

GRAIN SIZE

MATERIAL		SIEVE SIZE
Boulder		Larger than 12 inches
Cobble		3 inches to 12 inches
Gravel	- coarse	1 inch to 3 inches
	- medium	3/8 inch to 1 inch
	- fine	No. 4 to 3/8 inch
Sand	- coarse	No. 10 to No. 4
	- medium	No. 40 to No. 10
	- fine	No. 200 to No. 40
Silt and Clay		Less than No. 200

Standard Penetration Test: The number of blows required to drive a split spoon sampler into the soil with a 140 pound hammer dropped 30 inches. The number of blows required for each 6-inches of penetration is recorded. The total number of blows required for the second and third 6-inches of penetration is termed the penetration resistance, or the "N" value.

Split Spoon Sampler: Typically a 2-foot long, 2-inch diameter hollow steel tube that breaks apart or splits in two down the tube length.

Refusal: Depth in the boring where more than 100 blows per 5-inches are needed to advance the sample spoon.

Core Recovery (%): The total length of rock core recovered divided by the total core run.

RQD (%): Rock Quality Designation – the total length of all the pieces of the rock core longer than 4-inches divided by the total length of the rock core run.

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-1
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Rain, 60°	**Engineer**	E. Ashley
Date Started	06.13.2019	**Completed**	06.14.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	3						TOPSOIL
			8	15	11	1	0-2'	2'2"
	4	4						Loose red-brown moist SAND, little silt, trace gravel
			4	3	8	2	2-4'	4'0"
5	8	18						Dense tan-brown moist SILT, some sand, little to some gravel, trace clay
			27	31	45	3	4-6'	
	7	22						cobbles/boulders noted while augering
			51	50/3"	73	4	6-7'9"	
	30	25						S-4: very dense, damp
10			18	20	43	5	8-10'	S-5: damp
								12'5"
								Boring Terminated at 12'5" (Auger Refusal)
15								
20								
25								
30								

Notes:
1. Dry on completion. Auger left in overnight to check groundwater level; water at 10'6" in AM.
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-2
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Overcast,50°	**Engineer**	E. Ashley
Date Started	06.14.2019	**Completed**	06.14.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	4						TOPSOIL
			3	4	7	1	0-2'	2'6"
	3	3						Loose red-brown wet SAND, little silt, trace organic to 3'
			5	5	8	2	2-4'	
5	3	4						S-3: firm, wet to saturated
			9	10	13	3	4-6'	7'6"
	9	9						Firm red-brown wet to saturated varved SILT, CLAY and SAND 8'6"
			12	50/1"	21	4	6-8'	
	5	29						Very dense tan-brown moist SILT, some sand, some gravel, trace clay
10			41	50/2"	70	5	8-9'8"	
								cobbles/boulders noted while augering
	50/5"							S-6: tan-brown-grey, wet
15					50/5"	6	13-13'5"	14'6"
								Boring Terminated at 14'6" (Auger Refusal)
20								
25								
30								

Notes:
1. Water encountered at 4'0"
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.
4. Large obstruction (boulder) at 7'6". Moved boring 10' east, augered to 8' and resumed sampling

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-3
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Overcast,60°	**Engineer**	E. Ashley
Date Started	06.13.2019	**Completed**	06.13.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	4						TOPSOIL, little sand, trace gravel 1'0"
			5	7	9	1	0-2'	Firm brown moist SILT and GRAVEL, some sand, little organic
	7	6						cobbles noted while augering 3'6"
			6	6	12	2	2-4'	Firm tan-brown moist SAND, trace silt
5	9	8						
			9	10	17	3	4-6'	S-3: trace gravel, brown organic staining noted
	12	12						S-4: tan, trace to little silt
			11	10	23	4	6-8'	wet below 7'0" 8'0"
	5	8						Firm tan-brown saturated SAND, little silt,
10			7	8	15	5	8-10'	trace gravel (may run)
								11'0"
								Dense brown wet SAND, some gravel, little silt
								cobbles noted while augering
	22	18						
15			22	17	40	6	13-15'	
	22	26						S-7: compact, light brown, saturated (may run)
20			12	11	38	7	18-20'	
								20'0"
								Boring Terminated at 20'0"
25								
30								Notes: 1. Water at 15'1" upon completion 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-4
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.14.2019	**Completed**	06.14.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	12						TOPSOIL
			10	14	22	1	0-2'	Cobbles noted while augering 2'6"
	15	17						Compact brown moist GRAVEL, some sand, little silt
			12	10	29	2	2-4'	4'0"
5	8	7						Firm brown moist SAND, little silt, little gravel
			7	10	14	3	4-6'	6'0"
	8	9						Firm brown moist SAND some gravel,
			11	11	20	4	6-8'	trace to little silt
	9	8						cobbles noted while augering
10			7	6	15	5	8-10'	
	11	5						
15			5	6	10	6	13-15'	S-6: loose, saturated
								grades to SAND and GRAVEL, trace silt
	5	7						
20			13	13	20	7	18-20'	S-7: saturated
								20'0"
								Boring Terminated at 20'0"
25								
								Notes:
								1. Water at 13'4" upon completion
30								2. Advanced hole using hollow stem augers.
								3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-5
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Overcast,60°	**Engineer**	E. Ashley
Date Started	06.13.2019	**Completed**	06.13.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	4	4						TOPSOIL 0'6"
			5	2	9	1	0-2'	Loose red-brown moist SAND, some silt, little to some gravel, trace organic
	9	7						
			9	8	16	2	2-4'	S-2: no recovery - pushing gravel 4'0"
5	9	7						Firm red-tan-brown moist SAND, trace silt, trace gravel
			8	6	15	3	4-6'	
	5	4						S-4: loose, tan-brown wet
			4	4	8	4	6-8'	saturated below 7'6" (may run)
	5	3						saturated sand seam from 7'3"-7'6" 7'6"
10			8	25	11	5	8-10'	Firm brown moist SILT and SAND, little gravel, trace clay
								cobbles/boulders noted while augering
								13'0"
15								Boring Terminated at 13'0" (Auger Refusal)
20								
25								
30								Notes: 1. Water encountered at 8'0" 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-6
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Overcast,50°	**Engineer**	E. Ashley
Date Started	06.14.2019	**Completed**	06.14.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	3						TOPSOIL 0'8"
			3	4	6	1	0-2'	Loose red-brown wet SAND, some silt, trace gravel trace organic 2'6"
	10	12						
			11	12	23	2	2-4'	Firm brown moist-wet SAND, some gravel, little to some silt, trace clay
5	9	15						
			25	19	40	3	4-6'	S-3: compact, wet 7'0"
	18	18						
			17	23	35	4	6-8'	Compact red-brown saturated SAND, little silt, trace gravel (may run) 8'0"
	8	22						
10			16	12	38	5	8-10'	Compact brown saturated SAND, some gravel, little silt
								cobbles./boulders noted while augering 13'0"
	23	52						Very dense grey-brown saturated GRAVEL, little to some sand, trace to little silt
15			50/1"		102/7"	6	13-14'1"	15'6"
								Boring Terminated at 15'6" (Auger Refusal)
20								
25								
30								Notes: 1. Water encountered at 6'0" 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils. 4. Sand rose in augers 8-inches at 13'0"

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-7
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Rain, 50°	**Engineer**	E. Ashley
Date Started	06.13.2019	**Completed**	06.13.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	4						TOPSOIL 0'9"
			3	3	7	1	0-2'	Loose red-brown moist SAND, little silt, little gravel
	3	1						S-2: poor recovery
			1	3	2	2	2-4'	4'0"
5	3	6						Firm brown moist SAND and GRAVEL, trace silt 5'0"
			9	10	15	3	4-6'	Firm tan-brown moist SILT, some sand, some gravel, trace clay
	12	14						
			16	19	30	4	6-8'	S-4: compact
	8	18						
10			24	24	42	5	8-10'	S-5: dense
								Cobbles/boulders noted while augering
	13	20						
15			24	50/1"	44	6	13-14'7"	S-6: dense
								17'0"
								Boring Terminated at 17'0" (Auger Refusal)
20								
25								
30								Notes: 1. Dry upon completion. 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-8
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Overcast,60°	**Engineer**	E. Ashley
Date Started	06.13.2019	**Completed**	06.13.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	2						TOPSOIL 0'8"
			3	3	5	1	0-2'	Loose tan-brown wet SILT, some sand, some gravel, trace clay
	5	9						
			14	15	23	2	2-4'	S-2: firm wet
5	3	12						moist below 2'6"
			25	29	37	3	4-6'	S-3: compact
	51	50/3"						S-4: very dense
					50/3"	4	6-6'9"	cobbles/boulders noted while augering.
	21	50						
10			50/4"		108/10	5	8-9'4"	S-5: very dense, damp, little gravel
	32	50/1"						
15					50/1"	6	13-13'7"	S-6: very dense, damp 14'1"
								Boring Terminated at 14'1" (Auger Refusal)
20								
25								
								Notes:
								1. Dry upon completion.
								2. Advanced hole using hollow stem augers.
								3. Bore hole backfilled using auger spoils.
								4. Boring Terminated at 500 psi downpressure for 15± minutes with no advancement
30								

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-9
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Overcast,60°	**Engineer**	E. Ashley
Date Started	06.14.2019	**Completed**	06.14.2019	**Driller**	J. Loomis
Drilling Company:	Target Drilling Co.				

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	4						TOPSOIL 0'8"
			11	9	15	1	0-2'	Firm brown moist SILT, little sand, trace gravel trace to little organics to 2'6"
	7	7						
			7	7	14	2	2-4'	
5	1	2						
			3	5	5	3	4-6'	S-3: loose, little gravel, trace to little clay
	4	6						
			18	35	24	4	6-8'	(rock fragments from 7'6" to 8'0") 8'0"
	9	19						Dense grey-brown-yellow moist GRAVEL, little to some sand, little silt, trace clay
10			22	31	41	5	8-10'	
								cobbles/boulders noted while augering
								12'6"
								Boring Terminated at 12'6" (Auger Refusal)
15								
20								
25								
30								Notes: 1. Dry upon completion. 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-10
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.17.2019	**Completed**	06.30.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	5						TOPSOIL 0'8"
			6	6	11	1	0-2'	Firm brown damp SILT, some fine sand, trace organics
	4	5						
			5	6	10	2	2-4'	S-2: medium, little fine sand, little clay
5	2	4						
			1	5	5	3	4-6'	wet from 5'6"-6'6"
	3	6						6'6"
			12	11	18	4	6-8'	Loose grey-brown damp SILT, some sand, some gravel, trace clay
	10	8						
10			8	5	16	5	8-10'	S-5: No recovery
								11'6"
								Stiff orange-brown wet SILT, some clay, little sand, little gravel
	2	2						13'0"
15			W/H	W/H	2	6	13-15"	Loose grey saturated GRAVEL, trace to little sand, trace silt (poor recovery)
								S-7: very dense
	38	50/2"						18'8"
20					50/2"	7	18-18'8"	Boring Terminated at 18'8"
25								
30								

Notes:
1. Water encountered at 10'0"
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-11
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	1	5						TOPSOIL 2'0"
			5	10	10	1	0-2'	Firm brown damp SAND, little silt, little gravel, trace organics
	7	9						
			10	14	19	2	2-4'	cobbles/boulders noted at 3'0" while augering
5	3	7						5'0"
			8	12	15	3	4-6'	Firm brown damp SILT, little sand, little gravel, trace to little clay
	6	31						
			19	17	50	4	6-8'	S-4: dense, grey-brown moist
	10	8						
10			10	11	18	5	8-10'	S-5: moist
	3	4						
15			5	12	9	6	13-15"	S-6: no recovery - rock in shoe
								18'0"
	3	3						Loose grey saturated GRAVEL, some sand, little silt
20			2	1	5	7	18-20'	20'0"
								Boring Terminated at 20'0"
25								
								Notes:
								1. Water encountered at 13'0"
30								2. Advanced hole using hollow stem augers.
								3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-12
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar / E. Ashley
Date Started	06.17.2019	**Completed**	06.17.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth
	2	2					
			3	4	5	1	0-2'
	4	4					
			3	5	7	2	2-4'
5	3	4					
			3	4	7	3	4-6'
	7	17					
			10	6	27	4	6-8'
	4	5					
10			20	14	25	5	8-10'
15	50/5"				50/5"	6	13-15"
20							
25							
30							

Visual Soil and Rock Classifications

Remarks

TOPSOIL 1'3"

Loose brown damp SILT, some sand, trace clay, trace organics

3'0"

Loose red-brown-tan moist to wet varved SILT, SAND and CLAY 4'0"

Loose red-brown saturated fine SAND, some silt, trace clay

few silty clay seams, trace fine gravel below 7'0"

7'6"

Compact grey moist GRAVEL, little to some sand, little to some silt, trace clay

S-5: firm, wet to saturated, SILT and SAND

S-6: very dense grey-brown, white mineral inclusions poor recovery

14'6"

Boring Terminated at 14'6" (Auger Refusal)

Notes:
1. Water encountered at 8'0"
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-13
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.14.2019	**Completed**	06.14.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	2						TOPSOIL 0'9"
			4	7	6	1	0-2'	Loose brown moist SILT, some sand, some gravel, trace organic to 2'0"
	14	22						
			38	40	60	2	2-4'	S-2: very dense
5	40	50/4"						cobbles/boulders noted while augering
					50/4"	3	4-4'10"	S-3: very dense
								augered through very dense till to 8'
	57	50/4"						
10					50/4"	4	8-8'10"	S-4: very dense, tan-brown, damp
	50/5"							S-5: very dense tan-brown damp 13'6"
15					50/5"	5	13-13'5"	Boring Tewrminated at 13'6" (Auger Refusal)
20								
25								
30								Notes: 1. Dry upon completion 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils. 4. Boring terminated at 600 psi downpressure on augers in dense till.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-14
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	1	4						TOPSOIL 1'8"
			4	6	8	1	0-2'	Loose brown damp SILT, some sand, trace organic
	5	6						
			7	6	13	2	2-4'	S-2: grades into SILT & SAND 4'0"
5	5	4						
			3	7	7	3	4-6'	Firm grey-brown saturated SILT, little sand, trace gravel, trace clay, trace organic
	5	6						white mineral inclusions at 6'0" 6'0"
			6	8	12	4	6-8'	Medium red-brown moist SILT, some clay
	3	3						S-4: no recovery 8'0"
10			4	6	7	5	8-10'	Loose orange-brown moist SILT, little sand, little gravel, trace clay (poor recovery)
								12'0"
								Loose brown-grey saturated GRAVEL, some sand, little silt, trace clay
	1	1						
15			1	1	2	6	13-15"	
								cobbles/boulders noted at 16'0"
								18'0"
	50/0"			50/0"	0	7	18'0"	Boring Tterminated @ 18'0"
20								
25								
30								

Notes:
1. Dry upon completion
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-15
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	4						TOPSOIL
			9	6	13	1	0-2'	
	8	9						2'6"
			9	8	18	2	2-4'	Firm gray-brown moist GRAVEL, some sand, some silt, trace organic
5	12	17						cobbles/boulders noted below 3'0", rough augering
			19	17	36	3	4-6'	S-3: compact, wet (no organic)
	9	22						6'6"
			25	30	47	4	6-8'	Dense brown wet SILT, some sand, little gravel
	25	39						
10			50/5"		89/11"	5	8-9'5"	S-5: very dense, grey-brown damp, some gravel, little sand
	14	50						S-6: very dense brown-grey, little sand, trace gravel
15			27	20	77	6	13-15"	
								18'0"
	14	50/4"						Very dense GRAVEL some sand
20					50/4"	7	18-20'	20'0"
								Boring Terminated at 20'0"
25								Notes:
								1. Water encountered at 15'0"
								2. Advanced hole using hollow stem augers.
								3. Bore hole backfilled using auger spoils.
								4. Offset +-8' north due to pond. Obstruction encountered at 3'0"; moved boring 4'0"± east and augered down to 4'0" to resume sampling.
30								

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-16
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	3						TOPSOIL
			3	2	6	1	0-2'	1'8"
	2	3						Loose brown damp SAND, little silt
			3	2	6	2	2-4'	
5	4	4						
			4	7	8	3	4-6'	S-3: trace gravel, wet at 5'4"
	5	11						S-4: wet, little to some gravel, trace clay
			13	25	24	4	6-8'	
	13	20						grey weathered rock at 8'0" 8'0"
10			23	25	43	5	8-10'	Dense brown moist SILT, some sand, little to some gravel, trace clay
	4	9						
15			11	9	20	6	13-15"	S-6: no recovery
								18'0"
	1	2						Loose grey saturated GRVAEL, some clay, little silt poor recovery
20			1	2	3	7	18-20'	20'0"
								Boring Terminated @ 20'0"
25								
								Notes:
								1. Water encountered at 10'5"
								2. Advanced hole using hollow stem augers.
30								3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-17
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.17.2019	**Completed**	06.17.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	5						TOPSOIL 0'9"
			6	8	11	1	0-2'	Firm brown moist SILT, some sand, little to some gravel, trace clay
	12	18						
			15	9	33	2	2-4'	S-2: compact, tan-brown
5	3	8						cobbles/boulders noted while augering 4'0"
			5	7	13	3	4-6'	Medium red-brown moist SILT, little to some clay, little sand, little gravel
	8	7						
			7	9	14	4	6-8'	S-4: brown, poor recovery
	14	41						
10			26	14	67	5	8-10'	S-5: hard, grey-brown
								11'6"
								Firm grey wet SILT, some sand, some gravel, trace clay
								cobbles/boulders noted while augering
	5	5						
15			7	10	12	6	13-15"	
								16'6"
								Soft grey wet SILT, some clay, trace sand, trace gravel
	5							
20		3	2	2	5	7	18-20'	4" saturated gravel seam at 18'0"
								20'0"
								Boring terminated @ 20'0"
25								
30								

Notes:
1. Water encountered at 13'0" during drilling; water level at 7'6" upon completion
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-18
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.17.2019	**Completed**	06.17.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	3						TOPSOIL 1'6"
			4	5		1	0-2'	Loose brown moist SAND, some silt 3'0"
	4	4						
			4	4	8	2	2-4'	Loose brown moist SILT, little sand, trace gravel cobbles/boulders noted while augering 5'6"
5	3	4						
			3	5	7	3	4-6'	Loose brown damp SAND and GRAVEL, little silt (poor recovery) 6'0"
	6	11						
			10	17	21	4	6-8'	Firm brown-grey damp GRAVEL, some sand, little silt
	38	40						
10			15	7	55	5	8-10'	S-5: very dense, damp (poor recovery) cobbles/boulders noted below 9'
	18	23						
15			16	11	39	6	13-15"	S-6: compact
	13	13						
20			10	9	23	7	18-20'	S-7: firm, brown, saturated 20'0"
								Boring terminated @ 20'0"
25								
30								

Notes:
1. Water encountered at 18'0"
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-19
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	A. Viar
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	4	6						TOPSOIL 2'0"
			6	7	12	1	0-2'	Firm brown damp SAND, little silt, little gravel
	9	11						
			11	13	22	2	2-4'	
5	10	9						
			7	6	16	3	4-6'	S-3: some gravel, grey-brown below 5'5" 6'0"
	10	15						Compact grey-brown damp GRAVEL, some sand, little silt 8'0"
			17	22	32	4	6-8'	Compact light brown damp SAND, some gravel, little silt
	8	9						
10			19	13	27	5	8-10'	cobbles/boulders noted @ 10'0"
								11'6"
								Compact brown moist SILT, little clay, little gravel, trace to little sand
	6	11						
15			14	14	25	6	13-15"	
	7	22						
20			25	27	47	7	18-20'	S-7: dense 20'0"
								Boring terminated @ 20'0"
25								
30								Notes: 1. Dry upon completion 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-20
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company:	Target Drilling Co.				

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	1	2						TOPSOIL 1'1"
			3	4		1	0-2'	Loose red-brown moist SILT, little sand, trace to little organic, trace gravel
	2	6						3'0"
			9	9	15	2	2-4'	Firm brown moist GRAVEL, some sand, trace to little silt
5	15	8						cobbles/boulders noted while augering
			16	11	24	3	4-6'	S-3: moist to damp 6'0"
	8	9						Firm brown moist SILT, little clay, little sand, little gravel
			9	15	18	4	6-8'	few silty sand seams 8'0"
	6	5						Loose tan-brown moist SILT, some sand,
10			3	2	8	5	8-10'	some gravel 9'0"
								Loose red-brown-orange moist SILT, little sand, little gravel, trace clay 11'6"
								Loose tan-brown wet SILT, some sand, little gravel, trace clay
	3	5						
15			2	2	7	6	13-15"	
								16'6"
								Very dense grey saturated GRAVEL, trace silt
	50	50/4"					18'-	18'10"
20					50/4"	7	18'10"	Boring terminated @ 18'10"
25								
30								

Notes:
1. Water encountered at 11'0"
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-21
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	1	2						TOPSOIL 0'9"
			3	7	5	1	0'-2'	Loose brown moist SILT, little to some sand, trace fine gravel,trace organic/rootlets 2'0"
	3	6						
			9	9	15	2	2'-4'	Firm brown moist SILT, little clay, little sand, little gravel
5	5	12						cobbles/boulders noted while augering
			12	12	24	3	4'-6'	
	11	13						
			14	18	27	4	6'-8'	S-4: compact, little to some gravel
	11	19						
10			27	42	46	5	8'-10'	
	9	25						
15			31	50/5	56	6	13'-15'	S-6: dense
	21	41						
20			48	50/4"	89	7	18'-19'10"	S-7: very dense 19'10"
								Boring Terminated at 19'10"
25								
30								

Notes:
1. Dry upon completion
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-22
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.18.2019	**Completed**	06.30.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	7						TOPSOIL 0'10"
			5	7	12	1	0'-2'	Firm tan-brown damp SAND and GRAVEL, trace silt
	8	10						
			8	7	18	2	2'-4'	4'0"
5	5	8						Firm light brown fine SAND, little silt 5'0"
			8	8	16	3	4'-6'	Firm brown moist SAND and GRAVEL, trace silt
	7	8						saturated below 6" 7'0"
			7	6	15	4	6'-8'	Firm tan-brown saturated fine SAND,
	5	8						little to some silt (may run) 9'11"
10			18	11	26	5	8'-10'	Compact brown wet SAND, some gravel, little silt cobbles/boulders noted while augering
	16	31						
15			34	50/3"	65	6	13'-14'9"	S-6: very dense, sand rose in augers ±6" 15'0"
								Boring Terminated at 15'0" (Auger Refusal)
20								
25								
30								

Notes:
1. Water encountered at 7'8" while drilling, water at 6'0" upon completion.
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-23
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company: Target Drilling Co.					

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	2	5						TOPSOIL 0'8"
			8	7	13	1	0'-2'	Firm tan-brown moist SILT, some sand, little gravel, trace organics/rootlets (possible fill)
	4	16						
			10	11	26	2	2'-4'	
5	2	3						
			3	3	6	3	4'-6'	S-3: loose, brown, poor recovery 6'0"
	3	4						Loose brown moist SAND and GRAVEL,
			4	5	8	4	6'-8'	trace to little silt (possible fill)
	3	3						
10			2	1	5	5	8'-10'	S-5: wet 11'6'
								Dense grey moist SILT, some sand, some gravel, trace clay
	11	16						
15			29	19	45	6	13'-15'	
	56	50/4"			50/4"	7	18'-18'10"	S-7: very dense, grey-brown, moist 18'10"
20								Boring Terminated at 18'10"
25								
								Notes: 1. Dry on completion. 2. Advanced hole using hollow stem augers. 3. Bore hole backfilled using auger spoils.
30								

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

Boring Log

Project No.	4618.0	**Page** 1	**of** 1	**Test Boring No.**	P-24
Project Name	Yellow Mills Road Solar Array, 466 Yellow Mills Road, Farmington, New York				
Client	Delaware River Solar LLC, 33 Irving Place, Suite 1090, New York, New York				
Elevation		**Weather**	Sunny, 60°	**Engineer**	E. Ashley
Date Started	06.18.2019	**Completed**	06.18.2019	**Driller**	J. Loomis
Drilling Company:	Target Drilling Co.				

Ft.	Blows Per Six Inches 0"/6"	6"/12"	12"/18"	18"/24"	N Value	Sample No.	Depth	Visual Soil and Rock Classifications / Remarks
	3	2						TOPSOIL 0'10"
			4	8	6	1	0'-2'	Loose red-brown moist SILT, trace to little fine sand, trace organic/rootlets 2'4"
	6	5						Loose brown moist SILT, little to some sand
			5	4	10	2	2'-4'	little to some gravel, trace clay, trace organic 4'0"
5	7	12						Firm brown moist SAND and GRAVEL, trace silt, poor recovery
			10	7	22	3	4'-6'	cobbles/boulders noted while augering
	6	7						
			11	8	18	4	6'-8'	S-4: poor recovery (rough augering)
	19	25						
10			13	12	38	5	8'-10'	S-5: compact
								11'6"
								Very dense grey moist GRAVEL, little sand
	7	26						
15			28	19	54	6	13'-15'	
								17'1"
								Boring Terminated at 17'1"
20								
25								
30								

Notes:
1. Water at 10'6" overnight.
2. Advanced hole using hollow stem augers.
3. Bore hole backfilled using auger spoils.

N=No. of blows to Drive 2" Spoon 12" with 140 lb. Wt. 30" Ea. Blow Hammer: Drop Rods: 2-inch

Foundation Design, P.C.

SOIL • BEDROCK • GROUNDWATER

June 27, 2019

Delaware River Solar
33 Irving Place
New York, New York 10003

Attention: Mr. Peter Dolgos

Reference: Yellow Mills Road Solar Farm
466 Yellow Mills Road, Farmington, New York
Laboratory Test Results, 4618.0

Dear Mr. Dolgos:

Foundation Design, P.C. is pleased to present the following results of the laboratory testing performed on the referenced project. The testing was performed in accordance with the following ASTM test methods:

7	Sieve Analysis	ASTM D-422/ASTM D-1140
11	Moisture Content Test	ASTM D-2216
1	Plastic Limits/Liquid Limits/Plasticity Index	ASTM D-4318
3	pH Test	ASTM D-4972
3	Laboratory Soil Box Resistivity Test	ASTM G187-12a
4	4 Point Resistivity Test	ASTM G-57
8	Soil Thermal Conductivity Test	ANSI/IEEE 442

We appreciate the opportunity to provide these testing services and look forward to hearing from you again in the near future.

Very truly yours,

FOUNDATION DESIGN, P.C.

Elizabeth Ashley

Elizabeth Ashley, P.G.
Laboratory Manager

Foundation Design, P.C.

SOIL • BEDROCK • GROUNDWATER

Yellow Mills Road Solar Farm
466 Yellow Mills Road
Farmington, New York
4618.0

June 19, 2019

Moisture Content Test Report
(ASTM D-2216)

Moisture Content Test Results				
Boring Number	P-1	P-2	P-3	P-3
Sample Number	S-2	S-4	S-4	S-6
Depth	2'-4'	6'-8'	6'-8'	13'-15'
Moisture Content (%)	**13.2**	**19.2**	**21.2**	**10.2**

Moisture Content Test Results				
Boring Number	P-4	P-6	P-8	P-10
Sample Number	S-5	S-3	S-5	S-2
Depth	8'-10'	4'-6'	8'-9'4"	2'-4'
Moisture Content (%)	**7.2**	**9.4**	**7.9**	**24.9**

Moisture Content Test Results			
Boring Number	P-13	P-15	P-20
Sample Number	S-3	S-4	S-4
Depth	4'-4'10"	6'-8'	6'-8'
Moisture Content (%)	**6.7**	**10.1**	**11.9**

Foundation Design, P.C.

SOIL • BEDROCK • GROUNDWATER

Yellow Mills Road Solar Farm
Yellow Mills Road, Farmington, New York
4618.0

In-place Density Test and Soil Thermal Conductivity Test Report
(ASTM D-1557 and ANSI/IEEE 442)

P-4					
Depth:		3'0"			
Soil Classification:		Compact brown GRAVEL, some sand, little silt			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
107.5	94.1	13.4	2.436	41.0	15.96

P-5					
Depth:		3'0"			
Soil Classification:		Compact red-brown SAND, some silt, little gravel			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
124.5	111.0	13.4	1.694	59.0	16.65

P-6					
Depth:		2'6"			
Soil Classification:		Compact red-brown SAND, some gravel, little silt, trace clay			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
125.0	105.8	19.1	2.760	36.2	17.09

P-7					
Depth:		3'0"			
Soil Classification:		Loose red-brown SAND, little silt, little gravel			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
122.8	108.1	14.7	1.075	93.0	15.80

Foundation Design, P.C.

SOIL • BEDROCK • GROUNDWATER

Yellow Mills Road Solar Farm
Yellow Mills Road, Farmington, New York
4618.0

In-place Density Test and Soil Thermal Conductivity Test Report
(ASTM D-1557 and ANSI/IEEE 442)

P-10					
Depth:		3'0"			
Soil Classification:		Firm brown SILT, little sand, trace clay			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
115.7	92.5	23.2	1.998	50.1	14.80

P-11					
Depth:		3'0"			
Soil Classification:		Firm brown SAND, little silt, little gravel, few cobbles/boulders			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
150.4	139.9	15.1	3.861	25.9	12.96

P-19					
Depth:		3'0"			
Soil Classification:		Firm brown SAND, little silt, little gravel, few cobbles/boulders			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
152.4	140.9	8.2	0.889	112.5	16.98

P-23					
Depth:		3'0"			
Soil Classification:		Firm brown SILT, some sand, little gravel			
Wet Density (pcf)	**Dry Density (pcf)**	**Moisture Content (%)**	**Thermal Conductivity (W/(m*K))**	**Thermal Resistivity (°C*(cm/W))**	**Initial Temp. (°C)**
114.4	99.4	15.1	1.665	60.1	15.99

Foundation Design, P.C.

SOIL • BEDROCK • GROUNDWATER

Yellow Mills Road Solar Farm
466 Yellow Mills Road
Farmington, New York
4618.0

June 19, 2019

pH and Resistivity Test Report
(ASTM D-4972 and ASTM G-57)

	pH and Laboratory Resistivity Test Results		
Boring Number	**P-9**	**P-17**	**P-19**
Sample Number	S-3 & S-4	S-3 & S-4	S-3 & S-4
Depth	4'-8'	4'-8'	4'-8'
pH	7.4	7.3	7.7
Resistivity(Ω·cm) Natural Moisture	5200	4200	21000
Resistivity(Ω·cm) Saturated Moisture	5300	9300	3700
Natural Moisture Content (%)	16.5	13.5	4.6
Saturated Moisture Content (%)	28.9	20.3	22.4

Soil Resistivity Test

Foundation Design, P.C.

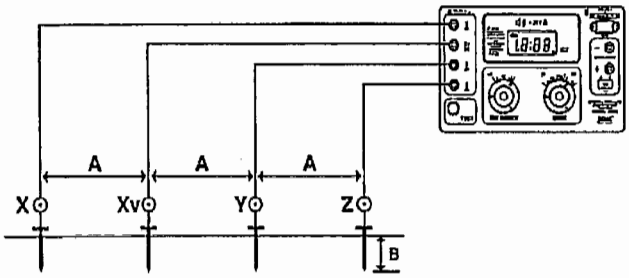
Test Date 06.21.19

Test Location Yellow Mills Road Solar, Farmington, New York P-6

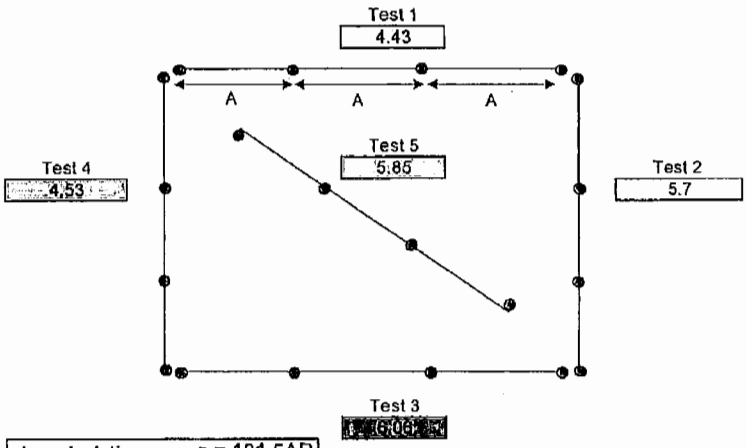
Address 466 Yellow Mills Road, Farmington, New York

Model AEMC 4620 Operator Name: J. Goggin

Test Conditions				
Soil Condition:	[X] Moist	[ ] Dry	Temperature 70's °F °C	
Soil Type:	[ ] Clay	[ ] Limestone	[X] Sand & Gravel	
	[ ] Granite	[ ] Shale	[ ] Sandstone	
	[X] Loam	[ ] Slate	[ ] Other	



Electrode Spacing (A) 10 ft Electrode depth (B) 0.5 ft



rho calculation ρ = 191.5AR

	Test Reading	Soil Resistivity
Test	R	ρ
1	4.43	8483.45
2	5.7	10915.5
3	[illegible]	11604.9
4	4.53	8674.95
5	5.85	11202.8

Effective soil resistivity: **10176.31** Ω - cm

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Soil Resistivity Test

Foundation Design, P.C.

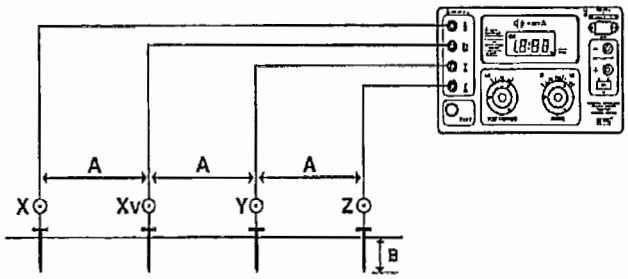
Test Date 06.21.19

Test Location Yellow Mills Road Solar, Farmington, New York P-7

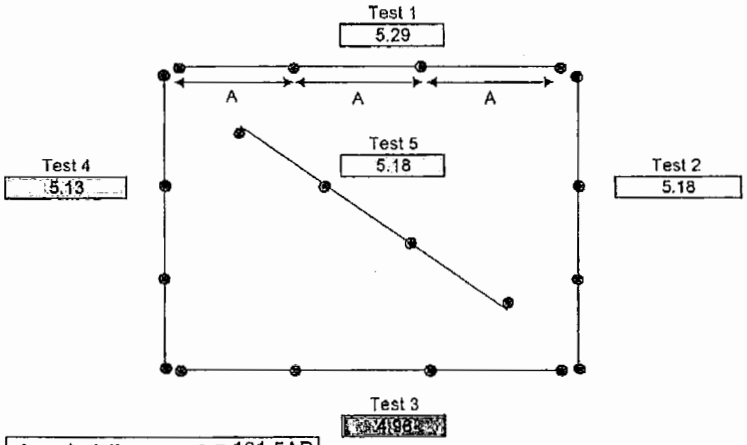
Address 466 Yellow Mills Road, Farmington, New York

Model AEMC 4620 Operator Name: J. Goggin

Test Conditions			
Soil Condition:	[X] Moist	[ ] Dry	Temperature 70's °F °C
Soil Type:	[ ] Clay [ ] Granite [X] Loam	[ ] Limestone [ ] Shale [ ] Slate	[X] Sand & Gravel [ ] Sandstone [ ] Other



Electrode Spacing (A) 10 ft Electrode depth (B) 0.5 ft



rho calculation $\rho = 191.5AR$

	Test Reading	Soil Resistivity
Test	R	ρ
1	5.29	10130.4
2	5.18	9919.7
3	4.96	9498.4
4	5.13	9823.95
5	5.18	9919.7

Effective soil resistivity: **9858.42** Ω - cm

AEMC® INSTRUMENTS
CHAUVIN ARNOUX GROUP

Soil Resistivity Test

Foundation Design, P.C.

Test Date 06.21.19

Test Location Yellow Mills Road Solar, Farmington, New York P-19

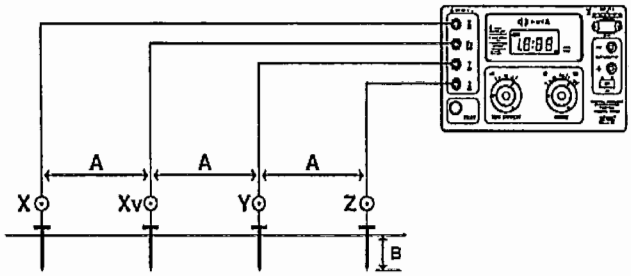
Address 466 Yellow Mills Road, Farmington, New York

Model AEMC 4620 Operator Name: J. Goggin

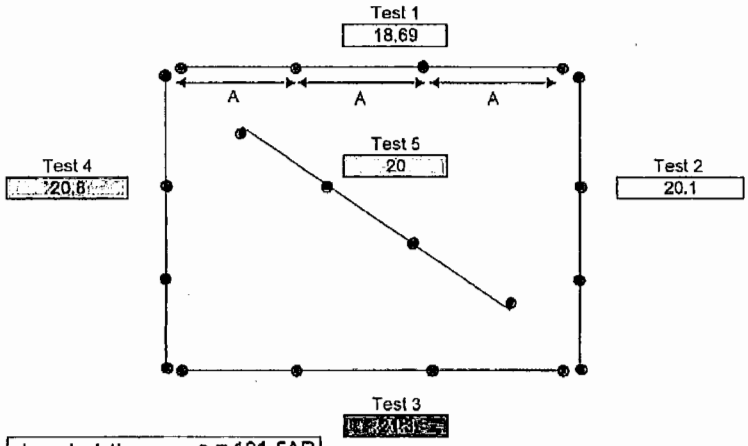
Test Conditions

Soil Condition: [X] Moist [ ] Dry Temperature 70's °F °C

Soil Type: [ ] Clay [ ] Limestone [X] Sand & Gravel [ ] Granite [ ] Shale [ ] Sandstone [X] Loam [ ] Slate [ ] Other



Electrode Spacing (A) 10 ft Electrode depth (B) 0.5 ft



rho calculation ρ = 191.5AR

	Test Reading	Soil Resistivity
Test	R	ρ
1	18.69	35791.4
2	20.1	38491.5
3	[redacted]	40789.5
4	20.8	39832
5	20	38300

Effective soil resistivity: **38640.87 Ω - cm**

AEMC® INSTRUMENTS
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Technical Assistance (800) 343-1391

www.aemc.com

Soil Resistivity Test

Foundation Design, P.C.

Test Date 06.21.19

Test Location: Yellow Mills Road Solar, Farmington, New York P-23

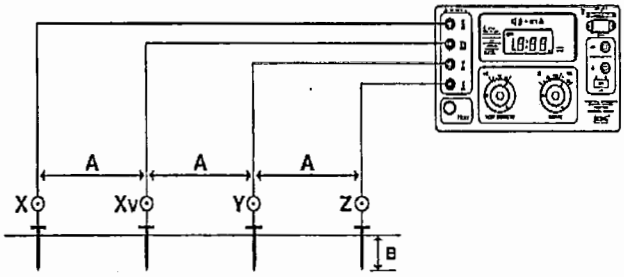
Address: 466 Yellow Mills Road, Farmington, New York

Model: AEMC 4620 Operator Name: J. Goggin

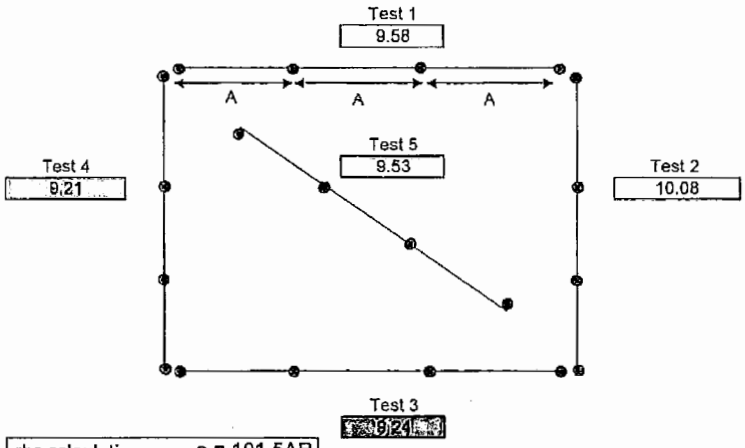
Test Conditions

Soil Condition: [X] Moist [ ] Dry Temperature 70's °F °C

Soil Type: [ ] Clay [ ] Limestone [X] Sand & Gravel [ ] Granite [ ] Shale [ ] Sandstone [X] Loam [ ] Slate [ ] Other



Electrode Spacing (A) 10 ft Electrode depth (B) 0.5 ft



rho calculation ρ = 191.5AR

	Test Reading	Soil Resistivity
Test	R	ρ
1	9.58	18345.7
2	10.08	19303.2
3	9.24	17694.6
4	9.21	17637.2
5	9.53	18250

Effective soil resistivity: **18246.12** Ω - cm

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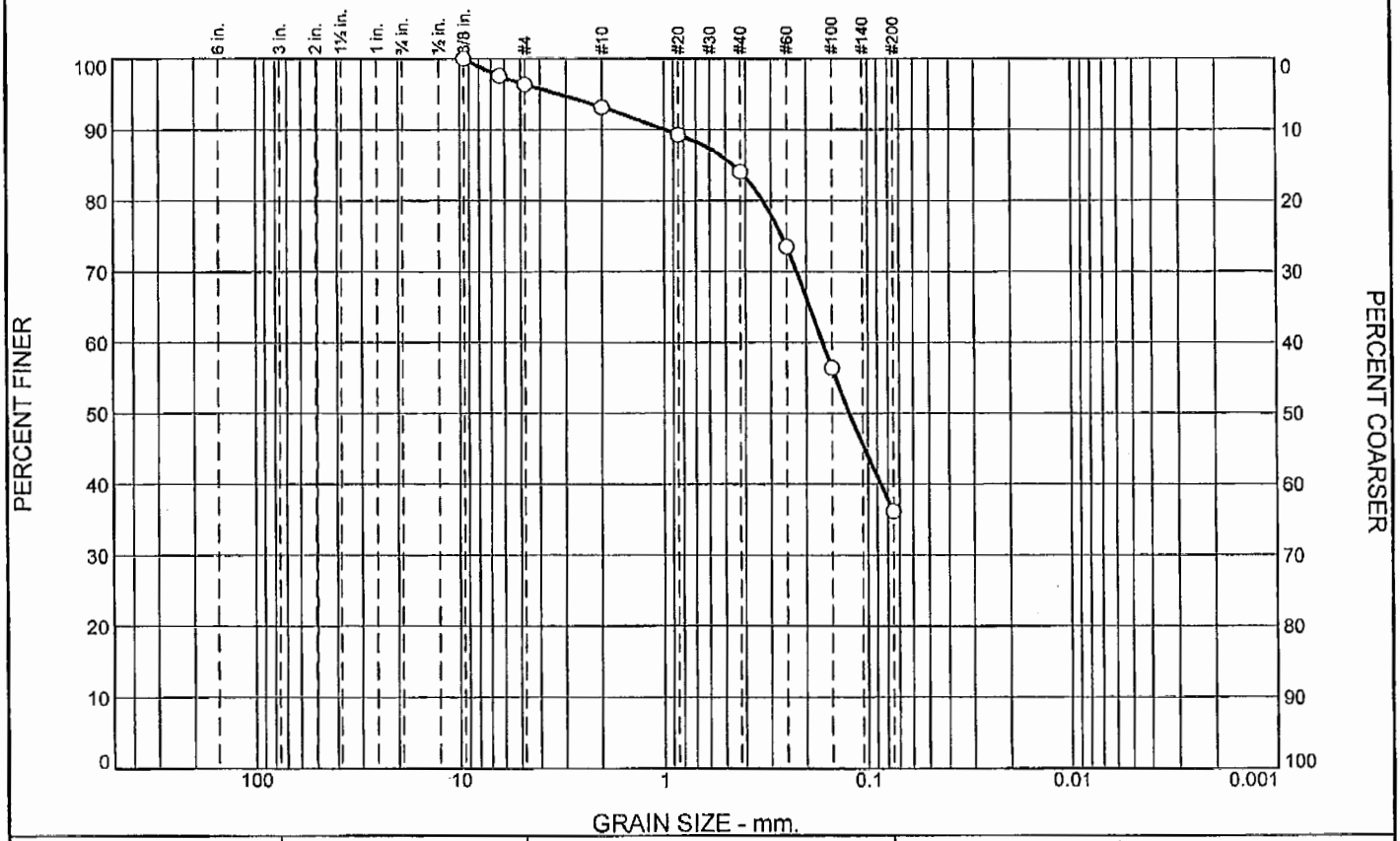
Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	0	4	3	9	48	36	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8"	100		
1/4"	98		
#4	96		
#10	93		
#20	89		
#40	84		
#60	74		
#100	56		
#200	36		

* (no specification provided)

Material Description

Tan cmf SAND, some silt/clay, trace fine gravel

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.9884 D_{85}= 0.4586 D_{60}= 0.1667
D_{50}= 0.1229 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 287.59 grams of oven dried split spoon sample

Source of Sample: P-1 **Depth:** 2'-4'
Sample Number: S-2

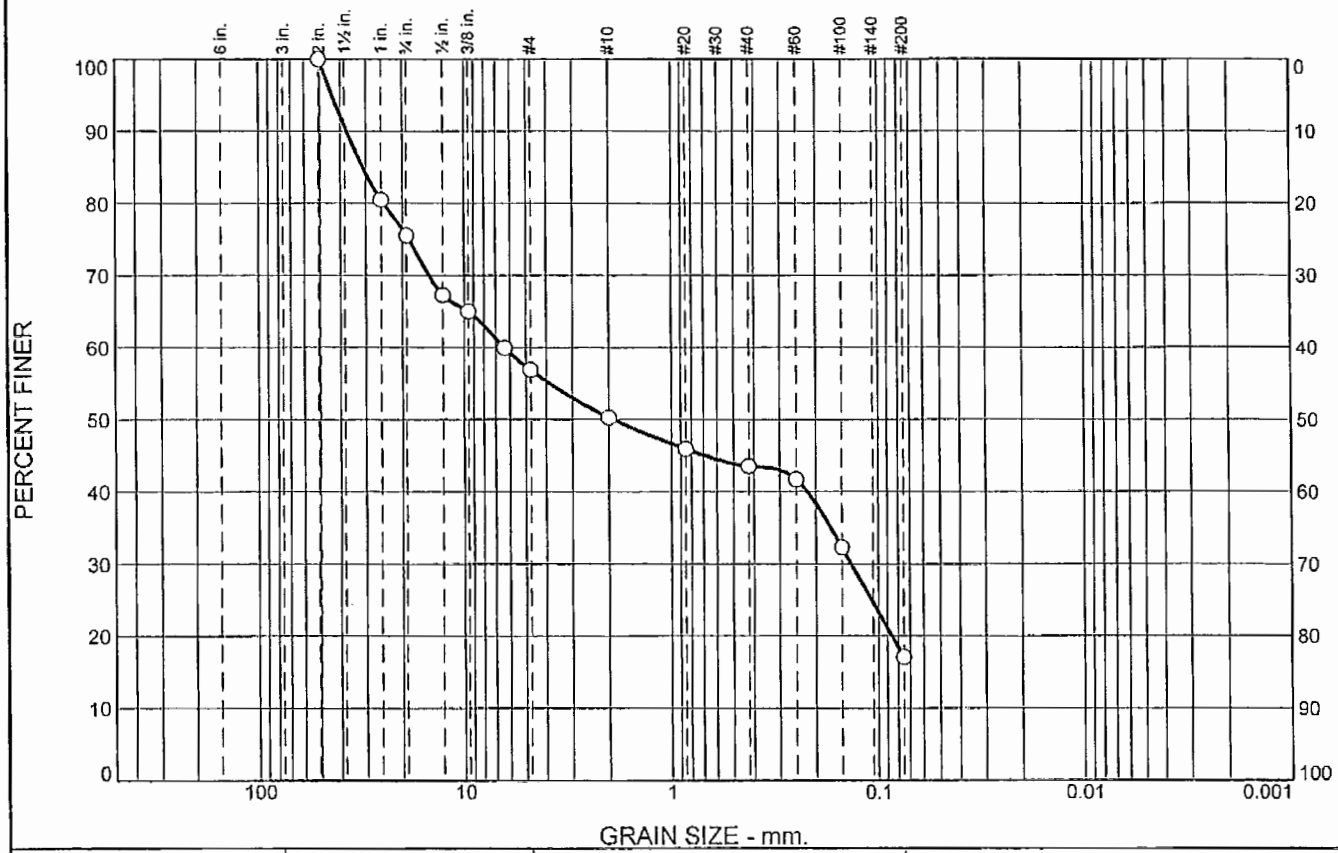
Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 **Figure**

Tested By: TJB **Checked By:** EAA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	24	19	7	6	27	17	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2"	100		
1"	80		
3/4"	76		
1/2"	67		
3/8"	65		
1/4"	60		
#4	57		
#10	50		
#20	46		
#40	44		
#60	42		
#100	32		
#200	17		

* (no specification provided)

Material Description

Tan cf GRAVEL, some cmf sand, little silt/clay

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 37.0923 D_{85}= 31.0245 D_{60}= 6.3849
D_{50}= 1.9254 D_{30}= 0.1353 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 292.64 grams of oven dried split spoon sample

Source of Sample: P-3 Depth: 13'-15'
Sample Number: S-6

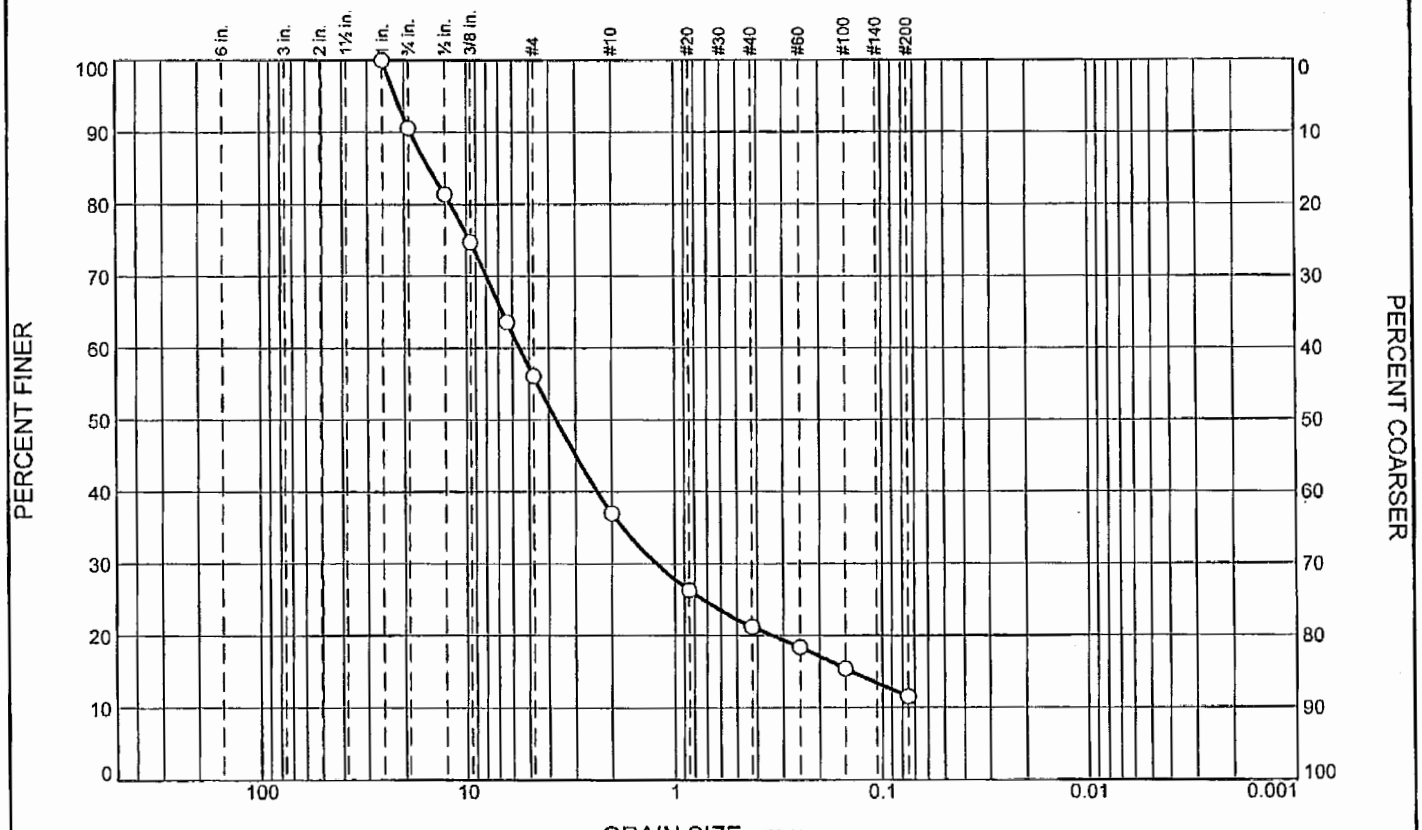
Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 Figure

Tested By: TJB Checked By: EAA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	9	35	19	16	10	11	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1"	100		
3/4"	91		
1/2"	81		
3/8"	75		
1/4"	64		
#4	56		
#10	37		
#20	26		
#40	21		
#60	18		
#100	15		
#200	11		

* (no specification provided)

Material Description

Tan cmf SAND, some cf gravel, little silt/clay

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 18.6246 D_{85}= 15.0983 D_{60}= 5.5408
D_{50}= 3.7067 D_{30}= 1.2291 D_{15}= 0.1409
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 428.43 grams of oven dried split spoon sample

Source of Sample: P-4 **Depth:** 8'-10'
Sample Number: S-5

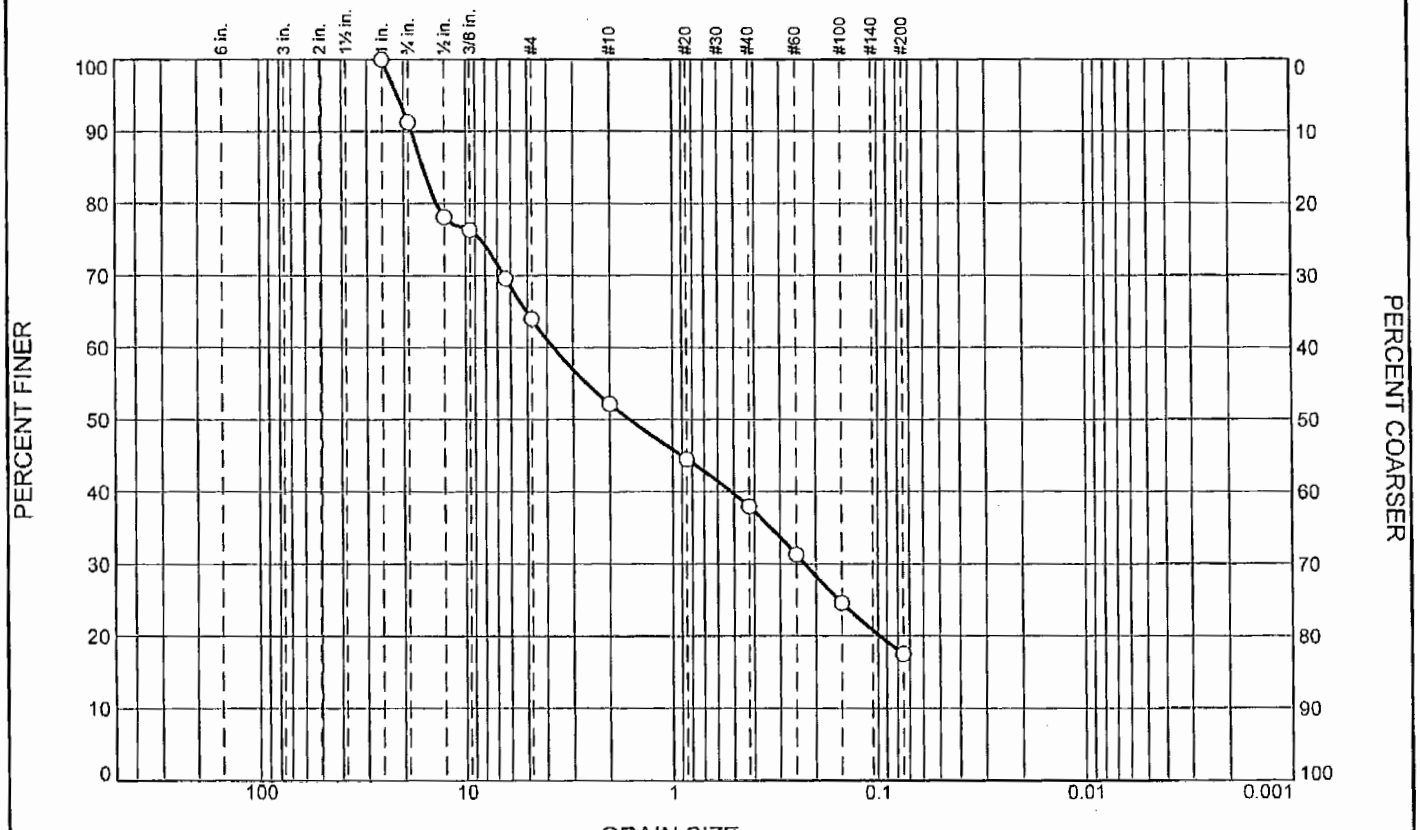
Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 **Figure**

Tested By: TJB **Checked By:** EAA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	9	27	12	14	21	17	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1"	100		
3/4"	91		
1/2"	78		
3/8"	76		
1/4"	70		
#4	64		
#10	52		
#20	44		
#40	38		
#60	31		
#100	25		
#200	17		

* (no specification provided)

Material Description

Tan cmf SAND, some cf gravel, little silt/clay

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 18.3786 D_{85}= 16.0970 D_{60}= 3.7384
D_{50}= 1.6097 D_{30}= 0.2274 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 368.55 grams of oven dried split spoon sample

Source of Sample: P-6 Depth: 4'-6'
Sample Number: S-3

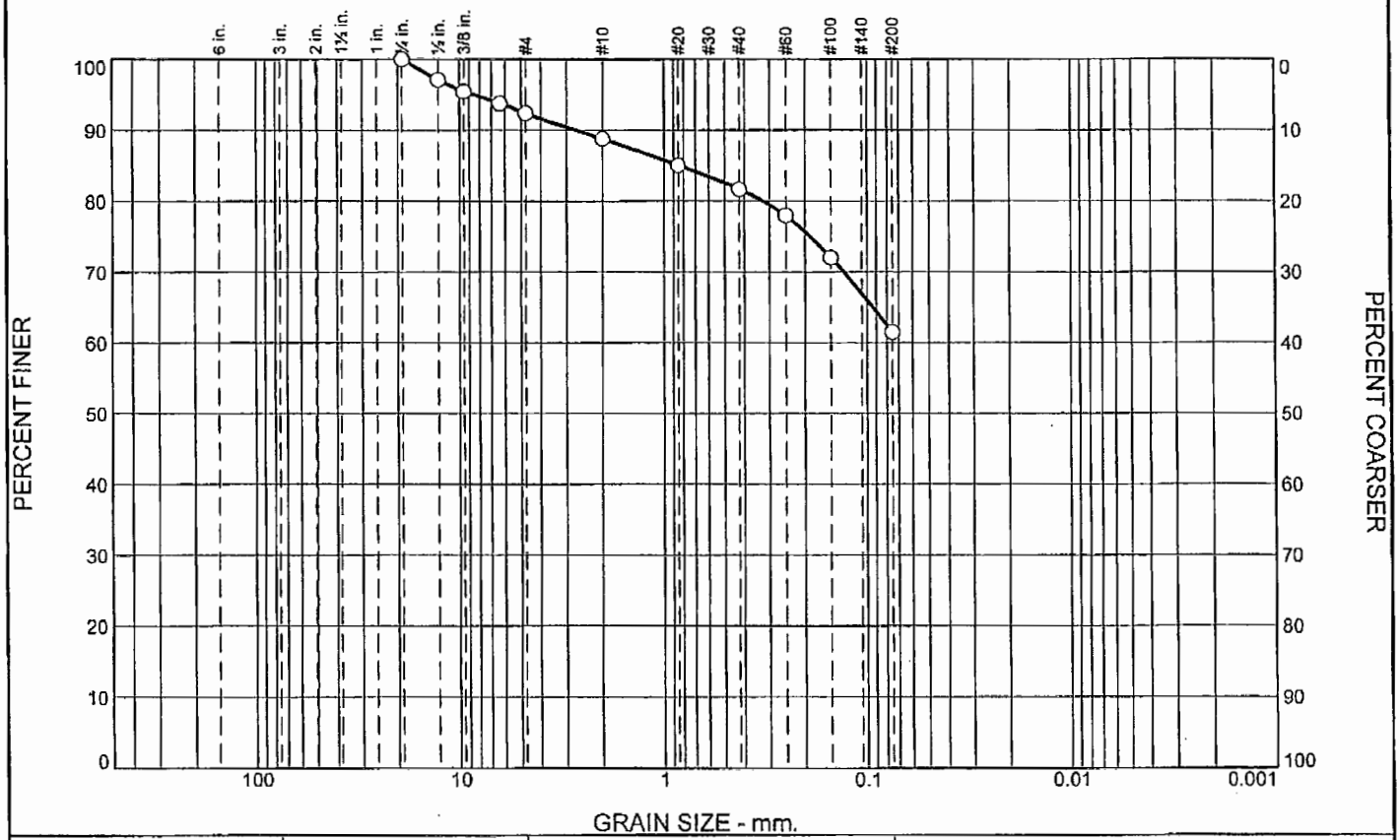
Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 Figure

Tested By: TJB Checked By: EAA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	0	8	3	7	21	61	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4"	100		
1/2"	97		
3/8"	95		
1/4"	94		
#4	92		
#10	89		
#20	85		
#40	82		
#60	78		
#100	72		
#200	61		

* (no specification provided)

Material Description

Tan SILT/CLAY, some cmf sand, trace fine gravel

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 2.7053 D_{85}= 0.8446 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 284.48 grams of oven dried split spoon sample

Source of Sample: P-8 **Depth:** 8'-9'4"
Sample Number: S-5

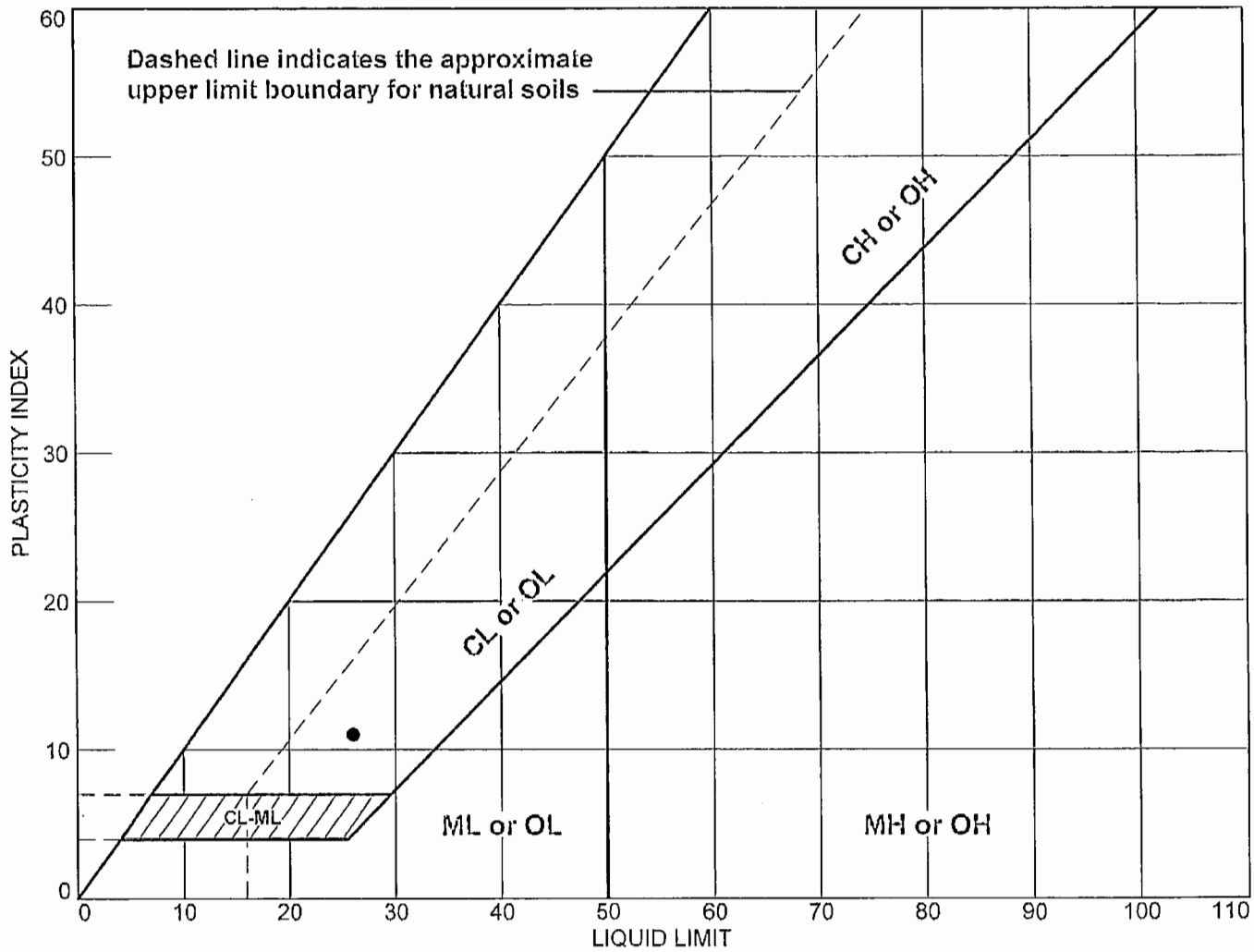
Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 **Figure**

Tested By: TJB **Checked By:** EAA

LIQUID AND PLASTIC LIMITS TEST REPORT



SOIL DATA								
SYMBOL	SOURCE	SAMPLE NO.	DEPTH	NATURAL WATER CONTENT (%)	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	USCS
●	P-10	S-2	2'-4'	24.9	15	26	11	

Foundation Design, P.C.

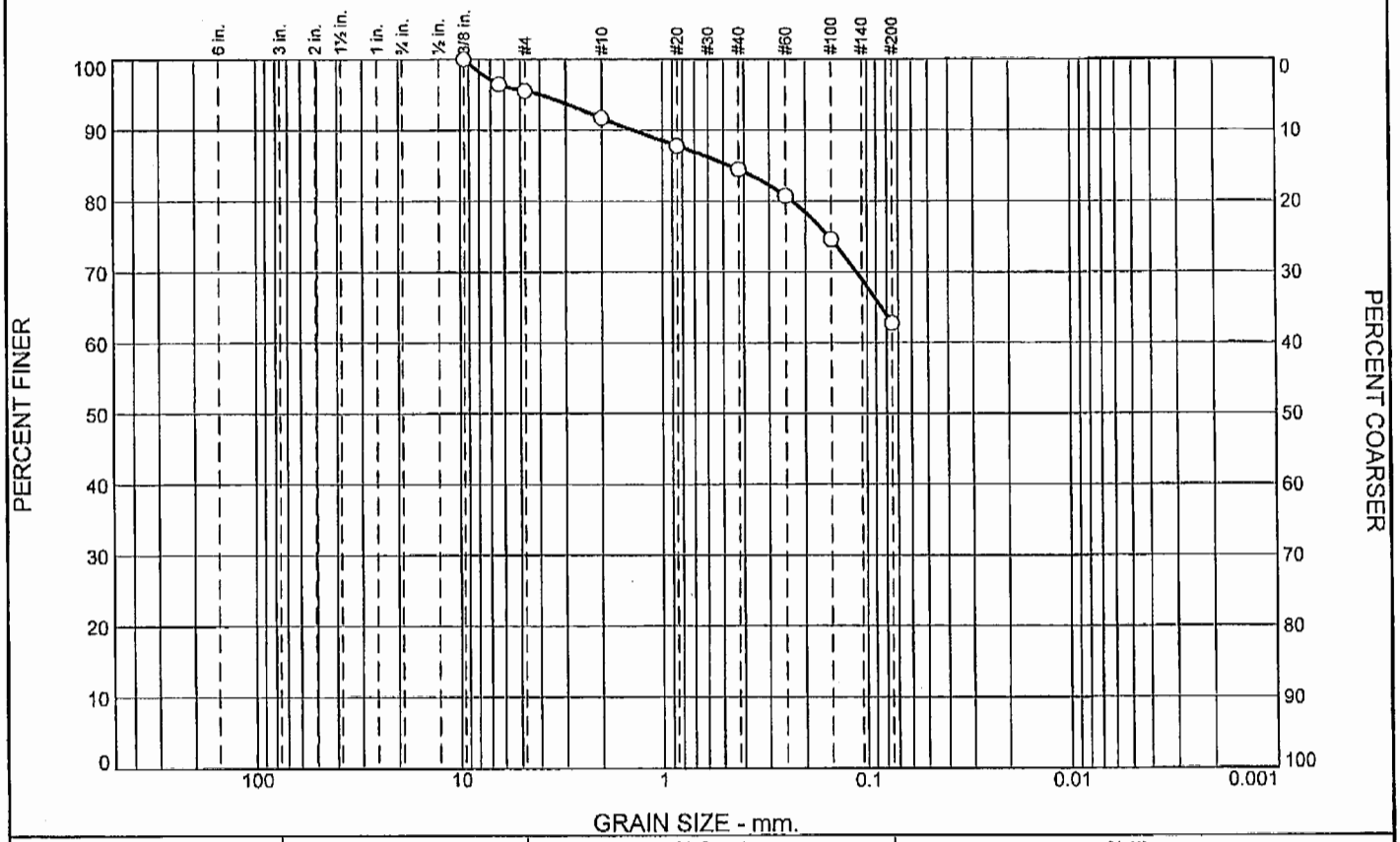
Client: Delaware River Solar, 33 Irving Place, New York, New York

Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York

Project No.: 4618.0 **Figure**

Tested By: EAA Checked By: TB

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	0	4	4	8	21	63	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8"	100		
1/4"	97		
#4	96		
#10	92		
#20	88		
#40	84		
#60	81		
#100	75		
#200	63		

* (no specification provided)

Material Description

Tan SILT/CLAY, some cmf sand, trace fine gravel

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 1.3978 D_{85}= 0.4694 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 316.35 grams of oven dried split spoon sample

Source of Sample: P-15 Depth: 6'-8'
Sample Number: S-4

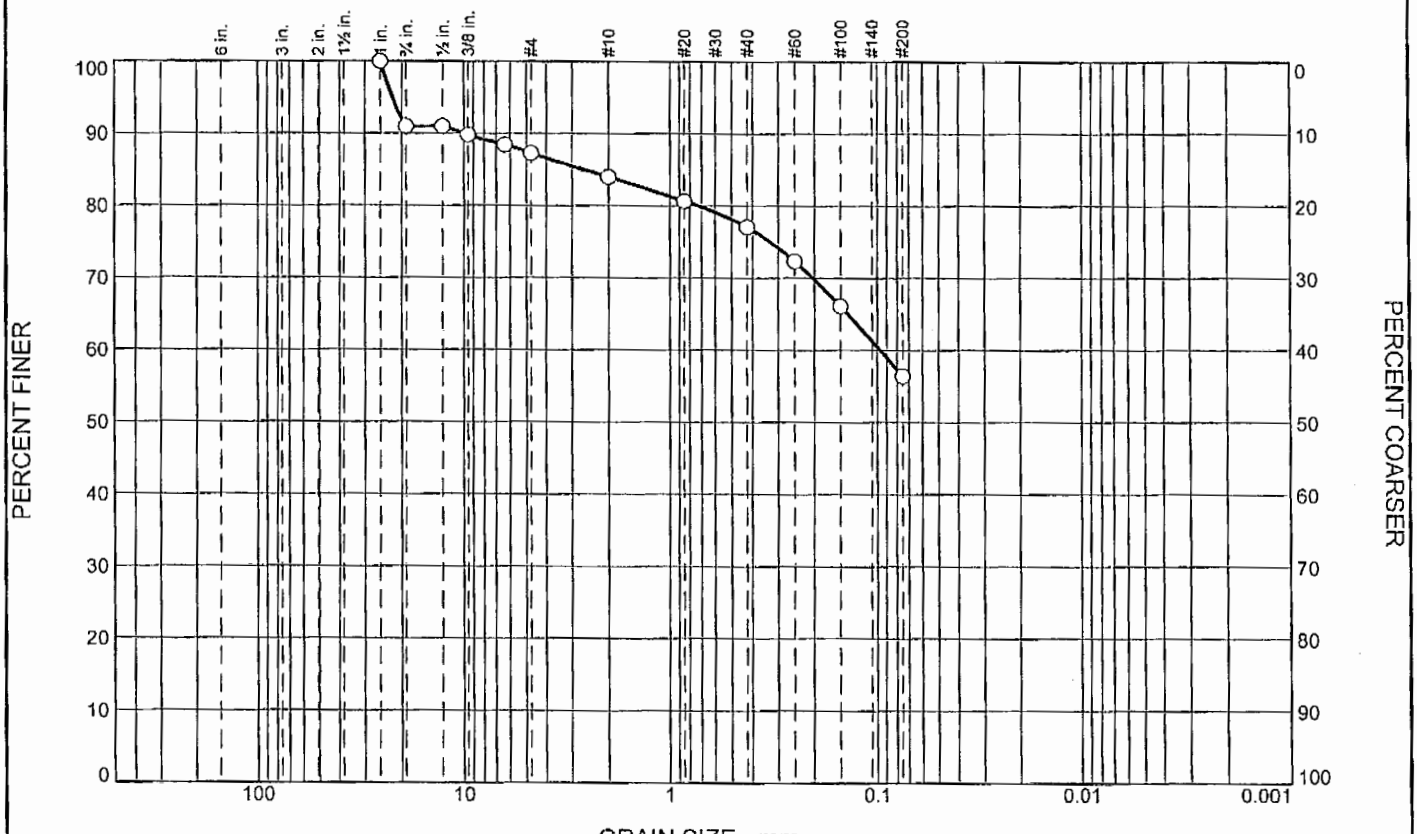
Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 Figure

Tested By: TJB Checked By: EAA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	9	4	3	7	21	56	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1"	100		
3/4"	91		
1/2"	91		
3/8"	90		
1/4"	88		
#4	87		
#10	84		
#20	81		
#40	77		
#60	72		
#100	66		
#200	56		

* (no specification provided)

Material Description

Tan SILT/CLAY, some cmf sand, little cf gravel

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 9.8914 D_{85}= 2.6218 D_{60}= 0.0966
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Test performed on 332.25 grams of oven dried split spoon sample

Source of Sample: P-20 Depth: 6'-8'
Sample Number: S-4

Date: 06.19.19

Foundation Design, P.C.

Client: Delaware River Solar, 33 Irving Place, New York, New York
Project: Yellow Mills Road Solar Farm, 466 Yellow Mills Road, Farmington, New York
Project No: 4618.0 Figure

Tested By: TJB Checked By: EAA

June 26, 2019

Service Request No:R1905667

Mr. Jeff Netzband
Foundation Design
46A Sager Drive
Rochester, NY 14607

Laboratory Results for: Yellow Mills Solar

Dear Mr.Netzband,

Enclosed are the results of the sample(s) submitted to our laboratory June 19, 2019
For your reference, these analyses have been assigned our service request number **R1905667.**

All testing was performed according to our laboratory's quality assurance program and met the requirements of the TNI standards except as noted in the case narrative report. Any testing not included in the lab's accreditation is identified on a Non-Certified Analytes report. All results are intended to be considered in their entirety. ALS Environmental is not responsible for use of less than the complete report. Results apply only to the individual samples submitted to the lab for analysis, as listed in the report. The measurement uncertainty of the results included in this report is within that expected when using the prescribed method(s), and represented by Laboratory Control Sample control limits. Any events, such as QC failures or Holding Time exceedances, which may add to the uncertainty are explained in the report narrative or are flagged with qualifiers. The flags are explained in the Report Qualifiers and Definitions page of this report.

Please contact me if you have any questions. My extension is 7471. You may also contact me via email at Brady.Kalkman@alsglobal.com.

Respectfully submitted,

ALS Group USA, Corp. dba ALS Environmental

Brady Kalkman
Project Manager

ADDRESS 1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
PHONE +1 585 288 5380 FAX +1 585 288 8475
ALS Group USA, Corp
dba ALS Environmental

ALS Environmental

Narrative Documents

ALS Environmental—Rochester Laboratory
1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
Phone (585) 288-5380 Fax (585) 288-8475
www.alsglobal.com

1565 Jefferson Rd, Building 300, Rochester, NY 14623 | 585-288-5380 | www.alsglobal.com

ALS Environmental

Client: Foundation Design
Project: Yellow Mills Solar
Sample Matrix: Soil

Service Request: R1905667
Date Received: 06/19/2019

CASE NARRATIVE

All analyses were performed consistent with the quality assurance program of ALS Environmental. This report contains analytical results for samples for the Tier II level requested by the client.

Sample Receipt:

Three soil samples were received for analysis at ALS Environmental on 06/19/2019. Any discrepancies upon initial sample inspection are annotated on the sample receipt and preservation form included within this report. The samples were stored at minimum in accordance with the analytical method requirements.

General Chemistry:

No significant anomalies were noted with this analysis.

SMO:

No significant anomalies were noted with this analysis.

Approved by Brady Kuller Date 06/26/2019

SAMPLE DETECTION SUMMARY

CLIENT ID: P-17, S-1/S-2, 0-4			Lab ID: R1905667-001			
Analyte	Results	Flag	MDL	MRL	Units	Method
Total Solids	92.3				Percent	ALS SOP

CLIENT ID: P-9, S-1/S-2, 0-4			Lab ID: R1905667-002			
Analyte	Results	Flag	MDL	MRL	Units	Method
Total Solids	88.4				Percent	ALS SOP

CLIENT ID: P-24, S-1/S-2, 0-4			Lab ID: R1905667-003			
Analyte	Results	Flag	MDL	MRL	Units	Method
Total Solids	86.1				Percent	ALS SOP

ALS Environmental

Sample Receipt Information

ALS Environmental—Rochester Laboratory
1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
Phone (585) 288-5380 Fax (585) 288-8475
www.alsglobal.com

Client: Foundation Design

Project: Yellow Mills Solar/4618.0

Service Request: R1905667

SAMPLE CROSS-REFERENCE

SAMPLE #	CLIENT SAMPLE ID	DATE	TIME
R1905667-001	P-17, S-1/S-2, 0-4	6/17/2019	
R1905667-002	P-9, S-1/S-2, 0-4	6/14/2019	
R1905667-003	P-24, S-1/S-2, 0-4	6/17/2019	

CHAIN OF CUSTODY/LABORATORY ANALYSIS REQUEST FORM

49453

ALS

1565 Jefferson Road, Building 300, Suite 360 • Rochester, NY 14623 | +1 585 288 5380 +1 585 288 8475 (fax) PAGE 1 OF 1

Project Name: Yellow Mills SOLAR	Project Number: 4618.0
Project Manager: Jeff Netzband	Report CC:
Company/Address: FOUNDATION DESIGN, P.C. 46A SAGER DRIVE Rochester, NY 14607	
Phone #: 585-458-0824	Email: JNETZBAND@FoundationDesignPC.com
Sampler's Signature: Liz Ashley	Sampler's Printed Name: LIZ ASHLEY

ANALYSIS REQUESTED (Include Method Number and Container Preservative)

Preservative Key: 0. NONE 1. HCL 2. HNO_3 3. H_2SO_4 4. NaOH 5. Zn. Acetate 6. MeOH 7. $NaHSO_4$ 8. Other _____

CLIENT SAMPLE ID	FOR OFFICE USE ONLY LAB ID	SAMPLING DATE	SAMPLING TIME	MATRIX	NUMBER OF CONTAINERS	GC/MS VOAs • 8260 • 624 • CLP	GC/MS SVOAs • 8270 • 625	GC VOAs • 8021 • 601/602	PESTICIDES • 8081 • 608	PCBs • 8082 • 608	METALS, TOTAL (List in comments below)	METALS, DISSOLVED (List in comments below)	Chlorides	SULFATES						REMARKS/ ALTERNATE DESCRIPTION
P-17, S-1/S-2, 0'-4'		6/17		S	2								X	X						combine both samples
P-9, S-1/S-2, 0'-4		6/14		S	2								X	X						combine both samples
P-24, S-1/S-2, 0'-4'		6/17		S	2								X	X						combine Both samples

SPECIAL INSTRUCTIONS/COMMENTS
Metals

See QAPP ☐

STATE WHERE SAMPLES WERE COLLECTED

TURNAROUND REQUIREMENTS
____ RUSH (SURCHARGES APPLY)
____ 1 day ____ 2 day ____ 3 day
____ 4 day X 5 day
REQUESTED REPORT DATE _____

REPORT REQUIREMENTS
____ I. Results Only
____ II. Results + QC Summaries (LCS, DUP, MS/MSD as required)
____ III. Results + QC and Calibration Summaries
____ IV. Data Validation Report with Raw Data
Edata ____ Yes ____ No

INVOICE INFORMATION
PO #
BILL TO:

RELINQUISHED BY	RECEIVED BY	RELINQUISHED BY	RECEIVED BY	RELINQUISHED BY	RECEIVED BY
Signature: Adam Vest	Signature: Brady Kirkman	Signature	Signature	Signature	Signature
Printed Name: Adam Vest	Printed Name: Brady Kirkman	Printed Name	Printed Name	Printed Name	Printed Name
Firm: Foundation Design	Firm: ALS	Firm	Firm	Firm	Firm
Date/Time: 6/19/19 11:17	Date/Time: 6/19/19 11:13	Date/Time	Date/Time	Date/Time	Date/Time

R1905667 5
Foundation Design
Yellow Mills Solar

Distribution: White - Lab Copy; Yellow - Return to Originator

Cooler Receipt and Preservation Check Form

R1905667 **5**
Foundation Design
Yellow Mills Solar

Project/Client: Foundation Folder Number: _____

Cooler received on: 6/19/19 by: [illegible] **COURIER:** ALS UPS FEDEX VELOCITY CLIENT

1	Were **Custody seals** on outside of cooler?	Y N	5a	**Perchlorate** samples have required headspace?	Y N NA
2	**Custody papers** properly completed (ink, signed)?	Y N	5b	Did VOA vials, Alk,or Sulfide have sig* **bubbles**?	Y N NA
3	Did all bottles arrive in good **condition** (unbroken)?	Y N	6	Where did the bottles originate?	ALS/ROC CLIENT
4	Circle: **Wet Ice Dry Ice Gel packs** present?	Y N	7	Soil VOA received as:	Bulk Encore 5035set NA

8. Temperature Readings Date: 6/19/19 Time: 1150 ID: IR#7 IR#10 From: Temp Blank Sample Bottle

Observed Temp (°C)	23.8						
Correction Factor (°C)	—						
Corrected Temp (°C)	23.8						
Temp from:Type of bottle	—						
Within 0-6°C?	Y N	Y N	Y N	Y N	Y N	Y N	Y N
If <0°C, were samples frozen?	Y N	Y N.	Y N	Y N	Y N	Y N	Y N

If out of Temperature, note packing/ice condition: _____ Ice melted Poorly Packed (described below) Same Day Rule

&Client Approval to Run Samples: _____ Standing Approval Client aware at drop-off Client notified by: _____

All samples held in storage location: R-002 by e on 6/19/19 at 1200
5035 samples placed in storage location: _____ by _____ on _____ at _____

Cooler Breakdown/Preservation Check**: Date: 6/19/19 Time: 1845 by: [illegible]

9. Were all bottle labels complete (*i.e.* analysis, preservation, etc.)? YES NO
10. Did all bottle labels and tags agree with custody papers? YES NO
11. Were correct containers used for the tests indicated? YES NO
12. Were 5035 vials acceptable (no extra labels, not leaking)? YES NO N/A
13. Air Samples: Cassettes / Tubes Intact with MS? Canisters Pressurized Tedlar® Bags Inflated N/A

pH	Lot of test paper	Reagent	Preserved? Yes	Preserved? No	Lot Received	Exp	Sample ID Adjusted	Vol. Added	Lot Added	Final pH
≥12		NaOH								
≤2		HNO_3								
≤2		H_2SO_4								
<4		$NaHSO_4$								
5-9		For 608pest			No=Notify for 3day					
Residual Chlorine (-)		For CN, Phenol, 625, 608pest, 522			If +, contact PM to add $Na_2S_2O_3$ (625, 608, CN), ascorbic (phenol).					
		$Na_2S_2O_3$								
		ZnAcetate	-	-						
		HCl	**	**						

**VOAs and 1664 Not to be tested before analysis. Otherwise, all bottles of all samples with chemical preservatives are checked (not just representatives).

Bottle lot numbers: client

Explain all Discrepancies/ Other Comments:

CLRES	BULK
DO	FLDT
HPROD	HGFB
HTR	LL3541
PH	SUB
SO3	MARRS
ALS	REV

Labels secondary reviewed by: [illegible]

PC Secondary Review: _____

*significant air bubbles: VOA > 5-6 mm : WC >1 in. diameter

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Miscellaneous Forms

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1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
Phone (585) 288-5380 Fax (585) 288-8475
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REPORT QUALIFIERS AND DEFINITIONS

U Analyte was analyzed for but not detected. The sample quantitation limit has been corrected for dilution and for percent moisture, unless otherwise noted in the case narrative.

J Estimated value due to either being a Tentatively Identified Compound (TIC) or that the concentration is between the MRL and the MDL. Concentrations are not verified within the linear range of the calibration. For DoD: concentration >40% difference between two GC columns (pesticides/Arclors).

B Analyte was also detected in the associated method blank at a concentration that may have contributed to the sample result.

E Inorganics- Concentration is estimated due to the serial dilution was outside control limits.

E Organics- Concentration has exceeded the calibration range for that specific analysis.

D Concentration is a result of a dilution, typically a secondary analysis of the sample due to exceeding the calibration range or that a surrogate has been diluted out of the sample and cannot be assessed.

* Indicates that a quality control parameter has exceeded laboratory limits. Under the "Notes" column of the Form I, this qualifier denotes analysis was performed out of Holding Time.

H Analysis was performed out of hold time for tests that have an "immediate" hold time criteria.

\# Spike was diluted out.

\+ Correlation coefficient for MSA is <0.995.

N Inorganics- Matrix spike recovery was outside laboratory limits.

N Organics- Presumptive evidence of a compound (reported as a TIC) based on the MS library search.

S Concentration has been determined using Method of Standard Additions (MSA).

W Post-Digestion Spike recovery is outside control limits and the sample absorbance is <50% of the spike absorbance.

P Concentration >40% difference between the two GC columns.

C Confirmed by GC/MS

Q DoD reports; indicates a pesticide/Aroclor is not confirmed (≥100% Difference between two GC columns).

X See Case Narrative for discussion.

MRL Method Reporting Limit. Also known as:
LOQ Limit of Quantitation (LOQ)
The lowest concentration at which the method analyte may be reliably quantified under the method conditions.

MDL Method Detection Limit. A statistical value derived from a study designed to provide the lowest concentration that will be detected 99% of the time. Values between the MDL and MRL are estimated (see J qualifier).

LOD Limit of Detection. A value at or above the MDL which has been verified to be detectable.

ND Non-Detect. Analyte was not detected at the concentration listed. Same as U qualifier.

ACCREDITED IN ACCORDANCE WITH nelac

Rochester Lab ID # for State Certifications[1]

Connecticut ID # PH0556	Maine ID #NY0032	Pennsylvania ID# 68-786
Delaware Approved	New Hampshire ID # 2941	Rhode Island ID # 158
DoD ELAP #65817	New York ID # 10145	Virginia #460167
Florida ID # E87674	North Carolina #676	

[1] Analyses were performed according to our laboratory's NELAP-approved quality assurance program and any applicable state or agency requirements. The test results meet requirements of the current NELAP/TNI standards or state or agency requirements, where applicable, except as noted in the case narrative. Since not all analyte/method/matrix combinations are offered for state/NELAC accreditation, this report may contain results which are not accredited. For a specific list of accredited analytes, contact the laboratory or go to https://www.alsglobal.com/locations/americas/north-america/usa/new-york/rochester-environmental

ALS Laboratory Group

Acronyms

ASTM	American Society for Testing and Materials
A2LA	American Association for Laboratory Accreditation
CARB	California Air Resources Board
CAS Number	Chemical Abstract Service registry Number
CFC	Chlorofluorocarbon
CFU	Colony-Forming Unit
DEC	Department of Environmental Conservation
DEQ	Department of Environmental Quality
DHS	Department of Health Services
DOE	Department of Ecology
DOH	Department of Health
EPA	U. S. Environmental Protection Agency
ELAP	Environmental Laboratory Accreditation Program
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrometry
LUFT	Leaking Underground Fuel Tank
M	Modified
MCL	Maximum Contaminant Level is the highest permissible concentration of a substance allowed in drinking water as established by the USEPA.
MDL	Method Detection Limit
MPN	Most Probable Number
MRL	Method Reporting Limit
NA	Not Applicable
NC	Not Calculated
NCASI	National Council of the Paper Industry for Air and Stream Improvement
ND	Not Detected
NIOSH	National Institute for Occupational Safety and Health
PQL	Practical Quantitation Limit
RCRA	Resource Conservation and Recovery Act
SIM	Selected Ion Monitoring
TPH	Total Petroleum Hydrocarbons
tr	Trace level is the concentration of an analyte that is less than the PQL but greater than or equal to the MDL.

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Client: Foundation Design
Project: Yellow Mills Solar/4618.0

Service Request: R1905667

Non-Certified Analytes

Certifying Agency: New York Department of Health

Method	Matrix	Analyte
ALS SOP	Soil	Total Solids

ALS Group USA, Corp.
dba ALS Environmental

Analyst Summary report

Client: Foundation Design
Project: Yellow Mills Solar/4618.0

Service Request: R1905667

Sample Name: P-17, S-1/S-2, 0-4
Lab Code: R1905667-001
Sample Matrix: Soil

Date Collected: 06/17/19
Date Received: 06/19/19

Analysis Method	Extracted/Digested By	Analyzed By
9056A	CWOODS	CWOODS
ALS SOP		KAWONG

Sample Name: P-9, S-1/S-2, 0-4
Lab Code: R1905667-002
Sample Matrix: Soil

Date Collected: 06/14/19
Date Received: 06/19/19

Analysis Method	Extracted/Digested By	Analyzed By
9056A	CWOODS	CWOODS
ALS SOP		KAWONG

Sample Name: P-24, S-1/S-2, 0-4
Lab Code: R1905667-003
Sample Matrix: Soil

Date Collected: 06/17/19
Date Received: 06/19/19

Analysis Method	Extracted/Digested By	Analyzed By
9056A	CWOODS	CWOODS
ALS SOP		KAWONG

INORGANIC PREPARATION METHODS

The preparation methods associated with this report are found in these tables unless discussed in the case narrative.

Water/Liquid Matrix

Analytical Method	Preparation Method
200.7	200.2
200.8	200.2
6010C	3005A/3010A
6020A	ILM05.3
9014 Cyanide Reactivity	SW846 Ch7, 7.3.4.2
9034 Sulfide Reactivity	SW846 Ch7, 7.3.4.2
9034 Sulfide Acid Soluble	9030B
9056A Bomb (Halogens)	5050A
9066 Manual Distillation	9065
SM 4500-CN-E Residual Cyanide	SM 4500-CN-G
SM 4500-CN-E WAD Cyanide	SM 4500-CN-I

Solid/Soil/Non-Aqueous Matrix

Analytical Method	Preparation Method
6010C	3050B
6020A	3050B
6010C TCLP (1311) extract	3005A/3010A
6010 SPLP (1312) extract	3005A/3010A
7196A	3060A
7199	3060A
9056A Halogens/Halides	5050
300.0 Anions/ 350.1/ 353.2/ SM 2320B/ SM 5210B/ 9056A Anions	DI extraction

For analytical methods not listed, the preparation method is the same as the analytical method reference.

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Sample Results

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1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
Phone (585) 288-5380 Fax (585) 288-8475
www.alsglobal.com

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General Chemistry

ALS Environmental—Rochester Laboratory
1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
Phone (585) 288-5380 Fax (585) 288-8475
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Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	06/17/19
Sample Matrix:	Soil	**Date Received:**	06/19/19 11:13
Sample Name:	P-17, S-1/S-2, 0-4	**Basis:**	Dry
Lab Code:	R1905667-001		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Chloride	9056A	33 U	mg/Kg	33	1	06/25/19 18:10	06/25/19	
Sulfate	9056A	33 U	mg/Kg	33	1	06/25/19 18:10	06/25/19	

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Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	06/17/19
Sample Matrix:	Soil	**Date Received:**	06/19/19 11:13
Sample Name:	P-17, S-1/S-2, 0-4	**Basis:**	As Received
Lab Code:	R1905667-001		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Total Solids	ALS SOP	**92.3**	Percent	-	1	06/26/19 08:50	NA	

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dba ALS Environmental

Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	06/14/19
Sample Matrix:	Soil	**Date Received:**	06/19/19 11:13
Sample Name:	P-9, S-1/S-2, 0-4	**Basis:**	Dry
Lab Code:	R1905667-002		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Chloride	9056A	34 U	mg/Kg	34	1	06/25/19 18:17	06/25/19	
Sulfate	9056A	34 U	mg/Kg	34	1	06/25/19 18:17	06/25/19	

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Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	06/14/19
Sample Matrix:	Soil	**Date Received:**	06/19/19 11:13
Sample Name:	P-9, S-1/S-2, 0-4	**Basis:**	As Received
Lab Code:	R1905667-002		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Total Solids	ALS SOP	88.4	Percent	-	1	06/26/19 08:50	NA	

ALS Group USA, Corp.
dba ALS Environmental

Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	06/17/19
Sample Matrix:	Soil	**Date Received:**	06/19/19 11:13
Sample Name:	P-24, S-1/S-2, 0-4	**Basis:**	Dry
Lab Code:	R1905667-003		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Chloride	9056A	35 U	mg/Kg	35	1	06/25/19 18:23	06/25/19	
Sulfate	9056A	35 U	mg/Kg	35	1	06/25/19 18:23	06/25/19	

ALS Group USA, Corp.
dba ALS Environmental

Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	06/17/19
Sample Matrix:	Soil	**Date Received:**	06/19/19 11:13
Sample Name:	P-24, S-1/S-2, 0-4	**Basis:**	As Received
Lab Code:	R1905667-003		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Total Solids	ALS SOP	**86.1**	Percent	-	1	06/26/19 08:50	NA	

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QC Summary Forms

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1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
Phone (585) 288-5380 Fax (585) 288-8475
www.alsglobal.com

General Chemistry

ALS Environmental—Rochester Laboratory
1565 Jefferson Road, Building 300, Suite 360, Rochester, NY 14623
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dba ALS Environmental

Analytical Report

Client:	Foundation Design	**Service Request:**	R1905667
Project:	Yellow Mills Solar/4618.0	**Date Collected:**	NA
Sample Matrix:	Soil	**Date Received:**	NA
Sample Name:	Method Blank	**Basis:**	Dry
Lab Code:	R1905667-MB		

Inorganic Parameters

Analyte Name	Analysis Method	Result	Units	MRL	Dil.	Date Analyzed	Date Extracted	Q
Chloride	9056A	30 U	mg/Kg	30	1	06/25/19 17:56	06/25/19	
Sulfate	9056A	30 U	mg/Kg	30	1	06/25/19 17:56	06/25/19	

ALS Group USA, Corp.
dba ALS Environmental

QA/QC Report

Client:	Foundation Design	**Service Request:**	R1905667
Project	Yellow Mills Solar/4618.0	**Date Collected:**	06/17/19
Sample Matrix:	Soil	**Date Received:**	06/19/19
		Date Analyzed:	06/26/19

Replicate Sample Summary
General Chemistry Parameters

Sample Name:	P-17, S-1/S-2, 0-4	**Units:**	Percent
Lab Code:	R1905667-001	**Basis:**	As Received

Analyte Name	Analysis Method	MRL	Sample Result	Duplicate Sample R1905667-001DUP Result	Average	RPD	RPD Limit
Total Solids	ALS SOP	-	92.3	91.4	91.9	<1	20

Results flagged with an asterisk (*) indicate values outside control criteria.

Results flagged with a pound (#) indicate the control criteria is not applicable.

Percent recoveries and relative percent differences (RPD) are determined by the software using values in the calculation which have not been rounded.

ALS Group USA, Corp.
dba ALS Environmental

QA/QC Report

Client: Foundation Design
Project: Yellow Mills Solar/4618.0
Sample Matrix: Soil

Service Request: R1905667
Date Analyzed: 06/25/19

Lab Control Sample Summary
General Chemistry Parameters

Units:mg/Kg
Basis: Dry

Lab Control Sample
R1905667-LCS

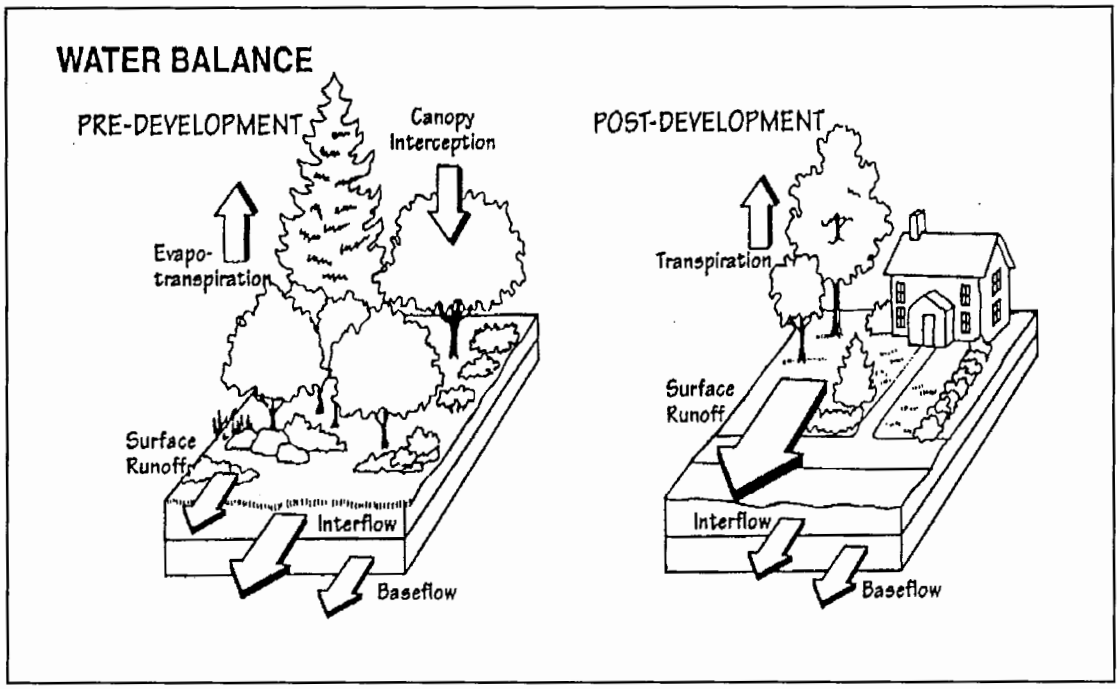
Analyte Name	Analytical Method	Result	Spike Amount	% Rec	% Rec Limits
Chloride	9056A	200	200	100	80-120
Sulfate	9056A	207	200	104	80-120

EXHIBIT F

Chapter 2: Impacts of New Development

Urban development has a profound influence on the quality of New York's waters. To start, development dramatically alters the local hydrologic cycle (see Figure 2.1). The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the forest floor that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff.

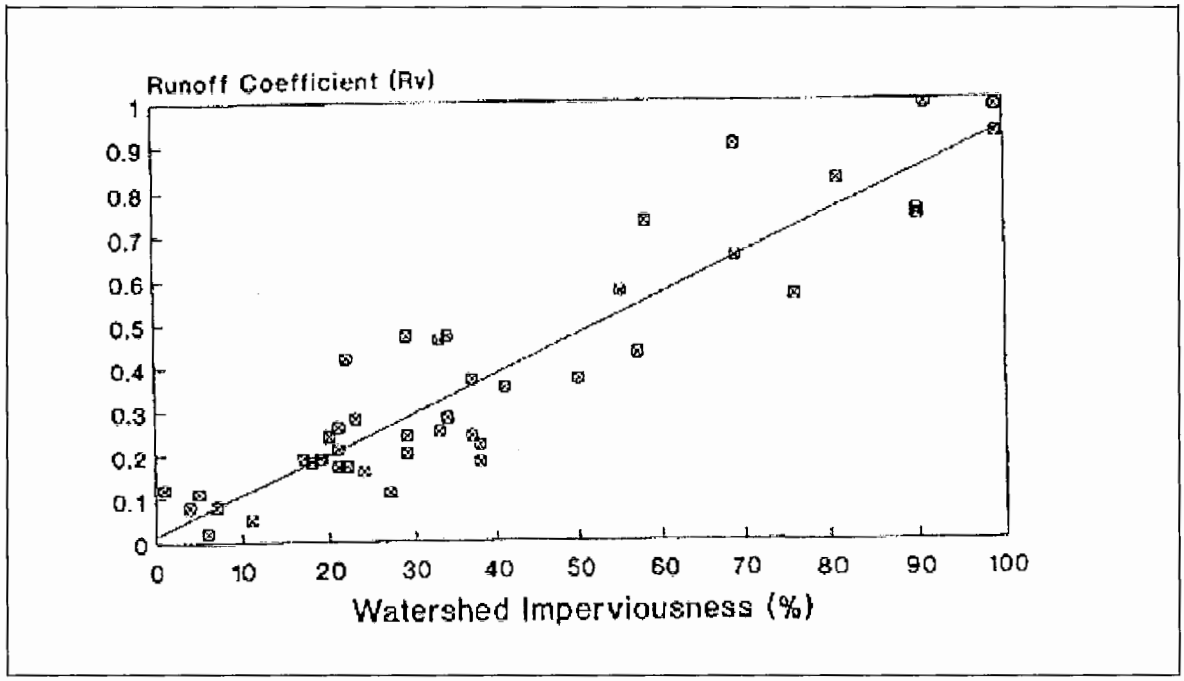
Figure 2.1 Water Balance at a Developed and Undeveloped Site (Schueler, 1987)



The situation worsens after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in Figure 2.2, which shows the increase in the volumetric runoff coefficient (R_v) as a function of site imperviousness. The runoff coefficient expresses the fraction of rainfall volume that is converted into stormwater runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre parking lot can produce 16 times more stormwater runoff than a one-acre meadow each year (Schueler, 1994).

The increase in stormwater runoff can be too much for the existing drainage system to handle. As a result, the drainage system is often "improved" to rapidly collect runoff and quickly convey it away (using curb and gutter, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, reservoirs, lakes or estuaries.

Figure 2.2 Relationship Between Impervious Cover and Runoff Coefficient (Schueler, 1987)



Section 2.1 Declining Water Quality

Impervious surfaces accumulate pollutants deposited from the atmosphere, leaked from vehicles, or windblown in from adjacent areas. During storm events, these pollutants quickly wash off, and are rapidly delivered to downstream waters. Some common pollutants found in urban stormwater runoff are profiled in Table 2.1.

Sediment (Suspended Solids)

Sources of sediment include washoff of particles that are deposited on impervious surfaces and erosion from streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997).

Table 2.1 National Median Concentrations for Chemical Constituents in Stormwater

Constituent	Units	Concentration
Total Suspended Solids[1]	mg/l	54.5
Total Phosphorus[1]	mg/l	0.26
Soluble Phosphorus[1]	mg/l	0.10
Total Nitrogen[1]	mg/l	2.00
Total Kjeldhal Nitrogen[1]	mg/l	1.47
Nitrite and Nitrate[1]	mg/l	0.53
Copper[1]	ug/l	11.1
Lead[1]	ug/l	50.7
Zinc[1]	ug/l	129
BOD[1]	mg/l	11.5
COD[1]	mg/l	44.7
Organic Carbon[2]	mg/l	11.9
PAH[3]	mg/l	3.5*
Oil and Grease[4]	mg/l	3.0*
Fecal Coliform[5]	col/100 ml	15,000*
Fecal Strep[5]	col/ 100 ml	35,400*
Chloride (snowmelt)[6]	mg/l	116

* Represents a Mean Value
Source:
1: Pooled NURP/USGS (Smullen and Cave, 1998)
2: Derived from the National Pollutant Removal Database (Winer, 2000)
3: Rabanal and Grizzard 1995
4: Crunkilton et al. (1996)
5: Schueler (1999)
6: Oberts 1994

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, lakes and estuaries. Turbidity resulting from sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. In addition, the reflected energy from light reflecting off of suspended sediment can increase water temperatures (Kundell and Rasmussen, 1995). Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems, and smothering benthic organisms such as clams and mussels. Finally, sediment transports many other pollutants to the water resource.

Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, lakes, reservoirs and estuaries. This process is known as eutrophication. Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, animal waste, organic matter, and stream bank erosion. Another nitrogen source is fossil fuel combustion from automobiles, power plants and industry. Data from the upper Midwest suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer *et al.*, 1997; Waschbusch *et al.*, 2000; Bannerman *et al.*, 1993).

Nutrients are of particular concern in lakes and estuaries, and are a source of degradation in many of New York's waters. Nitrogen has contributed to hypoxia in the Long Island Sound, and is a key pollutant of concern in the New York Harbor and the Peconic Estuary. Phosphorus in runoff has impacted the quality of a number of New York natural lakes, including the Finger Lakes and Lake Champlain, which are susceptible to eutrophication from phosphorus loading. Phosphorus has been identified as a key parameter in the New York City Reservoir system. The New York City DEP recently developed water quality guidance values for phosphorus for City drinking water reservoirs (NYC DEP, 1999); a source-water phosphorus guidance value

of 15 μg/l has been proposed for seven reservoirs (Kensico, Rondout, Ashokan, West Branch, New Croton, Croton Falls, and Cross River) in order to protect them from use-impairment due to eutrophication, with other reservoirs using the State recommended guidance value of 20 μg/l.

Organic Carbon

Organic matter, washed from impervious surfaces during storms, can present a problem in slower moving downstream waters. Some sources include organic material blown onto the street surface, and attached to sediment from stream banks, or from bare soil. In addition, organic carbon is formed indirectly from algal growth within systems with high nutrient loads.

As organic matter decomposes, it can deplete dissolved oxygen in lakes and tidal waters. Declining levels of oxygen in the water can have an adverse impact on aquatic life. An additional concern is the formation of trihalomethane (THM), a carcinogenic disinfection by-product, due to the mixing of chlorine with water high in organic carbon. This is of particular importance in unfiltered water supplies, such as the New York City Reservoir System.

Bacteria

Bacteria levels in stormwater runoff routinely exceed public health standards for water contact recreation. Some stormwater sources include pet waste and urban wildlife. Other sources in developed land include sanitary and combined sewer overflows, wastewater, and illicit connections to the storm drain system. Bacteria is a leading contaminant in many of New York's waters, and has lead to shellfish bed closures in the New York Bight Area, on Long Island, and in the Hudson-Raritan Estuary. In addition, Suffolk, Nassau, and Erie Counties issue periodic bathing-beach advisories each time a significant rainfall event occurs (NRDC, 2000).

Hydrocarbons

Vehicles leak oil and grease that contain a wide array of hydrocarbon compounds, some of which can be toxic to aquatic life at low concentrations. Sources are automotive, and some areas that produce runoff with high runoff concentrations include gas stations, commuter parking lots, convenience stores, residential parking areas, and streets (Schueler, 1994).

Trace Metals

Cadmium, copper, lead and zinc are routinely found in stormwater runoff. Many of the sources are automotive. For example, one study suggests that 50% of the copper in Santa Clara, CA comes from brake pads (Woodward-Clyde, 1992). Other sources of metals include paints, road salts, and galvanized pipes.

These metals can be toxic to aquatic life at certain concentrations, and can also accumulate in the bottom sediments of lakes and estuaries. Specific concerns in aquatic systems include bioaccumulations in fish and macro-invertebrates, and the impact of toxic bottom sediments on bottom-dwelling species.

Pesticides

A modest number of currently used and recently banned insecticides and herbicides have been detected in urban and suburban streamflow at concentrations that approach or exceed toxicity thresholds for aquatic life. Key sources of pesticides include application to urban lawns and highway median and shoulder areas.

Chlorides

Salts that are applied to roads and parking lots in the winter months appear in stormwater runoff and meltwater at much higher concentrations than many freshwater organisms can tolerate. One study of four Adirondack streams found severe impacts to macroinvertebrate species attributed to chlorides (Demers and Sage, 1990). In addition to the direct toxic effects, chlorides can impact lake systems by altering their mixing cycle. In 1986, incomplete mixing in the Irondequoit Bay was attributed to high salt use in the region (MCEMC, 1987). A primary source of chlorides in New York State, particularly in the State's northern regions, is salt applied to road surfaces as a deicer.

Thermal Impacts

Runoff from impervious surfaces may increase temperature in receiving waters, adversely impacting aquatic organisms that require cold and cool water conditions (e.g., trout). Data suggest that increasing development can increase stream temperatures by between five and twelve degrees Fahrenheit, and that the increase is related to the level of impervious cover in the drainage area (Galli, 1991). Thermal impacts are a serious concern in trout waters, where cold temperatures are critical to species survival.

Trash and Debris

Considerable quantities of trash and debris are washed through the storm drain networks. The trash and debris accumulate in streams and lakes and detract from their natural beauty. Depending on the type of trash, this material may also lead to increased organic matter or toxic contaminants in water bodies.

Snowmelt Concentrations

The snow pack can store hydrocarbons, oil and grease, chlorides, sediment, and nutrients. In cold regions, the pollutant load during snowmelt can be significant, and chemical traits of snowmelt change over the course of the melt event. Oberts (1994) studied this phenomenon, and describes four types of snowmelt runoff (Table 2.2). Oberts and others have reported that 90% of the hydrocarbon load from snowmelt occurs during the last 10% of the event. From a practical standpoint, the high hydrocarbon loads experienced toward the end of the season suggest that stormwater management practices should be designed to capture as much of the snowmelt event as possible.

Table 2.2 Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)

Snowmelt Stage	Duration/ Frequency	Runoff Volume	Pollutant Characteristics
Pavement Melt	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants, Cl, nitrate, lead. Total load is minimal.
Roadside Melt	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants.
Pervious Area Melt	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants, moderate to high concentrations of particulate pollutants, depending on flow.
Rain-on-Snow Melt	Short	Extreme	High concentrations of particulate pollutants, moderate to high concentrations of soluble pollutants. High total load.

Section 2.2 Diminishing Groundwater Recharge and Quality

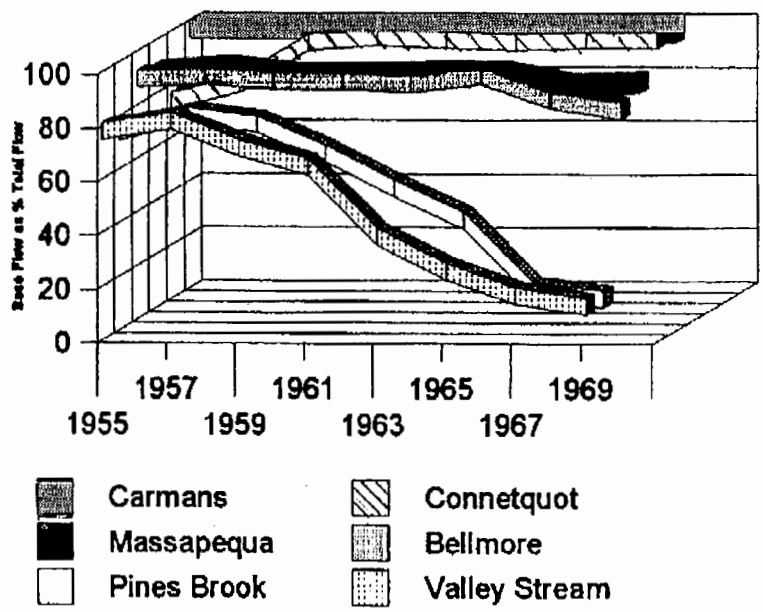
The slow infiltration of rainfall through the soil layer is essential for replenishing groundwater. Groundwater is a critical water resource across the State. Not only do many residents depend on groundwater for their drinking water, but the health of many aquatic systems is also dependent on its steady discharge. For example, during periods of dry weather, groundwater sustains flows in streams and helps to maintain the hydrology of non-tidal wetlands.

Because development creates impervious surfaces that prevent natural recharge, a net decrease in groundwater recharge rates can be expected in urban watersheds. Thus, during prolonged periods of dry weather, streamflow sharply diminishes. Another source of diminishing baseflow is well drawdowns as

populations increase in the watershed. In smaller headwater streams, the decline in stream flow can cause a perennial stream to become seasonally dry. One study in Long Island suggests that the supply of baseflow decreased in some developing watersheds, particularly where the water supply was sewered (Spinello and Simmons, 1992; Figure 2.3).

Urban land uses and activities can also degrade *groundwater quality,* if stormwater runoff is infiltrated without adequate treatment. Certain land uses and activities are known to produce higher loads of metals and toxic chemicals and are designated as *stormwater hotspots*. Soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some polycyclic aromatic hydrocarbons (PAH's) can migrate into groundwater and potentially contaminate wells. Stormwater runoff from designated hotspots should never be infiltrated, unless the runoff receives full treatment with another practice.

Figure 2.3 Declining Baseflow in Response to Development



Notes:

Carmans and Connetquot: Rural/suburban, watersheds are unsewered

Bellmore and Massapequa: Moderately urbanized, not sewered until 1989

Valley Stream and Pine Brook: Urbanized and densely populated watersheds, sewer systems completed in 1960s

1953-1964: Period of sanitary sewer construction in eastern Nassau County

1962-1966: Drought years

Section 2.3 Impacts to the Stream Channel

As pervious meadows and forests are converted into less pervious urban soils, or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, the bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975). As Figure 2.4 demonstrates, the total flow beyond the "critical erosive velocity" increases substantially after development occurs. The increased energy resulting from these more frequent bankfull flow events results in erosion and enlargement of the stream channel, and consequent habitat degradation.

Figure 2.4 Increased Frequency of Erosive Flow After Development

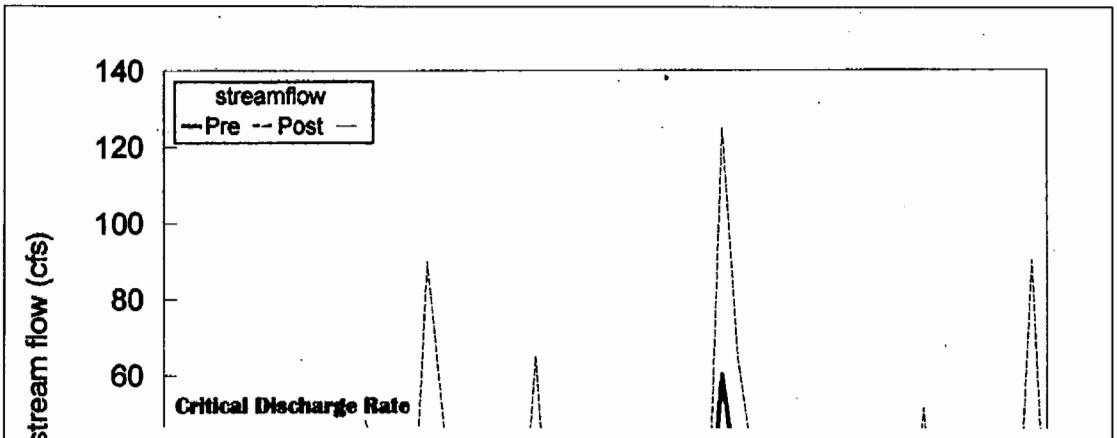
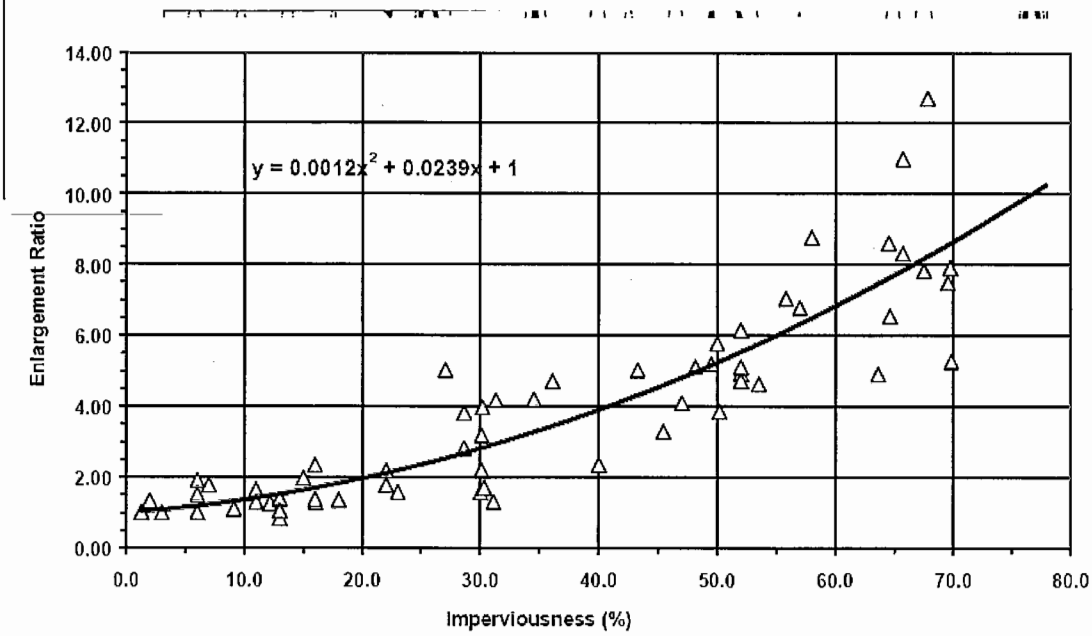


Figure 2.5 Relationship Between Impervious Cover and Channel Enlargement



Channel enlargement in response to watershed development has been observed for decades, with research indicating that the stream channel area expands to between two and five times its original size in response to upland development (Hammer, 1972; Morisawa and LaFlure, 1979; Allen and Narramore, 1985; Booth, 1990). One researcher developed a direct relationship between the level of impervious cover and the "ultimate" channel enlargement, the area a stream will eventually reach over time (MacRae, 1996; Figure 2.5).

Historically, New York has used two-year control (i.e., reduction of the peak flow from the two-year storm to predeveloped levels) to prevent channel erosion, as required in the 1993 SPDES General Permit (GP-93-06). Research suggests that this measure does not adequately protect stream channels (McCuen and Moglen,

1988, MacRae, 1996). Although the peak flow is lower, it is also extended over a longer period of time, thus increasing the duration of erosive flows. In addition, the bankfull flow event actually becomes more frequent after development occurs. Consequently, capturing the two-year event may not address the channel-forming event.

This stream channel erosion and expansion, combined with direct impacts to the stream system, act to decrease the habitat quality of the stream. The stream will thus experience the following impacts to habitat (Table 2.3):

- Decline in stream substrate quality (through sediment deposition and embedding of the substrate)
- Loss of pool/riffle structure in the stream channel
- Degradation of stream habitat structure
- Creation of fish barriers by culverts and other stream crossings
- Loss of "large woody debris," which is critical to fish habitat

Table 2.3 Impacts to Stream Habitat

Stream Channel Impact	Key Finding	Reference	Year
Habitat Characteristics			
Embeddedness	Interstitial spaces between substrate fill with increasing watershed imperviousness	Horner *et al.*	1996
Large Woody Debris (LWD)	Important for habitat diversity and anadramous fish.	Spence *et al.*	1996
	Decreased LWD with increases in imperviousness	Booth *et al.*	1996
Changes in Stream Features	Altered pool/riffle sequence with urbanization	Richey	1982
	Loss of habitat diversity	Scott *et al.*	1986

Direct Channel Impacts			
Reduction in 1st Order Streams	Replaced by storm drains and pipes increases erosion rate downstream	Dunne and Leopold	1972
Channelization and hardening of stream channels	Increase instream velocities often leading to increased erosion rates downstream	Sauer *et al.*	1983
Fish Blockages	Fish blockages caused by bridges and culverts	MWCOG	1989

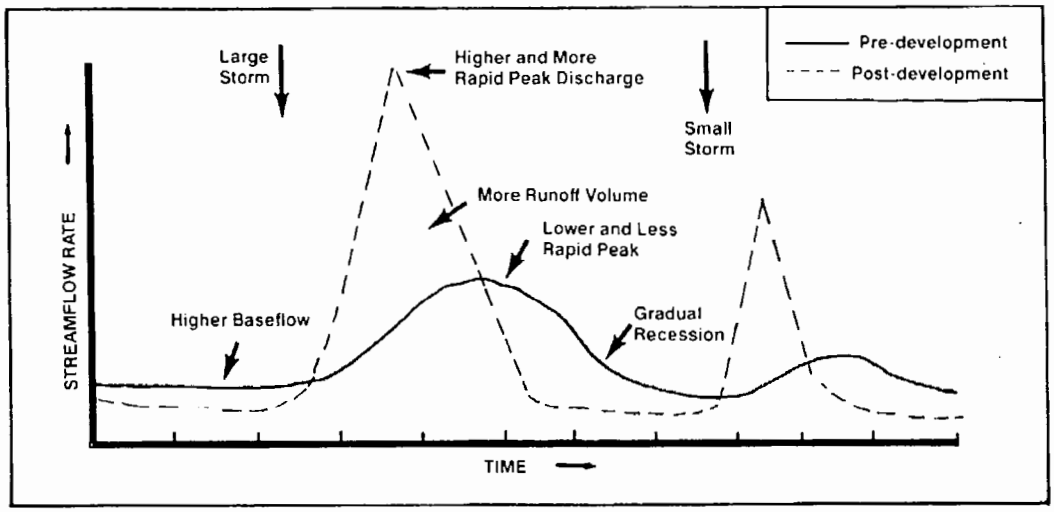
Section 2.4 Increased Overbank Flooding

Flow events that exceed the capacity of the stream channel spill out into the adjacent floodplain. These are termed "overbank" floods, and can damage property and downstream structures. While some overbank flooding is inevitable and sometimes desirable, the historical goal of drainage design in New York has been to maintain pre-development peak discharge rates for both the two- and ten-year frequency storm after development, thus keeping the level of overbank flooding the same over time. This management technique prevents costly damage or maintenance for culverts, drainage structures, and swales.

Overbank floods are ranked in terms of their statistical return frequency. For example, a flood that has a 50% chance of occurring in any given year is termed a "two-year" flood. The two-year event is also known as the "bankfull flood," as researchers have demonstrated that most natural stream channels in the State have just enough capacity to handle the two-year flood before spilling out into the floodplain. Although many factors, such as soil moisture, topography, and snowmelt, can influence the magnitude of a particular flood event, designers typically design for the "two-year" storm event. In New York State, the two-year design storm ranges between about 2.0 to 4.0 inches of rain in a 24-hour period. Similarly, a flood that has a 10% chance of occurring in any given year is termed a "ten-year flood." A ten-year flood occurs when a storm event produces between 3.2 and 6.0 inches of rain in a 24-hour period. Under traditional engineering practice, most channels and storm drains in New York are designed with enough capacity to safely pass the peak discharge from the ten-year design storm.

Urban development increases the peak discharge rate associated with a given design storm, because impervious surfaces generate greater runoff volumes and drainage systems deliver it more rapidly

Figure 2.6 Hydrographs Before and After Development



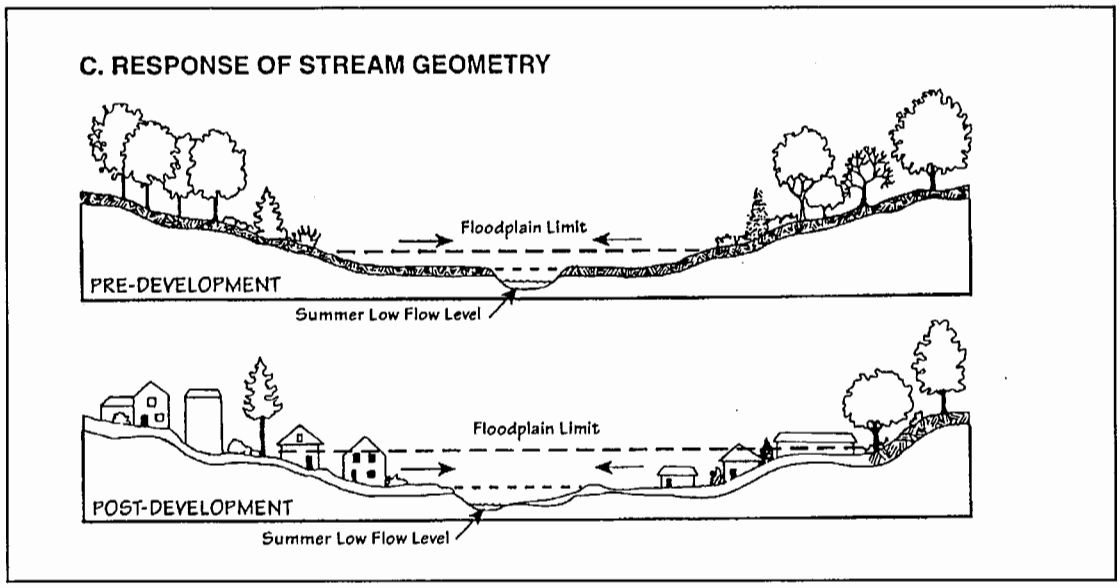
to a stream. The change in post-development peak discharge rates that accompany development is profiled in Figure 2.6. Note that this change in hydrology increases not only the magnitude of the peak event, but the total volume of runoff produced.

Section 2.5 Floodplain Expansion

In general, floodplains are relatively low areas adjacent to rivers, lakes, and oceans that are periodically inundated. For the purposes of this document, the floodplain is defined as the land area that is subject to inundation from a flood that has a one percent chance of being equaled or exceeded in any given year. This is typically thought of as the 100-year flood. In New York, a 100-year flood typically occurs after between five and eight inches of rainfall in a 24-hour period (i.e., the 100-year storm). However, snow melt combined with precipitation can also lead to a 100-year flood. These floods can be very destructive, and can pose a threat to property and human life.

As with overbank floods, development sharply increases the peak discharge rate associated with the 100-year design storm. As a consequence, the elevation of a stream's 100-year floodplain becomes higher and the boundaries of its floodplain expand (see Figure 2.7). In some instances, property and structures that had not previously been subject to flooding are now at risk. Additionally, such a shift in a floodplain's hydrology can degrade wetland and forest habitats.

Figure 2.7 Floodplain Expansion with New Development



Section 2.6 Impacts to Aquatic Organisms

The decline in the physical habitat of the stream, coupled with lower base flows and higher stormwater pollutant loads, has a severe impact on the aquatic community. Research suggests that new development impacts aquatic insects, fish, and amphibians at fairly low levels of imperviousness, usually around 10% impervious cover (Table 2.4). New development appears to cause declining **richness** (the number of different species in an area or community), **diversity** (number and relative frequency of different species in an area or community), and **abundance** (number of individuals in a species).

Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms

Watershed Indicator	Key Finding	Reference	Year	Location
Aquatic insects and fish	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had substantially lower EPT scores (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and IBI scores in the poor range.	Crawford & Lenat	1989	North Carolina
Insects, fish, habitat, water quality	Steepest decline of biological functioning after 6% imperviousness. There was a steady decline, with approx 50% of initial biotic integrity at 45% I.	Horner *et al.*	1996	Puget Sound Washington
Fish, aquatic insects	A study of five urban streams found that as land use shifted from rural to urban, fish and macroinvertebrate diversity decreased.	Masterson & Bannerman	1994	Wisconsin
Insects, fish, habitat, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the percentage of total impervious area exceeded the 5-10% range.	May et al.	1997	Washington
Aquatic insects and fish	There was significant decline in the diversity of aquatic insects and fish at 10% impervious cover.	MWCOG	1992	Washington, DC
Aquatic insects and fish	Evaluation of the effects of runoff in urban and non-urban areas found that native fish and insect species dominated the non-urban portion of the watershed, but native fish accounted for only 7% of the number of species found in urban areas.	Pitt	1995	California
Wetland plants, amphibians	Mean annual water fluctuation inversely correlated to plant & amphibian density in urban wetlands. Declines noted beyond 10% impervious area.	Taylor	1993	Seattle

Table 2.4 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms

Watershed Indicator	Key Finding	Reference	Year	Location
Aquatic insects & fish	Residential urban land use in Cuyahoga watersheds created a significant drop in IBI scores at around 8%, primarily due to certain stressors that functioned to lower the non-attainment threshold When watersheds smaller than 100mi^2 were analyzed separately, the level of urban land use for a significant drop in IBI scores occurred at around 15%.	Yoder et. al.	1999	Ohio
Aquatic insects & fish	All 40 urban sites sampled had fair to very poor index of biotic integrity (IBI) scores, compared to undeveloped reference sites.	Yoder	1991	Ohio

IBI: Index of Biotic Integrity: A measure of species diversity for fish and macroinvertebrates

EPT: A measure of the richnies of three sensitive macro-invertebrates (may flies, caddis flies, and stone flies), used to indicate the ability of a waterbody to support sensitive organisms.

EXHIBIT G

R. Pitt and O. Ogburn
Aug 25 2013

Contributions of Heavy Metals from Material Exposures to Stormwater

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Introduction

This report section reviews the contributions of selected heavy metals from different materials exposed to rain or runoff. This information is being used to assist in the calibration of WinSLAMM for naval facilities to account for the contributions of these materials exposed at various locations.

The section starts with a review of an extensive literature review that was recently conducted by Olga Ogburn during her PhD research at the University of Alabama. Much of the literature focusses on roofing materials and galvanized metals. Her leaching test results of different pipe and tank materials are also summarized. Washdown tests conducted by SPAWAR personnel during this project are also summarized in this section. An overall summary of these data was also prepared for an overview of the most critical exposed materials and likely concentrations and loss rates.

The treatability of stormwater heavy metals is also briefly discussed based on their characteristics as observed during these tests and from the literature. The most important characteristics affecting treatability include: concentrations, filterable fraction, likely complexation, ionic state, and associations with different particle sizes.

Trace Heavy Metals in Wet Weather Flows

The material in the literature review and leach test sections are summarized from the research conducted by Dr. Olga Ogburn as part of her dissertation research: Ogburn, Olga. Ph.D. *Urban Stormwater Contamination Associated with Gutter and Pipe Material Degradation*. Department of Civil, Construction, and Environmental Engineering at the University of Alabama. 2013. This research was mostly funded by the National Science Foundation (grant no. EPS-0447675). The NSF project included tasks conducted at UA supporting the Center for Optical Sensors and Spectroscopies (COSS) at UAB's Department of Physics by applying emerging technologies to solve current environmental problems.

This research investigated pipe and tank material sources of heavy metals in wet weather flows, to supplement the large amount of available information concerning roof runoff degradation (along with their chemical characteristics and associated treatability). This section shows that many of the heavy metals in stormwater could be related to material selection and that use of proper materials could result in decreased heavy metals in wet weather flows. This section presents the results of a literature review of heavy metal releases from different materials (mostly roofing types) and the results of several controlled leaching tests that examined a variety of roof gutter, piping, and storage tank materials.

Literature Review: Contaminants Associated with Rooftop and Drainage System Materials

Roofing drainage systems are often made of metallic materials or may have metals as components, including aluminum, zinc, and copper. Researchers have determined these heavy metals are common contaminants in roof runoff at potentially high

concentrations (Clark, et al. 2008 a, b; Wallinder 2001; Pitt, et al. 1995; Förster 1996; Morquecho 2005; Tobiason 2004). The metal's chemical forms (speciation) are determined by such factors as pH, temperature, and inorganic and organic anionic complexation. The presence of other cations in the water also influences metal bioaccumulation and toxicity (US EPA 2007a; Morquecho 2005). The following includes summary tables containing observed concentrations from the different monitoring studies associated with material exposure.

Zinc

When exposed to the atmosphere, metal material surfaces are in contact with many forms of moisture (condensed water from high humidity, rain, mist, dew, or melting snow) and the materials undergo corrosion (oxidation) processes (Veleva, et al. 2007). When zinc material is exposed to the atmosphere, a protective patina layer (zinc oxides/hydroxides/carbonates) is formed, which serves as a physical barrier between the metal surface and the atmosphere, slowing down further oxidation (Legault and Pearson 1978; Zhang 1996). The patina can be removed physically by winds and sand erosion or by partial dissolution of some soluble patina components when exposed to rain or water condensation on the metal surface, re-exposing the material to continued oxidation. Zinc runoff can lead to zinc accumulations in the soils, and in surface and ground waters (Veleva, et al. 2007). In urban areas, the highest zinc runoff concentrations are found in runoff from roofs having galvanized steel components (such as roofing sheets, flashing, or gutters and downspouts) (Burton and Pitt 2002; Förster 1999; Bannerman, et al. 1983; Pitt, et al. 1995). The following table summarizes zinc concentrations or runoff yields from different materials reported by various researchers.

Zinc releases from various sources (Ogburn 2013)

Materials	Test conditions	Zn concentrations or runoff yields	Reference
Uncoated Galvanized Steel Roofing Materials			
New uncoated galvanized steel roof	4 mo field test. Pilot Scale. Harrisburg, PA.	3.5 and 9.8 mg/L	Clark, et al. (2008a)
Galvanized metal roof	Field Seattle	0.09 and 0.48 mg/L	Tobiason and Logan (2000)
Hot dip galvanized steel	2 year field test. The Gulf of Mexico	6.52– 7.98 g m^{-2} during the 1st year 2.70 and 3.28 g m^{-2} during the 2nd year	Veleva, et al. (2010)
Hot dip galvanized steel panel	Stockholm, Sweden. 1 year test	2.7 g/m^2 per year	Wallinder, et al. (2001)
Hot-dip galvanized steel	5 years pilot scale test. Dubendorf, Switzerland	2.4 g/m^2 per year	Faller and Reiss (2005)
Galvanized steel roof	Stockholm, Sweden. 1 year test.	1.2-5.5 mg/L	Heijerick, et al. (2002)
Galvanized material	Hannover, Germany, 3 year test	4.51 g/m^2 per year	Lehmann (1995)
Pure Zn and hot dip galvanized steel	Urban and rural areas. The Gulf of Mexico, 18 mo test	6.5 – 8.5 ± 0.30 g/ m^2 per yr.	Veleva, et al. (2007)
14 year old zinc roof	Germany, 1 year test	0.3 - 30 mg/L 3.73 g/m^2 per year	Schriewer, et al. (2008)
40 year old zinc panel	Stockholm, Sweden. 1 year test	3.5 g/m^2 per year	Wallinder, et al. (2001)
Zinc roof	Filed test. Bayreuth, Germany.	17.6 mg/L	Forster (1999)
Zinc roof	Stockholm, Sweden. 1 year test.	3.8-4.4 mg/L	Heijerick, et al. (2002)
40 years old zinc roof	Stockholm, Sweden. 1 year test.	8.4 mg/L	Heijerick, et al. (2002)
Zinc materials	Stockholm, Sweden. 1 year test.	3.0 - 3.3 g/m/^{2} per year	He, et al. (2001a)
Zinc sheet (0.07% Ti, 0.17% Cu) panel	1 year field test. Olen, Belgium. Industrial area	4.5 and 5.7 g/m^2 per year	Wallinder, et al. (2000)
Clay tiles (70%) + zinc sheets, zinc sheets; roofs and gutters	Field test. Central Paris. July 1996 and May 1997	0.8 - 38 mg/L	Gromaire-Mertz, et al. (1999)
Zinc gutters	Filed test. Bayreuth, Germany.	2-4 mg/L	Forster (1999)
zinc roofing	Paris, France. 10 mo. test	34 - 64 metric tons per year for City	Gromaire, et al. (2002)

Zinc releases from various sources (Ogburn 2013), continued

Coated Galvanized Steel Roofing Materials			
New coated galvanized metal roof	4 mo field test. Pilot Scale. Harrisburg, PA	< 0.5 mg/L	Clark, et al. (2008a)
60 years old painted galvanized metal roof in the field	Leaching test in the lab	5 - 30 mg/L	Clark, et al. (2008b)
60 years old painted galvanized metal roof stored in the barn	Leaching test in the lab	5 - 30 mg/L	Clark, et al. (2008b)
Prepainted galvanized steel panel	Stockholm, Sweden. 1 year test	0.07 g/m^2 per year	Wallinder, et al. (2001)
Zinc with different surface treatment	5 years pilot scale test. Dubendorf, Switzerland	1.9 to 3.2 g/m^2 per year	Faller and Reiss (2005)
Prepatinated zinc	5 years pilot scale test. Dubendorf, Switzerland	3.2 g/m^2 per year	Faller and Reiss (2005)
Prepainted galvanized steel roof	Stockholm, Sweden. 1 year test.	0.16-0.63 mg/L	Heijerick, et al. (2002)
Uncoated Galvanized Aluminum Roofing Materials			
Galvalume roofs	Pilot-scale scale in Austin, Texas. Several rain events in 2010	0.208 – 0.852 mg/L during the first flush; 0.077 – 0.362 mg/L for later samples	Mendez, et al. (2011)
Galvalume roof	Stockholm, Sweden. 1 year test.	0.6-1.6 mg/L	Heijerick, et al. (2002)
Unpainted Galvalume roof	Field	0.42 - 14.7 mg/L	Tobiason (2004)
Coated Galvanized Aluminum Roofing Materials			
Kynar®-coated Galvalume®	Full scale in Austin, Texas. Several rain events in 2010	0.098 – 0.179 mg/L during first flush, 0.058 – 0.177 mg/L for later samples	Mendez, et al. (2011)
New prepainted 55% aluminum-zinc alloy coated steel (Galvalume) roof	2 years field test. Pilot Scale. Harrisburg, PA	<0.25 mg/L	Clark, et al. (2008b)

Zinc releases from various sources (Ogburn 2013), continued

Other Roofing Materials			
Black phosphatated titanium-zinc	5 years pilot scale test. Dubendorf, Switzerland	1.9 g/m^2 per year	Faller and Reiss (2005)
Titanium-zinc sheet after 5 years exposure	5 years pilot scale test. Dubendorf, Switzerland	2.6 g/m^2/year	Faller and Reiss (2005)
Aluminum, stainless steel and titanium	5 years pilot scale test. Dubendorf, Switzerland	< detection limit (0.01 mg/L)	Faller and Reiss (2005)
Polyester roof	Zurich, Switzerland. 2 year test	<0.160 mg/L	Zobrist, et al. (2000)
Gravel roof	Zurich, Switzerland. 2 year test	<0.035 mg/L	Zobrist, et al. (2000)
Drinking Water Distribution Systems (DWDS)			
At the tap after galvanized metal parts in distribution systems	St. Maarten Island, Netherlands	0.006 to 2.29 mg/L (average of 0.19 mg/L)	Gumbs and Dierberg (1985)
DWDS made of asbestos, polyethylene, and iron pipes; piping system materials in houses and buildings were galvanized	DWDS in Zarrinshahr, Iran	$0.73*10^{-3}$ - $5.80*10^{-3}$ mg/L	Shahmansouri, et al. (2003)
DWDS made of asbestos, polyethylene, and iron pipes; piping system materials in houses and buildings were galvanized	DWDS in Mobarakeh, Iran	$0.20*10^{-3}$ - $5.80*10^{-3}$ mg/L	Shahmansouri, et al. (2003)

The largest sources of zinc in stormwater runoff are galvanized materials, such as zinc-based roofing materials, galvanized roof drainage systems, and galvanized pipes. Galvanized materials have a large potential for contributing zinc to runoff during their useful life. Zinc runoff yields were generally observed to increase with the age of the material. Zinc concentrations in runoff from galvanized materials ranged from 100's of µg/L to 10's of mg/L. Zinc concentrations in roof runoff samples frequently exceeded the water quality criteria established by the U.S. EPA and regulatory agencies from other countries.

Copper

Clark, et al. (2008 a and b) monitored runoff from a pilot-scale selection of roofing materials and other materials at the campus of Penn State Harrisburg for 2 years under natural rain conditions. The copper concentrations from non-copper metal and vinyl

materials did not exceed 25 µg/L (a typical toxicant value for certain aquatic plants). The results from laboratory leaching tests showed that copper concentrations may continue to leach out in an acid rain environment during the material's useful life (Clark, et al. 2008b).

For fresh copper sheet, cuprite (Cu_2O) was the main crystalline patina constituent during the first 12 weeks of exposure, followed by the formation of paratacamite ($Cu_2(OH)_3Cl$) after that exposure period. Formation of paratacamite was a result of significantly higher deposition rates of chlorides between 12 and 26 weeks. After months of atmospheric exposure, basic copper compounds like ($Cu_2(OH)_3Cl$), brochantite ($Cu_4SO_4(OH)_6$) and cuprite (Cu_2O) and Posnjakite ($Cu_4SO_4(OH)_6 \cdot H_2O$) can be formed depending on the contamination in the environment (Sandberg et. al. 2006; Faller and Reiss 2005; Kratschmer, et al. 2002). Brochantite ($Cu_4SO_4(OH)_6$) and posnjakite ($Cu_4SO_4(OH)_6 \cdot H_2O$) are common compounds in sulfate containing environments; ($Cu_2(OH)_3Cl$) are often found in chloride rich environments (Kratschmer, et al. 2002). The brochantite phase was still detected after one year of exposure (Sandberg, et al. 2006). The bioavailable portion (available for uptake by an organism) of the released copper was a small fraction (14–54%) of the total copper concentration due to Cu complexation with organic matter in impinging seawater aerosols (Sandberg, et al. 2006). The following table summarizes copper concentrations and runoff yields from different materials reported by various researchers.

Copper Releases from Various Sources (Ogburn 2013)

Material	Test descriptions	Cu concentrations or runoff yields	Reference
Uncoated Copper Roofing Materials			
Copper roof	2 year field test. Stockholm, Sweden	Average 1.3 - 1.5 $g/m^2/year$	Wallinder, et al. (2000)
Copper roof	Stockholm, Sweden. 2 year test	1.3 $g/m^2/year$	Faller and Reiss (2005)
Fresh copper sheet	Brest, France. 1 year test	1.5 $g/m^2/year$	Sandberg, et al. (2006)
Untreated rolled copper sheet	Dubendorf, Switzerland. 5 year test	1.3 $g/m^2/year$	Faller and Reiss (2005)
After copper roof and cast iron and concrete downspouts	Field. Suburban Farsta, Stockholm. Several rains during 2006-2008	5-101 µg/L (median 15 µg/L)	Wallinder, et al. (2009)
After copper roof and cast iron and concrete downspouts and concrete drain system pipe	Field. Suburban Farsta, Stockholm .Several rains during 2006-2008	2 -175 µg/L (median 18 µg/L)	Wallinder, et al. (2009)
Copper material	(salt spray) Medellin, Colombia. 1 year test	16.0 $g/m^2/year$ mass loss	Corvo, et al. (2005)
Copper material	(salt spray) Havana, Cuba. 1 year test	32.8 $g/m^2/year$ mass loss	Corvo, et al. (2005)
Copper material	(natural conditions) Havana, Cuba. 1 year test	9.4 $g/m^2/year$ mass loss	Corvo, et al. (2005)
Copper materials	Stockholm, Sweden	1.0 - 2.0 $g/m^2/year$	He, et al. (2001a)

Copper Releases from Various Sources (Ogburn 2013), continued

Other Roofing Materials			
Pilot-scale Galvalume roofs	Austin, Texas. Several rain events in 2010	<0.63 - 9.88 µg/L during first flush; <0.63 - 4.84 µg/L for later samples	Mendez, et al. (2011)
Full-scale Kynar®-coated Galvalume® roof	Austin, Texas. Several rain events in 2010	<0.02 µg/L	Mendez, et al. (2011)
New uncoated galvanized steel roof	4 mo. Field test. Pilot Scale. Harrisburg, PA	< 3µg/L	Clark, et al. (2008a)
Clay tiles, clay tiles (70%) + zinc sheets, zinc sheets, and slate	Central Paris. July 1996 and May 1997	3 - 247 µg/L (median 37 µg/L)	Gromaire-Mertz, et al. (1999)
Metal and vinyl materials panels	4 mo. Field test. Pilot Scale. Harrisburg, PA	< 25 µg/L	Clark, et al. (2008a)
New vinyl roof	14 mo. Field test. Pilot Scale. Harrisburg, PA	< 20 µg/L	Clark, et al. (2007)
Tile roof	Zurich, Switzerland. 14 rain events	400 and 50 µg/L; average 1623 µg/m^2	Zobrist, et al. (2000)
New asphalt shingles roof	4 mo. Field test. Pilot Scale. Harrisburg, PA	25 µg/L (median) 112 µg/L (75th percentile	Clark, et al. (2008a)
Tar-covered roofs	Washington	166 µg/L	Good (1993)
New cedar shakes roof	4 mo. Field test. Pilot Scale. Harrisburg, PA	from 1,500 to 27,000 µg/L	Clark, et al. (2008a)

Copper Releases from Various Sources (Ogburn 2013), continued

Aged/Patinated Copper Materials			
Naturally patinated copper sheet	Brest, France. 1 year test	1.3 $g/m^2/year$	Sandberg, et al. (2006)
Naturally aged copper roof	Field. Suburban Stockholm, Sweden. Several rains during 2006-2008	0.74 - 1.6 $g/m^2/year$ (median 1.0 $g/m^2/year$)	Wallinder, et al. (2009)
Naturally patinated copper of varying age	Field. Stockholm, Sweden	1.0 - 1.5 $g/m^2/year$	Karlen, et al. (2002)
Naturally patinated copper of varying age	Field. Stockholm, Sweden	900 - 9700 µg/L	Karlen, et al. (2002)
Fresh and brown prepatinated copper roofs	Stockholm, Sweden	1.1-1.6 $g/m^2/year$	Wallinder, et al. (2002a)
Fresh and brown prepatinated copper roofs	Singapore	5.5-5.7 $g/m^2/year$	Wallinder, et al. (2002a)
130 years old copper roof sheet and green prepatinated copper sheet	Singapore, Stockholm	1.6-2.3 $g/m^2/year$	Wallinder, et al. (2002a)
Green pre-patinated copper roof sheet	Singapore	8.4-8.8 $g/m^2/year$	Wallinder, et al. (2002a)
Copper Pipes			
Copper pipes		200 - 800 µg/L	Dietz, et al. (2007)
New copper drains	Zurich, Switzerland. 14 rain events	7.8 $g/(m^2\ y^1)$	Zobrist, et al. (2000)
15 - year old drains	Zurich, Switzerland. 14 rain events	3.5 $g/(m^2\ y^{-1})$	Zobrist, et al. (2000)
Copper facade	1 year test	$10^3 – 10^4$ µg/L	Boller and Steiner (2002)

As expected, the highest copper runoff rates were noted from exposed copper materials. Copper-based paints can also be a significant source of copper in runoff. Some studies indicated relatively constant copper runoff yields with time during 5 years of exposure. However, other studies found that new copper materials had higher copper runoff yields compared to older copper materials. Galvanized steel, vinyl, and galvalume materials had copper runoff concentrations that were less than 25 µg/L. The major portion of the copper in the runoff at the source was in the most bioavailable form (hydrated cupric ion), but when the stormwater runoff passes through cast iron and concrete drainage systems, copper may be retained or form complexes with organic matter and change chemical speciation to less toxic or less bioavailable forms.

Lead

Lasheen, et al. (2008) studied the effect of pH, stagnation time, pipe age, and pipe material on the concentrations of lead released from polyvinyl chloride (PVC), polypropylene (PP) and galvanized iron (GI). PVC pipes were found to be the greatest source of lead. The authors found that the concentrations of lead were higher after 72 hours of exposure time than after 48 hours at pH 7.5. The authors also found that as pipe age increased, the lead concentrations also increased. For example, the mean lead concentrations were 95 and 120 µg/L in 2 and 20 weeks aged PVC pipes, respectively after stagnation of 72 h. For galvanized iron pipes, after 72 h of stagnation, mean lead concentrations were 53 and 64 µg/L in 2 and 20 weeks aged pipes. As pH increased (to pH=8), the concentration of lead decreased. The authors observed that increasing the ratio of Cl/SO_4 from 0.83 to 2 resulted in an increase of lead concentrations from GI pipes. The levels of lead increased in PVC pipes as the Cl/SO_4 ratio increased, however the lead concentrations were less than that in control pipes (Lasheen, et al. 2008). The following table summarizes lead concentrations or release rates from different materials reported by various researchers.

Lead Releases from Various Sources (Ogburn 2013)

Material tested	Test conditions	Observed lead concentrations, or runoff yields	Reference
Uncoated Galvanized Steel Roofing Materials			
Galvanized roof	Pilot scale	Just above 1 µg/L	Clark, et al. (2007)
Galvanized roof	Leaching test in the lab	0.002-0.02 g/kg/48hr	Clark, et al. (2007)
Zinc sheet, zinc and PVC gutters	Bayreuth, Germany	10 µg/L	Forster (1999)
Clay tiles, flat clay tiles (70%) + zinc sheets, zinc sheets, and slate roofing materials	Field. Paris, France.	16 - 2764 µg/L (the median 493 µg/L)	Gromaire-Mertz, et al. (1999)
Cistern surface water (after galvanized iron roof)	St. Maarten Island, Netherlands	0.1 - 75.1 µg/L (avg. 0.9 µg/L).	Gumbs and Dierberg (1985)
The bottom of the cisterns (after galvanized iron roof)	St. Maarten Island, Netherlands	Avg. 19.4 µg/L	Gumbs and Dierberg (1985)
Uncoated Galvanized Aluminum Roofing Materials			
Galvalume roofs	Pilot-scale. Austin, Texas	<0.12 - 6.40 µg/L during first flush, <0.12 - 5.65 µg/L for later samples	Mendez, et al. (2011)

Lead Releases from Various Sources (Ogburn 2013), continued

Coated Galvanized Aluminum Roofing Materials			
Kynar®-coated Galvalume® roof	Full-scale Austin, Texas	<0.01 - 0.21 µg/L during first flush; <0.12 µg/L for later samples	Mendez, et al. (2011)
Aged Galvanized Steel Roofing Materials			
Rusty galvanized metal roof	Field test during first flush. The coast of Washington	302 µg/L	Good (1993)
60 years old painted galvanized metal roof exposed in the filed	Leaching test in the lab	0.01 - 1 g/kg/48hr	Clark, et al. (2008b, 2007)
60 years old painted galvanized metal roof stored in the barn	Leaching test in the lab	0.01 - 1 g/kg/48hr	Clark, et al. (2008b, 2007)
14 year-old zinc roof, titanium–zinc gutters and the down spout	Germany	31 µg/L	Schriewer, et al. (2008)
Other Roofing Materials			
Tile roof	Zurich, Switzerland, 14 rain events	249 µg/m^2	Zobrist, et al. (2000)
Painted Materials			
Metal roof coated with aluminum paint, tar roof painted with fibrous reflective aluminum paint, anodized aluminum roof	Field test during first flush. The coast of Washington	10 - 15 µg/L	Good (1993)
Painted wood	Field test	2.6-380 µg/L (Q10[1]-Q90[2])	Davis and Burns (1999)
Painted brick	Field test	3.3-240 µg/L (Q10-Q90)	Davis and Burns (1999)
Painted block	Field test	<2-110 µg/L (Q10-Q90)	Davis and Burns (1999)
>10 year paint	Field test	6.9 - 590 µg/L (Q10-Q90)	Davis and Burns (1999)
5-10 year paint	Field test	<2-240 µg/L (Q10-Q90)	Davis and Burns (1999)
0-5 year paint	Field test	<2-64 µg/L (Q10-Q90)	Davis and Burns (1999)

Lead Releases from Various Sources (Ogburn 2013), continued

Drinking Water Distribution Systems			
Galvanized iron pipe after 2 weeks of use, 72 hr of stagnation	increasing the ratio of Cl/SO_4 from 0.83 to 2	58 µg/L	Lasheen, et al. (2008)
Galvanized iron pipe after 20 weeks of use, 72 hr of stagnation	increasing the ratio of Cl/SO_4 from 0.83 to 2	70 µg/L	Lasheen, et al. (2008)
PVC pipes after 2 weeks of use, 72 hr of stagnation	pH 7.5	95 µg/L	Lasheen, et al. (2008)
PVC pipes after 20 weeks of use, 72 hr of stagnation	pH 7.5	120µg/L	Lasheen, et al. (2008)
PVC pipes after 2 weeks of use, 72 hr of stagnation	pH 6	100µg/L	Lasheen, et al. (2008)
PVC pipes after 20 weeks of use, 72 hr of stagnation	pH 6	130µg/L	Lasheen, et al. (2008)
PVC pipes after 2 weeks of use, 72 hr of stagnation	pH 8	110µg/L	Lasheen, et al. (2008)
PVC pipes after 20 weeks of use, 72 hr of stagnation	pH 8	20µg/L	Lasheen, et al. (2008)
PVC pipe after 2 weeks of use, 72 hr of stagnation	increasing the ratio of Cl/SO_4 from 0.83 to 2	80µg/L	Lasheen, et al. (2008)
PVC pipe after 20 weeks of use, 72 hr of stagnation	increasing the ratio of Cl/SO_4 from 0.83 to 2	100µg/L	Lasheen, et al. (2008)
Unplasticized PVC pipe after 10 h of exposure	-	430µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 48 h of exposure	-	780µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 48 h of exposure	pH 5	1000µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 12 h of exposure	UV exposure	115µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 5 days of exposure	UV exposure	312 µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 14 days of exposure	UV exposure	799µg/L	Al-Malack (2001)

Lead Releases from Various Sources (Ogburn 2013), continued

PVC, lined cast iron, unlined cast iron, and galvanized steel aged pipes (40+ years)	Phosphorus or SiO_2 inhibitor	< 5 µg/L	Dietz, et al. (2007)
PVC, lined cast iron, unlined cast iron, and galvanized steel aged pipes (40+ years)	pH control	max.65 µg/L	Dietz, et al. (2007)
Galvanized piping systems, asbestos, polyethylene, iron pipes	Pilot scale. Zarrinshahr, Iran	1.60 - 16.00 µg/L (avg. 5.7 µg/L)	Shahmansouri, et al. (2003)
Galvanized piping systems, asbestos, polyethylene, iron pipes	Pilot scale. Mobarakeh, Iran	0.60 - 18.70 µg/L (avg. 7.8 µg/L)	Shahmansouri, et al. (2003)
At the tap (after galvanized iron roof, gutter and down spout, distribution system)	St. Maarten Island, Netherlands	0.2-70.0 µg/L (average of 2.1 µg/L)	Gumbs and Dierberg (1985)

[1] and [2] 10th and 90th percentiles of data values, respectively

Galvanized steel, PVC and unplasticized PVC, galvalume, and zinc materials can be sources of lead concentration increases in water. Lead concentrations released from galvanized steel and PVC materials increase with increased exposure time, increased pipe age, and pH decreases. Also, exposure to UV-radiation was determined to promote the migration of lead from unplasticized PVC pipes. Additionally, painted materials can be a source of lead in stormwater, with lead releases being higher from older types of paints. The rise in the ratio of Cl/SO_4 from 0.83 to 2 resulted in an increase in lead concentrations from galvanized iron and PVC pipe exposure.

Cadmium

Gromaire-Mertz, et al. (1999) examined runoff from different roofing materials and gutters in Paris, France, between July 1996 and May 1997. Roofing materials included clay tiles, zinc sheets, and slate. Cadmium concentrations in roof runoff (1 to 5 µg/L) were below the level 2 water quality criteria (1,000 µg/L) with the exception of runoff from the zinc sheet roof runoff samples. Cadmium concentrations were extremely high in roof runoff from the zinc roofs. Leaching of cadmium is explained by the erosion of the zinc roofing material, in which cadmium is a minor constituent. Förster (1996) found that generally, the dissolved fraction of cadmium was greater than the particulate fraction for roof runoff. The following table summarizes cadmium concentrations and release rates from different materials reported by various researchers.

Cadmium Releases from Various Sources (Ogburn 2013)

Materials tested	Test conditions	Observed cadmium concentrations or runoff yields	Reference
Uncoated Galvanized Roofing Materials			
Parisian zinc roofs	Paris, France	15 - 25 kg/year for the city	Gromaire, et al. (2002)
Cistern surface water (after galvanized iron roof)	St. Maarten Island, Netherlands	< 0.02-0.40 µg/L (avg. 0.03 µg/L)	Gumbs and Dierberg (1985)
The bottom of the cisterns (after galvanized iron roof)	St. Maarten Island, Netherlands	Avg. 0.99 µg/L	Gumbs and Dierberg (1985)
clay tiles, flat clay tiles (70%) + zinc sheets, zinc sheets, and slate	Paris, France. July 1996 and May 1997	0.1-32 µg/L (median of 1.3 µg/L)	Gromaire-Mertz, et al. (1999)
Aged Galvanized Steel Roofing Materials			
14 year-old zinc roof runoff	Germany, 1 year test	0.5 µg/L (DL) – 0.8µg/L	Schriewer, et al. (2008)
Other Roofing Materials			
Clay tile roof with 15-year old copper gutter	Filed test. Tuffenwies, Switzerland	2.5 µg/m^2 per event	Zobrist, et al. (2000)
Tar felt roof	Bayreuth, Germany	0.5µg/L	Forster (1999)
Drinking Water Distribution Systems (DWDS)			
Unplasticized PVC pipe after 48 hrs of exposure	-	88 µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 14 days of exposure	Change from pH 9 to pH 6	increase from 53 to 89 µg/L	Al-Malack (2001)
Unplasticized PVC pipe after 48 hrs of exposure	Exposure to UV-radiation	800 µg/L	Al-Malack (2001)
At the tap (after galvanized iron roof, gutter and down spout, distribution system)	St. Maarten Island, Netherlands	<0.02-30.2 µg/L (average 0.12 µg/L)	Gumbs and Dierberg (1985)
Drinking Water Distribution System (asbestos, polyethylene, and iron pipes), after min of 6 hrs.	Zarrinshahr, Iran	Before DWDS 0.08 µg/L, after DWDS 0.11 µg/L	Shahmansouri, et al. (2003)
Drinking Water Distribution System (asbestos, polyethylene, and iron pipes), after min of 6 hrs.	Mobarakeh, Iran	Before DWDS 0.06 µg/L, after DWDS 0.8 µg/L	Shahmansouri, et al. (2003)

PVC, zinc, tile, tar felt, and galvanized iron materials can all be sources of cadmium in runoff. Exposure to UV-radiation promoted the migration of cadmium stabilizers from unplasticized PVC pipes. A decrease in the pH of the water was also found to increase the cadmium concentrations released from the uPVC pipes.

Iron

Corrosion of iron is the primary cause of iron release. When metal surfaces are covered with corrosion scales, iron may be released by the corrosion of iron metal, the dissolution of ferrous components of the scales, and hydraulic scouring of particles from the scales (Sarin, et al. 2004). The corrosion rate of clean iron surfaces typically increases with the increase of the oxidant (such as oxygen) concentrations. When scale layers are formed during the corrosion process, they can influence the rate of diffusion of oxygen to the metal, and slow down corrosion. The environment inside the corrosion scales present in water distribution pipes is characterized with highly reducing conditions and high concentrations of Fe (II). Sarin, et al. (2004) also noted that iron releases increased with stagnation time, while the DO concentration diminished. For initial DO concentration of 6.2 mg/L and pH of 8.9, iron releases from the iron pipe were approximatelly100 µg/m of pipe length after 20 hours of stagnation, and reached 375 µg/m of pipe length after 120 hours of stagnation. The following table summarizes iron concentrations and runoff yields from different materials reported by various researchers.

Iron Releases from Various Sources (Ogburn 2013)

Materials tested	Test conditions	Observed iron concentrations or runoff yields	Reference
Uncoated Galvanized Aluminum Roofing Materials			
Galvalume roofs	Pilot-scale. Austin, Texas	18 - 1690 µg/L during first flush, and 8.94 - 563.00 µg/L for later samples	Mendez, et al. (2011)
Coated Galvanized Aluminum Roofing Materials			
7-year-old Kynar®-coated Galvalume® roof	Full-scale. Austin, Texas	6.23 - 23.8 µg/L during first flush; 4.10 - 7.88 µg/L for later samples	Mendez, et al. (2011)
Other Roofing Materials			
Stainless steel	1 year field exposure. Stockholm, Sweden	10 - 200 mg/ m^2/year	Wallinder, et al. (2002b)
Carbon steel	(salt spray) Medellin, Colombia. 1 year test	1280 g/m^2/year mass loss	Corvo, et al. (2005)
Carbon steel	(salt spray) Havana, Cuba. 1 year test	Samples (2mm x100 mm x150 mm) completely destroyed by corrosion after 6 months of exposure	Corvo, et al. (2005)
Carbon steel	(natural conditions) Havana, Cuba. 1 year test	280 g/m^2/year mass loss	Corvo, et al. (2005)
Clay tile roof with 15-year old copper	Field test. Tuffenwies, Switzerland	Average 2.05 mg/m^2 per event	Zobrist, et al. (2000)

Iron Releases from Various Sources (Ogburn 2013), continued

Drinking Water Distribution Systems (DWDS)			
2 weeks aged galvanized iron pipes after 72 h of contact time	Lab test	Avg. 0.7 mg/L	Lasheen, et al. (2008)
20 weeks aged galvanized iron pipes after 72 h of contact time	Lab test	Avg. 1.44 mg/L	Lasheen, et al. (2008)
2 weeks aged galvanized iron pipes after 72 h of contact time	pH = 6	Avg. 0.99 mg/L	Lasheen, et al. (2008)
20 weeks aged galvanized iron pipes after 72 h of contact time	pH = 6	Avg. 1.65 mg/L	Lasheen, et al. (2008)
2 weeks aged galvanized iron pipes after 72 h of contact time	pH = 8	Avg. 1.44 mg/L	Lasheen, et al. (2008)
20 weeks aged galvanized iron pipes after 72 h of contact time	pH = 8	Avg. 1.3 mg/L	Lasheen, et al. (2008)
Drinking Water Distribution System (asbestos, polyethylene, and iron pipes), after min of 6 hrs.	Zarrinshahr, Iran	Before DWDS 0.08 µg/L, after DWDS 0.71 µg/L	Shahmansouri, et al. (2003)
Drinking Water Distribution System (asbestos, polyethylene, and iron pipes), after min of 6 hrs.	Mobarakeh, Iran	Before DWDS 0.05 µg/L, after DWDS 0.85 µg/L	Shahmansouri, et al. (2003)
2 weeks aged PVC pipes after 72 h of contact time	Lab test	Avg. 0.058 mg/L	Lasheen, et al. (2008)
20 weeks aged PVC pipes after 72 h of contact time	Lab test	Avg. 0.07 mg/L	Lasheen, et al. (2008)

Iron Releases from Various Sources (Ogburn 2013), continued

2 weeks aged PVC pipes after 72 h of contact time	pH = 6	Avg. 0.068 mg/L	Lasheen, et al. (2008)
20 weeks aged PVC pipes after 72 h of contact time	pH = 6	Avg. 0.08 mg/L	Lasheen, et al. (2008)
2 weeks aged PVC pipes after 72 h of contact time	pH = 8	Avg. 0.07 mg/L	Lasheen, et al. (2008)
20 weeks aged PVC pipes after 72 h of contact time	pH = 8	Avg. 0.06 mg/L	Lasheen, et al. (2008)
2 weeks aged polypropylene pipes after 72 h of contact time	Lab test	Avg. 0.06 mg/L	Lasheen, et al. (2008)
20 weeks aged polypropylene pipes after 72 h of contact time	Lab test	Avg. 0.07 mg/L	Lasheen, et al. (2008)
2 weeks aged polypropylene pipes after 72 h of contact time	pH = 6	Avg. 0.073 mg/L	Lasheen, et al. (2008)
20 weeks aged polypropylene pipes after 72 h of contact time	pH = 6	Avg. 0.083 mg/L	Lasheen, et al. (2008)
2 weeks aged polypropylene pipes after 72 h of contact time	pH = 8	Avg. 0.069 mg/L	Lasheen, et al. (2008)
20 weeks aged polypropylene pipes after 72 h of contact time	pH = 8	Avg. 0.06 mg/L	Lasheen, et al. (2008)

PVC, polypropylene, galvanized iron, clay tile, polyester, stainless steel, galvanized iron, and Galvalume® metal materials were found to release iron into runoff water. Exposure time had an effect on iron released from PVC, polypropylene, and galvanized iron materials. Greater iron runoff concentrations were observed for aged PVC, polypropylene, and galvanized iron pipes compared to new materials. As pH decreased, iron concentrations leaching from PVC, polypropylene, and galvanized iron, cast iron,

and galvanized steel materials increased. High Cl^-/SO_4^{2-} ratios increased iron concentrations from PVC, polypropylene, and galvanized iron pipes. The mass loss of carbon steel is influenced by the frequency and the amount of rain and is proportional to the chloride deposition rate.

Aluminum

Mendez, et al. (2011) studied the effects of roofing material on water quality for rainwater harvesting systems. The authors examined the quality of harvested rainwater using five pilot-scale roofs (asphalt fiberglass shingle, Galvalume® metal, concrete tile, cool, and green) and three full-scale roofs (two asphalt fiberglass shingle and one 7-year-old Kynar®-coated Galvalume® metal) in Austin, Texas. The authors found that aluminum concentrations released by full-scale 7 year old Kynar®-coated Galvalume® roof were substantially lower than from the pilot-scale Galvalume® roof. Aluminum concentrations in harvested rainwater from pilot-scale Galvalume roofs ranged between 20 and 2,000 µg/L for the first flush sample, and between 14 and 550 µg/L for later samples. The aluminum concentrations in the rain ranged between 4.1 and 560 µg/L. Aluminum concentrations in harvested rainwater from full-scale Kynar®-coated Galvalume® roof ranged between 0.06 and 12 µg/L for the first flush sample, and between 0.06 and 6.7µg/L for later samples. The aluminum concentrations in the rain water during these tests ranged between 12 and 55 µg/L. The following table summarizes aluminum concentrations from different materials.

Aluminum Releases from Various Sources (Ogburn 2013)

Materials tested	Test conditions	Observed aluminum concentrations	Reference
Pilot-scale Galvalume roofs	Austin, Texas. Several rain events in 2010	20 to2050 µg/L during first flush; 14 to555 µg/L for later samples	Mendez, et al. (2011)
Full-scale Kynar®-coated Galvalume® roof	Austin, Texas. Several rain events in 2010	0.06 to 12 µg/L during first flush sample; 0.06 to6.7µg/L for later samples	Mendez, et al. (2011)

Laboratory Tests and Model Fitting to Predict Metal Releases from Material Exposures

Ogburn (2013) conducted exposure tests to determine the losses of heavy metals and other constituents as a function of exposure time under different pH and conductivity conditions. Roof runoff was used for roofing materials and parking lot runoff was used for the other piping materials; later tests used river water and saline bay water. She presented the data as time series plots indicating the accumulative total losses on an area basis. Linear regression analyses on the log-transformed metal releases per pipe

surface area vs. log time for different pipe and gutter materials under controlled and natural pH conditions, after supporting statistical analyses were used to identify groupings of the data. The majority of the scatterplots revealed that first order polynomials can be fitted to the log of metal releases vs. log of time.

Modeling the Effects of Material Type, Exposure Time, pH, and Salinity on Metal Releases and Toxicity

Spearman correlation analyses were used to determine the associations between constituents and the degree of that association, while cluster analyses were conducted to identify more complex relationships between the parameters. Principle component analyses were conducted to identify groupings of parameters having similar characteristics. The significant factors identified from the factorial analyses were used to combine the data into groups. The final model can be used to determine which materials can be safely used for short contact times such as for gutters and pipes, and for longer term storage, such as for tanks.

Full 2^3 Factorial Analyses

Full 2^3 factorial analyses were performed on Cu, Zn, Pb constituents (using the release rates of mg per $m^2$of surface area of exposed materials) and toxicities in percent light reductions at 15 and 45 min of Microtox bacteria exposure times. These analyses therefore examined the effects of time, pH, and material and their interactions for the first testing series data and the effects of time, conductivity, and material and their interactions during for the second testing series. The levels for the different factors defining how the data were organized are shown on the table below. Kruskal-Wallis tests were initially performed for each constituent to determine if the data for 1, 2, and 3 months of pipe and gutter exposure could be used together to represent long term exposure times. The tests indicated that there were no statistically significant differences (at 0.05 significance level) between these data so they were combined into one data category. Kruskal–Wallis tests were also conducted for each constituent on the data after 0.5 and 1h of exposure to indicate if they could be combined to represent short exposure periods. These tests similarly showed that these data could be combined into one category for short term exposure times.

2^3 Factorial Experiment. Factors and levels (Ogburn 2013)

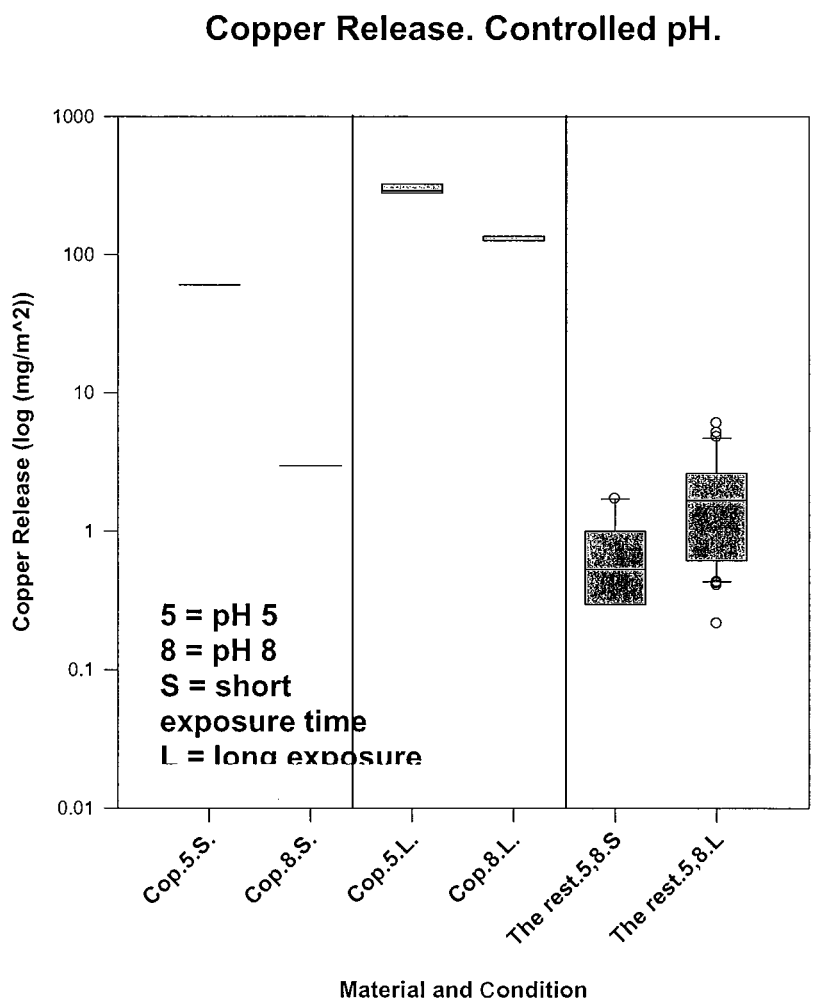
Constituent	Factors and levels		
	Time	pH or Conductivity	Material
Cu (mg/m^2)	short (0.5h, 1h) (-) vs. long (1mo, 2mo,3mo) (+)	pH 5 (-) vs. pH8 (+)	copper (-) vs. the rest of the materials (+)
Cu (mg/m^2)	short (1h) (-) vs. long (1mo, 2mo,3mo) (+)	high cond. (-) vs. low cond. (+)	copper (-) vs. the rest of the materials (+)
Zn (mg/m^2)	short (0.5h, 1h) (-) vs. long (1mo, 2mo,3mo) (+)	pH 5 (-) vs. pH8 (+)	galv. steel (-) vs. the rest of the materials (+)
Zn (mg/m^2)	short (1h) (-) vs. long (1mo, 2mo,3mo) (+)	high cond. (-) vs. low cond. (+)	galv. steel (-) vs. the rest of the materials (+)
Pb (mg/m^2)	short (0.5h, 1h) (-) vs. long (1mo, 2mo,3mo) (+)	pH 5 (-) vs. pH8 (+)	galv. steel (-) vs. the rest of the materials (+)
Pb (mg/m^2)	short (1h) (-) vs. long (1mo, 2mo,3mo) (+)	high cond. (-) vs. low cond. (+)	galv. steel (-) vs. the rest of the materials (+)

The factorial effect/pooled standard error ratio of the factorial analysis were used to determine whether or not the data could be combined into groups for each constituent based on the effect (or absence of effect) of the factors and their interactions. The ratios of Effect/SE that were greater than three are highlighted in red, and those that are greater than five are highlighted in bold red, indicating likely significant factors and interactions. For each constituent, effects and their interactions were sorted into significant, marginally significant, and not significant groups, according to the absolute values of their effects.

Combined Data Group Analyses

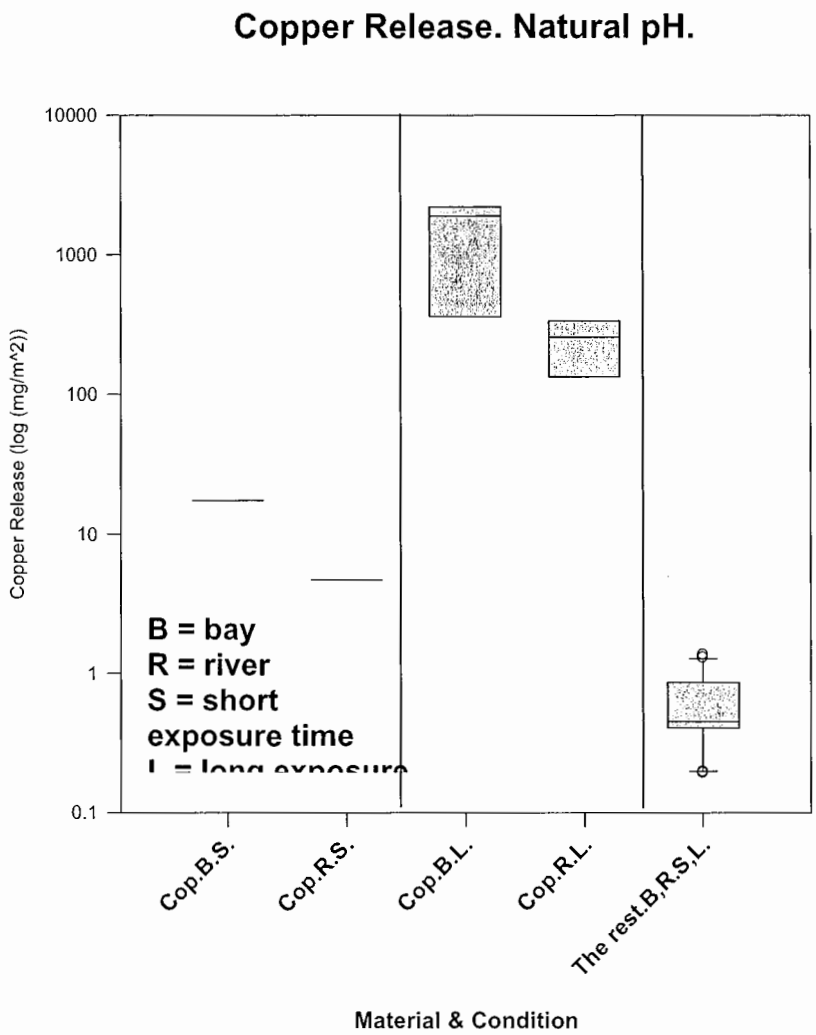
The following figures show metal releases for the combined data groups, based on the prior analyses. The significant factors and their interactions from 2^3 factorial analyses were used for grouping the samples and conditions. The box plots were constructed only for the groups that were found to be significant. Group box plots were plotted for these constituents to illustrate the variations and differences between each group. The group box plot of copper releases compares the copper material samples with the all of the other samples for pH 5 and 8 conditions during both short and long exposure times. Full 2^3 factorial analyses showed that the three-way interaction of pH x material x time was significant, therefore the main effects should not be interpreted separately (Navidi 2006).The data was combined into the groups according to the interaction of pH, material, and time. Copper materials were the most significant source of copper, as expected. Lower pH conditions increased the copper releases from the copper materials. The copper releases in the sample groups of all materials increased with exposure time. The combination of conditions, such as copper materials under pH 5 water conditions during short exposure time, significantly increased copper releases. Similarly, copper releases increased dramatically for copper materials immersed into pH 5 water for long exposure periods, as well as for copper materials immersed into pH 8 waters for long exposure periods. The groups combining the rest of the materials for pH 5 and pH 8 conditions during short exposure time into one group is also shown, with the

rest of the materials for pH 5 and pH 8 conditions during long exposure time combined into one group.



Group box plot for copper release in mg/m^2 for materials immersed in pH 5 and pH 8 waters (Ogburn 2013).

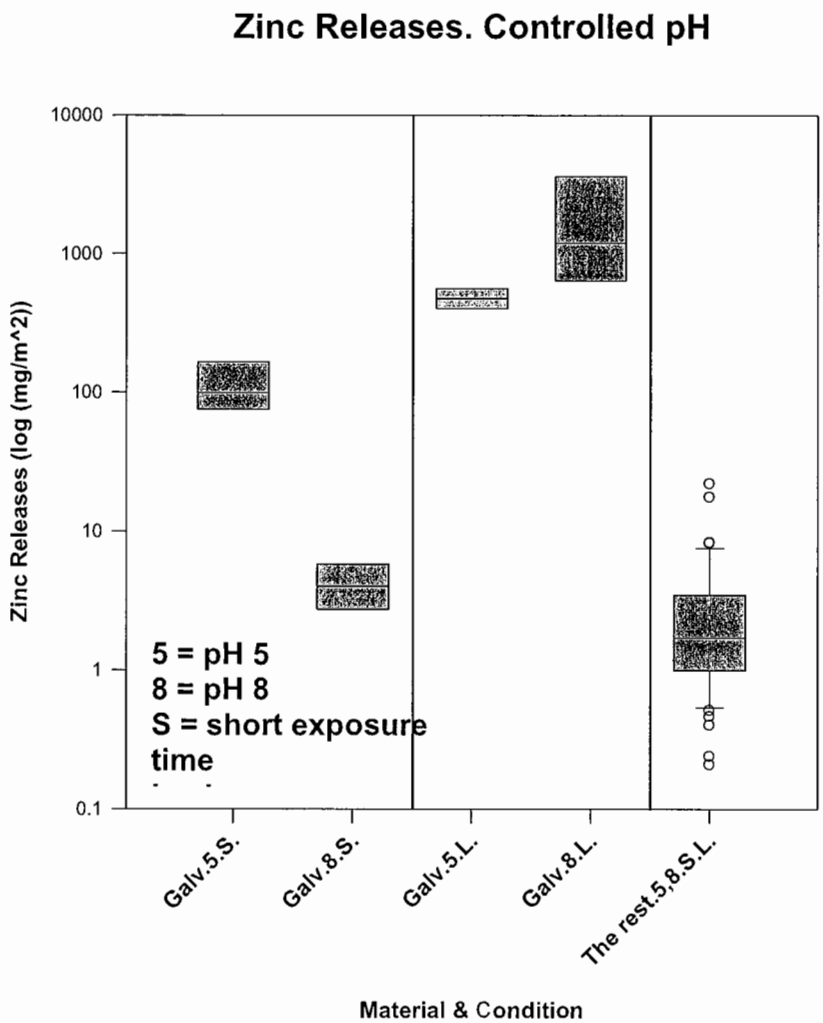
The following figure shows copper releases in the pipe and gutter samples immersed in bay and river waters. Copper releases were detected during both short and long exposures for controlled pH conditions and for both the natural bay and river water tests. Copper concentrations were greater for bay water exposure tests compared to river water exposure tests. Exposure time also increased copper releases in the samples with copper gutter materials. The combination of copper materials, high conductivity, and long exposure periods, as well as copper materials, low conductivity, and long exposure periods, significantly increased copper releases.



Group box plot for copper release in mg/m^2 for materials immersed in bay and river waters (Ogburn 2013).

The following figure is a group box plot of zinc releases for the galvanized steel samples compared to the rest of the material samples for pH 5 and8 conditions during short and long exposure periods. Galvanized steel materials were the greatest source of zinc. During short exposure times, low pH conditions increased zinc releases in the samples with galvanized materials, however during long exposure times, zinc releases were greater under controlled pH 8 conditions compared to controlled pH 5 conditions. Exposure time increased zinc releases in the samples with galvanized materials. The combination of such factors as galvanized materials, pH 5 resulted in significant increases in zinc releases during the short exposure periods. Similarly, zinc releases were much higher for galvanized materials immersed into pH 5 waters for long exposure

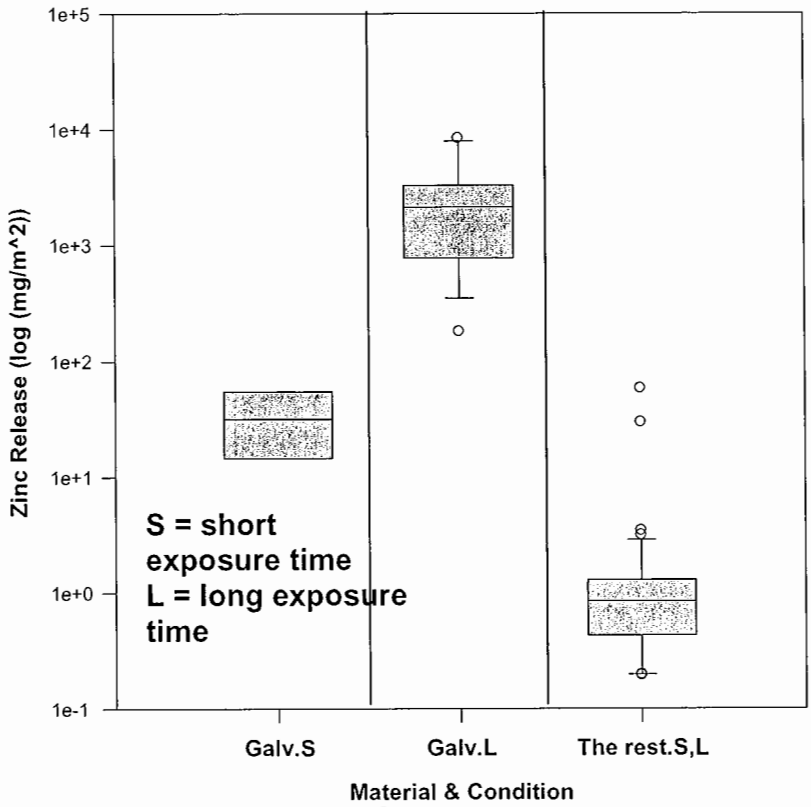
periods, and for galvanized materials immersed into pH 8 waters for long exposure periods. The other figure shows "the rest" of the materials at pH 5 and pH 8 conditions during short and long exposure periods combined into one group.



Group box plot for zinc release in mg/m^2 for materials immersed in pH 5 and pH 8 waters (Ogburn 2013).

Zinc releases also increased with exposure time for galvanized steel pipes and gutters immersed in bay and river waters. In this example, the interaction of material and exposure time was significant. Galvanized materials exposed to natural pH waters resulted in elevated zinc releases even during short periods. The combination of galvanized materials exposed to natural pH waters for long periods further increased zinc releases.

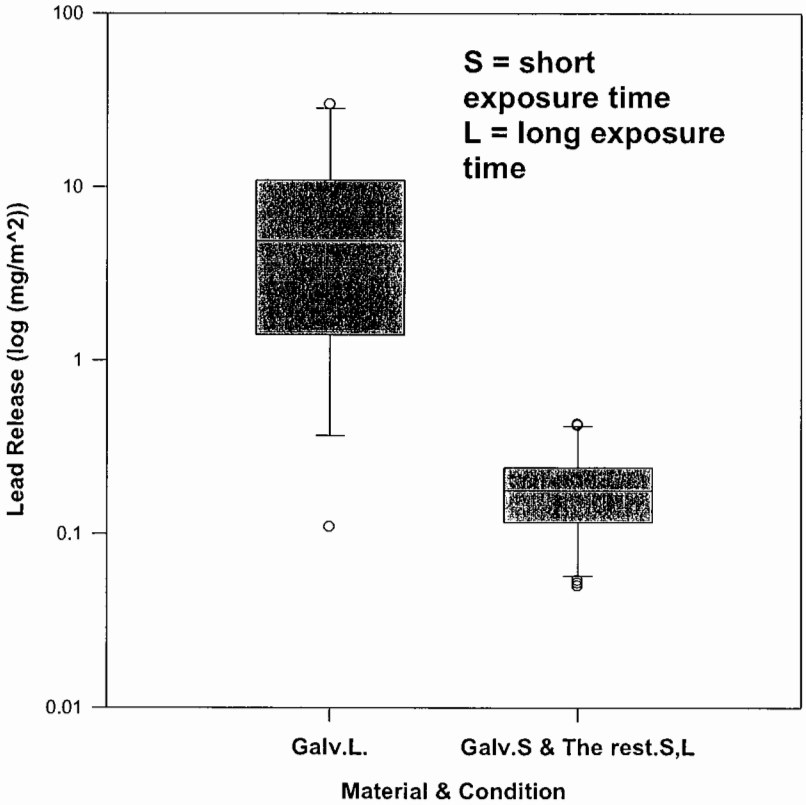
Zinc Releases. Natural pH.



Group box plot for zinc release in mg/m^2 for materials immersed in bay and river waters (Ogburn 2013).

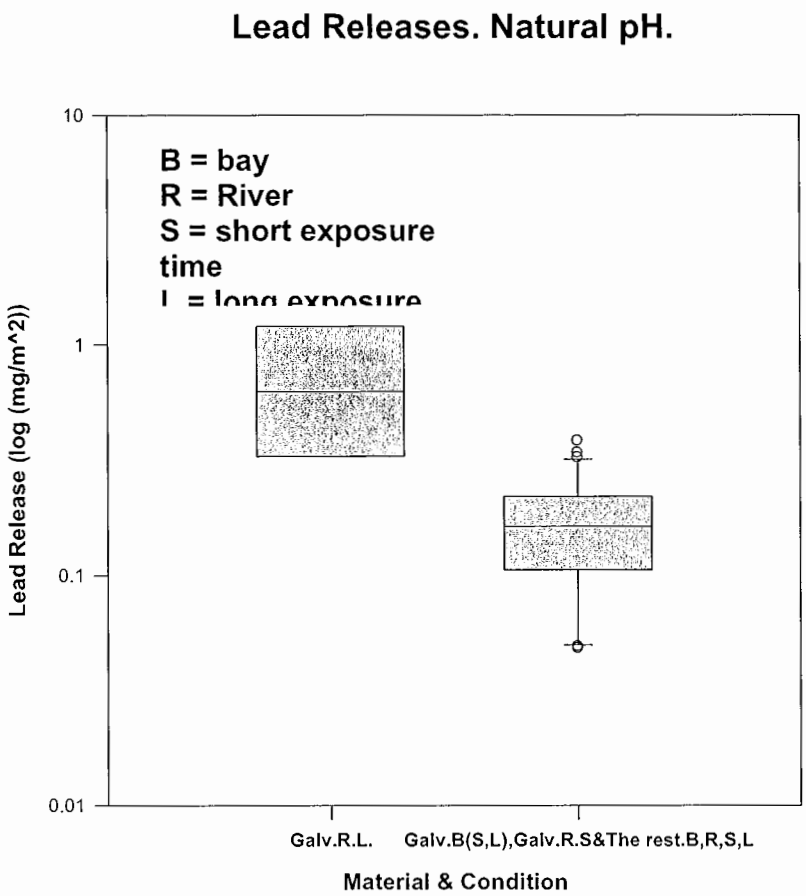
Galvanized steel materials were the only source of lead releases detected. For lead releases under controlled pH conditions, there was a difference between the groups of galvanized materials during long exposure times and the group of galvanized materials during short exposure times and the rest of the materials during both short and long exposure times. Under controlled pH conditions, lead releases significantly increased for galvanized materials and long exposure periods.

Lead Releases. Controlled pH.



Group box plot for lead release in mg/m^2 for materials immersed in pH 5 and pH 8 waters (Ogburn 2013).

Long exposure periods increased lead releases in the samples with galvanized materials immersed into river water. However this tendency was not observed for galvanized steel materials immersed in bay water and can be explained by the metal releases being close to detection limit. Lead releases were combined in two groups.



Group box plot for lead release in mg/m^2 for materials immersed in bay and river waters (Ogburn 2013).

Predictive Models of Metal Releases from Different Pipe and Gutter Materials

The results from the full factorial experiments were used to build empirical models in order to determine which materials can safely be used for long term storage of water and for short term exposures such as for roof gutters and drainage pipes.

The following tables represent simple models that quantify the expected contaminant releases for different material selections for different application uses (drainage system vs., storage tanks) and water types (low and high pHs and saline and non-saline waters). It was found that copper materials are not advised for drainage system applications, especially when acidic rain conditions are expected, due to high copper releases and associated high toxicity. Galvanized materials should also be avoided as gutter and pipe materials as they release high zinc concentrations under all pH and exposure conditions. For stormwater drainage systems (gutters and pipes) exposed at pH 5 and pH 8 conditions, plastic and concrete materials can be used for most conditions. Galvanized steel and copper materials also should be avoided for storage

tanks applications due to very high metal releases and toxicities. For stormwater storage applications, concrete, HDPE, and vinyl materials can be safely used due to their small, or non-detected, metal releases.

Model based on 2^2 Factorial analyses. Steel pipe. Controlled pH tests (Ogburn 2013)

Constituent	Galvanized Steel Pipe. Controlled pH Conditions
Pb, mg/m^2	Pb (mg/m^2) = 0.0092*Time (hr); R^2 = 59.2%; p-value for regression =0.00
Cu, mg/m^2	Avg.= 0.60 - 1.28; Median = 0- 0.02; Min= 0; Max= 4.785; # of Pts above DL: 3

Model based on 2^2 Factorial analyses. Steel materials. Controlled pH tests (Ogburn 2013)

Constituent	Galvanized Steel Materials (Pipe and Gutter). Controlled pH Conditions	
Zn, mg/m^2	Log Zn (mg/m^2) @pH5 = 2.138 +0.1904*logTime (hr); R^2 = 68.2%; p-value for regression = 0.001	Log Zn (mg/m^2) @pH8 = 0.7236 +0.7643*logTime (hr); R^2 = 94.0%; p-value for regression = 0.000

Model groups based on 2^2 Factorial analyses. Steel pipe. Natural pH tests (Ogburn 2013)

Constituent	Galvanized Steel Pipe. Natural pH Conditions			
Pb, mg/m^2	S.B-: Avg.= 0.4 (COV = 0.22)	S.R.: Avg.= 0.1 (COV = 0.02)	L.B-: Avg.= 0.1 (COV = 0.02)	L.R.: Avg.= 0.42 (COV = 0.79)
Cu, mg/m^2	ND in bay and river waters			
Zn, mg/m^2	Log Zn (mg/m^2) = 1.63 +0.51*logTime (hr); R^2 = 81.2%; p-value for regression = 0.00			

Footnote: S. = short exposure time; L. = long exposure time; B- = bay; R. = river; ND = non-detects.

Model based on 2^2 Factorial analyses. Copper gutter. Controlled pH tests (Ogburn 2013)

Constituent	Copper Gutter. Controlled pH Conditions	
Pb, mg/m^2	ND at pH 5 and 8	
Cu, mg/m^2	pH5: Avg.= 250 (COV = 0.66)	pH 8: Avg.= 70.5 (COV = 0.96)
Zn, mg/m^2	pH5: Avg.= 3.2 (COV = 0.81)	pH 8: Avg.= 0.22 (COV = 1.55)

Footnote: ND = non-detects.

Model based on 2^2 Factorial analyses. Copper gutter. Natural pH tests (Ogburn 2013)

Constituent	Copper Gutter. Natural pH Conditions	
Pb, mg/m^2	ND in bay and river waters	
Cu, mg/m^2	Bay Water: Log Cu (mg/m^2) = 1.25 +0.59*logTime (hr); R^2 = 91.4%; p-value for regression = 0.002	River Water: Log Cu (mg/m^2) = 0.72 +0.52*logTime (hr); R^2 = 98.0%; p-value for regression = 0.00
Zn, mg/m^2	Avg.= 3.46 - 3.79; Median = 1.27-1.62; Min= -0.67**; Max= 29.51; # of Pts above DL: 9	

Footnote: ND = non-detects.
** the mg/m^2 releases are compared to initial time zero conditions without the material in the test water. If the observed concentrations decreased with time (such as from precipitation on the material), the observed release rate was negative. Obviously, zero should be used in predictions instead of negative values.

The models showed that copper materials had elevated copper releases in pH 5 waters (250 mg/m^2) and in bay and river waters during short exposure times (180 and 840 mg/m^2 respectively). Long term exposure periods of copper materials under both high and low salinity conditions also resulted in high copper releases (1490 and 240 mg/m^2 respectively). Zinc concentrations released from galvanized steel materials were very high under both low and high pH conditions and during both short and long exposure times for controlled pH experiments (the average of 480 and 1860 mg/m^2 for galvanized steel materials at pH 5 and pH8 conditions respectively during long exposure time). For natural pH tests, long exposure periods resulted in high zinc concentrations released from galvanized pipes for waters with both high and low salinities (2,230 mg/m^2). Galvanized steel gutters immersed in bay and river waters had very high zinc releases during long term exposures (840 and 5,387 mg/m^2 for bay and river waters respectively). Elevated lead releases from galvanized steel materials were observed for pH 5 and 8 waters during long exposure periods, and for bay waters during short exposure periods and river waters during long exposure periods for steel pipe and for steel gutter during natural pH tests.

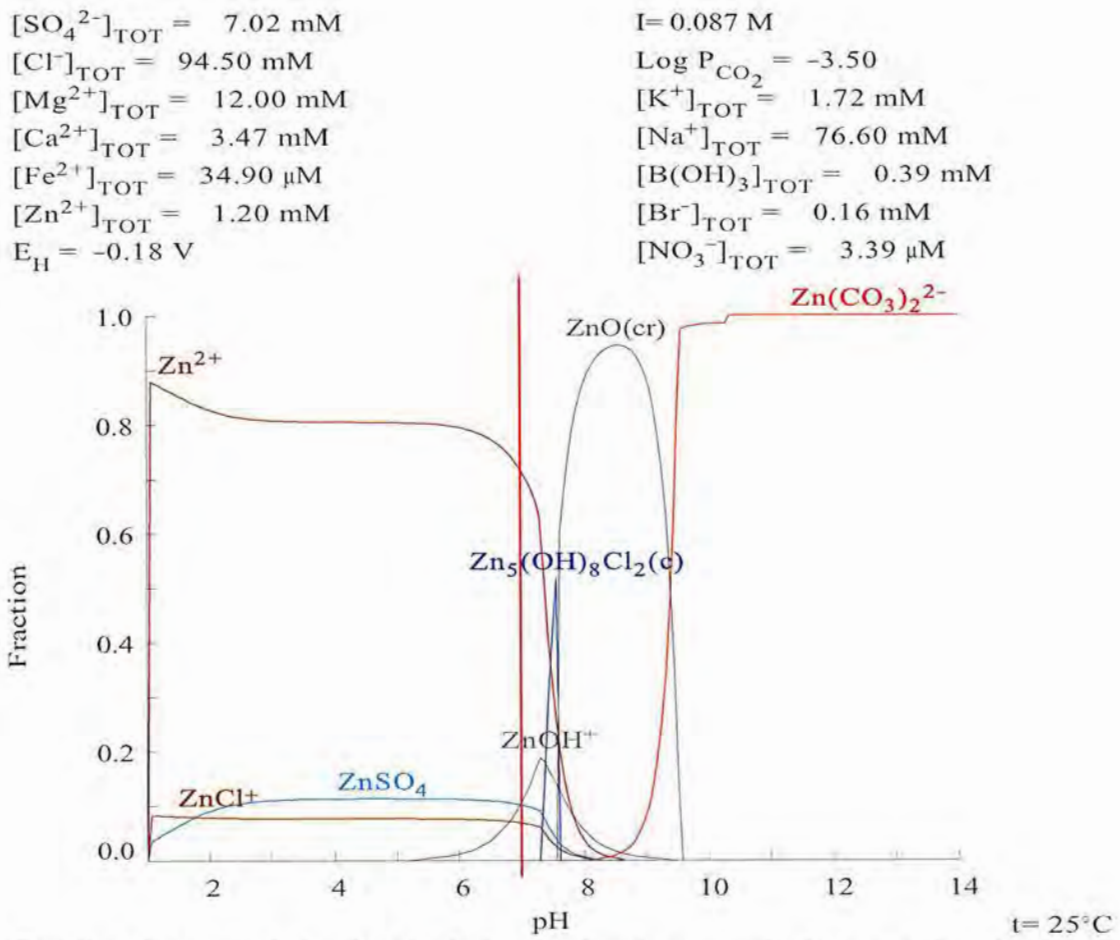
Chemical Speciation Modeling of Heavy Metals (Medusa Water Chemistry Modeling Environment)

In stormwater, many heavy metals can sorb to inorganic and organic particulate matter that accumulate as bed sediments. Water chemistry, the suspended sediment and substrate sediment composition influence the behavior of heavy metals in natural waters. The sorption of heavy metals to particulates is affected by chemical identity, redox conditions, water pH, and complexation and precipitation chemistry (Clark and Pitt 2012). The forms of metal species present in the environment will affect toxicity and treatability of heavy metals. Comprehensive water chemistry modeling was conducted to predict the forms of the measured metals. Medusa software (Medusa, KTH, available at http://www.kemi.kth.se/medusa/) was used. Phase, Fraction, and Pourbaix diagrams show the predominant species of metals and their concentrations. For all chemical

components in Medusa files, only the concentrations at and above the detection limit were used. The diagrams and summary tables were made for zinc, copper, and lead.

For Medusa input files, an assumption was made that equilibrium was reached during the static experiments. For the buffered test, total hardness and calcium hardness, chloride, and sulfate were measured after 3 months of exposure and were assumed to be representative of conditions during the whole time of the experiment. In the buckets with copper gutter at pH 5 and with aluminum gutter at pH 8, Ca hardness was less than the detection limit of 0.02 mg/L as CaCO3. For the un-buffered test, total hardness and calcium hardness were measured at time zero and after 3 months of exposure, therefore the hardness values after one day of exposure and was assumed to be equal to those measured at time zero. Since only one form of phosphorus species can be included into a Medusa file, $H_2PO_4^-$ was used for solutions with pH 5 since at this pH, $H_2PO_4^-$ is the predominant phosphorus species, and HPO_4^{2-} for solutions with pH 8 since at pH 8, HPO_4^{2-} is a predominant phosphorus species (Golubzov 1966). Other major ions (fluoride, nitrate, total phosphorus, bromide Br^-, manganese, Boron, silicon, sodium, potassium, chloride, and sulfate) for un-buffered tests were measured in the source water were assumed to be the same for all the containers during the whole duration of the experiment.

The tables with predominant species include the concentrations of the metal species in mol/L which were converted to mg/L of a compound, and then converted to the concentration of heavy metal of interest in mg/L. The cumulative percentage of a heavy metal was calculated in mg/L as a heavy metal constituent and was based on the sorted concentration of the corresponding compounds in mg/L. The predominant species tables show the predominant forms of heavy metal species that account for 99.9% of total metal concentration. For example, the following figure is the phase diagram for steel pipe sample submerged into bay water after three months of exposure. In this water sample, the pH is 7 and zinc is predominantly in the free ion form (Zn^{2+}). Full phase diagrams that contain information for a wide range of pH values and contain information for large numbers of potential species in the diagram look overwhelming. Therefore, the phase diagrams for the study area were constructed that showed a smaller portion of full phase diagrams and included the pH values observed during these experiments and a few metal species of interest that had the greatest concentrations. Also shown is the Fraction diagram of zinc shows the distribution of zinc species in this sample and also confirms that at pH 7 zinc is mainly in Zn^{2+} form. The Pourbaix diagram figure also shows that at pH 7 and Eh = -0.18V, free ion Zn^{2+} is the predominant species. This information is important in assessing the water toxicity which is greatly affected by the species of heavy metals in the water.



Fraction diagram of zinc for steel pipe section immersed into bay water after three months of exposure (Ogburn 2013).

I= 0.087 M

$[SO_4^{2-}]_{TOT}$= 7.02 mM

$[Cl^-]_{TOT}$= 94.50 mM

$[Mg^{2+}]_{TOT}$= 12.00 mM

$[Ca^{2+}]_{TOT}$= 3.47 mM

$[Fe^{2+}]_{TOT}$= 34.90 μM

$[Zn^{2+}]_{TOT}$= 1.20 mM

Log P_{CO_2}= -3.50

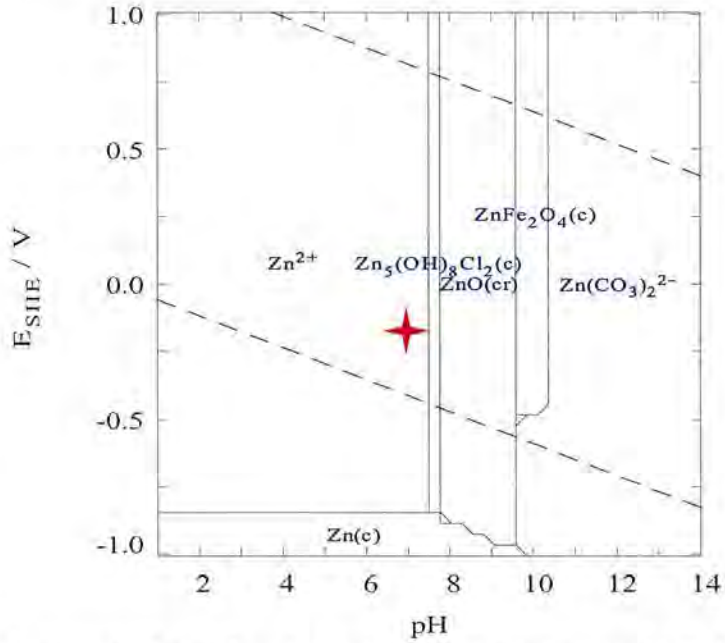
$[K^+]_{TOT}$= 1.72 mM

$[Na^+]_{TOT}$= 76.60 mM

$[B(OH)_3]_{TOT}$= 0.39 mM

$[Br^-]_{TOT}$= 0.16 mM

$[NO_3^-]_{TOT}$= 3.39 μM



t= 25°C

Pourbaix diagram of zinc for steel pipe section immersed into bay water after three months of exposure. Note: the symbol is located at the conditions measured during these tests (Ogburn 2013).

The modeled concentrations of zinc compounds in the containers were examined and compared with the theoretical maximum possible solubility of those compounds to determine if zinc would have continued to dissolve in the water if the experiment had continued for a longer time. The calculations were performed for the solubility of those zinc compounds which had the greatest concentrations in those containers. During these calculations, the assumption was made that those zinc compounds are dissolved in pure water (Kreshkov 1971).

The solubility of several compounds:

Solubility $CuH_2(PO_4)_2^{2-}$ = (Solubility Product/(108 γ_{Cu}^{2+} $(\gamma_H^+)^2$ $(\gamma_{PO4}^{2-})^2$))$^{1/5}$

Solubility $CuH_3(PO_4)_2^-$ = (Solubility Product/(108 γ_{Cu}^{2+} $(\gamma_H^+)^3$ $(\gamma_{PO4}^{2-})^2$))$^{1/6}$

Solubility $Zn_5(OH)_6(CO_3)_2$ = (Solubility Product/(0.48 $(\gamma_{Zn}^{2+})^5$ $(\gamma_{OH^-})^6$ $(\gamma_{CO3}^{2-})^2$))$^{1/13}$

The solubility of compounds with the KtAn formula (Kreshkov 1971):
Solubility $KtAn^-$ = (Solubility $Product_{KtAn}/(\gamma_{Kt}\ \gamma_{An}))^{1/2}$

Where,
Kt = cation
An = anion
γ = activity coefficient of cation or anion.

The solubility of compounds with the $KtAn_2$ formula (Kreshkov 1971):
Solubility $KtAn_2$ = (Solubility $Product_{KtAn2}/(4\ \gamma_{Kt}\ (\gamma_{An})^2))^{1/3}$

The solubility of compounds with the Kt_2An formula (Kreshkov 1971):
Solubility Kt_2An = (Solubility $Product_{Kt2An}/(4\ (\gamma_{Kt})^2\ \gamma_{An}))^{1/3}$

The solubility of compounds with the Kt_3An_2formula (Kreshkov 1971):
Solubility Kt_3An_2 = (Solubility $Product_{Kt3An2}/(108\ (\gamma_{Kt})^3\ (\gamma_{An})^2))^{1/5}$

The solubility formulas of other compounds can be found in Kreshkov 1971.

The following table shows solubility products for some reactions. The rest of the solubility products were taken from Medusa. Medusa is available from http://www.kemi.kth.se/medusa/.

Solubility products

Equation	Solubility Product, K_{sp}	Reference
$Zn(OH)_2 \leftrightarrow Zn^{2+} + 2OH^-$	$1.4 * 10^{-17}$	(Lurie 1989)
$ZnCO3 \leftrightarrow Zn^{2+} + CO_3^{2-}$	$1.45 * 10^{-11}$	(Lurie 1989)

Medusa results showed that during the buffered pH tests, $Zn_3(PO_4)_2{:}4H_2O(c)$ likely precipitated in the containers with galvanized steel pipe immersed in pH 5 and pH 8 waters after three months of exposure. The solubility product for $Zn_3(PO_4)_2{:}4H_2O(c)$ is very small ($K_{sp} = 9.1 * 10^{-33}$ (Lurie 1989)) and $Zn_3(PO_4)_2{:}4H_2O(c)$ easily precipitates. In pure water, not taking into consideration hydrolysis of phosphoric acid and complex formation, the amount of $Zn_3(PO_4)_2{:}4H_2O$ that can dissolve in water is 5.6E-07mol/L (0.11 mg/L as Zn), however due to hydrolysis and complexation the amount of dissolved $Zn_3(PO_4)_2{:}4H_2O$ was greater that the theoretical value and reached 3.37E-05 mol/L (6.62 mg/L as Zn) in the container with galvanized steel pipe immersed into pH 5 water. Golubzov (1966) pointed out that hydrolysis increases the solubility of insoluble salts in the solution.

The following tables show total measured metal concentrations and modeled metal species at time zero (base water alone), after one day of exposure and after three months of exposure. The total percent of compound valence doesn't always add up to 100 due to the rounding. At time zero (water without pipes and gutters), zinc and zinc compounds were predominantly in valence two state in the containers with pH 5 water, and were mostly in valence one state in the containers with pH 8 water. At time zero, copper and copper compounds in the buckets with pH 5 and 8 waters were mainly in valence two state.

After one day of exposure, zinc and zinc compounds were predominantly in valence two state in the samples with steel, copper, and plastic materials immersed in pH 5 water, and mainly in zero and one valence states in the samples with steel, copper, aluminum, and plastic materials immersed in pH 8 water. After one day of exposure, copper and copper compounds in containers with copper materials immersed into pH 5 water were approximately equally distributed between valence states of two, one, and zero, however for the buffered pH 8 waters, copper compounds in containers with copper gutters were predominantly in valence two state which can be explained by the formation of copper complexes with phosphate and other ions. Copper was generally in valence zero state in the samples with copper materials immersed in bay and river waters.

Sandberg, et al. (2006) examined corrosion-induced copper runoff from copper sheet, naturally patinated copper and pre-patinated copper in a chloride-rich marine environment during one year. The bioavailable concentration (the portion that is available for uptake by an organism) of released copper comprised a small fraction (14–54%) of the total copper concentration due to complexation towards organic matter in impinging seawater aerosols (Sandberg, et. al., 2006). The authors concluded that released copper is complexed with other ligands which reduce the bioavailability. Factors that influence the bioavailability of copper include alkalinity, hardness, pH and dissolved organic matter. Seawater contains organic matter that is primarily of biotic origin, and a significant portion of copper is most likely complexed with these ligands, which leads to reduction of the bioavailability (Sandberg, et. al., 2006). In this research, the results from Medusa modeling showed that copper released in the containers with copper gutter materials immersed into bay water was almost all in valence zero state. For containers with galvanized steel materials immersed into buffered pH 8 and bay waters, lead was mainly in valence zero after one day of exposure.

After three months of exposure, zinc and zinc compounds in the containers with galvanized steel, copper, aluminum, and plastic materials immersed into buffered pH 5 water were mainly in valence two state after; for galvanized steel, copper, aluminum, concrete, and plastic materials immersed into buffered pH 8, bay, and river waters, zinc was in one or zero valence states. For containers with copper materials immersed into pH 5 water, the valence state of copper and cooper compounds was approximately equally distributed between two, one, and zero and for copper materials submerged into buffered pH 8, bay, and river waters copper was predominantly in zero valence state

after three months of exposure. Lead in containers with galvanized steel materials immersed into pH 5, pH 8, bay and river waters was mainly in zero valence state after three months of exposure. The following tables summarize these observations.

Total measured zinc concentrations and modeled species after one day (Ogburn 2013)

Sample	Total Measured Zn Concentration (mg/L as Zn)	Compound Valence, mg/L as Zn			Compound Valence, %		
		Two or greater	One	Zero	Two or greater	One	Zero
pH 5 P. PVC	0.22	2.2E-01 Zn^{2+} $Zn(SO_4)_2^{2-}$	5.9E-04 $ZnOH^+$ $ZnHCO_3^+$	10E-04 $ZnSO_4$ $ZnCO_3$ $Zn(OH)_2$	99	0.27	0.45
pH 5 P. HDPE	0.02	2.0E-02 Zn^{2+} $Zn(SO_4)_2^{2-}$	2.6E-05 $ZnOH^+$ $ZnHCO_3^+$	1.0E-05 $ZnSO_4$ $ZnCO_3$ $Zn(OH)_2$	100	0.13	0.05
pH 5. P. Steel	10.20	10 Zn^{2+} $Zn(SO_4)_2^{2-}$	5.8E-02 $ZnOH^+$ $ZnHCO_3^+$	1.7E-02 $ZnSO_4$ $ZnCO_3$ $Zn(OH)_2$	99	0.57	0.17
pH 5. G. Steel	14.20	14 Zn^{2+} Zn_2OH^{3+}	4.4E-02 $ZnOH^+$ $ZnHCO_3^+$	9.3E-03 $ZnSO_4$ $ZnCO_3$ $Zn(OH)_2$	100	0.31	0.07
pH 5. G. Copper	0.04	4.0E-02 Zn^{2+} $Zn(SO_4)_2^{2-}$	7.0E-05 $ZnOH^+$ $ZnHCO_3^+$	3.5E-05 $ZnSO_4$ $ZnCO_3$ $Zn(OH)_2$	100	0.17	0.09
pH 8 P. PVC	0.16	0.054 Zn^{2+} $Zn(CO_3)_2^{2-}$	0.083 $ZnOH^+$ $ZnHCO_3^+$	0.023 $ZnCO_3$ $Zn(OH)_2$ $ZnSO_4$	34	52	14
pH 8 P. HDPE	0.02	2.0E-02 Zn^{2+} $Zn(SO_4)_2^{2-}$	3.4E-05 $ZnOH^+$ $ZnHCO_3^+$	1.6E-06 $ZnSO_4$ $ZnCO_3$ $Zn(OH)_2$	100	0.17	0.01
pH 8. P. Steel	1.01	5.4E-02 Zn^{2+} $Zn(CO_3)_2^{2-}$	9.0E-02 $ZnOH^+$ $ZnHCO_3^+$	8.7E-01 $Zn_3(PO_4)_2{:}4H_2O(c)$ $ZnCO_3$ $Zn(OH)_2$	5.3	8.8	86
pH 8. G. Alum	0.02	6.3E-03 Zn^{2+} $Zn(CO_3)_2^{2-}$	1.0E-02 $ZnOH^+$ $ZnHCO_3^+$	3.3E-03 $ZnCO_3$ $Zn(OH)_2$ $ZnSO_4$	31	52	17
pH 8. G. Steel	2.09	5.8E-02 Zn^{2+} $Zn(CO_3)_2^{2-}$	9.9E-02 $ZnOH^+$ $ZnHCO_3^+$ $Zn(OH)_3^-$	1.9 $Zn_3(PO_4)_2{:}4H_2O(c)$ $ZnCO_3$ $Zn(OH)_2$	2.8	4.7	93

Total measured zinc concentrations and modeled species after one day (Ogburn 2013), continued

pH 8. G. Copper	0.02	5.9E-03 Zn^{2+} $Zn(CO_3)_2^{2-}$	1.0E-02 $ZnOH^+$ $ZnHCO_3^+$	3.8E-03 $ZnCO_3$ $Zn(OH)_2$ $ZnSO_4$	30	52	19
Bay P. Steel	8.4	0.2 Zn^{2+} $Zn(CO_3)_2^{2-}$ $Zn(SO_4)_2^{2-}$	0.42 $ZnOH^+$ $ZnCl^+$ $ZnHCO_3^+$	7.8 $Zn_5(OH)_6(CO_3)_2$ (c) $ZnFe_2O_4$(c) $ZnCO_3$	2.3	5.0	93
Bay G. Steel	4.8	0.20 Zn^{2+} $Zn(CO_3)_2^{2-}$ $Zn(SO_4)_2^{2-}$	0.42 $ZnOH^+$ $ZnCl^+$ $ZnHCO_3^+$	4.2 $Zn_5(OH)_6(CO_3)_2$ (c) $ZnFe_2O_4$(c) $ZnCO_3$	4.1	8.7	87
Bay G. Copper	0.05	1.4E-02 Zn^{2+} $Zn(CO_3)_2^{2-}$ $Zn(SO_4)_2^{2-}$	2.6E-02 $ZnOH^+$ $ZnCl^+$ $ZnHCO_3^+$	1.0E-02 $ZnCO_3$ $Zn(OH)_2$ $ZnSO_4$	28	52	20
River P. Steel	6.1	0.25 $Zn(CO_3)_2^{2-}$ Zn^{2+} $Zn(SO_4)_2^{2-}$	0.17 $ZnOH^+$ $ZnHCO_3^+$ $Zn(OH)_3^-$	5.6 $Zn_5(OH)_6(CO_3)_2$ (c) $ZnCO_3$ $ZnFe_2O_4$(c)	4.2	2.8	93
River G. Steel	1.20	0.19 $Zn(CO_3)_2^{2-}$ Zn^{2+} $Zn(SO_4)_2^{2-}$	0.20 $ZnOH^+$ $ZnHCO_3^+$ $Zn(OH)_3^-$	0.82 $Zn_5(OH)_6(CO_3)_2$ $ZnCO_3$ $ZnFe_2O_4$(c)	16	16	68
River G. Copper	0.02	3.2E-03 Zn^{2+} $Zn(CO_3)_2^{2-}$ $Zn(SO_4)_2^{2-}$	1.1E-02 $ZnOH^+$ $ZnHCO_3^+$ $ZnCl^+$	5.4E-03 $ZnCO_3$ $Zn(OH)_2$ $ZnSO_4$	16	57	27

Total measured copper concentrations and modeled species after one day (Ogburn 2013)

Sample	Total Measured Cu Concentration (mg/L as Cu)	Compound Valence, mg/L as Cu			Compound Valence, %		
		Two or greater	One	Zero	Two or greater	One	Zero
pH 5 P. PVC	0.08	3.7E-02 $CuH_2(PO_4)_2^{2-}$ Cu^{2+} $CuH_3(PO_4)_2^{2-}$	2.1E-02 $CuH_2PO_4^+$ $CuH_3(PO_4)_2^-$ Cu^+	2.3E-02 $CuHPO_4$ CuH_2PO_4 $Cu(H_2PO_4)_2$	46	26	28
pH 5 G. Copper	6.82	2.5 $CuH_2(PO_4)_2^{2-}$ Cu^{2+} $CuH_3(PO_4)_2^{2-}$	2.5 $CuH_2PO_4^+$ $CuH_3(PO_4)_2^-$ Cu^+	1.8 $CuHPO_4$ $Cu(H_2PO_4)_2$ CuH_2PO_4	37	36	27
pH 8 P. PVC	0.08	7.8E-02 $CuH_2(PO_4)_2^{2-}$ $CuH_3(PO_4)_2^{2-}$ Cu^{2+}	1.2E-04 $Cu(OH)_2^-$ Cu^+ $CuOH^+$	1.7E-03 $CuHPO_4$ $CuCO_3$ $Cu(OH)_2$	98	0.15	2.1
pH 8 G. Copper	0.29	2.8E-01 $CuH_2(PO_4)_2^{2-}$ Cu^{2+} $CuH_3(PO_4)_2^{2-}$	2.5E-04 $Cu(OH)_2^-$ $CuOH^+$ Cu^+	6.5E-03 $CuHPO_4$ $CuCO_3$ $Cu(OH)_2$	98	8.8E-02	2.2
Bay G. Copper	2.11	1.1E-04 $CuCl_3^{2-}$ $Cu_2Cl_4^{2-}$ Cu^{2+}	3.2E-03 $CuCl_2^-$ Cu^+ $Cu(OH)_2^-$	2.1 Cu(c) $CuFeO_2$(c) $CuSO_4$	5.0E-03	0.15	100
River G. Copper	0.60	5.5E-09 $CuCl_3^{2-}$ Cu^{2+} $Cu(CO_3)_2^{2-}$	1.9E-05 $CuCl_2^-$ $Cu(OH)_2^-$ Cu^+	0.6 Cu(c) $CuFeO_2$(c) $CuCO_3$	9.2E-07	3.2E-03	100

Total measured lead concentrations and modeled species after one day (Ogburn 2013)

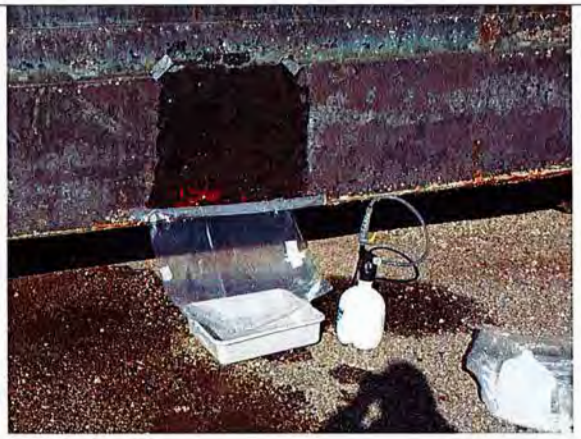
Sample	Total Measured Pb Concentration (mg/L as Pb)	Compound Valence, mg/L as Pb			Compound Valence, %		
		Two or greater	One	Zero	Two or greater	One	Zero
pH 8 G. Steel	0.008	5.9E-05 $Pb(CO_3)_2^{2-}$ Pb^{2+}	1.8E-05 $PbOH^+$ $PbHCO_3^+$	8.0E-03 $Pb_3(PO_4)_2(c)$ $PbCO_3$ $PbHPO_4$	0.73	0.22	99
Bay P. Steel	0.012	1.1E-03 $Pb(CO_3)_2^{2-}$ Pb^{2+} $Pb(SO_4)_2^{2-}$	4.6E-04 $PbOH^+$ $PbCl^+$ $PbHCO_3^+$	1.1E-02 $PbCO_3$ $PbSO_4$ $Pb(OH)_2$	9.3	3.8	87
Bay G. Steel	0.005	4.7E-04 $Pb(CO_3)_2^{2-}$ Pb^{2+} $Pb(SO_4)_2^{2-}$	1.9E-04 $PbOH^+$ $PbCl^+$ $PbHCO_3^+$	4.4E-03 $PbCO_3$ $PbSO_4$ $Pb(OH)_2$	9.3	3.8	87

Washdown Tests of Exposed Materials at Naval Facilities

SPAWARSYSCEN-PACIFIC Navy personnel conducted a series of material washoff tests as part of this research project. The following pictures show the how these tests were conducted for several different types of materials. Generally, 2 to 4 L of DI water was gently sprayed over a known area (about 2 ft^2) with the wash water collected in a plastic tray. Each test lasted about 15 to 30 minutes. The wash water was then chemically analyzed for a suite of heavy metals. This section includes photographs of many of the materials tested, and the data grouped by material type. The 79 materials were sorted into the following 16 categories for these data summaries: aluminum ramp, artificial turf, brick wall, concrete, galvanized metal (bare), galvanized metal (painted), galvanized metal (coated), barge hull, metal (bare), metal (painted), plaster, roof, rubber, wood (bare), wood (painted), and wood (treated). Some of these categories have only a single sample, while others have many.

The data are presented by metal. The first table shows the available data for each category, along with simple summary statistics. These data were then evaluated in SigmaPlot (version 15) using the non-parametric Kruskal-Wallis one way analysis of variance on ranks to determine if at least one group is significantly different from any of the others (this test only examines single groups). Simultaneously, grouped box and whisker plots were prepared in SigmaPlot for these groups. These results were then used to group the groups into a fewer number of combined groups indicating materials that had low washoff concentrations, high concentrations, and the other categories. Box and whisker plots and Kruskal-Wallis analyses were also used to evaluate these

categories. These data summaries, plots, and analyses were made for both the concentration and the unit area loading washoff data.



Washdown setups showing sprayer, plastic sheet below target area and plastic tray to capture washdown water (barge hull).

Washdown sampling for untreated wood.

Washdown sampling for engine block.

Washdown sampling for tires.

Washdown sampling of galvanized stair steps.

1) Aluminum ramp

Walkway, aluminum; Everett

2) Artificial turf

Turf, artificial; NBSD

3) Brick wall

Wall, brick; NB Kitsap

4) Concrete

Concrete wall; SSC-PAC

Concrete barrier, uncoated; Saint Julian

5) Galvanized, bare

Galvanized shed, sides; NBK Bangor

Galvanized rail; SUBASE

Galvanized fence; SUBASE

Galvanized scaffold stack, laydown area; SUBASE

Causeway, portion with zinc anode; Little Creek

Pallet, galvanized (folded); Saint Julian

Utility pole, galvanized; NB Kitsap

Sheath, over concrete barrier edge; Everett

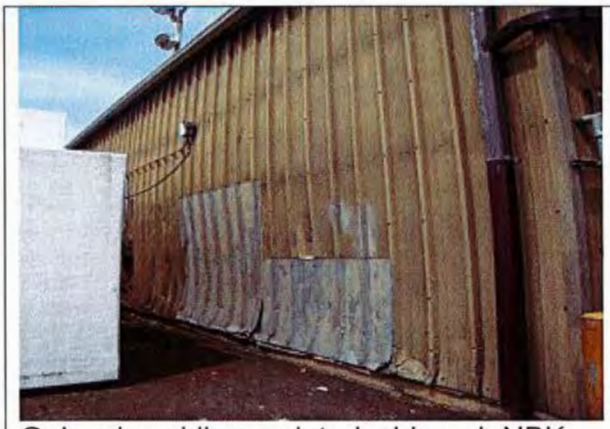
Stairs, galvanized; Everett

Scaffold parts, galvanized; Pt. Loma Subase

Grate 1, stormwater drain; NBSD

Grate 2, stormwater drain; NBSD

6) Galvanized, painted



Galvanize siding, painted, chipped; NBK Bangor

Metal panel, painted galvanized, building side; Saint Julian

Fence, painted galvanized; NB Kitsap

7) Galvanized, coated

Coated galvanized fence; SSC=PAC

8) Barge hull

Barge hull; Little Creek

Barge hull; Little Creek

9) Metal, bare

 Pipe, uncoated steel; Little Creek	 Engine block; Saint Julian
 Metal panel, uncoated iron, "weathered"; Bangor	

10) Metal, painted

Dumpster, green; SSC-PAC

Building side, yellow, panels; NAS Whidbey

Building side, yellow, panels; NAS Whidbey

Building side, yellow, panels; NAS Whidbey

Building side, green coated metal;

AC unit, gray; SSC-PAC

NAVSTA Everett	
 Electrical vault, green; SSC-PAC	 Keel blocks, metal painted; Little Creek
 Causeway, gray painted side; Little Creek	 Metal panel, light yellow (temp. buildings); NB Kitsap
 Metal panel, painted light yellow; Bangor	 Metal, painted, brick red; Bangor

Fire hydrant, red; Everett

Guard rail, painted yellow; Pt. Loma Subase

Water riser, potable, blue (w/brass part); Pt. Loma Subase

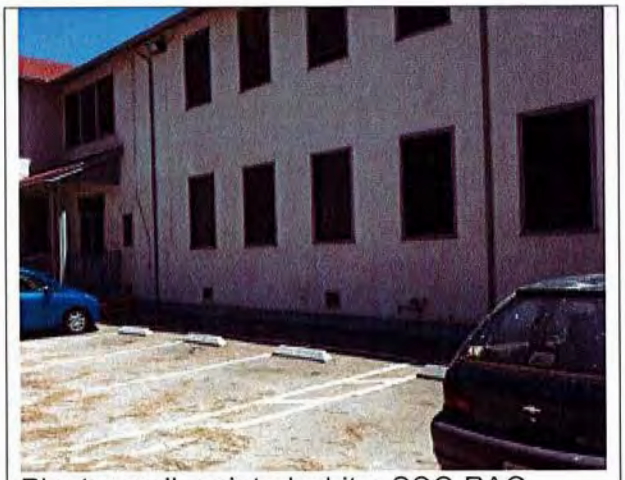
Water riser, potable, blue; Pt. Loma Subase

Pipe supports, metal, painted brown; Pt. Loma Subase

Dumpster (blue), cardboard recycle; SSC-PAC

Dumpster (blue), cardboard recycle w/guano, heron; SSC-PAC

11) Plaster siding


Plaster wall, painted white; SSC-PAC

12) Roof

 Shed roof, green coated metal; NAVSTA Everett	 Shingles, asphalt; Bangor
 Roof, (via gutter); Bangor	

13) Rubber

Cable, black, 4" diameter; SUBASE

Cable, black, 4" diameter; SUBASE

Tires, rubber; Saint Julian

Bumpers, large, black; Everett

Cables, electrical 3 in. diameter; Pt. Loma Subase

14) Wood, bare

Crate, wooden; Saint Julian

15) Wood, painted

Wood wall, painted; SSC-PAC

16) Wood, treated

Wood, treated, green; NBK Bangor

Treated wood, green painted; SUBASE

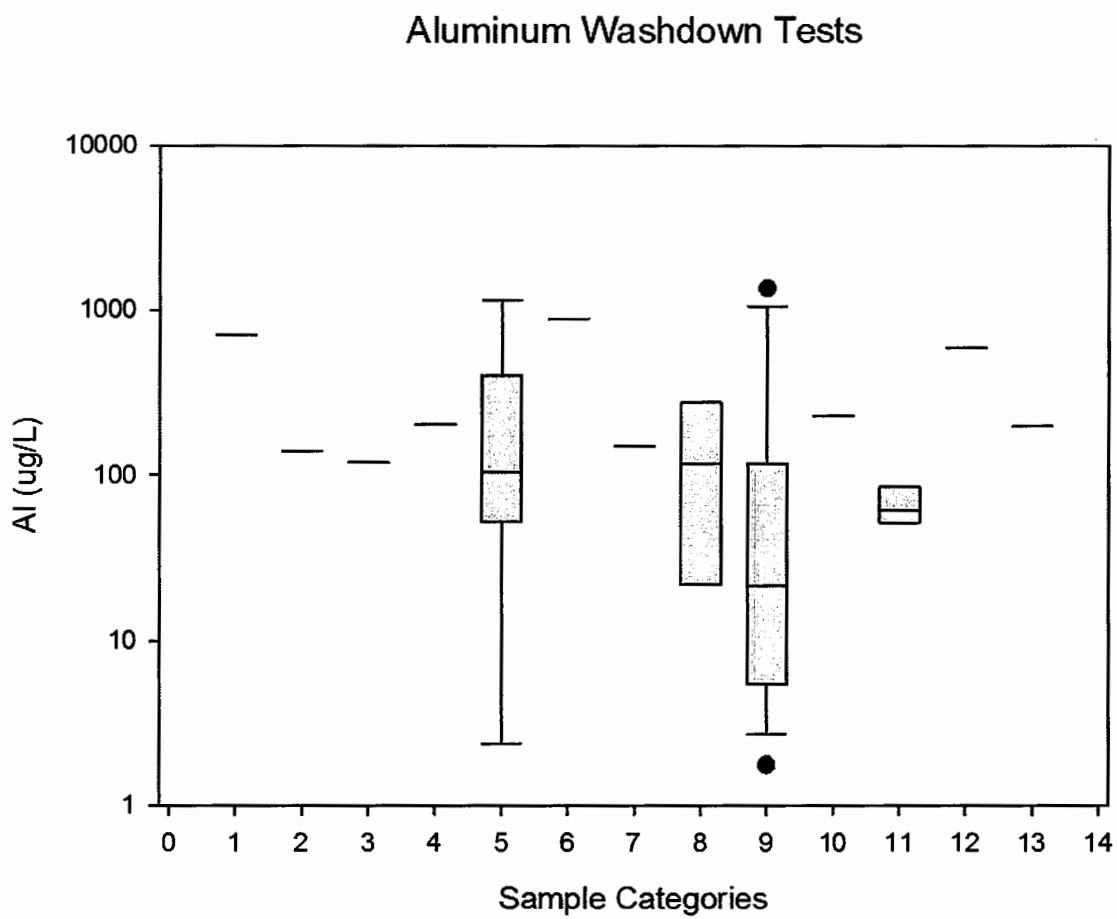
Wood, treated (copper azole); Little Creek

Treated wood label; Little Creek

Aluminum

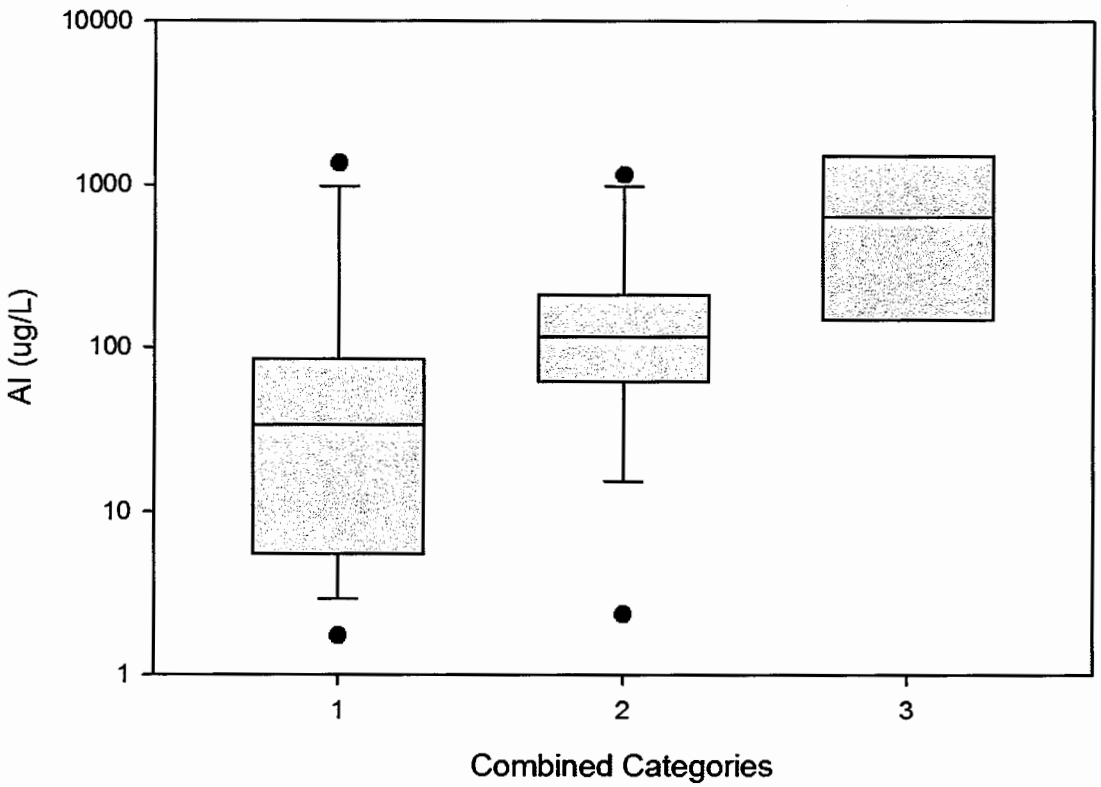
Aluminum Washdown Concentrations (µg/L)

Grouped Category:	high	other	other	other	other	high	other	other	low	other	low	high	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	702	141	119	204	103	1,777	150	20	185	446	52	586	197
					584	4		211	22	11	85		
					115			26	8		62		
					46			298	48				
					2				1,364				
					214				46				
					60				51				
					69				6				
					1,153				597				
									14				
									5				
									2				
									4				
Grouped Category:	high	other	other	other	other	high	other	other	low	other	low	high	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					2	4		20	2	11	52		
max					1,153	1,777		298	1,364	446	85		
average					261	890		139	181	229	66		
median	702	141	119	204	103	890	150	118	22	229	62	586	197
st dev					377	1,253		138	391	308	17		
COV					1.4	1.4		1.0	2.2	1.3	0.3		


Aluminum Washdown Tests
10000
1000
100
10
1
Al (ug/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Al concentrations)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	14	0	34	5.5	85
others	12	0	117	62	211
high	4	0	644	150	1510
H = 4.947 with 2 degrees of freedom. (P = 0.08)					

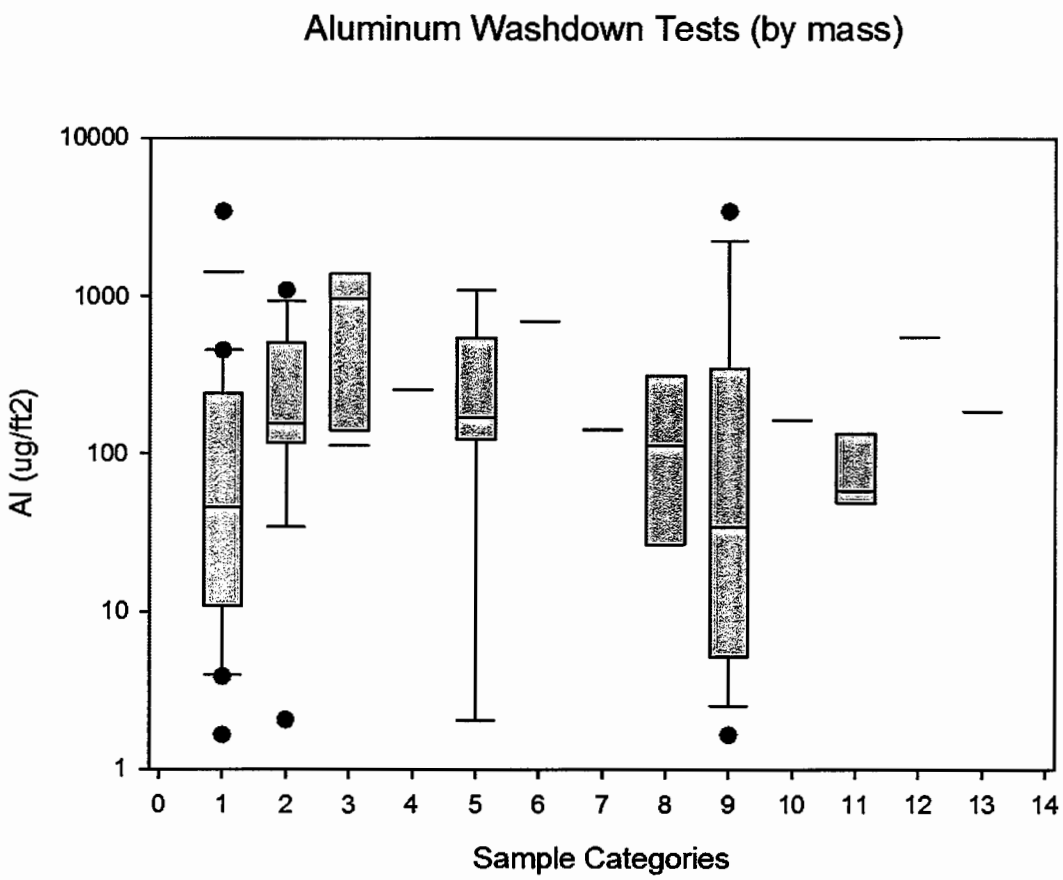

10000
1000
100
10
1
Al (ug/L)
1
2
3
Combined Categories

Summary Statistics for Aluminum Concentration Grouped Categories

Grouped category:	low	all others	high
Sample Category in Groups:	metal painted rubber	artificial turf brick wall concrete galv bare barge hull metal bare roof wood treated	Al ramp galv painted
number	14	12	4
min	1.8	2.4	4.0
max	1,360	1,150	1,780
average	172	234	770
median	34	117	644
st dev	380	326	739
COV	2.2	1.4	1.0

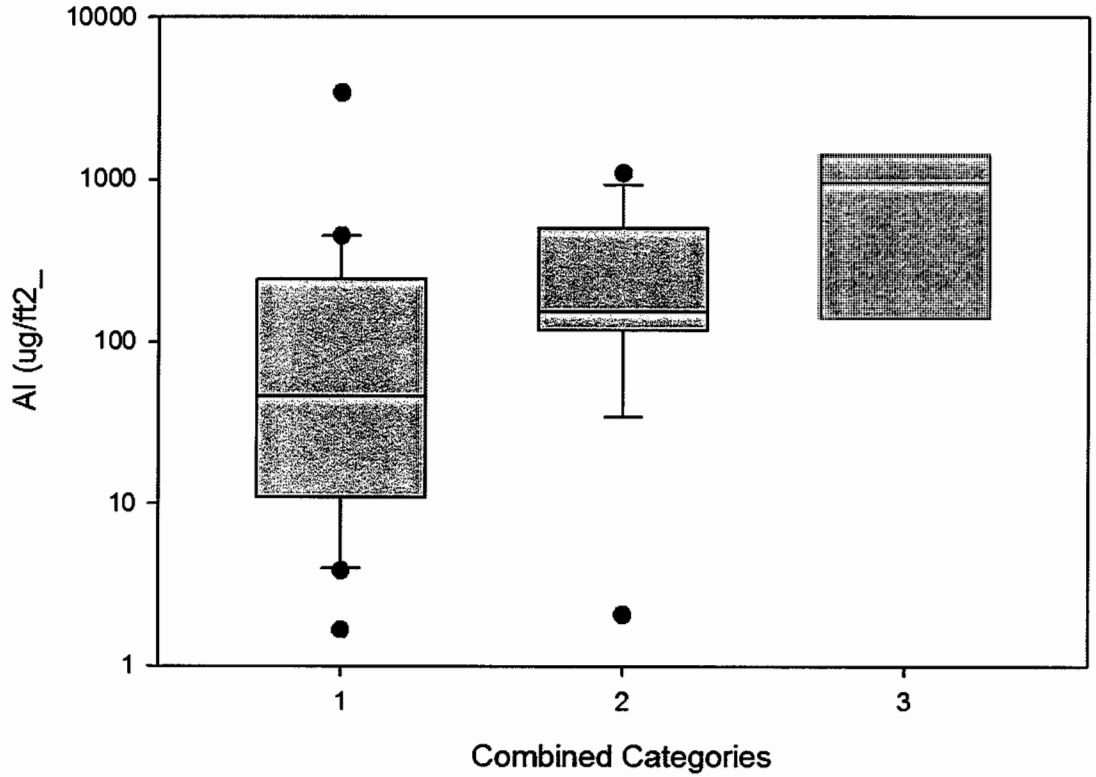
Aluminum Washdown Mass (μg/ft^2)

Grouped Category:	high	other	other	other	other	high	other	low	low	other	low	high	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	1,418	133	113	257	391	1,378	142	26	4	317	49	555	187
					552	4		200	447	10	137		
					109			29	20		58		
					138			357	8				
					2				116				
					540				3,442				
					169				43				
					140				259				
					1,091				5				
									452				
									35				
									5				
									2				
Grouped Category:	high	other	other	other	other	high	other	low	low	other	low	high	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					2	4		26	2	10	49		
max					1,091	1,378		357	3,442	317	137		
average					348	691		153	372	164	81		
median	1,418	133	113	257	169	691	142	114	35	164	58	555	187
st dev					341	972		158	937	217	48		
COV					1.0	1.4		1.0	2.5	1.3	0.6		


Aluminum Washdown Tests (by mass)
10000
1000
100
10
1
Al (ug/ft2)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Al mass)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	20	0	46	11	240
others	12	0	155	120	500
high	4	0	970	140	1410
H = 5.077 with 2 degrees of freedom. (P = 0.079)					


10000
1000
100
10
1
Al (ug/ft2_
1
2
3
Combined Categories

Summary Statistics for Aluminum Mass Grouped Categories

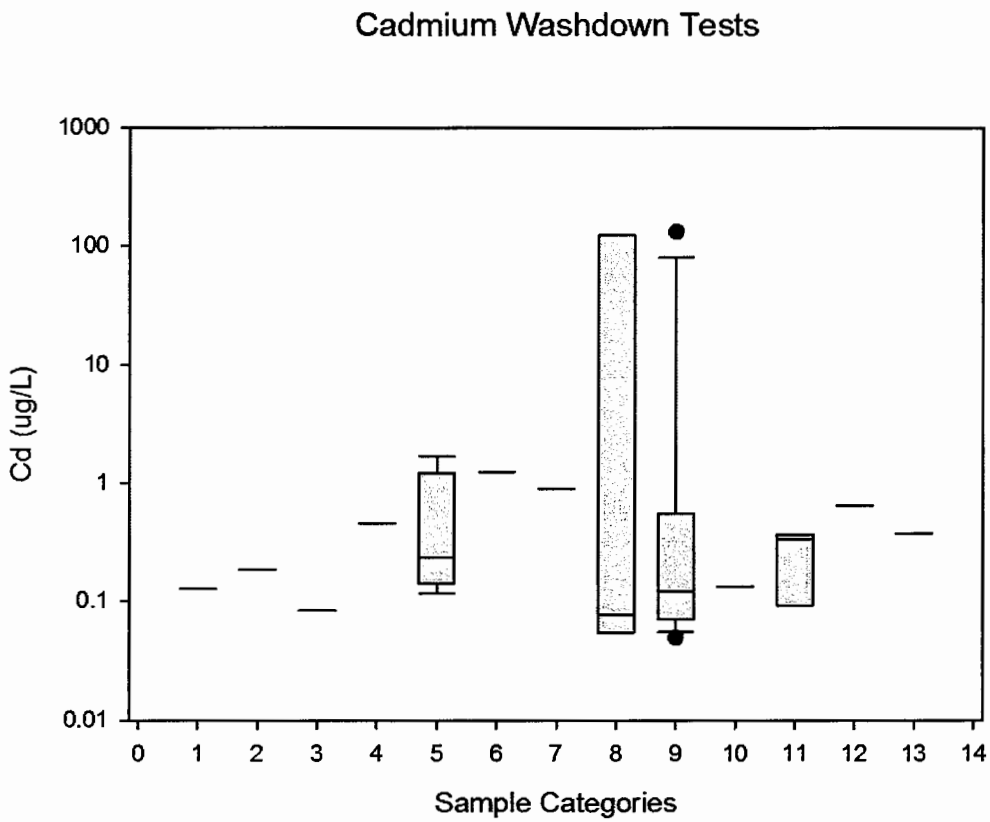
Grouped Category:	low	others	high
Sample Categories in Groups:	metal bare metal painted rubber	artificial turf brick wall concrete galv bare barge hull roof wood treated	Al ramp galv painted wood bare
number	20	12	4
min	1.7	2.1	3.8
max	3,440	1,090	1,420
average	285	303	839
median	46	155	966
st dev	758	304	684
COV	2.7	1.0	0.8

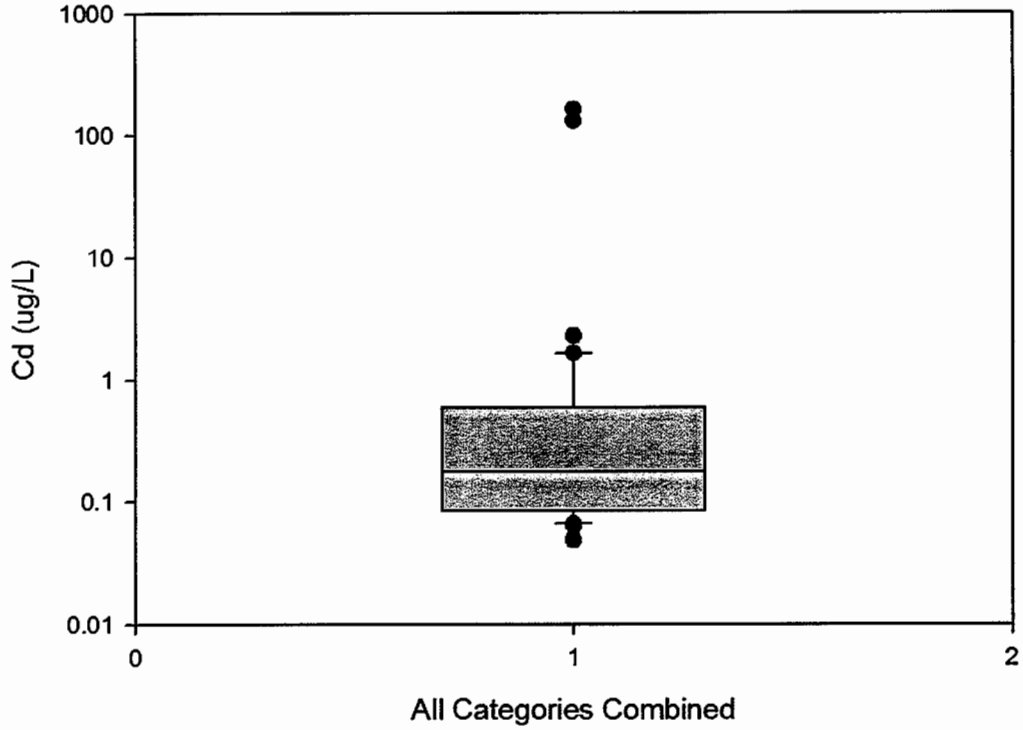
Cadmium

Cadmium Washdown Concentrations (µg/L)

Grouped Category:	other	other	other	other	other	other	other	other	other	other	other	other	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	0.1	0.2	0.1	0.5	0.1	2.3	0.9	0.1	0.0	0.2	0.1	0.6	0.4
					1.1	0.2		163	131	0.1	0.4		
					0.1			0.1	0.2		0.3		
					1.7			0.0	0.1				
					0.3				0.2				
					1.4				0.9				
					0.2				0.1				
					0.2				0.1				
					0.1				0.1				
									0.9				
									0.2				
									0.1				
									0.1				
Sample Category:	Al ramp	artifical turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					0.1	0.2		0.0	0.0	0.1	0.1		
max					1.7	2.3		163.0	131.3	0.2	0.4		
average					0.6	1.2		40.8	10.3	0.1	0.3		
median	0.1	0.2	0.1	0.5	0.2	1.2	0.9	0.1	0.1	0.1	0.3	0.6	0.4
st dev					0.6	1.5		81.5	36.4	0.1	0.1		
COV					1.1	1.2		2.0	3.5	0.6	0.6		

One bare metal and one painted metal sample had very high (>100 ug/L) Cd concentrations; all others were very low (<1 µg/L). No significant groupings of data.





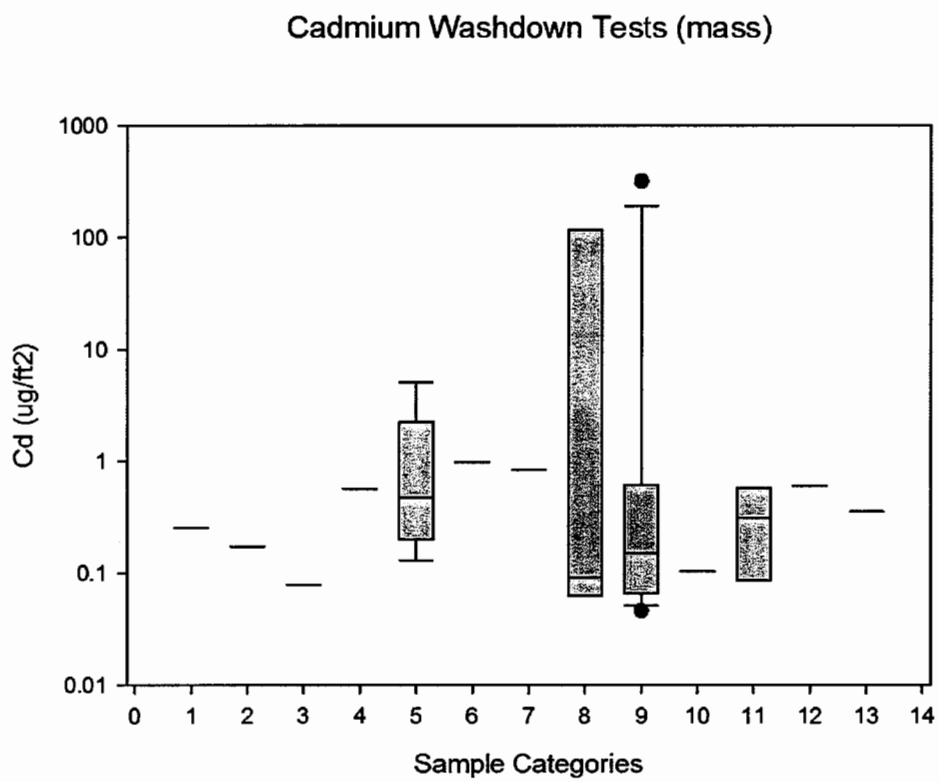
Summary Statistics for Cadmium Concentration Grouped Categories

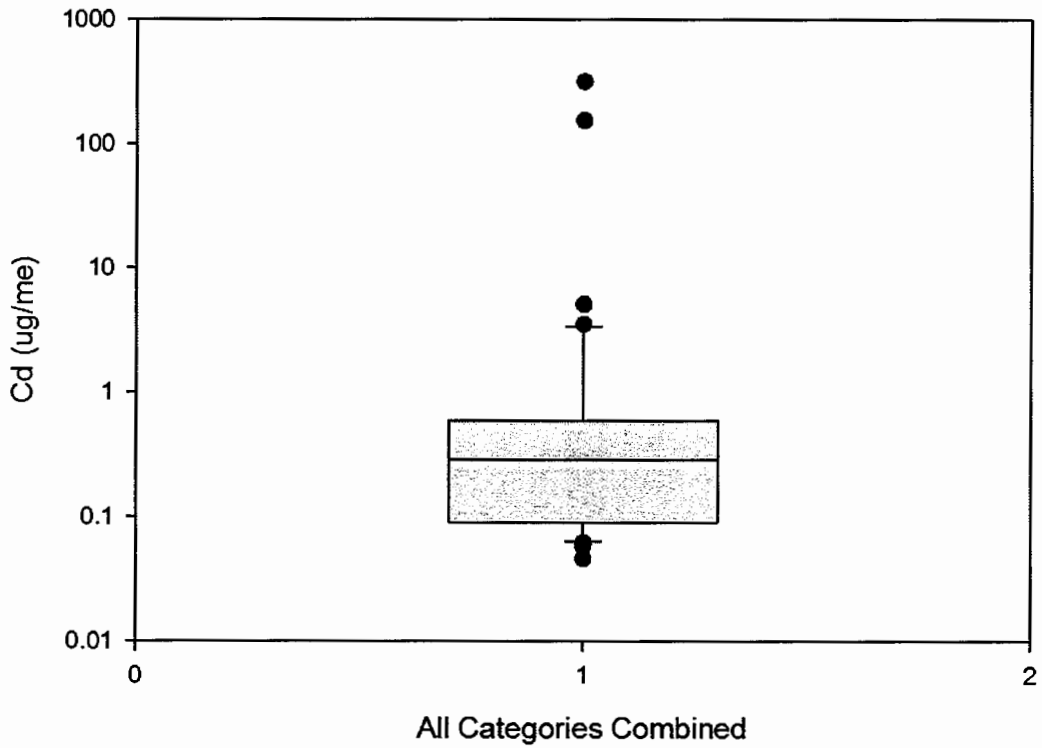
	All combined
number	40
min	0.05
max	160
average	7.7
median	0.18
st dev	33
COV	4.2

Cadmium Washdown Mass (μg/ft^2)

Grouped Category:	other	other	other	other	other	other	other	other	other	other	other	other	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	0.3	0.2	0.1	0.6	0.4	1.8	0.8	0.1	0.0	0.1	0.1	0.6	0.4
					1.0	0.2		154.4	316.6	0.1	0.6		
					0.1			0.1	0.2		0.3		
					5.1			0.1	0.1				
					0.3				0.5				
					3.5				2.3				
					0.5				0.1				
					0.5				0.6				
					0.1				0.1				
									0.7				
									0.4				
									0.1				
									0.1				
Sample Category:	Al ramp	artifical turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1.0	1.0	1.0	1.0	9.0	2.0	1.0	4.0	13.0	2.0	3.0	1.0	1.0
min					0.1	0.2		0.1	0.0	0.1	0.1		
max					5.1	1.8		154	317	0.1	0.6		
average					1.3	1.0		38.7	24.7	0.1	0.3		
median	0.3	0.2	0.1	0.6	0.5	1.0	0.8	0.1	0.2	0.1	0.3	0.6	0.4
st dev					1.8	1.1		77.2	87.7	0.0	0.2		
COV					1.4	1.2		2.0	3.5	0.4	0.8		

One bare metal and one painted metal had very high Cd washdown masses (>150 μg/ft^2); two bare galv, one painted galv, and one painted metal had a moderate washdown Cd mass (1.7 to 5.1 μg/ft^2); all the others were <1 μg/ft^2. Combined together as no significant groupings identified.





Summary Statistics for Cadmium Mass Grouped Categories

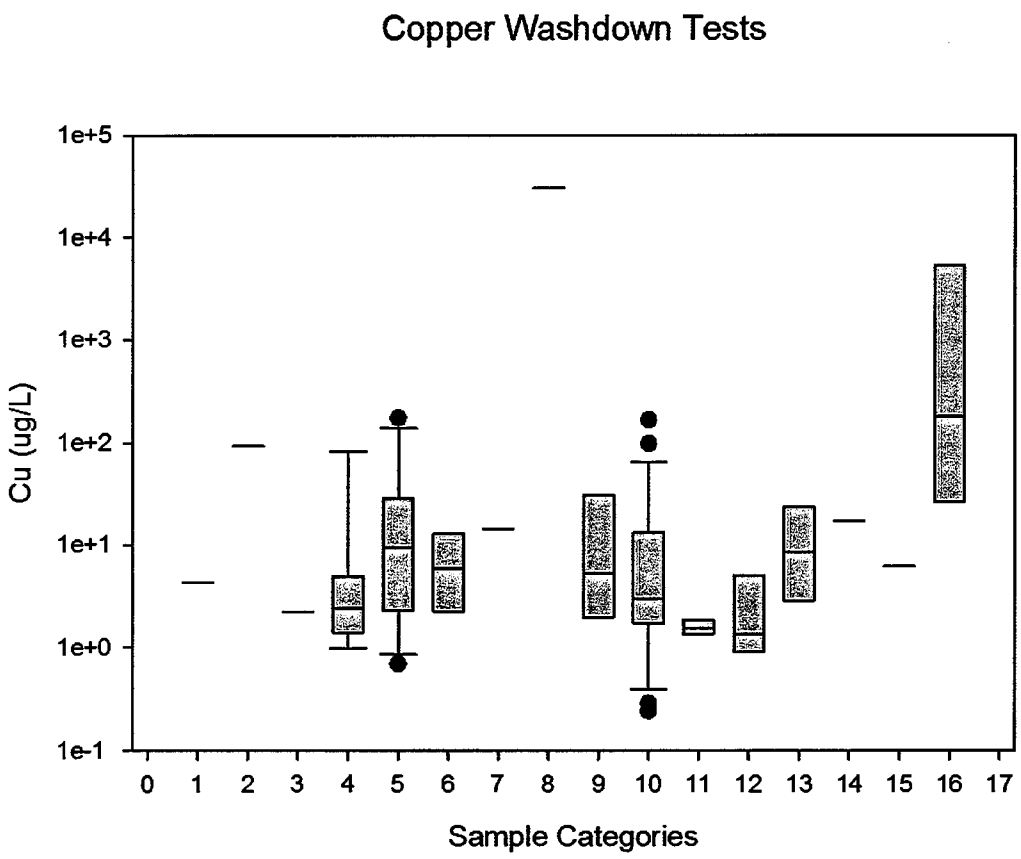
	All Combined
number	40
min	0.05
max	316
average	12.3
median	0.29
st dev	55
COV	4.5

Copper

Copper Washdown Concentrations (µg/L)

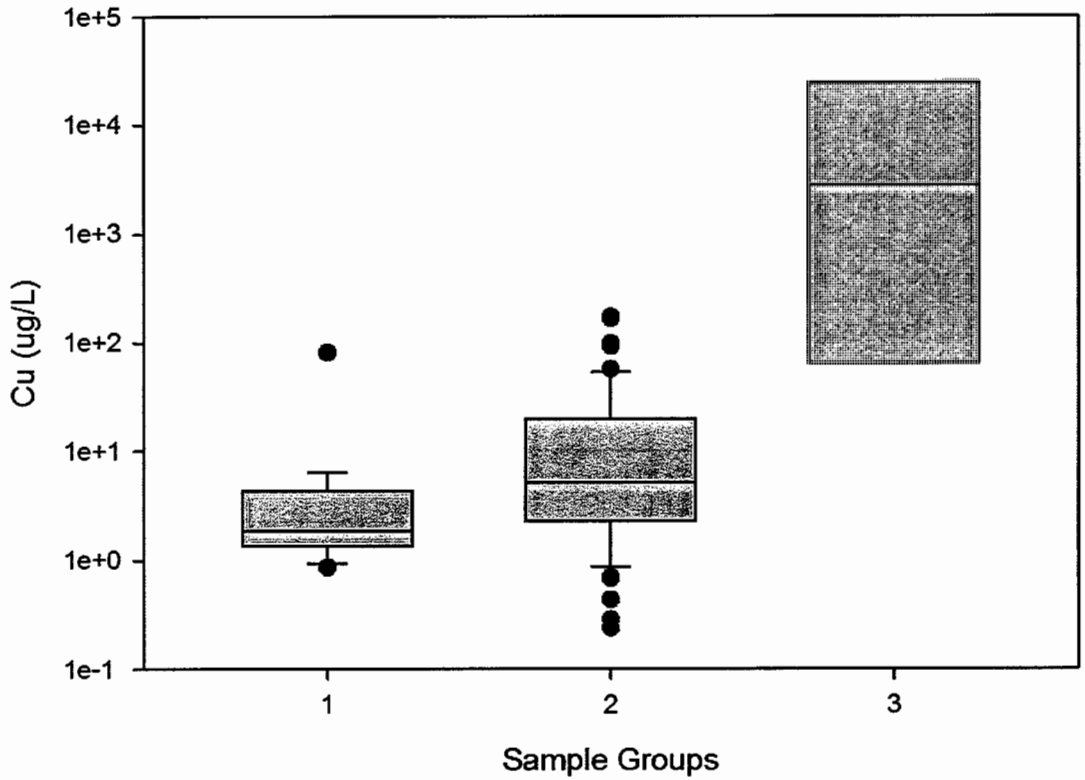
Grouped Category:	low	other	low	low	other	other	other	high	other	other	low	low	other	other	other	high
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
	4	93	2	81	1	6	15	30,334	57	42	2	5	1	17	6	5,417
				1	2	13			5	12	2	5	20			179
				2	29	2			1	4	1	1	6			27
				2	7				3	51		1	34			
				1	2				5	10		1	11			
				1	1					4			3			
				3	3					98						
				6	52					167						
				4	12					3						
					27					3						
					174					3						
					22					2						
										1						
										2						
										24						
										3						
										1						
										19						
										0						
										11						
										2						
										0						
										0						
										3						
										3						
										3						
Grouped Category:	low	other	low	low	other	other	other	high	other	other	low	low	other	other	other	high
Sample	Al	artificial	brick	concrete	galv	galv	galv	barge	metal	metal	plaster	roof	rubber	wood	wood	wood

Category:	ramp	turf	wall		bare	painted	coated	hull	bare	painted				bare	painted	treated
number	1	1	1	9	12	3	1	1	5	26	3	5	6	1	1	3
min				1	1	2			1	0	1	1	1			27
max				81	174	13			57	167	2	5	34			5,417
average				11	28	7			14	18	2	3	13			1,874
median	4	93	2	2	9	6	15	30,334	5	3	2	1	9	17	6	179
st dev				26	49	5			24	37	0	2	13			3,069
COV				2.3	1.8	0.8			1.7	2.1	0.2	0.8	1.0			1.6


Copper Washdown Tests
Cu (ug/L)
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Cu concentrations)

Kruskal-Wallis One Way Analysis of Variance on Ranks	Sunday, August 04, 2013, 4:39:28 PM				
Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	19	0	1.866	1.346	4.301
all others	56	0	5.25	2.293	19.969
high	4	0	2797.907	64.806	24104.41
H = 15.654 with 2 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)					
To isolate the group or groups that differ from the others use a multiple comparison procedure.					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
high vs low	47.605	3.771	Yes		
high vs all others	32.518	2.738	Yes		
all others vs low	15.087	2.476	Yes		


1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
Cu (ug/L)
1
2
3
Sample Groups

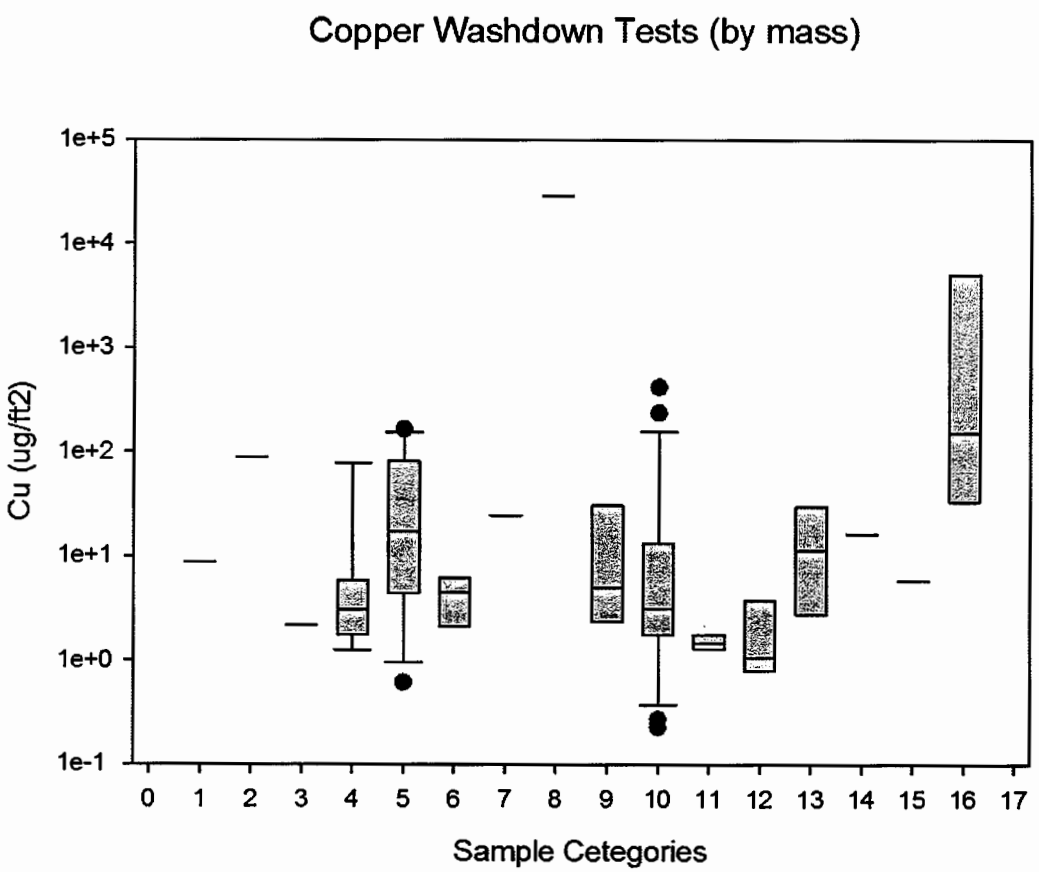
Summary Statistics for Copper Concentration Grouped Categories

Grouped category:	low	all others	high
Sample Category in Groups:	Al ramp brick wall concrete plaster roof	artificial turf galv bare galv painted galv coated metal bare metal painted rubber wood bare wood painted	barge hull wood treated
number	19	47	4
min	1	0	27
max	81	174	30334
average	7	21	8989
median	2	4	2798
st dev	18	39	14449
COV	2.7	1.8	1.6

Copper Washdown Mass (µg/ft2)

Grouped Category:	others	others	low	low	others	low	others	high	others	others	low	low	others	others	others	high
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
	9	88	2	77	5	5	24	28,703	7	40	2	3	1	16	6	5,125
				2	2	6			54	12	1	4	33			153
				2	28	2			1	4	1	1	7			34
				3	7				4	122		1	29			
				1	7				5	9		1	16			
				2	1					4			3			
				4	4					237						
				8	131					420						
				3	34					3						
					93					2						
					164					2						
					44					2						
										1						
										2						
										16						
										2						
										1						
										95						
										0						
										9						
										4						
										0						
										0						
										3						
										3						
										3						
Grouped Category:	others	others	low	low	others	low	others	high	others	others	low	low	others	others	others	high
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
number	1	1	1	9	12	3	1	1	5	26	3	5	6	1	1	3

min				1	1	2			1	0	1	1	1			34
max				77	164	6			54	420	2	4	33			5,125
average				11	43	4			14	38	2	2	15			1,771
median	9	88	2	3	17	5	24	28,703	5	3	1	1	11	16	6	153
st dev				25	56	2			22	94	0	2	13			2,906
COV				2.2	1.3	0.5			1.6	2.5	0.2	0.8	0.9			1.6


Copper Washdown Tests (by mass)
Cu (ug/ft2)
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Sample Cetegories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Cu mass)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	21	0	2.133	1.37	3.848
others	54	0	6.198	2.395	30.124
high	4	0	2639.045	63.388	22808.8
H = 16.060 with 2 degrees of freedom. (P = <0.001)					

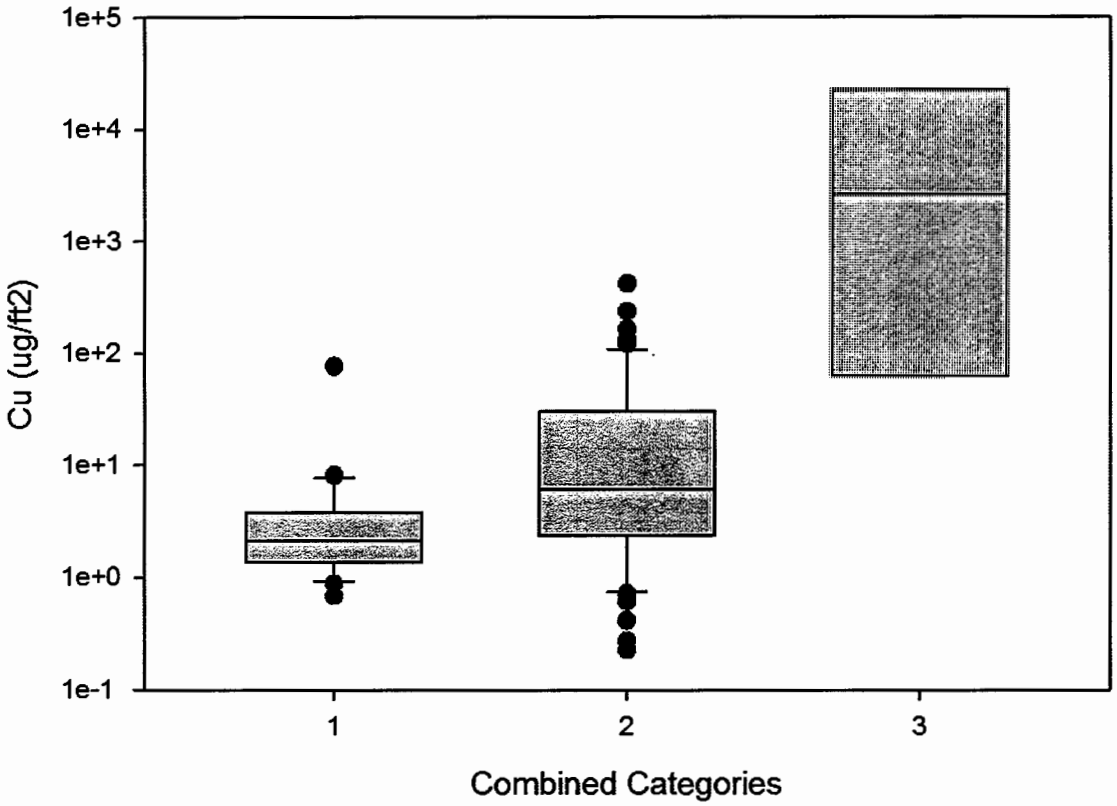
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	Q	P<0.05
high vs low	46.595	3.722	Yes
high vs others	30.889	2.597	Yes
others vs low	15.706	2.661	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.


1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
Cu (ug/ft2)
1
2
3
Combined Categories

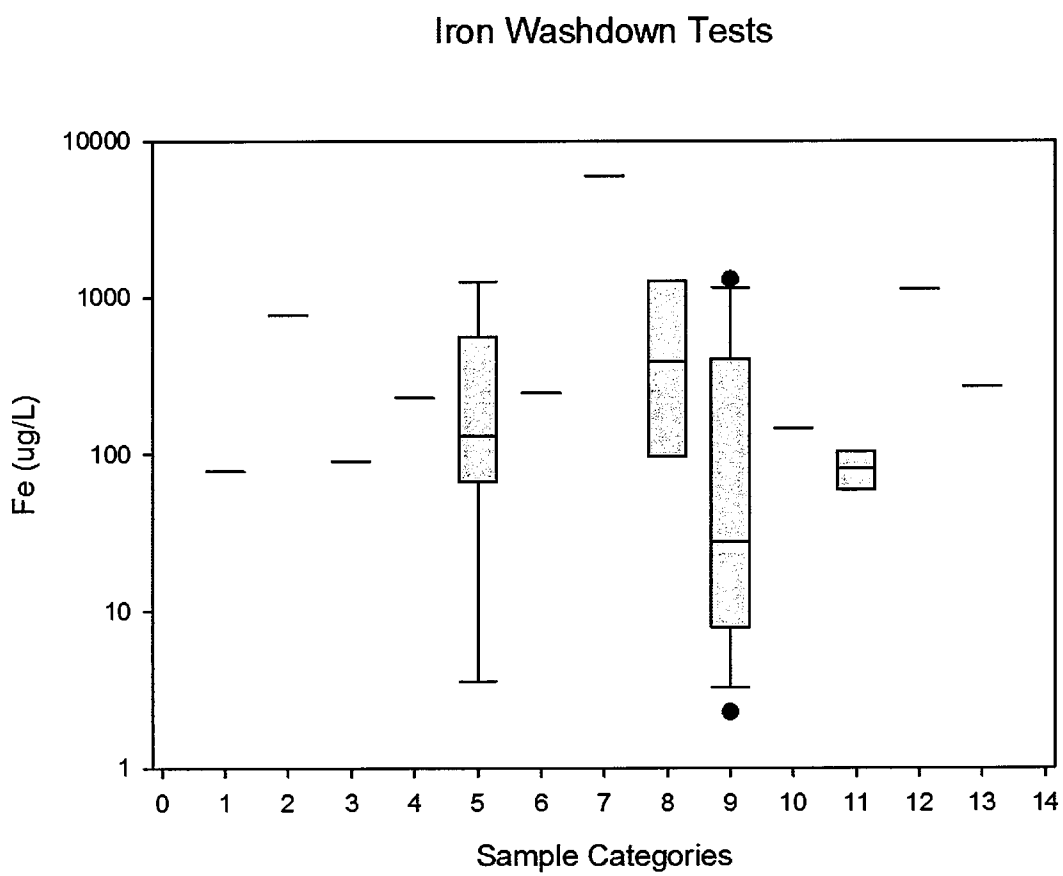
Summary Statistics for Copper Mass Grouped Categories

Grouped Category:	low	others	high
Sample Categories in Groups:	brick wall concrete galv painted plaster roof	Al ramp artificial turf galv bare galv coated metal bare metal painted rubber wood bare wood painted	barge hull wood treated
number	21	54	4
min	1	0	34
max	77	420	28,703
average	6	34	8,504
median	2	6	2,639
st dev	16	71	13,674
COV	2.6	2.1	1.6

Iron

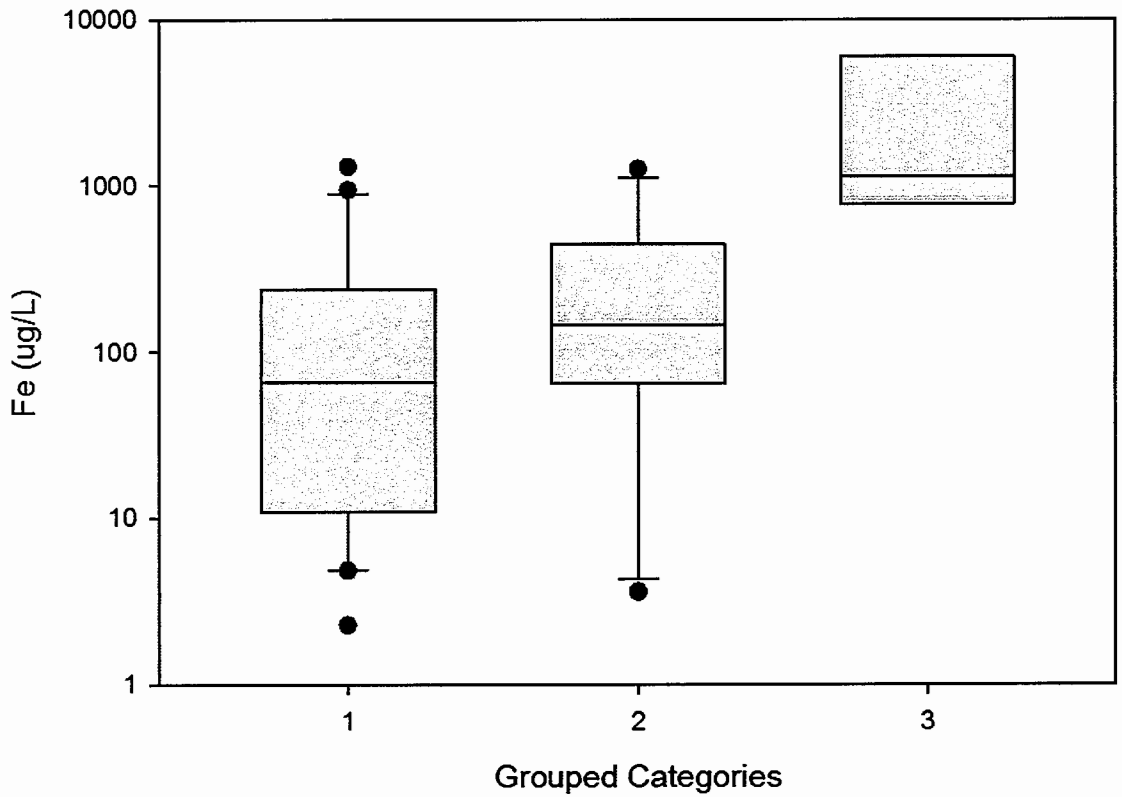
Iron Washdown Concentrations (µg/L)

Fe (µg/L)	low	high	low	other	other	other	high	other	low	low	low	high	other
	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	78	769	90	227	71	480	5,995	373	16	281	59	1,135	269
					783	6		399	393	6	103		
					158			4	28		81		
					63			1,571	10				
					4				46				
					332				1,301				
					74				74				
					131				412				
					1,258				6				
									938				
									13				
									5				
									2				
Grouped Category:	low	high	low	other	other	other	high	other	low	low	low	high	other
Fe (µg/L)	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					4	6		4	2	6	59		
max					1,258	480		1,571	1,301	281	103		
average					319	243		587	249	143	81		
median	78	769	90	227	131	243	5,995	386	28	143	81	1,135	269
st dev					425	335		680	418	194	22		
COV					1.3	1.4		1.2	1.7	1.4	0.3		


Iron Washdown Tests
10000
1000
100
10
1
Fe (ug/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Fe concentrations)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	20	0	66.461	10.813	236.464
others	12	0	144.818	64.608	443.176
high	3	0	1134.599	768.534	5995.28
H = 7.405 with 2 degrees of freedom. (P = 0.025)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.025)					
To isolate the group or groups that differ from the others use a multiple comparison procedure.					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
high vs low	16.9	2.664	Yes		
high vs others	12.667	1.915	No		
others vs low	4.233	1.131	No		
Note: The multiple comparisons on ranks do not include an adjustment for ties.					

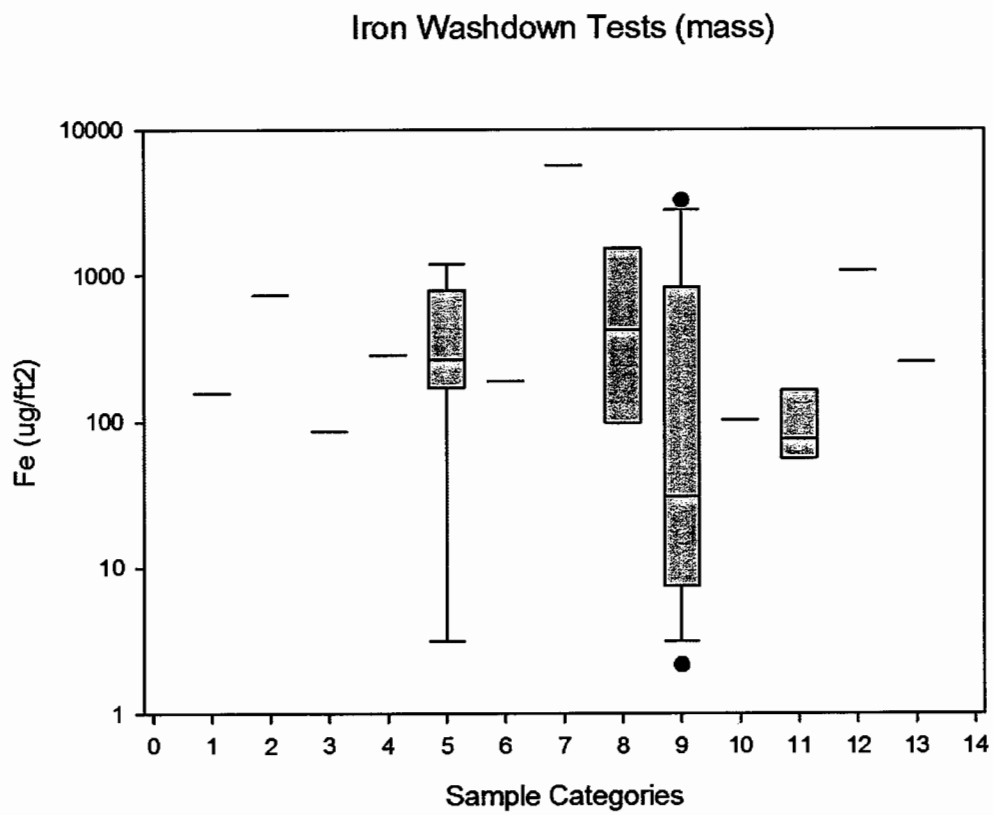

10000
1000
100
10
1
Fe (ug/L)
1
2
3
Grouped Categories

Summary Statistics for Iron Concentration Grouped Categories

Grouped category:	low	others	high
Sample Category in Groups:	Al ramp brick wall metal painted roof rubber	concrete galv bare galv painted metal bare wood treated	artificial turf barge hull wood bare
number	20	12	3
min	2	4	769
max	1,301	1,258	5,995
average	197	299	2,633
median	66	145	1,135
st dev	344	378	2,918
COV	1.7	1.3	1.1

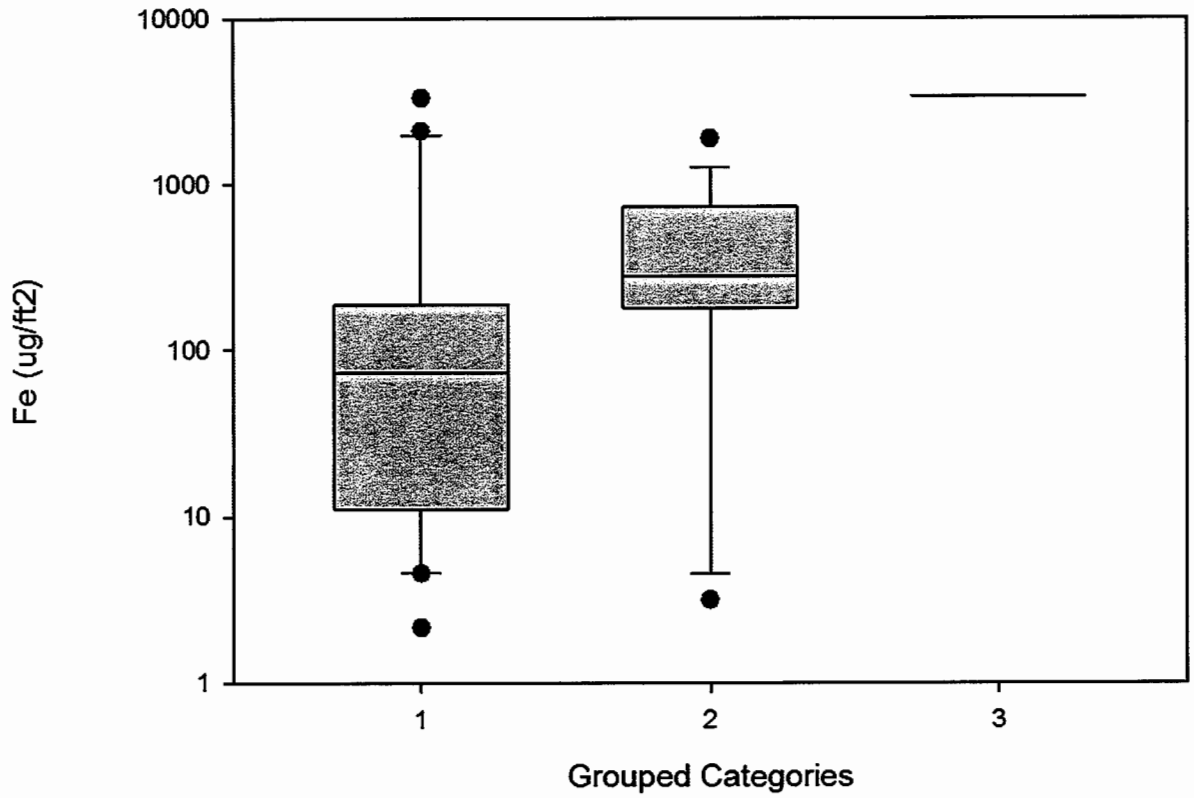
Iron Washdown Mass (µg/ft2)

	low	other	low	other	other	other	high	other	low	low	low	high	other
	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	157	727	85	286	267	372	5,673	471	15	199	56	1,074	254
					741	6		378	949	6	165		
					150			5	26		76		
					190			1,882	10				
					3				110				
					839				3,282				
					212				70				
					265				2,078				
					1,191				5				
									710				
									30				
									5				
									2				
	low	other	low	other	other	other	high	other	low	low	low	high	other
	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					3	6		5	2	6	56		
max					1,191	372		1,882	3,282	199	165		
average					429	189		684	561	103	99		
median	157	727	85	286	265	189	5,673	424	30	103	76	1,074	254
st dev					397	259		824	1,018	137	58		
COV					0.9	1.4		1.2	1.8	1.3	0.6		


Iron Washdown Tests (mass)
10000
1000
100
10
1
Fe (ug/ft2)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Fe mass)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	20	0	73.065	11.011	190.947
others	18	0	276.548	179.659	730.653
high	2	0	3373.324	1073.614	5673.034
H = 8.140 with 2 degrees of freedom. (P = 0.017)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.017)					
To isolate the group or groups that differ from the others use a multiple comparison procedure.					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
high vs low	21.35	2.463	Yes		
high vs others	14.056	1.613	No		
others vs low	7.294	1.921	No		
Note: The multiple comparisons on ranks do not include an adjustment for ties.					


10000
1000
100
10
1
Fe (ug/ft2)
1
2
3
Grouped Categories

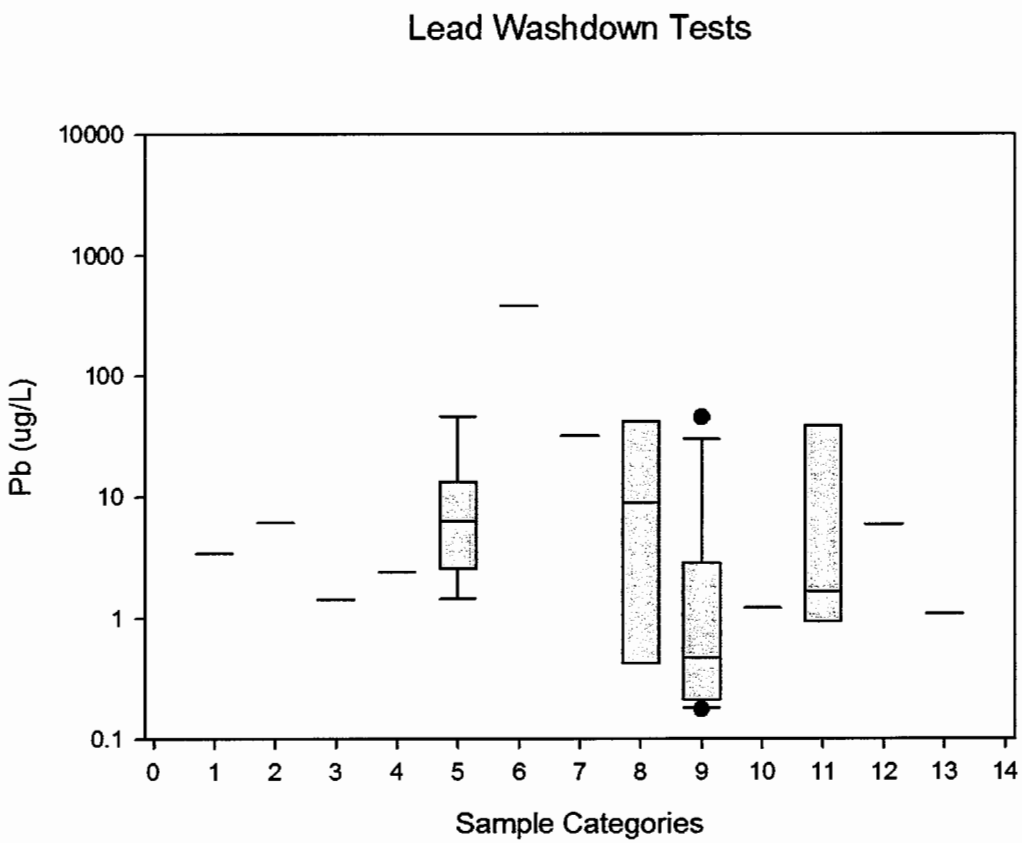
Summary Statistics for Iron Mass Grouped Categories

Grouped Category:	low	others	high
Sample Categories in Groups:	Al ramp brick wall metal painted roof rubber	artificial turf concrete galv bare galv painted metal bare wood treated	barge hull wood bare
number	20	18	2
min	2	3	1,074
max	3,282	1,882	5,673
average	402	458	3,373
median	73	277	3,373
st dev	840	477	3,252
COV	2.1	1.0	1.0

Lead

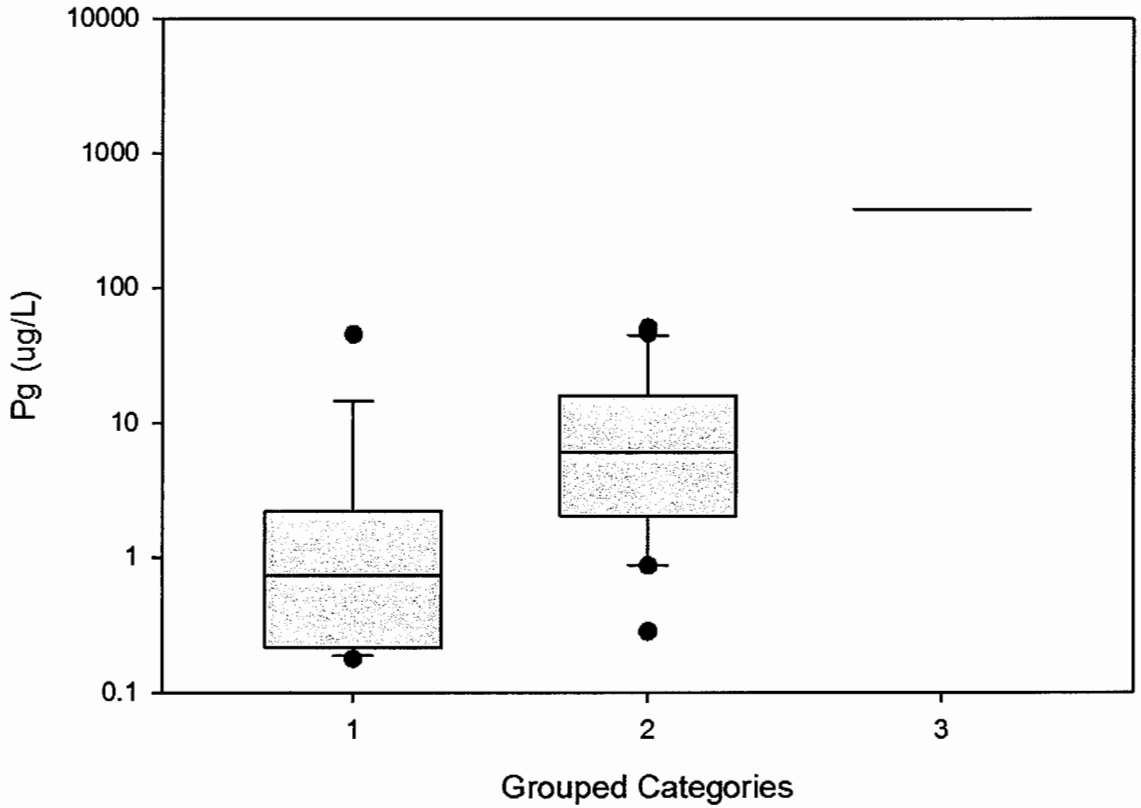
Lead Washdown Concentrations (µg/L)

Grouped Category:	other	other	low	other	other	high	other	other	low	low	other	other	low
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	3.4	6.2	1.4	2.4	1.4	764.0	31.9	0.3	0.2	2.2	0.9	6.0	1.1
					46.2	1.5		50.7	3.6	0.2	38.5		
					2.7			17.1	0.7		1.7		
					12.1			0.9	0.5				
					4.2				2.1				
					14.6				45.3				
					6.4				0.2				
					10.5				1.8				
					2.4				0.2				
									6.7				
									0.3				
									0.2				
									0.2				
Grouped Category:	other	other	low	other	other	high	other	other	low	low	other	other	low
Pb (µg/L)	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					1.4	1.5		0.3	0.2	0.2	0.9		
max					46.2	764.0		50.7	45.3	2.2	38.5		
average					11.2	382.8		17.3	4.8	1.2	13.7		
median	3.4	6.2	1.4	2.4	6.4	382.8	31.9	9.0	0.5	1.2	1.7	6.0	1.1
st dev					13.9	539.2		23.6	12.3	1.4	21.5		
COV					1.2	1.4		1.4	2.6	1.2	1.6		


Lead Washdown Tests
10000
1000
100
10
1
0.1
Pb (ug/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Pb concentrations

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	17	0	0.735	0.216	2.186
other	21	0	6.002	2.03	15.841
high	2	0	382.757	1.514	764
H = 11.673 with 2 degrees of freedom. (P = 0.003)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.003)					

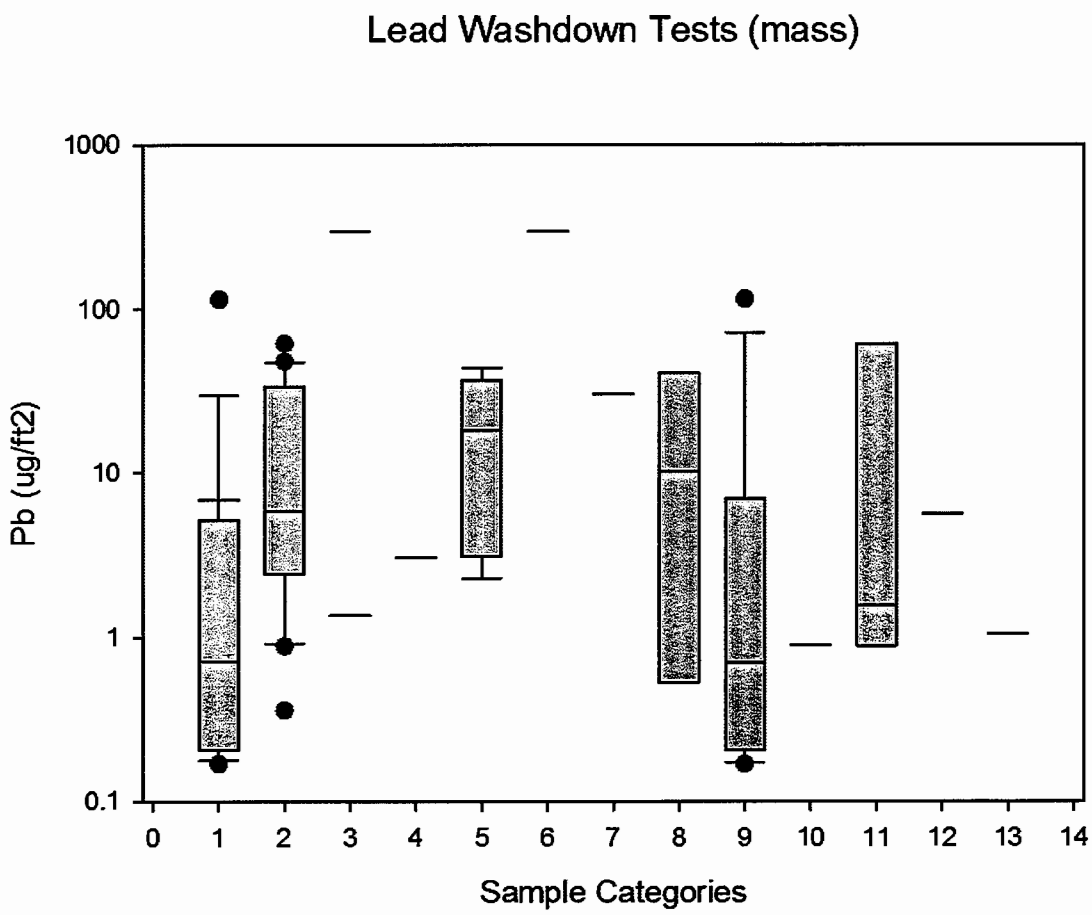

10000
1000
100
10
1
0.1
Pg (ug/L)
1
2
3
Grouped Categories

Summary Statistics for Lead Concentration Grouped Categories

Grouped category:	low	others	high
Sample Category in Groups:	brick wall metal painted roof wood treated	Al ramp artificial turf concrete galv bare barge hull metal bare rubber wood bare	galv painted
number	17	21	2
min	0.2	0.3	1.5
max	45.3	50.7	764.0
average	3.9	12.4	382.8
median	0.7	6.0	382.8
st dev	10.8	15.7	539.2
COV	2.7	1.3	1.4

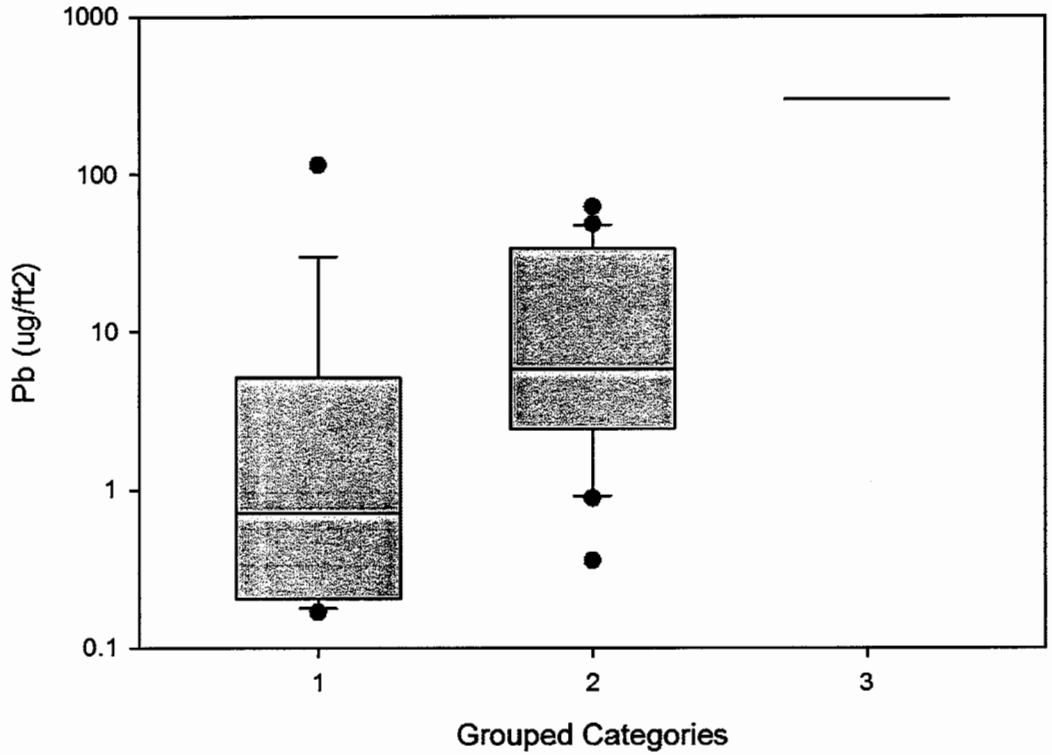
Lead Washdown Mass (µg/ft2)

Grouped Category:	other	other	low	other	other	high	other	other	low	low	other	other	low
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
	6.9	5.8	1.4	3.1	5.5	592.6	30.2	0.4	0.2	1.6	0.9	5.7	1.0
					43.7	1.4		48.0	8.7	0.2	61.8		
					2.6			19.5	0.7		1.6		
					36.7			1.0	0.4				
					3.6				5.2				
					36.7				114.4				
					18.1				0.2				
					21.1				8.8				
					2.3				0.2				
									5.1				
									0.7				
									0.2				
									0.2				
Grouped Category:	other	other	low	other	other	high	other	other	low	low	other	other	low
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	barge hull	metal bare	metal painted	roof	rubber	wood bare	wood treated
number	1	1	1	1	9	2	1	4	13	2	3	1	1
min					2.3	1.4		0.4	0.2	0.2	0.9		
max					43.7	592.6		48.0	114.4	1.6	61.8		
average					18.9	297.0		17.2	11.2	0.9	21.4		
median	6.9	5.8	1.4	3.1	18.1	297.0	30.2	10.2	0.7	0.9	1.6	5.7	1.0
st dev					16.6	418.0		22.4	31.2	1.0	35.0		
COV					0.9	1.4		1.3	2.8	1.1	1.6		


Lead Washdown Tests (mass)
1000
100
10
1
0.1
Pb (ug/ft2)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Pb mass

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	17	0	0.705	0.204	5.129
others	21	0	5.82	2.438	33.43
high	2	0	297.001	1.433	592.57
H = 10.049 with 2 degrees of freedom. (P = 0.007)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.007)					


1000
100
10
1
0.1
Pb (ug/ft2)
1
2
3
Grouped Categories

Summary Statistics for Lead Mass Grouped Categories

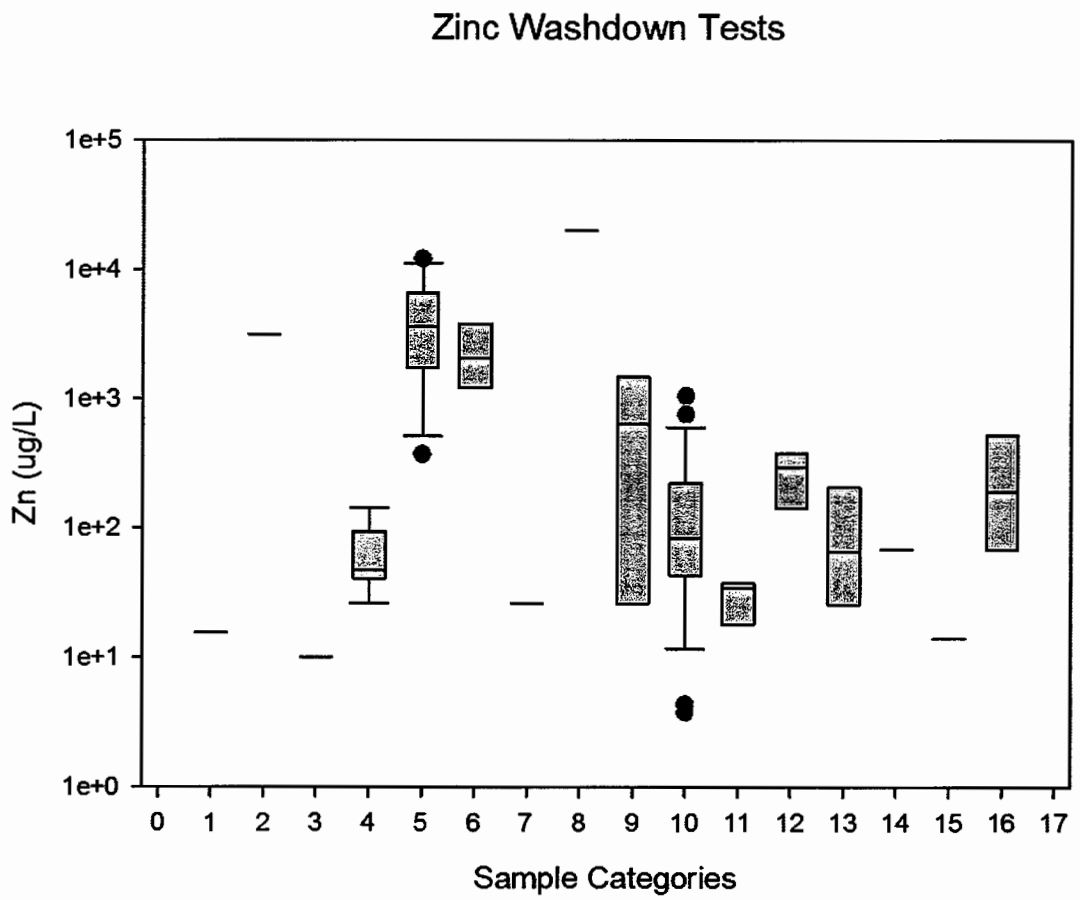
Grouped Category:	low	others	high
Sample Categories in Groups:	brick wall metal painted roof wood treated	Al ramp artificial turf concrete galv bare barge hull metal bare rubber wood bare	galv painted
number	17	21	2
min	0.2	0.4	1.4
max	114.4	61.8	592.6
average	8.8	16.9	297.0
median	0.7	5.8	297.0
st dev	27.4	18.7	418.0
COV	3.1	1.1	1.4

Zinc

Zinc Washdown Concentrations (µg/L)

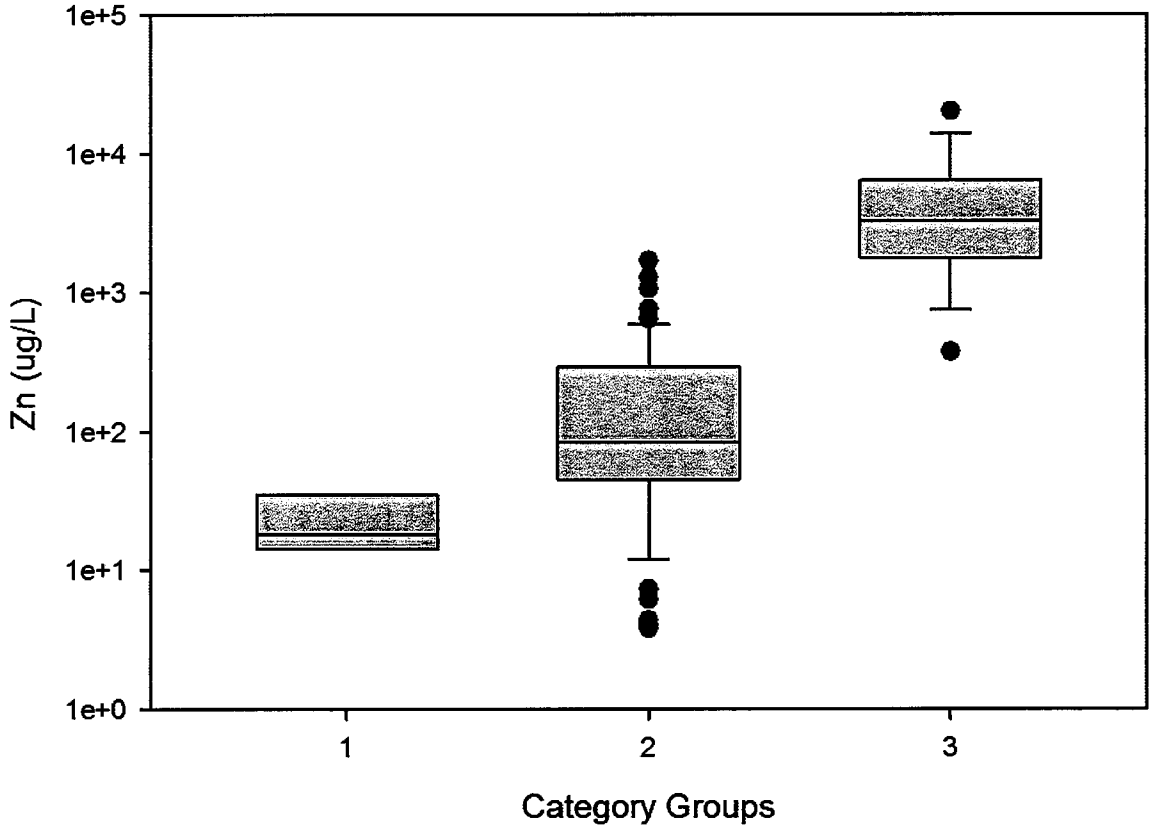
Grouped Category:	low	high	low	other	high	high	low	high	other	other	low	other	other	other	low	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
	16	3,155	10	127	377	1,216	27	20,269	7	1,070	38	284	6	70	14	69
				63	6,942	3,855			650	86	35	447	148			534
				55	9,214	2,062			45	85	18	320	45			193
				48	3,287				1,705	547		304	401			
				47	4,112				1,290	118		4	89			
				41	850					15			33			
				41	4,097					85						
				27	12,281					548						
				142	3,261					293						
					5,907					73						
					1,491					48						
					2,417					46						
										36						
										66						
										33						
										96						
										78						
										4						
										151						
										79						
										15						
										4						
										440						
										205						
										121						
										768						

Grouped Category:	low	high	low	other	high	high	low	high	other	other	low	other	other	other	low	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
number	1	1	1	9	12	3	1	1	5	26	3	5	6	1	1	3
min				27	377	1,216			7	4	18	4	6			69
max				142	12,281	3,855			1,705	1,070	38	447	401			534
average				66	4,520	2,378			740	197	30	272	120			265
median	16	3,155	10	48	3,692	2,062	27	20,269	650	85	35	304	67	70	14	193
st dev				40	3,539	1,347			752	266	11	163	146			241
COV				0.6	0.8	0.6			1.0	1.4	0.4	0.6	1.2			0.9


Zinc Washdown Tests
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
Zn (ug/L)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Zn concentrations)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	7	0	18.094	14.203	35.11
others	55	0	84.609	44.581	292.835
high	17	0	3286.721	1776.302	6424.577
H = 43.131 with 2 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)					
To isolate the group or groups that differ from the others use a multiple comparison procedure.					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
high vs low	58.429	5.669	Yes		
high vs others	35.655	5.599	Yes		
others vs low	22.774	2.473	Yes		
Note: The multiple comparisons on ranks do not include an adjustment for ties.					


1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
Zn (ug/L)
1
2
3
Category Groups

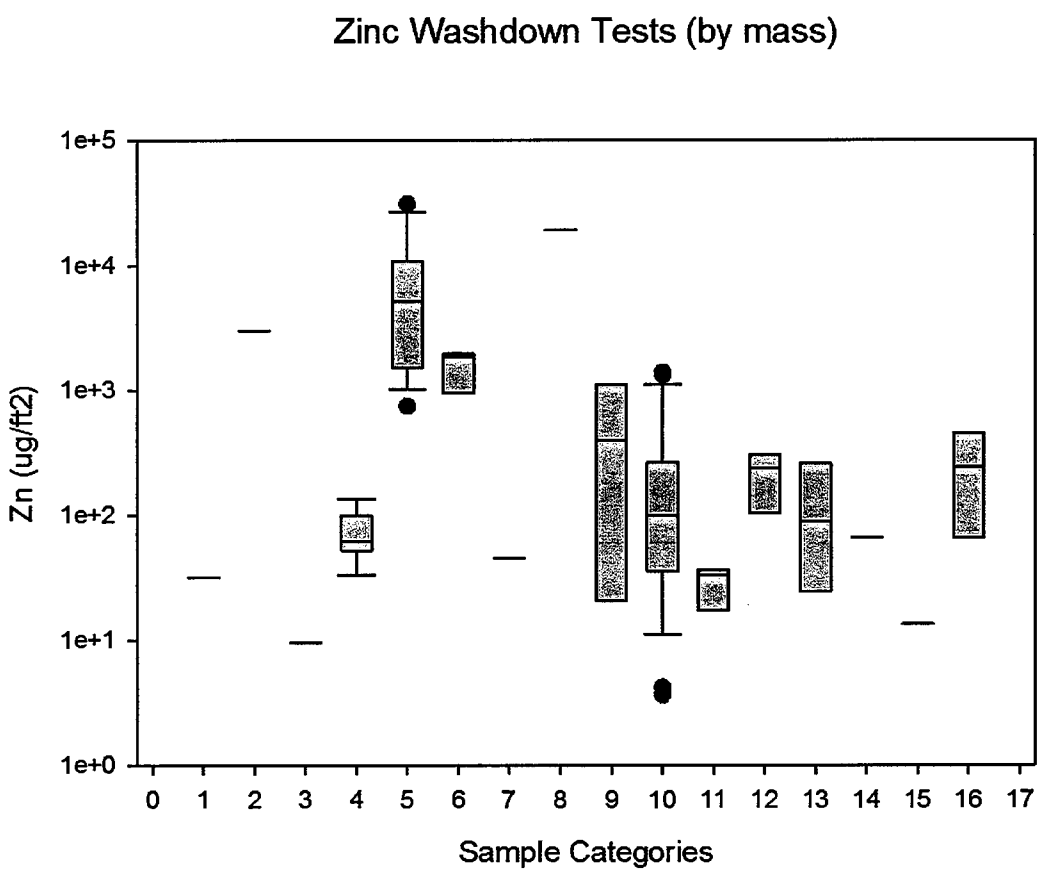
Summary Statistics for Zinc Concentration Grouped Categories

Grouped category:	low	all others	high
Sample Category in Groups:	Al ramp brick wall galv coated plaster wood painted	concrete metal bare metal painted roof rubber wood bare wood treated	artificial turf galv bare galv painted barge hull
number	7	51	17
min	10	4	377
max	38	1,705	20,269
average	23	225	4,988
median	18	85	3,287
st dev	11	343	5,008
COV	0.5	1.5	1.0

Zinc Washdown Mass (µg/ft2)

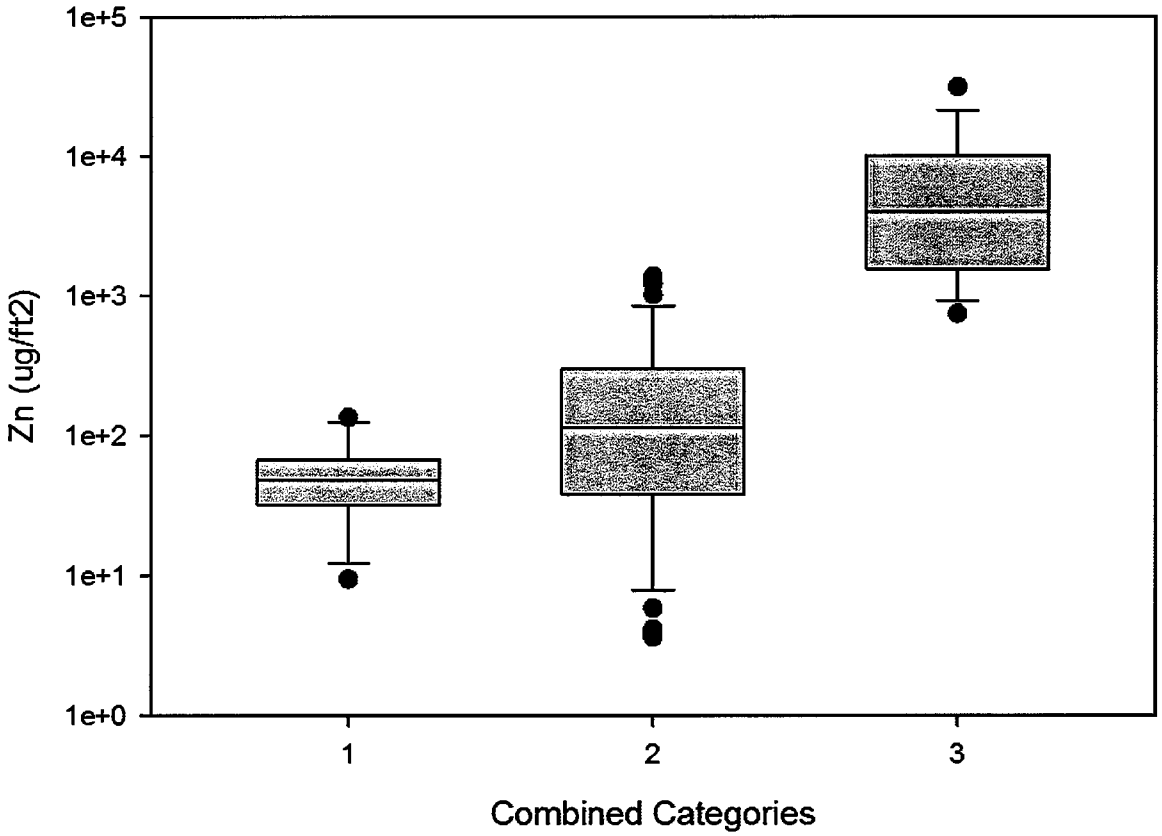
Grouped Category:	low	high	low	low	high	high	low	high	other	other	low	other	other	other	low	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
	32	2,986	9	120	1,427	944	45	19,180	9	1,012	36	202	6	66	13	66
				79	5,375	1,824			1,221	89	33	353	237			455
				70	8,719	1,951			739	80	17	253	54			243
				61	3,110				54	1,319		240	343			
				59	12,451					111		4	124			
				52	743					14			31			
				52	5,169					206						
				34	30,990					1,382						
				135	9,279					727						
					20,123					222						
					1,411					55						
					4,879					36						
					1,613					35						
										41						
										44						
										31						
										78						
										395						
										4						
										115						
										191						
										14						
										4						
										416						
										194						
										114						

Grouped Category:	low	high	low	low	high	high	low	high	other	other	low	other	other	other	low	other
Sample Category:	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
number	1	1	1	9	13	3	1	1	4	26	3	5	6	1	1	3
min				34	743	944			9	4	17	4	6			66
max				135	30,990	1,951			1,221	1,382	36	353	343			455
average				73	8,099	1,573			506	267	29	210	132			254
median	32	2,986	9	61	5,169	1,824	45	19,180	397	100	33	240	89	66	13	243
st dev				33	8,784	549			582	396	10	128	132			195
COV				0.5	1.1	0.3			1.2	1.5	0.4	0.6	1.0			0.8


Zinc Washdown Tests (by mass)
Zn (ug/ft2)
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Sample Categories

Kruskal-Wallis One Way Analysis of Variance on Ranks (Zn mass)

Normality Test (Shapiro-Wilk)	Failed	(P < 0.050)			
Group	N	Missing	Median	25%	75%
low	16	0	48.381	32.152	67.343
others	45	0	114.072	38.359	297.853
high	18	0	3994.475	1566.44	10072.18
H = 43.608 with 2 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)					
To isolate the group or groups that differ from the others use a multiple comparison procedure.					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
high vs low	48.306	6.126	Yes		
high vs others	35.589	5.561	Yes		
others vs low	12.717	1.904	No		
Note: The multiple comparisons on ranks do not include an adjustment for ties.					


1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
Zn (ug/ft2)
1
2
3
Combined Categories

Summary Statistics for Zinc Mass Grouped Categories

Grouped Category:	low	others	high
Sample Categories in Groups:	Al ramp brick wall concrete galv coated plaster wood painted	metal bare metal painted roof rubber wood bare wood treated	artificial turf galv bare galv painted barge hull
number	16	45	18
min	9	4	743
max	135	1,382	30,990
average	53	258	7,343
median	48	114	3,994
st dev	35	355	8,377
COV	0.7	1.4	1.1

Summary of Washoff Tests

Due to the varying number of observations for the different material categories, some of the test statistics are incomplete, but they do enable the identification of the types of materials of greatest interest. The following table summarizes the "low," "other," and "high" categories for each sample type and metal. In almost all cases, the concentration and mass washoff categories are the same; for the few that differ, the differences are not large (low/other or other/high). Most of these groupings are obvious and as expected, such as the bare galvanized metal being the highest category for zinc, and the aluminum ramp being the highest for aluminum. Other findings are interesting and potentially important, such as:

- Aluminum ramp high for aluminum (as expected)
- Artificial turf high for zinc and possibly high for iron, possibly due to recycled rubber tire crumbles used to support artificial grass leaves
- Bare galvanized metal high for zinc (as expected)
- Painted galvanized metal high for zinc, and high for aluminum and lead (the aluminum and lead are higher than for bare galvanized materials, likely due to the metal primers or paints; coated galvanized metals were much lower for all metals)
- Barge hull high for zinc, copper, and iron, possibly associated with anti-fouling paints
- Bare wood high for aluminum and iron
- Treated wood high for copper (as expected)

The high metals associated the artificial turf and the high metals associated with the barge hull are important findings, but are only represented by single samples. Additional sample collections representing these two categories are therefore highly recommended to determine if these findings are consistent.

Summary of Washdown Tests for Various Materials

	Al ramp	artificial turf	brick wall	concrete	galv bare	galv painted	galv coated	barge hull	metal bare	metal painted	plaster	roof	rubber	wood bare	wood painted	wood treated
Zn conc	low	high	low	other	high	high	low	high	other	other	low	other	other	other	low	other
Zn mass	low	high	low	low	high	high	low	high	other	other	low	other	other	other	low	other
Cu conc	low	other	low	low	other	other	other	high	other	other	low	low	other	other	other	high
Cu mass	others	others	low	low	others	low	others	high	others	others	low	low	others	others	others	high
Al conc	high	other	other	other	other	high	n/a	other	other	low	n/a	other	low	high	n/a	other
Al mass	high	other	other	other	other	high	n/a	other	low	low	n/a	other	low	high	n/a	other
Fe conc	low	high	low	other	other	other	n/a	high	other	low	n/a	low	low	high	n/a	other
Fe mass	low	other	low	other	other	other	n/a	high	other	low	n/a	low	low	high	n/a	other
Cd conc	other	other	other	other	other	other	n/a	other	other	other	n/a	other	other	other	n/a	other
Cd mass	other	other	other	other	other	other	n/a	other	other	other	n/a	other	other	other	n/a	other
Pb conc	other	other	low	other	other	high	n/a	other	other	low	n/a	low	other	other	n/a	low
Pb mass	other	other	low	other	other	high	n/a	other	other	low	n/a	low	other	other	n/a	low

Contaminated Soils Analyses at Navy Facilities

In addition to the washoff tests described above, SPARWARS-PACIFIC personnel also collected several soil and sediment samples, especially from likely contaminated areas. The following photographs are examples of some of these sampling activities.

Contaminated dry soil sampling.

Clean dry soil sampling.

Sampling of accumulated sediment near inlet.

Sampling of sediment in ponded water.

Comparison of Recent Navy Facility Source Area Water Quality Observations with Other Data (WinSLAMM Calibration File Preparation)

The following tables summarize the literature information, along with recent short-term leachate results, and recent washoff test results for different materials likely exposed to rainwater and stormwater. These results are shown as concentrations and as mass losses. The results are not directly comparable due to the different testing conditions used (water chemistries, water volumes, and contact times), but do illustrate typical concentrations that have been observed and identify the most consistently problematic materials.

The most common material associated with elevated heavy metal concentrations are galvanized metals: painted or bare galvanized steel and galvanized aluminum resulting in very high zinc concentrations. The single test for artificial turf also resulted in very high zinc concentrations. Factory coated galvanized materials are shown to usually have much lower resulting zinc concentrations in the leachate or washoff water, if the coatings are in good condition.

Any exposed copper (especially aged patinated copper) also results in very high copper concentrations, but these materials are most likely limited to older roof flashings. Treated wood and special paints used on ship hulls (based on a single barge hull analysis) also result in elevated copper concentrations.

High lead concentrations were reported in the literature and observed during the washoff tests associated with uncoated galvanized materials and some water distribution systems. Some high cadmium concentrations were observed associated with uncoated galvanized steel and drinking water systems. Very high iron concentrations were associated with uncoated galvanized materials, bare wood and painted barge hull (single samples). The highest aluminum concentrations were associated with the exposed aluminum materials and painted galvanized metals.

During the controlled leachate tests, almost all metal concentrations increased dramatically with increased exposure times. The data presented in this section focused on one hour exposure periods, but if materials were exposed for extended periods (such as for water storage tanks or if materials were in ponds or small puddles), then the concentrations could be more than 100 times higher than indicated here. In addition, in most cases, reduced pH (about 5) resulted in much greater concentrations compared to higher pH (about 8) conditions. Lower pH would be associated with roof exposures, while higher pH occurs after runoff flows across most surfaces or is discharged into receiving waters.

These data are used in developing the special WinSLAMM categories for material exposures (mainly exposed galvanized metals and scrapyard/storage yard contaminated soils) and associated expected concentrations from those areas.

Literature, Leaching Tests, and Washoff Data Comparisons for Zinc

	uncoated galvanized steel		coated galvanized steel		painted galvanized steel		uncoated galvanized aluminum		coated galvanized aluminum		water systems with some galv pipe	
	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)
literature	90 to 30,000	2.4 to 8.5	160 to 30,000	0.07 to 15	n/a	n/a	200 to 1,600	n/a	60 to 180	n/a	6 to 2,000	n/a
	galvanized steel		copper		other materials (aluminum, concrete, plastics)							
UA (1 hr exposure)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)						
avg	1,600	0.055	15	0.001	11	0.001						
range	150 to 2,500	0.005 to 0.15	<10 to 30	0 to 0.002	<10 to 15	0.0005 to 0.002						
Navy Washoff Tests	low (Al ramp, brick wall, galv coated, plaster, and wood painted)		others (concrete, metal bare, metal painted, roof, rubber, wood bare, and wood treated)		high (artificial turf, galv bare, galv painted, and barge hull)							
	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)						
avg	23	0.57	53	2.80	5,000	79						
range	10 to 38	0.10 to 1.5	4 to 1,700	0.04 to 15	380 to 20,200	8 to 335						

Literature, Leaching Tests, and Washoff Data Comparisons for Copper

	Uncoated copper roofing		Other roofing materials (galv, Al, vinyl, shakes)		Aged (Patinated) copper		Copper pipes	
	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)
literature	2 to 175	1 to 33	<1 to 250	n/a	900 to 9,000	0.75 to 9	200 to 10,000	3.5 to 8
	galvanized steel		copper		other materials (aluminum, concrete, plastics)			
UA (1 hr exposure)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)		
avg	<1	0.001	360	0.03	15	<0.001		
range	<1	<0.001 to 0.004	50 to 1,000	<0.01 to 0.08	<10 to 30	<0.001		
Navy Washoff Tests	low (Al ramp, brick wall, concrete, plaster, and roof)		others (artificial turf, galv bare, galv painted, galv coated, metal bare, metal painted, rubber, wood bare, and wood painted)		high (barge hull and wood treated)			
	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)		
avg	7	0.06	21	0.37	9,000	91		
range	1 to 81	0.01 to 0.8	0 to 174	0 to 4.5	27 to 30,000	0.4 to 310		

Literature, Leaching Tests, and Washoff Data Comparisons for Lead

	uncoated galvanized steel		uncoated galvanized aluminum		coated galvanized aluminum		painted wood		water distribution systems	
	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)
literature	1 to 2,700	n/a	<0.1 to 6	n/a	<10 to 200	n/a	<2 to 400	n/a	<5 to 1,000	n/a
	galvanized steel		copper		other materials (aluminum, concrete, plastics)					
UA (1 hr exposure)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)				
avg	<5	<0.001	<5	<0.001	<5	<0.001				
range	<5	<0.001	<5	<0.001	<5	<0.001				
Navy Washoff Tests	low (brick wall, metal painted, roof, and wood treated)		others (Al ramp, artificial turf, concrete, galv bare, barge hull, metal bare, rubber, and wood bare)		high (galv painted)					
	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)				
avg	3.9	0.09	12	0.18	380	3.2				
range	0.2 to 45	0.002 to 1.2	0.3 to 51	0.004 to 0.7	1.5 to 770	0.015 to 6.4				

Literature, Leaching Tests, and Washoff Data Comparisons for Cadmium

	uncoated galvanized steel		Drinking water systems	
	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)
literature	<0.02 to 32	15 to 25	<0.02 to 88	n/a
Navy Washoff Tests	all sources			
	concentration (µg/L)	mass loss (g/m^2)		
avg	7.7	0.13		
range	0.05 to 160	0.0005 to 3.4		

Literature, Leaching Tests, and Washoff Data Comparisons for Iron

	uncoated galvanized aluminum		coated galvanized aluminum		drinking water systems	
	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)	concentration (µg/L)	mass loss ($g/m^2/yr$)
literature	18 to 1,700	n/a	6 to 24	n/a	0.06 to 1.4	n/a
Navy Washoff Tests	low (Al ramp, brick wall, metal painted, roof, and rubber)		others (artificial turf, concrete, galv bare, galv painted, metal bare, and wood treated)		high (barge hull and wood bare)	
	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)	concentration (µg/L)	mass loss (g/m^2)
avg	200	4.3	300	4.9	2600	36.6
range	2 to 1,300	0.02 to 36	4 to 1,260	0.03 to 21	770 to 6,000	12 to 62

Literature, Leaching Tests, and Washoff Data Comparisons for Aluminum

Navy Washoff Tests	low (metal painted and rubber)		others (artificial turf, brick wall, concrete, galv bare, barge hull, metal bare, roof, and wood treated)		high (Al ramp and galv painted)	
	concentration (μg/L)	mass loss (g/m^2)	concentration (μg/L)	mass loss (g/m^2)	concentration (μg/L)	mass loss (g/m^2)
avg	172	3.1	230	3.2	770	9.0
range	1.8 to 1,400	0.02 to 37	2.4 to 1,200	0.023 to 12	4 to 1,800	0.04 to 15

Trace Heavy Metal Treatability

The form of the pollutant species plays an important role in selecting an appropriate treatment technology (Clark and Pitt 2012). Many heavy metals are associated predominantly with particulates, and therefore their treatability is influenced by the removal of the associated particulates. The association of heavy metals with particulates depends on pH, oxidation-reduction potential, particulate organic matter. The treatability of stormwater solids and associated heavy metals is dependent on their size (Morquecho, et al. 2005; House, et al. 1993; Li, et al. 2005; Kim and Sansalone, 2008). Sedimentation and physical filtration can be used to remove the particulates with the attached pollutants from stormwater (Pitt, et al. 1996). For sedimentation, the median suspended solids removal efficiency is between 70 and 80% (Clark and Pitt 2012; Hossain, et al. 2005; International Stormwater BMP Database 2011). The sedimentation effectiveness is dependent upon the size of suspended solids. The removal of large suspended solids is efficient; however the suspended solids removal diminishes with the increase of content of smaller particulates (Clark and Pitt 2012; Greb and Bannerman, 1997). The heavy metal removal by sedimentation is very efficient at locations where the particulates are large (highways, for example) and the heavy metals are predominantly associated with the larger particulates (Clark and Pitt 2012; Kim and Sansalone, 2008).

Effectively designed wet detention ponds have restricted short-circuiting and low surface overflow rates (SOR). The sedimentation basins are not very effective for the removal of very small particles (< 2 μm) due to the repulsive forces caused by the negative charges on colloids and clay-sized particles that keep solids in suspension and prevent the particles from settling (Clark and Pitt 2012). The sedimentation can be improved by coagulation/flocculation that neutralized the electrical charges on the particles and causes the solids to settle out. Testing will be necessary since it is impossible to predict the settling of the floc theoretically (Clark and Pitt 2012; Metcalf and Eddy, 2003). For metals that are predominantly associated with particles in the range of colloidal and clay particles (< 1 μm), filtration with a chemically-active media may be necessary if low numeric discharge limits must be met (Clark and Pitt 2012; Pitt and Clark 2010). Sand with oxide coatings can be used to remove colloidal pollutants (Clark and Pitt 2012; Sansalone and Kim 2006).

The removal of dissolved contaminants may be needed due to their high mobility and to meet permit requirements and reduce surface and groundwater contamination potential (Pitt, et al. 1996; Clark and Pitt 2012). Heavy metals in ionic forms are the most bioavailable. The toxicity of a heavy metal is affected by metal bioavailability which is controlled by speciation and partitioning of a metal. Metals in ionic forms are generally more bioreactive than metal complexes. Treatment techniques for metals associated with dissolved fractions include chemical treatment. To remove dissolved metals from stormwater, organic filter media (such as compost or peat), a mix of peat moss and sand, zeolite, and compost can be used. Zn^{2+} is highly reactive and is more amenable to ion exchange.

In physisorption reactions, the electrical bonds between the contaminants and the media are reversible and weak. On the other hand, during chemisorption and precipitation reactions stronger bonds are formed and the pollutant retention is permanent if the solution pH and dissolved oxygen level do not change significantly (Evangelou, 1998; Watts, 1998; Clark and Pitt 2012). Sorption and ion exchange remove pollutants through electrostatic interactions between the media and contaminants (Clark and Pitt 2012). The high sodium content during the snowmelt can regenerate the ion exchanging media and release the already retained heavy metals back into the effluent (Clark and Pitt 2012), in addition to increasing the sodium adsorption ratio (SAR) that can greatly hinder infiltration rates in soils or media having even small amounts of clay. Granular activated carbon (GAC) technology is costly and therefore is not regularly used for stormwater applications, but is used when very low permit limits must be met (Pitt and Clark 2012).

The valence charge of a metal and its complexation, among other contaminant properties, influence the choice of stormwater treatment technology (Clark and Pitt 2012). Strongly charged, small molecules can be removed effectively by zeolites (Clark and Pitt 2011 and 2012). Zeolites are not effective in the removal of compounds of zero valence and compounds with large size (Clark and Pitt 2012). Peat, compost and soils remove pollutants by chemisorption that is generally irreversible (Watts 1998; Evangelou 1998). Peat can be used as a filtration media for treatment of heavy metals and likely their complexes (Clark and Pitt 2012 and 1999). Peat's effectiveness is due to the wide range of binding sites (carboxylic acid, etc.) present in the humic materials and ligands in the peat (Cohen, et. Al. 1991; Sharma and Foster 1993; Clark and Pitt 2012). An advantage of peat media is that it can treat many heavy metals during relatively short (10 minutes) contact times (Pitt and Clark 2010; Clark and Pitt 2012). The peat's drawbacks (especially for Sphagnum peat) includes the leaching of colored humic and fulvic acids and the release of hydronium ions (H_3O^+) in exchange for metals which can lower the pH of the treated water by as much as 1 to 2 pH units and increase the solubility of the metals that were associated with stormwater runoff solids or media (Clark and Pitt 2012, 1999). Another disadvantage of using peat is the release of nutrients from the filter during the first flush under microanaerobic conditions in the media which may occur between storms (Clark and Pitt 2009b), although this is not as problematic as for compost media. Compost (including municipal leaf waste compost) can also be used to treat metals (Sharma and Foster 1993; Guisquiani, et al. 1995). The advantage of compost is that it is not likely to reduce the pH of the treated water (Clark and Pitt 1999). However, the disadvantage is that it can release nutrients, depending on the compost's source material, during the first few years of its life (Hathaway, et al. 2008, Pitt, et al. 1999; Pitt and Clark 2010). Treatment trains, like the multi-chambered treatment train (MCTT) can be effectively used for metal treatment and include catch basins for retaining the largest sediment, settling chambers for retaining fine sediment and particle-bound pollutants, and an sorption/ion exchange chamber with mixed media (peat moss, sand) for capturing filterable contaminants through sorption/ion-exchange (Pitt, et al. 1999). The upflow filter was also found to be an effective method for controlling stormwater and uses sedimentation, screens for floatable solids, sorption, and ion exchange (Togawa and Pitt, available online). Grass swales may be effective

for removing metals. They capture heavy metals by sedimentation, infiltration/sorption, and biological uptake, can treat high volumes of water and are relatively inexpensive (Johnson, et al. 2003).

The data for total and filtered metal concentrations of lead, copper, zinc, and aluminum analyzed after three months of exposure during the buffered tests was compared to estimate metal association with the particulate matter by Ogburn (2013). Analytical methods having smaller detection limits are necessary to account for non-detected values. The following tables summarize particulate and filterable lead and zinc fractions in different samples during the buffered pH tests. Generally, most of the lead was associated with the particulate fraction under pH 5 conditions and with the dissolved fraction (> 76%) under pH 8 conditions during the buffered tests after three months of exposure. For pH 5 waters, no detectable concentrations of lead were associated with the dissolved fraction. Under pH 8 conditions, most of the lead was associated with the dissolved fraction, while24% of the lead was associated with particulates for galvanized steel pipe, and only 4% for galvanized steel gutter.

Filterable and particulate fractions of lead and zinc in buffered waters after three months of exposure (Ogburn 2013)

Water	Material	% Filterable Pb	% Particulate Pb	% Filterable Zn	% Particulate Zn
pH 5	Concrete Pipe	n/a	n/a	n/a	n/a
	PVC Pipe	n/a	n/a	89	11
	HDPE Pipe	n/a	n/a	83	17
	Steel Pipe	< 2.0	> 98	24	76
	Vinyl Gutter	n/a	n/a	n/a	n/a
	Aluminum Gutter	n/a	n/a	100	0
	Steel Gutter	< 13.5	> 86	51	49
	Copper Gutter	n/a	n/a	< 15	> 85
pH 8	Concrete Pipe	n/a	n/a	< 67	> 33
	PVC Pipe	n/a	n/a	18	82
	HDPE Pipe	n/a	n/a	100	0
	Steel Pipe	76	24	0.34	100
	Vinyl Gutter	n/a	n/a	100	0
	Aluminum Gutter	n/a	n/a	24	76
	Steel Gutter	96	4	1.7	98
	Copper Gutter	n/a	n/a	100	0

Filterable and particulate fractions of copper and aluminum in buffered waters after three months of exposure (Ogburn 2013)

Water	Material	% Filterable Cu	% Particulate Cu	% Filterable Al	% Particulate Al
pH 5	Concrete Pipe	n/a	n/a	n/a	n/a
	PVC Pipe	96	4	100	0
	HDPE Pipe	100	0	n/a	n/a
	Steel Pipe	n/a	n/a	n/a	n/a
	Vinyl Gutter	100	0	n/a	n/a
	Aluminum Gutter	133	0	100	0
	Steel Gutter	n/a	n/a	n/a	n/a
	Copper Gutter	100	0	n/a	n/a
pH 8	Concrete Pipe	n/a	n/a	n/a	n/a
	PVC Pipe	71	29	< 100	> 0
	HDPE Pipe	100	0	100	0
	Steel Pipe	67	33	n/a	n/a
	Vinyl Gutter	100	0	50	50
	Aluminum Gutter	100	0	100	0
	Steel Gutter	100	0	50	50
	Copper Gutter	17	83	n/a	n/a

Practically all copper was associated with the dissolved fraction (>67 %) for all the pipes under pH 5 and pH 8 conditions after three months of exposure. The exception was for copper gutter samples under pH 8 conditions for which the filtered copper concentration was 83%.

For plastic PVC and HDPE pipes immersed in the pH 5 water, almost all of the zinc concentrations were in dissolved forms. For metal pipes under pH 5 conditions, from 49% to more than 92% of the zinc was associated with particulates, with the exception of the aluminum gutter sample where all zinc was associated with the filterable fraction. For HDPE, vinyl, and copper materials under pH 8 conditions, all zinc was associated with the dissolved fraction. For the rest of the materials (concrete, PVC, aluminum, and galvanized steel pipe and gutter) immersed into pH 8 water, from 67% to practically 100% of zinc was associated with particulates.

Under both pH 5 and 8 conditions, aluminum was predominantly associated with the dissolved fraction (from 50 to 100%).

The following table summarizes particulate and filterable iron fractions during natural pH tests. After three months of exposure during natural pH tests, iron in containers with PVC and HDPE pipes and with vinyl and aluminum gutters were associated

predominantly with dissolved fraction (70% and greater), while iron in containers with the rest of the materials were mainly associated with particulates.

Filterable and particulate fractions of iron in natural pH waters after three months of exposure (Ogburn 2013)

Water	Material	% Filterable Fe	% Particulate Fe
Bay	Concrete Pipe	29	71
	PVC Pipe	90	10
	HDPE Pipe	84	16
	Steel Pipe	49	51
	Vinyl Gutter	92	8
	Aluminum Gutter	88	12
	Steel Gutter	41	59
	Copper Gutter	43	57
River	Concrete Pipe	18	82
	PVC Pipe	73	27
	HDPE Pipe	77	23
	Steel Pipe	6	94
	Vinyl Gutter	69	31
	Aluminum Gutter	70	30
	Steel Gutter	19	81
	Copper Gutter	16	84

Morquecho, et al.2005 studied the percent of pollutant reductions that were associated with removal of particulates of different sizes. It was found the tin sheetflow samples collected in Tuscaloosa, AL, a large percentage of copper (> 60%) was associated with particles smaller than 0.45 µm and are not removed by sedimentation and physical filtration techniques (Morquecho, et al. 2005; Clark and Pitt 2012). For these samples, lead was reduced on the average by 62% and zinc by 70% by removing the particles greater than 5µm and lead was reduced by 76% and zinc by 70% by removing the particles greater than 1 µm, indicating that sedimentation and physical filtration would be an appropriate pretreatment technologies since it is considered that the reliable sedimentation is occurring for particles in the range of 2 to 5 µm (Camp 1952; Clark and Pitt 2012). Frequently, lead that is in ionic form (approximately < 0.45 µm) is in very low quantities, but if necessary, it can be treated with ion exchange technology using zeolites (Clark and Pitt 2012). Chemically-active media filtration using compost, peat, and soil can be used to treat lead complexes formed with hydroxides and chlorides (Clark and Pitt 2012).

Zero-valent iron (ZVI) was found to be an efficient medium for treating stormwater heavy metal ions as Cu^{2+} and Zn^{2+} (Rangsivek and Jekel 2005, Shokes and Moller 1999; Wilkin and McNeil 2003). Rangsivek and Jekel (2005) found that a significant fraction of Cu^{2+} is transformed to insoluble CuO and Cu_2O species. Zn^{2+} is removed by adsorption and co-precipitation with iron oxides. Zero-valent iron removes inorganic pollutants via cementation (reduction of redox sensitive compounds to insoluble forms, for example, $Cu^{2+}+Fe^0 \rightarrow Cu^0+Fe^{2+}$), adsorption and metal hydroxide precipitation (Rangsivek and Jekel 2005, Cantrell, et al. 1995; Shokes and Moller 1999; Blowes, et al. 2000; Naftz, et al. 2002; Wilkin and McNeil 2003). Higher values of water pH, dissolved oxygen (DO), temperature, and ionic strength increased the removal rates of Zn^{2+}. At higher pH values and in the presence of dissolved oxygen (DO), adsorption and co-precipitation with iron oxide are predominantly occur (Rangsivek and Jekel 2005). On the other hand, at low pH values in the absence of DO, the cementation is very effective (Rangsivek and Jekel 2005; Strickland and Lawson 1971; Ku and Chen 1992).

ZVI was found to have capacity comparable to a commercial adsorbent granular ferric hydroxide (GFH). The advantages of zero-valent iron (ZVI) are that it is inexpensive and can provide environmental benefits when used in the reclamation of solid waste (Rangsivek and Jekel 2005). Also, ZVI can be installed in an on-site remediation system as a fixed-bed barrier (Morrison, et al. 2002). Drawbacks of ZVI include the release of dissolved iron and complexes of iron oxides with other heavy metals. Therefore, a post-treatment process that includes aeration and sand filtration may be necessary. The removal of such substances as oil from iron's surfaces may be required if iron was acquired as solid waste.

A virgin coconut hull granular activated carbon (GAC), which has a limited chemical capacity, can be used for nitrate (NO_3^-) treatment (Pitt and Clark 2010). To remove nitrate and nitrite, vegetated systems can be utilized (Baker and Clark 2012; Lucas and Greenway 2008, 2011; Hunt, et al. 2006; Hunt, et al. 2008). For nitrogen removal, zeolites, commercial resins, and some native soils may be used. Current work on the removal of nitrogen compounds is focusing on denitrification in anaerobic systems and on bacterial processes in subsurface gravel wetlands and biofilters.

Sedimentation can be utilized to treat particulate bound phosphorus. To remove phosphorus associated with colloids or are in dissolved forms, vegetative systems may be used (Clark and Pitt 2012).

Ionic fractions for zinc, copper, and cadmium can range from 25 to 75% (Clark and Pitt 2012). Sedimentation and physical filtration can be used to treat metals that are bound to particles. These metals can be associated with very small particles, therefore the efficiency of physical filtration to remove metals will depend on size of associated particulates. Treatment technologies for metals associated with dissolved fraction include chemical methods. To remove dissolved metals from stormwater, peat moss, mixtures of peat moss and sand, zeolite, and compost can be used, especially with long contact times. These metals can form soluble complexes with different inorganic and organic ligands. The complex valence can range from -2 to +2. Organic and inorganic

complexes may be treated by chemically active filtration through compost, peat, and soil. Also, granular activated carbon (GAC) can be used to remove complexes with organic matter.

The choice of treatment methods depends on form of heavy metals and desired level of metal removal. If high degree of metal reduction is required, it is necessary to use multiple techniques (Clark and Pitt 2012). Generally, low numeric discharge limits can be met through combinations of pre-treatment by sedimentation and filtration with a chemically and biologically active media.

Summary of Heavy Metal Treatability

Many heavy metals are associated predominantly with particulates, and therefore their treatability is influenced by the removal of the associated particulates. The association of heavy metals with particulates depends on pH, oxidation-reduction potential, and particulate organic matter. The treatability of stormwater solids and associated heavy metals is dependent on their size. The removal of dissolved contaminants may be needed to meet stringent numeric discharge permit requirements and reduce surface and groundwater contamination potentials.

The valence charge of a metal and its complexation, among other contaminant properties, influence the choice of stormwater treatment technology. Strongly charged, small molecules can be removed effectively by zeolites. Zeolites are not effective in the removal of compounds of zero valence and compounds with large size. Peat can be used as a filtration media for treatment of heavy metals and likely their complexes. Peat's effectiveness is due to the wide range of binding sites (carboxylic acid, etc.) present in the humic materials and ligands in the peat. An advantage of peat media is that it can treat many heavy metals during relatively short (as short as 10 minutes) contact times.

Tests were conducted over a three month exposure period of pipe, gutter, and storage tank materials. Generally, most of the lead was associated with the particulate fraction under pH 5 conditions and with the dissolved fraction (> 76%) under pH 8 conditions after three months of exposure. Practically all copper was associated with the dissolved fraction (>67 %) for all the pipes under pH 5 and pH 8 conditions after three months of exposure. For plastic PVC and HDPE pipes immersed in pH 5 buffered stormwater, almost all of the zinc concentrations were in dissolved forms. For metal pipes under pH 5 conditions, from 49% to more than 92% of the zinc was associated with particulates, with the exception of the aluminum gutter sample where all zinc was associated with the filterable fraction.

Prior research found that ionic fractions for zinc, copper, and cadmium in stormwater can range from 25 to 75%. These metals can be associated with very small particles, therefore the efficiency of physical filtration to remove metals will depend on size of associated particulates. Treatment technologies for metals associated with dissolved fractions include chemical methods. To remove dissolved metals from stormwater, peat moss, mixtures of peat moss and sand, zeolite, and compost can be used, especially

with long contact times. These metals can form soluble complexes with different inorganic and organic ligands. The complex valences can range from -2 to +2. Organic and inorganic complexes may be treated by chemically active filtration through compost, peat, and soil. Also, granular activated carbon (GAC) can be used to remove complexes with organic matter.

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EXHIBIT H

Biological Report 10
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Contaminant Hazard Reviews
Report 26

Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review

by
Ronald Eisler

U.S. Department of the Interior
Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel Maryland 20708

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Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review

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U.S. Department of the Interior
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Abstract. Ecological and toxicological aspects of zinc in the environment are reviewed with emphasis on natural resources. Subtopics include sources and uses; chemical and biochemical properties; carcinogenicity, mutagenicity, teratogenicity; background concentrations in biological and nonbiological compartments; effects of zinc deficiency; toxic and sublethal effects on terrestrial plants and invertebrates, aquatic organisms, birds, and mammals; and recommendations for the protection of sensitive resources.

The estimated world production of zinc is 7.1 million metric tons; the United States produces about 4% of the total and consumes 14%. Zinc is used primarily in the production of brass, noncorrosive alloys, and white pigments; in galvanization of iron and steel products; in agriculture as a fungicide and as a protective agent against soil zinc deficiency; and therapeutically in human medicine. Major sources of anthropogenic zinc in the environment include electroplaters, smelting and ore processors, mine drainage domestic and industrial sewage, combustion of solid wastes and fossil fuels, road surface runoff corrosion of zinc alloys and galvanized surfaces, and erosion of agricultural soils.

Zinc has its primary effect on zinc-dependent enzymes that regulate RNA and DNA. The pancreas and bone are primary targets in birds and mammals; the gill epithelium is a primary target site in fish. Dietary zinc absorption is highly variable in animals; in general, it increases with low body weight (BW) and low zinc status and decreases with excess calcium or phytate and by deficiency of pyridoxine or tryptophan. Low molecular weight proteins called metallothioneins play an important role in zinc homeostasis and in protection against zinc poisoning; zinc is a potent inducer of metallothioneins. Zinc interacts with many chemicals to produce altered patterns of accumulation, metabolism, and toxicity; some interactions are beneficial to the organism and others are not depending on the organism, its nutritional status, and other variables. Knowledge of these interactions is essential to the understanding of zinc toxicokinetics.

In natural waters, dissolved zinc speciates into the toxic aquo ion $[Zn(H_2O)_6]^{2+}$, other dissolved chemical species, and various inorganic and organic complexes zinc complexes are readily transported. Aquo ions and other toxic species are most harmful to aquatic life under conditions of low pH, low alkalinity, low dissolved oxygen, and elevated temperatures. Most of the zinc introduced into aquatic environments is eventually partitioned into the sediments. Zinc bioavailability from sediments is enhanced under conditions of high dissolved oxygen, low salinity low pH, and high levels of inorganic oxides and humic substances.

Zinc and its compounds induce testicular sarcomas in birds and rodents when injected directly into the testes; however zinc is not carcinogenic by any other route. Growth of animal tumors is stimulated by zinc and retarded by zinc deficiency. Under some conditions, excess zinc can suppress carcinoma growth, although the mechanisms are imperfectly understood. Organozinc compounds are effective mutagens when presented to susceptible cell populations in an appropriate form; the evidence for the mutagenic potential of inorganic zinc compounds is incomplete. Zinc deficiency can lead to chromosomal aberrations, but excess zinc was not mutagenic in the majority of tests. Excess zinc is teratogenic to frog and fish embryos, but conclusive evidence of teratogenicity in higher vertebrates is lacking. In mammals, excess zinc may protect against some teratogens. Zinc deficiency may exacerbate the teratogenic effects of known teratogens, especially in diabetic animals.

Background concentrations of zinc seldom exceed 40 µg/L in water 200 mg/kg in soils and sediment, or 0.5 $\mu g/m^3$ in air. Environments heavily contaminated by anthropogenic activities may contain up to 99 mg Zn/L in

water, 118 g/kg in sediments, 5 g/kg in soft, and 0.84 μg/m^3 in air. Zinc concentrations in field collections of plants and animals are extremely variable and difficult to interpret. Most authorities agree on six points: (1) elevated concentrations (i.e., >2 g Zn/kg fresh weight [FW]) are normally encountered in some species of oysters, scallops, barnacles, red and brown algae, and terrestrial arthropods; (2) concentrations are usually <700 mg Zn/kg dry weight (DW) tissue in fish, <210 mg Zn/kg DW tissue in birds, and <210 mg Zn/kg DW tissue in mammals; (3) concentrations are higher in animals and plants collected near zinc-contaminated sites than in the same species collected from more distant sites; (4) zinc content in tissue is not proportionate to that of the organism's immediate surroundings; (5) for individual species, zinc concentration varies with age, sex, season, tissue or organ, and other variables; and (6) many species contain zinc loadings far in excess of immediate needs, suggesting active zinc regulation.

The balance between excess and insufficient zinc is important. Zinc deficiency occurs in many species of plants and animals and has severe adverse effects on all stages of growth, development, reproduction, and survival. In humans, zinc deficiency is associated with delayed sexual maturation in adolescent males; poor growth in children; impaired growth of hair, skin, and bones; disrupted vitamin A metabolism; and abnormal taste acuity, hormone metabolism, and immune function. Severe zinc deficiency effects in mammals are usually prevented by diets containing >30 mg Zn/kg DW ration. Zinc deficiency effects are reported in aquatic organism at nominal concentrations between 0.65 and 6.5 μg Zn/L of medium and in piscine diets at <15 mg Zn/kg FW ration. Avian diets should contain >25 mg Zn/kg DW ration for prevention of zinc deficiency effects and <178 mg kg DW for prevention of marginal sublethal effects.

Sensitive terrestrial plants die when soil zinc levels exceed 100 mg/kg (oak and maple seedlings), and photosynthesis is inhibited in lichens at >178 mg Zn/kg DW whole plant. Sensitive terrestrial invertebrates have reduced survival when soil levels exceeded 470 mg Zn/kg (earthworms), reduced growth at >300 mg Zn/kg diet (slugs), and inhibited reproduction at >1,600 mg Zn/kg soil (woodlouse). The most sensitive aquatic species were adversely affected at nominal water concentrations between 10 and 25 μg/L, including representative species of plants, protozoans, sponges, molluscs, crustaceans, echinoderms, fish, and amphibians. Acute LC50 (96 h) values were between 32 and 40,930 μg/L for freshwater invertebrates, 66 and 40,900 μg/L for freshwater teleosts, 195 and >320,000 μg/L for marine invertebrates, and 191 and 38,000 μg/L for marine teleosts. Acute toxicity values were markedly affected by the age and nutrient status of the organism, by changes in the physicochemical regimen, and by interactions with other chemicals, especially copper salts. Pancreatic degeneration occurred in ducks fed diets containing 2,500 mg Zn/kg ration. Ducks died when fed diets containing 3,000 mg Zn/kg feed or when given single oral doses >742 mg Zn/kg BW. Domestic poultry are routinely fed extremely high dietary levels of 20 g Zn/kg ration as a commercial management technique to force the molting of laying hens and the subsequent improvement of long-term egg production that molting produces. However, poultry chicks died at 8 g Zn/kg diet, had reduced growth at 2-3 g Zn/kg diet, and experienced pancreas histopathology when fed selenium-deficient but zinc-adequate (100 mg Zn/kg) diets. Mammals are comparatively resistant to zinc, as judged by their tolerance of extended periods on diets containing >100 times the minimum daily zinc requirement. But excessive zinc through inhalation or ingestation harms mammalian survival, metabolism, and well-being. The most sensitive species of mammals were adversely affected at dietary concentrations of 90 to 300 mg Zn/kg, drinking water concentrations >300 mg Zn/L, daily intakes >9 mg Zn/kg BW, single oral doses >350 mg Zn/kg BW, and air concentrations >0.8 mg Zn/m^3. Humans are comparatively sensitive to excess zinc. Adverse effects occur in humans at >80 mg Zn/kg diet or at daily intakes >2.3 mg/kg BW.

Proposed criteria for protection of aquatic life include mean zinc concentrations of <47 to <59 μg/L in freshwater and <58 to <86 μg Zn/L in seawater. Results of recent studies, however, show significant adverse effects on a growing number of freshwater organisms in the range of 5 to 51 μg Zn/L and on saltwater biota between 9 and 50 μg Zn/L, suggesting that some downward modification in the proposed criteria is necessary.

Although tissue residues are not yet reliable indicators of zinc contamination, zinc poisoning usually occurs in birds when the liver or kidney contains >2.1 g Zn/kg DW and in mammals when concentrations exceed 274 mg Zn/kg DW in kidney, 465 mg Zn/kg DW in liver, or 752 mg Zn/kg DW in pancreas. The proposed air quality criterion for human heath protection is <5 mg Zn/m^3, but guinea pigs were more sensitive and adverse effects were evident at >0.8-4.0 mg/m^3.

Current research needs include the development of protocols to (1) separate, quantitate, and verify the different chemical species of zinc (2) identify natural from anthropogenic sources of zinc; (3) establish toxicity thresholds based on accumulation; (4) evaluate the significance of tissue concentrations in target organs as indicators of zinc stress; and (5) measure the long-term consequences of zinc interactions with other nutrients in animals of various age and nutrient status. (Eisler, R. 1993. Zinc hazards to fish, wildlife, and invertebrates: a synoptic review. U. S. Fish and Wildlife Service Biological Report 10. 106 pp.).

Key words: Zinc, metals, toxicity, deficiency, criteria, residues, agriculture, nutrition, metallothionein, fish, invertebrates, birds, wildlife, livestock.

Zinc is an essential trace element for all living organisms. As a constituent of more than 200 metalloenzymes and other metabolic compounds, zinc assures stability of biological molecules such as DNA and of biological structures such as membranes and ribosomes (Vallee 1959; National Academy of Sciences [NAS] 1979; Casey and Hambidge 1980; Mason et al. 1988; Llobet et al. 1988b; Leonard and Gerber 1989). Plants do not grow well in zinc-depleted soils, and deficiency has resulted in large losses of citrus in California and pecans in Texas (Vallee 1959). Clinical manifestations of zinc deficiency in animals include growth retardation, testicular atrophy, skin changes, and poor appetite (Prasad 1979). The ubiquity of zinc in the environment would seem to make human deficiencies unlikely; however, reports of zinc-associated dwarfism and hypogonadism in adolescent males are now confirmed (Casey and Hambidge 1980) and reflect the fact that much of their dietary zinc is not bioavailable. Zinc deficiency was a major factor in the syndrome of nutritional dwarfism in adolescent males from rural areas of Iran and Egypt in 1961--about 3% of the population in these areas was affected--and a similar syndrome was found in Turkey, Tunisia, Morocco, Portugal, and Panama (Casey and Hambidge 1980). The use of unleavened bread as a major staple food contributed to severe zinc deficiency in the Middle East. Unleavened bread may contain adequate amounts of zinc for nutrition, and intakes may exceed recommended allowances by a wide margin; however, zinc is largely unavailable for absorption because of the high levels of fiber and phytic acid esters in unleavened bread (Casey and Hambidge 1980). Marginal deficiency of zinc in hums is probably widespread and common throughout the world, including the United States (Prasad 1979). Dietary zinc replacement usually reverses the pathologic events of zinc depletion in humans and animals (NAS 1979). But zinc repletion seems to be of little value in rat offspring with congenital malfunctions or behavioral abnormalities associated with zinc depletion (NAS 1979).

Zinc poisoning has been documented in dogs, cats, ferrets, birds, cattle, sheep, and horses, usually as a result of ingesting galvanized metal objects, certain paints and fertilizers, zinc-containing coins, and skin and sunblock preparations containing zinc oxide (Wentink et al. 1985; Ogden et al. 1988; Lu and Combs 1988a; Binnerts 1989; Robinette 1990). Signs of acute poisoning include anorexia, depression, enteritis, diarrhea, decreased milk yield, excessive eating and drinking and, in severe cases, convulsions and death (Ogden et al. 1988). Emissions from zinc smelters at Palmerton, Pennsylvania, destroyed wildlife habitat; reduced prey abundance; poisoned deer, songbirds, and shrews; and eliminated terrestrial amphibians from the mountainside at Lehigh Gap (Beyer et al. 1985; Sileo and Beyer 1985; Beyer 1988). Aquatic populations are frequently decimated in zinc-polluted waters (Solbe and Flook 1975; Everall et al. 1989b). Zinc in the aquatic environment is of particular importance because the gills of fish are physically damaged by high concentrations of zinc (NAS 1979).

Zinc toxicosis in humans is not a common medical problem, although it may appear in some metal workers and others under special conditions (NAS 1979). Industrial processes such as welding, smelting, or fabrication of molten metals can produce ultrafine metal oxides at harmful concentrations. Inhalation of these metal oxides, including oxides of zinc, causes the industrial malady known as metal fume fever (Lain et al. 1985; Lu and Combs 1988a; Llobet et al. 1988b). Symptoms occur several hours after exposure and include fever, chills, perspiration, tachycardia, dyspnea, and chest pains. Recovery is normally complete within 24 h, but susceptible workers can have persistant pulmonary impairment for several days after exposure (Lain et al. 1985). Most reports of human zinc intoxication have been in response to food poisoning from lengthy storage of acidic foods or beverages in galvanized containers (Llobet et al. 1988b; Fosmire 1990).

Historically zinc has been used by humans for industrial, ornamental, or utilitarian purposes for nearly 2,000 years and may have been used as an ointment to treat skin lesions by the ancient Egyptians and other Mediterraneans (NAS 1979). In biblical times, the Romans were known to have produced brass by mixing copper with a zinc ore (Elinder 1986). In its isolated form, zinc was not recognized until the 15th century when smelting occurred accidentally (NAS 1979). The Chinese probably were the first to extract zinc metal, although its first description in 1597 by an occidental traveler, Liborius, related that the process was observed in India (Vallee 1959). Commercial smelting began in the 18th century when it was realized that zinc could be obtained from the calamine ore used to make brass; no reports of zinc toxicosis in any form were recorded from these early accounts (NAS 1979). The first documented use of orally administered zinc was in 1826 to treat discharges from various body orifices (NAS 1979). Zinc was recognized as an essential nutrient for plants and animals in 1869. Its occurrence in biological matter, for example, human liver, was first described in 1877 (Vallee 1959). In 1934, zinc was conclusively demonstrated to be essential to normal growth and development in animals (Prasad 1979).

Zinc composes 0.004% of the earth's crust and is 25th in order of abundance of the elements (Vallee 1959). Uses of zinc include the production of noncorrosive alloys, galvanizing steel and iron products, and the therapeutic treatment of zinc deficiency (Elinder 1986). Zinc is found in coal and many manufactured products such as motor oils, lubricants, tires, and fuel oils (NAS 1979).

Ecological and toxicological aspects of zinc in the environment have been reviewed by many authorities, including Vallee (1959), Skidmore (1964), NAS (1979), Prasad (1979, 1980), U.S. Environmental Protection Agency [EPA] (1980, 1987), Nriagu (1980), Weatherley et al. (1980), Eisler (1981), Spear (1981), Apgar (1985), Elinder (1986), Vymazal (1986), Greger (1989), U.S. Public Health Service [PHS] (1989), and Sorensen (1991).

This report is part of a series of synoptic reviews on hazards of selected chemicals to plants and animals with emphasis on fishery and wildlife resources. It was prepared in response to requests for information on zinc from environmental specialists of the U.S. Fish and Wildlife Service.

Sources and Uses

World production of zinc increased from 0.5 million metric tens in 1900 to 6.1 million metric tons in 1978 (Elinder 1986) and 7.1 million metric tons in 1987 (PHS 1989). The principal ores of zinc are sulfides, such as sphalerite and wurtzite (Elinder 1986). The major world producers include Canada, the former Soviet Union, and Japan--which collectively account for about half the production--and, secondly, the United States, Australasia, Mexico, and Peru (Weatherley et al. 1980; Elinder 1986). Zinc is now available as ingots, lumps, sheets, wire, shot, strips, granules, and powder (PHS 1989). The United States produced 240,000 metric tons of zinc in 1987--mostly from Tennessee, Mississippi, and New York but also from 16 other states--and imported an additional 774,000 metric tons, thus consuming 14% of the world zinc production while producing 3.4% (PHS 1989).

Zinc is mainly used in the production of noncorrosive alloys and brass and in galvanizing steel and iron products. Zinc undergoes oxidation on the surface, thus protecting the underlying metal from degradation. Galvanized products are widely used in construction materials, automobile parts, and household appliances (Elinder 1986). Zinc oxide is used to form white pigments in rubber processing and to coat photocopy paper (EPA 1987; PHS 1989). Zinc sulfate is used as a cooperative agent in fungicides and as a protective agent against zinc deficiency in soils. When incorporated with copper compounds or arsenic-lead wettable powders and applied by spraying, it can minimize the toxic effects of these metals on fruits such as plums, apples, and peaches; in Japan alone, about 250 metric tons of zinc sulfate is sprayed in fields each year (Maita et al. 1981). Zinc is used therapeutically in human medicine in the treatment of zinc deficiency, various skin diseases, wound healing, and to reduce pain in sickle cell anemia patients (Prasad 1979; Spear 1981; EPA 1987; Warner et al. 1988).

Zinc is discharged into the global environment at an estimated yearly rate of 8.8 million metric tons; 96% of the total is a result of human activities (Leonard and Gerber 1989). Major sources of anthropogenic zinc discharges to the environment include electroplaters, smelting and ore processors, drainage from active and inactive mining operations, domestic and industrial sewage, combustion of fossil fuels and solid wastes, road surface runoff, corrosion of zinc alloys and galvanized surfaces, and erosion of agricultural soils (Weatherley et al. 1980; Spear 1981; Mirenda 1986; Llobet et al. 1988a; Buhl and Hamilton 1990). During smelting, large amounts of zinc are emitted into the atmosphere. In the United States alone during 1969, about 50,000 metric

tons of zinc were discharged into the atmosphere during smelting operations (Elinder 1986). Another 20,000 metric tons are discharged annually into U.S. estuaries (Table 1). Zinc is also dispersed from corroded galvanized electrical transmission towers for at least 10 km by runoff and by wind-driven spray and water droplets from the towers (Jones and Burgess 1984). Discharges from placer mining activities usually contain 75-165 µg Zn/L, sometimes up to 882 µg Zn/L in active mines, and these concentrations may represent acute hazards to salmonids in areas downstream of placer mine effluents (Buhl and Hamilton 1990). In Maine, galvanized culverts significantly increased zinc concentrations in stream waters, particularly in newer culverts. Zinc concentrations in culverts were highest during elevated temperatures and low flow; levels of zinc sometimes exceeded the avoidance threshold (0.05 mg/L) of Atlantic salmon (*Salmo salar*); invertebrates seemed unaffected, except for a freshwater sponge, *Spongilla* sp. (Gregory and Trial 1975). Zinc sources implicated in livestock poisonings include galvanized iron wire and troughs and zinc-containing fertilizers and fungicides (Allen et al. 1983; Reece et al. 1986). Zinc toxicosis in humans has been reported from consumption of milk stored in galvanized vessels and from food contaminated with particles of zinc from a zinc pigment plant (Zee et al. 1985). Zinc toxicity is discussed later in greater detail.

Table 1. Estimated annual zinc inputs to U.S. coastal marine ecosystems; study area comprised 116,000 km^2 (Young et al 1980).

Source	Metric tons per year
Rivers	5,950
Atmosphere	4,300
Barged wastes	3,490
Storm channels	3,060
Municipal wastewater	2,500
Direct industrial discharges	710
Vessel protection	360
Dredging release	10
Thermal discharges	2
Groundwater	1
Total	20,383

Chemical and Biochemical Properties

General

Most of the zinc introduced into aquatic environments eventually is partitioned into the sediments. Zinc release from sediments is enhanced under conditions of high dissolved oxygen, low salinity and low pH. Dissolved zinc usually consists of the toxic aquo ion ($Zn(H_2O)_6)^{2+}$) and various organic and inorganic complexes. Aquo ions and other toxic species have their greatest effects on aquatic organisms under conditions of comparatively low pH, low alkalinity, low dissolved oxygen, and elevated temperatures.

Zinc has its primary metabolic effect on zinc-dependent enzymes that regulate RNA and DNA. Low molecular weight proteins, metallothioneins, play an important role in zinc homeostasis and in protection against zinc poisoning in animals; zinc is a potent inducer of metallothioneins. The pancreas and bone seem to be primary targets of zinc intoxication in birds and mammals; gill epithelium is the primary target site in fish.

Effects of excess zinc on natural resources are modified by numerous variables, especially by interactions with other chemicals. Interactions frequently produce radically altered patterns of accumulation, metabolism, and toxicity some of which are beneficial to the organism whereas others are harmful.

Chemical Properties

Zinc is a bluish-white metal that dissolves readfly in strong acids. In nature, it occurs as a sulfide, oxide, or carbonate. In solution, it is divalent and can form hydrated Zn^{2+} cations in acids, and zincated anions--probably $Zn(OH)_4^{-2}$-- in strong bases (EPA 1980, 1987). Zinc dust and powder are sold commercially under a variety of trade names: Asarco, Blue powder, CI 77949, CI pigment metal 6, Emanay zinc dust, granular zinc, JASAD Merrillite, L15, and PASCO (PHS 1989). Selected physical and chemical properties of zinc, zinc chloride, and zinc sulfate are listed in Table 2.

Because zinc ligands are soluble in neutral and acidic solutions, zinc is readily transported in most natural waters (EPA 1980, 1987). But zinc oxide, the compound most commonly used in industry, has a low solubility in most solvents (Elinder 1986). Zinc mobility in aquatic ecosystems is a function of the composition of suspended and bed sediments, dissolved and particulate iron and manganese concentrations, pH, salinity, concentrations of complexing ligands, and the concentration of zinc (EPA 1980). In freshwater, zinc is most soluble at low pH and low alkalinity: 10 mg Zn/L of solution at pH 6 that declines to 6.5 mg Zn/L at pH 7, 0.65 mg Zn/L at pH 8, and 0.01 mg/L at pH 9 (Spear 1981). Dissolved zinc rarely exceeds 40 µg/L in Canadian rivers and lakes; higher concentrations are usually associated with zinc-enriched ore deposits and anthropogenic activities. Marine waters usually contain <10 µg Zn/L, most adhering to suspended solids; however, saturated seawater may contain 1.2 - 2.5 mg Zn/L (Spear 1981).

In water the free zinc ion is thought to coordinate with six water molecules to form the octahedral aquo ion $(Zn(H_2O)_6)^{2+}$ in the absence of other complexing or adsorbing agents (Spear 1981). In freshwater zinc exists almost exclusively as the aquo ion at pH >4 and <7 (Campbell and Stokes 1985). In freshwater at pH 6, the dominant forms of dissolved zinc are the free ion (98%) and zinc sulfate (2%); at pH 9 the dominant forms are the monohydroxide ion (78%), zinc carbonate (16%), and the free ion (6%; EPA 1987). In typical river waters, 90% of the zinc is present as aquo ion and the remainder consists of $ZnHCO_3^+$, $ZnCO_3$, and $ZnSO_4$ (Spear 1981).

Table 2. Some properties of zinc, zinc chloride, and zinc sulfate (PHS 1989).

Property	Zinc	Zinc chloride	Zinc sulfate
Formula	Zn	$ZnC1_2$	$ZnSO_4$
CAS number	7440-66-6	7646-85-7	7733-02-0
Molecular weight	65.38	136.29	161.44
Melting point, ° C	419.5	290	Decomposes at 600
Boiling point, °C	908	732	
Density	7.14	2.907	3.54
Physical state	Bluish-white lustrous solid	Solid white granules	Colorless solid
Solubility	Insoluble in water, soluble in acetic acid and alkali	61.4 g/L water, 769 g/L alcohol, 500 g/L glycerol	Soluble in water, slightly soluble in alcohol

Zinc bioavailability and toxicity to aquatic organisms are highest under conditions of low pH, low alkalinity, low dissolved oxygen, and elevated temperatures (Weatherley et al. 1980). Soluble chemical species of zinc are the most bioavailable and most toxic (Spear 1981). The aquo ion predominates over other dissolved species and is suspected of being most toxic; however, aquo ion concentrations decrease under conditions of high

alkalinity, at pH >7.5, and increasing salinity (Spear 1981). Under conditions of high alkalinity and pH 6.5, the most abundant species are $ZnHCO_3^+$, Zn^{2+}, and $ZnCO_3$; at low alkalinity and an elevated pH 8.0, the descending order of abundance was Zn^{2+}, $ZnCO_3$, zinc humic acid, $ZnOH^+$, and $ZnHCO_3^+$ (Spear 1981). Water hardness is the principal modifier of acute zinc toxicity. Increased alkalinity or water hardness decreases toxicity to freshwater organism when all zinc is dissolved; this effect is associated with decreased concentration of aquo ions and is heightened by increased pH. Increased water hardness at pH <8.5 when zinc is in suspension increases toxicity associated with increased suspended $ZnCO_3$. Increased water hardness at pH >8.5 when zinc is in suspension decreases toxicity and increases suspended $Zn(OH)_2$. Suspended zinc carbonate may also be toxic, although its toxicity decreases under conditions suitable to zinc hydroxide formations; suspended $Zn(OH)_2$ is relatively nontoxic. Thus, $ZnCO_3$ composes <1% of the dissolved zinc at low pH and low alkalinity but is the predominant chemical species at high pH and high alkalinity. Organozinc complexes are not stable and under reducing conditions may dissociate, liberating Zn^{2+} (Spear 1981).

In seawater zinc exists in a dissolved state, as a solid precipitate, or adsorbed to particle surfaces. Soluable zinc in seawater exists as uncomplexed free (hydrated) ions, as inorganic complexes (the primary form in the open sea), or as organic complexes (Young et al. 1980). In seawater at pH 8.1, the dominant species of soluble zinc are zinc hydroxide (62%), the free ion (17%), the monochloride ion (6.4%), and zinc carbonate (5.8%). At pH 7, the percentage of dissolved zinc present as the free ion increases to 50% (EPA 1987). In the presence of dissolved organic materials, most of the dissolved zinc is present as organozinc complexes (EPA 1987). In estuaries and other marine environments, the relative abundance of zinc species changes with increasing salinity. At low salinities, $ZnSO_4$ and $ZnC1^+$ predominate; at higher salinities, the aquo ion predominates (Spear 1981). But as salinity decreases, the concentration of free zinc ion increases and the concentration of zinc-chloro complexes decreases, resulting in increased bioavailability of the free metal ion and increased bioconcentration by resident organisms (Nugegoda and Rainbow 1989b).

In solution, zinc is adsorbed by organic agents such as humic materials and biogenic structures (i.e., cell walls of plankton) and by inorganic adsorbing agents such as mineral particles, clays, and hydrous oxides of manganese, iron, and silicon (Spear 1981). Particulate materials in the medium may contain as little as 2% and as much as 100% of the total zinc (Sprague 1986). Formation of zinc-ligand complexes increases the solubility of zinc and probably increases the tendency for zinc to be adsorbed (EPA 1980). Sorption to particulates was lower at higher salinities because of displacement of sorbed zinc ions by alkali and alkaline earth cations (EPA 1987). Increased pH increases zinc sorption to particulates and seems to be independent of water salinity or hardness (EPA 1987).

Most of the zinc introduced into aquatic environments is sorbed onto hydrous iron and manganese oxides, clay minerals, and organic materials and eventually is partitioned into the sediments (EPA 1987). Zinc is present in sediments as precipitated zinc hydroxide, ferric and manganic oxyhydroxide precipitates, insoluble organic complexes, insoluble sulfides, and other forms. As the sediments change from a reduced to an oxidized state, soluble zinc is mobilized and released however, the bioavailability of different forms of sediment zinc varies substantially and the mechanisms of transfer are poorly understood (EPA 1987). Sorption to sediments was complete at pH >7, but was negligible at pH <6 (EPA 1987). Zinc is dissolved from sediments at low salinities because of displacement of adsorbed zinc ions by alkali and alkaline earth cations that are abundant in brackish waters (EPA 1980). Sulfide precipitation in sediments is an important control of zinc mobility in reducing environment; precipitation of the hydroxide, carbonate, or sulfate may occur when zinc is present in high concentrations (EPA 1980).

Extractable concentrations of sediment-bound zinc positively correlated with zinc concentrations in deposit feeding clams (Luoma and Bryan 1979). Availability of sediment zinc to bivalve molluscs was higher at increased sediment concentrations of amorphous inorganic oxides or humic substances and lower at increased concentrations of organic carbon and ammonium acetatemanganese. Zinc uptake by euryhaline organisms was enhanced at low water salinity (Luoma and Bryan 1979).

Metabolism

Zinc is ubiquitous in the tissues of plants and animals (Rosser and George 1986) and is essential for normal growth, reproduction, and wound healing (Prasad 1979; Stahl et al. 1989a). More than 200 different enzymes require zinc for maximum catalytic activity, including carbonic anhydrase, alkaline phosphatase, alcohol dehydrogenase, acid phosphatase, lactic dehydrogenase, carboxypeptidase, and superoxide dismutase (Prasad 1979, 1980; Casey and Hambidge 1980; Rosser and George 1986; Blesbois and Mauger 1989; Thompson et al. 1989). Zinc has its primary effect on zinc-dependent enzymes that regulate the biosynthesis and catabolic rate of RNA and DNA (Prasad 1979; Casey and Hambidge 1980; Gipouloux et al. 1986; Sternlieb 1988). Zinc exerts a protective effect on liver by inhibiting lipid peroxidation and stabilizing lysosomal membranes (Sternlieb 1988); aids neurotransmission in the brain of fish, birds, reptiles, and mammals (Smeets et al. 1989); prolongs muscular contractions; increases oxygen affinity of myoglobin; is necessary for the growth and differentiation of muscle fiber types (Rosser and George 1986); increases numbers and birthweights of lambs of zinc-supplemented ewes; is essential for wound healing in most studied organisms (Ireland 1986); and is used therapeutically in treating patients with skin diseases, zinc deficiency and other symptoms (Mooradian et al. 1988; Sternlieb 1988).

Zinc enters the gastrointestinal tract as a component of low molecular weight proteins secreted by the salivary glands, intestinal mucosa, pancreas, and liver (Goyer 1986). Usually, only dissolved zinc is sorbed or bound. But zinc dissolution probably occurs in the alimentary tract of animals after ingestion of particulates containing undissolved zinc (EPA 1987). After ingestion, zinc is absorbed across several physiologically active membranes: gut mucosa, alveocapillary membranes, and tissue and organ membranes. The exact transport mechanism are unknown but may be associated with formation of a tetrahedral quadredentate ligand with a small organic molecule (NAS 1979). Some of the zinc taken up by the intestinal epithelial cells is rapidly transferred to the portal plasma where it associates with albumin, 2 macroglobulin, and amino acids; about 67% of the zinc in plasma is bound to albumin and about 3% is stored in the liver (Sternlieb 1988). Soluble organozinc complexes are passively absorbed across the plasma membrane of the mucosa of the intestinal villi; the soluble, nondiffusable complexes are transported in the intestinal products and excreted in feces (NAS 1979). Zinc loss from urine and sweat is usually small (Casey and Hambidge 1980). In a normal human adult about 2 g zinc is filtered by the kidneys daily and about 0.3-0.6 mg is actually excreted each day (Goyer 1986). Zinc homeostasis in rats, unlike in most mammals, is maintained by zinc secretion from the intestines rather than by regulation of zinc absorption (Elinder 1986). Initial uptake of zinc from the rat gastrointestinal tract involves binding to albumin and transport of the zinc-albumin complex from the intestines to the liver (Hoadley and Cousins 1988).

Foods rich in zinc include red meat, milk, gelatin, egg yolks, shellfish, liver, whole grain cereals, lentils, peas, beans, and rice (Sternlieb 1988). About 20-30% of zinc in the diet is absorbed, but this is highly variable and ranges from <10% to >90% (Prasad 1979; Casey and Hambidge 1980; Elinder 1986). Increased zinc absorption, for example, was associated with low body weight (BW), poor zinc status, and various prostaglandins; decreased absorption was caused by excess dietary calcium or phytate and by a deficiency of pyridoxine or tryptophan (Elinder 1986; Goyer 1986). The half-time persistence of zinc in most mammalian tissues is between 100 and 500 days; it is longer in bone and muscle and shorter in the liver (Elinder 1986).

Metallothioneins play an important role in metal homeostasis and in protection against heavy metal toxicity in vertebrates and invertebrates (Engel 1987; Overnell et al. 1987a; Andersen et al. 1989; Olsson et al. 1989; Richards 1989b; Eriksen et al. 1990). Metallothioneins are cysteine-rich (>20%), low (about 6,000) molecular weight proteins with a high affinity for copper, silver, gold, zinc, copper, and mercury. These heat-stable, metal-binding proteins are in all vertebrate tissues and are readily inducible by a variety of agents to which they bind through thiolate linkages. Zinc is a potent inducer of metallothioneins, and a redistribution of zinc from enzymes to metallothioneins is one way to maintain low intracellular zinc concentrations. Metallothioneins also serve as temporary storage proteins for zinc and other metals during early development and may function by maintaining the pool of available zinc at an appropriate concentration. Metallothioneins are quite similar among organisms, that is, all metallothioneins are small proteins of molecular weight 6,000-10,000, rich in sulfur and cysteine, and lack aromatic amino acids (Sprague 1986). Metallothioneins isolated from cattle, sheep, horses, pigs, and other livestock contain 61 amino acids; thioneine, the metal-free protein, is a single chain polypeptide with a molecular weight of about 6,000 (Richards 1989b). Chicken thioneine consists of 63 amino acids, including histidine, an

amino acid not present in mammalian metallothioneins. The unusually high cysteine content enables metallothioneins to selectively bind up to 7 zinc and 12 copper atoms per mole of protein (Richards 1989a).

Metallothioneins are involved in zinc homeostasis in the chick, rat, and calf. When zinc is present at high dietary concentrations, a temporary zinc storage protein aids in counteracting zinc toxicity (Oh et al. 1979). Zinc absorption in mice is directly proportional to intestinal metallothionein levels and implies a significant role of metallothionein in zinc absorption (Starcher et al. 1980). Chick embryo hepatic metallothionein is highly responsive to exogenous zinc introduced into the yolk and increases in a dose-dependent manner; a similar pattern is evident in turkey development (Fleet and McCormick 1988). Zinc protects against subsequent exposure to zinc insult, and protection is believed to be mediated by metallothioneins (Woodall et al. 1988). For example, preexposure of South African clawed frog (*Xenopus laevis*) tadpoles to 5 mg $ZnSO_4$ ($7H_2O$)/L for 96 h resulted in no deaths during subsequent exposure to 15 mg Zn/L for 90 h but in 45% deaths in the nontreated group; at 20 mg Zn/L, 15% died in the pretreated group versus 50% in the nontreated group (Woodall et al. 1988). Metallothioneins are an important factor in zinc regulation during the period of exogenous vitellogenesis in rainbow trout (*Oncorhynchus mykiss*). In female rainbow trout, for example, metallothioneins maintain homeostasis of hepatic zinc during egg formation (Olsson et al. 1989). In plaice (*Pleuronectes platessa*), a marine fish, intraperitoneal injection of zinc raised hepatic metallothionein-ike species by a factor of 15; metallothionein levels remained elevated for the next 4 weeks (Overnell et al. 1987a).

In marine molluscs and crustaceans, excess zinc is usually sequestered by metal-binding proteins and subsequently transported to storage or detoxification sites; soluble proteins and amino acids may contain 20-70% zinc (Sprague 1986). Metallothioneins are actively involved in zinc regulation during normal growth processes in the blue crab (*Callinectes sapidus*), as judged by a decrease in zinc content in the hemolymph and the digestive gland during molting (Engel 1987).

Elevated metallothionein levels are not necessarily indicative of heavy metal insult. Starcher et al. (1980) show that liver metallothionein levels in mice are elevated after acute stress or starvation and that this effect is blocked by actinomycin D, a protein synthesis inhibitor. It is further emphasized that not all zinc-binding proteins are metallothioneins (Webb et al. 1985; Andersen et al. 1989; Richards 1989a; Eriksen et al. 1990). Low molecular weight metal-binding proteins---not metallothioneins--were induced in snails and polychaete annelids in metals-contaminated environments (Andersen et al. 1989). A high molecular weight protein fraction was detected in the plasma of laying turkey (*Meleagris gallopavo*) hens that bound significant amounts of zinc and that coeluted with vitellogenin; vitellogenin, a metalloprotein, from laying hens contained 0.54 mg Zn/kg protein (Richards 1989a). In rock oysters (*Saccostrea cuccullata*) collected near an iron-ore shipping terminal, some of the tissue zinc was bound to a high molecular weight (around 550,000), iron-binding protein called ferritin (Webb et al. 1985). Ferritin accounts for about 40% of the protein-bound zinc in rock oysters and most probably in other bivalves containing elevated tissue levels of zinc (Webb et al. 1985); however, this requires verification. In four species of sediment-feeding marine polychaete annelids, zinc was mainly associated with high molecular weight proteins, suggesting that metallothionein-like proteins may not be satisfactory for monitoring purposes and that other cytosolic components should be studied (Eriksen et al. 1990).

High zinc levels induce copper deficiency in rats and interfere with metabolism of calcium and iron (Goyer 1986). Excess zinc interferes with normal metabolism of the pancreas, bone, gall bladder and kidney in mammals and gill in fish. The pancreas is a target organ for zinc toxicity in birds and mammals. Pancreatic alterations are documented from experimentally produced zinc toxicosis in cats, sheep, dogs, calves, chickens, and ducklings and naturally in sheep and calves. Pancreatic changes were limited to acinar cells, specifically cytoplasmic vacuolation, cellular atrophy, and eventually cell death (Lu and Combs 1988a; Kazacos and Van Vleet 1989). Excess zinc may cause stimulation of bone resorption and inhibition of bone formation in chicks, dogs, monkeys, and rats (Kaji et al. 1988). By preferentially accumulating in bone, zinc induces osteomalacia--a softening of the bone caused by deficiency of calcium, phosphorus, and other minerals (Kaji et al. 1988). Zinc plays a role in bone metabolism of aging rats (Yamaguchi et al. 1989b). Normally, the femoral zinc diaphysis content in rats increases from 50 to 150 mg/kg fresh weight (FW) during the first 3 weeks of life and remains constant thereafter. Oral administration of zinc (5-20 mg/kg BW daily for 3-day-old to 28-week-old rats) increased alkaline phosphatase activity and calcium content in the femur and delayed bone deterioration in aging rats (Yamaguchi et al. 1989b). Its high affinity for electrons causes zinc to bind covalently to proteins, mostly at imidazole and cysteine residues. In the mud puppy (*Necturus maculosus*), zinc blocks apical membrane anion exchange in gallbladder epithelium and blocks chloride channels in nerve and muscle cells.

The slow onset and reversal of the effects suggest a covalent modification of the exchanger or an effect requiring Zn^{2+} transport to the cell interior (Kitchens et al. 1990).

Zinc toxicity to aquatic organisms is dependent on the physical and chemical forms of zinc, the toxicity of each form, and the degree of interconversion among the various forms. Aquatic plants and fish are relatively unaffected by suspended zinc, but many aquatic invertebrates and some fish may be adversely affected from ingesting enough zinc-containing particulates (EPA 1987). Zinc toxicosis affects freshwater fish by destruction of gill epithelium and consequent tissue hypoxia. Signs of acute zinc toxicosis in freshwater fish includes osmoregulatory failure, acidosis and low oxygen tensions in arterial blood, and disrupted gas exchange at the gill surface and at internal tissue sites (Spear 1981). Zinc exerts a critical influence on mammalian and piscine immune systems (Ghanmi et al. 1989). Lymphocytes from the pronephros of common carp (*Cyprinus carpio*) were transformed by various mitogenetic agents; zinc added to lymphocyte cultures enhanced thymidine incorporation and inhibited the response of the mitogenetic agents--although Zn^{2+} itself was toxic at these concentrations (650 µgZn^{2+}/L; Ghanmi et al. 1989).

Interactions

Zinc interacts with numerous chemicals. The patterns of accumulation, metabolism, and toxicity from these interactions sometimes greatly differ from those produced by zinc alone. Recognition of these interactions is essential to the understanding of zinc kinetics in the environment.

Cadmium

Calcium-zinc interactions are typical because sometimes they act to the organism's advantage and sometimes not, depending on the organism, its nutritional status, and other variables.

Dietary cadmium accentuates signs of zinc deficiency in turkeys, chicks, rodents, and pigs (NAS 1979). Chicks on a zinc-deficient diet showed an increased frequency of muscle and feather abnormalities when 40 mg Cd/kg diet was added; however, supplementation of the diet with 200 mg Zn/kg for 14-15 days lessened or reversed the adverse effects of cadmium (Supplee 1963). But cadmium promotes the growth of zinc-limited phytoplankton (Price and Morel 1990). Substitution of trace metals or metalloenzymes could be a common strategy for phytoplankton in trace-metal impoverished environments such as the ocean and could result in an effective colimitation of phytoplankton growth by several bioactive elements (Price and Morel 1990). Zinc-deficient marine diatoms (*Thalassiosira weissflogii*), for example, can grow at 90% of their maximum rate when supplied with cadmium (which substitutes for zinc in certain macromolecules); cobalt can also substitute for zinc, although less efficiently than cadmium (Price and Morel 1990).

Zinc diminishes or negates the toxic effects of cadmium. Specifically, zinc protected embryos of the toad (*Bufo arenarum*) and other amphibian embryos against cadmium-induced developmental malformations (Herkovits et al. 1989; Herkovits and Perez-Coll 1990; Rivera et al. 1990). Zinc counteracted adverse effects of cadmium on limb regeneration and on the growth of the fiddler crab (*Uca pugilator*; Weis 1980). Preexposure of a freshwater amphipod (*Gammarus pulex*) to 10 µg Zn/L for 2 weeks increased whole body zinc content from 74 to 142 mg/kg dry weight (DW) and protected against the toxic effects of subsequent cadmium exposure of 500 µg Cd/L for 96 h (Howell 1985). In crickets (*Acheta domesticus*), excess zinc in diets of larvae protected against cadmium toxicity (Migula et al. 1989). Zinc protected rats (*Rattus* sp.) against the toxic effects of cadmium such as testicular lesions, reduced sperm counts, hepatotoxicity, and lung damage (Sato and Nagai 1989; Saxena et al. 1989a). Zinc protected mouse (*Mus* sp.) embryos against cadmium toxicity (Yu and Chan 1988. An effective protection ratio of cadmium to zinc was 1:1 for mouse embryos, but for free living embryos of the toads, this ratio of cadmium to zinc was 1:8 (Belmonte et al. 1989). Zinc reversed the toxic action of cadmium on natural killer cells of mice: 500 mg Zn/L drinking water negated the toxic action of 50 mg Cd/L (Chowdhury and Chandra 1989). The mechanisms of zinc protection against cadmium were variously attributed to metallothionein induction (Sato and Nagai 1989), enhanced detoxification rates of cadmium (Rivera et al. 1990), and competition with cadmium for the same metalloenzyme sites (Yu and Chan 1988; Rivera et al. 1990).

Waterborne solutions of zinc-cadmium mixhires were usually additive in toxicity to aquatic organisms, including freshwater fish (Skidmore 1964) and amphipods (de March B. G. E. 1988), and to marine fish (Eisler and Gardner 1973), copepods (Verriopoulos and Dimas 1988), and amphipods (Ahsanullah et al. 1988).

However, mixtures of zinc and cadmium were less toxic than expected to *Daphnia magna*, as judged by acute lethality studies (Attar and Maly 1982).

Zinc exerted antagonistic effects on uptake of cadmium by gills of the freshwater clam (*Anodonta cygea*) but accelerated cadmium transport from gills towards internal organs (Hemelraad et al. 1987). Cadmium uptake in tissues of *Anodonta* was reduced by about 50% during exposure for 16 weeks to water containing 25 µg Cd/L and 2.5 mg Zn/L (Hemelraad et al. 1987). In a marine prawn (*Pandalus montagui*), cadmium exposure had no effect on tissue zinc levels, but zinc enhanced cadmium uptake in hepatopancreas at the expense of the carcass (Ray et al. 1980). In marine fish, cadmium was taken up more rapidly at elevated seawater zinc levels; however, zinc concentrations in fish tissues decreased with increasing tissue cadmium burdens, suggesting competition between these two metals for the same physiologically active site (Eisler 1981). Zinc concentrations in larval shrimp (*Palaemon serratus*) within its threshold regulation range of 75-525 µg Zn/L were not affected by the addition of 100 µg Cd/L (Devineau and Amiard Triquet 1985). In zebrafish (*Brachydanio rerio*), zinc did not affect cadmium uptake by the whole body or gills but inhibited intestinal uptake and tended to increase gill cadmium elimination rates (Wicklund et al. 1988). Among marine vertebrates, cadmium is selectively accumulated over zinc (Eisler 1984). In ducks, zinc selectively competes with cadmium on high and low molecular weight protein pools in the kidney and liver. Once the high molecular weight protein pool is zinc-saturated excess zinc is stored on metal binding proteins with serious implications for waterfowl stressed simultaneously with cadmium and zinc (Brown et al. 1977). On the other hand, a cadmium-induced disease in bone collagen of chicks was prevented by zinc because of preferential accumulation of zinc (Kaji et al. 1988).

Copper

Mixtures of zinc and copper are generally acknowledged to be more-than-additive in toxicity to a wide variety of aquatic organisms, including oyster larvae (Sprague 1986), marine fish (Eisler and Gardner 1973; Eisler 1984), freshwater fish (Skidmore 1964; Hilmy et al. 1987a) and amphipods (de March 1988), and marine copepods (Sunda et al. 1987; Verriopoulos and Dimas 1988). But zinc-copper mixtures were less-than-additive in toxicity to marine amphipods (*Allorchestes compressa*; Ahsanullah et al. 1988).

Zinc added to the ambient water depressed copper accumulations in tissues of juvenile catfish (*Clarias lazera*), but copper added to the medium depressed zinc uptake Hilmy et al. 1987a). A similar situation was reported in barnacles (*Elminius modestus*); however, simultaneous exposure to copper and zinc resulted in enhanced uptake of both metals (Elliott et al. 1985).

In higher organisms, zinc is a copper antagonist and potentiates the effects of nutritional copper deficiency in rats and chicks. This effect only occurs at extremely high zinc to copper dietary ratios. The addition of copper to the diet of chicks or rats in physiological amounts counteracted all observed signs of zinc intoxication (Tom et al. 1977). No antagonism was evident between dietary copper and zinc fed to channel catfish (*Ictalurus punctatus*) fingerlings; therefore, the high levels of supplemental zinc required in practical feeds should not impair copper status if normal dietary copper levels are present (Gatlin et al. 1989).

High levels of administered zinc limit copper uptake in humans and certain animals (Samman and Roberts 1988) and provides protection against toxicosis produced by copper in pigs and sheep (Allen et al. 1983). Excessive zinc in humans interferes with copper absorption from the intestine, resulting in copper deficiency and eventually in cardiovascular diseases; high zinc intakes also decrease iron bioavailability, leading to a reduction of erythrocyte life span by 67% (Saxena et al. 1989b). Copper deficiency induced by excess dietary zinc is associated with lameness in horses, donkeys, and mules (NAS 1979; Bridges 1990; Ostrowski et al. 1990).

Lead

Lead-zinc mixtures were more-than-additive in toxicity to marine copepods (Verriopoulos and Dimas 1988) and significantly delayed development of mud crab (*Rithropanopeus harrisii*) larvae (EPA 1987). Lead is accumulated up to 10 times more rapidly by marine fish at elevated zinc concentrations in seawater (Eisler 1981).

Among terrestrial animals, zinc protects against lead toxicosis. Dietary zinc reduced the toxic effects of dietary lead to larvae of the house cricket (Migula et al. 1989). Zinc at 100-200 µg/egg (1 mg Zn/kg egg) significantly protected developing white leghorn chicks against lead-induced 50 µg/egg) deformities and death

when injected into the yolk sac on day 7 of incubation (Anwer et al. 1988). Zinc also protects against lead toxicity in horses (Anwer et al. 1988) and against testicular injury induced by lead in rats (Saxena et al. 1989a).

Nickel

Nickel-zinc mixtures were additive in toxicity to marine copepods (Verriopoulos and Dimas 1988) and to the three-spined stickleback (Skidmore 1964).

Oral nickel toxicity in chicks was prevented by increased dietary zinc (Warner et al. 1988). Nickel is a leading cause of allergic contact dermatitis in many industrial nations; about 6% of the general public and about 11% of dermatology clinic patients are sensitive to nickel (Warner et al. 1988). Zinc prevents nickel sulfate-induced allergic contact dermatitis in guinea pigs (*Cavia* spp.) through addition of 100-200 mg Zn/L drinking water for 4 weeks before nickel insult (Warner et al. 1988). Nickel and other metals that cause allergic contact dermatitis penetrate the skin, complex with selected ligands, and stimulate a delayed hypersensitivity. Zinc is thought to block the sites where nickel complexes to the protein (Warner et al. 1988).

Other Chemicals

Zinc interacts with a wide variety of inorganic, organic, and biological agents, but in most cases the available information is fragmentary and the mechanisms of action are unknown. Mice pretreated with zinc at 6.5 mg Zn/kg BW for 9 days showed increased resistance to arsenic toxicosis during a 30-day observation period (Kreppel et al. 1988). Oral zinc therapy was effective in treating biological agents such as infectious pododermatitis in cattle; ovine foot rot in sheep; sporidesmin in sheep, cattle, and rodents; and the toxins of the fungus *Phomopsis leptostromiformis* in sheep (Allen et al. 1983). Calcium modifies zinc toxicity to freshwater aquatic organisms, and increased calcium is associated with decreased acute toxicity (Everall et al. 1989b; Handy et al. 1989). Zinc absorption in the rat gut is decreased after ingestion of phosphorus as polyphosphate or as orthophosphate and high levels of calcium (Greger 1989). Zinc cytotoxicity is blocked by increased calcium or iron but not by magnesium (Borovansky and Riley 1989). Zinc reportedly protects rats against carbon tetrachloride poisoning (Allen et al. 1983).

Various cheating agents, including disodium ethylene diamine tetraacetic acid (EDTA), disodium calcium cyclohexanediamine tetraacetate, D-penicillamine, 2,3-dimercapto-l-propane sulfonic acid, and 2,3-dimercaptosuccinic acid protect mice against zinc acetate poisoning (Llobet et al. 1988b). Zinc protects toad embryos against agents known to produce malformations, including excess Vitamin A, acetazolamide, calcium-EDTA, and acetaminophen (Herkovits et al. 1989). Venom of the jararaca (*Bothrops jararaca*), a venomous Brazilian serpent, contains a zinc metalloprotease called J protease; the proteolytic activity of J protease is inactivated by EDTA and other sequestering agents (Tanizaki et al. 1989).

Chromium-zinc mixtures were more than additive in toxicity to *Tisbe holothuriae*, a marine copepod. Zinc in combination with chromium was more toxic to copepods than mixtures of zinc with copper, lead, nickel, or cadmium (Verriopoulos and Dimas 1988).

Renal tubular absorption of zinc in mice was impaired by certain diuretics and was further influenced by dietary proteins (Goyer 1986).

Zinc absorption in rats was depressed after consumption of high levels of inorganic iron; absorption was normal with organoirons (Greger 1989).

Mercury-zinc mixtures were more-than-additive in toxicity to oyster larvae (Sprague 1986). Preexposure of common mussels (*Mytilus edulis*) to 50 µg Zn/L for 28 days conferred increased tolerance to 75 µg Hg/L (Roesijadi and Fellingham 1987). Zinc inhibited the accumulation of mercury in marine snails and crustaceans (Andersen et al. 1989).

Zinc deficiency places an increased demand on selenium pools in daphnids. As little as 5 µg Se/L in zinc-free water eliminated overt cuticle damage and substantially increased reproduction but did not alter the shortened life span. Cladocerans at the threshold of selenium deficiency become overly selenium-deficient when zinc supplies are lacking (Keating and Caffrey 1989). Insufficient copper introduces cuticle problems in daphnids similar to those introduced by insufficient zinc or selenium, increasing the likelihood of a proposed

relation between glutathione peroxidase (which contains selenium) and copper-zinc superoxide dismutase (Keating and Caffrey 1989).

High levels of dietary tin increased zinc loss from rats (Greger 1989). Zinc prevented toxic effects of vanadium (10 mg/kg BW) on bone metabolism of weanling rats (Yamaguchi et al. 1989a).

Carcinogenicity, Mutagenicity, Teratogenicity

General

When injected directly into the testes, zinc can induce testicular sarcomas in birds and rats but has not been shown to be tumorogenic by any other route. Zinc promotes tumor growth after conditions of zinc deficiency but excess zinc may suppress or inhibit tumor proliferation, although the mechanisms of the action are imperfectly understood. Chromosomal aberrations were observed under conditions of zinc deficiency, but excess zinc was not mutagenic in most tests. Organozinc compounds are effective mutagens when presented to susceptible cell populations in an appropriate form, but the evidence for inorganic zinc is incomplete. Zinc is teratogenic to frog and fish embryos, but conclusive evidence of teratogenicity in mammals is lacking. Zinc may protect against the effects of some mammalian teratogens. Under conditions of mild zinc deficiency, however, diabetes and effects of various teratogens are exacerbated.

Carcinogenicity

Carbamate esters of zinc, zineb, and ziram are carcinogenic and teratogenic in animals, which is, however, attributed to the action of the carbamate esters and not to zinc (Elinder 1986). Results of studies with small mammals showed zinc to be cocarcinogenic with 4-nitroquinoline-N-oxide on oral cancer and with N-ethyl-N-nitrosourea on brain cancer (Leonard and Gerber 1989).

There is conclusive evidence that repeated intratesticular injections of zinc salts can induce testicular sarcomas in birds and rats (NAS 1979; Elinder 1986; Goyer 1986; PHS 1989). Testicular teratomas in roosters were first produced experimentally in 1926 when zinc salts were injected into the testes as a method of practical castration; tumors could be induced only by intratesticular injection during the spring period of gonadal growth (Guthrie 1971). Teratomas of the testes were observed in fowl given testicular injections of 2 mL of 10% $ZnSO_4$ solution (PHS 1989). Teratomas were induced in Japanese quails (*Coturnix coturnix japonica*) by intratesticular injections of 3% zinc chloride solutions during a period of testicular growth stimulated by increased photoperiod; tumors were similar to those of domestic fowl and have histological features in common with spontaneous testicular teratomas in humans (Guthrie 1971). Testicular tumors in rats were produced by direct intratesticular injection of zinc; no other carcinogenic effects were produced by any other route regardless of dose (Goyer 1986). It is emphasized that zinc and zinc compounds are not conclusively carcinogenic except when injected directly into the testes; no field or experimental evidence exists showing zinc to be tumorogenic through any other route (NAS 1979; Phillips and Kindred 1980; Elinder 1986; Leonard and Gerber 1989; PHS 1989).

Zinc is essential for the growth of rapidly proliferating cells such as tumors. The high zinc requirements of these cells in tumor disease can result in latent zinc deficiency. Accordingly, growth of animal tumors is stimulated by zinc and retarded by zinc deficiency (Prasad 1979; Leonard and Gerber 1989). In mouse fibro-sarcoma cells, zinc inhibits endonucleases, subsequently blocking DNA fragmentation and tumor cell lysis, allowing tumors to grow (Flieger et al. 1989). There is no evidence that zinc deficiency causes cancer (NAS 1979), although deficiency was associated with decreasing tumor growth (Prasad 1979; Phillips and Kindred 1980). Malignant human tissues, for example, frequently contained less zinc than normal tissue, that is, 78 mg/kg FW in a normal liver versus 18 mg/kg FW in a cancerous liver (Phillips and Kindred 1980).

Zinc can also inhibit tumor growth (NAS 1979), although the mechanisms of zinc suppression of carcinomas are imperfectly understood (Phillips and Kindred 1980). Zinc inhibits the growth of mouse melanoma cells at concentrations between 8.2 and 9.9 mg Zn/L culture medium (Borovansky and Riley 1989). The addition of 100 mg $ZnSO_4$/L to drinking water of hamsters inhibited formation of dimethylbenzanthracene-induced carcinomas (Phillips and Kindred 1980). High zinc diets of 500 mg/kg ration reduced growth of a chemically induced hepatoma in rats (Phillips and Kindred 1980). Intramuscular injections of zinc oxide or zinc acetate administered together with nickel sulfide--a potent muscle carcinogen--delayed but did not prevent 100% tumor incidence in rats during a 66-week observation period (Kasprzak et al. 1988). Administration of zinc slows the carcinogenic

process induced by nickel from the production of water-soluble and water-insoluble zinc compounds, despite markedly different retention times in muscle of zinc compounds (Tb½ ZnO = 24 days, zinc acetate = 2.5 days, Ni_3S_2 = 21 days). Zinc in either form exerted no measurable influence on nickel retention at the injection site or early local cellular reactions to nickel (Kasprzak et al. 1988). Testicular tumors in rats caused by injection of cadmium were suppressed by zinc injection (Leonard and Gerber 1989) when the zinc to cadmium molar ratio was about 100:1 (Phillips and Kindred 1980). Inhibition of cadmium carcinogenesis by zinc is a complex phenomenon, depending on dose, route, and target site (Waalkes et al. 1989). For example, the number of cadmium-induced testicular tumors in rats was reduced by 50% during a 2-year period after three subcutaneous injections of 65.4 mg Zn/kg BW given within 18 h of the initial cadmium insult, although unlike controls, this group had a marked elevation in prostatic tumors; tumor number was reduced by 92% when rats were given 100 mg Zn/L in drinking water (Waalkes et al. 1989).

Mutagenicity

Results of mutagenicity studies with whole organisms were usually negative because homeostatic controls of absorption and protein binding preclude the likelihood of zinc being genotoxic under standard feeding conditions (Thompson et al. 1989). However, zinc is an effective mutagen and clastogen when presented to a susceptible cell population in an appropriate form (Thompson et al. 1989). Zinc acetate produced dose-related positive responses in the mouse lymphoma assay and also in a cytogenetic assay with Chinese hamster ovary cells; however, results of mutagenicity assays with inorganic zinc were negative in the *Salmonella* mutation assay and in unscheduled DNA synthesis on primary cultures of rat hepatocytes (Thompson et al. 1989). Organozinc compounds have mutagenic potential, as judged by the positive responses with zinc 2,4-pentanedione and *Salmonella* (Thompson et al. 1989).

Structural chromosome aberrations, particularly chromatid gaps and increased frequency of fragment exchange, were observed in rat bone marrow cells after 14 days of exposure to 240 mg Zn/L drinking water (Kowalska-Wochna et al. 1988). Chromosomal aberrations were observed in bone marrow cells of mice fed diets equivalent to 650 mg Zn/kg BW daily in mice exposed to zinc oxide by inhalation, and in mice maintained on a low calcium diet (PHS 1989). Aberrations in bone marrow of mice given 5,000 mg Zn/kg diet may be associated with calcium deficiency (Leonard and Gerber 1989). Calcium is displaced by zinc in calcium-depleted conditions, leading to chromosomal breaks and interference in the repair process (PHS 1989).

Zinc chloride induces chromosomal aberrations in human lymphocytes in vitro (Elinder 1986). A higher incidence of chromosome anomalies in leukocytes occurs among workers exposed to zinc (Elinder 1986), but these aberrations are probably due to other (unspecified) mutagenic factors in the work environment (Leonard and Gerber 1989).

Zinc inhibits the mutagenic action of some carcinogens because it is a constituent of mutagen detoxifying enzymes or because it acts directly on the microsomal monooxygenases forming the ultimate carcinogen (Leonard and Gerber 1989). Zinc significantly reduced a genotoxic effect of lead in rat bone marrow cells (500 mg Pb/L drinking water followed by 240 mg Zn/L for 2 weeks) and also protected against lead accumulations in erythrocytes and lead-induced inhibition of delta-amino levulinic acid dehydratase (Kowalska-Wochna et al. 1988). Zinc deficiency can lead to chromosomal aberrations, but excess zinc was not mutagenic in the majority of tests for DNA damage--except for zinc-containing fungicides wherein the organic dithiocarbamate constituents were the mutagenic agents and for zinc chromate wherein the chromate ion was the active agent (Leonard and Gerber 1989). Frequencies of sister chromatid exchanges in calves with hereditary zinc deficiency, also known as Lethal Trait A46, are lower than in healthy normal cows, suggesting a fundamental association between disturbed zinc metabolism and the low incidence of sister chromatid exchanges in A46 cattle (Bosma et al. 1988).

Teratogenicity

Excess zinc is teratogenic to frog and fish embryos, possibly by inhibition of DNA synthesis (Dawson et al. 1988; Fort et al. 1989). Zinc at 150 mg/kg in rat diets was associated with inhibited fetal implantation but this needs confirmation (Elinder 1986). No conclusive evidence now exists demonstrating that excessive zinc produces any teratogenic effect in mammals (NAS 1979; Dawson et al. 1988; Leonard and Gerber 1989).

Excess zinc may protect against some teratogens, such as calcium EDTA (Leonard and Gerber 1989). Also, teratogenic effects of cadmium salts in golden hamsters was reduced by simultaneous administration of zinc salts (NAS 1979).

Zinc deficiency is clearly teratogenic in mammals (Dawson et al. 1988; Leonard and Gerber 1989). Severe maternal zinc deficiency is known to be teratogenic in rats. Fetal malformations--especially calcification defects--from maternal zinc deficiency affect almost every tissue (Ferreira et al. 1989). Skeletal malformations are most common, possibly because of a reduction in cellular proliferation and in activity of bone alkaline phosphatase (Leonard and Gerber 1989). Human zinc deficiency may act teratogenically, either directly or indirectly through other toxic agents (Jameson 1980). Zinc deficiency may exacerbate effects of several teratogenic agents such as thalidomide; there is also the possibility that zinc deficiency may increase the incidence of spina bifida and anencephaly, but this needs verification (Leonard and Gerber 1989). Diabetes during pregnancy can amplify the effects of a mild maternal zinc deficiency. In one study, diabetic and nondiabetic rat strains were fed a low zinc diet (4.5 mg Zn/kg diet), an adequate zinc diet (24.5 mg/kg), or a high zinc diet (500 mg/kg) throughout gestation. Fetuses from diabetic dams were smaller, weighed less, and had less calcified skeletons and more malformations than fetuses from control dams. In controls, maternal dietary zinc had a minor effect on fetal malformation frequency. In diabetic strains, however, the low zinc diet had a strong teratogenic effect (Uriu-Hare et al. 1989).

Background Concentrations

General

Total zinc concentrations in nonbiological samples seldom exceed 40 µg/L in water, 200 mg/kg in soils and sediments, or 0.5 $\mu g/m^3$ in air. Environments heavily contaminated by anthropogenic activities may contain up to 99 mg Zn/L in water 118 g/kg in sediments, 5 g/kg in soil, and 0.84 $\mu g/m^3$ in the atmosphere. Zinc was detectable in all samples of plants and animals measured. Grossly-elevated (i.e., >4 g/kg DW) concentrations were normally encountered in selected tissues of marine bivalve molluscs, barnacles, and polychaete annelids. In general, zinc concentrations were elevated in organisms collected near anthropogenic point sources of zinc contamination but were modified substantially by the organism's diet, age, reproductive state, and zinc-specific sites of accumulation as well as by inherent interspecies differences.

Nonbiological

Zinc concentrations in freshwater, seawater, groundwater, sewage sludge, sediments, and soils are listed in Table 3. These data are considered reliable, although newer clean laboratory techniques suggest that dissolved zinc concentrations in nonpolluted rivers may be 10 to 100 times lower than previously reported (Shiller and Boyle 1985).

Zinc concentrations in water seldom exceed 40 µg/L except near mining, electroplating and similar activities--where concentrations between 260 and 954 µg/L were frequently recorded. Drinking water usually contains <10 µg Zn/L, although concentrations >2 mg/L may occur after passage through galvanized pipes (Goyer 1986). Zinc-contaminated streams in the Platte River Basin sometimes contain up to 99 mg Zn/L and in Arkansas up to 79 mg/L (Mirenda 1986). Zinc concentrations in water downstream of placer mining activities in Alaska sometimes exceed the concentrations that are toxic to the Arctic grayling, *Thymallus arcticus* (Buhl and Hamilton 1990). The disappearance of the stone loach (*Noemacheilus barbatulus*) in the United Kingdom from streams receiving industrial wastes was attributed directly to zinc concentrations in the stream rising from 1 mg/L to a lethal 5 mg/L (Solbe and Flook 1975).

Table 3. Zinc concentrations (milligrams of zinc per kilogram fresh weight [FW] or dry weight [DW] in representative nonbiological materials.

Material	Concentration[a] (mg/kg or mg/L)	Reference[b]
Earth's crust	40 DW	11
Freshwater		
Canada		
Normal	<0.04 FW	1
Acidic mine tailings wastes, Sudbury, Ontario	0.9 FW, Max. 3.3 FW	2
United States		
Alaska		
Contaminated streams	0.029-0.882 FW	3
Downstream of placer mining activities	0.125 (0.075-0.165) FW	3
Nationwide	0.0005-0.010 FW	4
Worldwide, rivers	0.021 FW	2,5
Groundwater, near Lake Erie	Max 0.954 FW	1
Seawater		
Australia (polluted)	0.134 FW	6
Canada	0.01-0.04 FW	1
Irish Sea		
Coastal	0.007 FW	6
Near shore	0.003 FW	6
Offshore	0.003 FW	6
Open ocean		
Deep water	0.0006 FW	6
Surface	0.000002-0.0001 FW	4
United Kingdom		
Clyde estuary	0.006 FW	7
Heavily polluted	0.026 FW	6
Polluted	0.007-0.012 FW	6
Severn estuary	0.022 FW	7
United States, San Diego		
Coastal	0.0005 FW	6
Harbor	0.0026 FW	6
Western Mediterranean		
Coastal	0.0015-0.002 FW	6
Estuary	Max 0.010 FW	6
Near Shore	0.0036 FW	6

Sediments		
Australia	35 DW; Max. 280	8
Canada		
Lakes	55-160 DW	1
Marine	64-180 DW	1
Streams and rivers	50-138 DW	1
Mediterranean	5-20 DW	S
Sweden and Norway	Usually <130 DW; Max. 118,000	8
United Kingdom	70-245 DW; Max. 825 DW	8
United States		
Corpus Christi, Texas		
Bay	10-229 DW	9
Harbor	229-11,000 DW	9
New York Bight		
Uncontaminated site	18 DW	9
Sewage dump site	252 (54-416) DW	9
Northeast	15-20 DW; Max. 1,500 DW	8
Puget Sound	65 DW; Max. 185 DW	8
Rhode Island, near electroplaters		
Narragansett Bay	110 (53-168) DW	9
Providence River	490 DW	9
Southern California Bight	55-75 DW; Max. 2,800	8
Sewage Sludge		
United Kingdom, Glasgow	1,125 DW	7
United States		
Average	1,409 DW	10
Missouri	1,200 (170-13,000) DW	10
Soils		
United States	54 (<25-2,000) DW	10
Uncontaminated	10-300 DW	11
Near smelters	5,000 DW	11

[a]Concentrations are shown as means, range (in parentheses), and maximum (Max.).

[b] 1. Spear 1981; 2. Mann et al. 1989; 3. Buhl and Hamilton 1990; 4. EPA 1987; 5. Mann and Fyfe 1988; 6. Sprague 1986; 7. Nugegoda and Rainbow 1988b; 8. Young et al. 1980; 9. Eisler et al. 1977; 10. Beyer 1990; 11. Elinder 1986.

Concentrations of zinc in sediments and soils usually do not exceed 200 mg/kg but can range between 3 and 118 g/kg as a result of human activities (Table 3). Atmospheric zinc levels were almost always <1 $\mu g/m^3$, although they tended to be higher over industrialized areas (Goyer 1986). Average zinc concentrations were <0.001 $\mu g/m^3$ atmosphere at the South Pole, 0.01-0.02 $\mu g,/m^3$ atmosphere in rural areas of the United States, <0.01-0.84 $\mu g/m^3$ atmosphere in U.S. cities, and 0.06-0.35 $\mu g/m^3$ atmosphere at various locations in the United Kingdom (Elinder 1986).

Biological

Zinc measurements in field collections of plants and animals (Table 4) show several trends. (1) Zinc is present in all tissues of all organisms measured. (2) Concentrations are elevated in organisms near anthropogenic point sources of zinc contamination. (3) Concentrations are normally grossly elevated (>4 g/kg FW soft parts) in bivalve molluscs and barnacles. (4) Zinc-specific sites of accumulation include the frond in algae; the kidney in molluscs; the hepatopancreas in crustaceans; the jaws in polychaete annelids; the viscera, gonad, and brain in fish; the liver, kidney, and bone in birds; and the serum, pancreas, feces, liver, kidney, and bone in mammals. (5) Interspecies variations in zinc content are considerable, even among taxonomically closely-related species. (6) Intraspecies differences in zinc content vary with age, size, sex, season, and other modifiers. (7) Many species regulate zinc within a threshold range of concentrations.

Additional information on background concentrations of zinc is given in Vallee (1959), NAS (1979), Young et al. (1980), and Eisler (1980, 1981).

Terrestrial Plants and Invertebrates

Zinc concentrations in forest plants vary considerably. Some species of oaks (*Quercus* spp.), for example, are accumulators whereas others may be termed discriminators. In descending order of concentration zinc is in the roots, foliage, branches, and trunk of individual species (Van Hook et al. 1980). Small lateral roots accumulate zinc to much greater levels than other vegetation components and are probably most sensitive to changes in zinc inputs. Half-time persistence of zinc in forest ecosystems varies from about 3 years in organic matter components to >200 years in large soil pools (Van Hook et al. 1980).

Table 4. Effects of zinc on representative terrestrial plants and invertebrates.

Taxonomic group, organism, and other variables	Concentration[a] (mg/kg)	Reference[b]
Aquatic plants		
Euglena sp., from acidic mine tailings waste discharges (0.9 mg Zn/L, Max. 3.3 mg/L)	143 DW; Max. 410 DW	1
Aquatic moss, *Fontinalis squamosa*		
Contaminated river, Wales, 1985	Max. 2,810 DW	2
Uncontaminated site	<400 DW	2
Marine plants		
Phytoplankton	38 DW	3
Seaweeds	90 DW	3
Eelgrass, *Zostera marina*		
Leaf	Max. 195 DW	4
Rhizome	Max. 70 DW	4
Root	Max. 155 DW	4
Stem	Max. 85 DW	4
Terrestrial plants and invertebrates		
Honey bee, *Apis mellifera*, Czechoslovakia, 1986-87		
Drones	77-89 DW	5

Honey	0.6-4.5 DW	5
Pollen in combs	39-55 DW	5
Wax	11-249 DW	5
Workers, whole		
Foragers, spring	116-204 DW	5
Dead overwintering	8-13 DW	5
Young	83-160 DW	5
Grey field slug, *Deraceras reticulatum*, near lead-zinc mine		
Digestive gland	3,968 DW	6
Foot-head	308 DW	6
Gonads	118 DW	6
Intestine	380 DW	6
Whole	800 DW	7
Earthworms, north-eastern United States, whole		
From uncontaminated soils (23-200 mg Zn/kg DW), 6 species	120-650 DW	8
From mining sites (100-2,500 mg Zn/kg DW), 5 species	200-950 DW	8
From industrial sites (24-320 mg Zn/kg DW soil), 6 species	320-1,600 DW	8
Near galvanized towers (28-270 mg Zn/kg DW soil), 1 species	340-690 DW	8
Earthworms, whole, gut empty		
Dendrodrilus rubidus	(308-1,683) DW	9
Lumbricus rubellus	(394-3,873) DW	9
Gastropods, whole, near abandoned mine, soil contained 1,377 mg Zn/kg DW		
Arion ater	900 DW	7
Arion hortensis	600 DW	7
Arion subfuscus	1,200 DW	7
Derocerus caruanae	1,000 DW	7
Lichen, *Lasallia papulosa*		
Near zinc smelter	2,560 DW	10

Control population	214 DW	10
Isopod, *Oniscus asellus*, whole, from soil containing various concentrations of zinc (mg Zn/kg soil DW)		
<0.3Max. 150 DW		11
1-10	Max. 350 DW	11
>50	Max. >500 DW	11
Plants, terrestrial	Average 100 DW	114
Woodlouse, *Porcellio scaber*		
Near metal smelter of maximum soil zinc of 24,900 mg/kg DW, and soil litter of 4,150 mg/kg DW		
Hepatopancreas	Max. 13,500 DW	12
Whole	Max. 1,500 DW	12
From soil containing various concentrations of zinc (mg Zn/kg soil DW), whole organism		
<0.3	Max. 350 DW	11
1-10	Max. 550 DW	11
>50	Max. >1,000 DW	11
Protozoans, marine	63-279 DW	13
Coelenterates		
Soft coral, *Alcyonia alcyonium*, whole	9.6 FW	14
Plumose anemone, *Metridium senile*, whole	18 FW	14
Various species, whole		
Uncontaminated areas	50 DW	3
Noncontaminated areas	<80 FW; <120 DW	13
Contaminated areas	Max. 603 DW	13
Molluscs, aquatic		
Abalones, soft parts	55 (38-100) DW	17
Bivalves		
Kidney granules	10,000-43,320 DW	15
Soft parts	91-660 DW	16
Cephalopods		

Soft parts	81-150 DW; Max. 580 DW	16,17
Whole	250 DW	3
Chitons, soft parts	290-700 DW	17
Clams, soft parts	81-115 DW; Max. 510 DW	17
Sydney rock oyster, *Crassostrea commercialis*, soft parts, Southeast Asia	800 (64-1,920) DW	18
American oyster, *Crassostrea virginica*, soft parts		
Chesapeake Bay	3,975 (60-12,800) DW	18
Gulf of Mexico	2,150 (485-10,000) DW	18
South Carolina	2,410 (280-6,305) DW	18
United States	1,018-1,641 (204-4,000) FW	19
Drills, soft parts	536-3,470 DW	17
Gastropods, soft parts	84-763 DW	16
Limpets, soft parts		
18 species	112 (14-760) DW	17
7 species	196 (86-430) DW	17
Clam, *Macoma balthica*, adults, San Francisco Bay, soft parts	200-600 DW	20
Mussels, soft parts	109-267 DW; Max. 7,700 DW	17
Common mussel, *Mytilus edulis*		
Soft parts, 0.43 g DW		
Visceral mass	34-100 DW	21
Gills and palps	47-94 DW	21
Remainder	48-110 DW	21
Soft parts, 0.22 g DW		
Visceral mass	28-112 DW	21
Gills and palps	38-158 DW	21
Remainder	40-130 DW	21
Kidney, Newfoundland		
October 1984	144 (50-427) DW	22
April 1985	828 (94-3,410) DW	22
Oyster drill, *Ocenebra erinacea*, soft parts	1,451-2,169 DW	23
European flat oyster, *Ostrea edulis*, soft parts		
Contaminated site	10,560 (4,700-12,640) DW	24
Clean site	98 DW	24
Oysters		
Sort parts	1,960-7,270 DW; Max. 49,000 DW	17
Soft parts	100-271 FW	19

Scallop, *Pecten* sp.		
Kidney	32,000 DW	17
Kidney granules	120,000 DW	17
Soft parts	200 DW	17
Scallops, soft parts	105-212 DW; Max. 462 DW	
Green-lipped mussel,		
Perna viridis, Hong Kong		
Soft parts, 1986-87	56-134 DW	25
Soft parts, 1986		
March	63-150 DW	26
May	77-94 DW	26
Clam, *Pitar morrhuana*,	Max. 276 DW	27
soft parts, near		
electroplating plant,		
Rhode Island, 1973		
Rock oyster, *Saccostrea*		
cuccullata, soft parts,		
Hong Kong, 1986		
March	2,082-3,275 DW	26
May	2,210-2,863 DW	26
Whelks, soft parts	198 (13-650) DW	17
Crustaceans		
Amphipods, marine, whole,		
western British coastal waters		
Orchestia gammarellus	104-392 DW	28
Orchestia mediterranea	120-506 DW	28
Talitrus saltator	178-306 DW	28
Talorchestia deshayesii	199-208 DW	28
Amphipods, *Themisto* spp., whole	76 (72-81) DW	29
Barnacle, *Balanus amphitrite*,	Max. 1,937 DW	30
soft parts		
Barnacle, *Balanus balanoides*,	1,028-3,438 FW	31
soft parts		
Crustaceans, marine		
Northeast Atlantic ocean,		
July 1985, whole		
Decapods	35-57 DW	32
Euphausids	44-96 DW	32
Mysids	24-44 DW	32
Soft parts		
Amphipods	73-109 DW	16
Barnacles	690-27,837 DW	16
Barnacles	1,050-5,140 DW; Max. 113,000 DW	17

Copepods	60-170 DW	16
Copepods	164-177 DW; Max. 1,300 DW	17
Crabs	68-102 DW; Max. 340 DW	17
Euphausids	53-83 DW	16
Isopods	94 DW	16
Shrimps	14-69 DW; Max. 150 DW	17
Various species		
Blood	0.2-87 FW	19
Excretory organs	Max. 29 FW	19
External eggs	24-107 FW	19
Gills	8-69 FW	19
Hepatopancreas	34-169 FW	19
Muscle		
Leg	15-68 FW	19
Abdominal	10-24 FW	19
Shell	5-17 FW	19
Stomach fluid	1-92 FW	19
Ovary	26-82 FW	19
Vas deferens	13-30 FW	19
Urine	Max. 2.2 FW	19
Whole	18-54 FW	19
Hermit crab, *Eupagurus bernhardus*, whole	282 FW	19
Euphausid, *Euphausia superba*, whole	68 (42-75) DW	29
Euphausid, *Meganyctiphanes norvegica*, whole		
Firth of Clyde	43 (27-62) DW	29
Northeast Atlantic Ocean	102 (40-281) DW	29
Euphausids, whole	13 FW	33
American lobster, *Homarus americanus*		
Gill	102-126 DW	34
Green gland	114-148 DW	34
Hepatopancreas	70-135 DW	34
Muscle		
Pincer	100-127 DW	34
Tail	80 DW	34
Crayfish, *Orconectes virilis*, collected 12-150 km from metal smelter		
Hepatopancreas		
12 km	190 DW	35
30 km	166 DW	35
150 km	92 DW	35
Digestive tract		
12 km	154 DW	35

30 km	100 DW	35
150 km	111 DW	35
Muscle		
12 km	93 DW	35
30 km	97 DW	35
150 km	80 DW	35
Grass shrimp, *Palaemonetes pugio*		
From sediments containing 627 mg Zn/kg DW		
Exoskeleton	58 FW	36
Muscle	55 FW	36
From sediments containing 8 mg Zn/kg DW		
Exoskeleton	18 FW	36
Muscle	30 FW	36
Prawn, *Pandalus montagui*		
Cuticle	57 DW	37
Eye	70 DW	37
Gill	106 DW	37
Hepatopancreas	30 DW	37
Muscle	57 DW	37
Whole	58 DW	37
Pink shrimp, *Penaeus brasiliensis*, adults, whole	(47-75) DW; (181-290) FW	38
Insects, marine, whole	110-197 DW	13
Chaetognaths, whole	76-90 DW	13
Annelids, aquatic		
Annelids, marine		
Jaws		
Total	5,000-24,000 DW	13
Basal section	1,790 DW	13
Distal section	34,950 DW	13
Whole body	22-1,564 DW	13
Lugworm, *Arenicola, marina*, whole	1.8 FW	14
Freshwater leech, *Erpobdella octoculata*, adults, whole body	Upstream (18 µg Zn/L) from zinc-polluted mine waste discharge, whole body content of 1,439-1,559 DW; reproduction normal. Downstream (180 µg Zn/L), concentration after 19-month exposure was 1,932-2,432 DW; reproduction impaired	116
Sandworm, *Nereis diversicolor*		

Head	843-995 DW	39
Parapodia	216-418 DW	39
Trunk	158-218 DW	39
Echinoderms, various species, whole	Usually 100 DW or lower, frequently >100 DW; Max. 245 FW, 1,500 DW	3,13
Tunicates, whole	200 DW; Max. 64 FW, 370 DW	3, 13
Fish		
Catostomids, 3 species, Missouri, blood		
Site contaminated with mine tailings	10.9-13.4 FW, 94-119 DW	40
Uncontaminated site	8.7-11.2 FW, 76-86 DW	40
White sucker, *Catostomus commersoni*		
From metals-contaminated lake (400 µg Zn/L)		
Eggs	83-158 DW	41
Larvae	511 DW	41
Ovaries		
Prespawning	114 DW	41
Postspawning	290 DW	41
Testes, postspawning	89 DW	41
From control lake (2.7 µg Zn/L)		
Eggs	69-108 DW	41
Larvae	163 DW	41
Ovaries		
Prespawning	84 DW	41
Postspawning	317 DW	41
Testes, postspawning	163 DW	41
New Brunswick, whole	92-93 DW	42
Nova Scotia, whole	98-122 DW	42
African sharptooth catfish, *Clarias gariepinus*, age 4-8 years, South Africa, 1988-89, lake sediments contained 1,104 mg Zn/kg DW (595-2,189)		
Brain	335 DW	43
Fat	5O DW	43
Gill	177 DW	43
Gonad	126 DW	43
Heart	196 DW	43
Intestine	143 DW	43
Kidney	143 DW	43
Liver	143 DW	43
Muscle	59 DW	43
Spleen	163 DW	43

Vertebrae	75 DW	43
Baltic herring, *Clupea harengus*, liver	23 FW	14
Freshwater fish, various species		
Great Lakes		
Whole, less intestines, 4 species	12-20 FW	19
Liver, 10 species	11-48 FW	19
Greece, 1987-88, muscle, 11 species	7 (3-37) FW	44
United States, nationwide, whole		
1978-79	25 (8-168) FW	45
1980-81	24 (9-109) FW	45
1984		
Geometric mean	21.7 FW	121
85th percentile	34.2 FW	121
Maximum	118.4 FW	121
From metals-contaminated (636 µg dissolved Zn/L) lake, Indiana, whole		
Bowfin, *Amia calva*	93 DW	46
White sucker, *Catostomus commersoni*	102 DW; Max. 152 DW	46
Brown bullhead, *Ictalurus nebulosus*	127 DW; Max. 139 DW	46
Warmouth, *Lepomis gulosus*	140 DW; Max. 166 DW	46
Orangespot sunfish, *Lepomis humilis*	248 DW	46
Redear sunfish, *Lepomis microlophus*	477 DW; Max. 820 DW	46
Largemouth bass, *Micropterus salmoides*	119 DW; Max. 207 DW	46
Golden shiner, *Notemigonus crysoleucas*	160 DW; Max. 171 DW	46
Yellow perch, *Perca flavescens*	160 DW; Max. 171 DW	46
Black crappie, *Pomoxis nigromaculatus*	123 DW	46
From metals-contaminated stream, Missouri, muscle, 5 species	3.1-24 FW	47,115
Shortfin mako, *Isurus oxyrinchus*, vertebrae	36 (5-127) DW	48
Marine fish, various species		
Muscle		
54 species	0-5 FW	19
32 species	5.1-10 FW	19
7 species	10.1-15 FW	19
4 species	15.1-20 FW	19

2 species	20.1-25 FW	19
Whole	80 DW	3
Red Sea, 1980-82		
Triggerfish, *Balistoides viridiscens*		
Muscle	66 DW	49
Liver	154 (81-227) DW	49
Ovaries	291 (287-792) DW	49
Surgeonfish, *Ctenochaetus strigosus*, muscle	29 (11-43) DW	49
Halfbeak, *Hemiramphus marginatus*, muscle	32 DW	49
Labrids, 3 species, muscle	33 (19-51) DW	49
Lethrinids *Lethrinus* spp.		
Muscle	33 (13-112) DW	49
Liver	95 (43-146) DW	49
Ovaries	146 (72-259) DW	49
Testes	152 (141-164) DW	49
Snapper, *Lutianus fulviflamma*, muscle	48 (25-70) DW	49
Parrotfish, *Scarys gyttatus*		
Liver	17 DW	49
Muscle	62 DW	49
Serranids, 4 species		
Muscle	51 (8-112) DW	49
Liver	130 (78-183) DW	49
Rabbitfish, *Siganus oramin*		
Muscle	55 (18-195) DW	49
Liver	179 (68-611) DW	49
Sparids, 2 species, muscle	56 (34-76) DW	49
Goatfish, *Upeneus tragula*, muscle	51 (37-68) DW	49
Pacific hake, Merluccius productus		
Muscle	4 (3-6) FW	33
Whole	12 FW	33
Catfish, *Mystus gulio*, juveniles, whole, India		
From contaminated estuary (100-120 µg Zn/L, 120-145 mg Zn/kg sediment DW)	160-180 DW	50
From uncontaminated estuary (10 µg Zn/L, 30 mg Zn/kg sediment)	15 DW	50
Yellow perch, *Perca flavescens*, whole		

New Brunswick	81-103 DW	42
Nova Scotia	68-85 DW	42
Blue shark, *Prionace glauca*, vertebrae	95 (32-210) DW	45
Atlantic salmon, *Salmo salar*		
Eggs		
Hatchery	20-35 FW	51
Native	19-28 FW	51
Liver, juveniles		
Hatchery	29-41 FW	51
Native	34 FW	51
Muscle	13 DW	52
Ovaries	166 DW	52
Spines	79-219 DW	52
Stomach contents	78 DW	52
Brook trout, *Salvelinus fontinalis*, whole		
New Brunswick	87-158 DW	42
Nova Scotia	90-110	42
Atlantic mackerel, *Scomber scombrus*, liver	31 FW	14
King mackerel, *Scomberomorus cavalla*, otolith		
Age <1 year	16 DW; Max. 50 DW	53
Age 2 years	11 DW	53
Age 10 years	8 DW	53
Lesser spotted dogfish, *Scyliorhinus caniculus*, liver	8.7 FW	14
Monkfish, *Squatina squatina*, liver	8 FW	14
Reptiles		
American alligator, *Alligator mississippiensis*, eggs (less shell), Florida, 1984	4.9-9.2 FW	54
Birds		
Blue-winged teal, *Arias discors*, Texas, 1983		
Muscle		
Males	13.8 FW	55
Females	11.3 FW	55
Liver		
Autumn	41.4 FW	55
Spring	33.7 FW	55
Mallard, *Anas platyrhynchos*, liver	54 FW	56
Canvasback, *Aythya valisineria*, Chesapeake Bay liver	41 FW	56

Nicobar pigeon, *Caloenas nicobarica*, zinc-poisoned		
Kidney	2,107 DW	57
Liver	3,575 DW	57
Ovary	654 DW	57
Turkey vulture, *Cathartes aura*, California, 1980-81		
Liver	21-44 FW	58
Kidney	16-24 FW	58
Feather	81-110 DW	58
Common raven, *Corvus corax*, California, 1980-81		
Liver	14-45 FW	58
Kidney	17-33 FW	58
Feather	110-160 DW	58
Trumpeter swan, *Cygnus buccinator*, USA, 7 western states, 1976-87, found dead		
Liver, kidney, femur	96 (61-160) FW	118
Blood	5.2 (3.7-8.8) FW	118
Dutch Wadden Sea		
Knots, 3 species, recently-formed primary feathers		
Juveniles	100-400 DW	59
Adults	Max. 977 DW	59
Geese, 3 species, feather vane	93-164 DW; Max. 330 DW	59
Little egret, *Egretta garzetta*, France, found dead		
Bone	100 DW	60
Feather	80 DW	60
Gizzard	140 DW	60
Kidney	70 DW	60
Liver	120 DW	60
Lung	50 DW	60
Muscle	70 DW	60
Stomach	65 DW	60
Chicken, *Gallus* sp.		
Egg yolk	64 DW	61
Kidney	70 DW	61
Liver	69 DW	61
Liver	32 (25-56) FW	62
Pancreas	88 DW	61
Seminal plasma		

Age 30 weeks	9.8 FW	63
Age 60 weeks	9.8-25 FW	63
California condor, *Gymnogyps californianus*, dead on collection, 1980-86		
Nestlings (died from handling shock)		
Liver	22 FW	64
Kidney	17 FW	64
Juveniles (died from cyanide poisoning)		
Liver	33 FW	64
Feather	99-100 DW	64
Subadults (died from lead poisoning)		
Liver	30 FW	64
Kidney	33 FW	64
Feather	85 DW	64
Adults (died from lead poisoning), liver	27-250 FW	64
California, 1980-81, feather	46-130 DW	58
Kern County, California, 1976		
Liver	49 FW	65
Kidney	16 FW	65
White-tailed eagle, *Haliaeetus albicilla*		
Blood, clotted	7.5 FW	66
Brain	20 FW	66
Feather	88 DW	66
Femur	284 (175-390) DW	66
Heart	28 (21-39) FW	
Intestine	50 (27-76) FW	66
Kidney	43 (35-60) FW	66
Liver	68 (38-100) FW	66
Lung	14 (11-17) FW	66
Muscle	55 (42-80) FW	66
Stomach	25 (20-30) FW	66
Bald eagle, *Haliaeetus leucocephalus*, egg, 1968		
Wisconsin	30-56 DW; 4-8 FW	67
Maine	32-52 DW; 4-7 FW	67
Florida	36-65 DW; 5-8 FW	67
Glaucous gull, *Larus hyperboreus*		
Liver	32 (26-47) FW	68
Kidney	46 (37-57) FW	68
Turkey, *Meleagris gallopavo*		
Laying hens		
Serum	6.9 FW	117

Liver	75 DW	117
Nonlaying hens		
Serum	1.6 FW	117
Liver	39 DW	117
Red-breasted merganser, *Mergus serrator*, egg, Lake Michigan, 1978	15 (12-20) FW	69
Black-crowned night-heron, *Nycticorax nycticorax*, liver, prefledglings, 1979		
Massachusetts	602 (482-784) DW	70
North Carolina	649 (479-857) DW	70
Rhode Island	503 (246-885) DW	70
Osprey, *Pandion haliaetus*		
Eastern United States, 1975-82, liver		
Iowa	98 FW	71
Maryland	19-34 FW	71
Massachusetts	89 FW	71
New Jersey	63-120 FW	71
North Carolina	69 FW	71
South Carolina	73 FW	71
Wisconsin	59 FW	71
Virginia	27-150 FW	71
Eastern United States, 1964-73, liver		
Florida	27-36 FW	56
Maryland	18-93 FW	56
New Jersey	22 FW	56
Ohio	60-80 FW	56
All ospreys, liver		
Immatures	67 FW	56
Adults	38 FW	56
Brown pelican, *Pelecanus occidentalis*		
Egg contents		
South Carolina, 1971-72	6.4 (5.5-8.0) FW	119
Florida, 1969-70	6.4 (4.3-8.3) FW	119
Liver		
Found dead		
South Carolina, 1973	26 FW	119
Florida, 1972-73	41-50 FW	119
Georgia, 1972	33 FW	119
Shot		
Florida, 1970	32-55 FW	119

South Carolina, 1973	31-38 FW	119
Greater flamingo, *Phoenicopterus ruber*		
Bone	123 (103-145) DW	60,72
Feather		
Inner barbs	66 (38-105) DW	60,72
Outer barbs	101 (45-190) DW	60,72
Kidney	115 (90-167) DW	60,72
Liver	758 (525-963) DW	60,72,73
Lung	43 (33-56) DW	60,72
Muscle	53 (38-78) DW	60,72
Seabirds		
Albatrosses, 3 species		
Liver	(29-86) FW	68
Kidney	(31-65) FW	68
Fulmars, 2 species		
Liver	36-95 FW	68
Kidney	32-96 FW	
Penguins, 4 species		
Liver	(27-73) FW	68
Kidney	(25 -71) FW	68
Petrels, 7 species		
Liver	(28-81) FW	68
Kidney	(15-78) FW	68
Shearwaters, 2 species		
Liver	(28-54) FW	68
Kidney	(27-88) FW	68
Skuas, 3 species		
Liver	(21-51) FW	68
Kidney	(22-53) FW	68
South Atlantic Ocean, adults, 15 species		
Kidney	28-63 (15-88) FW	74
Liver	22-67 (18-86) FW	74
Spain, infertile eggs, 1985-86		
Golden eagle, *Aquila chrysaetos*	8.4 (5.5-11.9) FW	75
Buzzard, *Buteo buteo*	14 FW	75
White stork, *Ciconia ciconia*	9.8 (6.2-19.2) FW	75
Peregrine, *Falco peregrinus*	11.8 (8.8-16.7) FW	75
Booted eagle, *Hieraetus pennatus*	9.4 (7.7-13.0) FW	75
Black kite, *Milvus migrans*	12.6 (6.4-29.4) FW	75
Common blackbird, *Turdus merula*, from metals-contaminated area (1,750 mg Zn/kg DW soil), feathers of various age (days), feathers washed or unwashed before analysis		

4, unwashed	(100) DW	76
400, unwashed	(546) DW	76
26, washed	(90) DW	76
150, washed	(100) DW	76
400, washed	(162) DW	76
Hoopoe, *Upupa epops*, nestling feathers, age (days)		
7	(200) DW	77
21	(600) DW	77
35	(1,000) DW	77
Mammals		
Antelopes, zoo animals, 7 species, blood serum	4.6-9.4 (1.9-12.9) FW	78
Cattle, cow, *Bos* spp.		
Brain, fetus	50-86 DW	79
Feces		
Normal	220 DW	57
Zinc-poisoned	8,740 DW	57
Food items		
Cereal grains, normal	20-30 DW	80
Grasses, normal	25-60 DW	80
Turnips, beets, chicory roots, potatoes	67-390 DW	80
Hair, distance from Czechoslovakian power plant		
6 km	167 (114-199) FW	81
26 km	32 (21-43) FW	81
Heart, fetus	78-160 DW	79
Kidney		
Adult	92-133 DW	79
Age 2+ years	16 (13-17) FW	82
Fetus	83-251 DW	79
Normal	18 (11-56) FW; 80 DW	57, 82
Zinc-poisoned	670 DW	57
Liver		
Adult	116-150 DW	79
Age 2+ years	40 (27-49) FW	82
Fetus	548-703 DW	79
Normal	135 DW	57
Zinc-poisoned	2,000 DW	57
Milk, days postpartum		
0	21 FW	83
1	12 FW	83
30	6 FW	83

150	4 FW	83
Muscle, Age 2+ years	49 (28-80) FW	82
Dog, *Canis familiaris*		
Serum		
Normal	1.7 (0.6-2.0) FW	84
Zinc-poisoned	29 FW	84
Seminal plasma	1,750 DW	85
Spermatozoa		
Ejaculated	1,040 DW	85
Nonejaculated	150-180 DW	85
Goat, *Capra* sp., milk, days postpartum		
0	17-25 FW	83
1	8-15 FW	83
90	5-6 FW	83
150	3-5 FW	83
Red deer, *Cervus elaphus*, Germany		
Kidney	131 DW	86
Kidney cortex	33 (20-184) FW	87
Liver	111 DW	86
Bank vole, *Clethrionomys glareolus*		
Diet		
Spring	56-70 DW	88
July-December	37-43 DW	88
Bone	145-199 DW	88
Heart	69-74 DW	88
Kidney	79-91 DW	88
Liver	78-103 DW	
Muscle	44-51 DW	
Testes		
December-September	126-163 DW	88
October-November	ND	88
Hooded seal, *Cystophora cristata*, liver	57 FW	89
Indian elephant, *Elephas maximas*, serum		
Young, age <15 years	2.0 FW	90
Adult females	2.8 FW	90
Big brown bat, *Eptesicus fuscus*, captive colony, guano	340 DW	91
Horse, *Equus caballus*, near zinc smelter versus control location		
Kidney	150 DW vs. 17 DW	92
Liver	402 DW vs. 23 DW	92

Pancreas	788 DW vs. 7 DW	92
Serum	2.65 FW vs. 0.8-1.2 FW	92
Kidney cortex	41 FW	87
Plasma, mares, Australia		
All	0.5-1.2 FW	93
Thoroughbreds	0.47 FW	94
Farm horses		
Pregnant	0.52 FW	94
Lactating	0.44 FW	94
Northern sea lion, *Eumetopias jubata*		
Brain	(33-51) DW	95
Heart	(94-101) DW	9'5
Kidney	(99-202) DW	95
Liver	(102-247) DW	95
Lung	(42-69) DW	95
Muscle	(90-140) DW	95
Pancreas	(78-262) DW	95
Spleen	(56-117) DW	95
Long-finned pilot whale, *Globicephala melaena*, Newfoundland, Canada, stranded, 1980-82		
Blubber	1.5 (0.6-3.0) DW	96
Kidney	99 (58-139) DW	96
Liver	234 (68-716) DW	96
Muscle	62 (38-80) DW	96
Gorilla, *Gorilla gorilla gorilla*, captives, plasma	2.4 (0.9-7.3) FW	97
Gray seal, *Halichoerus grypus*		
Blubber	5 FW	14
Kidney	37 FW	14
Liver	84 FW	14
Muscle	43 FW	14
Human, *Homo sapiens*		
Diet		
Protein-rich foods (meat, seafood)	10-50 FW	113
Grains	10-100 FW	113
Vegetables, fruits	<5 FW	113
Erythrocytes	10. 1 - 13.4 FW	98
Hair	>105 FW	98
Milk	3 FW	113
Plasma	0.7-1.6 FW	97,98
Prostate	100 FW	113
Semen	100-350 FW	19
Skin	20-1,000 DW	19

White-beaked dolphin, *Lagenorhynchus albirostris*, Newfoundland, Canada, ice-entrapped, 1980-82, 2-6 years old		
Kidney	85 (68-112) DW	96
Liver	100 (43-136) DW	96
Muscle	53 (36-89) DW	96
Rhesus monkey, *Macaca mulatta*, plasma	0.66-0.98 FW	99
Marine mammals		
Pinnipeds, 9 species		
Liver	(27-97) FW; (123-406) DW	68
Kidney	(11-78) FW; (146-353) DW	68
Muscle	(14-49) FW	68
Cetaceans, 9 species		
Liver	(18-109) FW	68
Kidney	(4-86) FW	68
Muscle	(7-51) FW	68
Sirenians		
Liver	(58-1,101) FW	68
Kidney	(14-54) FW	68
Muscle	(8-28) FW	68
Southeastern bat, *Myotis austroriparius*, Florida, 1981-83, liver		
Near battery salvage plant	31 (27-35) FW	91
Noncontaminated site	28 (26-30) FW	91
Gray bat, *Myotis grisescens*, Florida, 1981-83, guano		
Near battery salvage plant	640 DW	91
Distant sites	390-530 DW	91
Mule deer, *Odocoileus hemionus*, Montana		
Kidney	97 FW	86
Liver	113 FW	86
White-tailed deer, *Odocoileus virginianus*		
Illinois, liver	70 DW	86
Pennsylvania, various distances from zinc smelter		
< 8 km		
Feces	577 (185-1,797) DW	86
Kidney	310 (211-454) DW	86
Liver	167 (137-205) DW	86

10-20 km		
Feces	574 (1,384) DW	86
Kidney	274 (212-355) DW	86
Liver	167 (137-205) DW	86
>100 km		
Feces	185 (77-445) DW	86
Kidney	145 (103-205) DW	86
Liver	132 (95-182) DW	86
Sheep, *Ovis* sp., kidney	22 (14-38) FW	62
Ringed seal, *Phoca hispida*.		
Liver	176 (121-576) DW	100
Kidney	209 (104-441) DW	100
Muscle	79 (52-135) DW	100
Harbor porpoise, *Phocoena phocoena*		
Blubber	4 FW	14
Liver	37 FW	14
Muscle	22 FW	14
Dall's porpoise, *Phocoenoides dalli*		
Adults		
Bone, skin	270-296 FW	101
Heart, liver, pancreas, kidney, whole body	25-51 FW	101
Brain, lung, testes	11-20 FW	101
Blubber, blood, muscle	4-9 FW	101
Fetus		
Liver	82 FW	101
Other tissues	<6 FW	101
Rat, *Rattus* sp., spermatozoa		
Ejaculated	890 DW	85
Nonejaculated	860 DW	85
Striped dolphin, *Stenella coeruleoalba*		
Blubber	16 FW	14
Muscle	11 FW	14
Pig, *Sus* spp., adults		
Kidney	22 (16-33) FW	62,82
Liver	74 (28-160) FW	82
Muscle	24 (8-53) FW	82
Bottle-nosed dolphin, *Tursiops truncatus*		
Blubber	20 FW	14
Muscle	11 FW	14
Polar bear, *Ursus maritimus*		
Kidney	33 (20-49) FW	120
Liver	58-63 (33-100) FW	58,120

Integrated studies		
Electrical transmission towers		
(corroded, galvanized), Ontario, Canada		
Soils		
Near towers	11,480 DW	102
1 km	10,431 DW	102
2 km	10,869 DW	102
5 km	362 DW	102
10 km	160 DW	102
25-50 km	54-70 DW	102
Plants, 5 species, roots and shoots		
Near towers	Max. 1,535 DW	102
1-5 km	Max. 297 DW	102
12-25 km	Max. 55 DW	102
Estuary, Calcasieu River, Louisiana		
Invertebrates		
Periphyton, whole	264 (49-1,300) DW	103
Zooplankton, whole	330 (31-3,550) DW	103
Ctenophores, whole	31-64 DW	103
Hooked mussel,	61 (39-86) DW	103
Brachidontes exustus, soft parts		
American oyster,	3,300 (1,000-7,794) DW	103
Crassostrea virginica, soft parts		
Blue crab, *Callinectes sapidus*, muscle	112 (106-213) DW	103
Brown shrimp, *Penaeus aztecus*, whole	46-61 DW	103
White shrimp, *Penaeus setiferus*, whole	44-62 DW	103
Fish, muscle		
Gulf menhaden, *Brevoortia patronus*	115 DW	103
Gizzard shad, *Dorosoma cepedianum*	25 DW	103
Threadfin shad, *Dorosoma petenense*	29 DW	103
Blue catfish, *Ictalurus furcatus*	35 (16-61) DW	103
Spot, *Leiostomus xanthurus*	22 (217-31) DW	103
Spotted gar, *Lepisosteus oculatus*	(22-239) DW	103
Atlantic croaker, *Micropogonias undulatus*	31 (15-95) DW	103
White mullet, *Mugil curema*	86 DW	103
Southern flounder, *Paralichthys lethostigma*	24 DW	103
Flotation mill (lead-zinc),		
Greenland		
Near outfall		
Suspended particulates	11,600 (1,058-25,700) FW	104
Sediments	Max. 6,799 FW	104
Water	0.035 FW	104

Mussel, *Mytilus edulis*, soft parts	502 (340-813) FW	104
Seaweed, *Fucus disticus*	300 FW	104
Control site		
Suspended particulates	123 FW	104
Sediments	129 FW	104
Water	0.0002 FW	104
Mussel	100 FW	104
Seaweed	8 FW	104
Freshwater lake, India		
Water	0.2 FW	105
Sediment	540 FW	105
Phytoplankton	11-15 FW	105
Zooplankton	60 FW	105
Fish, whole	10 FW	105
Grassland ecosystem		
On a revegetated mine tailings dam		
Soil (1-8 cm depth)	1,915-2,160 DW	106
Vegetation		
Live	157-201 DW	106
Dead	303-646 DW	106
Invertebrates, whole		
Herbivores	355-746 DW	106
Carnivores	403-515 DW	106
Detritivores	769-1,275 DW	106
Field vole, *Microtus agrestis*		
Bony tissues	183-226 DW	106
Soft tissues	160-281 DW	
Common shrew, *Sorex araneus*		
Bony tissues	438-547 DW	
Soft tissues	160-281 DW	106
Control grassland ecosystem		
Soil (1-8 cm depth)	52-62 DW	106
Vegetation		
Live	23-41 DW	106
Dead	24-56 DW	196
Invertebrates, whole		
Herbivores	133-299 DW	106
Carnivores	277-372 DW	106
Detritivores	248-1,095 DW	106
Field vole		
Bony tissues	178-249 DW	106
Soft tissues	53-121 DW	106

Common shrew		
Bony tissues	847-420 DW	106
Soft tissues	145-204 DW	106
Lead smelter, South Australia, marine outfall, whole organisms		
Samples collected 2.5-5.2 km from source		
Sediments	1,270 DW; Max. 16,700 DW	107
Seagrasses, 5 species	823 DW; Max. 3,540 DW	107
Crustaceans, 5 species	148 DW; Max. 767 DW	107
Tunicate, *Polycarpa pediculata*	153 DW; Max. 345 DW	107
Bivalve molluscs, 5 species	4,880 DW; Max. 20,300 DW	107
Carnivorous fish, 8 species	163 DW; Max. 440 DW	107
Omnivorous fish, 3 species	222 DW; Max. 619 DW	107
Herbivorous fish, six-lined trumpeter, *Siphamia cephalotes*	310 DW; Max. 480 DW	107
Samples collected 18-18.8 km from outfall		
Sediments	21 DW	107.
Seagrasses	72 DW	107
Crustaceans	68 DW	107
Tunicate	98 DW	107
Bivalve molluscs	2,590 DW	107
Carnivorous fish	78 DW	107
Omnivorous fish	105 DW	107
Herbivorous fish	97 DW	107
Metals-contaminated forest versus control location, Poland		
Yellow-necked field mouse, *Apodemus flavicollis*		
Liver	119 DW vs. 109 DW	108
Kidney	220 DW vs. 87 DW	108
Hair	179 DW vs. 122 DW	108
Carcass	109 DW vs. 98 DW	108
Bank vole, *Clethrionomys glareolus*		
Liver	120 DW vs. 116 DW	108
Kidney	156 DW vs. 143 DW	108
Hair	243 DW vs. 169 DW	108
Carcass	148 DW vs. 153 DW	108
Old-field community, Ohio, treated with sewage sludge for 10 consecutive years		
Treated area		
Sludge	866 DW	109
Soil	107 DW	109
Perennial plant, *Rubus frondosus*	41 DW	109
Giant foxtail, *Setaria faberii*	97 DW	109

Earthworm, *Lumbricus rubellus*	615 DW	169
Bluegrass, *Poa* spp.	85 DW	109
Japanese brome, *Bromus japonicum*	80 DW	109
Control area		
Perennial plant	14 DW	109
Bluegrass	35 DW	109
Japanese brome	35 DW	109
Zinc smelter, Palmerton, Pennsylvania		
Site 2 km downwind of smelter		
Soil	24,000 DW	110
Foliage, 8 species	660 DW	110
Acorns and berries, 4 species	59 DW	110
Fungi, 4 species	320 DW	110
Moths, 6 species	250-480 DW	110
Beetle, *Dendroides* sp.	1,450 DW	110
Caterpillar, *Porthetria dispar*	280 DW	110
Birds, 10 species, carcasses	140 (93-210) DW	110
White-footed mouse, *Peromyscus leucopus*, carcass	192 DW	110
Short-tailed shrew, *Blarina brevicauda*, carcass	377 DW	110
Site 10 km upwind of smelter		
Soil	960 DW	110
Foliage	118 DW	110
Acorns and berries	27 DW	110
Fungi	120 DW	110
Moths, 9 species	140-340 DW	110
Beetles, 2 species	470 DW	110
Caterpillar, *P. dispar*	170 DW	110
Birds, 10 species, carcasses	120 (78-170) DW	110
White-footed mouse, carcass	145 DW	110
Short-tailed shrew, carcass	201 DW	110
Zinc smelter, Peru, South America, 1980-84		
Soil, kilometers from smelter		
1	575 DW	111
13	183 DW	11]
27	154 DW	111
33	52 DW	111
35-55	16-29 DW	111
Domestic sheep, *Ovis aries*, liver, kilometers from smelter		
13	305 DW	111
29	165 DW	111

>100	77 DW	111
Zinc smelters, various		
Soils	Max. 80,000 DW	112
Trees, foliage	Max. 4,500 DW	112

[a] Concentrations are shown as means, range (in parentheses), maximum (Max.), and nondetectable (ND).

[b] 1. Mann et al. 1989; 2. Mason and Macdonald 1988; 3. Young et al. 1980; 4. Brix and Lyngby 1982; 5. Veleminsky et al. 1990; 6. Greville and Morgan 1989a; 7. Greville and Morgan 1989; 8. Beyer and Cromartie 1987; 9. Morgan and Morgan 1988; 10. Nash 1975; 11. Hopkin et al. 1989; 12. Hopkin et al. 1986; 13. Eisler 1981; 14. Morris et al. 1989; 15. Sullivan et al. 1988; 16. White and Rainbow 1985; 17. Sprague 1986; 18. Prestey et al. 1990; 19. NAS 1979; 20. Cain and Luoma 1986; 21. Amiard et al. 1986; 22. Lobel 1986; 23. Amiard-Triquet et al. 1988; 24. Bryan et al. 1987; 25. Chan 1988a; 26. Chu et al. 1990; 27. Eisler et al. 1978; 28. Weeks and Moore 1991; 29. Rainbow 1989; 30. Anil and Wagh 1988; 31. Walker et al. 1975; 32. Ridout et al. 1989; 33. Cutshall et al. 1977; 34. Waiwood et al. 1987; 35. Bagatto and Alikhan 1987; 36. Khan et al. 1989; 37. Nugegoda and Rainbow 1998b; 38. Shrestha and Morales 1987; 39. Fernandez and Jones 1989; 40. Schmitt et al. 1984; 41. Munkittrick and Dixon 1989; 42. Peterson et al. 1989; 43. Bezuidenhout et al. 1990; 44. Lazos et al. 1989; 45. Lowe et al. 1985; 46. Murphy et al. 1978; 47. Schmitt and Finger 1987; 48. Vas et al. 1990; 49. Hanna 1989; 50. Joseph 1989; 51. Craik and Harvey 1988; 52. Poston and Ketola 1989; 53. Grady et al. 1989; 54. Heinz et al. 1991; 55. Warren et al. 1990; 56. Wiemeyer et al. 1980; 57. Zee et al. 1985; 58. Wiemeyer et al. 1986; 59. Goede 1985; 60. Cosson et al. 1988; 61. Williams et al. 1989; 62, Ellen et al. 1989; 63. Blesbois and Mauger 1989; 64. Wiemeyer et al. 1988; 65. Wiemeyer et al. 1983; 66. Falandysz et al. 1988; 67. Krantz et al, 1970; 08. Thompson 1990; 69. Haseltine et al. 1981; 70. Custer and Mudhern 1983; 71. Wiemeyer et al. 1987; 72. Cosson et al. 1988a; 73. Cosson 1989; 74. Muirhead and Furness 1988; 75. Hernandez et al. 1988; 76. Weyers et al. 1988; 77. Kaur 1989; 78. Vahala et al. 1989; 79. Gooneratne and Christensen 1989; 80. Binnerts 1989; 81. Pisa and Cibulka 1989; 82. Jorhem et al. 1989; 83. Park and Chukwu 1989; 84. Latimer et al. 1989; 85. Saito et al. 1967; 86. Sileo and Beyer 1985; 87. Holterman et al. 1984; 88. Wlostowski et al. 1988; 89. Nielsen and Dietz 1990; 943. Sreekumar and Nirmalan 1989; 91. Clark et al. 1986; 92. Gunson et al. 1982; 93. Auer et al. 1988b; 94. Auer et al. 1988a; 95. Hamanaka et al. 1982; 96. Muir et al. 1988; 97. McGuire et al. 1989; 98. Casey and Hambidge 1980; 99. Keen et al. 1989; 100. Wagemann 1989; 101. Fujise et al. 1988; 102. Jones and Burgess 1984; 103. Ramelow et al. 1989; 104. Loring and Astound 1989; 105. Prahalad and Seenayya 1989; 106. Andrews et al. 1989; 107. Ward et al. 1986; 108. Sawicka-Kapusta et al. 1987; 109. Levine et al. 1989; 110 Beyer et al. 1985; 111. Reif et al. 1989; 112. Buchauer 1971; 113. Elinder 1986; 114. Vymazal 1986; 115. Dwyer et al. 1988; 116. Willis 1985a; 117. Richards 1989; 118. Blus et al. 1989; 119. Blus et al. 1977; 120. Norheim et al. 1992; 121. Schmitt and Brumbaugh 1990.

Terrestrial plants growing beneath corroded galvanized fencing have been poisoned by zinc (Jones and Burgess 1984). Vegetables are relatively low in zinc, but growing plants can accumulate zinc applied to soils (Geyer 1986). High soil level of zinc is the primary cause of vegetation damage near zinc smelters (Buchauer 1971; Leonard and Gerber 1989). Elevated zinc concentrations in soils near zinc smelters inhibit seedling root elongation and probably prevent establishment of invader species in denuded areas (Buchauer 1971). Lichen species richness and abundance were reduced by about 90% in lichen communities near a Pennsylvania zinc smelter; elevated zinc concentrations were the probable cause of the impoverished lichen flora (Nash 1975). Soils and vegetation surrounding zinc smelters in Palmerton, Pennsylvania were grossly contaminated with zinc, cadmium, and lead. Zinc was primarily responsible for the destruction of trees and subsequent erosion of the soil, reductions in moss and lichen flora, reductions in litter arthropod populations, and reductions in species diversity of soil fungi and bacteria; zinc residues were elevated in slugs and millipedes (Sileo and Beyer 1985; Beyer 1988). Soil litter invertebrates were rare or absent 2 km downwind of the smelter; unlike soil litter invertebrates from more distant sites, invertebrates collected up to 10 km upwind of the smelters had significantly elevated zinc concentrations (Beyer et al. 1985).

The maximum zinc concentration in earthworms collected from a contaminated site was 1,600 mg/kg DW whole animal; for uncontaminated sites it was 650 mg/kg (Beyer and Cromartie 1987). Whole body zinc concentrations in earthworms (*Dendrodrilus rubidus*, *Lumbricus rubellus*) tended to reflect zinc concentrations in

soil, although zinc accumulations in both species seem to be physiologically regulated when soil zinc values exceeded 1,000 mg/kg DW (Morgan and Morgan 1988).

Whole body zinc content of terrestrial isopods seems to reflect soil zinc levels and may be a useful indicator of soil contamination (Hopkin et al. 1989). *Porcellio scaber*, a terrestrial isopod known as a woodlouse, is recommended as a biological indicator of zinc contamination because of the positive correlation between zinc content in soil or leaf litter and woodlouse hepatopancreas. Zinc content in *Porcellio*, litter, and soil near a zinc smelter was >1,000 mg/kg DW in whole isopod, >9,000 mg/kg DW in hepatopancreas, > 10,000 mg/kg DW in litter, and >50,000 mg/kg DW in soil (Hopkin et al. 1986).

Interspecies variability in zinc content of terrestrial invertebrates is large and governed by numerous modifiers. For example, whole body zinc content in closely-related species of terrestrial gastropods collected from a single contaminated site was between 600 and 1,200 mg/kg DW (Greville and Morgan 1989a). In grey field slugs (*Deroceras reticulatum*), zinc was highest in late spring and lowest in summer and positively correlated with tissue cadmium concentrations; starvation for 16 days had no effect on body zinc concentrations (Greville and Morgan 1989b). Zinc tends to concentrate in mechanical structures of various invertebrates, such as mandibular teeth. High concentrations of zinc are reported in jaws of polychaete worms, cutting edges of the mandibles of herbivorous insects, mandibles of various species of beetles, copepod mandibles, chaetognath teeth and spines, mandibular teeth of ants, and fangs of spiders (Schofield and Lefevre 1989). Honey bees (*Apis mellifera*) collected near a lead smelting complex at East Helena, Montana, had depressed whole body zinc concentrations despite increased ambient air zinc values; however, whole body burdens of arsenic, cadmium, copper, and lead were significantly elevated and may have influenced zinc kinetics (Bromenshenk et al. 1988). Also, pollen was usually the most indicative source of zinc and other heavy metals in bees (Veleminsky et al. 1990).

Aquatic Organisms

Concentrations of zinc in tissues of aquatic organisms are usually far in excess of that required for normal metabolism. Much of the excess zinc is bound to macromolecules or present as insoluble metal inclusions in tissues (Eisler 1981, 1984; EPA 1987). Diet is the most significant source of zinc to aquatic organisms and is substantially more important than uptake from seawater (Eisler 1981, 1984). In general, zinc concentrations in sediments and tissues of aquatic organisms are elevated in the vicinity of smelters and other point sources of zinc and decrease with increasing distance (Ward et al. 1986; Table 4).

Freshwater algae in Canadian mine tailing environments heavily concentrate zinc and other metals and may retard metal dispersion through the water column (Mann and Fyfe 1988). Zinc levels in field collections of marine algae and macrophytes are usually at least several orders of magnitude higher than zinc concentrations in the surrounding seawater (Eisler 1981). In general, concentrations in marine aquatic flora were high when seawater zinc concentrations were elevated, although the relation was not linear. Marine flora, especially red and brown algae, are among the most effective marine zinc accumulators. Increasing accumulations of zinc in marine algae were associated with decreasing light intensity, decreasing pH, increasing temperature, decreasing levels of DDT, and increasing oxygen. Ionic zinc was accumulated more rapidly than other forms of zinc (Eisler 1981). Many species of marine algae had zinc concentrations >1 g/kg DW (Eisler 1980). These grossly elevated levels were usually associated with nearby industrial or domestic outfalls containing substantial amounts of zinc (Eisler 1981). In eelgrass (*Zostera marina*), zinc concentrations increased with age of leaf (Brix and Lyngby 1982).

In the Fal estuary, England, long-term metal pollution during the past 120 years resulted in zinc sediment levels between 679 and 1,780 mg/kg DW, producing benthic communities that favor zinc-tolerant organisms, such as oysters and nereid polychaetes, and a general impoverishment of mussels, cockles, non-nereid polychaetes, and gastropods (Bryan et al. 1987).

Zinc in molluscs is usually associated with high molecular weight proteins, with diet (as opposed to ambient water zinc concentrations), from collection locales with elevated sediment zinc burdens, and with particulate matter from dredging and storm perturbations (Eisler 1981). Zinc levels in molluscs were highest in animals collected near anthropogenic point sources of zinc. Excess zinc accumulations do not seem to affect normal molluscan life processes, and zinc is frequently accumulated far in excess of the organism's immediate needs (Eisler 1981). American oysters (*Crassostrea virginica*), for example, may naturally contain up to 4 g Zn/kg FW

soft parts; this is comparable to accumulations observed in oysters exposed to 0.2 mg Zn/L for 20 weeks (NAS 1979). Zinc tends to accumulate in the molluscan digestive gland and stomach as excretory granules and in the kidney as concretions (Eisler 1981; Sprague 1986; Sullivan et al. 1988). The preferred storage site in mussels and scallops is the kidney and in oysters, the digestive gland (Sprague 1986). In oysters, granules may contain up to 60% of the total body zinc, explaining, in part, how some shellfish can exist with such high body burdens (Sprague 1986).

Zinc in molluscan tissues is usually elevated under conditions of increasing water temperature and pH and decreasing salinity (Eisler 1981); however, zinc accumulation kinetics in molluscs vary considerably among species (Chu et al. 1990). Variations in zinc content of clam tissues were associated with seasonal changes in tissue weights (Cain and Luoma 1986). Unlike conspecifics collected at more distant sites, gastropods nearest a ferronickel smelter had elevated zinc concentrations in the hepatopancreas; however, there were no consistent seasonal variations (Nicolaidu and Nott 1990). Fluctuations in zinc content of common mussels (*Mytilus edulis*) related to size or season of collection were sufficient to conceal low chronic or short-term pollution (Amiard et al. 1986). Diet, which is the primary route of zinc accumulation in most molluscs, had no significant effect on whole body zinc content of certain predatory marine gastropods. Whole body zinc concentrations of gastropod oyster drills (*Ocenebra erinacea*) were between 1,451 and 2,169 mg/kg DW and remained unchanged after feeding for 6 weeks on Pacific oysters (*Crassostrea gigas*) containing 1,577 mg Zn/kg DW or common mussels (*Mytilus edulis*) containing 63 mg Zn/kg DW (Amiard-Triquet et al. 1988).

High zinc concentrations in crustaceans are usually associated with industrial contamination. In barnacles (*Balanus* spp.), high (>3.3 g/kg DW soft parts) levels are attributed to inorganic granules that contain up to 38% zinc and that accumulate in tissue surrounding the midgut (Eisler 1980, 1981). In descending order of chemical abundance, the granules consist of phosphorus, zinc, potassium, sulfur, and chlorine (Thomas and Ritz 1986). These insoluble, membrane-limited spheres form in response to high zinc levels in the ambient seawater within 12 days of exposure and concentrate in specified cells around the gut: the stratum perintestinale (Walker et al. 1975; Sprague 1986; Thomas and Ritz 1986). Zinc granules in barnacles represent a detoxification mechanism for surplus zinc (Thomas and Ritz 1986). Older barnacles have greater whole body zinc accumulations than younger stages, and accumulations change seasonally (Anil and Wagh 1988). Zinc concentrations in marine crustacean tissues are usually <75 mg/kg FW or <100 mg/kg DW; exceptions include hepatopancreas, molts, eggs, fecal pellets, and barnacles (Table 4). In crustaceans, zinc is slightly elevated in hepatopancreas but in most tissues only 2 to 3 times higher than in muscle (Sprague 1986). For marine crustaceans, the highest concentration recorded in muscle was 57 mg Zn/kg FW in the king crab, *Paralithodes camtschatika* (NAS 1979), and was associated with two metal binding proteins of molecular weight 11,500 and 27,000 (Eisler 1981). In crustacean tissues, zinc levels were higher in summer at lower salinities and in young animals (Eisler 1981), although young amphipods had higher zinc residues than older stages (Rainbow 1989). Seasonal accumulations of whole body zinc in the shrimp (*Palaemon serratus*) during spring and summer and loss in winter seem to reflect water zinc concentrations in the range of 0.0 to 9.0 µg/L (Alliot and Frenet-Piron 1990). Zinc is present in crustacean serum at concentrations >1,000 times greater than in ambient seawater in serum, it serves primarily as a cofactor of carbonic anhydrase--the principal enzyme involved in calcification. Serum zinc concentrations in crustaceans seem to be independent of season and water temperature or salinity (Sprague 1986).

Molting results in a 33-50% loss of total zinc in marine crustaceans; molts, together with fecal pellets, constitute an important vehicle of zinc transfer in marine ecosystems (Eisler 1981). The freshwater opossum shrimp (*Mysis relicta*) can transport zinc from sediments into the water column and in the reverse during their migratory cycle. *Mysis relicta* and other benthic invertebrates play an important role in determining the concentration of zinc and other metals in lake sediments (Van Duyn-Henderson and Lasenby 1986). Unlike decapod crustaceans, marine amphipods do not regulate body zinc concentrations; amphipod body burdens of zinc may reflect sediment total zinc levels and suggest that certain groups may be suitable bioindicators (Rainbow et al. 1989). Molting had no effect on body zinc concentration in four species of adult marine amphipods (Weeks and Moore 1991), and this forces a reexamination of the role of cast exuviae in zinc transport.

In annelids, zinc content was highest in nonselective deposit feeders, omnivores, and carnivores and from animals collected from sediments with elevated zinc levels (Eisler 1981). Freshwater tubificid worms have the potential to increase zinc concentrations in the water column, particularly during short episodes of high

burrowing activity (Krantzberg and Stokes 1985). A high zinc content seems to be a structural characteristic of jaws of marine nereid worms (Table 4). In the marine polychaete worm *Nereis diversicolor*, zinc is localized in the gut wall, epidermis, nephridia, and blood vessels; most of the body zinc is present in wandering amoebocytic cells of excretory organs. Zinc in *Nereis* may be present as insoluble granules in membrane bound vesicles; excretion is through exocytosis with the aid of amoebocytes (Fernandez and Jones 1989). Unlike the insoluble zinc phosphate granules of molluscs and crustaceans, zinc granules in *Nereis* were very soluble and retained only by sulfide precipitation (Pirie et al. 1985).

Marine vertebrates, including fish and elasmobranchs, have lower zinc concentrations in tisues (6-400 mg/kg DW) than marine plants and invertebrates (Eisler 1980, 1981, 1984). Highest concentrations in muscle of marine fish (20.1-25.0 mg/kg FW) were recorded in the northern anchovy (*Engraulis mordax*) and the Atlantic menhaden (*Brevoortia tyrannus*; NAS 1979). The highest zinc concentrations measured in whole freshwater fish in the conterminous United States in 1978-79 were in common carp (*Cyprinus carpio*) from Utah; concentrations in carp from Utah were between 70 and 168 mg Zn/kg FW versus an average of 63 mg Zn/kg FW for this species collected elsewhere (Lowe et al. 1985). Zinc concentrations in fish tend to be higher near urban areas (Peterson et al. 1989); highest in eggs, viscera and liver (Eisler and LaRoche 1972; Eisler 1981); lowest in muscle (Eisler 1981); positively correlated with metallothionein concentrations (Overnell et al. 1987b); lower in all tissues with increasing age and growth (Eisler and LaRoche 1972; Eisler 1981, 1984; Grady et al. 1989); and relatively unaffected by water salinity, temperature, or copper concentrations (Eisler and LaRoche 1972; Eisler 1981). Zinc residue data from marine fish that were dead on collection are of limited worth because dead fish accumulate zinc from seawater at a substantially higher rate than living teleosts (Eisler 1981).

Zinc concentrations in fish and other aquatic vertebrates are modified by diet, age of the organism, reproductive state, and other variables. In fish, diet is the major route of zinc uptake and juveniles accumulate zinc from the medium more rapidly than embryos or larvae (Cutshall et al. 1977; Eisler 1981). Because the diet of many teleost carnivores changes drastically with age and because upper trophic level vertebrates are frequently used as indicators of water quality, more research into zinc burdens in prey organisms is needed (Eisler 1984). A reduction in serum zinc during egg formation in a flatfish (*Pleuronectes platessa*) may represent a transfer of zinc to eggs (Overnell et al. 1987b). High (>35 mg/kg FW) zinc concentrations in eggs of Atlantic salmon are sometimes associated with increasing mortality, although low (14 mg/kg FW) concentrations seem to have no adverse effect on survival (Craik and Harvey 1988). Zinc concentrations in Atlantic salmon milt ranged from 0.5 to 5.5 mg Zn/kg and was linearly proportional to spermatozoan abundance (Poston and Ketola 1989). In lakes containing 1,150 mg Zn/kg sediment and 209-253 µg Zn/L water column, white sucker (*Catostomus commersoni*) females did not grow after sexual maturity and had increased incidences of spawning failure. Alterations in growth and reproduction were related, in part, to nutritional deficiencies as a result of chronic effects of elevated sediment zinc on the food base of the sucker, that is, invertebrate fauna were absent in the uppermost 7 m (Munkittrick and Dixon 1988). Eggs of the white sucker incubated at a metals-contaminated site (400 µg Zn/L), but not eggs of conspecifics, at a noncontaminated (2.7 µg Zn/L) site, produced larvae with a decreased tolerance to copper and with elevated zinc body burdens; larval size and fertilization rate were the same at both sites (Munkittrick and Dixon 1989).

Birds

Zinc residues were elevated in birds collected near zinc smelters (Beyer 1988). In general, the highest concentrations of zinc in birds are in the liver and kidney and the lowest in muscle (Eisler 1981, 1984). In giant Canada geese (*Branta canadensis maxima*), more zinc is contained in red muscle than in white muscle and more in slow contracting muscle than in fast muscle (Rosser and George 1986). Zinc concentrations in marine birds normally are between 12 mg/kg FW in eggs and 88 mg/kg FW in the liver. The highest recorded concentration of zinc in a marine bird was 541 mg/kg DW in the liver of a booby (*Sula* sp.) that died from polychlorinated biphenyl poisoning. Elevated zinc levels in these birds may have been a manifestation of toxicant-induced stress (i.e., breakdown in osmoregulatory processes), as in other taxonomic groups (Eisler 1981). Seabirds with high zinc concentrations in the liver and kidney tend to have high cadmium levels in these tissues (Muirhead and Furness 1988). In flamingos, zinc in the liver positively correlated with copper levels in the liver and kidney and with metallothionein levels in the kidney (Cosson 1989). In egrets, zinc positively correlated with metallothionein protein levels in the liver (Cosson 1989). In blue-winged teals (*Anas discors*), zinc concentrations were higher in the liver than in muscle, higher in males than in females, and higher in

autumn than in spring (Warren et al. 1990). Zinc concentrations in the liver of black-crowned night-herons (*Nycticorax nycticorax*) were usually higher in younger birds, although weight and sex had no direct effect on zinc content (Custer and Mulhern 1983). Zinc concentrations in tissues and feathers of dead California condors (*Gymnogyps californianus*) that had died from a variety of causes (Table 4) were similar to those in turkey vultures (*Cathartes aura*), common ravens (*Corvus corax*), and ospreys (*Pandion haliaetus*) and are considered normal (Wiemeyer et al. 1988). The highest recorded concentration in condor liver of 250 mg/kg FW approaches those in livers of mallards (*Anas platyrhynchos*) that died from high dietary loadings of zinc (Wiemeyer et al. 1988). Zinc concentrations in the liver of ospreys were similar between age groups and sexes (Wiemeyer et al. 1987). With the onset of egg production in turkeys (*Meleagris gallopavo*), serum zinc in hens increased from 1.6 to 6.9 mg/L and remained significant elevated throughout egg laying; during this same period, zinc concentration in the liver declined from 75 to 39 mg/kg DW, although total zinc in the liver increased because of an increase in liver weight (Richards 1989a).

Zinc concentrations in the sediments of the Rhine River increased about 6 times between 1900 and 1950 and have remained stable since then. But migratory waterfowl from this collection locale do not have elevated zinc concentrations in their primary feathers (Goede 1985). Zinc content in feathers of the hoopoe (*Upupa epops*) increased from 200 mg/kg DW at age 7 days to 1,000 mg/kg DW at age 35 days (Kaur 1989). Hoopoe populations are declining in India and this decline is said to be associated with increasing zinc concentrations in feathers (Kaur 1989). Feathers of the greater flamingo (*Phoenicopterus ruber*) are proposed indicators of atmospheric zinc contamination: the average zinc content was 53% more in outer barbs of the black primary feathers exposed to air pollution than in inner barbs (Cosson et al. 1988a). More research into the use of feathers as indicators of zinc contamination is needed.

Zinc concentrations in seminal plasma are about 100 times lower in domestic chickens (*Gallus* sp.) than in humans and most other mammals, except sheep. Concentrations of zinc in fowl seminal plasma after in vivo storage of spermatozoa for 24 h at 4°C were near the threshold values toxic to spermatozoa (Blesbois and Mauger 1989), suggesting that poultry spermatozoa normally function near their lower lethal zinc threshold.

Mammals

White-tailed deer (*Odocoileus virginianus*) collected near a zinc smelter, but not conspecifics from more distant sites, had elevated tissue zinc concentrations. Deer with zinc concentrations of 150 mg/kg FW (750 mg/kg DW) in the renal cortex potion of the kidney had swollen joints, lameness, and joint lesions similar to those of zinc-posioned horses from the same area (Sileo and Beyer 1985). Zinc was elevated in the kidney cortex of red deer (*Cervus elaphus*) and older deer tended to have higher concentrations (as high as 184 mg/kg DW) than younger deer (as low as 20 mg/kg FW); in older deer, zinc was associated with the metallothionein fraction (Holterman et al. 1984). Zinc residues were usually elevated in rodents near smelters (Beyer et al. 1988). Rodents from metals-contaminated forests had zinc loadings in tissues similar to those from control locations, although lead and cadmium were significantly elevated in the contaminated zone (Sawicka-Kapusta et al. 1987). Elevated zinc concentrations in mine tailings reportedly do not represent a notable contamination hazard to the invading mammalian fauna, although zinc concentrations in invertebrates, especially earthworms, and vegetation were elevated (Andrews et al. 1989; Table 4).

Otters (*Lutra lutra*) were found only on a single unpolluted tributary of a river system contaminated by zinc mine drainage waste, suggesting that a contaminated food supply may be responsible for the avoidance by otters of otherwise suitable habitat (Mason and Macdonald 1988).

Marine mammals collected near heavily urbanized or industrialized areas or near zinc pollution point sources, but not individuals of the same species and of similar age from relatively pristine environments, usually had elevated zinc concentrations (Eisler 1984). Zinc concentrations in tissues of the ringed seal (*Phoca hispida*) were essentially the same in animals near a lead-zinc mine and in animals in a distant reference site, although lead and selenium burdens were elevated in the vicinity of the mine site (Wagemann 1989). Concentrations of zinc in tissues of the Northern sea lion (*Eumetopias jubata*) were highest in the liver and pancreas and next highest in descending order in the kidney, muscle, heart, spleen, and lung; this rank order is comparable to that in human tissues (Hamanaka et al. 1982). There is considerable variation among species in tissue zinc concentrations; threefold differences are not uncommon for the same tissue in different species of marine mammals (Muir et al. 1988). Marine mammals contained the lowest zinc concentrations (2-505 mg/kg DW, elevated in the liver) of all groups of marine organisms examined. Because zinc is usually available in sufficient

quantity in the marine environment and is usually accumulated in excess of the organism's immediate needs, it remains unclear why zinc is comparatively depressed in tissues of marine mammals (Eisler 1981).

Zinc toxicosis in horses near a zinc smelter was characterized by lameness, swollen joints, and unkempt appearance, particularly in foals. Zinc concentrations in afflicted foals, but not in foals at more distant sites, were elevated in the pancreas, liver, kidney, and serum (Gunson et al. 1982). Foals born near the smelter had joint swellings that were attributable to generalized osteochondrosis; lesions were similar to those induced experimentally in animals fed high zinc diets and may have been the result of a zinc-induced abnormal copper metabolism (Gunson et al. 1982). Concentration of zinc in tissues of horses from farms near the Palmerton smelter were extremely high and approaching lethal thresholds in some cases; zinc poisoning was a cause of debility and death of foals (Sileo and Beyer 1985). Grazing mares managed with standard husbandry had significant monthly variations in plasma zinc because, in part, of dietary factors such as nutritional supplementation and seasonal variations in the quality of grazing pasture (Auer et al. 1988b). Peak plasma zinc levels in horses positively relate to age (in weanlings age 22-52 weeks) and to summer diets (Cymbaluk and Christison 1989).

Dairy cattle near a lead and zinc ore processing facility did not have elevated blood or hair zinc levels, although daily zinc intake was 5.6 mg/kg BW versus 1.2 mg/kg BW daily by cattle in a control area (Milhaud and Mehannaoui 1988). In cattle, proximity to zinc refineries did not result in significant elevation of zinc concentrations in the liver and kidney (Spierenburg et al. 1988). However, cows living within 6 km of a power plant in Czechoslovakia, but not a herd at a 26-km distance, had elevated zinc loadings in hair and poor reproduction (Pisa and Cibulka 1989). In adult bovines, zinc reserves are usually small and located primarily in the skeleton and muscle, although appreciable hepatic accumulations can occur in the fetus. At 270 days of gestation, for example, 30% of zinc in fetal cattle is in the liver; zinc concentration is about 4 times higher in the fetal than in the maternal liver (Gooneratne and Christensen 1989). Liver concentrations >120 mg Zn/kg DW in cattle are frequently associated with elevated dietary zinc loadings (Binnerts 1989). Concentrations of zinc in milk of cows and goats varied significantly between breeds and with zinc level in diet and declined markedly after parturition (Park and Chukwu 1989).

A normal 70-kg human male contains 1.5-2.0 g zinc or about 21-29 mg Zn/kg BW; normal zinc uptake is 12-15 mg daily, equivalent to 0.17-0.21 mg/kg BW (Prasad 1979). Foods rich in zinc are seafoods, meats, grains, dairy products, nuts, and legumes (Goyer 1986). About 90% of the total body zinc is in the musculoskeletal system (Rosser and George 1986). Highest zinc concentrations of 100-200 mg/kg occur in the prostate, eye, brain, hair, bone, and reproductive organs; intermediate concentrations of 40-50 mg/kg occur in the liver, kidney, and muscle (NAS 1979; Casey and Hambidge 1980). In blood, about 80% of the total zinc is in red cells where it is associated with carbonic anhydrase. The mean plasma zinc level is about 0.9 mg/L; about half is in a freely-exchangeable form loosely bound to albumin; most of the remainder is tightly bound to macroglobulins and amino acids, especially histidine and cysteine (Casey and Hambidge 1980; Goyer 1986). The greatest zinc concentration in the human body is in the prostate and may be related to the elevated levels of acid phosphatase, a zinc-containing enzyme in that organ (Goyer 1986). The prostate gland contributes zinc to spermatozoa in dogs--a necessary process for canine fertility and fecundity; in rats, however, the prostate does not contribute to zinc in spermatozoa, and its function is not essential for reproduction in rats (Saito et al. 1967).

Zinc Deficiency Effects

General

Zinc is important in the metabolism of proteins and nucleic acids and is essential for the synthesis of DNA and RNA. Zinc deficiency has been reported in humans and a wide variety of plants and animals--with severe effects on all stages of reproduction, growth, and tissue proliferation in the young. In early gestation, zinc deficiency may cause severe congenital abnormalities. Later in gestation, deficiency can cause growth inhibition and brain growth impairment, leading to altered behavioral development after birth. Feeding a low zinc diet to lactating dams produces signs of zinc deficiency in suckling pups. In humans, zinc deficiency is associated with delayed sexual maturation in adolescent males; poor growth in young children; impaired growth of hair, skin, and bone; disrupted Vitamin A metabolism; and abnormal taste acuity, hormone metabolism, and immune function.

Terrestrial Plants

Zinc deficiencies in citrus groves in California, pecan trees in Texas, and various crops in Australia resulted in large crop losses (Vallee 1959). Applications of zinc salts were effective under acidic soil conditions. But neutral or alkaline soils rendered zinc salts insoluble and zinc therapy ineffective. Zinc salts sprayed on leaves or injected into tree trunks overcame the problems of soil solubility and have generally been successful (Vallee 1959). Zinc is usually bound strongly in plants, particularly in grains, markedly decreasing its availability to animal consumers. Binding is attributed mainly to high content of phytate and also to high levels of fiber hemicelluloses, and amino acid-carbohydrate complexes (Casey and Hambidge 1980). Whole-grain cereals and legumes are considered rich sources of zinc (Casey and Hambidge 1980).

Aquatic Organisms

Nutritional zinc deficiency is rare in aquatic organisms (Spear 1981), although reports are available of experimentally-induced zinc deficiency in algae, sponges, daphnids, echinoderms, fish, and amphibians.

Experimental zinc deficiency in euglenoids (*Euglena gracilis*) was associated with arrested growth and abnormal cell differentiation and development, leading to extensive teratological abnormalities. Zinc-deprived *Euglena* survived for extended periods through decreased metabolism (Falchuk et al. 1985; Falchuk 1988). Marine algae stopped growing when ambient zinc concentrations fell below 0.7 µg/L, and zinc-deficient cultures of freshwater algae were unable to metabolize silicon (Vymazal 1986).

A freshwater sponge (*Ephydatia fluviatilis*) grew normally at a concentration of 0.65 µg Zn/L, but growth was reduced at lower concentrations (Francis and Harrison 1988).

Daphnids (*Daphnia pulex*, *Daphnia magna*) reared for six brood cycles in zinc-free water showed reduced survival, inhibited reproduction, and cuticle damage (Keating and Caffrey 1989).

Zinc is important in pH regulation of sperm of marine invertebrates. Zinc reduction in semen to <6.5 µg/L adversely affected sperm pH and motility in sea urchins (*Strongylocentrotus purpuratus*, *Lytechnicus pictus*), horseshoe crab (*Limulus polyphemus*), and starfish (Clapper et al. 1985a, 1985b).

Rainbow trout fry fed diets containing 1-4 mg Zn/kg ration had poor growth, increased morality, cataracts, and fin erosion; supplementing the diet to 15-30 mg Zn/kg alleviate these signs (Spry et al. 1988). Spry et al. (1988) also fed rainbow trout fry diets containing 1, 90, or 590 mg Zn/kg ration and simultaneously exposed them to a range of waterborne zinc concentrations of 7, 39, 148, or 529 µg Zn/L. After 16 weeks, the 7 µg Zn/L plus 1 mg/kg diet group showed clear signs of deficiency including a significantly reduced plasma zinc concentration (which was evident as early as the first week of exposure), reduced growth (with no growth after week 12), decreased hematocrit, and reduced plasma protein and whole body zinc concentration. Elevating waterbone zinc to 39 or 148 µg Zn/L partially corrected the deficiency but did not restore plasma or whole body zinc to initial levels or in fish raised for 16 weeks on a zinc-adequate diet of 90 mg Zn/kg ration. There were no toxic effects at any other dietary-waterborne zinc mixture. It was concluded that zinc uptake from water was independent of uptake from diet because at any dietary zinc level, an increase in the waterborne zinc resulted in an increase in whole body zinc. In freshwater, where waterborne concentrations of <10 µg Zn/L are most commonly encountered, waterborne zinc contributions to whole body zinc loadings are probably insignificant. When dietary zinc was adequate (i.e., 90 mg Zn/kg ration), the contribution of waterborne zinc was significant in the case of rainbow trout (Spry et al. 1988). In marine teleosts, diet is the major zinc source when seawater contained <15 µg Zn/L; at higher ambient concentrations of 600 µg Zn/L, waterborne zinc contributed up to 50% of the total body zinc burden (Spry et al. 1988).

Experimentally-produced zinc deficiency in toad embryos resulted in adults with abnormal ovarian development, altered meiotic and ovulation processes, and embryos with a high incidence of congenital malformations (Herkovits et al. 1989).

Birds

Zinc deficiency in the chicken, turkey, and Japanese quail is characterized by low survival, reduced growth rate and food intake, poor feathering, shortening and thickening of long bones of legs and wings, reduced egg production and hatchability, skeletal deformities in embryos, an uncoordinated gait, reduced bone alkaline

phosphatase activity, and increased susceptibility to infection (Blamberg et al. 1960; NAS 1979; Prasad 1979; Apgar 1985; O'Dell et al. 1989); Stahl et al. 1989a).

Laying hens (*Gallus* sp.) had low egg hatchability on diets that contained 6 mg Zn/kg and produced chicks that were weak and poorly feathered; these chicks usually died within a few days on 8-9-mg Zn/kg diets (Blamberg et al. 1960). Zinc-deficient chicks (13-16 mg Zn/kg DW diet for 4 weeks) had pathological defects in epiphyseal cartilage; no interference with calcification was noted in controls fed diets containing 93-96 mg Zn/kg feed (Westmoreland and Hoekstra 1969). Pullets fed diets containing 28 mg Zn/kg for 4 months and then 4 mg Zn/kg ration for 4.5 months produced few hatchable eggs after 4 months; prevalent malformations included faulty trunk and limb development, missing vertebrae, missing limbs and toes, abnormal brain morphology, small eyes, and skeletal malformations (Blamberg et al. 1960). Most zinc deficiency effects were reversed by increasing dietary zinc concentrations to 96-120 mg/kg (Blamberg et al. 1960).

Chicks of the Japanese quail fed an excess of zinc (25-30 mg Zn/kg diet) during their first week of life were protected during a subsequent period of zinc deprivation (1 mg Zn/kg diet for 1 week). Birds that received an initial intake of zinc in excess of requirements grew significantly better than birds on a minimal amount of zinc. Japanese quails may store excess zinc in bones; this zinc store may become available during a subsequent period of zinc deprivation, especially during a period of rapid bone growth (Harland et al. 1975); but this requires verification.

Egg production constitutes a major loss of zinc and other trace metals by the laying hen. Vitellogenin mediates the transfer of zinc from the liver to the maturing oocyte, ultimately resulting in deposition into yolk of the newly formed egg (Richards 1989a). More research into the role of zinc in avian reproduction seems needed.

Mammals

Compared with zinc toxicity, zinc deficiency is a much more frequent risk to mammals (Leonard and Gerber 1989). Zinc is required in all stages of the cell cycle, and deficiency adversely affects metabolism of DNA, RNA, proteins, and activity of carbonic anhydrase, lactic dehydrogenase, mannosidase, and other enzymes (NAS 1979; Prasad 1979, 1980; Apgar and Everett 1988). In zinc deficiency, the activity of various zinc-dependent enzymes are reduced in testes, bone, esophagus, and kidney of rats, and alkaline phosphatase activity is reduced in bone and plasma of zinc-deficient rats, pigs, and cows (Prasad 1979; Vergnes et al. 1990). Deficiency leads to loss of appetite and taste, skin disturbances, slow wound healing, impaired brain development, deficient immune system, and disrupted water metabolism (Binnerts 1989). Zinc deficiency adversely affected testicular function in humans and animals and seems to be essential for spermatogenesis and testosterone metabolism (Prasad 1980). Zinc deficiency in young men with very low zinc intakes resulted in testicular lesions and reduced accessory gland weights, primarily from reduced food intake and growth (Apgar 1985). Zinc deficiency during pregnancy produced low birth weight, malformations, and poor survival in rats, lambs, and pigs; the role of zinc in human reproductive problems is still unclear (Apgar 1985). Zinc-deficient diets for ruminants and small laboratory animals usually contain <1 mg Zn/kg ration, although rats show deficiency at <12 mg Zn/kg ration (Elinder 1986). Zinc deficiency has been documented in humans, small laboratory animals, domestic livestock, minks, and monkeys; signs of severe zinc deficiency in mammals include decreased food intake, growth cessation, fetal malformations, testicular atrophy, swelling of feet, excessive salivation, dermal lesions, parakeratosis of the esophagus, impaired reproduction, hair loss; unkempt appearance, stiffness, abnormal gait, skin and organ histopathology, and hypersensitivity to touch (NAS 1979; Jameson 1980; Elinder 1986; Gupta et al. 1988; O'Dell et al. 1989). Selected examples of zinc deficiency in various species follow.

Zinc deficiency in humans is rare and usually associated with severe malabsorption, parenteral alimentation lacking zinc, or geophagia (Sternlieb 1988). Symptoms of zinc deficiency depend in part on age, acuteness of onset, duration and severity of the zinc depletion, and the circumstances in which deficiency occurs. Many of the features of zinc deficiency observed in humans are similar to those in zinc-deficient animals (Casey and Hambidge 1980). Simple nutritional deficiency from marginal zinc intake may be common even in the United States (Casey and Hambidge 1980). Factors of zinc deficiency include inadequate dietary intake (protein-calorie malnutrition), decreased availability (high fiber-phytate diets), decreased absorption, excessive losses (increased sweating, burns), increased requirements (rapid growth, pregnancy, lactation), as well as old age, alcoholism, and possible genetic defects (Casey and Hambidge 1980). Zinc deficiency may also occur as a

result of liver or kidney disease, gastrointestinal disorders, skin disorders, parasitic infections, diabetes, and genetic disorders, such as sickle cell disease (Prasad 1979). Clinical disorders aggravated by zinc deficiency include ulcerative colitis, chronic renal disease, and hemolytic anemia (Goyer 1986). In the 40 years since human zinc deficiency was demonstrated, it has been observed in a wide variety of geographic areas and economic circumstances. Severe zinc deficiency occurs in some areas of the Middle East and North Africa and is frequently associated with the consumption of unrefined cereals as a major part of the diet (Casey and Hambidge 1980). Chronic zinc deficiency in humans is associated with dwarfism, infantile testes, delayed sexual maturity, birth defects, poor appetite, mental lethargy, immunodeficiency, skin disorders, night blindness, impotence, spleen and liver enlargement, defective mobilization of vitamin A, delayed wound healing, impaired taste acuity, abnormal glucose tolerance, impaired secretion of luteinizing hormone, and iron and folate deficiency (Prasad 1979, 1980; Casey and Hambidge 1980; Elinder 1986; Goyer 1986; Sternlieb 1988; Mackay-Sim and Dreosti 1989). A deficiency of zinc in the growing age period results in growth retardation; a severe zinc deficiency may be fatal if untreated (Prasad 1980). Zinc-deficient humans excrete <100 µg zinc daily in urine rather than a normal daily >300 µg zinc (Goyer 1986). Zinc deficiency may exacerbate impaired copper nutrition; interactions with cadmium and lead may modify the toxicity of these metals (Goyer 1986). Acrodermatitis enterohepatica is a disease characterized by skin eruptions, gastrointestinal disorders, and low serum zinc levels. One causative factor is poor intestinal absorption of zinc; a complete cure was accomplished by oral administration of 135 mg zinc daily as 600 mg zinc sulfate (Elinder 1986). Using radiozinc-65, it was shown that afflicted individuals had a greater turnover of plasma zinc, a smaller pool of exchangeable zinc, and a reduced excretion of zinc in stool and urine (Prasad 1979). Zinc deficiency in humans is usually treated by oral administration of 1 mg Zn/kg BW daily (Casey and Hambidge 1980). However, zinc-deficient humans given daily intravenous injections of 23 mg zinc experienced profuse sweating blurred vision, and hypothermia (Saxena et al. 1989b). An endemic zinc deficiency syndrome among young men has been reported from Iran and Egypt and is characterized by retarded growth, infantile testes, delayed sexual maturation, mental lethargy, anemia, reduced concentration of zinc in plasma and red cells, enlarged liver and spleen, and hyperpigmentation; oral supplementation of 30 mg zinc daily had a prompt beneficial effect (Prasad 1979; Elder 1986). A zinc deficiency syndrome during human pregnancy includes increased maternal morbidity, abnormal taste sensations, prolonged gestation, inefficient labor, atonic bleeding, and increased risks to the fetus (Jameson 1980). Pregnant women with initially low and subsequently decreasing serum zinc levels had a high frequency of complications at delivery, including congenital malformations in infants. (Jameson 1980). Multiple severe skeletal abnormalities and organ malformations in human fetuses have been attributed to zinc deficiency (Casey and Hambidge 1980). In newborns, zinc deficiency is manifested by growth retardation, dermatitis, hair loss, impaired healing, susceptibility to infections, and neuropsychologic abnormalities (Casey and Hambidge 1980; Goyer 1986).

Hereditary zinc deficiency occurs in certain strains of cattle (*Bos* spp.) and affects the skin and mucous membranes of the gastrointestinal tract. The disease, Lethal Trait A46, is caused by failure of a single autosomal recessive gene regulating zinc absorption from the intestine. Affected animals die within a few months from secondary bacterial infections unless treated daily with high oral doses of zinc compounds (Bosma et al. 1988). Certain imported breeds of cattle in the western Sudan with low zinc serum levels (i.e., <0.6 mg/L) showed signs of zinc deficiency, including stunted growth, weakness, skin lesions, and loss of hair pigment (Damir et al. 1988). Cows fed a low (25 mg/kg ration) but adequate zinc diet had liver zinc concentrations below the expected 125 mg Zn/kg DW; increasing the total zinc dietary loading to 45 or 50 mg/kg DW is recommended for counteracting reduced zinc absorption in diets with soybean products (Binnerts 1989). Cows and calves fed low zinc diets of 25 mg Zn/kg ration showed a decrease in plasma zinc from 1.02 mg/L at start to 0.66 mg/L at day 90; cows fed 65 mg Zn/kg diet had a significantly elevated (1.5 mg Zn/L) plasma zinc level and increased blood urea and plasma proteins (Ramachandra and Prasad 1989). Biomarkers to identify zinc deficiency in bovines include zinc concentrations in plasma, unsaturated zinc-binding capacity, ratio of copper to zinc in plasma, and zinc concentrations in other blood factors; indirect biomarkers include enzyme activities, red cell uptake, and metallothionein content in the plasma and liver (Binnerts 1989).

Domestic goats (*Capra* sp.) fed a zinc-deficient diet (15 mg Zn/kg developed skin histopathology and alopecia (hair loss) after 177 days; zinc-deficient diets lacking vitamin A hastened the process, and signs were evident between 46 and 68 days (Chhabra and Arora 1989). No signs were evident in goats fed vitamin A-adequate diets containing 80 mg Zn/kg ration (Chhabra and Arora 1989).

Guinea pigs (*Cavia* spp.) fed a zinc-deficient diet (1.25 mg Zn/kg FW) for 60 days had significant reductions in zinc concentration in the serum (0.5 mg/L), kidney (10 mg/kg FW), testes (9.5 mg/kg FW), and liver (9.4 mg/kg FW). Guinea pigs fed 1.25 mg Zn/kg FW diet for 45 days followed by a zinc-replete diet of 100 mg/kg FW for 15 days had normal concentrations of zinc in serum (1.6-2.0 mg/kg FW), kidney (18-20 mg/kg FW), testes (19-27 mg/kg FW), and liver (15-17 mg/kg FW; Gupta et al. 1988). Zinc-deficient guinea pigs (<3 mg Zn/kg diet, 1 mg Zn/L drinking water), but not zinc-adequate animals (<3 mg Zn/kg diet, 15 mg Zn/L), exposed from day 30 of gestation to term on day 68 produced young with a low birth weight and severe skin lesions, were sensitive to handing and slow in recovering balance when turned on side, and had a peculiar stance; fetal zinc concentrations were depressed 15-33% in the liver and placenta (Apgar and Everett 1988). Disrupted immunocompetence responses and disordered protein metabolism were found in guinea pigs fed a zinc-deficient diet of 1.25 mg/kg FW ration for 45 days; marked, although incomplete, restoration occurred when this group was switched to 100 mg Zn/kg ration for 15 days (Verma et al. 1988). Neuromuscular pathology was evident in weanling guinea pigs fed a zinc-deficient diet (<1 mg Zn/kg) for 4 weeks, as judged by abnormal posture, skin lesions, and disrupted vocalizations; signs became severe after 5-6 weeks, but a single intraperitoneal injection of 1.3 mg Zn/kg BW (as $ZnSO_4$) caused remission within 7 days (O'Dell et al. 1989). Acute experimental allergic encephalomyelitis was induced in guinea pigs maintained on low (6 mg/kg), normal (20 mg/kg), and high (200 mg/kg) levels of zinc in the diet. Acute experimental allergic encephalomyelitis is usually a fatal disease of the central nervous system induced by inoculation with protein found in myelin of the central nervous system. Those on the zinc-deficient diet exhibited the expected signs of zinc deficiency but, unlike other groups, did not develop neurological signs of acute experimental allergic encephalomyelitis (Scelsi et al. 1989). Experimental allergic encephalomyelitis suppression in the zinc-deficient guinea pigs is ascribed to the influence of zinc deficiency of the T-cell function. A model of autoimmune central nervous system disease such as experimental allergic encephalomyelitis that requires a prominent T-lymphocyte sensitization can be altered or suppressed when the immunoregulatory mechanisms are impaired by zinc deficiency (Scelsi et al. 1989).

Unlike conspecifics on diets containing 100 mg Zn/kg, rhesus monkeys (*Macaca mulatta*) fed a marginally deficient zinc diet (4 mg Zn/kg diet) between age 5.5 and 30.0 months had lower plasma zinc levels, delayed onset of accelerated weight gain and linear growth, and no loss of subcutaneous fat--typical of early adolescence (Golub et al. 1988). Marginal dietary zinc deprivation also depressed immune function in rhesus monkeys by about 30% and impaired both learning and reversal of a visual discrimination task by 33-66% (Golub et al. 1988). When pregnant rhesus monkeys are fed a diet marginally deficient in zinc (4 mg/kg), perturbations in the mother's immune system can occur. Their infants, but not controls (100 mg Zn/kg diet), had reduced immune responsiveness despite the absence of marked differences in plasma or soft tissue zinc concentrations (Keen et al. 1989). Infant rhesus monkeys from zinc-deprived (4 mg Zn/kg ration) pregnant dams and subsequently fed the same low zinc diet showed delayed skeletal maturation during their first year. The condition was most severe at age 6 months but began to return to normal despite continuation of the marginally zinc-deficient diet (Leek et al. 1988).

Mice (*Mus* sp.) fed a zinc-deficient diet of 0.7 mg Zn/kg ration for 40 days, unlike mice fed a zinc-adequate diet of 36.5 mg Zn/kg, had a reduced growth rate, impaired phagocytic function, increased susceptibility to lead poisoning, and reduced zinc content in the blood (0.7 mg/L vs. 1.0-1.1 mg/L) and liver (12 mg Zn/kg FW vs. 17-19 mg Zn/kg FW; Tone et al. 1988). Zinc deficiency during early development affects neural tube development through arrested cell growth (Mackay-Sim and Dreosti 1989). Zinc deficiency in mice may disrupt olfactory function through interference with zinc-containing neurons in higher olfactory centers. Adult mice fed a zinc-deficient diet of 5 mg Zn/kg ration for 42 days, unlike mice given 100 mg Zn/kg diet, could not distinguish odors, although olfactory epithelia seemed normal (Mackay-Sim and Dreosti 1989).

Mink (*Mustela vison*) kits fed a zinc-deficient diet of 4.1 mg Zn/kg FW ration for 4 days retained 0.49 mg Zn/kit and lost weight. Kits fed a zinc-adequate diet (35-45 mg Zn/kg FW, 100-150 mg/kg DW) retained 2.5 mg Zn/kit, and those fed 83 mg Zn/kg FW diet retained 7.8 mg Zn/kit. Kits on low doses ate less than other groups. The most important excretory route was urine in the zinc-deficient group and feces in higher dose groups (Mejborn 1989).

Domestic sheep (*Ovis aries*) fed a low zinc diet (2.2 mg Zn/kg DW diet) for 50 days, unlike sheep fed a zinc-adequate diet (33 mg Zn/kg DW diet), excreted less zinc (<4 mg daily vs. 23-25 mg), consumed less food (409 g daily vs. 898 g), and had lower plasma zinc concentrations (0.18 mg/L vs. 0.53-0.58 mg/L); a reduction in

plasma alkaline phosphatase activity and an increase in plasma zinc binding capacity were also noted (Khandaker and Telfer 1990). Sensitive indicators of zinc deficiency in lambs include significant reductions in plasma alkaline phosphatase activity and plasma zinc concentrations; signs were clearly evident in lambs fed 10.8 mg Zn/kg DW diet for 50 to 180 days (Vergnes et al. 1990). A normal diet for lambs contains 124-130 mg Zn/kg DW ration and 33 for adults (Vergnes et al. 1990). One recommended treatment for zinc-deficient sheep is ruminal insertion of zinc-containing boluses every 40 days; bolus zinc release is about 107 mg daily (Khandaker and Telfer 1990).

Zinc-deficient pregnant laboratory white rats (*Rattus* sp.) have reduced litter size, a high frequency of fetal deformities, low birth weight, and a prolonged parturition; dams are inactive and seem indifferent toward young (Harland et al. 1975). Fetal skeletal defects are prominent in rats fed zinc-deficient diets of 10 mg/kg ration during a 21-day gestation period. About 91% of zinc-deficient fetuses had multiple skeletal malformations, but controls fed 76 mg Zn/kg diet had none (Ferreira et al. 1989). Zinc-deficient (1.5 mg Zn/kg diet) pregnant rats also had increased iron levels in the liver, kidney, and spleen; depleted liver glycogen: and reduced levels of zinc in the pancreas and duodenum (Mamba et al. 1989). Zinc deficiency causes testicular atrophy and hypogonadism in rats; the effects include spermatic arrest, histopathology of seminiferous tubules and interstitial cells, reduced serum testicular testosterone levels, and reduced testicular zinc concentrations (Hafiez et al. 1990). Zinc is required in Leydig cells for normal testosterone activity. Calcitonin inhibits transmembrane influx of zinc in the isolated rat Leydig cell, but these effects usually take >2 days and are critical only in states of borderline zinc deficiency (Chausmer et al. 1989). Zinc deficiency during pubertal development of rats depresses the activity of dipeptidyl carboxypeptidase in the testes and epididymis; this enzyme is required for maturation and development of sperm cells and reduced activity may cause suppression of sexual maturity (Reeves 1990). Laboratory white rats fed zinc-deficient diets for 20 days show an aversion to the zinc-deficient diet. They readily consumed a familiar zinc-adequate diet for 15 days, but the previously deficient animals continued to avoid zinc-deficient diets when given a choice (Cannon et al. 1988). Zinc deficiency in rats (<1 mg Zn/kg diet for 26 days) significantly reduced blood pressure and this correlated positively with serum angiotensin converting enzyme activity; increasing the dietary intake of calcium had no effect on these responses (Reeves and O'Dell 1988). During zinc deficiency, zinc is mobilized from bone in young immature animals and may be available for metabolic processes including growth (Calhoun et al. 1978). Diabetic rats are at risk of developing zinc deficiency because of zinc's role in modulating immune system dysfunction in diabetes mellitus (Mooradian et al. 1988). Cadmium toxicity is related to the zinc status of the body. Zinc-deficient rats (<1 mg Zn/kg diet) and zinc-adequate rats (40 mg/kg) were both challenged with cadmium. The zinc-deficient group had accelerated zinc loss from the kidneys; enlarged liver, kidneys, spleen and lungs; and increased distribution of cadmium in tissues (Sato and Nagai 1989). Other signs in zinc-deficient laboratory white rats included decreased food intake and loss of body weight (Vallee 1959; Cannon et al. 1988; Reeves and O'Dell 1988; Dib et al. 1989; Ferreira et al. 1989; Mamba et al. 1989; Mansour et al. 1989; Sato and Nagai 1989); reduced serum zinc (Calhoun et al. 1978; Reeves and O'Dell 1988); altered cholesterol metabolism (Samman and Roberts 1988); increased serum magnesium (Reeves and O'Dell 1988); lowered bone (femur) zinc concentrations (Calhoun et al. 1978); degenerated olfactory epithelium (Mackay-Sim and Dreosti 1989); reduced serum total proteins (Mansour et al. 1989); decreased activity of glutamate, glycine, methionine, arginine, lysine, and proline (Bettger 1989); and increased dental caries (Goldberg et al. 1990).

Zinc deficiency in domestic pigs (*Sus* sp.) is associated with a condition known as porcine parakeratosis, characterized by dermatitis, diarrhea, vomiting, anorexia, severe weight loss, and eventually death; the condition is exacerbated by high calcium levels (Vallee 1959).

Lethal and Sublethal Effects

General

Significant adverse effects on growth, reproduction, and survival are documented for sensitive marine and freshwater species of aquatic plants, invertebrates, and vertebrates at nominal water concentrations between 10 and 25 µg Zn/L. Sensitive terrestrial plants died when soil zinc concentrations were >100 mg/kg and showed decreased photosynthesis when total plant contained >178 mg Zn/kg DW. Representative soil invertebrates showed reduced growth at 300-1,000 mg Zn/kg diet and reduced survival at 470-6,400 mg Zn/kg soil. Domestic poultry and avian wildlife had reduced growth at >2,000 mg Zn/kg diet, and reduced survival at >3,000 mg Zn/kg diet or at a single oral dose >742 mg Zn/kg BW; younger stages (i.e., chicks, ducklings) were least resistant.

Sensitive species of livestock and small laboratory animals were adversely affected at >0.8 mg Zn/m^3 air, 90-300 mg Zn/kg diet, >90 mg Zn/kg BW daily, >300 mg Zn/L drinking water, and >350 mg Zn/kg BW single oral dose.

Terrestrial Plants and Invertebrates

Sensitive terrestrial plants die when soil zinc levels exceed 100 mg/kg or when plant zinc content exceeds 178 mg/kg DW (Table 5). The phytotoxic zinc level for barley (*Hordeum vulgare*) is not known, but zinc content of barley leaf rarely exceeds 100 mg/kg DW (Chang et al. 1983). Uptake of zinc from soils by plants is dependent on soil type; for example, uptake is lower in coarse loamy soils than in fine loamy soils (Chang et al. 1983). Zinc uptake by barley leaf is greater with increasing rate of sludge application, but the relation is not proportional (Table 5).

Among terrestrial invertebrates, adverse effects on earthworm survival were documented at 470-662 mg/kg soil, slugs had reduced food consumption at 300 mg Zn/kg diet and reduced growth at 1,000 mg Zn/kg diet, and woodlice had impaired reproduction at 1,600 mg Zn/kg soil and reduced survival at 5,000 mg Zn/kg diet or 6,400 mg Zn/kg soil (Table 5).

High zinc concentrations in soils are responsible for reductions in populations of soil invertebrates near brass mills and zinc smelters (Beyer 1990). Soils in the vicinity of zinc smelters contained up to 35 g Zn/kg and had decreased populations of arthropods; experimentally, 20 g of total zinc per kilogram of soil could account for the decreased survival (Beyer et al. 1984). Zinc concentrations exceeding 1,600 mg/kg soil litter are associated with reduced natural populations of decomposer organisms in contaminated forest soil litter, and this has been verified experimentally (Beyer and Anderson 1985). Poisoning of decomposer organisms, such as the woodlouse (*Porcellio scaber*), may disrupt nutrient cycling and reduce the number of invertebrates available as wildlife food (Beyer and Anderson 1985). The woodlouse contains higher concentrations of zinc than other terrestrial invertebrates: up to 152 mg Zn/kg DW whole organism (Hopkin and Martin 1985). It is speculated that the large zinc stores in *P. scaber* repels predators that find zinc distasteful (Hopkin and Martin 1985).

Table 5. Effects of zinc on representative terrestrial plants and invertebrates.

Organism, dose, and other variables	Effect	Reference[a]
Plants		
Fir, *Abies pindrow,* wooden stakes coated with 10% zinc oxide	Protects wood against termite damage for 5 years compared with 4 years for copper sulfate, 2 years for calcium carbonate, and <6 months for untreated wood	1
Red maple, *Acer rubrum*, 100 mg Zn/kg culture medium	Lethal to seedlings	2
Lichen, *Cladonia uncialis*, whole plant zinc content	Depressed photosynthesis when whole lichen burden is >178 mg Zn/kg DW; decreased respiration at >3,550 mg Zn/kg DW	3
Barley, *Hordeum vulgare*, leaf, from soil treated with sludge for 3 years		
No sludge	21-25 mg/kg DW	4
80 kg Zn/ha/year	26-47 mg/kg DW	4
160 kg Zn/ha/year	29-56 mg/kg DW	4
320 kg Zn/ha/year	41-57 mg/kg DW	4

Lichen, *Lasallia papulosa*, whole plant zinc content	Significant depression in photosynthesis at >308 mg Zn/kg DW and in respiration at >3,300 mg Zn/kg DW	3
Oak, *Quercus rubra*, culture medium contained 100 mg Zn/kg	Lethal to seedlings	2
Corn, *Zea mays*, grown on sludge amended loam plots; soil contains a maximum of 460 mg Zn/kg DW	Leaf contains a maximum of 293 mg Zn/kg DW (60 mg Zn/kg for controls); grain contains a maximum of 65 mg Zn/kg DW (32 mg Zn/kg for controls)	5
Invertebrates		
Earthworm, *Aporrectodea tuberculata*; concentrations of zinc in soil ranged from 28 mg/kg DW to 470 mg/kg DW versus concentrations in whole worms (less gut contents)	At soil zinc concentration of 28 mg/kg DW (control), worms contained 320 mg Zn/kg DW. At soil zinc levels of 97, 110, 190, and 320 mg/kg DW, whole worms contained 810, 1,300, 1,100, and 650 mg Zn/kg DW, respectively. No worms were found at soil zinc levels of 470 mg/kg DW	6
Slug, *Arion ater*, fed diets containing 10, 25, 50, 100, 300, or 1,000 mg Zn/kg ration for 27 days	No deaths in any group. Significantly reduced food consumption in 300 and 1,000 mg/kg diets. All groups weighed less than controls at day 27, but growth was statistically impaired only in the 1,000 mg/kg group	7
Slug, *Arion ater*, fed diets containing up to 1,000 mg/kg feed for 30 days	No adverse effects except for glycogen depression at 1,000 mg/kg diet	8,9
Spider, *Dysdera crocata*, fed woodlice (*Porcellio scaber*) at rate of one every 3 days for 36 days		
Woodlice from uncontaminated site (87 mg Zn/kg DW whole organism)	Whole spider contains 182 mg Zn/kg DW	10
Woodlice from contaminated site (152 mg Zn/kg DW whole organism)	Whole spider contains 118 mg Zn/kg DW (116 mg Zn/kg DW in starved spiders)	10
Earthworm, *Eisenia foetida*		
10-12 µg Zn/cm^2 applied to epidermis	LC50 (48 h)	11
662 mg Zn/kg artificial soil (95% C.I. 574-674)	LC50 (2 weeks)	11
Woodlice, *Porcellio scaber*, fed soil litter containing up to 12,800 mg Zn/kg for 64 weeks	Soil litter containing ≥1,600 mg Zn/kg had adverse effects on reproduction; adult survival was reduced at >6,400 mg Zn/kg litter	12

Woodlice, *Porcellio scaber*, fed diets containing up to 20,000 mg Zn/kg feed for 8 weeks	Decreased survival at ≥5,000 mg/kg	13

[a] 1. Roomi et al. 1990; 2. Buchauer 1971; 3. Nash 1975; 4. Chang et al. 1983; 5. Hinesly et al. 1977; 6. Beyer et al. 1987; 7. Marigomez et al. 1986; 8. Recio et al. 1988a; 9. Recio et al. 1988b; 10. Hopkin and Martin 1985; 11. Neuhauser et al. 1985; 12. Beyer and Anderson 1985; 13. Beyer et al. 1984.

Slugs (*Arion ater*) are resistant to high dietary zinc intakes (1,000 mg/kg feed) for 30 days, although zinc accumulations occur in excretory and calcium cells of the digestive gland (Recio et al. 1988a, 1988b). Histochemical detection of zinc in digestive glands of *Arion* is an indication of high levels of zinc in the environment (Recio et al. 1988a). Zinc elimination in *Arion* occurs directly from lipofuscin material of excretory cells and from spherules of calcium cells; excretion of lipofuscin material through feces is the major excretory route (Recio et al. 1988a).

Zinc normally aids wound healing in terrestrial invertebrates. Wounding of the optic tentacle, foot tissue, and partial shell removal in *Helix aspersa*, a terrestrial gastropod, resulted in deposition of zinc in the wound area after 2 to 5 days. Increased zinc in *Helix* wound areas may be necessary to promote protein synthesis, collagen, formation, and mitotic cell division (Ireland 1986).

Aquatic Organisms

Significant adverse effects of zinc on growth, survival, and reproduction occur in representative sensitive species of aquatic plants, protozoans, sponges, molluscs, crustaceans, echinoderms, fish, and amphibians at nominal water concentrations between 10 and 25 µg Zn/L (Table 6).

Table 6. Effects of zinc on representative aquatic plants and animals. Concentrations are in micrograms of zinc per liter of medium.

Taxonomic group, organism, and other variables	Concentration (ppb)	Effects	Reference[a]
Plants			
Alga, *Amphidinium carteri*	400	Growth inhibition	1
Aquatic plants, various	30->200,000	Adverse effects	2
Brown alga, *Ascophyllum nodosum*	100	No effect on growth in 10 days	2
Ascophyllum nodosum	250	Decreased growth in 10 days	2
Coccolithophorid, *Cricosphaera carterae*	77	Growth reduced 50% in 4 days	2
Freshwater algae, 11 species	140-800	Growth inhibition	3
Freshwater algae, most species	>1,000	Growth inhibition	1
Brown macroalgae, *Fucus serratus*	9.5	Bioconcentration Factor (BCF) of x10,770 in 140 days	2
Fucus serratus	8.8	Altered lipid metabolism	2
Marine macroalgae, *Fucus vesiculosus*	3,500	No adverse effects	2
Fucus *vesiculosus*	7,000	Growth retardation	2
Dinoflagellate, *Glenodinium halli*	20	Chlorophyll reduced 65% in 2 days	2
Dinoflagellate, *Gymnodinium*	110-392	Chlorophyll reduced about 65%	2

splendens		in 2 days in temperature range 16-30° C	
Gymnodinium *splendens*	100	Growth inhibition in 38 days	3
Alga, *Isochrysis galbana*	74	Chlorophyll reduced 65% in 48 h at 16 ppt salinity, 20° C	2
I. galbana	430	Chlorophyll reduced 65% in 48 h at 16° C, 16 ppt salinity	2
Kelp, *Laminaria digitata*	100	Growth inhibition in 24 days	1
Brown macroalga, *Laminaria hyperborea*	250 8-10 days	Reduced growth of sperophytes in	2
Marine algae, 4 species	50-500	Decrease in cell numbers	1
Marine algae, 5 species	100	Growth inhibited in 48 h	2
Marine macroalgae, 4 species	100	No adverse effects	2
Marine macroalgae, 4 species	1,400	Growth reduction	2
Diatom, *Nitzschia closterium*	271-300	50% growth inhibition in 4 days	2
Diatom, *Nitzschia longissima*	100	Growth stimulated during exposure for 1-5 days	2
Dinoflagellate, *Procentrum micans*	319	50% growth inhibition in 4 days	2
Diatom, *Phaeodactylum tricornutum*	250	BCF of x1,800 in 3 days	2
P. tricornutum	4,800	6.7% increase in growth during 12-day exposure	2
Phytoplankton	15	Primary productivity reduced in 14 days	2
Marine alga, *Rhizosolenia* sp.	15-25	Photosynthesis reduction	3
Alga, *Scenedesmus quadricauda*	2	Adverse effects	4
S. quadricauda	64	Growth inhibition in 14 days	2
S. quadricauda	300	Lethal	4
Diatom, *Schroederella schroederi*	19	Growth inhibited 50% in 48-96 h	2
Freshwater alga, *Selenastrum capricornutum*	30	Some growth inhibition in 7 days	1
S. cupricornutum	40-68	95% growth inhibition in 14 days	1
S. capricornutum	100	100% growth inhibition in 7 days	1
Diatom, *Skeletonema costatum*	19.6	Adverse effects	4
S. costatum	50-100	Growth reduced 20-23% in 10-15 days	2
S. costatum	200	Growth stimulated in 1-5 days	2
S. costatum	265	Metabolic disruption in 3 days	2
Diatom, *Thalassiosira pseudonana*	65	Adverse effects	4
T. pseudonana	500	Growth reduced 41% in 11-15 days	2
T. pseudonana	823	Growth reduced 50% in 72 h	2
Green macroalga, *Ulva lactuca*	65	BCF of x255 in 6 days	2
Protists			
Protozoan, *Cristigera* sp.	50-125	Growth reduced in 5-h exposure	1,2
Bacterium, *Escherichia coli*	650-1,400	Growth inhibition	3
Microorganisms, various	650-1,100	Growth inhibition, usually	3

Paramecium, *Paramecium multi-micronucleatum*	560-10,000	LC50 (3 h)	3
Bacterium, *Pseudomonas* sp.	1,000-10,000	Growth inhibition	3
Protozoan, *Vorticella convallaria*	50	LC50 (48 h)	3
Porifera			
Freshwater sponge, *Ephydatia fluviatilis*			
Adults	6.5	No effect on growth; no tolerance developed with long-term exposure	5
Adults	26	After exposure for 10 days, tissue deterioration and death during 3-week postexposure period	5
Rotifers			
Rotifer, *Philodena acutiformis*			
Adults	500	LC50 (48 h), 25° C	
Adults	1,550	LC50 (48 h), 5° C	2
Molluscs			
Freshwater snail, *Ancylus fluviatilis*			
Juvenile	80	LC50 (100 days), shell length <2 mm	6
Adult	100	No adverse effect on reproduction in 100 days	6
Juvenile	130	LC50 (100 days), shell length >3 mm	6
Adult	180	Reproduction reduced in 100 days	6
Bay scallop, *Argopecten irradians*			
Larvae	50	Growth rate reduced 22% in 9 days	7
Larvae	109	Growth reduced 50% in 9 days	7
Larvae	120	LC50 (9 days), increased shell deformities	7
Larvae	150-200	All dead at metamorphosis	7
Juvenile	2,250	LC50 (96 h)	8
Freshwater snail, *Biomphalaria glabrata*	500	By day 33 of exposure, embryo survival was reduced 50% and adult growth and reproduction inhibited	9
Asiatic clam, *Corbicula fluminea*	<20	Residues were 169 mg/kg dry weight (DW) parts after feeding on periphyton containing 393-1,327 mg/kg DW for 30 days	11
C. fluminea	25	Normal growth during exposure for 30 days	10
C. fluminea	34	Residues were 433 mg/kg DW soil parts in 30 days after feeding on periphyton containing 956-4,369 mg Zn/kg DW;	11

		growth reduced; cellulase enzyme activity reduced	
C. fluminea	50-500	Growth inhibited between days 20 and 30 of exposure	10
C. fluminea	218	BCF of x126 in 28 days	2
C. fluminea	1,000	After exposure for 30 days, about 30% died. Survivors had osmoregulatory impairment and residues of 2,000 mg Zn/kg DW soft parts (200 mg Zn/kg DW soft parts in controls). Depuration complete by day 17 postexposure, and growth rate returns to normal	10
Pacific oyster, *Crassostrea gigas*			
Larvae	10-20	Reduced larval settlement in 20 days	1
Larvae	30-35	Reduced larval settlement in 6 days	2
Larvae	50	Normal growth and development in 5 days	12
Larvae	70	Abnormal shell development in 48 h	1
Larvae	75	No deaths in 48 h	1
Larvae	80-95	Growth reduced 50% in 4 days	2
Larvae	119-310	LC50 (48 h)	1,13
Larvae	125	Substrate attachment inhibited in 5 days	1,2
Larvae	200	No growth in 5 days	12
Embryo	233	LC50 (96 h)	2
Larvae	250	Increasing incidence of abnormal development and mortality	12
Sperm	444	Fertilization success reduced 50% in 60 min	2
Larvae	500	All died in 48 h	1
American oyster, *Crassostrea virginica*			
Adult	100	Whole body concentration of 2,560-2,708 mg Zn/kg fresh weight (FW) soil parts after 20-week exposure (1,036-1,708 mg Zn/kg FW soil parts in controls)	14
Adult	200	After exposure for 20 weeks, residues were 3,185-3,813 mg Zn/kg FW soft parts	14
Embryo	230	LC50 (96 h)	2
Larvae	340	LC50 (48 h)	13
Red abalone, *Haliotis rufescens*			

Larvae	19	No adverse affects after 9-day exposure	13
Larvae	41	Normal development during 48-h	13
Larvae	50	50% abnormal development during exposure for 9 days	13
Larvae	68	50% abnormal development in 48-h exposure	13
Marine gastropod, *Littorina littorea*			
Adult	0.2 (controls)	Zinc concentrations in all tissues were <185 mg/kg DW, except kidney, which was 372 mg/kg DW	15
Adult	10	After exposure for 42 days, tissue zinc residues were: head-foot 120 mg/kg DW, gills 255 mg/kg DW, whole soft parts 605 mg/kg DW, viscera 1,322 mg/kg DW, stomach 1,918 mg/kg DW, and kidney 2,153 mg/kg DW	15
Freshwater pond snail, *Lymnaea luteola*, adult	1,680	LC50 (96h)	85
Hard shell clam, *Mercenaria mercenaria*			
Larvae	50	5% died in 12 days	1
Larvae	168	50% dead or abnormal in 48 h	1
Embryo	195	LC50 (96 h)	2
Larvae	195-341	LC50 (10-12 days)	1
Larvae	279	All died in 48 h	1
Softshell clam, *Mya arenaria*			
Adult	10	Soft parts contained 9.5 mg Zn/kg FW after 16 weeks at 0-10° C, and 11 mg/kg after 2 weeks at 16-22° C	14
Adult	200	BCF of x85-135 in 50 days	2
Adult	500	Soft parts contained 31-48 mg Zn/kg FW after exposure for 6-16 weeks at 0-10° C, and 59-82 mg/kg after 1-2 weeks exposure at 16-22° C	14
Adult	900	No deaths in 7 days at 22° C	16
Adult	1,550	LC50 (7 days) at 22° C	16
Adult	25,000	All dead after 70-day exposure at 0-10° C; at exposure temperature of 16-22° C, all dead by day 14	17
Common mussel, *Mytilus edulis*			
Adult	25	Maximum kidney zinc residue after 18 days was 14.1 g/kg DW (4.9 g/kg in controls)	18

Adult	60	Shell growth rate reduced 50% in 2-6 days of exposure	2
Embryo	96-314	Development inhibited 50% in 72 h	2
Adult	100	No accumulations in tissues after 4-day exposure	19
Adult	230-860	In 7-h exposure, pumping rate decreased with increasing zinc, and was completely stopped at >470 µg/L; recovery on return to background levels	20
Adult	1,000	After exposure for 24 h, zinc concentration in soil parts rose from 150 mg/kg DW to 252 mg/kg DW and remained elevated for at least 6 weeks postexposure	21
Larvae	1,752	LC50 (48 h)	13
Adult	1,800	Reduced byssal thread production	2
Adult	5,000	LC50 (7 days)	2
Adult	5,000	LC100 (16 days)	19
Adult	20,800	LC50 (24-h exposure plus 6 weeks postexposure); none dead during exposure	22
Sperm	65,400	Respiration inhibited 50% in 20 min	23
Mud snail, *Nassarius obsoletus*			
Adult	200	Decreased oxygen consumption in 72 h	1
Egg	650	Abnormal veliger development	24
Adult	5,000	No deaths in 168 h	25
Green-lipped mussel, *Perna virdis*			
Adult	<178-362	Maintains constant body concentration over 21-day exposure period	26
Adult	>362	Accumulation in tissue	26
Adult	6,090	LC50 (96 h)	26
Freshwater snail, *Physa heterostropha*, juvenile	241	LC50 (96 h)	2
Surf clam, *Spisula solidissima*, juvenile	2,950	LC50 (96 h)	8
Bryozoans			
Bryozoan, *Bugula neritina*, larvae	200	LC50 (5 h)	3
Bryozoan, *Watersipora cucullata*, larvae	650	LC50 (5 h)	3
Crustaceans			

Copepod, *Acartia tonsa*	290	50% immobilized in 48 h	
A. tonsa	294	LC50 (96 h)	2
Amphipod, *Allorchestes compressa*	580-2,000	LC50 (96 h)	3,27
Brine shrimp, *Artemia* sp.	14-1,360	Egg hatching significantly reduced in dose-dependent manner; no effect on survival of prenauplii larvae	28
Cladoceran, *Ceriodaphnia reticulata*	51	LC50 (96 h)	2
Hermit crab, *Clibanarius olivaceous*			
Larvae	1-90	Molting delayed in dose-dependent manner	29
Larvae	100	LC50 (96 h)	29
Larvae	125	LC100 (96 h)	29
Daphnid, *Daphnia galeata mendotae*	15	BCF of x9,400 in 2 weeks	2
D. g. mendotae	30	BCF of x5,833 in 2 weeks	2
D. g. mendotae	60	BCF of x6,333 in 2 weeks	2
Daphnid, *Daphnia magna*	5-14	LC50 (72 h) at 30° C	2
D. magna	25	No effect in soft water (50 mg $CaCO_3$/L) in 50 days	30
D. magna	42-52	MATC [b]; water contains 104-211 mg $CaCO_3$/L	1,2
D. magna	68-655	LC50 (96 h)	31
D. magna	70	Reproduction reduced 16% in 21 days	2
D. magna	100	LC50 (48 h), starved	84
D. magna	250	Nonlethal in 6 weeks when sediments present in test container. Final sediment value of 13,400 mg/kg DW (600 mg/kg DW in controls). Organisms had whole body residues of 450 mg/kg DW	32
D. magna	280	LC50 (48 h), fed	3
D. magna	560	LC50 (24 h) at 25° C	84
D. magna	560	50% immobilized in 48 h	33
D. magna	2,300	LC50 (24 h) at 5° C	3
Daphnid, *Daphnia pulex*	253	LC50 (96 h)	2
D. pulex	280	LC50 (48 h)	
D. pulex	500	LC50 (24 h) at 25° C	3
D. pulex	1,550	LC50 (24 h) at 5° C	3
Copepod, *Eudiaptomus padanus*	500	LC50 (48 h)	
Amphipod, *Gammarus duebeni*			
Natural population	>100	Survival reduced in 7 days	34
Natural population	1,000	All dead in 7 days at 10 ppt	

		salinity, 84% dead at 30 ppt	34
Zinc-tolerant population	1,000	50% dead in 14 days at 10 ppt salinity, 33% dead at 30 ppt	34
American Lobster, *Homarus americanus*			
Larvae	130	LC50 (17 days)	3
Larvae	381	LC50 (96 h)	2
Adult	13,000	LC50 (11 days)	3
Mysid, *Mysidopis bahia*	120-230	MATC[b]	1,2
M. bahia	499	LC50 (96 h)	2,13
Crayfish, *Orcenectes virilis*	130,000	No deaths in 10 days	35
Hermit crab, *Pagurus longicarpus*			
Adult	200	LC50 (168 h)	25
Adult	400	LC50 (96 h)	1,2
Prawn, *Palaemon elegans*	562	LC67 (21 days)	36
Shrimp, *Pandalus montagui*	65	BCF of x 3.7 in 14 days	2
Mysid, *Praunus flexuosus*	2,000	LC50 (192 h), 5°C, 4.5 ppt salinity	37
Mudcrab, *Rithropanopeus harrisii*, larvae	50	Delayed development in 16-days exposure	1
Copepod, *Tisbe holothuriae*			
Life Cycle	7	No effect on population size after exposure for 4 generations	38
Life Cycle	10	Some deaths in fourth generation	38
Life Cycle	70	All dead by end of first generation	38
Copepodid	421	LC50 (48 h)	39
Adults	620-700	LC50 (48 h)	38,40
Females with egg sacs	713	LC50 (48 h)	39
Copepod, *Tropocyclops praisinus mexicanus*, Quebec lakes, uncontaminated	52-26	LC50 (48 h) in soft water	41
T.P. mexicanus, Quebec lakes, contaminated	2,934	LC50 (48 h) in hard water lake; metal preexposure protective effect hypothesized	41
Aquatic insects			
Mayfly, *Epeorus latifolium*			
Larvae	30	Gradual decrease in growth rate in 4-week exposure; some deaths before emergence	42
Larvae	100-300	Growth inhibited after 2 weeks; all dead before emergence	42
Midge, *Tanytarsus dissimilis*, embryo through third instar	37	LC50 (10 days)	1,2

Annelids			
Polychaete worm, *Capitella capitata*			
Larvae	50-100	Abnormal development during 16 day exposure	2
Adult	1,250	LC50 (28 days)	2
Adult	10,700	LC50 (48 days)	13
Leech, *Erpobdella octoculata*			
Juveniles	60	LC50 (70 days)	43
Adults	100	LC50(70 days)	43
Adults	180	High frequency of abnormal eggs produced in 60-day exposure	43
Adults	320	Inhibited reproduction in 60-day exposure	43
Juveniles	390	LC50 (40 days)	43
Juveniles	2,100	LC50 (96 h)	43
Adults	4,800	LC50 (40 days)	43
Adults	8,800	LC50 (96 h)	43
Polychaete, *Neanthes arenaceodentata*, juveniles	900	LC50 (28 days)	3
Sandworm, *Nereis diversicolor*			
Adults	1,500	No deaths in 168 h	25
Adults	2,600	LC50 (168 h)	25
Adults	10,000	Whole body zinc concentration in survivors after exposure for 34 days was 2,500 mg/kg DW (180 mg/kg DW in controls)	14
Adults	10,000	After 96-h exposure at; 6° C, zinc residues were 1,031 mg/kg DW in head (843 mg/kg DW in controls), 366 mg/kg DW in trunk (158 mg/kg DW in controls), and 455 mg/kg DW in parapodia (275 mg/kg DW in controls); uptake was higher at 12° and 20° C	44
Adults	20,000	No death in 96 h	44
Adults	40,000	LC50 (47 h) for nontolerant strains; LC50 (70 h) for zinc-tolerant strains	45
Worm, *Spirorbis lamellora*, larvae	350	LC50 (3 h)	3
Echinoderms			
Sea urchin, *Anthocidarius crassispina*			
Egg	65	No effect on fertilization membrane formation or development in eggs transferred 1 min after insemination	46
Egg	326	Irreversible inhibition of	

		fertilization membrane formation in eggs transferred 10 s after insemination	46
Starfish, *Asterias rubens*			
Adult females	240	Increased steroid metabolism in pyloric caeca after 21 days	47
Adults	1,000	No deaths in 168 h	25
Adults	2,300	LC50 (168 h)	25
Sand dollar, *Dendraster excentricus*, sperm	28	Fertilization success reduced 50% in 60 min	2
Echinoderms, 3 species, embryos	60-200	Embryonic development inhibited	46
Red sea urchin, *Strongylocentrotus franciscanus*, sperm	313	Fertilization success reduced 50%	2
Purple sea urchin, *Strongylocentrotus purpuratus*, embryos	23	Development inhibited 50% in 5 days	2
Fish			
Longfin dace, *Agosia chrysogaster*,	228	LC50 (96 h)	2
Murrel, *Channa punctatus*, fingerlings, 31-day exposure	12,000	Growth rate reduced by day 19; liver RNA and proteins decreased by day 20; muscle RNA and proteins reduced by day 30	49,50
Texas cichlid, *Cichlasoma cyanoguttatum*, adults, exposure for 4 weeks	40 (control), 65, or 90	Residues were 0.8, 28, and 34 mg Zn/kg FW in muscle; 6, 56, and 25 mg Zn/kg FW in viscera; 6, 59, and 98 mg Zn/kg FW in gills; and 12, 66, and 92 mg Zn/kg FW in bone	51
Air-breathing catfish, *Clarias lazera*, juveniles	26,000-52,000	LC50 (96 h) at 25.1° C (26,000) through 9.3° C (52,000); at 88,000 µg/L and 18.5° C, 50% died and survivors had BCF of x544 in gill, x425 in liver, and x250 in muscle	52
Baltic herring, *Clupea harengus*, eggs exposed from fertilization through hatching	500, 2,000, 6,000, or 12,000	Histopathology of epidermis and kidney in larvae at >6,000 µg/L; no measurable effects at < 2,000 µg/L	53,54
Atlantic herring, *Clupea harengus harengus*, embryos and larvae	50	Significant increase in incidence of jaw and branchial abnormalities	2
Freshwater fish, 4 species, adults	4,600-17,300	LC50 (5 days)	55
Mummichog, *Fundulus heteroclitus*			
Adults	810	BCF of x16 in whole fish after 56 days	2
Adults	10,000	Zinc concentration in scale, rose from 229 mg/kg DW at start to 746 mg/kg DW	56

		after 45 days and to 1,608 mg/kg DW after 94 days	
Adults	10,000	Zinc content in scale after 45 days exposure and 21 to 49 days in uncontaminated water fell from 746 mg/kg DW to 422-498 mg/kg DW	56
Adults	43,000	No deaths in 8 days; no significant increase in tissue zinc levels	57
Adults	52,000-66,000	LC50 (8 days)	25,57
Adults	71,000-153,000	LC50 (48 h)	58
Mosquitofish, *Gambusia affinis*, adults, muscle	18,000	After 24 h, zinc increased from 82 to 134 µg/kg FW; significant increases in glycogen, total lipids, phospholipids, and cholesterol; decreases in RNA and proteins	59
Flagfish, *Jordanella floridae*			
Life cycle	26-51	MATC [b]	2
Larvae	85	LC80 (30 days)	3
Adults	139	BCF of x417 in whole fish in 100 days	2
Cypriniform freshwater fish, *Labeo rohita*			
Juveniles and adults	20,000	No deaths in 96 h	60
Juveniles	65,000	LC50 (96 h); liver glycogen reduced; BCF of x22 in whole fish	60
Adults	77,000	LC50 (96 h); survivors had disrupted respiration and decreased liver glycogen	60
Spangled perch, *Leiopotherapon unicolor*, adults, exposed for 2 h	5,000, 10,000, or 20,000	Temporary decrease in ventilation rate at 5 mg/L; significant increase in ventilation rate at 10 and 20 mg/L; bradycardia at 20 mg/L	61
Spot, *Leiostomus xanthurus*	38,000	LC50 (96 h)	62
Bluegill, *Lepomis macrochirus*			
Adults	76-235	Reproduction inhibition	3
Adults	100	Hyperactivity	3
Fry	235	Lethal in 3 days	1,2
Adults, exposed for 7 days, then placed in a lethal NaC1 salinity (1.46%) for 60 h	2,350	Exposed fish all dead in 60 h (8 h for controls); plasma chloride declined in zinc-exposed fish, suggesting that zinc reduces permeability of gills to chloride	63
Adults	5,400	LC50 (96 h) at 20 mg $CaCO_3$/L	3
Adults	40,900	LC50 (96 h) at 360 mg $CaCO_3$/L	3

Marine fish, most species	>1,000	LC50 (96 h)	1
Tidewater silverside, *Menidia peninsulae*	5,600	LC50 (96 h)	62
Striped bass, *Morone saxatilis*			
Larvae	100-119	LC50 (96 h)	1,2
Fry	430-1,180	LC50 (96 h)	1,2
Adults	6,700	LC50 (96 h)	1
Stone loach, *Noemacheilus barbatulus*, adults	1,900-2,000	LC50 (25 days)	3,55
N. barbatulus	3,500	LC50 (96 h)	55
Loach, *Noemacheilus* sp.	25,000	LC50 (96 h)	64
Cutthroat trout, *Oncorhynchus clarki*	61-600	LC50 (96 h)	1,65
O. clarki	360	None dead in 14 days	66
O. clarki	670	LC50 (14 days)	3,66
Coho salmon, *Oncorhynchus kisutch*			
Water hardness <50 mg $CaCO_3$/L	280	LC50 (96 h)	3
Juveniles	500-10,700	Decreased white blood cell count in 24h	3
0.5-0.9 g BW	820-1,810	LC50 (96 h)	67
Rainbow trout, *Oncorhynchus mykiss*			
Immatures	5.6	Avoidance, 10- to 20-rain tests	1,2
Larvae and alevins	10	LC54 (28 days)	3
Immatures	47	94% avoidance, 40-rain tests	2
Early life stages	70-140	LC50 (25 days)	3
Juveniles	81	Hyperglycemia in 24 h	3
Fry	90-93	LC50 (96 h)	1,2
Life cycle	140-547	MATC [b]	1,2
Weight 0.6 g	169	LC50 (96 h)	67
Juveniles	210-1,120	Increased blood glucose in 7-63 days	3
Parr	240-830	LC50 (96 h) at 30 mg CaCO3/L	1
Juveniles	310	LC20 (14 days)	66
Immatures	352	Hyperglycemia in 9 days	2
Larvae and alevins	400-2,800	LC50 (120 h)	3
Juveniles	410	LC50 (14 days)	66
Juveniles	430	LC59 (96 h) at 26 mg CaCO3/L	3
Juveniles	520	LC50 (96 h) at 47 mg CaCO3/L	3
Fry	689	LC50 (96 h)	2
Juveniles	690	Increased respiration in 24 h	3
Immatures	1,030	LC50 (96 h) value for group acclimatized to 80 µg Zn/L for 28 days (469 µg Zn/L in nonacclimatized group)	68

Adults	1,120	Reduced growth in 85 days	3
Parr	1,190-4,520	LC50 (96 h) at 350 mg CaCO3/L	1
Juveniles	2,960	LC50 (96 h) at 179 mg CaCO3/L	3
Parr	4,700	LC50 (96 h) at 500 mg CaCO3/L	1
Juveniles	4,800-7,200	LC50 (96 h) at 333-504 mg CaCO3/L	3
Fry	10,000	16°/o dead in 90 h versus none dead in group pretreated with 5 mg Zn/L for 96 h	69
Fry	15,000	79% dead in 90 h versus 20% dead in group pretreated with 5 mg Zn/L for 96 h	69
Sockeye salmon, *Oncorhynchus nerka*			
Embryo through smolt	242	No measurable effects in 18-month exposure	1
Immatures	447	LC50 (115 h)	1
Immatures	750	LC50 (96 h)	3
Chinook salmon, *Oncorhynchus tshawytscha*			
Swim up	97	LC50 (96 h)	1
Chronic exposure	270-510	MATC [b]	1,2
Smolts	446	LC50 (96 h)	2
Minnow, *Phoxinus phoxinus*			
Yearlings	50-130	Reduced growth during exposure for 150 days; no deaths	70
Larvae	60	Decreased swimming ability after exposure for 108 days	3
Larvae	80	LC37 (40 days)	3
Adults	130	Reduced growth during 150-day exposure; some deaths	70
Juveniles	160	Decreased swimming ability after 109 days	3
Adults	200	Decreased swimming ability after 100 days	3
Adults	200	Reduced growth during 30-day exposure; some deaths	70
Adults	250	LC50 (150 days)	3
Fathead minnow, *Pimephales promelas*			
Life cycle	78-145	MATC [b]	1,2
Juveniles	125	Reduced growth in 7 days	2
Larvae	152-294	LC84 (8 weeks)	3
Adults	180	65 to 83% reduction in fecundity in 10-month exposure	1,2
Adults	480	Reduced growth in 30 days	3

Embryo-larvae	500-1,400	50% developmental malformations in 96h	71
Larvae	600	LC50 (96 h)	3
Adults	600	Preexposure for 14 days increased resistance 28% over controls in 96-h zinc toxicity assays	72
Adults	800	LC50 (30 days)	3
Adults	870	LC50 (96 h) at 20 mg $CaCO_3$/L,	3
Adults	1,800	Exposure for 7 days decreased tolerance 63% in 96-h zinc toxicity assays; tolerance decreased 74% after exposure for 14 days	72
Adults	2,800	LC15 (10 months), no eggs deposited	73
Embryo-larvae	3,600	LC50 (6 days)	71
Adults	4,700-6,100	LC50 (96 h) at 50 mg $CaCO_3$/L	3
Adults	6,400-10,900	LC50 (96 h) at 100 mg $CaCO_3$/L	3
Adults	7,100	LC50 (96 h) at 166 mg $CaCO_3$/L	3
Adults	8,200-21,000	LC50 (96 h) at 200 mg $CaCO_3$/L	3
Adults	33,400	LC50 (96 h) at 360 mg $CaCO_3$/L	3
Guppy, *Poecilia reticulata*			
Age 5 days	128	After 134 days, whole body zinc content of 0.6 mg/kg DW (0.3 mg/kg DW in controls); growth reduced	74
Adults	173	Whole body BCF of x466-965 in 30 days	2
Age 5 days	250	Delayed sexual maturation after 134 days	74
Age 5 days	500	Reproduction inhibited	74
Age 5 days	1,350-1,500	LC50 (96 h)	74
Adult males	4,400-5,700	LC50 (96 h)	74
Adult females	5,600-7,300	LC50 (96 h)	74
Atlantic salmon, *Salmo salar*			
Parr	50	50% avoidance in 4 h	2
Parr	100	Avoidance within 20 rain	3
Immatures, Water hardness	100-500	LC50 (21 days)	1
14 mg $CaCO_3$/L	420	LC50 (96 h)	1
20 mg $CaCO_3$/L	600	LC50 (96 h)	1
Brown trout, *Salmo trutta*			
Yolk-sac fry	4.9	40% with noncalcified vertebrae center; all dead in 18 days at pH 4.5 and soft water	75

Yolk-sac fry	9.8-19.6	60% to 75% dead in 20-30 days; 6% to 21% with abnormal vertebrae in pH 4.5 and soft water	75
Yearlings	<140	LC50 (96 h) at pH 8, 10 mg CaCO3/L	76
Adults	570	LC17 (14 days)	66
Adults	640	LC50 (14 days)	66
Yearlings	3,200	LC50 (96 h) at pH 5, 204 mg CaCO3/L	76
Brook trout, *Salvelinus fontinalis*			
Chronic exposure	534-1,360	MATC [b]	1,2
Adults	630	LC17 (14 days)	
Adults	960	LC50 (14 days)	3,66
Cabezon, *Scorpaenichthys marmoratus*, larvae	192	LC50 (96 h)	2
Dogfish, *Scyliorhinus* sp., exposure for 25 days	15,000	No significant accumulations in kidney and muscle, but elevated levels, as judged by BCF values in gill filament (x1.6), spleen (x1.7), pancreas (x2.7), and liver (x5.2)	77,78
Arctic grayling, *Thymallus arcticus*			
BW 0.2-1.8 g	112-168	LC50 (96 h)	67
Fry	315	LC50 (96 h)	67
Alevins	1,580-2,920	LC50 (96 h)	67
Tilapia, *Tilapia sparrmanii*, adults, exposure for 72 h	98,000	Decreased oxygen consumption, mucous precipitation on gills, histopathology of gill epithelium	79
Bolti, *Tilapia zilli*			
Adults	13,000	LC50 (96 h) at 25° C	52
Adults	21,000	LC50 (96 h) at 21° C; residues in survivors were 38,000 mg/kg DW in gill (70 mg/kg DW in controls); 23,000 mg/kg DW in liver (50 mg/kg DW controls); and 2,000 mg/kg DW in muscle, blood, serum, and liver chemistry (10 mg/kg DW in controls)	58,80
Adults	27,000	LC50 (96 h) at 15.3° C	52
Adults	33,000	LC50 (96 h) at 9.3° C	52
Amphibians			
Marbled salamander, *Ambystoma opacum*, embryos	2,380	50% dead or deformed in 8 days	2
Narrow-mouthed toad, *Gastrophryne*	10	50% dead or deformed in 7 days	2

carolinensis, embryos			
Leapfrog; *Rana dalmutina*, larvae, exposed during formation of gonadal structures	9,000	Toxic effect on larval gonad, especially on germ cells of ovarian structure	S1
Newt, *Triturus cristatus*, adults, held in tank with a zinc-plated base	200 to 3,000 over a 7-day period	Zinc-poisoned newts were lethargic, ate poorly, and has skin darkening before death. Zinc residues were elevated in kidney, brain, liver, and intestine, when compared to controls. The hippocampus region of the brain of poisoned newts contained zinc-rich cells	82
South African clawed frog, *Xenopus laevis*			
Embryos	>1,500	At 96 h, some midgut malformations and pericardial edema	83
Embryos	2,700	50% malformations in 96 h	83
Embryos	3,600	50% developmental malformations in 6 days	71
Embryos	>4,000	Severe edema of the pericardium and eye, gut miscoiling, and head and mouth malformations. At high sub-lethal concentrations, severe skeletal kinking, micropthalamia, and microencephaly	83
Tadpoles, pretreated with 5 mg Zn/L for 96 h	15,000-20,000	At 15 mg/L, none died in pretreated group versus 45% dead in controls at 90 h; at 20 mg/L, 15% died in pretreated group versus 50% in untreated controls	69
Embryos	34,500	LC50 (96 h)	71,83

[a]1. EPA 1980; 2. EPA 1987; 3. Spear 1981; 4. Vymazal 1986; 5. Francis and Harrison 1988; 6. Willis 1988; 7. Yantian 1989; 8. Nelson et al. 1988; 9. Munzinger and Guarducci 1988; 10. Belanger et al. 1986; 11. Farris et al. 1989; 12. Brereton et al. 1973; 13. Hunt and Anderson 1989; 14. Eisler 1980; 15. Mason 1988; 16. Eisler 1977a; 17. Eisler 1977b; 18. Lobel and Marshall 1988; 19. Amiard-Triquet et al. 1986; 20. Redpath and Davenport; 1988; 21. Hietanen et al. 1988b; 22. Hietanen et al. 1988a; 23. Akberali et al. 1985; 24. Conrad 1988; 25. Eisler and Hennekey 1977; 26. Chan 1988a; 27. Ahsanullah et al. 1988; 28. Bagshaw et al. 1986; 29. Ajmalkhan et al. 1986; 30. Paulauskis and Winner 1988; 31. Attar and Maly 1982; 32. Memmert 1987; 33. Khangarot and Ray 1989; 34. Johnson and Jones 1989; 35. Mirenda 1986; 36. Nugegoda and Rainbow 1989c; 37. McLusky and Hagerman 1987; 38. Verriopoulos and Hardouvelis 1988; 39. Verriopoulos and Moraitou-Apostolopoulou 1989; 40. Verriopoulos and Dim as 1988; 41. Lalande and Pinel-Alloul 1986; 42. Hatakeyama 1989; 43. Willis 1989; 44. Fernandez and Jones 1989; 45. Grant, et al. 1989; 46. Nakamura et al. 1989; 47. Voogt et al. 1987; 48. Eisler 1981; 49. Shukla and Pandey 1986b; 50. Shukla and Pandey 1986a; 51. Villegas-Navarro and Villarreal-Trevino 1989; 52. Hilmy et al. 1987c; 53. Somasundaram 1985; 54. Somasundaram et

al. 1985; 55. Solbe and Flook 1975; 56. Sauer and Warabe 1989a; 57. Eisler 1967; 58. Burton and Fisher 1990; 59. Taneja et al. 1958; 60. Bengeri and Patil 1986; 61. Gehrke 1988; 62. Mayer 1987; 63. Heath 1987; 64. Pundir 1989; 65. Mayer and Ellersieck 1986; 66. Nehring and Goettl 1974; 67. Buhl and Hamilton 1990; 68. Anadu et al. 1989; 69. Woodall et al. 1988; 70. Bengtsson 1974; 71. Dawson et al. 1988; 72. Hobson and Birge 1989; 73. Brungs 1969; 74. Pierson 1981; 75. Sayer et al. 1989; 76. Everall et al. 1989b; 77. Floe et al. 1979; 78. Crespo et al. 1979; 79. Grobler et al. 1989; 80. Hilmy et al. 1987c; 81. Gipouloux et al. 1986; 82. Taban et al. 1982; 83. Fort et al. 1989; 84.. NAS 1979; 85. Khangarot and Ray 1988.

[b]MATC = maximum acceptable toxicant concentration. Lower value in each MATC pair indicates highest concentration tested producing no measurable effect on growth, survival, reproduction, and metabolism during chronic exposure; higher value indicates lowest concentration tested producing a measurable effect.

Acute LC50 (96 h) values for freshwater invertebrates were between 32 and 40,930 µg Zn/L; in fish, this range was 66 to 40,900 µg/L (EPA 1987). For marine invertebrates the LC50 (96 h) range was 195 µg/L for embryos of the hard-shelled clam (*Mercenaria mercenaria*) to >320 mg/L for adults of the Baltic clam (*Macoma balthica*). For marine telcosts LC50 (96 h) values were between 191 µg/L for larvae of the cabezon (*Scorpaenichthys marmoratus*) to 38 mg/L for juvenile spot, (*Leiostomus xanthurus*; EPA 1987). Many factors are known to modify the biocidal properties of zinc in aquatic environment. In general, zinc was more toxic to embryos and juveniles than to adult, to starved animals, at elevated temperatures, in the presence of cadmium and mercury, in the absence of chelating agent, at reduced salinities, under conditions of marked oscillations in ambient zinc concentrations, at decreased water hardness and alkalinity, and at low dissolved oxygen concentrations (Skidmore 1964; Weatherley et al. 1980; Spear 1981; EPA 1987; Paulauskis and Winner 1988; Table 6).

Bioconcentration factors (BCF) for zinc accumulation from the medium varied widely between and within species of aquatic organisms. For representative freshwater organisms, BCF values ranged from 107 to 1,130 for insects and from 51 to 432 for fish (EPA 1980). In marine environments, the most effective zinc accumulators included red and brown algae, ostreid and crassostreid oysters, and scallops. The ranges of BCF values for representative marine groups were 370 to 64,000 for algae, 85 to 1,500,000 for crustaceans, 15 to 500 for echinoderms, as much as 4 million for scallop kidneys, and 1,900 to 6,900 for fish (Eisler 1980). Significant zinc accumulations were reported after death in algae and fish, suggesting that residue data from these and other organisms found dead on collection are of limited worth (Eisler 1980). Maximum net daily accumulation rates by various whole marine organisms were 1.3 mg Zn/kg FW for the alga *Ascophyllum nodosum*, 7.7 mg Zn/kg FW for the common mussel *Mytilus edulis*, 19.8 mg Zn/kg FW for the oyster *Crassostrea virginica*, 32 mg Zn/k FW for the killifish *Fundulus heteroclitus*, 32 mg Zn/kg FW for the softshell clam *Mya arenaria*, and 223 mg Zn/kg FW for the sandworm *Nereis diversicolor*; in general, accumulation rates and total accumulations were higher at elevated water temperatures and at higher ambient zinc water concentrations (Eisler 1980).

Algae and Macrophytes

Blue green algae are among the most zinc-resistant aquatic plants (Vymazal 1986). Algae are classified by Vymazal (1986) as very resistant (>10 mg Zn/L), resistant (2-10 mg/L), moderately resistant (0.5-2 mg/L), low resistant (0.1-0.5 mg/L; *Navicula*, *Synedra*), and very low resistant (<0.1 mg Zn/L; *Diatoma*, *Tabellaria*, *Microspora*, *Ulothrix*).

The most sensitive aquatic plant was *Schroederella schroederi*, a diatom; 19 µg Zn/L was sufficient to inhibit growth by 50% in 48 h (EPA 1987). Freshwater aquatic plants are usually absent from areas containing >2.0 mg Zn/L; in hard waters of artificial streams containing 170 mg $CaCO_3$/L, a water concentration of 1.1 mg Zn/L caused a 50% decrease in the number of algal species (Spear 1981). Most freshwater diatom populations decreased in the range of 175-380 µg Zn/L; this sensitivity may be useful as an indicator of zinc contamination (Spear 1981). Zinc and cadmium are strongly synergistic in their toxic action to plants. Any level of cadmium >10 µg/L should be suspected of producing a significant increase in the toxicity of available zinc to freshwater plants (Whitton 1980).

In heavily-contaminated zinc environments (130-6,500 µg Zn/L), zinc-tolerant species are dominant (Spear 1981). Highly-tolerant strains of algae require 1.5-1.65 mg Zn/L for normal growth; at least three species of

some tolerant strains can live in water containing 3 g Zn/L (Vymazal 1986). Highly tolerant mutant strains of *Anacystis nidulans* required 1.5-16.5 mg Zn/L. In France, at least 17 species of freshwater algae seemed to be flourishing at 42.5 mg Zn/L and pH 4.2 (Vymazal 1986). Zinc-tolerant strains of aquatic algae tolerate high zinc concentrations with little bioconcentration. A zinc-tolerant strain of *Euglena gracilis*, for example, tolerates >700 mg Zn/L but contains <500 mg Zn/kg DW whole organism versus 50 mg Zn/L and 5,000 mg/kg DW for nontolerant strains (Fukami et al. 1988a). Another zinc-tolerant strain of *Euglena* had normal growth at 300 mg Zn/L and residues of about 7,000 mg Zn/kg DW versus the population decline of nontolerant strains at 300 mg Zn/L (Fukami et al. 1988b).

Algae are effective accumulators of zinc. Three species of marine algae had a mean BCF of 1,530 in 12 days, 4,680 in 34 days, and 16,600 in 140 days (EPA 1980). Bioconcentration factors for zinc and various species of algae are quite variable and usually range from 76 to 163,750 (Vymazal 1986; EPA 1987). Many species of aquatic plants contain ≥150 mg Zn/kg DW. In one case, algae (*Mougeotia* spp.) from northern England in zinc-contaminated waters contained a spectacular 219 g Zn/kg DW (Vymazal 1986); it is probable that most of the zinc in *Mougeotia* was not biologically incorporated. Algal accumulations of zinc are modified significantly by physiochemical variables. Zinc concentrations in algae were higher under conditions of decreasing light intensity, water pH, DDT levels, copper, cadmium, phosphate, suspended sediments, organic chelators and other complexing agents, calcium, and magnesium and under conditions of increasing water temperature, dissolved oxygen, duration of exposure, and ambient zinc concentrations (Eisler 1980; Whitton 1980; Vymazal 1986).

Unlike algae, submerged aquatic macrophytes play a minor role in cycling of zinc (Lyngby et al. 1982). Rooted aquatic macrophytes may participate in heavy metal cycling in the aquatic environment either as a source or as a sink. But studies with eelgrass (*Zostera marina*) show that zinc exchange between the sediment and the water is insignificant (Lyngby et al. 1982).

Molluscs

Zinc was most toxic to representative molluscs at elevated temperatures (Eisler 1977a; Sprague 1986; Khangarot and Ray 1987), in comparatively soft water or to marine molluscs in low salinity (Sprague 1986; Khangarot and Ray 1987), at earlier developmental stages (Munzinger and Guarducci 1988), at low dissolved oxygen concentrations (Khangarot and Ray 1987), and with increasing exposure to high zinc concentrations (Amiard-Triquet et al. 1986).

High zinc accumulations in molluscs are usually linked to high levels of calcium in tissues, low ambient concentrations of iron or cobalt, exposure to organochlorine or organophosphorus insecticides, low salinity, elevated temperatures, increased particulate loadings in medium, increasing length of exposure to higher doses of zinc, increasing age of the organism, and especially to proximity of heavily carbonized and industrialized areas (Eisler 1980). Radiozinc-65 was rapidly accumulated in southern quahogs (*Mercenaria campechiensis*) during a 10-day period; accumulation in the kidney was linear over time and enhanced at elevated phosphate loadings in the medium (Miller et al. 1985).

Large variations in daily zinc accumulation rates by marine bivalve molluscs are typical. For example, softshell clams (*Mya arenaria*) immersed in 500 µg Zn/L at 16-22° C had daily accumulation rates of 2 mg/kg FW soft parts on day 1 of exposure, 7.7 mg Zn/kg FW soft parts between days 1 and 7, and 3.3 mg Zn/kg FW soft parts between days 7 and 14. At a lower temperature regimen of 0-10° C, immersion in 500 µg/L produced daily accumulation rates of 9.9 mg/kg FW soft parts for the first 42 days, but clams lost zinc at a rate of 0.24 mg/kg daily between days 42 and 112 (Eisler 1981). At 2,500 µg/L and 16-22° C, daily accumulation rates in surviving *Mya* were 32.0 mg Zn/kg FW soft parts on day 1 of exposure and 11.7 between days 1 and 7. Changes in accumulation rates of zinc by *Mya* reflect, at least partially, complex interactions between water temperature, ambient zinc concentrations, duration and season of exposure, and physiological saturation and detoxification mechanisms (Eisler 1977a, 1977b).

The half-time persistence (Tb½) of zinc in whole molluscs is extremely variable and reported to range from 4 days in the common mussel (*Mytilus edulis*) to 650 days in the duck mussel (*Anodonta nutalliana*); intermediate values were 23-40 days in the limpet (*Littorina irroratea*), 76 days in the California mussel (*Mytilus californianus*), and 300 days in the Pacific oyster (NAS 1979). Zinc persistence in selected organs also shows considerable variability and may be significantly different from Tb½ values in the whole animal. For example, the

Tb½ of zinc in the *Mytilus edulis* kidney was estimated at 2 to 3 months (Lobel and Marshall 1988) versus 4 days for whole animal (NAS 1979).

Mytilus edulis has been used extensively as a model for molluscan zinc kinetics. Results of selected studies follow. In mussels, zinc is taken up by the digestive gland, gills, and mantle and rapidly transported by hemolymph to the kidney where it is stored in insoluble granules (Lobel and Marshall 1988). There is a high degree of variability in soft tissues of *M. edulis* that is due entirely to an unusually high degree of variability in zinc of 97 to 7,864 mg/kg DW in the kidney (Lobel 1987). This variability in zinc content of the kidney is due largely to a low molecular weight zinc complex (700-1,300) that showed a high degree of variability and a positive correlation with zinc concentration in the kidney (Lobel and Marshall 1988). But at low ambient concentrations of 50 µg Zn/L, the most sensitive bioindicators of zinc exposure were gills and labial palps (Amiard-Triquet et al. 1986). Food composition had little effect on tissue distribution of radiozinc-65 in mussels as judged by 5-day feeding studies of radiolabeled diatoms (*Thalassiosira pseudonana*), green alga (*Dunaliella tertiolecta*), glass beads, and egg albumin particles (Fisher and Teyssie 1986). Soft part BCF values ranged from 12 to 35 times and was probably due to a rapid desorption of radiozinc from the food particles into the acidic gut, followed by binding to specific ligands or molecules. The Tb½ in mussel soft parts ranged from 42 to 80 days for all food items--including glass beads--and about 20 days in shell (Fisher and Teyssie 1986). Elevated temperatures in the range 10° to 25° C were associated with increased uptake rates of zinc from seawater by mussels (Watkins and Simkiss 1988). If the temperature is oscillated through this range during a 6-h period, there is a further enhancement of zinc uptake. This effect parallels decreases in zinc content of cytosol fractions and increases in granular fractions (Watkins and Simkiss 1988). Mussels were more sensitive to zinc than other tested bivalve molluscs. The pumping rate of mussels completely stopped for as long as 7 h on exposure to 470 to 860 µg Zn/L; however, other tested bivalves showed only a 50% reduction in filtration rates in the range of 750 to 2,000 µg Zn/L (Redpath and Davenport 1988). *Mytilus edulis* accumulates zinc under natural conditions but does not depurate under some conditions (Luten et al. 1986). This conclusion was based on results of a study of mussels that were transferred from a pristine environment in the Netherlands to a polluted estuary for 70 days and then returned for 77 days. At the start, zinc concentration was 106 mg/kg DW soft parts. By day 70, it had risen to 265 mg/kg DW at a linear daily uptake of 0.47 mg/kg. But mussels contained 248 mg/kg DW on day 147, indicating that elimination was negligible (Luten et al. 1986). In another study, zinc depressed sperm motility through respiratory inhibition at 6.5 mg/L, a concentration much higher than that normally found environmentally (Earnshaw et al. 1986). In mussel spermatozoa, zinc caused reductions of bound calcium and phosphorus in both acrosomes and mitochondria, suggesting increased permeability of organelle membranes to both elements (Earnshaw et al. 1986).

Arthropods

Arthropods were the most zinc-sensitive group of tested invertebrates (Table 6). Toxicity was usually greatest to marine crustaceans (Eisler 1981), to larvae (Eisler 1980), at elevated temperatures (Spear 1981; Sprague 1986; McLusky and Hagerman 1987), during extended exposures (EPA 1980, 1987), in soft water (Winner and Gauss 1986; Paulauskis and Winner 1988), under condition of starvation (NAS 1979; Verriopoulos and Moraitou-Apostolopoulou 1989), at salinity extremes above and below the isosmotic point (McLusky and Hagerman 1987), in summer (Eisler 1980), at low concentrations of humic acid (Winner and Gauss 1986; Paulauskis and Winner 1988), in proximity to anthropogenic discharges (Eisler 1980), and at low sediment particulate loadings (Memmert 1987). Acquired zinc tolerance is reported in amphipods collected from zinc-contaminated sewage wastes (Johnson and Jones 1989) and in fiddler crabs (*Uca* spp.) from a metals-contaminated area. *Uca* from zinc-contaminated areas were more resistant to zinc than crabs from pristine areas, as judged by increased survival and lower tissue zinc concentrations (Devi 1987; Devi and Rao 1989a, 1989b). More research into acquired zinc tolerance seems warranted.

Adverse effects of zinc insult to crustaceans include gill histopathology in prawns, *Macrobrachium hendersodyanum* (Patel and Kaliwal 1989); increased tissue total proteins, decreased glycogen, and decreased acid phosphatase activity in crabs, *Portunus pelagicus* (Hilmy et al. 1988); retardation of limb regeneration of fiddler crabs, *Uca pugilator* (Weis 1980); Waiwood et al. 1987). For example, tissue zinc residues in Homarus americanus exposed for 4 days to 25 mg Zn/L were especially high in gills (2,570 mg Zn/kg DW vs. 126 mg Zn/kg DW at start), hepatopancreas (734 mg Zn/kg DW vs. 135 mg Zn/kg DW), and green gland (1,032 mg Zn/kg DW vs. 148 mg Zn/kg DW). After 7 days in uncontaminated media tissue zinc residues remained elevated in gills (675 mg Zn/kg DW), hepatopancreas (603 mg Zn/kg DW), green gland (286 mg Zn/kg DW), and other

tissues (Waiwood et al. 1987). Zinc concentrations in crustacean soft tissues usually are between 50 and 208 mg/kg DW and exceed soft tissue zinc enzymatic requirements by factors of 1.4 to 6.0 (Depledge 1989).

Half-time persistence of zinc is about 17 days in the prawn (*Palaemon elegans*; Nugegoda and Rainbow 1988b) and between 30 and 270 days in five other crustacean species (NAS 1979). Differences in half-time persistence are linked to differences in excretion rates of ionic zinc and complexed zinc. In general, crustaceans excrete ionic zinc first and complexed zinc next; surface-adsorbed zinc is turned over faster than internally-adsorbed zinc; molting accounts for a 33-50% loss of the total body burden in crabs (Eisler 1981).

Crustaceans can accumulate zinc from both water and food (EPA 1987). In uncontaminated waters, the diet is probably the major source of zinc. Absorption from the stomach is efficient and occurs in part through the hepatopancreas. When a large pulse of zinc reaches the blood from the stomach, some is excreted, but much is resorbed and stored in the hepatopancreas in a relatively nonlabile form. Ultimately, stored zinc is also excreted, although removal through the gut is unimportant (Bryan et al. 1986). Zinc absorption is initially at the gill surface, is followed by transport on a saturable carrier in the cell wall, and is most efficient at low dissolved ambient zinc concentrations. Urinary excretion is an important body removal pathway, especially at high dissolved ambient concentrations when it can account for 70-80% of the total zinc excretion (Bryan et al. 1986).

Barnacles (*Elminius modestus*) usually accumulate zinc to high body concentrations without significant excretion. Barnacle detoxification mechanisms of the stored zinc includes production of metabolically inert zinc phosphate granules (Rainbow and White 1989). However, *Elminius modestus* transplanted from an area of high ambient zinc (101 µg/L) to an environment of low ambient zinc (4 µg/L) lost zinc slowly (0.3% body burden daily) during an 11-week period. Whole body zinc burdens declined from 1,554 to 125 mg/kg DW or at about 4.1 mg/kg DW daily (Thomas and Ritz 1986). In the case of *Balanus balanoides*, another barnacle, high BCF values were attributed to inorganic granules that contained as much as 38% zinc and accumulated in tissues surrounding the midgut (Eisler 1980).

Crustaceans--and other groups--can regulate body concentration of zinc against fluctuations in intake, although the ways in which regulation is achieved vary among species (Bryan et al. 1986). Regulation of whole body zinc to a constant level is reported for many crustaceans, including intertidal prawns (*Palaemon* spp.), sublittoral prawns (*Pandalus montagui*), green crabs (*Carcinus maenus*), lobsters (*Homarus gammarus*), amphipods (*Gammarus duebeni*), isopods (*Asellus communis*), and crayfish (*Austropotamobius pallipes*; Devineau and Amiard-Triquet 1985; Bryan et al. 1986; Lewis and McIntosh 1986; Nugegoda and Rainbow 1988b; Johnson and Jones 1989; Rainbow and White 1989). The body zinc concentration at which zinc is regulated in crustaceans usually increases with increasing temperature, salinity, molting frequency, bioavailability of the uncomplexed free metal ions, and chelators in the medium (Nugegoda and Rainbow 1987, 1988a, 1989a, 1989b). Lobsters (*Homarus gammarus*) are able to equilibrate over a 30-day period in seawater containing between 2 and 505 µg/L. In response to a 100-fold rise in seawater concentrations (from 5 to 500 µg/L), zinc levels in whole body, blood, hepatopancreas, excretory organs, and gills almost doubled but changed little in muscle. Zinc concentrations in shells increased about 12 times, largely through adsorption (Bryan et al. 1986). Regulation of zinc in lobster blood is achieved by balancing uptake through the gills against urinary excretion and loss over the body surface including the gills (Bryan et al. 1986). The sublittoral prawn (*Pandalus montagui*) can regulate total body zinc concentration to a constant level (75 mg/kg DW) in dissolved zinc concentrations up to 22 µg/L, beyond which there is net accumulation of body zinc. This threshold of zinc regulation breakdown is lower than that in *Palaemon elegans* (93 µg Zn/L) and *Palaemonetes varians* (190 µg Zn/L) under the same physiochemical conditions (Nugegoda and Rainbow 1987, 1988a, 1988b, 1989a, 1989b, 1989c; Rainbow and White 1989). The authors conclude that regulation of body zinc concentration is most efficient in decapods adapted to the fluctuating environments of littoral habitats, possibly, as a result of changes in permeability of uptake surfaces in combination with improved zinc excretion systems.

Freshwater crayfish (*Orconectes virilis*) are among the more resistant crustaceans (LC50 value of 84 mg Zn/L in 2 weeks) and can easily tolerate the recommended water quality criteria of 50-180 µg/L; nevertheless, some streams in Arkansas and Colorado contain 79-99 mg Zn/L (Mirenda 1986). *Orconectes virilis* exposed to extremely high sublethal ambient zinc concentrations of 63 mg/L for 2 weeks show whole body BCF values of only 2; a similar pattern was observed at other concentrations. In all cases, zinc tended to concentrate in gills and hepatopancreas at the expense of muscle, carapace, and intestine (Mirenda 1986). In freshwater crayfish (*Procambarus acutus acutus*), the major uptake route was the ambient medium and not diet, although retention

time of dietary zinc was greater (Giesy et al. 1980). When dietary zinc was the only zinc source, crayfish rapidly reached a steady state; when water was the only zinc source, crayfish did not reach a steady state (Giesy et al. 1980). Freshwater mysidaceans and their particulate wastes may play an important role in zinc cycling. The freshwater opossum shrimp (*Mysis relicta*) feeding on sediments ingested 2 to 4 times more zinc than mysids feeding on zooplankton. However, sediment-feeding mysids excreted 3 to 5 times more zinc than zooplankton consumers; zinc concentrations were up to 24 times higher in fecal pellets of sediment feeders than in food (Van Duyn-Henderson and Lasenby 1986). In the freshwater crayfish *Austropotamobius pallipes*, fecal excretion is a major zinc removal pathway; a similar case is made for the green crab (*Carcinus maenus*; Bryan et al. 1986).

Marine copepods (*Anomalocera*, *Acartia*, *Temora*) excreted 52% of the ingested zinc in fecal pellets that subsequently leached all zinc to seawater within 24 h (Fisher et al. 1991).

Freshwater insects, including many species of mayflies, damselflies, stoneflies, and caddisflies, are relatively tolerant to zinc, with LC50 values usually >1.33 mg/L--although some species were adversely affected at concentrations between 30 and 37 µg Zn/L (EPA 1987; Table 6). Mayfly (*Epeorus latifolium*) larvae were adversely affected at ambient water concentrations of 30 µg Zn/L but could tolerate dietary loadings of 600 mg Zn/kg DW ration without measurable effects on growth or emergence (Hatakeyama 1989). Chironomid insect populations were reduced or missing immediately downstream from coal mine drainage containing 5-10 mg Zn/L; populations further downstream recovered numerically but in comparison with upstream communities, their diversity was reduced (Wilson 1988).

Annelids

Populations of freshwater oligochaetes and leeches were reduced in numbers of individuals and number of taxa in mine tailing effluents containing 146-213 µg Zn/L or sediments containing >20 g Zn/kg DW (Willis 1985b). Leeches (*Erpobdella octoculata*) experienced a reduction in density and reproductive capacity in streams containing 25 to 310 µg Zn/L from mine wastes and did not avoid these harmful concentrations (Willis 1989).

The highest rate of net zinc absorption reported for any group of invertebrates was 2,230 mg Zn/kg BW daily in sandworms (*Nereis diversicolor*) from sediments with low zinc levels during exposure for 34 days in 250 mg Zn/L. At 10 mg Zn/L, the rate decreased to 55 mg Zn/kg BW daily (Eisler 1981). Zinc uptake in *Nereis* increased with increasing sediment zinc levels, at lower salinities (Eisler 1980), and at elevated temperatures (Fernandez and Jones 1987, 1989). Zinc had no significant effect on burrowing behavior of *Nereis*, even at acutely lethal concentrations (Fernandez and Jones 1987). Sandworms from zinc-contaminated sediments were more resistant to waterborne zinc insult by 10-100 times than sandworms from clean sediments (EPA 1987). Tolerance to zinc in sandworms may be a result of acclimatization or genetic adaption. In either event, the degree of metal tolerance decreases rapidly as the level of zinc contamination declines, suggesting that some zinc-tolerant worms may be competitively inferior to normal individuals in clean environments (Grant et al. 1989). More research on zinc-tolerant populations seems merited.

Unlike other major groups of marine benthic organisms, the polychaete *Neanthes arenaceodentata* has a limited capacity to regulate zinc (Mason et al. 1988). Uptake in *Neanthes* occurs from the free ionic pool of zinc whereas EDTA complexes and EDTA-zinc complexes are largely excluded. Zinc accumulates linearly over time (350 h) and the rate decreases with increasing temperature in the range 4-21° C. Mason et al. (1988) concluded that uptake and accumulation of zinc is passive in *Neanthes* and does not require metabolic energy. Zinc transfer across the plasma membrane is by way of diffusion. Inside the cell, zinc binds to a variety of existing ligands that maintain an inwardly directed diffusion gradient, preventing zinc efflux. Accumulation rats is determined by the number and binding characteristics of the available ligands and their accessibility to zinc. After 50 h of exposure, worms selectively accumulate zinc over cadmium from the medium by a process requiring metabolic energy, and this is attributed to a change in the turnover rate and to the size and nature of the pool of zinc-binding ligands (Mason et al. 1988).

Echinoderms

In echinoderms, zinc concentrations are usually higher in detrital feeders than in carnivores, higher in surface feeders than in sediment feeders, and higher in specimens collected inshore than those collected offshore in deeper waters (Eisler 1980). Sea cucumbers (*Stichopus tremulus*) accumulate radiozinc-65 from

seawater by a factor of 1,400; however, radiozinc accumulation data should be viewed with caution because addition of stable zinc can reduce radiozinc-65 accumulations in echinoderm viscera up to 10-fold (Eisler 1981). Zinc inhibits the formation of the fertilization membrane in sea urchin eggs, possibly by interfering with cortical granule-derived proteases and proteins (Nakamura et al. 1989).

Fish

Several trends are evident (Table 6): (1) freshwater fish are more sensitive to zinc than marine species; (2) embryos and larvae are the most sensitive developmental stages; (3) effects are lethal or sublethal for most species in the range 50-235 µg Zn/L and at 4.9-9.8 µg Zn/L for the brown trout (*Salmo trutta*); and (4) behavioral modifications, such as avoidance, occur at concentrations as low as 5.6 µg Zn/L. Signs of zinc poisoning in fish included hyperactivity followed by sluggishness before death, fish swam at the surface, were lethargic and uncoordinated, showed hemorrhaging at gills and base of fins, shed scales, and had extensive body and gill mucous (Bengeri and Patil 1986). Zinc is most toxic to yearlings of brown trout in soft water at pH 4-6 and pH 8-9; toxicity at alkaline pH is attributed to the formation of $ZnOH^+$, $Zn(OH)_2$, and $ZnCO_3$ in both hard and soft water--suggesting increased entrapment of metal precipitates within mucous and epithelial layers of the gill (Everall et al. 1989a). Acute zinc poisoning in fish is generally attributed to blockade of gas exchange across the gills, causing hypoxia at the tissue level. Tissue hypoxia in fish is a major physiological change before death once the gas exchange process at the gills is no longer sufficient to meet its oxygen requirements (Burton et al. 1972; NAS 1979; Everall et al. 1989a; Grobler et al. 1989). Cardiorespiratory responses to zinc in the spangled perch (*Leiopotherapon unicolor*) are similar to those induced by hypoxia; zinc-poisoned perch had damaged gill epithelia, resulting in impaired gas exchange and lowered oxygen tension in arterial blood (Gehrke 1988). Acute exposures to high lethal concentrations of zinc also caused histopathology of epithelia lining the oral capacity (Eisler and Gardner 1973).

Many factors modify the lethal properties of zinc to fish. Zinc is more toxic under conditions of comparatively low dissolved oxygen concentrations, high sodium concentrations, decreased loadings of organic complexing agents (Spear 1981), and low pH (NAS 1979). In guppies (*Poecilia reticulata*), females were more resistant than males to acute zinc insult; adults of both sexes were more resistant than 5-day-old fry (Pierson 1981). Dominant bluegills (*Lepomis macrochirus*) survived exposure to 32 mg Zn/L longer than submissive fish (NAS 1979). Water temperature is also an important modifier and it is generally agreed that zinc is more toxic at elevated temperatures (NAS 1979; Spear 1981; Hilmy et al. 1987c) when acclimatization temperature is considered. For example, cold-acclimatized (3° C) Atlantic salmon survived longer than warm-acclimatized (19° C) salmon when exposed to lethal concentrations of zinc at their respective acclimatization temperatures. However, at test temperatures lower than their former acclimatization temperatures, salmon were less tolerant of zinc (Hodson and Sprague 1975).

Fish surviving high sublethal concentrations of zinc had significant alterations in blood and serum chemistry, liver enzyme activity (Hilmy et al. 1987b), muscle glycogen, total lipids, phospholipids, cholesterol, RNA, and proteins (Taneja et al. 1988).

Reproductive impairment seems to be one of the more sensitive indicators of zinc stress in freshwater teleosts, and effects are evident in the 50-340 µg Zn/L range (Spear 1981). In some cases, reproduction was almost totally inhibited at zinc concentrations that had no effect on survival, growth, or maturation of these same fish (Brungs 1969). Zinc-induced developmental abnormalities were documented in marine teleosts, but concentrations were grossly elevated. Eggs of the Baltic herring (*Clupea harengus*), for example, exposed to >6 mg Zn/L had an altered rate of development and produced deformed larvae with cellular disruptions in the brain, muscle, and epidermis (Somasundaram 1985; Somasundaram et al. 1985).

Avoidance tests with fathead minnows (*Pimephales promelas*) showed that almost all except males with established territories avoid 284 µg Zn/L when given a choice; avoidance thresholds were 6.4 times higher for established males (Korver and Sprague 1989).

Limited tolerance to zinc was observed in freshwater fish preexposed to sublethal levels of zinc (Spear 1981; Heath 1987; Woodall et al. 1988; Anadu et al. 1989; Hobson and Birge 1989). In one case, rainbow trout acclimatized to 50 µg Zn/L for 21 days were as much as 5 times more tolerant to subsequent zinc exposures than nonacclimatized trout; this was not evident at 100 µg Zn/L; also, acclimatization to zinc produced tolerances to copper and cadmium in trout (Anadu et al. 1989). The mechanisms to account for this

phenomenon are unknown, but several theories are proposed: increased metallothionein synthesis (Woodall et al. 1988), although this is disputed by Hobson and Birge (1989); high mortality during preexposure may have caused the selection of more zinc-tolerant individuals (Spear 1981); and tolerance may be limited to strains capable of increased zinc excretion, although no evidence now exists linking genetic mechanisms to zinc resistance (Spear 1981).

The estimated half-time persistence (Tb½) of zinc in whole mosquitofish (*Gambusia affinis*) was 215 days (Newman and Mitz 1988). The half-time persistence of zinc in whole marine fish ranged from 35 to 75 days in the mummichog (*Fundulus heteroclitus*) to 295-313 days in a flatfish (*Pleuronectes platessa*); Tb½ in mummichogs was shortest at 30° C, longest at 10° C, and intermediate at 20° C (NAS 1979).

Fish can accumulate zinc from both the surrounding medium and from their diet (EPA 1987). The freshwater zebra danio (*Brachydanio rerio*) accumulated zinc from the medium, but there was no additional zinc enrichment from a *Daphnia* diet (Memmert 1987). In marine fish, however, diet was considered the major route of zinc intake and significantly more important than water zinc levels (Eisler 1980).

In freshwater fish, BCF values for whole individuals were between 51 and 500 times (EPA 1987) but are strongly influenced by dose, duration of exposure, water chemistry, and other variables. In mosquitofish, uptake rate from water and zinc elimination rate decreased with increasing age of the fish (Newman and Mitz 1988). In the three-spined stickleback (*Gasterosteus aculeatus*), uptake was greater in hard water than in soft water and greater in larger fish, suggesting a surface adsorption mechanism (Matthiessen and Brafield 1977). In brown trout, however, uptake was lower and excretion greater in hard water of 220 mg $CaCO_3$/L than in soft water of 9 mg $CaCO_3$/L, thereby reducing tissue burdens (Everall et al. 1989a). Starved rainbow trout accumulated zinc more rapidly than fed fish because of an increased contribution of waterborne zinc to total body zinc levels (Handy and Eddy 1990). Rapidly growing chinook salmon (*Oncorhynchus tshawytscha*) fingerlings removed radiozinc-65 from the medium and retained nearly all of it for 63 days after transfer to uncontaminated media. Most of the radiozinc-65 was translocated to vertebral column, head, and visceral mass (Joyner and Eisler 1961). The outer surface of the bone seems to be an ion-exchange medium capable of taking up large quantities of metal ions whether natural or foreign to the system. Metals thus exchanged from serum proteins may be prevented from undergoing further exchange by the overlayering action of growing bone (Joyner and Eisler 1961). Channel catfish (*Ictalurus punctatus*) fingerlings fed diets containing up to 200 mg Zn/kg FW ration for 12 weeks had elevated bone zinc levels (359 mg/kg DW vs. 254 mg/kg DW in controls) and reduced hematocrit, but survival and feed conversion efficiency was the same as by controls (Gatlin et al. 1989). Plasma zinc levels in four species of freshwater fish on diets containing 100-200 mg Zn/kg ration ranged between 9.3 and 15.1 mg Zn/L FW; in rainbow trout, zinc tended to concentrate in the erythrocyte membrane (Bettger et al. 1987).

In marine fish, zinc residues were usually higher in dead than in live or moribund animals, higher in smaller fish, higher in liver and viscera, and higher with decreasing water cadmium levels (Eisler 1980). Uptake from the medium by adult mummichogs was inversely related to zinc concentration in the water (EPA 1987). In mummichogs, zinc accumulates in scales during exposure to 10 mg Zn/L, significantly elevating the zinc to calcium ratio; ratios remained elevated for at least 4 months after transfer to low zinc media, and this phenomenon may have application for environmental monitoring (Sauer and Watabe 1989a).

Scale osteoblasts of zinc-exposed mummichogs showed an increase in the number of lysosome-like structures contained by cytoplasm and suggests that osteoblast lysosomes are involved in zinc accumulation in fish scales by enzymatic degradation of metallothioneins or other metal-binding proteins (Sauer and Watabe 1989). Dietary zinc is not well assimilated in marine flatfish. Turbot (*Scopthalmus maximus*) fed diets containing 100 (control) or 1,000 mg Zn/kg DW for 200 days were not different in renal and hepatic metallothionein levels or in zinc concentrations in the liver, kidney, muscle, skin, or bone; a similar case is made for other marine flatfish (Overnell et al. 1988). However, intraperitoneally injected (2 mg Zn/kg BW) turbots had an 18-fold increase in liver metallothionein constant and a 3-fold increase in liver zinc, confirming the ability of this species to synthesize metallothionein rapidly to a high concentration (Overnell et al. 1988).

Amphibians

Amphibian embryos are more sensitive to zinc than older stages; developmental abnormalities were evident in most species at concentrations >1.5 mg Zn/L (Table 6). Embryos of the narrowmouthed toad (*Gastrophryne carolinensis*) seem to be especially sensitive; adverse effects were reported at 10 µg Zn/L (EPA 1987), but this requires verification. Amphibians and other taxonomic groups were rare or absent in the vicinity of zinc smelters but not in more distant sites (Beyer et al. 1985).

In tests with isolated skin of frogs (*Rana* spp.), Zn^{2+} stimulates sodium transport and inhibits chloride-related tissue conductance; however, the skin of toads is relatively insensitive to zinc (Nagel et al. 1988). In early stages of embryonic development, Zn^{2+} stimulates multiplication of germ cells, but long-term treatment with $ZnSO_4$ has a toxic effect on the larval gonad and especially on the germ cells of the ovarian structure that is developed in frog larvae (Gipouloux et al. 1986).

Birds

Ducks (*Anas* spp.) had reduced survival when fed diets containing 2,500-3,000 mg Zn/kg ration or when force-fed zinc metal shot equivalent to 742 mg Zn/kg BW (Table 7). Domestic chickens (*Gallus* sp.) were more resistant: 8,000 mg Zn/kg ration was fatal to chicks, although higher doses were routinely fed to laying hens to induce molting; 2,000-3,000 mg Zn/kg ration inhibited chick growth; 178 mg Zn/kg feed caused immunosuppression in chicks; and dietary concentrations as low as 100 mg Zn/kg caused pancreas histopathology in chicks under conditions of selenium deficiency (Table 7). Excessive zinc (2,000 mg/kg diet for 21 days) fed to chicks (*Gallus* sp.) caused zinc accumulations in tissues, reduced tissue turnover of zinc, reduced liver turnover of iron, and reduced copper content of the liver and pancreas and iron in the tibia (Stahl et al. 1989b). However, hens were less sensitive and, when fed diets containing 2,000 mg Zn/kg for 44 weeks, produced chicks that had no apparent alteration in tissue zinc, copper, or iron metabolism (Stahl et al. 1990).

Table 7. Effects of zinc on representative birds.

Species, dose, and other variables	Effects	Reference[a]
Mallard, *Anas platyrhynchos*		
Fed diets containing 3,000 mg Zn/kg feed, and higher, for 30 days	At 3,000 mg/kg ration, ducks had leg paralysis and decreased food consumption; at >3,000 mg/kg diet, many deaths occurred	1
Age 7 weeks. Fed diets containing 3,000, 6,000, 9,000, or 12,000 mg Zn/kg dry weight (DW) diet for 60 days; zinc in form of zinc carbonate	Food intake reduced for all groups; the 9,000 and 12,000 mg/kg groups had almost zero intake. High mortality after 30 days in all groups; only 17% of 3,000 mg/kg group alive at day 60. Zinc residues at time of death or at day 60 for the 3,000 mg/kg group were 89 mg/kg fresh weight (FW) in pancreas (1,252 mg/kg FW in controls); 401 mg/kg FW in liver (54 mg/kg FW); 88 mg/kg FW in adrenals (45 mg/kg FW); 413 mg/kg FW in kidney (27 mg/kg FW); 32 mg/kg FW in muscle (14 mg/kg FW); 78 mg/kg FW in testes (17 mg/kg FW); and 71 mg/kg FW in ovary (31 mg/kg FW)	2
Age 1 year. Single oral dose of five number 6 zinc shot in gelatin capsules,	All shot retained in gizzard after 14 days; no adverse effects after 28 days. Residues at	3

equivalent to 0.40 g zinc or 495 mg Zn/kg body weight (BW)	28 days were 217 mg/kg DW in liver, 79 mg/kg DW in kidney, and 126 mg/kg DW in feather	
Drakes, 18 months old, force-fed eight number 6 zinc shot pellets	By day 30 posttreatment, 20% had died. The mean weight loss was 33% in dead birds and 22% in survivors. About 83% of survivors developed signs of zinc poisoning	4
Age 1 year. Single oral dose of ten number 6 zinc shot in gelatin capsules, equivalent to 0.80 g zinc or 990 mg Zn/kg BW	Two to 4 shot voided in first 48 h, but no further loss for 28 days. Residues at 28 days were 211 mg Zn/kg DW in liver (171 mg Zn/kg DW in control birds), 72 mg Zn/kg DW in kidney (61 mg Zn/kg DW), 143 mg Zn/kg DW in feather (128 mg Zn/kg DW)	3
Pekin duck, *Anas platyrhynchos*		
3-day-old male white ducklings fed diet containing 2,500 mg Zn/kg, as $ZnSO_4.H_2O$, for 56 days	Progressive ultrastructural degeneration of pancreatic acinar cells evident as early as day 5	5
Japanese quail, *Coturnix coturnix japonica*		
Intratesticular injection of 3% zinc chloride equivalent to 1 mg Zn/kg testes or 0.02 mg/kg BW	Testicular teratomas produced during a period of testicular growth stimulated by increased photoperiod	6
Hens fed diet containing 15,000 mg Zn/kg ration, as zinc oxide, for 7 days	Significant reduction in body weight, egg production approached zero at day 3, eggshell breaking strength reduced, molting induced	7
14-day-old quail fed diets containing various concentrations of zinc, as zinc phosphide (a rodenticide) for 5 days followed by 3 days of untreated feed	At 600 mg Zn/kg ration, 7% died and all had reduced food intake. At 990 mg Zn/kg diet, 53% died; at 1,634 mg/kg died, 93% died	8
Domestic chicken, *Gallus* sp.		
Developing embryos, 1 day old, with 0.76 mg Zn/yolk at start, supplemented with 0.2, 0.4, or 0.6 mg zinc	Hepatic metallothionein levels increased by factors of 3.9 (0.2 mg), 4.7 (0.4 mg), and 7.1 (0.6 mg)	9
Femurs from 9-day-old chick embryos cultivated for 6 days at 3.26 mg Zn/L	Inhibited calcium accumulations in bone and increased alkaline phosphatase activity of medium	10
As above, 6.5 mg Zn/L	Decrease in calcified tissues	10
Domestic breeding hens fed diets containing 28, 38, 48, 68, 94, or 178 mg Zn/kg ration for up to 9 months	Progeny growth after 3 weeks was not affected by maternal zinc feeding levels. A minimum of 38 mg Zn/kg diet was considered necessary for minimal feather fraying and maximal immune response in chicks. Diets containing 178 mg Zn/kg may be excessive and cause	11

	immunosuppression of young progeny without affecting growth	
Fed 28 (control), 48, 228, or 2,028 mg Zn/kg diets for 12 or 44 weeks. Hens were 56 weeks old at start of short-term study and 24 weeks old at start of long-tern study	Zinc treatments had no effect on overall egg production, feed conversion, feed consumption, hatchability, or progeny growth to age 3 weeks. Zinc was elevated in eggs from hens fed the 2,028 mg/kg diet, but chick performance and tissue zinc content were unaffected by maternal zinc nutritional status	12
Chicks fed diets containing 37 (control), 100, or 2,000 mg Zn/kg feed for 21 days	No accumulations in 100 mg/kg group; zinc excretion rate about x2 controls. No deaths in 2,000 mg/kg group, but growth rate was decreased, anemia evident, tissue copper and iron decreased, and tissue zinc increased	13
Day-old chicks fed selenium-deficient diets plus 100 mg Zn/kg FW, as zinc oxide, purified ration for 9 days	Elevated zinc concentrations in pancreas, and pancreas histopathology	14
Hens fed diets containing 218, 257, 1,762, or 1,861 mg Zn/kg diet for up to 40 weeks	Eggs from hens fed 218 or 257 mg Zn/kg diet contained a maximum of 14 mg/kg FW, equivalent to about 25% more zinc than eggs produced by control hens. Eggs from the two higher-dose diets had a maximum of 19 mg/kg FW or 57-90% more zinc than eggs produced by hens fed a control diet of 26-28 mg Zn/kg.	15
9-day-old chicks fed purified diet containing 500 mg Zn/kg ration for 2 weeks	Plasma alpha-tocopherol reduced 64%; plasma and pancreas zinc concentrations elevated	16
Day-old chicks fed selenium-adequate diet plus 2,000 mg Zn/kg FW, as zinc oxide, nonpurified ration for 9 days	Negligible effects on pancreas zinc concentration and on pancreas exocrine function	14
9-day-old chicks fed nonpurified diet containing 2,000 mg Zn/kg ration for 80 days.	No effect on plasma alpha-tocopherol or plasma and pancreas zinc content	16
Chicks fed diets containing 2,000 or 3,000 mg Zn/kg ration for 30 clays	Slight reduction in growth at 2,000 mg/kg; significant growth reduction at 3,000 mg/kg	1
Day-old chicks fed diets containing up to 4,000 mg Zn/kg ration for 4 weeks	No effect on growth, survival, or feed conversion. Zinc accumulated in tissue metallothioneins, especially in liver and kidney; levels normal after 5 days on zinc-deficient diet	17
Day-old chicks fed diets containing 4,000, 8,000, or 16,000 mg Zn/kg for 5 weeks	All dead at 16,000 mg/kg diet. The 8,000 mg/kg group had 80% mortality; survivors had significantly reduced growth and feed conversion. At 4,000 mg/kg, no significant effect on growth or	17

	survival; zinc concentrations elevated in kidney, liver, intestinal mucosa, and pancreas--but values normal after 10 days on basal diet	
Age 71 weeks, laying hens. Fed diet containing 10,000 mg Zn/kg feed for 2 days, then 5,000 mg/kg diet for 4 days	Hens started to molt and ceased laying. Feed intake decreased about 90%. Zinc concentrations increased in pancreas 7 times, in liver 6 times, in kidney 3 times, and were elevated in shell gland and yolk. High zinc levels in kidney reflect high zinc excretion rates; high pancreatic zinc (410 mg Zn/kg FW) may suppress the release of insulin by calmodulin inhibition, and could account for the rapid cessation of lay	18
White leghorns and brown layers were fed diets containing 10,000, 20,000, or 30,000 mg Zn/kg feed, as zinc oxide, for up to 3 weeks to induce molting	Cessation of egg laying in all treatments. On resumption of egg production, zinc levels in albumin or eggshell were not affected by the treatment or strain; zinc levels in yolk increased and depended on feed intake rather than dose. No increase in zinc content in eggs laid after egg production resumed, regardless of dose or duration of zinc treatment	19
White leghorn laying pullets and hens fed diet containing 20,000 mg Zn/kg feed for 5 days	Reduced body weight on day 5, and significantly lowered egg production for 4 weeks. Eggs collected 14-28 days after the 5-day study period had reduced fertility and hatchability. Normal growth, egg production, fertility, and hatch-ability during weeks 4-12 posttreatment	20
Laying hens fed diet containing 20,000 mg Zn/kg, as zinc oxide, for 4 days followed by 18 days on basal (35 mg Zn/kg) diet	At day 4, liver zinc concentrations increased 10 times, kidney 3 times, egg yolk 3 times, and pancreas 25 times; liver and kidney values returned to normal by day 22, but pancreas concentration (1,673 mg/kg DW) remained elevated when compared to controls (88 mg/kg DW). At day 10, reduced weight of ovary and oviduct	21
Turkey, *Meleagris gallopavo*		
Zinc concentration of sperm storage medium increased from 25 to 90 mg/L.	Fertilizing ability of stored sperm significantly reduced	22

[a] 1. NAS 1979; 2. Gasaway and Buss 1972; 3. French et al. 1987; 4. Grandy et al. 1968; 5. Kazacos and Van Vleet 1989; 6, Guthrie 1971; 7. Hussein et al. 1988; 8. Hill and Camardese 1986; 9. Fleet and McCormick 1988; 10. Kaji et al, 1988; 11. Stahl et al. 1989a; 12. Stahl et al. 1990; 13. Stahl et al. 1989b; 14. Lu and Combs 1988a; 15. Stahl et al. 1988; 16. Lu and Combs 1988b; 17. Oh et al 1979; 18. Veheyen et al. 1990; 19. Decuypere et al. 1988; 20. Palafox and Ho-A 1988; 21. Williams et al. 1989;p 22. Blesbois and Mauger 1989.

Zinc-poisoned mallards (*Anas platyrhynchos*) force fed zinc shot pellets developed ataxia, paresis, and total loss of muscular control of legs, including the ability to swim (Wobeser 1981). The muscular, weakness associated with zinc intoxication would probably make ducks highly susceptible to predation and argues against the use of zinc shot as a substitute for lead shot (Grandy et al. 1968). Mallards fed 3,000 mg Zn/kg DW ration for 60 days had diarrhea after 15 days; leg paralysis in 20 days; high mortality after 30 days; and zinc residues that were 14 times higher in pancreas than in controls, 7 times higher in liver, 15 times higher in kidney; and 2 to 4 times higher in the adrenals, muscle, testes, and ovary at day 60 (Gasaway and Buss 1972).

In Australia, almost all aviary birds are held in cages of galvanized wire mesh, resulting in sporadic cases of "new wire disease" caused by the ingestion of galvanized metal. In one case, peachfaced lovebirds (*Agapornis roseicollis*) died within 5 weeks of placement in a newly erected wire cage; dead birds had elevated liver zinc concentrations of 75-156 mg/kg DW versus normal values of 21-33 mg/kg DW (Reece et al. 1986). Zinc poisoning in a captive Nicobar pigeon (*Caloenas nicobarica*) was attributed to plated zinc metal fragments found in the gizzard--presumably ingested from the galvanized cage bars. In addition to elevated tissue zinc concentrations, this pigeon had a swollen liver and kidneys and extensive kidney histopathology (Zee et al. 1985). A zinc-poisoned blue and gold macaw (*Ara ararauna*) showed weakness, ataxia, extreme thirst, diarrhea, cyanosis, and a plasma zinc concentration of 15.5 mg/L after ingesting galvanized hardware cloth that was 24% zinc by weight and 0.2% lead. The bird was treated with 35 mg/kg BW calcium versanate intramuscularly and 30 mg thiamine hydrochloride per kilogram of BW; recovery following chelation therapy took 2 months, at which time plasma zinc was 0.6-0.8 mg/L versus 1.3-2.0 mg/L for normal birds (Morris et al. 1986). New galvanized wire used in aviary construction should weather for 1 to 2 months and then be scrubbed with a mild acidic solution such as vinegar and rinsed; flakes of galvanized metal--which contain up to 2.4 g Zn/kg--should be removed before birds are put in cages (Reece et al. 1986).

Zinc toxicosis was diagnosed in a gray-headed chachalaca (*Ortalis cinereiceps*) after it ingested a copper-plated zinc penny; necropsy showed pancreas histopathology and severe gizzard erosion; liver contained 1,910 mg Zn/kg FW (Droual et al. 1991).

Large amounts of zinc are crucial for new feather growth. Zinc deficiency during this period results in stunted, frayed, easily-broken feathers. Studies with the giant Canada goose (*Branta canadensis maxima*) showed that zinc was released from the pectoralis muscle during molt-induced atrophy and used for growth of feathers and leg muscles during this period (Rosser and George 1986).

Zinc phosphide--a rodenticide--is relatively toxic in comparison with elemental zinc or zinc oxide; most of the biocidal action is attributed to the phosphide fraction. Acute oral LD50 values for zinc phosphide were between 16 and 47 mg/kg BW in the ring-necked pheasant (*Phasianus colchicus*), golden eagle (*Aquila chrysaetos*), mallard, and horned lark (*Eremophila alpestris*; Hudson et al. 1984). Signs of zinc phosphide poisoning include excessive drinking, regurgitation, muscular incoordination, appetite loss, sluggishness, rapid breathing, and eyelid droop. Signs appeared as soon as 15 min after dosing, and death usually occurred between 2 and 21 h; remission took up to 1 month (Hudson et al. 1984).

High dietary levels of zinc are frequently fed to poultry to force molting and reduce egg deposition (Decuypere et al. 1988; Hussein et al. 1988). Extremely high dietary levels of 20 g Zn/kg ration have been used as a commercial management technique to force the molting of laying hens .and the subsequent improvement of long-term egg production that molting produces (Lu and Combs 1988a). Laying hens given high zinc diets increased their zinc uptakes 5-40 times in a dose-dependent pattern despite the decreased food intake associated with high zinc dietary levels. Zinc preferentially accumulated in chicken kidney, liver, pancreas, and gizzard; significant increases in egg zinc occurred at dietary levels of 10 and 20 g Zn/kg (Verheyen et al. 1990). Unlike adults, high dietary levels of zinc adversely affected pancreatic exocrine function in the chick; effects were exacerbated under conditions of selenium deficiency and feeding of purified diets (Lu and Combs 1988a). Impaired enteric absorption and transport of vitamin E as a consequence of zinc-induced pancreatic insufficiency is a major cause of reduced tissue concentrations of alpha-tocopherol produced in chicks by excess dietary zinc; these effects were magnified by diets low in corn, soybean meals, and other materials known to chelate zinc and thus reduce its biological availability (Lu and Combs 1988b). Excess dietary zinc causes pancreatic damage in the chick, including reduced activities of major digestive enzymes, elevated plasma amylase activities, reduced digestibility of starch, and reduced vitamin A activity; these changes were associated directly with elevated tissue zinc concentrations, especially in the pancreas (Lu et al. 1990).

Mammals

Livestock and small laboratory animals are comparatively resistant to zinc, as judged by their tolerance for extended periods to dietary loadings >100 times the minimum recommended daily zinc requirement (Table 8). Nevertheless, excessive zinc intake through inhalation or oral exposure can have drastic effects on survival, metabolism, and well being. Sensitive species mammals were affected at 90-300 mg Zn/kg diet, >300 mg Zn/L drinking water, > 90 mg/kg BW daily, > 350 mg Zn/kg BW as a single oral dose, and > 0.8 mg Zn/m^3 air (Table 8).

Zinc is relatively nontoxic in mammals. A wide margin of safety exists between normal intakes and those producing deleterious effects. In most cases, dietary levels up to 100 times the daily requirement for extended periods show no discernable effects (NAS 1979; Wentink et al. 1985; Goyer 1986; Leonard and Gerber 1989). The possibility of oral zinc intoxification in adult humans is unusually low, as judged by the low (40%) bioavailability of zinc from the gastrointestinal tract and the high tolerances to zinc reported in domestic livestock and small laboratory animals (Llobet et al. 1988a, 1988b). Humans ingesting up to 12 g of elemental zinc, equivalent to 33 mg/kg BW for a 60-kg adult, during a 2-day period show no evidence of hematologic, hepatic, or renal toxicity (Goyer 1986).

Excessive zinc intake adversely affects survival of all tested mammals --including humans--and produces a wide variety of neurological, hematological, immunological, hepatic renal, cardiovascular, developmental, and genotoxic effects (PHS 1989). The most sensitive species of mammals showed adverse effects at dietary levels of 80-90 mg Zn/kg in humans, 300 mg Zn/kg ration in domestic cats, and 500 mg Zn/kg feed in rats; drinking water concentrations of 300 mg/L in domestic mice and 800 mg Zn/L in laboratory white rats; daily whole body intakes >90 mg Zn/kg in horses; acute oral LD50 doses of 350-800 mg Zn/kg BW in rats; intraperitoneal injections of 13 mg Zn/kg BW in mice; and 0.8 mg Zn/m^3 air in guinea pigs (Table 8).

Metal fume fever is commonly encountered by industrial workers exposed to zinc fumes and is characterized by pulmonary irritation, fever, chills, and gastroenteritis (Saxena et al. 1989b). Attacks begin 4-8 h after exposure and recovery, in 24-48 h. The pathogenesis of metal fume fever is unknown but may be associated with endogenous pyrogens released by cell lysis (Goyer 1986). Rabbits, rats, and cats exposed to zinc oxide fumes for 3.5 h at concentrations of 110-600 mg/m^3 reacted with a transient fall in body temperature followed by leucocytosis; heavily-exposed animals had signs of bronchopneumonia (Elinder 1986). The current atmospheric threshold limit value for zinc is 5 mg/m^3; however, results of studies with guinea pigs suggest that the current threshold limit value for zinc oxide should be lowered (Lam et al. 1985; Table 8).

Excessive zinc uptake is associated with lameness, unthrifty appearance, and osteochondrosis in foals and pigs, nephrosis in ferrets, and pancreatic fibrosis in sheep (Gunson et al. 1982). Zinc-poisoned mammals are usually characterized by a decreased growth rate, subcutaneous hematomas, ulcerative gastritis, hemorrhagic enteritis, lesions of major limb joints, renal lesions, elevated serum and tissue zinc concentrations, acute diarrhea, copper deficiency, impaired reproduction, and decreased activity of cardiac and hepatic cytochrome oxidase (Saxena et al. 1989b). In severe cases, histopathological changes in the liver and especially in the pancreas, and degenerative changes in the kidney and gastrointestinal tract are evident and are followed by life-threatening hemolytic anemia (Straube et al. 1980; Allen et al. 1983; Robinette 1990). The pancreas is the key to the diagnosis of zinc toxicity and in estimation of the period of exposure; in sheep, it takes about 4 weeks of continued ingestion of toxic amounts of zinc before the pancreas is affected (Allen et al. 1983). More research into the role of the pancreas in zinc toxicokinetics is needed.

Zinc is important to the normal functioning of the central nervous system. At low concentrations, zinc protects mammalian brain neurons by blocking N-methyl-D-aspartate receptor-mediated toxicity. At high concentrations, zinc is a potent, rapidly acting neurotoxicant in the mammalian brain, as judged by zinc-induced neuronal injury of in vitro mature cortical cell cultures (Choi et al. 1988). Increased brain levels of zinc are associated with Pick's disease in certain strains of rodents with inherited epileptic seizures. Intravenous injection of zinc in rats with genetically inherited epilepsy produces seizures; a similar response occurs with intracranial injection of zinc in rabbits with inherited audiogenic seizures (Choi et al. 1988).

Table 8. Effects of zinc on representative mammals.

Organism, route of administration, dose, and other variables	Effects	Reference[a]
Cows, cattle, *Bos* spp.		
Dairy cows fed control diet (310 mg Zn/kg dry weight [DW] feed) or control diet supplemented with 1,000 or 2,000 mg Zn/kg DW ration (as $ZnSO_4 \cdot H_2O$)	The 1,000 mg/kg supplement has no adverse effects on milk production, feed intake, body weight, general health, or reproduction; there was a moderate increase in zinc content of plasma and milk. Cows fed the 2,000 mg Zn/kg diet, however, had decreased milk yield and feed intake after several weeks; calf weights were lower; adverse effects reversed when excess zinc was removed from diet	1
Calves fed diets containing 600 mg Zn/kg for 21 days	Appeared normal, although zinc levels were elevated in pancreas, liver, and kidney	2
Lactating dairy cows fed diets containing 700 or 1,000 mg Zn/kg feed for 6 weeks	No change in general health or milk production; no increase in milk zinc content	2
Lactating cows fed diets containing up to 1,386 mg Zn/kg feed for 5 weeks	No significant change in food intake, weight gain, milk production or in zinc concentrations in plasma (1.15-1.3 mg/kg fresh weight [FW]) or milk (3.7-4.3 mg/kg FW)	3
Calves and young female cattle fed roughage harvested in vicinity of a factory galvanizing steel tubes, and containing 3,000-7,300 mg Zn/kg DW roughage	Signs of chronic zinc poisoning evident after 12-14 months. Signs included reduced appetite, emaciation, submandibular edema, diarrhea, moderate anemia, elevated serum zinc (4.3-6.0 mg/L versus normal 1.8-2.1 mg/L), liver zinc (420-1,600 mg/kg DW versus normal 72-248 mg/kg DW), kidney zinc (910-1,680 mg/kg DW versus normal 40-114 mg/kg DW), and low serum calcium and magnesium	4

Dog, *Canis familiaris*		
Fed diets containing up to 1,000 mg Zn/kg ration for up to 1 year	No measurable signs of damage	2
Pomeranian, 2.2 kg, 4 months old, ingested four copper-clad zinc pennies	Hemolytic anemia, vomiting, salivation, serum zinc dropped from 29 mg/L to 4.4 mg/L 15 days after coins were surgically removed (normal dog serum zinc values range between 0.6 and 2.0 mg/L)	5
Zinc-poisoned oral route, (lethal) dose unspecified	Tissue zinc concentrations (in mg/L or mg/kg FW) were 32 in serum, 16-32 in plasma, 20-25 in urine, 369 in liver, and 295 in kidney. Normal values were 0.7-1.1 in serum, 0.6-1.0 in plasma, 1.3-2.0 in urine, 17-32 in liver, and 9-23 in kidney	6
Died from ingestion of 34 copper-clad zinc pennies	Elevated zinc levels in serum, liver, and kidney; jaundice, anoxeria, anemia, vomitation, dark red urine	7
Guinea pig, *Cavia* sp.		
Inhalation of 0.8 mg Zn/m^3 for 1 h	Difficulty in breathing	8
Inhalation of 4 mg Zn/m^3, 3 h daily for 6 days	Temporary lung damage	8
Inhalation of 5 mg Zn/m^3, as ultrafine zinc oxide, 3 h daily for 6 days	Decrease in lung capacity, alveolar volume, and diffusing capacity for carbon monoxide; values remained depressed for at least 72 h after last exposure. Persistent inflammation of proximal portion of alveolar ducts and adjacent alveoli	9, 10
Horse, *Equus caballus*		
Weanling foals, age 3 months, fed diets containing 7.7 mg Cu/kg plus 29, 250, 1,000, or 2,000 mg Zn/kg ration for 15 weeks. At start, serum zinc level was 0.6 mg/L and serum copper level 1.4 mg/L	Foals fed 29 or 250 mg Zn/kg diets had normal serum copper and zinc concentrations. Those fed 1,000 or 2,000 mg kg diet became hypocupremic in 5 to 6 weeks and developed lameness owing to cartilaginous disease similar to osteochondritis dessicous. Foals fed high zinc diets became lame when serum copper fell to 0.3 mg/L for >1 week; at end of study, arthritic foals had <0.2 mg Cu/L serum. Serum zinc	11

	concentrations rose to >2 mg/L within 2 weeks at 1,000 or 2,000 mg Zn/kg diet; liver zinc was <333 mg/kg DW at diets of 250 mg Zn/kg, 2,728-3,511 mg/kg DW at 1,000 mg Zn/kg diet, and 4,364-4,524 mg/kg DW at the highest dietary loading of 2,000 Zn/kg in 15 weeks	
Adults, vicinity of lead-zinc smelter, ingesting >90 mg Zn/kg body weight (BW) daily	Decreased growth, lameness, bone deformities, death.	2
Cat, *Felis domesticus*		
Fed diet containing 300 mg Zn/kg ration for 16 weeks	Weight loss and pancreas histopathology	2
Fed diets containing >600 mg Zn/kg ration	Diets rejected	2
Fed diet containing 9,000 mg Zn/kg ration for 3-53 weeks	Pancreas histopathology	8
Human, *Homo sapiens*		
Dietary route		
80 mg/kg ration for 6 weeks	Digestive problems	8
90 mg Zn/kg ration for 5 weeks	Decreased serum cholesterol levels	8
153 mg Zn/kg ration for 6 weeks	Altered immune system	8
<150 mg zinc daily	No effect on male plasma cholesterol; females have decreased cholesterol	12
160 mg zinc daily	Increased plasma cholesterol level in both sexes; increased risk of heart disease in males	12
Inhalation route, 600 mg Zn/m^3 for 10 min	Metal fume fever, that is, difficulty in breathing, flu-like symptoms	8
Oral route		
15-year-old girl who consumed 220 mg zinc sulfate twice daily "for some time"	Acute gastrointestinal bleeding ulcers	13
Boy who consumed 12 g of elemental zinc	Headache and lethargy	13
Single oral dose of 45 g zinc as $ZnS0_4$ (normal is 15-20 mg daily)	Death, preceded by dehydration, electrolyte imbalance, abdominal pain, nausea, vomiting, dizziness, muscular incoordination, and acute renal failure	14
Domestic mouse, *Mus* sp.		
Dietary route		
68, 682, or 6,820 mg Zn/kg ration for 13 weeks (fed as 300, 3,000, or	No observed effects at 682 mg/kg diet (and lower), equivalent to 104-109 mg Zn/kg BW daily. At	15

30,000 mg $ZnSO_4 \cdot 7H_2O$/kg ration)	6,820 mg Zn/kg ration, however, adverse effects were documented on survival, growth, food and water intake, and blood chemistry; lesions noted in pancreas, stomach, intestine, spleen, and kidney	
500 mg/kg for 3 months	Anemia	8
30,000 mg/kg ration for 13 weeks	Some deaths, liver and kidney histopathology	8
Drinking water, 300 mg/L, for 5-14 months	Pancreas histopathology	8
Intraperitoneal injection, four injections over 9-day period totaling 13 mg Zn/kg BW	Toxic. Severe weight loss and some deaths	23
European ferret, *Mustela putorius furo*		
Fed basal diet (27 mg Zn/kg feed) or basal diet plus 500, 1,500, or 3,000 mg Zn/kg ration for up to 197 days; four animals per group	Ferrets fed 500 mg/kg all survived with no significant histopathology; zinc concentrations were 148 mg/kg DW in liver (115 mg/kg DW in controls) and 383 mg/kg DW in kidney (180 mg/kg DW). At 1,500 mg/kg, all four ferrets were in extremis or dead by day 21. At death, liver zinc was 859 mg/kg DW and kidney zinc 1,000 mg/kg DW; ferrets had 40-50% loss in body weight; food intake had decreased 80%; and erythrocyte number, hemoglobin, and hematocrit had significantly decreased. Ferrets fed the 3,000 mg/kg diet died between days 9 and 13, lost up to 40% of initial BW, and food intake decreased 77%; postmortem examination showed blood in intestine, orange-colored liver, and kidney histopathology. Elevated zinc content in liver of 1,273 mg/kg DW and in kidney of 1,138 mg/kg DW	8,16,17
Rabbit, *Oryctolagus* sp.		
Single oral dose of 65 mg Zn/kg BW, as $ZnSO_4$	Half-time persistence of 713 min	8
Intravenous injection of 0.325 mg Zn/kg BW, as $ZnSO_4$	Half-time persistence of 268 min	8
Intraperitoneal injection of 3.4 mg zinc daily	Associated with lowered plasma cholesterol levels	12
Domestic sheep, *Ovis aries*		
Domestic ewe, age 5 years, found moribund, suspected zinc poisoning	Elevated zinc levels were 650 mg/kg DW in liver (144 mg/kg DW in controls) and 760 mg/kg DW in kidney (84 mg/kg DW); muscle residues same	18

	as controls, that is, 154 mg/kg DW (158 mg/kg DW); generalized jaundice; liver degeneration and blockage of bile ducts	
Found dead, zinc-poisoned naturally	Zinc concentrations were 463 mg/kg DW in liver (165 mg/kg DW in controls), 274 mg/kg DW in kidney (150 mg/kg DW), and 752 mg/kg DW in pancreas (88 mg/kg DW)	19
Zinc-poisoned experimentally, oral route	Zinc concentrations were 1,125-1,671 mg/kg DW in liver, 2,130-2,442 mg/kg DW in kidney, 1,440-1,932 mg/kg DW in pancreas, and 4,900 mg/kg DW in feces (158 mg/kg DW feces in controls)	19
Lambs fed diets containing 1,000 mg Zn/kg	Food intake reduced; approaching toxic level	2,7
Laboratory white rat, *Rattus* sp.		
Dietary route		
Adult males given 500 mg Zn/kg ration, as $ZnSO_4$, for 6 weeks	After 3 weeks, spermatogenesis was arrested at the primary spermatocyte stage. After 4 weeks, food consumption declined, forelimb lameness, and swelling in cervical lymph nodes. At 6 weeks, testes showed enlarged lumen and abnormal germinal epithelium	20
682 mg Zn/kg ration, as $ZnSO_4 \cdot 7H_2O$, for 13 weeks	No observable effect level, equivalent to 53-55 mg Zn/kg BW daily	15
2,000 mg Zn/kg ration, chronic exposure	Tolerated	2
4,000-5,000 Zn/kg ration for 18 days	Fetotoxic dose, poor reproduction	2,8
5,000-10,000 mg Zn/kg ration	Reduced growth, anemia, poor reproduction, disrupted liver catalase and cytochrome oxidase activity, copper deficiency	14
6,820 mg Zn/kg ration for 13 weeks	Retarded growth, low food intake, abnormal blood chemistry, regressive changes in pancreas	15
Drinking water route		
Doses equivalent to 0, 160, 320, and 640 mg Zn/kg BW daily for 3 months	No significant effect of any dose on organ weight, hematocrit, hemoglobin, glucose, and enzyme activity. Effects noted only at 640 mg kg BW daily: some deaths, less drinking water ingested, decreased volume of urine, significant increase in urea, and	21

	decrease in creatinine. Tissue residues were significantly elevated over controls in high dose group at 3 months: 60 mg Zn/kg FW in liver (20 mg Zn/kg FW in controls), 38 mg Zn/kg FW in kidney (16 mg Zn/kg FW), 330 mg Zn/kg FW in bone (92 mg Zn/kg FW), 21 mg Zn/kg FW in blood (3 mg Zn/kg FW), and 36 mg Zn/kg FW in spleen (16 mg Zn/kg FW). Residues were the same as controls in brain, lung, and muscle	
800 mg Zn/L for 30 days	Liver alterations	8
Intragastric administration		
180 g adults given single dose of 500 mg, equivalent to 2,777 mg/kg BW	Serum zinc reached a maximum of 3.5 mg Zn/L after 60 min and returned to normal (1.6 mg/L) within 24 h	22
165 g adults given 500 mg daily for up to 30 days, equivalent to 3,030 mg Zn/kg BW daily	Serum zinc after 7, 14, or 80 days was 1.9, 2.2, and 2.1 mg/L, respectively; 10 days after last dose, serum zinc was normal	22
Single oral dose, 350-800 mg Zn/kg BW	Acute oral LD50	2,21
Domestic pig, *Sus* sp.		
Weanlings fed diet containing 1,000 mg Zn/kg feed for 30 days	Decreased growth rate and food intake, arthritis, lameness, and inflammation of the gastrointestinal tract	13

[a] 1. Miller et al. 1989; 2. NAS 1979; 3. Gaynor et al. 1988; 4. Wentink et al. 1985; 5. Latimer et al. 1989; 6. Robinette 1990; 7. Ogden et al. 1988; 8. PHS 1989; 9. Lain et al. 1985; 10. Goyer 1986; 11. Bridges 1990; 12. Sammon and Roberts 1988; 13. Elinder 1986; 14. Prasad 1979; 15. Malta et al. 1981; 16. Straube et al. 1980; 17. Reece et al. 1986; 18. Schlosberg 1976; 19. Allen et al. 1983; 20. Saxena et al. 1989b; 21. Llobet et al. 1988a; 22. Castellano et al. 1988; 23. Kreppel et al. 1988.

Zinc fed to adult male rats at 500 mg/kg diet for 3 weeks or longer harms the testes and other male accessory organs; effects are a direct result of zinc cytotoxicity from transfer across the blood-testes barrier (Saxena et al. 1989a). Elevated dietary zinc also depresses bone calcium levels and increases fecal calcium loss in rats (Greger 1989). Increases in serum zinc levels of rats after acute zinc overload is due mainly to increases in the zinc bound to the albumin fraction and secondarily to that bound to the globulin fraction (Castellano et al. 1988). Albumin may play a new physiological role by fitting its binding capacity to serum zinc levels, essentially binding all excess zinc that arrives in the blood (Castellano et al. 1988).

Zinc toxicosis has been observed in humans and livestock after ingestion of acidic foods or drink prepared and stored in galvanized containers (Latimer et al. 1989). Symptoms occur within 24 h and include nausea, vomiting, diarrhea and abdominal cramps. The emetic dose for zinc in humans was estimated at 225-450 mg (3.2-6.4 mg Zn/kg BW), equivalent to 1-2 g zinc sulfate (Elinder 1986). Zinc poisoning in dogs is well documented as a result of ingestion of galvanized metal objects, calamine lotion, skin and sunblock preparations containing zinc oxide, staples, nails, fertilizers, some paints, products containing zinc undecylenate, metallic hardware items with a high zinc content, nuts on certain types of animal transport cages, and pennies (Latimer et al. 1989; Robinette 1990). The propensity of some individuals to throw pennies (U.S. coinage) into animal cages while visiting zoos and animal parks should be considered a potential source of zinc poisoning in captive animals. Pennies minted before 1982 contain 95% copper and 5% zinc; however, copper-clad pennies minted after 1981 contain 97.6% zinc and 2.4% copper (Ogden et al. 1988).

Humans given zinc supplements should be aware of possible complications attendant to their use (Fosmire 1990). Low intakes of 100-300 mg zinc daily in excess of the recommended dietary allowance of 15 mg zinc daily may produce induced copper deficiency, impaired immune function, and disrupted blood lipid profiles. Patients treated with zinc supplements (150 mg daily) to control sickle cell anemia and nonresponsive celiac disease developed a severe copper deficiency in 13 to 23 months; normal copper status was restored by cessation of zinc supplements and increased dietary copper (Fosmire 1990).

Because of false positives, zinc may confound interpretation of the paralytic shellfish poisoning mouse bioassay, one of the routine tests used to measure shellfish safety for human consumption. For example, mice injected intraperitoneally with extracts of healthy oyster tissues showed extreme weakness, a drop in body temperature, cyanosis, and some deaths (McCulloch et al. 1989). The threshold for a toxic paralytic shellfish poisoning response corresponds to a drained tissue zinc level >900 mg/kg FW, and this overlaps the zinc concentration range of 230-1,650 mg/kg FW (1,900-9,400 mg/kg DW) recorded in healthy oyster soft tissues (McCulloch et al. 1989).

Recommendations

For growing agricultural crops: (1) sewage sludge may be applied to soils if total zinc content does not exceed 150 to 560 kg/ surface hectare (Table 9); (2) a maximum permissible extractable soil zinc concentration of 23 mg/kg DW is recommended, according to Soviet agronomists (Beyer 1990); and (3) seedlings of oak (*Quercus* spp.) and red maple (*Acer rubrum*) will eventually die in culture medium containing >100 mg Zn/kg (Buchauer 1971), although total zinc concentrations for global crop production routinely exceed 100 mg/kg DW soil (Table 9). Research is needed in standardized methodology for measurement of bioavailable (i.e., extractable) soil zinc and on its relation to other soil measurements such as total zinc and depth of cultivation in the case of surface application.

Table 9. Proposed zinc criteria for the protection of natural resources and human health.

Resource, criterion, and other variables	Effective zinc concentration	Reference[a]
Crop plants		
Sewage sludge applied to agricultural soils		
Europe, acceptable	150-<300 kg/ha at pH 6.0-7.0	1
Florida		
Maximum permissible	205 kg/ha	1
Unacceptable	>10,000 mg/kg dry weight (DW)	1
Oregon[b], Wisconsin[b], acceptable	250 - < 1,000 kg/ha	1
Vermont[b], acceptable	280 - < 1,120 kg/ha	1
Maryland[b], Massachusetts[b], acceptable	280-<560 kg/hg	1
Minnesota[b], Missouri[b], acceptable	280-<1,120 kg/ha	1
Illinois, maximum	560 kg/ha	1
Soils		
Soviet Union, maximum permissible	23 mg/kg DW, extractable by ammonium acetate buffer at pH 4.8	1
Alberta, Canada, for growing livestock forage	<100 mg/kg DW	1
Quebec, Canada		

Background	200 mg/kg DW	1
Marginal	500 mg/kg DW	1
Unacceptable	>3,000 mg/kg DW	1
Netherlands		
Background	200 mg/kg DW	1
Marginal	500 mg/kg DW	1
Unacceptable	>3,000 mg/kg DW	1
Ontario, Canada, acceptable	<220 mg/kg DW	1
Germany, acceptable	<300 mg/kg DW	2
New Jersey, goal	<350 mg/kg BW	1
New York, acceptable		
Agricultural soils	168-<250 kg/ha DW	1
Forest soils	<560 kg/ha DW	1
Terrestrial Invertebrates		
Earthworms		
High accumulations, but otherwise safe	97 mg/kg DW soil	3
Adverse effects	>400 mg/kg DW soil	3
Slugs, diet, adverse effects	>300 mg/kg DW	4
Freshwater aquatic life		
Water		
Total recoverable zinc		
60 mg $CaCO_3$/L	47 µg/L, 24 h average; not to exceed 180 µg/L at any time	5
100 mg $CaCO_3$/L	47 µg/L, 24 h average; not to exceed 320 µg/L at any time	5
200 mg $CaCO_3$/L	47 µg/L, 24 h average; not to exceed 570 µg/L at any time	5
Acid-soluble zinc[C]	4-day average concentration not to exceed the numerical value e ((0.8473 [ln] hardness)+ 0.7614) more than once every 3 years on average; 1-h concentration not to exceed e((0.8473 [ln] hardness)+ 0.8604) more than once every 3 years on average. See below for examples	6
50 mg $CaCO_3$/L	4-day average not to exceed 59 µg/L; 1-h average not to exceed 65 µg/L	6
100 mg $CaCO_3$/L	4-day average not to exceed 110 µg/L; 1-h average not to exceed 120 µg/L	6
200 mg $CaCO_3$/L	4-day average not to exceed 190 µg/L; 1-h average not to exceed 210 µg/L	6
Adverse effects, most sensitive species		
Brown trout, *Salmo trutta*, embryos and fry	4.9-19.6 µg/L	7

Daphnid, *Daphnia magna*	5-14 µg/L	6
Rainbow trout, *Oncorhynchus mykiss*	5.6-10 µg/L	5,6,8
Narrow-mouthed toad, *Gastrophryne carolinensis*, embryos	10 µg/L	6
Daphnid, *Daphnia galeata mendotae*	15-30 µg/L	6
Freshwater sponge, *Ephydatia fluviatilis*	26 µg/L	9
Mayfly, *Epeorus latifolium*	30 µg/L	10
Midge, *Tanytarsus dissimilis*	37 µg/L	5,6
Atlantic salmon, *Salmo salar*	50 µg/L	6
Cladoceran, *Ceriodaphnia reticulata*	51 µg/L	6
Flagfish, *Jordanella floridae*	51 µg/L	6
Diet		
Channel catfish, *Ictalurus punctatus*		
Minimum	20 mg/kg DW	11
Recommended	150-200 mg/kg DW	11
Rainbow trout, *Oncorhynchus mykiss*		
Minimum	10-30 mg/kg DW; 15-30 mg/kg fresh weight (FW)	12,13
Adequate	90 mg/kg FW	13
Sediments		
Great Lakes		
Safe	<90 mg/kg DW	1
Marginal	90-200 mg/kg DW	1
Unacceptable	>200 mg/kg DW	1
Wisconsin and Ontario, for Great Lakes sediments dredged from harbors and for disposal in water	<100 mg/kg DW	1
Marine aquatic life		
Seawater		
Total recoverable zinc	58 µg/L, 24-h average; not to exceed 170 µg/L at any time	5
Acid-soluble zinc[c] (20)	4-day average concentration does not exceed 86 µg/L more than once every 3 years on average; 1-h average concentration does not exceed 95 µg/L more than once every 3 years on average	6
No adverse effect, most species		
Algae	<1,400 µg/L	14
Molluscs	<54 µg/L	15
Crustaceans	<230 µg/L	15
Adverse effects, most sensitive species		
Brown algae, *Fucus serratus*	8.8-9.5 µg/L	6

Copepod, *Tisbe holothuriae*	10 µg/L	16
Pacific oyster, *Crassostrea gigas*, larvae	10-20 µg/L	6
Alga, *Rhizosolenia* spp.	15-25 µg,/L	8
Diatom, *Schroederella schroederi*	19 µg/L	6
Diatom, *Skeletonema costatum*	19.6 µg/L	17
Dinoflagellate, *Glenodinium halli*	20 µg/L	6
Purple sea urchin, *Strongylocentrotus purpuratus,* embryos	23 µg/L	6
Sand dollar, *Dendraster excentricus*	28 µg/L	6
Atlantic herring, *Clupea harengus*, embryos	50 µg,/L	6
Mud crab, *Rithropanopeus harrisii,* larvae	50 µg/L	5
Diet, fish, adequate	90 mg/kg FW	13
Tissue residues, minimum theoretical requirement for whole molluscs and crustaceans	34.5 mg/kg DW	18
Birds		
Mallard, *Anas platyrhynchos*		
Zinc-poisoned		
Diet	2,500-3,000 mg/kg DW ration	19,20,21
Single oral dose	0.64; , 517-742 mg/kg body weight (BW)	22
Birds, various, tissue concentrations		
Normal		
Liver	21-33 mg/kg DW	23
Plasma	1.3-2.0 µg/L	24
Zinc-poisoned		
Liver	75-156 mg/kg DW	23
Plasma	15.5 mg/L	24
Japanese quail, *Coturnix coturnix japonica*, safe level	25-30 mg/kg DW diet	25
Chicken, *Gallus* sp.		
Recommended daily intake	>31 mg	26
Diet		
Adverse effects, zinc deficiency	<38 mg/kg DW ration	27,28,29
Adequate	93-120 mg/kg DW ration	28,29
Excessive	>178 mg/kg DW ration	27
Toxic	>2,000 mg/kg DW ration	20,30,31
Mammals		
Cattle, *Bos* spp.		
Diet		
Soluble zinc, recommended level		

Calves	>8 mg/kg DW	20
Adults		
Beef cattle	10-30 mg/kg DW	20
Dairy cattle	40 mg/kg DW	20
Total zinc		
Marginal	25 mg/kg DW	32
Recommended	45-60 mg/kg DW	32,33
Maximum tolerated		
Calves	500 mg/kg DW	35
Adults	1,000 mg/kg DW	34,35
Toxic	>900-2,000 mg/kg DW	34,35
Tissue residues		
Liver		
Zinc-deficient	<10 mg/kg DW	32
Suboptimal	10-30 mg/kg DW	32
Optimal	30-120 mg/kg DW	32
Excessive	>120 mg/kg DW	32
Lethal	>500 mg/kg DW	34
Plasma		
Zinc-deficient	<0.66 mg/L	33
Normal	1.02 mg/L	33
Elevated	1.5 mg/L	33
Serum, zinc-deficient	<0.6 mg/L	36
Recommended daily intake		
Calves		
5 months old	3 g (25-35 mg/kg BW)	34
14-18 months old	16 g (50-80 mg/kg BW)	34
Cows	55 g (110-140 mg/kg BW)	34
Dog, *Canis familiaris*, tissue concentrations, normal versus zinc-poisoned		
Serum	0.7-1.1 versus 33 mg/L	37
Plasma	0.6-1.0 versus 16-32 mg/L	37
Urine	1.3-2.0 versus 20-25 mg/L	37
Liver	17-32 versus 369 mg/kg FW	37
Kidney	9-23 versus 295 mg/kg FW	37
Guinea pig, *Cavia* spp.		
Air, adverse effects	0.8-4.0 mg Zn/m^3	38
Diet		
Deficient	3 mg/kg DW plus 1 mg/L drinking water	39
Adequate	3 mg/kg DW plus 15 mg/L drinking water	40
Normal	20 mg/kg DW	41

Adequate	100 mg/kg FW	39
High	200 mg/kg DW	41
Tissue concentrations, zinc deficient versus normal		
Serum	0.5 versus 1.6-2.0 mg/L	39
Liver	9.4 versus 15-17 mg/kg FW	39
Testes	9.5 versus 19-27 mg/kg FW	39
Kidney	10 versus 16-20 mg/kg FW	39
Domestic goat, *Capra* sp., diet		
Soluble zinc, recommended		
Adults	>4 mg/kg DW	20
Kids	>7 mg/kg DW	20
Total zinc		
Deficient	<15 mg/kg DW	42
Recommended	80 mg/kg DW	42
Bank vole, *Clethrionomys glareolus*, diet, recommended	30 mg/kg DW	43
Horse, *Equus caballus*		
Diet		
No adverse effects	250 mg/kg DW	44
Adverse effects	1,000 mg/kg DW	44
Daily intake, adverse effects	>90 mg/kg BW	20
Domestic cat, *Felis domesticus*, diet, adverse effects	300 mg/kg DW	20
Humans, *Homo sapiens*		
Air		
Safe levels		
Zinc chloride, fumes	<1 mg/m^3	20,38
Zinc oxide, fumes	<5 mg/m^3	28,38,45,46
Zinc and zinc oxides	5-10 mg/m^3	38
Zinc oxide, total dust	10 mg/m^3	38
Zinc oxide, fume and dust, ceiling limit	15 mg/m^3	38
Adverse effects, zinc oxides	600 mg/m^3 for 10 min	38
Daily intake		
Recommended dietary intake, assuming availability of 20%		
Children		
To age 1 year	3-6 mg	48
1-10 years	8-10 mg	48
No age specified	10 mg	2,20,26,47,49,50
Males		

Age 11-17	14-15 mg	48
Age 18+	11-15 mg	48
No age specified	15 mg	2,20,26, 47,49,50
Females		
Age 10-13	13-15 mg	48
Age 14+	11-15 mg	48
No age specified	12 mg	48
Pregnant	15-20 mg	48
Lactating	25-27 mg	47,48
Maximum safe total, adults		
Not zinc deficient	0.3-1.0 mg/kg BW	2
Zinc deficient	1 mg Zn/kg BW, oral administration	48
Adverse effects level	>160 mg (>2.3 mg/kg BW)	51
Diet		
Seafoods, safe level, Australia,	<40 mg/kg FW	14
Adverse effects		
Gastrointestinal disorders	>80 mg/kg DW diet for 6 weeks	38
Severe copper deficiency	150 mg zinc daily for 13-23 months	49
Vomiting	Single dose of 225-450 mg zinc or 1-2 g of $ZnSO_4$	49
Drinking water		
Safe level	5 mg/L	2,20,38
Adverse effects, acute GI distress	>280 mg/L	20
Intravenous injection, adverse effects	23 mg/kg BW daily	52
Soils, Canada, nonhazardous to human health		
Ontario, residential, parkland, commercial, industrial	<800 mg/kg DW	1
Alberta, noncrop uses	<700 mg/kg DW	1
Tissue residues		
Serum		
Normal	0.5-1.29 mg/L	38
No toxic effects	1.92 mg/L	38
Plasma		
Zinc-deficient	0.4-0.6 mg/L	45
Normal	0.7-1.1 mg/L	48
GI disturbances	1.51 mg/L	38
Rhesus monkey, *Macaca mulatta,* diet		
Deficient	4 mg/kg DW	52
Adequate	100 mg/kg DW	53
Mouse, *Mus* spp.		

Diet		
Zinc-deficient	<5 mg/kg DW	54
Zinc-adequate	36.5 mg/kg DW	54
Tolerated	100 mg/kg DW	54
Tolerated	682 mg/kg DW for 13 weeks (107 mg/kg BW)	55
Harmful	500 mg/kg DW for 3 months	38
Harmful	6,820 mg/kg DW	55
Fatal	30,000 mg/kg DW for 13 weeks	38
Drinking water, adverse effects	300 mg/L	38
Tissue residues		
Blood		
Deficient	0.7 mg/L	56
Normal	1.0-1.1 mg/L	56
Liver		
Deficient	12 mg/kg FW	56
Normal	17-19 mg/kg FW	56
European ferret, *Mustela putorius furo*, diet		
Tolerated	500 mg/kg DW	57
Fatal	1,500 mg/kg DW	38
Mink, *Mustela vison*, diet		
Zinc-deficient	4.1 mg/kg FW	58
Adequate	35-45 mg/kg FW; 100-150 mg/kg DW	58
Domestic sheep, *Ovis aries*		
Diet		
Soluble zinc, adequate		
Adults	>4 mg/kg DW	20
Lambs	>7 mg/kg DW	20
Total zinc		
Adults, adequate	33 mg/kg DW	59,60
Lambs		
Adequate	124-130 mg/kg DW	59
Harmful	>1,000 mg/kg DW	20,61,62
Recommended daily intake	>18 mg	26
Tissue residues		
Feces		
Normal	158 mg/kg DW	61
Zinc-poisoned	4,900 mg/kg DW	61
Kidney		
Normal	84-150 mg/kg DW	61,63
Elevated	>180 mg/kg DW	61
Zinc-poisoned	274-760 mg/kg DW	61,63
Liver		

Normal	144-165 mg/kg DW	61,63
Elevated	>250 mg/kg DW	61
Zinc-poisoned	463-650 mg/kg DW	61,63
Pancreas		
Normal	88 mg/kg DW	61
Zinc-poisoned	752 mg/kg DW	61
Laboratory white rat, *Rattus* sp.		
Diet		
Soluble zinc, recommended	15 mg/kgDW	20
Total zinc		
Zinc-deficient	<12 mg/kg DW	47
Adequate	76 mg/kg DW	64
Adverse effects	>500 mg/kg DW	52
Fetotoxic	>4,000 mg/kg DW	20,38
Daily intake		
Tolerated	320 mg/kg BW	65
Harmful	640 mg/kg BW	65
Single oral dose, harmful	>350 mg/kg BW	20,65
Domestic pig, *Sus* sp.		
Diet		
Soluble zinc, safe levels		
Normal	14-20 mg/kg DW	20
Cassava-rice-bran	>40 mg/kg DW	20
Soy base	50 mg/kg DW	20
Total zinc, harmful	1,000 mg/kg DW	47
Recommended daily intake	>20 mg	26

[a] 1. Beyer, 1990; 2. Leonard and Gerber 1989; 3. Beyer et al. 1987; 4. Marigomez et al. 1986; 5. EPA 1980; 6. EPA 1987; 7. Sayer et al. 1989; 8. Spear 1981; 9. Francis and Harrison 1988; 10. Hatakeyama 1989; 11. Gatlin et al. 1989; 12. Bettger et al. 1987; 13. Spry et al. 1988; 14. Eisler 1981; 15. Sprague 1986; 16. Verrioposulos and Hardouvelis 1988; 17. Vymazal 1986; 18. White and Rainbow 1985; 19. Kazacos and Van Vleet 1989; 20. NAS 1979; 21. Gasaway and Buss 1972; 22. Grandy et al. 1968; 23. Reece et al. 1986; 24. Morris et al. 1986; 25. Harland et al. 1975; 26. Ellen et al. 1989; 27. Stahl et al. 1989a; 28. Blamberg et al. 1960; 29. Westmoreland and Hoekstra 1969; 30. Stahl et al. 1990; 31. Oh et al. 1979; 32. Binnerts 1989; 3,3. Ramachandra and Prasad 1989; 34. Wentink et al. 1985; 35. Miller et al. 1989; 36. Damir et al. 1988; 37. Robinette 1990; 38. PHS 1989; 39. Gupta et al.. 1988; 40. Apgar and Everett 1988; 41. Scelsi et al. 1989; 42. Chhabra and Arora 1989; 43. Wlostowski et al. 1988; 44. Bridges 1990; 45. Goyer 1986; 46. Lain et al. 1985; 47. Elinder 1986; 48. Casoy and Hambidge 1980; 49. Fosmire 1990; 50. Sternlieb 1988; 51. Sammon and Roberts 1988; 52. Saxena et al. 1989b; 53. Golub et al. 1988; 54. Mackay-Sire and Dreosti 1989; 55. Malta et al. 1981; 56. Tone et al. 1988; 57. Straube et al. 1980; 58. Mejborn 1989; 59. Vergnes et al. 1990; 60. Khandaker and Telfer 1990; 61. Allen et al. 1983; 62. Ogden et al. 1988; 63. Schlosberg 1976; 64. Ferreira et al. 1989; 65. Llobet et al. 1988a.

[b] Higher values permissible for soils with higher cation exchange capacity (Beyer 1990).

[c] Zinc that passes through a 0.45 μm membrane filter after acidification to pH 1.5-2.0 with nitric acid (EPA 1987).

[d] Higher concentrations recommended to compensate for reduced bioavailability caused by excess calcium and phytate in diet (Gatlin et al. 1989).

Data on zinc hazards to terrestrial invertebrates are limited; however, sensitive species are adversely affected at dietary concentrations >300 mg Zn/kg or at soil concentrations >400 mg/kg (Table 9).

Water quality criteria protection of aquatic life should include both total recoverable zinc and acid-soluble zinc (EPA 1980, 1987). For example, if total recoverable zinc is substantially above the proposed criteria and acid-soluble zinc is below the limit, there is cause for concern (EPA 1987). To protect about 95% of freshwater animal genera, EPA recommends water concentrations that average <47 µg total recoverable zinc per liter, not to exceed 180 µg/L at any time in soft water (i.e., <50 mg $CaCO_3$/L), or a mean concentration of 59 µg acid soluable zinc per liter, not to exceed 65 µg/L at any time in soft water (Table 9). These criteria are unsatisfactory because lower ambient zinc concentrations between 5 and 51 µg/L clearly have significant negative effects on growth, survival, and reproduction of important species of freshwater fish, amphibians, insects, sponges, and crustaceans (Table 9). Some downward modification seems necessary in the current proposed zinc criteria for freshwater aquatic life protection.

To protect important species of marine animals, EPA recommends that total recoverable zinc in seawater should average <58 µg/L and never exceed 170 µg/L; for acid-soluble zinc, these values are <86 and 95 µg/L (Table 9). As was the case for freshwater biota, there is a growing body of evidence (Table 9) demonstrating that many species of marine plants, crustaceans, molluscs, echinoderms, and fish are adversely affected at ambient zinc concentrations between 9 and 50 µg/L or significantly below the current proposed criteria for marine life protection.

Effects of zinc deficiency were produced experimentally in freshwater sponges at <0.65 µg Zn/L (Francis and Harrison 1988), in rainbow trout fed diets containing <15 mg Zn/kg FW (Spry et al. 1988), in certain species of marine algae at <0.7 µg Zn/L (Vymazal 1986), and in certain species of marine invertebrates at <6.5 µg Zn/L (Clapper et al. 1985a, 1985b) or <34 mg Zn/kg DW whole organism (White and Rainbow 1985). Zinc deficiency in natural aquatic ecosystems has not yet been credibly documented.

In aquatic environments, Spear (1981) spotlights three research needs: (1) development of analytical procedures for measurement of individual dissolved zinc species, notably the aquo ion and zinc chloride, and for nondissolved species that occur in natural waters; (2) separation of natural from anthropogenic influences of sediment-water interactions on flux rates with an emphasis on anoxic conditions, the role of microorganisms, and the stability of organozinc complexes; and (3) establishment of toxicity thresholds for aquatic organisms based on bioaccumulation and survival to determine the critical dose and the critical dose rate with an emphasis on aquatic communities inhabiting locales where zinc is deposited in sediments. These research needs are still valid.

Bird diets should contain 25-38 mg Zn/kg DW feed to prevent zinc deficiency effects, 93-120 mg Zn/kg DW feed for adequate to optimal growth, <178 mg Zn/kg DW feed to prevent marginal sublethal effects, and <2,000 mg Zn/kg DW feed to prevent the death of chicks and ducklings (Table 9). Extremely high dietary levels of 20 g Zn/kg ration are fed routinely to laying hens by poultry managers to force molting and to improve long-term egg preduction (Lu and Combs 1988a); in these cases, zinc preferentially accumulates in the kidney, liver, pancreas, and eggs (Verheyen et al. 1990). Much additional work now seems warranted on the role of zinc in avian nutrition and on the significance of tissue concentrations as an indicator of zinc stress.

The normal daily intake for all human age groups ranges between 8 and 14 mg (Casey and Hambidge 1980), but pregnant women require an additional 350-375 mg zinc during their pregnancy (Jameson 1980). Zinc used therapeutically in humans at >160 mg daily may have deleterious effects on copper status (Samman and Roberts 1988). Lower levels--close to the recommended daily allowance of 15 mg--are reported to interfere with iron metabolism and with high density lipoprotein cholesterol concentrations (Fosmire 1990) but this requires verification. The proposed air quality criterion for human health protection is 5 mg Zn/m^3, although this is demonstrably harmful to guinea pigs (Table 9). It is not yet known whether guinea pigs are more sensitive than humans to atmospheric zinc or if some downward modification is needed in the current zinc air quality criterion for protection of human health and presumably wildlife.

Single oral doses >350 mg Zn/kg BW were fatal to rats, although doses of 320 mg/kg BW were tolerated (Table 9), suggesting a rapid breakdown in ability to regulate zinc in a relatively narrow critical threshold range. More research into zinc regulation of massive doses seems needed.

Data that link zinc concentrations in tissues with environmental zinc perturbations in mammals are rare. For example, elevated zinc concentrations were >120 mg Zn/kg DW tissue in cattle liver, >180 mg Zn/kg DW tissue in sheep kidney, and >250 mg Zn/kg DW tissue in sheep liver (Table 9). The significance of zinc residues in animal tissues is unclear. No international regulations or guidelines applicable to zinc are available (PHS 1989). No U.S. Food and Drug Administration action level or other maximum acceptable concentration exists for zinc, and therefore no Final Residue Value can be calculated (EPA 1987). This seems to be a research need of high priority.

Eating seafoods that contain high concentrations of zinc does not seem to present a threat to human health. However, oysters from Tasmania allegedly caused nausea and vomiting in some people who ate them; these oysters contained about 20 g Zn/kg FW soft parts or about 500 times more than the Australian food regulation of 40 mg/kg FW (Eisler 1981).

In mammals, large differences are evident between and within species in resistance to zinc poisoning and in sensitivity to zinc nutritional needs (Table 9). Adverse effects of excess dietary zinc occurred in sensitive species at 80 mg Zn/kg DW (in humans) and 300 mg Zn/kg DW (in cats); other tested species were significantly more resistant. Daily intake rates considered harmful over long periods ranged from about 2.3 mg/kg BW in humans to >90 mg/kg BW in horses. Dietary loadings that optimally prevented zinc deficiency were 30 mg Zn/kg DW diet for bank voles, 33 mg Zn/kg DW diet for adult sheep (124-130 mg Zn/kg DW diet for lambs), 37 mg Zn/kg DW diet for mice, 45-60 mg Zn/kg DW diet for cattle, 76 mg Zn/kg DW diet for rats, 80 mg Zn/kg DW diet for goats, 100 mg Zn/kg DW diet for monkeys, and 150 mg Zn/kg DW diet for minks; recommended daily intake ranged from about 0.2 mg/kg BW in humans to 110-140 mg/kg BW in cattle (Table 9). More research with animals of various age and nutrient status is needed to determine the interaction effects of zinc with proteins, calcium, chloride, and other trace elements and on the long-term consequences of nutrient interactions (Gregor 1989).

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EXHIBIT I

ONTARIO COUNTY PLANNING BOARD

Referrals for Review at the;

Coordinated Review Committee Meeting –September 12, 2018 at 3:30pm

County Planning Board Meeting –, 2018 at 7:30pm

2nd Floor Conference Room, Room 200, 20 Ontario Street, Canandaigua, NY 14424 - Telephone: 585-396-4455

Referral No	Municipality	Referring Board	Applicant	Application Type	Class	Page
142 - 2018	Town of Canandaigua	Zoning Board of Appeals	Smith, Evan & Kristen	Area Variance	AR 1	1
143 - 2018	Town of Canandaigua	Planning Board	Thormton, Glenn	Site Plan	1	2
143.1 - 2018	Town of Canandaigua	Planning Board	Thormton, Glenn	Special Use Permit	1	3
144 - 2018	Town of Canandaigua	Planning Board	McFarland Johnson	Site Plan	1	4
145 - 2018	Town of Canandaigua	Zoning Board of Appeals	Creek View Apartment Houisng Development	Area Variance	1	
146 - 2018	Town of Canandaigua	Planning Board	Marks Engineering	Site Plan	AR 2	
146.1 - 2018	Town of Canandaigua	Zoning Board of Appeals	Marks Engineering	Area Variance	AR 2	5
147 - 2018	Town of Canandaigua	Town Board	Town of Canandaigua	Text Amendment	2	6
148 - 2018	Town of Victor	Planning Board	Zac Holtz	Subdivision	Exempt	
149 - 2018	Town of Canandaigua	Planning Board	Murray Law Firm	Site Plan	2	
149.1 - 2018	Town of Canandaigua	Planning Board	Murray Law Firm	Special Use Permit	2	7
150 - 2018	Town of East Bloomfield	Planning Board	Clar, Rachel	Special Use Permit	2	
151 - 2018	Village of Manchester	Planning Board	Oldcastle Lawn & Garden	Site Plan	1	8
152 - 2018	Town of Bristol	Zoning Board of Appeals	Schwartz, Thomas	Area Variance	AR 1	9
153 - 2018	Town of Hopewell	Planning Board	Laity, Brian	Site Plan	1	10
153.1 - 2018	Town of Hopewell	Zoning Board of Appeals	Laity, Brian	Area Variance	1	
154 - 2018	Town of Hopewell	Planning Board	Fry, Rosmary	Subdivision	AR 1	11
155 - 2018	Town of Hopewell	Planning Board	King, Matt	Subdivision	1	12
155.1 - 2018	Town of Hopewell	Zoning Board of Appeals	King, Matt	Area Variance	1	
156 - 2018	Town of Farmington	Planning Board	MIII Enterprises LLC	Sign Site Plan	2	
156.1 - 2018	Town of Farmington	Town Board	MIII Enterprises LLC	Other	2	13
157 - 2018	Town of Farmington	Planning Board	WC Premiere Properties, LLC	Minor Subdivision	AR 1	
158 - 2018	Town of Farmington	Planning Board	Telsa Energy Operations Inc	Site Plan	1	14
159 - 2018	Town of Farmington	Planning Board	Delaware River Solar, LLC	Site Plan	2	15
159.1 - 2018	Town of Farmington	Planning Board	Delaware River Solar, LLC	Subdivision	2	
159.2 - 2018	Town of Farmington	Planning Board	Delaware River Solar, LLC	Special Use Permit	2	16
159.3 - 2018	Town of Farmington	Zoning Board of Appeals	Delaware River Solar, LLC	Area Variance	2	
160 - 2018	Town of Farmington	Planning Board	Orlando Crespo	Temporary Use Permit	1	

Class Abbreviations	
AR-1 – Administrative Review Class 1	
AR-2 – Administrative Review Class 2	

142 - 2018	Town of Canandaigua Zoning Board of Appeals	Class: AR 1
Referral Type:	Area Variance	
Applicant:	Smith, Evan & Kristen	
Tax Map No(s):	153.00-1-56.210	
Brief Description:	Variance for construction of a garage in the front yard of a home at 5325 ST 21 south of Monks Road in the Town of Canandaigua.	

Applicant is requesting a variance for placing a garage in the front yard, with a 10' front setback when 60' is required, and a 19.25' height when 16' is allowed.

Policy AR-5: Applications involving one single family residential site, including home occupations.
The intent of this policy is to:

1. Address residential development that may infringe on County ROW's or easements for roads and other infrastructure.
2. Address traffic safety along intermunicipal corridors by encouraging proper placement of residential driveways along County roads.
3. Address impacts to ground and surface waters

Section C - All other applications subject to policy AR-5.
Final Classification: Class 1
Findings:

1. One-and two-family residential uses represent 63% of the 49,354 parcels on the 2017 Ontario County assessment roll. Between 2012 and 2017 1,067 single family residential parcels were added and 13 two-family were removed. These parcels represent 89% of all parcels added county-wide.
2. Collectively individual residential developments have significant impacts on surface and ground water.
3. Proper design off on-site sewage disposal is needed to protect ground and surface waters.
4. Proper storm water and erosion control is also needed to achieve that same end.
5. Proper sight distance at access points along County roads is an important public safety issue of county wide significance.
6. Standards related to protecting water quality and traffic safety have been established by agencies such as the American Association of State Highway and Transportation Officials (AASHTO), and NYSEDC.
7. These issues can be addressed by consulting appropriate agencies during local review and ensuring that those standards are met

Final Recommendation – With the exception of applications described in Policy 5 Sections A and B, the CPB will make no formal recommendation to deny or approve applications involving one single family residential site, including home occupations.

Comments:

1. The Town is encouraged to grant only the minimum variance necessary to allow reasonable use of the lot. .
2. The applicant and referring agency are strongly encouraged to involve Ontario County Soil and Water Conservation District or Canandaigua Lake Watershed Manager as early in the review process as possible to ensure proper design and implementation of storm water and erosion control measures.

143 - 2018	Town of Canandaigua Planning Board	Class: 1
Referral Type:	Site Plan	
Applicant:	Thormton, Glenn	
Property Owner:	DeGraw, Kevin	
Tax Map No(s):	56.00-1-57.000	
Brief Description:	Site plan and special use permit for development of a 60'x40' boat sales building and related improvements as 2121 SR 332 south of Yerkes Road. http://www.co.ontario.ny.us/DocumentCenter/View/14758/143_18-Aerial	

The applicant and referring agency are strongly encouraged to involve Ontario County Soil and Water Conservation District as early in the review process as possible to ensure proper design and implementation of storm water and erosion control measures.

158 - 2018	Town of Farmington Planning Board	Class: 1
Referral Type:	Site Plan	
Applicant:	Telsa Energy Operations Inc	
Property Owner:	RGE	
Tax Map No(s):	17.00-2-18-2.00	
Brief Description:	Site plan amendment for electric battery and transformer installation adjacent to existing RG&E substation at 961 Hook Road just south of the NYS Thruway in the Town of Farmington.	

It appears from the aerial there are two electric substations on the existing 21 acre parcel that abuts the Thruway and is bisected by overhead electric lines. The proposed installation is the east of the existing access drive off Hook Road. The installation involves a 70'x70' concrete pad for the 63 batteries, related inverters and transformers, and an 8' fence with 1' of barbed wire surrounding the facility. The electrical connection between substation and battery installation will be underground.

The batteries will be installed in phases. The first phase of 37 batteries in fall 2018 is intended to meet the battery capacity mandates of NYS's Reforming the Energy Vision. An additional 15 batteries will be installed in spring 2019 will meet 10 year need. The remaining proposed batteries will be installed over the next 10 years to address reduced battery capacity as they age.

159 - 2018	Town of Farmington Planning Board	Class: 2
Referral Type:	Site Plan	
Applicant:	Delaware River Solar, LLC	
Property Owner:	Smith, Mr. & Mrs. Roger	
Representative:	Shultz Associates	
Tax Map No(s):	20.00-2-37.220	
Brief Description:	Site plan, subdivision, area variances, and special use permit for 7.0 MW community solar facility on 3 lots at 466 Yellow Mills Road at Fox Road in the Town of Farmington. http://www.co.ontario.ny.us/DocumentCenter/View/14771/156_18-Aerial	

The proposed project is a Community Solar project intended to provide low cost solar power to 1,000 homes and businesses in the Farmington area. The 3 proposed solar plants will be located on 40 leased acres in the central portion of a 135 acre parcel. The project involves installation of 7,000 solar panels covering approximately 3.1 acres for each plant. The total disturbed area is estimated at 37.5 acres, though only the inverter pad and road locations are expected to require grading. The solar panels will be located in rows with 19' aisles between rows. The applicant anticipates no change to project area drainage patterns or flows. The project area will be surrounded by an 8' fence and motion sensor lights will be installed on inverter equipment. There are two bio-retention areas with a total of 5,435 SF designed to treat stormwater runoff from the access road.

The Town of Farmington code requires 300' lot frontage. Lot 1 is 72 acres and includes the existing residence and land to a depth of 250' along most of the Yellow Mills Road frontage (1,900') as well as developable and undevelopable land that surrounds the 3 subdivided lots. Lot 2 is 22 acres and has 400' of frontage between the shared access road off Fox Road and Lot 3. Lots 3 and 4 have been configured to meet the frontage requirement with an acre of land 300' by 180' in the frontage area connected by 16' wide necks to the developed portion(s) of the lot. Lot 3 is 15 acres and has access off Fox Road. Lot 4 is 26 acres and has frontage along both Fox Road and Yellow Mills Road.

The Code also required 180' front setback and 160' rear setback. The applicant proposes to meet these setbacks where the 3 lots created for development of solar energy systems abut other lands. The applicant is seeking variances to allow 20' lot line setbacks for PV system components along interior front and rear lot lines between Lots 2 and 3 and 3 and 4. The variances are not intended to apply to other uses that may be developed on the lots in the future. The applicant has stated the variances reduce the impact to Prime Farmland without detriment to the health, safety or general welfare of the neighborhood.

The decommissioning plan uses cost guidance from NYSERDA and estimates from actual projects in Massachusetts. The estimated decommissioning cost per 2 MW solar plant is $126,000 with **$60,000** to be deposited in escrow at the beginning of the project with escalation payments deposited annually and cost estimates adjusted every 3 years as specified in Town code.

The agricultural data statement indicates 40 acres are currently used to grow hay and other areas of the parcel are used to graze cattle. The property and all surrounding lots are in Agricultural District #1. The Town has identified that the proposed solar project footprint would be on soils identified as Class 1 to 4. In accordance with Town Solar regulations, the applicant has certified that no alternative site location is feasible to avoid use of high value agricultural soils. The property owner intends to continue to grow crops and graze cattle on portions of the site not covered by solar panels along Yellow Mills Road and in the northwest corner of the site. The applicant also owns a 21 acre parcel with 900' of frontage along Fox Road to the west. According to OnCor, more than half of this property is unforested, very poorly drained and not prime farmland. A portion of this property is in the floodplain.

According to OnCor, the south west portion of the parcel proposed for development is wooded with a floodplain along the stream and surrounding areas classified as state and federal wetlands. There are two additional wetland areas shown on the site plan. One off the Fox Road frontage and one along an existing drainage path that bisects parcel 4. The soils on the remaining areas of the site, including those proposed for development are prime farmland and farmland of statewide importance as follows:

Palmyra Cobbly Loam 0-3 % slope 26.5 Acres 3 - 8 % slope 20 Acres **Both Prime Farmland**
Permeability: high **Erodibility:** medium
Hydrological Group B **Not Hydric**

Ontario Loam 0-3 % slopes- 4.7 acres **Prime Farmland** 3 - 8 % slopes-10 acres **Farmland of Statewide Importance**
8-15% slopes 4.5 acres **not prime farmland**
Permeability: moderately high **Erodibility:** Medium
Hydrological Group B **Not Hydric**

Phelps Gravelly Silt Loam 0-3 % slope 16.9 acres **Prime Farmland**
Permeability: high **Erodibility:** medium
Hydrological Group B/D **Not Hydric**

Farmington Solar Code Provisions relevant to development of large scale solar facilities on agricultural lands

- Planning Board must determine that there is no feasible alternative before allowing development of large scale solar energy facilities on class 1 to 4 soils (most valuable soils).
- Locate, size, and design access road(s), parking, & poles for overhead lines to minimize negative impacts to farm viability.
- Bury all cables a minimum of 48".
- Maintain natural drainage patterns, stockpile disturbed top soil, and decompact disturbed areas.
- Involve an Environmental Monitor and NYS Ag and Markets in post-construction restoration and decommissioning to minimize impacts to agriculture.

Comments

1. There should be cross access easements and provisions made to maintain the shared access road.
2. How will access and electric connections be provided to the portion of the PV facility on Lot 4 east of Wetland #3?
3. How will development be sequenced?
4. The site plan does not show perimeter vegetation to screen the project from the existing adjacent residence or other potential future neighboring uses.
5. A site SWPPP should be prepared and reviewed by the Town Engineer and the OCSWCD.
6. Why is the project being segmented? Would a 6 MW project trigger additional regulations?
7.

Farmington PRC Comments

1. Applicant indicates the subdivision is required by RGEs interconnection agreement; however the applicant intends to enclose the 3 projects in a single fence and to have 1 decommissioning plan/account.

OCSWCD Comments

1. Tile drainage may be present and any disturbance to subsurface infrastructure would require maintenance/drainage improvements to maintain structures. (as per Construction Notes)
2. Although plans indicate current drainage flow patterns will remain the same as predevelopment conditions. there is the possibility of concentrated flows due to impervious panel surfaces modifying flow patterns

159.1 - 2018	Town of Farmington Planning Board	Class: 2
Referral Type:	Subdivision	
Applicant:	Delaware River Solar, LLC	
Property Owner:	Smith, Mr. & Mrs. Roger	
Representative:	Shultz Associates	
Tax Map No(s):	20.00-2-37.220	
Brief Description:	Site plan, subdivision, area variances, and special use permit for 7.0 MW community solar facility on 3 lots at 466 Yellow Mills Road at Fox Road in the Town of Farmington.	

See information at 159-2018.

159.2 - 2018	Town of Farmington Planning Board	Class: 2
Referral Type:	Special Use Permit	
Applicant:	Delaware River Solar, LLC	
Property Owner:	Smith, Mr. and Mrs. Roger	
Representative:	Shultz Associates	
Tax Map No(s):	20.00-2-37.220	
Brief Description:	Site plan, subdivision, area variances, and special use permit for 7.0 MW community solar facility on 3 lots at 466 Yellow Mills Road at Fox Road in the Town of Farmington.	

See information at 159-2018.

159.3 - 2018	Town of Farmington Zoning Board of Appeals	Class: 2
Referral Type:	Area Variance	
Applicant:	Delaware River Solar, LLC	
Property Owner:	Smith, Mr. & Mrs. Roger	
Representative:	Shultz Associates	
Tax Map No(s):	20.00-2-37.220	
Brief Description:	Site plan, subdivision, area variances, and special use permit for 7.0 MW community solar facility on 3 lots at 466 Yellow Mills Road at Fox Road in the Town of Farmington.	

See information at 159-2018.

160 - 2018	Town of Farmington Planning Board	Class: 1
Referral Type:	Temporary Use Permit	
Applicant:	Orlando Crespo	
Property Owner:	Mathew Guche	
Tax Map No(s):	41.16-2-39.100	
Brief Description:	Temporty use permit for Finger Lakes Hots to operate at the Ontario Antiques Mall, 1740 SR 332 north of Canandaigua-Farmington Town Line Road in the Town of Farmington.	

The food card operation will occupy the 2 parking adjacent to the southern wing of the Antiques Mall.

EXHIBIT J

Town of Farmington

1000 County Road 8
Farmington, New York 14425

PLANNING BOARD
Wednesday, April 17, 2019, 7:00 p.m.

MINUTES—DRAFT #1

The following minutes are written as a summary of the main points that were made and are the official and permanent record of the actions taken by the Town of Farmington Planning Board. Remarks delivered during discussions are summarized and are not intended to be verbatim transcriptions. An audio recording of the meeting is made in accordance with the Planning Board adopted Rules of Procedure. The audio recording is retained for 12 months.

Clerk's Note: This meeting was held at the Farmington Highway Garage, 985 Hook Road, to accommodate the large number of attendees.

Board Members Present: Edward Hemminger, *Chairperson*
Adrian Bellis
Shauncy Maloy
Mary Neale

Board Member Excused: Douglas Viets

Staff Present:
Lance S. Brabant, CPESC, Town of Farmington Engineer, MRB Group D.P.C.
Ronald L. Brand, Town of Farmington Director of Development and Planning
David Degear, Town of Farmington Water and Sewer Superintendent
Dan Delpriore, Town of Farmington Code Enforcement Officer
Don Giroux, Town of Farmington Highway and Parks Superintendent
John Weidenborner, Assistant Chief, Farmington Volunteer Fire Association

Applicants Present:
Daniel Compitello, Solar Project Developer, Delware River Solar, 130 North Winton Road, #10526, Rochester, N.Y. 14610
James Cretekos, BME Associates, 10 Lift Bridge Lane East, Fairport, N.Y. 14450
David Matt, Project Engineer, Schultz Associates Engineers and Land Surveyors PC, 129 S. Union Street, Spencerport, N.Y. 14559
Terence Robinson, Esq., Boylan Code LLP, 28 South Main Street, Canandaigua, N.Y. 14424
Roger and Carol Smith, 4790 Fox Road, Palmyra, N.Y. 14522
James Swetman, Home Power Systems LLC, 1127 Corporate Drive, Farmington, N.Y. 14425

Residents Present:
Henry Adams, 4650 Kyte Road, Shortsville, N.Y. 14548
Greg Allen, 6210 Brownsville Road, Farmington, N.Y. 14425
Pamela Allen, 6250 Brownsville Road, Farmington, N.Y. 14425
Dan Bieck, 4392 Fox Road, Palmyra, N.Y. 14522
Terrence C. Bieck, 358 Stafford Road, P.O. Box 355, Palmyra, N.Y. 14522
Gerald A. Bloss, 81 Gannett Road, Farmington, N.Y. 14425
John and Elvira Boonstra, 5059 Maxwell Road, Farmington, N.Y. 14425
Erin and John Brandt, 117 Hook Road, Farmington, N.Y. 14425
Barbara and Nelson Case, 169 Ellsworth Road, Palmyra, N.Y. 14522
Petrina Case, 5191 Fox Road, Palmyra, N.Y. 14522
Kim and Mark Clement, 330 Ellsworth Road, Palmyra, N.Y. 14425
Brianna Cole-Allen, 6250 Brownsville Road, Farmington, N.Y. 14425
George Cretekos, 186 Hawthorne Circle, Farmington, N.Y. 14425
Ruth DeBrock, 129 W. Main Street, Shortsville, N.Y. 14548
Tim DeLucia, 1452 Mertensia Road, Farmington, N.Y. 14425
James R. Dennie, 595 Yellow Mills Road, Palmyra, N.Y. 14522
George Eckhardt, 357 County Road 28, Palmyra, N.Y. 14522
Marilyn Fair, 984 Stafford Road, Shortsville, N.Y. 14548
Nancy and Jim Falanga, 395 Ellsworth Road, Palmyra, N.Y. 14522
Jim and Ann Foley, 373 Ellsworth Road, Palmyra, N.Y. 14522
Bonnie Fowler, 6176 Hunters Drive, Farmington, N.Y. 14425
Daniel Geer, 568 Yellow Mills Road, Palmyra, N.Y. 14522
Caroline Heberle, for 531 Yellow Mills Road, c/o 53 Mildorf Street, Rochester, N.Y. 14609
Linda Heberle, for 531 Yellow Mills Road, c/o 53 Mildorf Street, Rochester, N.Y. 14609
Wendy Hokenson, Grew Up in Farmington
Peter Ingalsbe, 151 Galvin Court, Farmington, N.Y. 14425
Edward and Tammy Johnson, 126 Yellow Mills Road, Palmyra, N.Y. 14522
Frances Kabat, Esq., The Zoghlin Group PLLC, 300 State Street, Suite 502, Rochester, N.Y. 14614
Dale Kratzenberg, 630 Sheldon Road, Palmyra, N.Y. 14522
Jason Krenichyn, 4880 Fox Road, Palmyra, N.Y. 14522
Sharon and Earl Maltman, 179 County Road 28, Palmyra, N.Y. 14522
Patricia McClure, 5106 Rushmore Road, Palmyra, N.Y. 14522
Pat Murphy, 4995 Rushmore Road, Palmyra, N.Y. 14522
John Orbaker, 4960 Fox Road, Palmyra, N.Y. 14522
Sharyn and Joe Pate, 224 Yellow Mills Road, Palmyra, N.Y. 14522
Nick Patnode, 4938 Maxwell Road, Palmyra, N.Y. 14522
John C. Petura, 4923 Maxwell Road, Palmyra, N.Y. 14522
Chris Progno, 4465 Fox Road, Palmyra, N.Y. 14522
Chad Redmond, Fox Road and Stafford Road, Palmyra, N.Y. 14522
Jim Redmond for 4500 Fox Road, 175 Burnham Heights, Palmyra, N.Y. 14522
Lisa A. Reed, 4465 Fox Road, Palmyra, N.Y. 14522
Todd and Rachael Richenberg, 5007 Maxwell Road, Farmington, N.Y. 14425
John Scialdone, 1614 Wheatstone Drive, Farmington, N.Y. 14425
Andrew A. Strub, 4638 Rushmore Road, Palmyra, N.Y. 14522

Mr. Foley said that a group of residents has retained the law firm of The Zoghlin Group PLLC of Rochester, N.Y., to represent them. He said that Frances Kabat, Esq., their attorney, would like to address SEQR and other environmental issues this evening. Mr. Foley said that he would cede his time to her to enable her to put these issues on the record.

Ms. Kabat said that The Zoghlin Group focuses on land use and environmental law, and represents a group of landowners and residents who are concerned about the impacts of solar development in Farmington, specifically the Delaware River Solar applications for Subdivision, Site Plan and Special Use Permit approval. She said that she understands that this evening's focus is on SEQR and the environmental issues.

Ms. Kabat submitted a letter (dated April 16, 2019) to the board in which " . . . we ask you to issue a Positive Declaration of Environmental Significance ("Pos Dec") for the project, or, in the alternative, deny Delaware's applications for subdivision approval, site plan approval and a special use permit. . . . "

Ms. Kabat quoted from her letter, as follows:

> " . . . The Planning Board must issue a Pos Dec because the Project, as proposed may have a least one potentially significantly adverse environmental impact.
>
> "The primary purpose of SEQRA is 'to inject environmental considerations directly into governmental decision making.' To this end, SEQRA requires the preparation of an Environmental Impact Statement (EIS) when a proposed project 'may have a significant effect on the environment.'
>
> "Because the operative word triggering the requirement of an EIS is 'may,' there is a relatively low threshold for issuance of a Pos Dec and preparation of an EIS. Moreover, a Type I action (as is the one here) carries with it the presumption that it is likely to have a significant adverse effect on the environment and may require an EIS. An EIS is required when the Lead Agency determines that the action as proposed may include the potential for at least one significant adverse impact to the environment.
>
> "Here, the Planning Board must issue a Pos Dec because the Project, as proposed, ma hae at least one potentially significant adverse environmental impactr. The Project would take prime agricultural farmland out of production, and has the potential for adverse drainage impacts, adverse impacts to wetlands and water resources, adverse traffic impacts, damage to community charter, and reduction in property values."
>
> (*See* Correspondence File #82, received April 17, 2019, for the complete letter).

Mr. Vanderwall (125 Yellow Mills Road) asked who would be responsible for cleaning up the site after 30 or 35 years of use. He also asked what would happen if Delaware River Solar collapses [goes out of business]. Mr. Hemminger that the landowner and the company ultimately would be responsible for clean-up of the site, that the Town Code requires that Delaware River Solar submit and fund a decommissioning plan, and that the funding of the decommissioning plan must be reviewed periodically to assure that adequate funds are available in the future to restore the property after the decommissioning of the site.

Ms. Case (5191 Fox Road) said that she has not read anything in the materials about the contamination of underground soils. She said that the company has not talked about underground soils. She also said that she recently spotted a Peregrine Falcon on Fox Road about two miles from the site, and that she has also seen a wood duck in the area. She asked how the wildlife (the ducks and the geese) would react to the solar panels.

A resident from Sheldon Road asked if Material Safety Data Sheets (MSDS sheets) on the solar panels have been submitted by Delaware River Solar. He said that it is very important that the board have these materials. Mr. Hemminger agreed. Mr. Compitello said that MSDS sheets have been provided to the Town.

In response to Ms. Case's question on wildlife, Mr. Compitello said that information on the safety ratings of the solar panels also has been provided to the Town.

Ms. Clement (330 Ellsworth Road) said that the natural resources for wildlife will be impacted if [the Town] allows this type of solar power plant to invade Farmington. She said that she thought that at one time there was an agreement in Farmington that the northern portion of the Town was not to be developed. Ms. Clement said that if [the Town] allows this [project] to happen, [the Town] opens Pandora's Box and will lose wildlife.

Ms. Clement asked if it is true that they [Delaware River Solar] are asking for financial aid from Farmington [for this project]. Mr. Hemminger said that he has not seen any information like this. He acknowledged that Supervisor Ingasbe has indicated that the company is seeking no financial aid from the Town.

Linda Heberle (for 531 Yellow Mills Road) asked if the MSDS sheets are on the Town website. Mr. Delpriore said that he would make sure that they are posted online.

Ms. Heberle asked about this evening's public comments which Mr. Hemminger said should be related to the environmental issues of the applications. She said that she did not know this in advance and it would have been nice to have had this on the agenda. Mr. Hemminger said that he has informed everyone at each session of the Public Hearing that the environmental record (SEQR) is the Planning Board's first step. He said that the Zoning Board of Appeals cannot consider the four Area Variance applications and that the Planning Board cannot consider the Subdivision, Site Plan and Special Use Permit applications until the SEQR declaration has been made.

Ms. Heberle said that her family purchased their land on Yellow Mills Road in the 1960s because they wanted to live on a farm in an agricultural environment. She said that her family does not want an industrial environment and that she does not wish to see glass and metal across the road from her property. She said that if the board allows this, it will be located right in the middle of the agricultural land which her family is so desperately trying to observe.

Ms. Heberle also said that it has been difficult to follow the application process. She said that although the process has become more transparent since September, it is still difficult to find information. Mr. Hemminger said that he is trying to provide as much information as he can. Ms. Heberle said that the prodess is not all perfect yet.

Ms. Heberle said that this project involves 21,000 solar panels. She said that the neighbors have consistently tried to communicate to each of the town boards how devastating that this would be and that the result would be a decrease in the value of their properties. She said that the neighbors are asking the board to reject these power plants. She said that you [the Planning Board] have the power to approve it or deny it.

Ms. Fair (984 Stafford Road) said that she has spoken at previous meetings and that she agrees with Ms. Heberle. Ms. Fair said that the solar panels have carcinogens and that this is an environmental issue. She said that this project touches all of us, that there are no winners for the people, and that the project will drive up the cost of electricity. She said that someone has to fill in the gap and that the price will be paid by all of us. Ms. Fair said that solar energy is not clean. She said that it is a fantasy that it is clean. She said that solar energy is dirty to make, dirty to decommission and dirty to get rid of. She said that she is against this massive solar project.

Ms. Fair asked how 21,000 solar panels will be monitored. She said that a breach of these panels will leach into the acquifer, which will affect all of their wells. She asked how this would be fixed and how the damage to their water and wells would be repaired. She asked how can you promise this will not happen. Ms. Fair said that damage to property also has occurred from microbursts, which she has seen.

Ms. Fair also asked what happens when the panels are removed during decommissioning. She asked if it would be absolutely guaranteed that there would be no breakage and if the decommissioned panels would be considered as E-waste. She asked if they would sit on the Smith farm if no one would remove them. Ms. Fair said that the Town must think 10, 20 and 30 years down the line to the end of the story. She said that she did not think that she would make it in 30 years. She said that some of us will not be here. She said that those who come after us will pay the price.

Ms. Johnson (126 Yellow Mills Road) said that she was speaking as an advocate for Mother Earth and our future generations. She said that we are destroying our eco-systems, oceans and trees. Ms. Johnson discussed the film *WALL-E* (a computer-animated science fiction film produced by Pixar Animation Studios for Walt Disney Pictures; it follows a solitary trash compactor robot on a future uninhabitable deserted Earth, left to

clean up garbage). Ms. Johnson said that she is not sure if this is where we are headed but that she is advocating for our planet. She said that there is just not enough education in this. She said that she is not against the landowners at all who are trying to benefit, but that money can be the root of all evil and that she wants to stand up and advocate for her roots. She said that her roots are country, and that she wants to keep the "country" in "country."

Mr. Falanga (395 Ellsworth Road) thanked people for coming out this evening to provide unanimous opposition to the solar power plant in the agricultural setting. He asked if solar projects are also allowed in a residential setting. Mr. Hemminger said that the Town Code permits solar installations in all zoning districts. Mr. Falanga asked Mr. Hemminger if he was aware of, and would define, solar sprawl. Mr. Falanga defined it as where one comes in, others will follow.

Mr. Falanga asked about the status of a letter which he and other residents wrote to the Town Board, the Planning Board and the Zoning Board of Appeals (dated January 28, 2019), in which the residents asked for six studies to be conducted by independent sources. He then read a portion of the letter into the meeting record, as follows:

> "To that end and based on alarming new information our group has uncovered, we are requesting the following studies be conductec by independent sources:
>
> "1. White Noise Pollution Study. Despite opinions to the contrary, there is evidence that we can hear each other's conversations when we're outside. Sound carries. The hum of an Inverter Station and transmission of power are unacceptable 'trade-offs' for 'sustainable' energy.
>
> "2. Electromagnetic Field Impact Study. There is concern regarding the impacts of high emissions of electrical fields on the health of humans, domestic animals and wildlife. Assurances regarding this issue are sought by our leaders.
>
> "3. Energy Production Study. In considering this and other proposals for solar in our township, consider that short winter days, combined with cloudy days and 'down time' experienced during both winter and summer storms, a Solar Power Plant is truly prouctive some 35 percent of the time and delivers only 22 percent of their collected power in the northeast. Considering the amount of land that must be committed to such a product, is it worth the loss?
>
> "4. Traffic Study. The intersection of Fox and Yellow Mills Road is a well documented and a notoriously dangerous intersection with many accidents and fatalities. A large-scale Solar Power Plant with Inverter Stations would be a huge added driver distraction.

> "5. Threatened and Endangered Species Study. Our group has found dozens of examples of wildlife impaled on chain-linked fences surrounding solar arrays and examples of birds, migratory or others dying as a result of attracting birds to the lake effect produced by solar panels.
>
> "6. E-Waste Study. Often used panels end up in e-waste dumps in developing countries such as India, China and Ghana where these toxic chemicals create devastating health effects for residents."
>
> —January 28, 2019
>
> (Following the meeting, Mr. Falanga provided a copy of the letter to the clerk. *See* Correspondence File #81 for complete letter.)

Mr. Hemminger acknowledged receipt of the letter and the input of the residents. Mr. Hemminger and Mr. Brand indicated that they did not know the status of these studies at this time. Mr. Falanga said that the group of concerned citizens who submitted this letter have volunteered to act as an advisory board to the Planning Board.

Mr. Falanga also asked about the status of responses to 26 questions which residents asked at the Planning Board meeting on November 7, 2018, and which were discussed by Mr. Hemminger at the meeting of the Farmington Agriculture Advisory Committee on November 15, 2018. Mr. Falanga said that a number of these questions were related to the environment. Mr. Hemminger said that these questions were forwarded to Delaware River Solar for responses and that all responses will be reviewed prior to the Planning Board's decision.

Mr. Falanga asked if photographs have been received from damage in a wind storm to solar panels which have been installed on Whittier Road in the Town of Ogden (N.Y.). He said that the damage occurred six weeks after the solar panels were placed online. Mr. Hemminger said that the photographs have been received.

Petrina Case (5191 Fox Road) asked why information about the solar project was not included in the most recent issue of the Town newsletter. Mr. Hemminger suggested that she contact the Town supervisor about this.

Barbara Case (169 Ellsworth Road) said that to sum up we do not want to hurt the Smiths, we know they are our neighbors, but we just do not want it [the solar project].

Mr. Foley (373 Ellsworth Road) said that he finds it strange that this issue [the solar project] was not included in the most recent issue of the Town newsletter. He said that he would like to hear from each Town Board member on why they think this [the solar project] is such a good thing for the Town.

Mr. Hemminger said that the Planning Board and the Town Board have differing functions and that the Town Board members cannot influence the Planning Board members.

He said that the Town Board members do not, and have not, attempted to influence the Planning Board on this or any other application. He said that the two boards maintain an arms-length relationship.

Mr. Adams (4650 Kyte Road), who is the chairperson of the Farmington Agriculture Advisory Committee, clarified that the 26 questions which Mr. Hemminger discussed with the Agriculture Advisory Committee on November 15, 2018, and to which Mr. Falanga referred earlier in the meeting, were promulgated by the citizens at the Planning Board meeting on November 7, 2018. He said that the questions were not raised members of the Agriculture Advisory Committee and were discussed by Mr. Hemminger for the information of the Agriculture Advisory Committee at the meeting on November 15, 2018.

Mr. Adams also clarified the consensus of the Agriculture Advisory Committee on the Yellow Mils Road solar project which was discussed at the Committee meeting on October 18, 2018. The full text of the Agriculture Advisory Committee is as follows:

> **Consensus of the Farmington Agriculture Advisory Committee**
> **Delaware River Solar 7MW AC Community Solar Facility**
> **466 Yellow Mills Road**
>
> It is the consensus of the Farmington Agriculture Advisory Committee that the Committee understands the benefits of solar-generated electricity, that the Committee understands the long-standing concept of the property rights of landowners, and that the Committee supports the general intent of solar installations of 2MW or less. Following discussion and consideration of the Delaware River Solar application at a public meeting held on October 18, 2018, the Committee does not support the magnitude and impact that an installation of this size would have upon the neighboring open space and agricultural lands. Every effort should be made to ensure that the productive capacity of this land is not permanently lost with careful consideration given to minimally disruptive construction techniques; monitoring of safety, groundwater and environmental issues; and adequate funding set aside for eventual decommissioning.
>
> —October 18, 2018

In response to a question, Mr. Hemminger said that general public comments on any issue will be taken this evening during the "Public Comment" portion of the meeting at noted on the agenda.

Chad Redmond (Fox Road and Stafford Road) asked about the requested studies to which Mr. Falanga referred. He said that the Planning Board represents the citizens and that it seems as if the citizens' requests do not mean a whole lot. He said that it seems as if this is a horse and pony show. He said that these are real environmental concerns that we [the citizens] would like to have entertained. He said that 20 or 30 years down the line, he will

Town of Farmington
1000 County Road 8
Farmington, New York 14425

PLANNING BOARD
Wednesday, May 15, 2019, 7:00 p.m.

MINUTES—APPROVED

The following minutes are written as a summary of the main points that were made and are the official and permanent record of the actions taken by the Town of Farmington Planning Board. Remarks delivered during discussions are summarized and are not intended to be verbatim transcriptions. An audio recording of the meeting is made in accordance with the Planning Board adopted Rules of Procedure. The audio recording is retained for 12 months.

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Board Members Present: Edward Hemminger, *Chairperson*
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Shauncy Maloy
Mary Neale
Douglas Viets

Staff Present:
Lance S. Brabant, CPESC, Town of Farmington Engineer, MRB Group D.P.C.
Ronald L. Brand, Town of Farmington Director of Development and Planning
David Degear, Town of Farmington Water and Sewer Superintendent
Dan Delpriore, Town of Farmington Code Enforcement Officer
Tim Ford, Town of Farmington Deputy Highway and Parks Superintendent

Applicants Present:
Daniel Compitello, Solar Project Developer, Delware River Solar, 130 North Winton Road, #10526, Rochester, N.Y. 14610
David Matt, Project Engineer, Schultz Associates Engineers and Land Surveyors PC, 129 S. Union Street, Spencerport, N.Y. 14559
Terence Robinson, Esq., Boylan Code LLP, 28 South Main Street, Canandaigua, N.Y. 14424
Roger and Carol Smith, 4790 Fox Road, Palmyra, N.Y. 14522

Residents Present:
Jill Attardi, 337 Stonefield Lane, Farmington, N.Y. 14522
Linda and Bob Bailey, 5163 Fox Road, Palmyra, N.Y. 14522
Gerald A. Bloss, 81 Gannett Road, Farmington, N.Y. 14425

David Capps, 768 Hook Road, Farmington, N.Y. 14425
Barbara and Nelson Case, 169 Ellsworth Road, Palmyra, N.Y. 14522
Petrina Case, 5191 Fox Road, Palmyra, N.Y. 14522
Edith Chapman, 230 Ellsworth Road, Palmyra, N.Y. 14522
Ruth DeBrock, 129 W. Main Street, Shortsville, N.Y. 14548
Terrence C. Bieck, 358 Stafford Road, P.O. Box 355, Palmyra, N.Y. 14522
Tim DeLucia, 1452 Mertensia Road, Farmington, N.Y. 14425
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Caroline Heberle, for 531 Yellow Mills Road, c/o 53 Mildorf Street, Rochester, N.Y. 14609
Linda Heberle, for 531 Yellow Mills Road, c/o 53 Mildorf Street, Rochester, N.Y. 14609
Wiliam and Nancy Hood, 5023 Maxwell Road, Farmington, N.Y. 14425
Tammy Johnson, 126 Yellow Mills Road, Palmyra, N.Y. 14522
Frances Kabat, Esq., The Zoghlin Group PLLC, 300 State Street, Suite 502, Rochester, N.Y. 14614
Edward D. Lawrenz, 320 Yellow Mills Road, Palmyra, N.Y. 14522
Sharon and Earl Maltman, 179 County Road 28, Palmyra, N.Y. 14522
John Orbaker, 4960 Fox Road, Palmyra, N.Y. 14522
Rosemary Palmeri, 5976 Redfield Drive, Farmington, N.Y. 14425
Chad Redmond, Fox Road and Stafford Road, Palmyra, N.Y. 14522
Jim Redmond for 4500 Fox Road, 175 Burnham Heights, Palmyra, N.Y. 14522
Todd Richenberg, 5007 Maxwell Road, Farmington, N.Y. 14425
Bill Schell, 5976 Redfield Drive, Farmington, N.Y. 14425
John Scialdone, 1614 Wheatstone Drive, Farmington, N.Y. 14425
Stacey and Arnold Vandenburgh, 259 Ellsworth Road, Farmington, N.Y. 14522
Peter Vanderwall, 125 Yellow Mills Road, Palmyra, N.Y. 14522
Gershom E. Yahn, 5215 Fox Road, Palmyra, N.Y. 14522

Media Present:
Josh Williams, Messenger Post Media (Canandaigua *Daily Messenger*), Canandaigua, N.Y.

1. MEETING OPENING

The meeting was called to order at 7:00 p.m. After the Pledge of Allegiance was recited, Mr. Hemminger explained the emergency evacuation procedures. He asked everyone to please sign in and requested that cell phones and other devices be set on silent mode.

Mr. Hemminger said the meeting would be conducted according to the Rules of Procedure approved by the Planning Board on February 6, 2019.

right decision because we don't want to hear about Delaware River Solar any more. We don't want it in our community.

—Todd Richenberg , 5007 Maxwell Road

Mr. Falanga (395 Ellsworth Road) referred to Mr. Compitello's comment that 20 people attended the Open House. He said that he and Jim were in the parking lot counting heads, and if you look and see who actually signed in, you'll see that some people signed in twice. He said that take out the homeowners and there were eight registered voters who attended the Open House.

Mr. Falanga said that the members of his group did some investigation and came up with the minutes from the Ontario County Planning Board (OCPB) from August 8, 2018. He submitted Pages 1 and 2 and 7–10 for the record. Mr. Falanga said that it appears that Delware River Solar withdrew its Site Plan and Special Use Permit applications.

Mr. Compitello said that the applications were not withdrawn from the County. He said that there was a meeting date change when the Area Variance applications were not sent to the County along with the Planning Board applications. He said that the OCPB asked that the applications be moved to the next meeting so that they could review everything together.

(*Clerk's Note:* The Delaware River Solar applications from the Farmington Planning Board and the Farmington Zoning Board of Appeals were heard by the Ontario County Planning Board on September 12, 2018, Referral #159-2018—Site Plan, #159.1-2018—Subdivison, #159.2-2018—Special Use Permit and #159.3-2018—Area Variances.) *JMR*

Mr. Falanga then spoke about the Whitestone Solar application (OCPB Referral #140.1-2018, Site Plan and Special Use Permit for a 2 MW solar energy system at 5348 State Route 96 at the northwest corner of the intersection with Payne Road). He said that Mr. Compitello was present at that meeting and that Whitestone Solar later withdrew the application and walked away.

Mr. Falanga discussed the provision in the Farmington Solar Law which indicates that the Planning Board must determine that there is no feasible alternative prior to allowing development of large-scale solar facilities on Class 1 to 4 soils. He said that the OCPB minutes seem to support his group's interpretation as discussed at a previous meeting by Mr. Foley.

Ms. DeBrock (129 W. Main Street, Shortsville, N.Y.) said that she cannot believe all of you are telling someone what they can do with their land. She said that solar is what's coming and some of you don't even live in the area and you're talking about assessments. Across the road from this property there are four solar panels sitting in a yard. I think you all are being unreasonable. It's the way it's coming and you better get used to it.

Ms. Fair (984 Stafford Road) said that apparently not everyone understands what she has discussed about solar panels. She said that everyone needs to know what materials are used in the manufacturing of solar panels and that the Material Safety Data Sheets (MSDS) are necessary. She said that there is a world of difference among solar panels, that they must installed, monitored and removed carefully, and that the components within solar panels cause cancer.

Ms. Fair said that if the solar panels in the mega-array are ever damaged in any way—in case there is some kind of catastrophic weather event—you are going to face a tremendous issue in terms of water and environment. She said that's why we are against this. She said that we are not against solar but it's this massive array. Ms. Fair said that this is too much for the land, too much for the water supply and too much for the environment. She said that [workers] have to be careful when making solar panels, that anything that comes off could kill the people who make them. She also said that used solar panels are shipped out of the country as e-waste and that she does not want to see thousands of solar panels sitting on farmland.

Barbara Case (169 Ellsworth Road) asked in what country are the solar panels are made. Mr. Compitello said that the solar panels will not be purchased until the time of construction. He said that panels are made in the United States, Canada, Australia, China and Indonesia, and that most solar panels come from Asian countries.

Linda Heberle (531 Yellow Mills Road) said that without MSDS sheets we would not know what panels are being used. She said that when and if they [Delaware River Solar] figure out which panels they are going use, we want MSDS sheets provided to everyone so we don't have to guess what country they are from. Ms. Heberle said that she is against this project. She said that she is right across the street from it.

Ms. Heberle then used some of the photo simulations and drawings that were displayed by Mr. Compitello as visual renderings to show the board. Ms. Heberle noted that there is hardly any difference between the "before project" and "after project" renderings of the site. She said that the applicant's plans to "hide" the solar arrays will not work and that witch hazel bushes will hide nothing after five years. Ms. Heberle said that trees—big pine trees—are needed if this thing [the project] goes in. She said that the intersection of Fox Road and Yellow Mills Road is a busy corner and that the solar panels will be seen from all angles.

Ms. Vandenburgh (259 Ellsworth Road) said that she just returned from volunteering at the Visit Rochester booth at the Lilac Festival. She said that this region attracts millions of visitors from throughout the world. She read a letter to the editor that was not published in the Canandaigua *Messenger Post* newspaper. She speculated that the letter was not printed probably because the newspaper seems to be more in favor of this project being constructed, rather than hearing from a resident who lives less than a half-mile away.

To the Editor,

> The northeast corner of Farmington is one of the last remaining areas of our town that still retains rural character and historic beauty. Beautifully maintained cobblestone homes flank acres of viable farmland. It lies among the Hill Cumorah, the Finger Lakes wildlife [?] and the 1816 Farmington Quaker Meetinghouse. We urge our Planning Board and Zoning Board to reject Delaware River Solar's plan to construct a 40-acre solar power plant containing 21,000 solar power panels on the corner of Fox and Yellow Mills Roads.
>
> Why would they take this precious topsoil out of cultivation for 35 years? Perhaps the land could be better used by a new generation of farmers who successfully grow hops, for [an] expanded mircrobrewery industry, or [to] supply organic produce for farm-to-table restaurants and [?] markets in our area. Farmington is a part of the Finger Lakes—an important tourist destination. Why would we see an ugly, massive power plant on land located very near the "Welcome to Farmington" sign on Fox Road. We should choose to keep the "Farm in Farmington" and help our local farmers.
>
> Thank you.
>
> —Stacey Vandenburgh, 259 Ellsworth Road

Ms. Johnson (126 Yellow Mills Road) asked about the SEQR process and if it has been determined where the solar panels will be made. She asked if they [Delaware River Solar] have to determine from where the panels are coming before the SEQR declaration is determined. Ms. Johnson asked how do we know what is in the panels.

Mr. Compitello said that MSDS sheets have been submitted to the Town. He said that all solar panels used by Delaware River Solar must be classified safe to use by the Environmental Protection Agency (EPA). Mr. Compitello said that the panels are tested by breaking with water and leaching tests to assure that no toxic chemicals will be released into the environment. Ms. Johnson asked if all solar panels used by the company meet these standards. Mr. Compitello said that all solar panels used by Delaware River Solar meet the EPA standards.

Petrina Case (5191 Fox Road) said that she has discussed this application with many people to get their feedback and to make sure that she does not have a closed mind. She expressed concern that property owners may give up the mineral rights on their land if they enter into a lease agreement with a solar company. Ms. Case said that these agreements may lock up the land for 35 years.

Mr. Foley (373 Ellsworth Road) asked how the Planning Board could make the environmental decision on this application when we do not know what solar panels are going to be installed. He said that the Town would be giving the developer a blank check to decide on the type of panels at the time of construction. Mr. Foley said that this seems like a lawyer saying that he wished he had asked 10 more questions after the jury comes back with the verdict. Mr. Foley said that he is concerned about what happens to the solar

panels if they become defective and break open. He said that this has not yet been determined and that a piece of the environmental review process is missing. He said that this is concerning.

Mr. Hemminger said that the type of solar panels has been determined but that the manufacturer of the panels has not yet been determined.

Mr. Compitello said that all panels used by Delaware River Solar meet EPA standards. He said that the specification sheets are the same for all panels that are purchased by the company.

Mr. Falanga asked when the next meeting will be held. Mr. Hemminger said that the date of the next meeting will be scheduled later this evening based upon the possible actions of the board at tonight's meeting. He said that that the next meeting will be held here at the highway garage.

Mr. Hemminger asked if there were any additional comments or questions from those in attendance this evening. There were no further comments or questions.

Mr. Hemminger then asked Mr. Brand to review the next steps for the board.

Mr. Brand said that the board may extend the Public Hearing and also may determine that they have a complete environmental record to begin the SEQR determination process. He said that the correspondence abstract has now reached 101 items.

Mr. Brand said that the board must determine if there are any remaining questions to which there has been no response from Delaware River Solar. He said that the board can begin Part 2 of the Full Environmental Assessment Form (Identification of Potential Project Impacts) under SEQR if the board can determine that it has a complete record. He said that the board members have each received a blank Part 2 form to review and to work with independently prior to this evening's meeting.

Assuming that the environmental record is complete, Mr. Brand said that the board can consider Part 2 of the Full Environmental Assessment Form. He said that this consists of 18 categories. If the board checks "No" in a category, then they move on to the next category. If the board checks "Yes" in a category, then they must check every box in the category identifying either "No, or small impact may occur" or "Moderate to large impact may occur."

Mr. Brand said that the State form is not 100 percent clear. An identified impact may not be related, or it may be a small impact. He said that the board must identify the distinctions.

Following completion of Part 2 of the Full Environmental Assessment Form, Mr. Brand said that the board may need to ask for clarification (a supplemental narrative) from the applicant for any category that the board has determined to have a "Moderate to large

EXHIBIT K

Appendix A - 11-28 - Typical Solar Panel Specification Sheets

REC Americas LLC
1820 Gateway Drive, Suite 170
San Mateo, CA 94404
www.recgroup.com

REC

SOLAR'S MOST TRUSTED

Toxicity Test Report
Prepared September 11, 2018
REC Twin Peak 2 PV Solar Panel

REC

SOLAR'S MOST TRUSTED

Mr. Manuel Folgado
Delaware River Solar
33 Irving Pl, 10th Floor
New York, NY 10003

Mr. Folgado,

Please see the attached TCLP test report for the REC Twin Peak solar module, which REC will be supplying for your forthcoming projects. The test was performed by TestAmerica Laboratories, Inc., of Irvine, CA. As noted in the results on pages 5 and 6, REC solar panels fall well within all federal limits for toxic materials.

REC modules are widely recognized as the standard for quality materials, workmanship, and longevity in the solar business. We look forward to working with you now and in the future.

Should you have any questions or wish to discuss this further, please do not hesitate to call me.

Sincerely,

George McClellan
Senior Technical Sales Manager
REC Americas LLC

REC
SOLAR'S MOST TRUSTED

Test Specification	Test Result:
Toxicity Characterization Leaching Procedure (TCLP)	PASS

RESULTS SUMMARY:

No analyte concentrations exceeded the maximums allowed. (see addendum report)

EPA Waste Number	Contaminant	Regulatory Level (mg/l)
D004	Arsenic	5.000
D005	Barium	100.000
D006	Cadmium	1.000
D007	Chromium	5.000
D008	Lead	5.000
D009	Mercury	.2000
D010	Selenium	1.000
D011	Silver	5.000

DETAILED TEST RESULTS: (see attached)

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.
TestAmerica Irvine
17461 Derian Ave
Suite 100
Irvine, CA 92614-5817
Tel: (949)261-1022

TestAmerica Job ID: 440-219289-1
Client Project/Site: REC Americas - Solar PV Panel- TCLP

For:
REC Americas LLC
111 Narlene Way
Pismo Beach, California 93449

Attn: George McClellan

Authorized for release by:
9/11/2018 12:15:10 PM

Rossina Tomova, Project Manager I
(949)261-1022
rossina.tomova@testamericainc.com

The test results in this report meet all 2003 NELAC and 2009 TNI requirements for accredited parameters, exceptions are noted in this report. This report may not be reproduced except in full, and with written approval from the laboratory. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

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Sample Summary

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

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Lab Sample ID	Client Sample ID	Matrix	Collected	Received
440-219289-1	REC Twin Peak Solar Module	Solid	09/03/18 09:00	09/04/18 09:10

Job ID: 440-219289-1

Laboratory: TestAmerica Irvine

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Narrative

Job Narrative
440-219289-1

Comments
No additional comments.

Receipt
The sample was received on 9/4/2018 9:10 AM; the sample arrived in good condition, properly preserved and, where required, on ice. The temperature of the cooler at receipt was 2.1° C.

GC/MS VOA
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

GC/MS Semi VOA
Method(s) 8270C: Surrogate Phenol-d6 (Surr) recovery for the following sample was outside control limits: (440-219289-A-1-F MS). Evidence of matrix interference is present; however, low recovery due to less than optimal extraction conditions cannot be confirmed. Re-extraction and re-analysis was not performed because surrogate recoveries in the source sample are within acceptable limits.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Metals
Method(s) 6010B: The method blank for preparation batch 440-497277 and 440-497508 and analytical batch 440-498189 contained Lead above the method detection limit. This target analyte concentration was less than the reporting limit (RL); therefore, re-extraction and/or re-analysis of samples was not performed.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Organic Prep
Method(s) 3520C: Insufficient sample volume was available to perform a matrix spike duplicate (MS/MSD) associated with preparation batch 440-497277 and 440-497626; 3520C_8270-TCLP. Only MS reported.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

VOA Prep
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Client Sample Results

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Client Sample ID: REC Twin Peak Solar Module

Lab Sample ID: 440-219289-1
Date Collected: 09/03/18 09:00
Matrix: Solid
Date Received: 09/04/18 09:10

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Method: 8260B - Volatile Organic Compounds (GC/MS) - TCLP

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	ND		0.020	0.0028	mg/L			09/06/18 12:13	1
Carbon tetrachloride	ND		0.050	0.0028	mg/L			09/06/18 12:13	1
Chloroform	ND		0.020	0.0033	mg/L			09/06/18 12:13	1
1,1-Dichloroethene	ND		0.050	0.0042	mg/L			09/06/18 12:13	1
1,2-Dichloroethane	ND		0.020	0.0028	mg/L			09/06/18 12:13	1
2-Butanone (MEK)	ND		0.10	0.047	mg/L			09/06/18 12:13	1
Tetrachloroethene	ND		0.020	0.0032	mg/L			09/06/18 12:13	1
Trichloroethene	ND		0.020	0.0026	mg/L			09/06/18 12:13	1
Vinyl chloride	ND		0.050	0.0040	mg/L			09/06/18 12:13	1
Chlorobenzene	ND		0.020	0.0036	mg/L			09/06/18 12:13	1
1,4-Dichlorobenzene	ND		0.020	0.0037	mg/L			09/06/18 12:13	1
Hexachlorobutadiene	ND		0.050	0.0038	mg/L			09/06/18 12:13	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Toluene-d8 (Surr)	*103*		*80 - 128*		*09/06/18 12:13*	*1*
4-Bromofluorobenzene (Surr)	*98*		*80 - 120*		*09/06/18 12:13*	*1*
Dibromofluoromethane (Surr)	*107*		*76 - 132*		*09/06/18 12:13*	*1*

Method: 8270C - Semivolatile Organic Compounds (GC/MS) - TCLP

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
2-Methylphenol	ND		0.050	0.015	mg/L		09/06/18 12:16	09/10/18 15:24	1
1,4-Dichlorobenzene	ND		0.050	0.013	mg/L		09/06/18 12:16	09/10/18 15:24	1
2,4-Dinitrotoluene	ND		0.050	0.018	mg/L		09/06/18 12:16	09/10/18 15:24	1
Hexachlorobenzene	ND		0.050	0.015	mg/L		09/06/18 12:16	09/10/18 15:24	1
Hexachlorobutadiene	ND		0.050	0.020	mg/L		09/06/18 12:16	09/10/18 15:24	1
Hexachloroethane	ND		0.050	0.018	mg/L		09/06/18 12:16	09/10/18 15:24	1
Nitrobenzene	ND		0.20	0.015	mg/L		09/06/18 12:16	09/10/18 15:24	1
Pentachlorophenol	ND		0.20	0.018	mg/L		09/06/18 12:16	09/10/18 15:24	1
Pyridine	ND		0.050	0.013	mg/L		09/06/18 12:16	09/10/18 15:24	1
2,4,5-Trichlorophenol	ND		0.10	0.015	mg/L		09/06/18 12:16	09/10/18 15:24	1
2,4,6-Trichlorophenol	ND		0.10	0.023	mg/L		09/06/18 12:16	09/10/18 15:24	1
3-Methylphenol + 4-Methylphenol	ND		0.050	0.015	mg/L		09/06/18 12:16	09/10/18 15:24	1
Total Cresols	ND		0.025	0.013	mg/L		09/06/18 12:16	09/10/18 15:24	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
2-Fluorobiphenyl	*79*		*50 - 120*	*09/06/18 12:16*	*09/10/18 15:24*	*1*
2-Fluorophenol (Surr)	*70*		*30 - 120*	*09/06/18 12:16*	*09/10/18 15:24*	*1*
Nitrobenzene-d5 (Surr)	*77*		*45 - 120*	*09/06/18 12:16*	*09/10/18 15:24*	*1*
Terphenyl-d14 (Surr)	*81*		*10 - 150*	*09/06/18 12:16*	*09/10/18 15:24*	*1*
2,4,6-Tribromophenol (Surr)	*79*		*40 - 120*	*09/06/18 12:16*	*09/10/18 15:24*	*1*
Phenol-d6 (Surr)	*60*		*35 - 120*	*09/06/18 12:16*	*09/10/18 15:24*	*1*

Method: 6010B - Metals (ICP) - TCLP

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Arsenic	ND		0.20	0.070	mg/L		09/05/18 21:45	09/06/18 13:51	1
Barium	0.61		0.20	0.060	mg/L		09/05/18 21:45	09/06/18 13:51	1
Cadmium	ND		0.10	0.020	mg/L		09/05/18 21:45	09/06/18 13:51	1
Chromium	ND		0.10	0.020	mg/L		09/05/18 21:45	09/06/18 13:51	1
Lead	1.1	B	0.10	0.040	mg/L		09/05/18 21:45	09/06/18 13:51	1
Selenium	ND		0.10	0.080	mg/L		09/05/18 21:45	09/06/18 13:51	1

Client Sample Results

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Client Sample ID: REC Twin Peak Solar Module
Date Collected: 09/03/18 09:00
Date Received: 09/04/18 09:10

Lab Sample ID: 440-219289-1
Matrix: Solid

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Method: 6010B - Metals (ICP) - TCLP (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Silver	ND		0.20	0.060	mg/L		09/05/18 21:45	09/06/18 13:51	1

Method: 7470A - Mercury (CVAA) - TCLP

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	ND		0.0020	0.0010	mg/L		09/06/18 12:26	09/06/18 23:32	1

Method Summary

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Method	Method Description	Protocol	Laboratory
8260B	Volatile Organic Compounds (GC/MS)	SW846	TAL IRV
8270C	Semivolatile Organic Compounds (GC/MS)	SW846	TAL IRV
6010B	Metals (ICP)	SW846	TAL IRV
7470A	Mercury (CVAA)	SW846	TAL IRV
1311	TCLP Extraction	SW846	TAL IRV
3010A	Preparation, Total Metals	SW846	TAL IRV
3520C	Liquid-Liquid Extraction (Continuous)	SW846	TAL IRV
5030B	Purge and Trap	SW846	TAL IRV
7470A	Preparation, Mercury	SW846	TAL IRV

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Protocol References:

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL IRV = TestAmerica Irvine, 17461 Derian Ave, Suite 100, Irvine, CA 92614-5817, TEL (949)261-1022

Lab Chronicle

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Client Sample ID: REC Twin Peak Solar Module **Lab Sample ID: 440-219289-1**
Date Collected: 09/03/18 09:00 **Matrix: Solid**
Date Received: 09/04/18 09:10

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
TCLP	Leach	1311			25.07 g	500 mL	497278	09/04/18 23:38	CDH	TAL IRV
TCLP	Analysis	8260B		1	1 mL	10 mL	497545	09/06/18 12:13	AYL	TAL IRV
TCLP	Leach	1311			99.98 g	2000 mL	497277	09/04/18 23:34	CDH	TAL IRV
TCLP	Prep	3520C			200 mL	2.0 mL	497626	09/06/18 12:16	JAA	TAL IRV
TCLP	Analysis	8270C		1			498096	09/10/18 15:24	HN	TAL IRV
TCLP	Leach	1311			99.98 g	2000 mL	497277	09/04/18 23:34	CDH	TAL IRV
TCLP	Prep	3010A			5 mL	50 mL	497508	09/05/18 21:45	CDH	TAL IRV
TCLP	Analysis	6010B		1			498189	09/06/18 13:51	VS	TAL IRV
TCLP	Leach	1311			99.98 g	2000 mL	497277	09/04/18 23:34	CDH	TAL IRV
TCLP	Prep	7470A			2 mL	20 mL	497631	09/06/18 12:26	DB	TAL IRV
TCLP	Analysis	7470A		1			497854	09/06/18 23:32	DB	TAL IRV

Laboratory References:
TAL IRV = TestAmerica Irvine, 17461 Derian Ave, Suite 100, Irvine, CA 92614-5817, TEL (949)261-1022

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QC Sample Results

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Method: 8260B - Volatile Organic Compounds (GC/MS)

Lab Sample ID: MB 440-497278/1-A
Matrix: Solid
Analysis Batch: 497545

Client Sample ID: Method Blank
Prep Type: TCLP

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	ND		0.020	0.0028	mg/L			09/06/18 09:44	1
Carbon tetrachloride	ND		0.050	0.0028	mg/L			09/06/18 09:44	1
Chloroform	ND		0.020	0.0033	mg/L			09/06/18 09:44	1
1,1-Dichloroethene	ND		0.050	0.0042	mg/L			09/06/18 09:44	1
1,2-Dichloroethane	ND		0.020	0.0028	mg/L			09/06/18 09:44	1
2-Butanone (MEK)	ND		0.10	0.047	mg/L			09/06/18 09:44	1
Tetrachloroethene	ND		0.020	0.0032	mg/L			09/06/18 09:44	1
Trichloroethene	ND		0.020	0.0026	mg/L			09/06/18 09:44	1
Vinyl chloride	ND		0.050	0.0040	mg/L			09/06/18 09:44	1
Chlorobenzene	ND		0.020	0.0036	mg/L			09/06/18 09:44	1
1,4-Dichlorobenzene	ND		0.020	0.0037	mg/L			09/06/18 09:44	1
Hexachlorobutadiene	ND		0.050	0.0038	mg/L			09/06/18 09:44	1

Surrogate	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Toluene-d8 (Surr)	*103*		*80 - 128*		*09/06/18 09:44*	*1*
4-Bromofluorobenzene (Surr)	*98*		*80 - 120*		*09/06/18 09:44*	*1*
Dibromofluoromethane (Surr)	*111*		*76 - 132*		*09/06/18 09:44*	*1*

Lab Sample ID: LCS 440-497278/2-A
Matrix: Solid
Analysis Batch: 497545

Client Sample ID: Lab Control Sample
Prep Type: TCLP

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Benzene	0.250	0.244		mg/L		97	68 - 130
Carbon tetrachloride	0.250	0.247		mg/L		99	60 - 150
Chloroform	0.250	0.249		mg/L		100	70 - 130
1,1-Dichloroethene	0.250	0.234		mg/L		94	70 - 130
1,2-Dichloroethane	0.250	0.222		mg/L		89	57 - 138
2-Butanone (MEK)	0.250	0.227		mg/L		91	44 - 150
Tetrachloroethene	0.250	0.259		mg/L		104	70 - 130
Trichloroethene	0.250	0.268		mg/L		107	70 - 130
Vinyl chloride	0.250	0.202		mg/L		81	59 - 133
Chlorobenzene	0.250	0.253		mg/L		101	70 - 130
1,4-Dichlorobenzene	0.250	0.251		mg/L		100	70 - 130
Hexachlorobutadiene	0.250	0.262		mg/L		105	10 - 150

Surrogate	*LCS %Recovery*	*LCS Qualifier*	*Limits*
Toluene-d8 (Surr)	*102*		*80 - 128*
4-Bromofluorobenzene (Surr)	*97*		*80 - 120*
Dibromofluoromethane (Surr)	*106*		*76 - 132*

Lab Sample ID: 440-219131-A-1-E MS
Matrix: Solid
Analysis Batch: 497545

Client Sample ID: Matrix Spike
Prep Type: TCLP

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Benzene	0.068		0.250	0.321		mg/L		101	66 - 130

Method: 8260B - Volatile Organic Compounds (GC/MS) (Continued)

Lab Sample ID: 440-219131-A-1-E MS
Matrix: Solid
Analysis Batch: 497545

Client Sample ID: Matrix Spike
Prep Type: TCLP

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Carbon tetrachloride	ND		0.250	0.254		mg/L		101	60 - 150
Chloroform	ND		0.250	0.250		mg/L		100	70 - 130
1,1-Dichloroethene	ND		0.250	0.230		mg/L		92	70 - 130
1,2-Dichloroethane	ND		0.250	0.229		mg/L		91	56 - 146
2-Butanone (MEK)	ND		0.250	0.233		mg/L		93	48 - 140
Tetrachloroethene	ND		0.250	0.253		mg/L		101	70 - 137
Trichloroethene	ND		0.250	0.276		mg/L		110	70 - 130
Vinyl chloride	ND		0.250	0.196		mg/L		78	50 - 137
Chlorobenzene	ND		0.250	0.255		mg/L		102	70 - 130
1,4-Dichlorobenzene	ND		0.250	0.260		mg/L		104	70 - 130
Hexachlorobutadiene	ND		0.250	0.279		mg/L		112	10 - 150

Surrogate	*MS %Recovery*	*MS Qualifier*	*Limits*
Toluene-d8 (Surr)	*99*		*80 - 128*
4-Bromofluorobenzene (Surr)	*99*		*80 - 120*
Dibromofluoromethane (Surr)	*107*		*76 - 132*

Lab Sample ID: 440-219131-A-1-E MSD
Matrix: Solid
Analysis Batch: 497545

Client Sample ID: Matrix Spike Duplicate
Prep Type: TCLP

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Benzene	0.068		0.250	0.328		mg/L		104	66 - 130	2	20
Carbon tetrachloride	ND		0.250	0.248		mg/L		99	60 - 150	2	25
Chloroform	ND		0.250	0.251		mg/L		100	70 - 130	0	20
1,1-Dichloroethene	ND		0.250	0.232		mg/L		93	70 - 130	1	20
1,2-Dichloroethane	ND		0.250	0.221		mg/L		88	56 - 146	3	20
2-Butanone (MEK)	ND		0.250	0.225		mg/L		90	48 - 140	3	40
Tetrachloroethene	ND		0.250	0.243		mg/L		97	70 - 137	4	20
Trichloroethene	ND		0.250	0.267		mg/L		107	70 - 130	3	20
Vinyl chloride	ND		0.250	0.197		mg/L		79	50 - 137	0	30
Chlorobenzene	ND		0.250	0.244		mg/L		98	70 - 130	4	20
1,4-Dichlorobenzene	ND		0.250	0.257		mg/L		103	70 - 130	1	20
Hexachlorobutadiene	ND		0.250	0.269		mg/L		108	10 - 150	4	20

Surrogate	*MSD %Recovery*	*MSD Qualifier*	*Limits*
Toluene-d8 (Surr)	*96*		*80 - 128*
4-Bromofluorobenzene (Surr)	*98*		*80 - 120*
Dibromofluoromethane (Surr)	*108*		*76 - 132*

QC Sample Results

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Method: 8270C - Semivolatile Organic Compounds (GC/MS)

Lab Sample ID: MB 440-497277/1-C
Matrix: Solid
Analysis Batch: 498096

Client Sample ID: Method Blank
Prep Type: TCLP
Prep Batch: 497626

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
2-Methylphenol	ND		0.050	0.015	mg/L		09/06/18 12:16	09/10/18 14:32	1
1,4-Dichlorobenzene	ND		0.050	0.013	mg/L		09/06/18 12:16	09/10/18 14:32	1
2,4-Dinitrotoluene	ND		0.050	0.018	mg/L		09/06/18 12:16	09/10/18 14:32	1
Hexachlorobenzene	ND		0.050	0.015	mg/L		09/06/18 12:16	09/10/18 14:32	1
Hexachlorobutadiene	ND		0.050	0.020	mg/L		09/06/18 12:16	09/10/18 14:32	1
Hexachloroethane	ND		0.050	0.018	mg/L		09/06/18 12:16	09/10/18 14:32	1
Nitrobenzene	ND		0.20	0.015	mg/L		09/06/18 12:16	09/10/18 14:32	1
Pentachlorophenol	ND		0.20	0.018	mg/L		09/06/18 12:16	09/10/18 14:32	1
Pyridine	ND		0.050	0.013	mg/L		09/06/18 12:16	09/10/18 14:32	1
2,4,5-Trichlorophenol	ND		0.10	0.015	mg/L		09/06/18 12:16	09/10/18 14:32	1
2,4,6-Trichlorophenol	ND		0.10	0.023	mg/L		09/06/18 12:16	09/10/18 14:32	1
3-Methylphenol + 4-Methylphenol	ND		0.050	0.015	mg/L		09/06/18 12:16	09/10/18 14:32	1
Total Cresols	ND		0.025	0.013	mg/L		09/06/18 12:16	09/10/18 14:32	1

Surrogate	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
2-Fluorobiphenyl	*87*		*50 - 120*	*09/06/18 12:16*	*09/10/18 14:32*	*1*
2-Fluorophenol (Surr)	*76*		*30 - 120*	*09/06/18 12:16*	*09/10/18 14:32*	*1*
Nitrobenzene-d5 (Surr)	*87*		*45 - 120*	*09/06/18 12:16*	*09/10/18 14:32*	*1*
Terphenyl-d14 (Surr)	*89*		*10 - 150*	*09/06/18 12:16*	*09/10/18 14:32*	*1*
2,4,6-Tribromophenol (Surr)	*87*		*40 - 120*	*09/06/18 12:16*	*09/10/18 14:32*	*1*
Phenol-d6 (Surr)	*80*		*35 - 120*	*09/06/18 12:16*	*09/10/18 14:32*	*1*

Lab Sample ID: LCS 440-497277/2-C
Matrix: Solid
Analysis Batch: 498096

Client Sample ID: Lab Control Sample
Prep Type: TCLP
Prep Batch: 497626

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
2-Methylphenol	0.500	0.346		mg/L		69	47 - 106
1,4-Dichlorobenzene	0.500	0.323		mg/L		65	10 - 96
2,4-Dinitrotoluene	0.500	0.419		mg/L		84	44 - 128
Hexachlorobenzene	0.500	0.381		mg/L		76	48 - 120
Hexachlorobutadiene	0.500	0.318		mg/L		64	21 - 95
Hexachloroethane	0.500	0.297		mg/L		59	10 - 97
Nitrobenzene	0.500	0.390		mg/L		78	42 - 112
Pentachlorophenol	1.00	0.767		mg/L		77	50 - 120
Pyridine	1.00	0.536		mg/L		54	27 - 110
2,4,5-Trichlorophenol	0.500	0.393		mg/L		79	44 - 116
2,4,6-Trichlorophenol	0.500	0.399		mg/L		80	48 - 107
3-Methylphenol + 4-Methylphenol	0.500	0.358		mg/L		72	47 - 109

Surrogate	*LCS %Recovery*	*LCS Qualifier*	*Limits*
2-Fluorobiphenyl	*79*		*50 - 120*
2-Fluorophenol (Surr)	*65*		*30 - 120*
Nitrobenzene-d5 (Surr)	*78*		*45 - 120*
Terphenyl-d14 (Surr)	*82*		*10 - 150*
2,4,6-Tribromophenol (Surr)	*81*		*40 - 120*
Phenol-d6 (Surr)	*68*		*35 - 120*

Method: 8270C - Semivolatile Organic Compounds (GC/MS) (Continued)

Lab Sample ID: 440-219289-1 MS — **Client Sample ID: REC Twin Peak Solar Module**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 498096 — **Prep Batch: 497626**

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
2-Methylphenol	ND		0.500	0.303		mg/L		61	50 - 120
1,4-Dichlorobenzene	ND		0.500	0.341		mg/L		68	35 - 120
2,4-Dinitrotoluene	ND		0.500	0.414		mg/L		83	65 - 120
Hexachlorobenzene	ND		0.500	0.394		mg/L		79	60 - 120
Hexachlorobutadiene	ND		0.500	0.328		mg/L		66	40 - 120
Hexachloroethane	ND		0.500	0.309		mg/L		62	35 - 120
Nitrobenzene	ND		0.500	0.393		mg/L		79	55 - 120
Pentachlorophenol	ND		1.00	0.817		mg/L		82	24 - 121
Pyridine	ND		1.00	0.445		mg/L		45	30 - 120
2,4,5-Trichlorophenol	ND		0.500	0.407		mg/L		81	55 - 120
2,4,6-Trichlorophenol	ND		0.500	0.393		mg/L		79	55 - 120
3-Methylphenol + 4-Methylphenol	ND		0.500	0.298		mg/L		60	45 - 120

Surrogate	*MS %Recovery*	*MS Qualifier*	*Limits*
2-Fluorobiphenyl	*81*		*50 - 120*
2-Fluorophenol (Surr)	*66*		*30 - 120*
Nitrobenzene-d5 (Surr)	*79*		*45 - 120*
Terphenyl-d14 (Surr)	*66*		*10 - 150*
2,4,6-Tribromophenol (Surr)	*83*		*40 - 120*
Phenol-d6 (Surr)	*19*	*X*	*35 - 120*

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Method: 6010B - Metals (ICP)

Lab Sample ID: MB 440-497277/1-B — **Client Sample ID: Method Blank**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 498189 — **Prep Batch: 497508**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Arsenic	ND		0.20	0.070	mg/L		09/05/18 21:45	09/06/18 13:45	1
Barium	ND		0.20	0.060	mg/L		09/05/18 21:45	09/06/18 13:45	1
Cadmium	ND		0.10	0.020	mg/L		09/05/18 21:45	09/06/18 13:45	1
Chromium	ND		0.10	0.020	mg/L		09/05/18 21:45	09/06/18 13:45	1
Lead	0.0400	J	0.10	0.040	mg/L		09/05/18 21:45	09/06/18 13:45	1
Selenium	ND		0.10	0.080	mg/L		09/05/18 21:45	09/06/18 13:45	1
Silver	ND		0.20	0.060	mg/L		09/05/18 21:45	09/06/18 13:45	1

Lab Sample ID: LCS 440-497277/2-B — **Client Sample ID: Lab Control Sample**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 498189 — **Prep Batch: 497508**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Arsenic	2.00	1.95		mg/L		98	80 - 120
Barium	2.00	1.99		mg/L		100	80 - 120
Cadmium	2.00	2.00		mg/L		100	80 - 120
Chromium	2.00	2.02		mg/L		101	80 - 120
Lead	2.00	1.98		mg/L		99	80 - 120
Selenium	2.00	1.75		mg/L		87	80 - 120
Silver	1.00	0.997		mg/L		100	80 - 120

QC Sample Results

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Lab Sample ID: 440-219289-1 MS — **Client Sample ID: REC Twin Peak Solar Module**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 498189 — **Prep Batch: 497508**

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Arsenic	ND		2.00	1.93		mg/L		97	75 - 125
Barium	0.61		2.00	2.56		mg/L		98	75 - 125
Cadmium	ND		2.00	1.96		mg/L		98	75 - 125
Chromium	ND		2.00	1.98		mg/L		99	75 - 125
Lead	1.1	B	2.00	3.11		mg/L		100	75 - 125
Selenium	ND		2.00	1.78		mg/L		89	75 - 125
Silver	ND		1.00	0.983		mg/L		98	75 - 125

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Lab Sample ID: 440-219289-1 MSD — **Client Sample ID: REC Twin Peak Solar Module**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 498189 — **Prep Batch: 497508**

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Arsenic	ND		2.00	1.96		mg/L		98	75 - 125	1	20
Barium	0.61		2.00	2.66		mg/L		103	75 - 125	4	20
Cadmium	ND		2.00	1.98		mg/L		99	75 - 125	1	20
Chromium	ND		2.00	2.00		mg/L		100	75 - 125	1	20
Lead	1.1	B	2.00	3.00		mg/L		94	75 - 125	4	20
Selenium	ND		2.00	1.79		mg/L		90	75 - 125	1	20
Silver	ND		1.00	0.987		mg/L		99	75 - 125	0	20

Method: 7470A - Mercury (CVAA)

Lab Sample ID: MB 440-497277/1-D — **Client Sample ID: Method Blank**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 497854 — **Prep Batch: 497631**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	ND		0.0020	0.0010	mg/L		09/06/18 12:26	09/06/18 23:28	1

Lab Sample ID: LCS 440-497277/2-D — **Client Sample ID: Lab Control Sample**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 497854 — **Prep Batch: 497631**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Mercury	0.0800	0.0702		mg/L		88	80 - 120

Lab Sample ID: 440-219289-1 MS — **Client Sample ID: REC Twin Peak Solar Module**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 497854 — **Prep Batch: 497631**

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Mercury	ND		0.0800	0.0694		mg/L		87	70 - 130

Lab Sample ID: 440-219289-1 MSD — **Client Sample ID: REC Twin Peak Solar Module**
Matrix: Solid — **Prep Type: TCLP**
Analysis Batch: 497854 — **Prep Batch: 497631**

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Mercury	ND		0.0800	0.0707		mg/L		88	70 - 130	2	20

QC Sample Results

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Method: 7470A - Mercury (CVAA) (Continued)

Lab Sample ID: MRL 440-497275/4-C
Matrix: Solid
Analysis Batch: 497854

Client Sample ID: Lab Control Sample
Prep Type: TCLP
Prep Batch: 497633

Analyte	Spike Added	MRL Result	MRL Qualifier	Unit	D	%Rec	%Rec. Limits
Mercury	10.0	9.03		ug/L		90	

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QC Association Summary

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

GC/MS VOA

Leach Batch: 497278

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	1311	
MB 440-497278/1-A	Method Blank	TCLP	Solid	1311	
LCS 440-497278/2-A	Lab Control Sample	TCLP	Solid	1311	
440-219131-A-1-E MS	Matrix Spike	TCLP	Solid	1311	
440-219131-A-1-E MSD	Matrix Spike Duplicate	TCLP	Solid	1311	

Analysis Batch: 497545

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	8260B	497278
MB 440-497278/1-A	Method Blank	TCLP	Solid	8260B	497278
LCS 440-497278/2-A	Lab Control Sample	TCLP	Solid	8260B	497278
440-219131-A-1-E MS	Matrix Spike	TCLP	Solid	8260B	497278
440-219131-A-1-E MSD	Matrix Spike Duplicate	TCLP	Solid	8260B	497278

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GC/MS Semi VOA

Leach Batch: 497277

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	1311	
MB 440-497277/1-C	Method Blank	TCLP	Solid	1311	
LCS 440-497277/2-C	Lab Control Sample	TCLP	Solid	1311	
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	1311	

Prep Batch: 497626

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	3520C	497277
MB 440-497277/1-C	Method Blank	TCLP	Solid	3520C	497277
LCS 440-497277/2-C	Lab Control Sample	TCLP	Solid	3520C	497277
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	3520C	497277

Analysis Batch: 498096

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	8270C	497626
MB 440-497277/1-C	Method Blank	TCLP	Solid	8270C	497626
LCS 440-497277/2-C	Lab Control Sample	TCLP	Solid	8270C	497626
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	8270C	497626

Metals

Leach Batch: 497275

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
MRL 440-497275/4-C	Lab Control Sample	TCLP	Solid	1311	

Leach Batch: 497277

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	1311	
MB 440-497277/1-B	Method Blank	TCLP	Solid	1311	
MB 440-497277/1-D	Method Blank	TCLP	Solid	1311	
LCS 440-497277/2-B	Lab Control Sample	TCLP	Solid	1311	
LCS 440-497277/2-D	Lab Control Sample	TCLP	Solid	1311	

QC Association Summary

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Metals (Continued)

Leach Batch: 497277 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	1311	
440-219289-1 MSD	REC Twin Peak Solar Module	TCLP	Solid	1311	

Prep Batch: 497508

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	3010A	497277
MB 440-497277/1-B	Method Blank	TCLP	Solid	3010A	497277
LCS 440-497277/2-B	Lab Control Sample	TCLP	Solid	3010A	497277
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	3010A	497277
440-219289-1 MSD	REC Twin Peak Solar Module	TCLP	Solid	3010A	497277

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Prep Batch: 497631

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	7470A	497277
MB 440-497277/1-D	Method Blank	TCLP	Solid	7470A	497277
LCS 440-497277/2-D	Lab Control Sample	TCLP	Solid	7470A	497277
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	7470A	497277
440-219289-1 MSD	REC Twin Peak Solar Module	TCLP	Solid	7470A	497277

Prep Batch: 497633

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
MRL 440-497275/4-C	Lab Control Sample	TCLP	Solid	7470A	497275

Analysis Batch: 497854

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	7470A	497631
MB 440-497277/1-D	Method Blank	TCLP	Solid	7470A	497631
LCS 440-497277/2-D	Lab Control Sample	TCLP	Solid	7470A	497631
MRL 440-497275/4-C	Lab Control Sample	TCLP	Solid	7470A	497633
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	7470A	497631
440-219289-1 MSD	REC Twin Peak Solar Module	TCLP	Solid	7470A	497631

Analysis Batch: 498189

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
440-219289-1	REC Twin Peak Solar Module	TCLP	Solid	6010B	497508
MB 440-497277/1-B	Method Blank	TCLP	Solid	6010B	497508
LCS 440-497277/2-B	Lab Control Sample	TCLP	Solid	6010B	497508
440-219289-1 MS	REC Twin Peak Solar Module	TCLP	Solid	6010B	497508
440-219289-1 MSD	REC Twin Peak Solar Module	TCLP	Solid	6010B	497508

Definitions/Glossary

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Qualifiers

GC/MS Semi VOA

Qualifier	Qualifier Description
X	Surrogate is outside control limits

Metals

Qualifier	Qualifier Description
B	Compound was found in the blank and sample.
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

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Accreditation/Certification Summary

Client: REC Americas LLC
Project/Site: REC Americas - Solar PV Panel- TCLP

TestAmerica Job ID: 440-219289-1

Laboratory: TestAmerica Irvine

Unless otherwise noted, all analytes for this laboratory were covered under each accreditation/certification below.

Authority	Program	EPA Region	Identification Number	Expiration Date
California	State Program	9	CA ELAP 2706	06-30-19

The following analytes are included in this report, but the laboratory is not certified by the governing authority. This list may include analytes for which the agency does not offer certification.

Analysis Method	Prep Method	Matrix	Analyte
8270C	3520C	Solid	3-Methylphenol + 4-Methylphenol
8270C	3520C	Solid	Total Cresols

Oregon	NELAP	10	4028	01-29-19

The following analytes are included in this report, but the laboratory is not certified by the governing authority. This list may include analytes for which the agency does not offer certification.

Analysis Method	Prep Method	Matrix	Analyte
7470A	7470A	Solid	Mercury
8270C	3520C	Solid	Total Cresols

Irvine
17461 Derian Ave
Suite 100
Irvine, CA 92614
phone 949.261.1022 | fax 949.260.3299

Chain of Custody Record

TestAmerica
THE LEADER IN ENVIRONMENTAL TESTING

TestAmerica Laboratories, Inc.

Client Contact	Project Manager: George McClellan	Site Contact:	Date:	COC No:
Your Company Name REC Americas LLC	Tel/Fax: 805 704 3226	Lab Contact:	Carrier:	1 of 1 COCs
Address 1820 Gateway Dr, Ste 170	Analysis Turnaround Time			Job No.
City/State/Zip San Mateo, CA 94404	Calendar (C) or Work Days (W) 3			
805 704 3226	TAT if different from Below 3			
(xxx) xxx-xxxx FAX	☐ 2 weeks			SDG No.
Project Name: REC Americas - Solar PV Panel- TCLP	☐ 1 week			
Site: USA	☐ 2 days			
P O # 44020962 -0	☐ 1 day			Sampler.

Sample Identification	Sample Date	Sample Time	Sample Type	Matrix	# of Cont.	Filtered Sample	6200 TCLP	6010 TCLP	7470 TCLP	8270	Sample Specific Notes:
REC Twin Peak Solar Module	3-Sep-18	9:00	coupon		1		X	X	X	X	

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other 1

Possible Hazard Identification
☒ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* *Poison B* ☐ *Unknown* ☐

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☒ *Disposal By Lab* ☐ *Archive For* _____ *Months*

Special Instructions/QC Requirements & Comments:

2-0/2-1 1288

Relinquished by:	Company.	Date/Time:	Received by:	Company:	Date/Time:
George McClellan	REC Americas	4Sep18 09:10			
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time.
Relinquished by:	Company:	Date/Time	Received by:	Company: TASW	Date/Time: 9/4/18 0910

440-219289 Chain of Custody

Form No. CA-C-WI-002, Rev. 2, dated 03/06/2012

Login Sample Receipt Checklist

Client: REC Americas LLC

Job Number: 440-219289-1

Login Number: 219289
List Number: 1
Creator: Skinner, Alma D

List Source: TestAmerica Irvine

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	N/A	Not present
Sample custody seals, if present, are intact.	N/A	Not Present
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	N/A	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

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SOLAR'S MOST TRUSTED REC

REC TWINPEAK 2S 72 SERIES

PREMIUM SOLAR PANELS WITH SUPERIOR PERFORMANCE

REC TwinPeak 2S 72 Series solar panels feature an innovative design with the higher panel efficiency of polycrystalline cells, enabling customers to get the most out of the space used for the installation.

Combined with industry-leading product quality and the reliability of a strong and established European brand, REC TwinPeak 2S 72 panels are ideal for commercial rooftops worldwide.

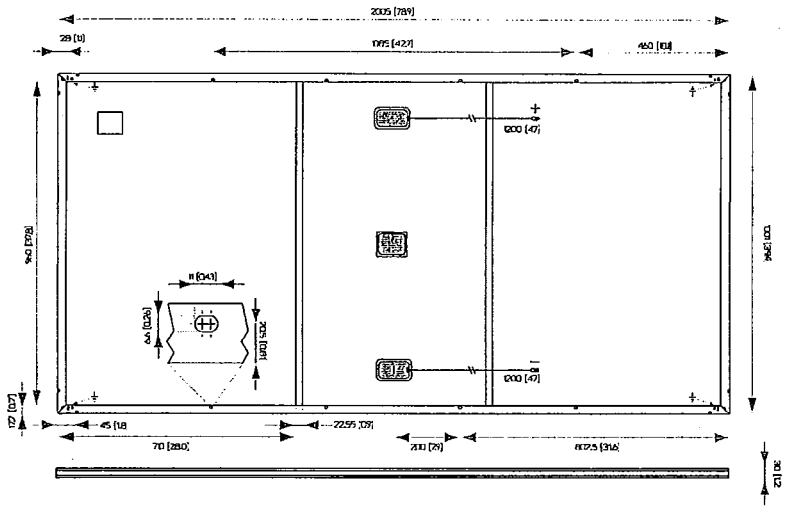
REDUCES BALANCE OF SYSTEM COSTS

IMPROVED PERFORMANCE IN SHADED CONDITIONS

INDUSTRY-LEADING LIGHTWEIGHT 72-CELL PANEL

100% PID FREE

REC TWINPEAK 2S 72 SERIES



Measurements in mm [in]

ELECTRICAL DATA @ STC	Product code*: RECxxxTP2S 72					
Nominal Power - P_{MPP} (Wp)	330	335	340	345	350	355
Watt Class Sorting - (W)	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5
Nominal Power Voltage - V_{MPP} (V)	38.1	38.3	38.5	38.7	38.9	39.1
Nominal Power Current - I_{MPP} (A)	8.67	8.75	8.84	8.92	9.00	9.09
Open Circuit Voltage - V_{OC} (V)	46.0	46.2	46.3	46.5	46.7	46.8
Short Circuit Current - I_{SC} (A)	9.44	9.52	9.58	9.64	9.72	9.78
Panel Efficiency (%)	16.5	16.7	16.9	17.2	17.4	17.7

Values at standard test conditions (STC: air mass AM 1.5, irradiance 1000 W/m², temperature 25°C), based on a production spread with a tolerance of V_{OC} & I_{SC} ±3% within one watt class. At low irradiance of 200 W/m² at least 95% of the STC module efficiency will be achieved.
*Where xxx indicates the nominal power class (P_{MPP}) at STC indicated above, and can be followed by the suffix XV for 1500 V rated modules.

ELECTRICAL DATA @ NMOT	Product code*: RECxxxTP2S 72					
Nominal Power - P_{MPP} (Wp)	244	252	257	260	264	268
Nominal Power Voltage - V_{MPP} (V)	34.9	35.5	35.7	35.8	36.0	36.2
Nominal Power Current - I_{MPP} (A)	6.99	7.10	7.19	7.25	7.32	7.39
Open Circuit Voltage - V_{OC} (V)	42.3	42.8	42.9	43.1	43.2	43.3
Short Circuit Current - I_{SC} (A)	7.44	7.74	7.79	7.84	7.90	7.95

Nominal module operating temperature (NMOT: air mass AM 1.5, Irradiance 800 W/m², temperature 20°C, windspeed 1 m/s).
*Where xxx indicates the nominal power class (P_{MPP}) at STC indicated above, and can be followed by the suffix XV for 1500 V rated modules.

CERTIFICATIONS

IEC 61215, IEC 61730 & UL 1703; MCS 005, IEC 62804 (PID)
IEC 62716 (Ammonia Resistance), IEC 60068-2-68 (Blowing Sand)
IEC 61701 (Salt Mist level 6), UNI 8457/9174 (Class A), ISO 11925-2
(Class E) ISO 9001: 2015, ISO 14001: 2004, OHSAS 18001: 2007

take e-way take-e-way WEEE-compliant recycling scheme

WARRANTY

10 year product warranty
25 year linear power output warranty
(max. degression in performance of 0.7% p.a.)
See warranty conditions for further details.

17.7% EFFICIENCY

10 YEARS PRODUCT WARRANTY

25 YEARS LINEAR PERFORMANCE WARRANTY

GENERAL DATA

MAXIMUM RATINGS

TEMPERATURE RATINGS*

MECHANICAL DATA

Founded in Norway in 1996, REC is a leading vertically integrated solar energy company. Through integrated manufacturing from silicon to wafers, cells, high-quality panels and extending to solar solutions, REC provides the world with a reliable source of clean energy. REC's renowned product quality is supported by the lowest warranty claims rate in the industry. REC is a Bluestar Elkem company with headquarters in Norway and operational headquarters in Singapore. REC employs more than 2,000 people worldwide, producing 1.4 GW of solar panels annually.

REC

www.recgroup.com

TÜVRheinland®

Report Date: 19 July 2016

File Number: 316G2244.001

Client: **JinkoSolar (U.S.) Inc.**
595 Market Street, Suite 2200
San Francisco, CA 94105 USA

Model(s) Identification: JK06D – 60 & 72 Cell Modules with Junction Box

Customer Test Instructions:

Test specification:	*Test result:*
Toxicity Characteristic Leaching Procedure **(TCLP)** –	**Pass**

Checked by:

Tested by:

Date	Name	Signature
7/19/2016	Cody Carson Laboratory Technician	

Date	Name	Signature
7/19/2016	Mark Smith Laboratory Manager	

Testing Period: July 11, 2016 - July19, 2016

RESULTS

Test Sample: **JK06D – 60 Cells Standard Module JB**
JK06D – 72 Cells Standard Module JB

Toxicity Characteristic Leaching Procedure **(TCLP)**

METHOD SUMMARY:

An aliquot of sample is leached with an acetic acid / sodium hydroxide solution at a 1:20 mix of sample to solvent. The leachate mixture is sealed in extraction vessel and tumbled for 18 hours to simulate an extended leaching time in the ground. It is then filtered and the solution is then analyzed for contaminants listed in Table 1.

RESULTS SUMMARY

No analyte concentrations are at a concentration greater than or equal to the respective value in Table 1

TABLE 1 – TCLP – Maximum Concentrations

EPA Waste Number	Contaminant	Regulatory Level (mg/l)
D004	Arsenic	5.000
D005	Barium	100.000
D006	Cadmium	1.000
D007	Chromium	5.000
D008	Lead	5.000
D009	Mercury	0.200
D010	Selenium	1.000
D011	Silver	5.000

Sample Photos:

--END--

1702 East Central Avenue Suite 10
Bentonville, AR 72712
479-271-7996 phone
479-271-8394 fax

Analytical Report

07/18/16 13:29

Client:	TUV Rheinland Of North America Inc. 2709 SE Otis Corley Suite 11 Bentonville AR, 72712	Work Order: Project Name: Project Number:	BG60047 TCLP 7-8-16 TCLP 7-8-16
Attn:	Mark Smith	Date Received:	07/12/16

Environmental Testing Group

Metals by EPA 6000 Series Methods

Analyte	Result	Q	Units	PQL	Dil Factor	Analyzed Date/Time	Analyst	Method	Batch
BG60047-01 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK06D 60 Cell Standard TC**					
Arsenic	ND		mg/L	0.100	100	07/15/16 09:32	MBM	SW846 6020A	B6G1401
Barium	ND		"	0.100	"	"	MBM	"	"
Cadmium	ND		"	0.100	"	"	MBM	"	"
Chromium	ND		"	0.100	"	"	MBM	"	"
Lead	ND		"	0.100	"	"	MBM	"	"
Mercury	ND		"	0.000500	25	07/15/16 12:20	MBM	"	B6G1501
Selenium	ND		"	0.100	100	07/15/16 09:32	MBM	"	B6G1401
Silver	ND		"	0.100	"	"	MBM	"	"
BG60047-02 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK06D 72 Cell Standard TC**					
Arsenic	ND		mg/L	0.100	100	07/15/16 09:32	MBM	SW846 6020A	B6G1401
Barium	ND		"	0.100	"	"	MBM	"	"
Cadmium	ND		"	0.100	"	"	MBM	"	"
Chromium	ND		"	0.100	"	"	MBM	"	"
Lead	ND		"	0.100	"	"	MBM	"	"
Mercury	ND		"	0.000500	25	07/15/16 12:20	MBM	"	B6G1501
Selenium	ND		"	0.100	100	07/15/16 09:32	MBM	"	B6G1401
Silver	ND		"	0.100	"	"	MBM	"	"
BG60047-03 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK07B 60 Cell MX JB TCLP**					
Arsenic	ND		mg/L	0.100	100	07/15/16 09:32	MBM	SW846 6020A	B6G1401
Barium	ND		"	0.100	"	"	MBM	"	"
Cadmium	ND		"	0.100	"	"	MBM	"	"
Chromium	ND		"	0.100	"	"	MBM	"	"
Lead	ND		"	0.100	"	"	MBM	"	"
Mercury	ND		"	0.000500	25	07/15/16 12:20	MBM	"	B6G1501
Selenium	ND		"	0.100	100	07/15/16 09:32	MBM	"	B6G1401
Silver	ND		"	0.100	"	"	MBM	"	"

1702 East Central Avenue Suite 10
Bentonville, AR 72712
479-271-7996 phone
479-271-8394 fax

Analytical Report

07/18/16 13:29

Client:	TUV Rheinland Of North America Inc.	Work Order:	BG60047
	2709 SE Otis Corley Suite 11	Project Name:	TCLP 7-8-16
	Bentonville AR, 72712	Project Number:	TCLP 7-8-16
Attn:	Mark Smith	Date Received:	07/12/16

Environmental Testing Group

Metals by EPA 6000 Series Methods

Analyte	Result	Q	Units	PQL	Dil Factor	Analyzed Date/Time	Analyst	Method	Batch
BG60047-04 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK07B 72 Cell MX JB TCLP**					
Arsenic	ND		mg/L	0.100	100	07/15/16 09:32	MBM	SW846 6020A	B6G1401
Barium	ND		"	0.100	"	"	MBM	"	"
Cadmium	ND		"	0.100	"	"	MBM	"	"
Chromium	ND		"	0.100	"	"	MBM	"	"
Lead	ND		"	0.100	"	"	MBM	"	"
Mercury	ND		"	0.000500	25	07/15/16 12:20	MBM	"	B6G1501
Selenium	ND		"	0.100	100	07/15/16 09:32	MBM	"	B6G1401
Silver	ND		"	0.100	"	"	MBM	"	"

TCLP Extraction by EPA 1311

Analyte	Result	Q	Units	PQL	Dil Factor	Analyzed Date/Time	Analyst	Method	Batch
BG60047-01 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK06D 60 Cell Standard TC**					
TCLP Filterable Solids	100		% by Weight	0.00100	1	07/15/16 09:32	MBM	EPA 1311	B6G1401
BG60047-02 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK06D 72 Cell Standard TC**					
TCLP Filterable Solids	100		% by Weight	0.00100	1	07/15/16 09:32	MBM	EPA 1311	B6G1401
BG60047-03 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK07B 60 Cell MX JB TCLP**					
TCLP Filterable Solids	100		% by Weight	0.00100	1	07/15/16 09:32	MBM	EPA 1311	B6G1401
BG60047-04 (Solid) Sampled: 07/08/16 12:45				**Client Sample Name: Jinko Solar JK07B 72 Cell MX JB TCLP**					
TCLP Filterable Solids	100		% by Weight	0.00100	1	07/15/16 09:32	MBM	EPA 1311	B6G1401

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Analytical Report

07/18/16 13:29

Client:	TUV Rheinland Of North America Inc.	Work Order:	BG60047
	2709 SE Otis Corley Suite 11	Project Name:	TCLP 7-8-16
	Bentonville AR, 72712	Project Number:	TCLP 7-8-16
Attn:	Mark Smith	Date Received:	07/12/16

Metals by EPA 6000 Series Methods - Quality Control

Environmental Testing Group

Analyte	Result	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch B6G1401 - EPA 200.8 v 5.4										
Blank (B6G1401-BLK1)				Prepared: 07/14/16 Analyzed: 07/15/16						
Cadmium	ND	0.00100	mg/L							
Silver	ND	0.00100	"							
Arsenic	ND	0.100	"							
Selenium	ND	0.00100	"							
Chromium	ND	0.00100	"							
Barium	ND	0.00100	"							
Lead	ND	0.00100	"							
LCS (B6G1401-BS1)				Prepared: 07/14/16 Analyzed: 07/15/16						
Silver	0.1994	0.0100	mg/L	0.200		99.7	90-110			
Arsenic	0.204	1.00	"	0.200		102	90-110			
Cadmium	0.208	0.0100	"	0.200		104	90-110			
Chromium	0.206	0.0100	"	0.200		103	80-120			
Selenium	0.197	0.0100	"	0.200		98.3	80-120			
Barium	0.206	0.0100	"	0.200		103	90-110			
Lead	0.207	0.0100	"	0.200		103	90-110			
Matrix Spike (B6G1401-MS1)		Source: BG60047-01		Prepared: 07/14/16 Analyzed: 07/15/16						
Selenium	0.198	0.100	mg/L	0.200	ND	99.0	75-125			
Chromium	0.199	0.100	"	0.200	ND	99.5	75-125			
Arsenic	0.211	10.0	"	0.200	ND	106	75-125			
Silver	0.1900	0.100	"	0.200	ND	95.0	75-125			
Cadmium	0.204	0.100	"	0.200	ND	102	75-125			
Barium	0.267	0.100	"	0.200	ND	104	75-125			
Lead	0.208	0.100	"	0.200	ND	92.5	75-125			
Matrix Spike Dup (B6G1401-MSD1)		Source: BG60047-01		Prepared: 07/14/16 Analyzed: 07/15/16						
Chromium	0.206	0.100	mg/L	0.200	ND	103	75-125	3.46	20	
Selenium	0.199	0.100	"	0.200	ND	99.5	75-125	0.504	20	
Silver	0.1850	0.100	"	0.200	ND	92.5	75-125	2.67	20	
Cadmium	0.205	0.100	"	0.200	ND	102	75-125	0.489	20	
Arsenic	0.210	10.0	"	0.200	ND	105	75-125	0.475	20	
Barium	0.263	0.100	"	0.200	ND	102	75-125	1.51	20	
Lead	0.209	0.100	"	0.200	ND	93.0	75-125	0.480	20	

ASTRONERGY

Declaration Letter

Date: Nov. 6th, 2017

To: M+W Energy, Inc.
Subject: Declaration letter for TCLP Report

We are pleased to inform you that our the solar module Toxicity Characteristic Leaching Procedure (TCLP) report is available for distribution. We confirm that the results fall within current EPA Standards.

Astronergy| Chint Solar
Anna Wang |Sales Director- the Americas
anna.wang@astronergy.com

Anna Wang

Hanwha SolarOne

Hanwha SolarOne PV Module Technical Specification

www. Hanwha-solarone.com
Hanwha SolarOne (Qidong) Co., Ltd.
Add: 888, Linyang Road, Qidong, Jiangsu 226200, China
Tel: +86-513-83606222
E-mail: market@hanwha-solarone.com

Module Technology Department
Version 1.0 / May 1, 2011

e technical specification of Hanwha SolarOne PV modules is
:quently updated and the content of this document is subject
change without prior notice.
ggestions and feedback are welcome as part of our continuous
provement program.

rsion 1.0

ınwha SolarOne (Qidong) Co., Ltd.
ɔdule Technology Department
ay 1, 2011

Catalogue

Standard series

SF160-24 (Mono) 4
SF190-27 (Poly) 8
SF220-30 (Poly) 12
SF260-36 (Poly) 16

X-tra series

SF160-24 (Mono) 20
SF190-27 (Poly) 24
SF220-30 (Poly) 28
SF260-36 (Poly) 32

E-star series

SF160-24 (Mono) 36
SF190-27 (Poly) 40
SF220-30 (Poly) 44
SF260-36 (Poly) 48

Black diamond series

SF160-24 (Mono) standard 52
SF160-24 (Mono) X-tra 56
SF160-24 (Mono) E-star 60

Appendix: Packaging details

Module Specifications:

Standard module

SF160-24-1Mxxx* (IEC) / SF160-24-Mxxx* (UL)

Hanwha SolarOne (Qidong)

1. Electrical Characteristics

*1.1 Electrical characteristics at STC***

** Pmax, Voc, Isc, Vmp and Imp tested at Standard Testing Conditions (STC) defined as irradiance of 1000W/m^2 at AM 1.5G solar spectrum and a temperature 25±2℃

Power tolerance of +/- 3% refers to measured performance.

Maximum Power (P_{max})	170W	175W	180W	185W	190W	195W
Open Circuit Voltage (V_{oc})	43.8V	44.0V	44.3V	44.6V	44.8V	45.0V
Short Circuit Current (I_{sc})	5.36A	5.48A	5.59A	5.68A	5.78A	5.85A
Maximum Power Voltage (V_{mp})	35.0V	35.2V	35.4V	35.6V	35.8V	36.0V
Maximum Power Current (I_{mp})	4.86A	4.98A	5.11A	5.21A	5.33A	5.42A
Module Efficiency (%)	13.3	13.7	14.1	14.5	14.9	15.3
Cell Efficiency (%)	15.4	15.8	16.3	16.7	17.2	17.6

*1.2 Electrical characteristics at NOCT****

*** Pmax, Voc, Isc, Vmp and Imp tested at Normal Operating Cell Temperature (NOCT) defined as irradiance of 800W/m^2; 45±3℃; Wind speed 1m/s

Power tolerance of +/- 3% refers to measured performance.

Maximum Power (P_{max})	122W	126W	130W	133W	137W	140W
Open Circuit Voltage (V_{oc})	40.3V	40.5V	40.8V	41.0V	41.2V	41.4V
Short Circuit Current (I_{sc})	4.34A	4.44A	4.53A	4.60A	4.68A	4.74A
Maximum Power Voltage (V_{mp})	31.5V	31.7V	31.9V	32.0V	32.2V	32.4V
Maximum Power Current (I_{mp})	3.89A	3.98A	4.09A	4.17A	4.26A	4.34A
Module Efficiency (%)	11.9	12.3	12.7	13.0	13.4	13.7
Cell Efficiency (%)	15.4	15.8	16.3	16.7	17.2	17.6

1.3 Performance at Low Irradiance

The typical relative change in module efficiency at an irradiance of 200 W / m^2 in relation to 1000 W / m^2 (both at 25°C and AM 1.5G spectrum) is less than 6%.

1.4 Temperature Coefficients

Temperature Coefficients of P	-0.44%/K; -0.44%/℃
Temperature Coefficients of V	-0.33%/K; -0.33%/℃
Temperature Coefficients of I	+0.03%/K; +0.03%/℃

1.5 Absolute Maximum Ratings

Storage Temperature	-40℃ to +85℃
Operating Temperature	-40℃ to +85℃
Hail Safety Impact Velocity	Hailstone (25mm) at 23m/s
Fire Safety Classification	Class C
Static Load Wind / Snow	2400Pa/5400Pa
Series Fuse Rating	10A
Maximum Reverse Current	1.35×Fuse rating

1.6 Maximum System Voltage and Certifications

Maximum System Voltage	1000 V (IEC) / 600 V (UL)
Certifications	TÜV and VDE (IEC61215 & IEC61730 Application Class A) MCS (IEC61215 & IEC61730 Application Class A) Golden Sun(IEC61215 & IEC61730 Application Class A) Kemco (IEC61215 & IEC61730 Application Class A) UL (UL1703) CE (LVD & EMC)

2. Mechanical Characteristics

Cell Technology	Hanwha SolarOne, 125 × 125 mm Mono-Si
Number of Cells (Pcs)	72 (6 × 12)
Dimensions	1580 × 808 × 40 mm
Weight	14 kg
Junction Box	protection class IP65, with bypass-diode
Output Cables / Connector	solar cable: 4 mm^2; length: 900 mm / MC4 compatible
Frame	anodized aluminum-alloy
Front / Encapsulant / Back	3.2mm tempered glass / EVA / white back sheet
Packing method	24pcs /carton, 672pcs/container

*Nominal power output

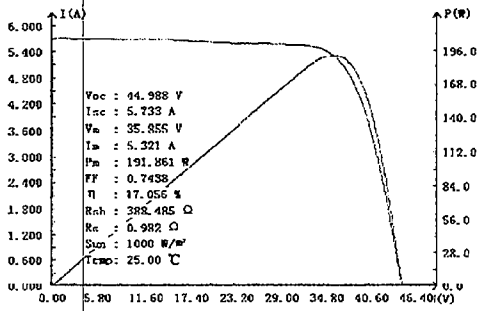
Hanwha SolarOne (Qidong) Co., Ltd.

Specifications subject to change at any time

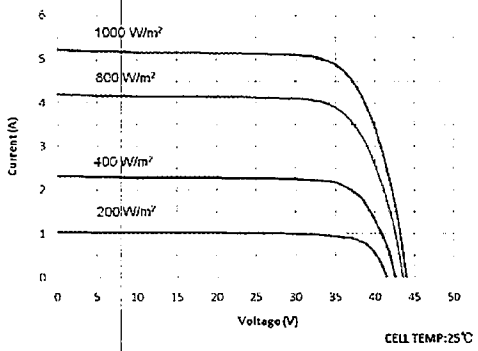
Version 1.0 / Updated: 2011-05-01

3. I-V Characteristic Curve

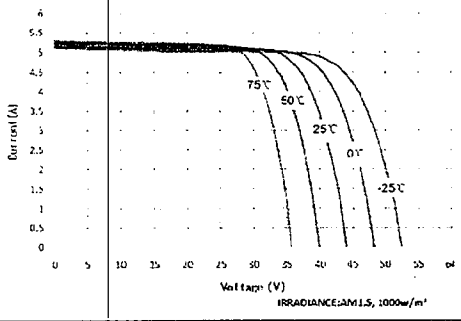
3.1 I-V Characteristic Curve of Module at STC



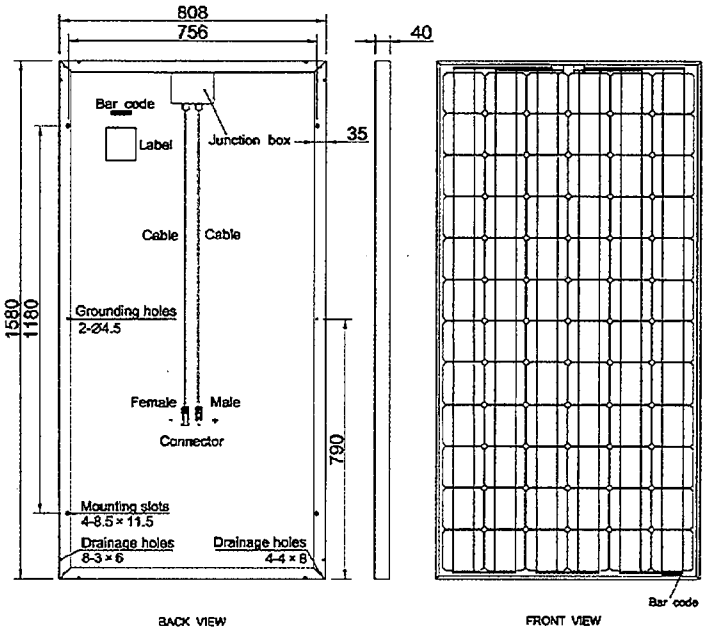
3.2 I-V Characteristic Curves at Various Irradiance Levels

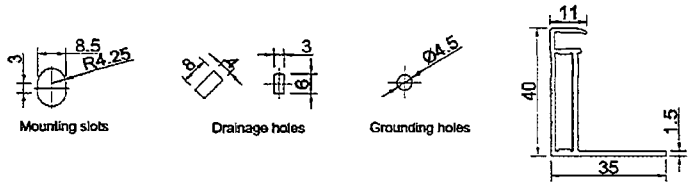


3.3 I-V Characteristic Curves at Various Cell Temperatures



4. Basic Dimensions





Hanwha SolarOne (Qidong) Co., Ltd.

888 Linyang Road

Qidong, Jiangsu Province, 226200, P. R. China

Phone: +86-513-83606222 Fax: +86-513-83606278

www. hanwha-solarone .com

Module Specifications:

Standard module

SF190-27-1Pxxx* (IEC) / SF190-27-Pxxx* (UL)

Hanwha SolarOne (Qidong)

1. Electrical Characteristics

*1.1 Electrical characteristics at STC***

** Pmax, Voc, Isc, Vmp and Imp tested at Standard Testing Conditions (STC) defined as irradiance of 1000W/m^2 at AM 1.5G solar spectrum and a temperature 25±2℃

Power tolerance of +/- 3% refers to measured performance.

Maximum Power (P_{max})	200W	205W	210W	215W	220W	225W
Open Circuit Voltage (V_{oc})	32.8V	32.9V	33.0V	33.1V	33.2V	33.3V
Short Circuit Current (I_{sc})	8.24A	8.35A	8.48A	8.54A	8.68A	8.75A
Maximum Power Voltage (V_{mp})	26.9V	27.0V	27.1V	27.2V	27.3V	27.5V
Maximum Power Current (I_{mp})	7.44A	7.60A	7.75A	7.91A	8.06A	8.18A
Module Efficiency (%)	13.4	13.7	14.0	14.4	14.7	15.1
Cell Efficiency (%)	15.4	15.8	16.2	16.5	16.9	17.3

*1.2 Electrical characteristics at NOCT****

*** Pmax, Voc, Isc, Vmp and Imp tested at Normal Operating Cell Temperature (NOCT) defined as irradiance of 800W/m^2; 45±3℃; Wind speed 1m/s

Power tolerance of +/- 3% refers to measured performance.

Maximum Power (P_{max})	148W	150W	152W	156W	160W	164W
Open Circuit Voltage (V_{oc})	30.9V	31.2V	31.4V	31.6V	31.8V	31.9V
Short Circuit Current (I_{sc})	6.76A	6.80A	6.82A	6.91A	7.02A	7.08A
Maximum Power Voltage (V_{mp})	23.8V	23.9V	24.2V	24.5V	24.8V	25.0V
Maximum Power Current (I_{mp})	6.22A	6.30A	6.35A	6.37A	6.45A	6.54A
Module Efficiency (%)	12.4	12.6	12.7	13.1	13.4	13.7
Cell Efficiency (%)	15.4	15.8	16.2	16.5	16.9	17.3

1.3 Performance at Low Irradiance

The typical relative change in module efficiency at an irradiance of 200 W / m² in relation to 1000 W / m² (both at 25°C and AM 1.5G spectrum) is less than 6%.

1.4 Temperature Coefficients

Temperature Coefficients of P	-0.45%/K; -0.45%/℃
Temperature Coefficients of V	-0.32%/K; -0.32%/℃
Temperature Coefficients of I	+0.04%/K; +0.04%/℃

1.5 Absolute Maximum Ratings

Storage Temperature	-40℃ to +85℃
Operating Temperature	-40℃ to +85℃
Hail Safety Impact Velocity	Hailstone (25mm) at 23m/s
Fire Safety Classification	Class C
Static Load Wind / Snow	2400Pa/5400Pa
Series Fuse Rating	15A
Maximum Reverse Current	1.35×Fuse rating

1.6 Maximum System Voltage and Certifications

Maximum System Voltage	1000 V (IEC) / 600 V (UL)
Certifications	TÜV (IEC61215 & IEC61730 Application Class A) MCS (IEC61215 & IEC61730 Application Class A) Golden Sun(IEC61215 & IEC61730 Application Class A) Kemco (IEC61215 & IEC61730 Application Class A) UL (UL1703) CE (LVD & EMC)

2. Mechanical Characteristics

Cell Technology	Hanwha SolarOne, 156 × 156 mm Poly-Si
Number of Cells (Pcs)	54(6 × 9)
Dimensions	1494 × 1000 × 40 mm
Weight	17 kg
Junction Box	protection class IP65, with bypass-diode
Output Cables / Connector	solar cable: 4 mm^2; length: 900 mm / MC4 compatible
Frame	anodized aluminum-alloy
Front / Encapsulant / Back	3.2mm tempered glass / EVA / white back sheet
Packing method	24pcs /carton, 720pcs/container

*Nominal power output

Hanwha SolarOne (Qidong) Co., Ltd.

Specifications subject to change at any time

Version 1.0 / Updated: 2011-05-01

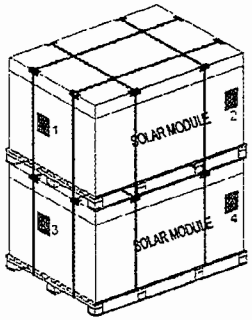
yle A (Standard): SF 160 Series: 40mm Frame

ckaging Details:

›dule dimension	1580×808 × 40mm
let dimensions	1625 × 1090 × 165 mm
:kage (double-stacked pallet) dimensions	1625 × 1090 × 1990 mm
›ss weight per package	765 kg
antity per carton	24 pcs
antity per pallet	24pcs
antity per package	48 pcs
›acity per container (40 ft)	672 pcs
›acity per container (20 ft)	288 pcs

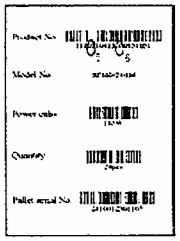
ckage Design:

- Total quantity: 48 modules
- Arrangement: 24 modules per carton, 1 cartons per pallet
- 2 stacked pallets per package
- Corrugated cardboard tab under each green packing belt for additional protection
- Entire package wrapped with plastic film for increased stability and protection from moisture
- Pallet construction: Solid wood



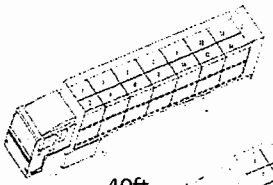
›el information:

- Four label positions on each package (as shown on the right)
- Package information included in product bar code
- 4th and 5th digit of product number represent module type, for instance "01" indicates SF 160
- 11th and 12th digit of product number represent frame type. for instance "03" indicates 40 frame

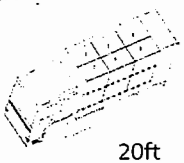


llet arrangement in container:

- Pallets arranged as shown in diagram
- 14 packages per container (672 modules)
- 6 packages per container (288 modules)
- 2 plastic bags in 40ft container;4 plastic bags in 20ft container



40ft



20ft

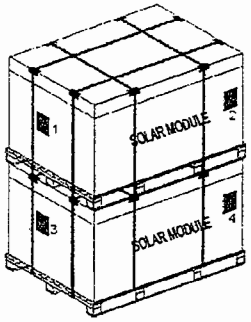
Style B (Standard): SF 190 Series: 40mm Frame

Packaging Details:

Module dimension	1494×1000×40mm
Pallet dimensions	1550× 1100× 165 mm
Package dimensions	1550 × 1100× 2370 mm
Gross weight per package	910 kg
Quantity per carton	24 pcs
Quantity per pallet	24pcs
Quantity per package	48 pcs
Capacity per container (40 hq)	720 pcs

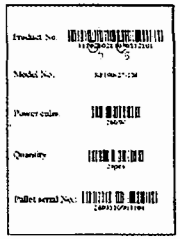
Package Design:

- Total quantity: 48 modules
- Arrangement: 24 modules per carton, 1 cartons per pallet
- 2 stacked pallets per package
- Corrugated cardboard tab under each green packing belt for additional protection
- Entire package wrapped with plastic film for increased stability and protection from moisture
- Pallet construction: Solid wood



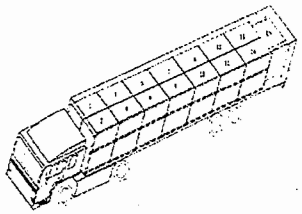
Label information:

- Four label positions on each package (as shown on the right)
- Package information included in product bar code
- 4th and 5th digit of product number represent module type, for instance "02" indicates SF 190
- 11th and 12th digit of product number represent frame type. for instance "03" indicates 40 frame



Pallet arrangement in container:

- Pallets arranged as shown in diagram
- 15 packages per container (720 modules)
- 2 plastic bags in 40ft container



40 ft high container

ANALABS

ANALYTICAL LABORATORIES (SINGAPORE) PTE LTD

Analytical Chemists; Environmental and Materials Testing
8 Kaki Bukit Place, Singapore 416186 Tel: 67460886 Fax: 67463830 Email: admin@analabs.com.sg
CO. REG NO. 197302347G GST REG NO. M2-0017430-5

ilac-MRA

ACCREDITED LABORATORY SAC-SINGLAS
Cert No: LA-1997-0006-A
Cert No: LA-1999-0167-F

REPORT

Lab No : AC/ES/2923/15
Company Name : REC Solar Pte Ltd
Date Received : 05/05/2015 **Date Reported:** 12/05/2015
Sample Description : One sample of Solar Panel
Date Tested: 08/05/2015-12/05/2015

The sample consisted of one roll of solar panel marked:

2004092670

The sample was extracted in accordance with EPA Method 1311 Toxicity Characteristic Leaching Procedure (TCLP).

On analysis of the leachate, the following results were obtained:

Test	Method	Result	TCLP Recommended Acceptable Criteria for suitability of Industrial Wastes for Landfill Disposal
Arsenic (As), ppm	ICP-MS	<0.1	5
Barium (Ba), ppm	Inductively Coupled Plasma	<0.5	100
Cadmium (Cd), ppm	Inductively Coupled Plasma	Not detected (<0.1)	1
Chromium (Cr), ppm	Inductively Coupled Plasma	Not detected (<0.2)	5
Copper (Cu), ppm	Inductively Coupled Plasma	<0.1	100
Total Cyanide (CN), ppm	APHA 4500-CN F	<0.1	10
Fluoride (F), ppm	APHA 4500-F C	0.3	150
Iron (Fe), ppm	Inductively Coupled Plasma	0.1	100
Lead (Pb), ppm	Inductively Coupled Plasma	4.2	5
Manganese (Mn), ppm	Inductively Coupled Plasma	Not detected (<0.1)	50
Mercury (Hg), ppm	ICP-MS	Not detected (<0.1)	0.2
Nickel (Ni), ppm	Inductively Coupled Plasma	Not detected (<0.1)	5
Phenolic Compounds (as Phenol), ppm	APHA 5530 D	<0.1	0.2
Selenium (Se), ppm	ICP-MS	<0.1	1
Silver (Ag), ppm	Inductively Coupled Plasma	Not detected (<0.1)	5
Zinc (Zn), ppm	Inductively Coupled Plasma	0.3	100

Notes:
1) ICP-MS = Inductively Coupled Plasma - Mass Spectrometry
2) APHA = American Public Health Association
3) EPA = Environmental Protection Agency
4) < = Less than
5) The above results are within the TCLP Recommended Acceptable Criteria for suitability of Industrial Wastes for Landfill Disposal.

Tan Siok Meng
Testing Officer

Phang Ken Aun
Acting Manager
ANALYTICAL LABORATORIES (S) PTE. LTD.

REC Solar Pte Ltd
20 Tuas South Avenue 14
Singapore 637312

ANALABS

ANALYTICAL LABORATORIES (SINGAPORE) PTE LTD

Analytical Chemists; Environmental and Materials Testing
8 Kaki Bukit Place, Singapore 416186 Tel: 67460886 Fax: 67463830 Email: admin@analabs.com.sg
CO. REG NO. 197302347G GST REG NO. M2-0017430-5

ilac-MRA

ACCREDITED LABORATORY SAC-SINGLAS Cert No: LA-1987-0006-A Cert No: LA-1999-0167-F

REPORT

Lab No : AC/ES/2923A/15

Company Name : REC Solar Pte Ltd

Date Received : 05/05/2015 **Date Reported:** 12/05/2015

Sample Description : One sample of Solar Panel

Date Tested: 08/05/2015-12/05/2015

The sample consisted of one roll of solar panel marked:

3004041181

The sample was extracted in accordance with EPA Method 1311 Toxicity Characteristic Leaching Procedure (TCLP).

On analysis of the leachate, the following results were obtained:

Test	Method	Result	TCLP Recommended Acceptable Criteria for suitability of Industrial Wastes for Landfill Disposal
Arsenic (As), ppm	ICP-MS	<0.1	5
Barium (Ba), ppm	Inductively Coupled Plasma	<0.5	100
Cadmium (Cd), ppm	Inductively Coupled Plasma	Not detected (<0.1)	1
Chromium (Cr), ppm	Inductively Coupled Plasma	Not detected (<0.2)	5
Copper (Cu), ppm	Inductively Coupled Plasma	0.2	100
Total Cyanide (CN), ppm	APHA 4500-CN F	<0.1	10
Fluoride (F), ppm	APHA 4500-F C	0.2	150
Iron (Fe), ppm	Inductively Coupled Plasma	<0.1	100
Lead (Pb), ppm	Inductively Coupled Plasma	4.3	5
Manganese (Mn), ppm	Inductively Coupled Plasma	Not detected (<0.1)	50
Mercury (Hg), ppm	ICP-MS	Not detected (<0.1)	0.2
Nickel (Ni), ppm	Inductively Coupled Plasma	Not detected (<0.1)	5
Phenolic Compounds (as Phenol), ppm	APHA 5530 D	<0.1	0.2
Selenium (Se), ppm	ICP-MS	<0.1	1
Silver (Ag), ppm	Inductively Coupled Plasma	Not detected (<0.1)	5
Zinc (Zn), ppm	Inductively Coupled Plasma	0.2	100

Notes:
1) ICP-MS = Inductively Coupled Plasma - Mass Spectrometry
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Tan Siok Meng
Testing Officer

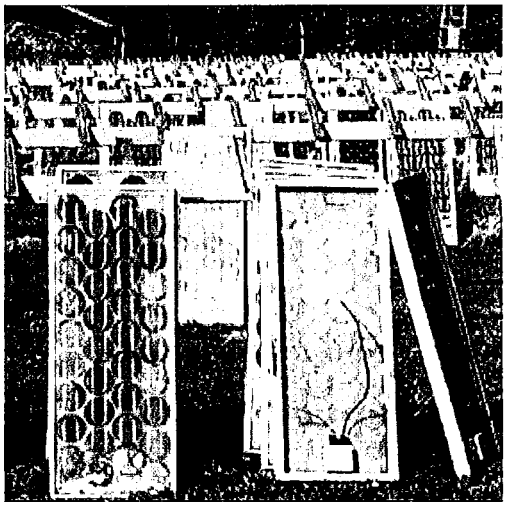
Phang Ken Aun
Acting Manager
ANALYTICAL LABORATORIES (S) PTE. LTD.

REC Solar Pte Ltd
20 Tuas South Avenue 14
Singapore 637312

EXHIBIT L

If Solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste?

Michael Shellenberger Contributor
Energy
I write about energy and the environment



Bell Labs, 1954. Solar Panel Waste, 2014 BELL LABS & PV CYCLE

Para la traducción al español, haga clic aquí

Klik hier voor de Nederlandse versie

The last few years have seen growing concern over what happens to solar panels at the end of their life. Consider the following statements:

- The problem of solar panel disposal "will explode with full force in two or three decades and wreck the environment" because it "is a huge amount of waste and they are not easy to recycle."

- "The reality is that there is a problem now, and it's only going to get larger, expanding as rapidly as the PV industry expanded 10 years ago."
- "Contrary to previous assumptions, pollutants such as lead or carcinogenic cadmium can be almost completely washed out of the fragments of solar modules over a period of several months, for example by rainwater."

Were these statements made by the right-wing Heritage Foundation? Koch-funded global warming deniers? The editorial board of the *Wall Street Journal*?

None of the above. Rather, the quotes come from a senior Chinese solar official, a 40-year veteran of the U.S. solar industry, and research scientists with the German Stuttgart Institute for Photovoltaics.

With few environmental journalists willing to report on much of anything other than the good news about renewables, it's been left to environmental scientists and solar industry leaders to raise the alarm.

"I've been working in solar since 1976 and that's part of my guilt," the veteran solar developer told *Solar Power World* last year. "I've been involved with millions of solar panels going into the field, and now they're getting old."

The Trouble With Solar Waste

The International Renewable Energy Agency (IRENA) in 2016 estimated there was about 250,000 metric tonnes of solar panel waste in the world at the end of that year. IRENA projected that this amount could reach 78 *million* metric tonnes by 2050.

Solar panels often contain lead, cadmium, and other toxic chemicals that cannot be removed without breaking apart the entire panel. "Approximately 90% of most PV modules are made up of glass," notes San Jose State environmental studies professor Dustin Mulvaney. "However, this glass often

cannot be recycled as float glass due to impurities. Common problematic impurities in glass include plastics, lead, cadmium and antimony."

Researchers with the Electric Power Research Institute (EPRI) undertook a study for U.S. solar-owning utilities to plan for end-of-life and concluded that solar panel "disposal in "regular landfills [is] not recommended in case modules break and toxic materials leach into the soil" and so "disposal is potentially a major issue."

California is in the process of determining how to divert solar panels from landfills, which is where they currently go, at the end of their life.

California's Department of Toxic Substances Control (DTSC), which is implementing the new regulations, held a meeting last August with solar and waste industry representatives to discuss how to deal with the issue of solar waste. At the meeting, the representatives from industry and DTSC all acknowledged how difficult it would be to test to determine whether a solar panel being removed would be classified as hazardous waste or not.

The DTSC described building a database where solar panels and their toxicity could be tracked by their model numbers, but it's not clear DTSC will do this.

"The theory behind the regulations is to make [disposal] less burdensome," explained Rick Brausch of DTSC. "Putting it as universal waste eliminates the testing requirement."

The fact that cadmium can be washed out of solar modules by rainwater is increasingly a concern for local environmentalists like the Concerned Citizens of Fawn Lake in Virginia, where a 6,350 acre solar farm to partly power Microsoft data centers is being proposed.

"We estimate there are 100,000 pounds of cadmium contained in the 1.8 million panels," Sean Fogarty of the group told me. "Leaching from broken panels damaged during natural events — hail storms, tornadoes, hurricanes, earthquakes, etc. — and at decommissioning is a big concern."

There is real-world precedent for this concern. A tornado in 2015 broke 200,000 solar modules at southern California solar farm Desert Sunlight.

"Any modules that were broken into small bits of glass had to be swept from the ground," Mulvaney explained, "so lots of rocks and dirt got mixed in that would not work in recycling plants that are designed to take modules. These were the cadmium-based modules that failed [hazardous] waste tests, so were treated at a [hazardous] waste facility. But about 70 percent of the modules were actually sent to recycling, and the recycled metals are in new panels today."

And when Hurricane Maria hit Puerto Rico last September, the nation's second largest solar farm, responsible for 40 percent of the island's solar energy, lost a majority of its panels.

Destroys Solar Farm in Puerto Rico BOB MEINETZ

Many experts urge mandatory recycling. The main finding promoted by IRENA's in its 2016 report was that, "If fully injected back into the economy, the value of the recovered material [from used solar panels] could exceed USD 15 billion by 2050."

But IRENA's study did not compare the value of recovered material to the cost of new materials and admitted that "Recent studies agree that PV material availability is not a major concern in the near term, but critical materials might impose limitations in the long term."

They might, but today recycling costs more than the economic value of the materials recovered, which is why most solar panels end up in landfills. "The absence of valuable metals/materials produces economic losses," wrote a team of scientists in the *International Journal of Photoenergy* in their study of solar panel recycling last year, and "Results are coherent with the literature."

Chinese and Japanese experts agree. "If a recycling plant carries out every step by the book," a Chinese expert told *The South China Morning Post*, "their products can end up being more expensive than new raw materials."

Toshiba Environmental Solutions told Nikkei Asian Review last year that,

> "Low demand for scrap and the high cost of employing workers to disassemble the aluminum frames and other components will make it difficult to create a profitable business unless recycling companies can charge several times more than the target set by [Japan's environment ministry].

Can Solar Producers Take Responsibility?

In 2012, First Solar stopped putting a share of its revenues into a fund for long-term waste management. "Customers have the option to use our services when the panels get to the end of life stage," a spokesperson told *Solar Power World*. "We'll do the recycling, and they'll pay the price at that time."

Or they won't. "Either it becomes economical or it gets mandated. " said EPRI's Cara Libby. "But I've heard that it will have to be mandated because it won't ever be economical."

Last July, Washington became the first U.S. state to require manufacturers selling solar panels to have a plan to recycle. But the legislature did not require manufacturers to pay a fee for disposal. "Washington-based solar panel manufacturer Itek Energy assisted with the bill's writing," noted Solar Power World.

The problem with putting the responsibility for recycling or long-term storage of solar panels on manufacturers, says the insurance actuary Milliman, is that it increases the risk of more financial failures like the kinds that afflicted the solar industry over the last decade.

[A]ny mechanism that finances the cost of recycling PV modules with current revenues is not sustainable. This method raises the possibility of bankruptcy down the road by shifting today's greater burden of 'caused' costs into the future. When growth levels off then PV producers would face rapidly increasing recycling costs as a percentage of revenues.

Since 2016, Sungevity, Beamreach, Verengo Solar, SunEdison, Yingli Green Energy, Solar World, and Suniva have gone bankrupt.

The result of such bankruptcies is that the cost of managing or recycling PV waste will be born by the public. "In the event of company bankruptcies, PV module producers would no longer contribute to the recycling cost of their products," notes Milliman, "leaving governments to decide how to deal with cleanup."

Governments of poor and developing nations are often not equipped to deal with an influx of toxic solar waste, experts say. German researchers at the Stuttgart Institute for Photovoltaics warned that poor and developing nations are at higher risk of suffering the consequences.

Maharashtra, India, 2014 DIPAK SHEELARE

> Dangers and hazards of toxins in photovoltaic modules appear particularly large in countries where there are no orderly waste management systems... Especially in less developed countries in the so-called global south, which are particularly predestined for the use of photovoltaics because of the high solar radiation, it seems highly problematic to use modules that contain pollutants.

The attitude of some solar recyclers in China appears to feed this concern. "A sales manager of a solar power recycling company," the *South China Morning News* reported, "believes there could be a way to dispose of China's solar junk, nonetheless."

"We can sell them to Middle East... Our customers there make it very clear that they don't want perfect or brand new panels. They just want them cheap... There, there is lots of land to install a large amount of panels to make up for their low performance. Everyone is happy with the result."

In other words, there are firms that may advertise themselves as "solar panel recyclers" but instead sell panels to a secondary markets in nations with less developed waste disposal systems. In the past, communities living near electronic waste dumps in Ghana, Nigeria, Vietnam, Bangladesh, Pakistan, and India have been primary e-waste destinations.

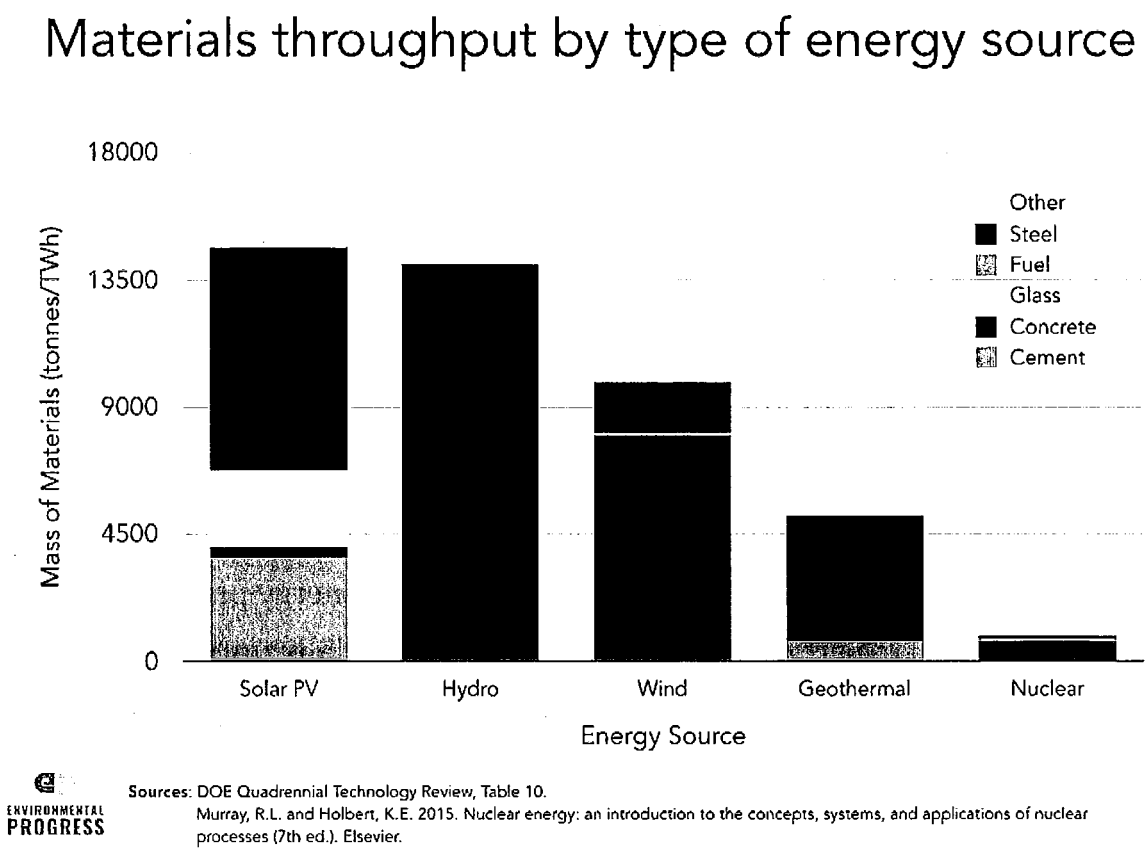
According to a 2015 United Nations Environment Program (UNEP) report, somewhere between 60 and 90 percent of electronic waste is illegally traded and dumped in poor nations. Writes UNEP:

> [T]housands of tonnes of e-waste are falsely declared as second-hand goods and exported from developed to developing countries, including waste batteries falsely described as plastic or mixed metal scrap, and cathode ray tubes and computer monitors declared as metal scrap.

Unlike other forms of imported e-waste, used solar panels can enter nations legally before eventually entering e-waste streams. As the United Nation Environment Program notes, “loopholes in the current Waste Electrical and Electronic Equipment (WEEE) Directives allow the export of e-waste from developed to developing countries (70% of the collected WEEE ends up in unreported and largely unknown destinations).”

A Path Forward on Solar Panel Waste

Perhaps the biggest problem with solar panel waste is that there is so much of it, and that's not going to change any time soon, for a basic physical reason: sunlight is dilute and diffuse and thus require large collectors to capture and convert the sun's rays into electricity. Those large surface areas, in turn, require an order of magnitude more in materials — whether today's toxic combination of glass, heavy metals, and rare earth elements, or some new material in the future — than other energy sources.



Solar requires 15x more materials than nuclear EP

All of that waste creates a large quantity of material to track, which in turn requires requires coordinated, overlapping, and different responses at the international, national, state, and local levels.

The local level is where action to dispose of electronic and toxic waste takes place, often under state mandates. In the past, differing state laws have motivated the U.S. Congress to put in place national regulations. Industry often prefers to comply with a single national standard rather than multiple different state standards. And as the problem of the secondary market for solar shows, ultimately there needs to be some kind of international regulation.

The first step is a fee on solar panel purchases to make sure that the cost of safely removing, recycling or storing solar panel waste is internalized into the price of solar panels and not externalized onto future taxpayers. An obvious solution would be to impose a new fee on solar panels that would go into a federal disposal and decommissioning fund. The funds would then, in the

future, be dispensed to state and local governments to pay for the removal and recycling or long-term storage of solar panel waste. The advantage of this fund over extended producer responsibility is that it would insure that solar panels are safely decommissioned, recycled, or stored over the long-term, even after solar manufacturers go bankrupt.

Second, the federal government should encourage citizen enforcement of laws to decommission, store, or recycle solar panels so that they do not end up in landfills. Currently, citizens have the right to file lawsuits against government agencies and corporations to force them to abide by various environmental laws, including ones that protect the public from toxic waste. Solar should be no different. Given the decentralized nature of solar energy production, and lack of technical expertise at the local level, it is especially important that the whole society be involved in protecting itself from exposure to dangerous toxins.

"We have a County and State approval process over the next couple months," Fogarty of Concerned Citizens of Fawn Lake told me, "but it has become clear that local authorities have very little technical breadth to analyze the impacts of such a massive solar power plant."

Lack of technical expertise can be a problem when solar developers like Sustainable Power Group, or sPower, incorrectly claim that the cadmium in its panels is not water soluble. That claim has been contradicted by the previously-mentioned Stuttgart research scientists who found cadmium from solar panels "can be almost completely washed out...over a period of several months...by rainwater."

Third, the United Nations Environment Programme's Global Partnership for Waste Management, as part of its International Environmental Partnership Center, should more strictly monitor e-waste shipments and encourage nations importing used solar panels into secondary markets to impose a fee to cover the cost of recycling or long-term management. Such a recycling and waste management fund could help nations address their other e-waste

problems while supporting the development of a new, high-tech industry in recycling solar panels.

None of this will come quickly, or easily, and some solar industry executives will resist internalizing the cost of safely storing, or recycling, solar panel waste, perhaps for understandable reasons. They will rightly note that there are other kinds of electronic waste in the world. But it is notable that some new forms of electronic waste, namely smartphones like the iPhone, have in many cases replaced things like stereo systems, GPS devices, and alarm clocks and thus reduced their contribution to the e-waste stream. And no other electronics industry makes being "clean" its main selling point.

Wise solar industry leaders can learn from the past and be proactive in seeking stricter regulation in accordance with growing scientific evidence that solar panels pose a risk of toxic chemical contamination. "If waste issues are not preemptively addressed," warns Mulvaney, "the industry risks repeating the disastrous environmental mistakes of the electronics industry."

If the industry responds with foresight, Mulvaney notes, it could end up sparking clean innovation including "developing PV modules without hazardous inputs and recycled rare metals." And that's something everyone can get powered up about.

Michael Shellenberger Contributor

I am a Time Magazine "Hero of the Environment," Green Book Award Winner, and President of Environmental Progress, a research and policy organization. My writings have ap...
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EXHIBIT M

Japanese Journal of Applied Physics

The Japan Society of Applied Physics

REGULAR PAPERS

Long-term leaching of photovoltaic modules

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REGULAR PAPER

Long-term leaching of photovoltaic modules

Jessica Nover[1*], Renate Zapf-Gottwick[1], Carolin Feifel[2], Michael Koch[2], Jörg W. Metzger[2], and Jürgen H. Werner[1]

[1]*Institute for Photovoltaics, University of Stuttgart, 70174 Stuttgart, Germany*
[2]*Institute for Sanitary Engineering, Water Quality and Solid Waste Management, University of Stuttgart, 70174 Stuttgart, Germany*

*E-mail: jessica.nover@ipv.uni-stuttgart.de

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Some photovoltaic module technologies use toxic materials. We report long-term leaching on photovoltaic module pieces of 5 x 5 cm^2 size. The pieces are cut out from modules of the four major commercial photovoltaic technologies: crystalline and amorphous silicon, cadmium telluride as well as from copper indium gallium diselenide. To simulate different environmental conditions, leaching occurs at room temperature in three different water-based solutions with pH 3, 7, and 11. No agitation is performed to simulate more representative field conditions. After 360 days, about 1.4% of lead from crystalline silicon module pieces and 62% of cadmium from cadmium telluride module pieces are leached out in acidic solutions. The leaching depends heavily on the pH and the redox potential of the aqueous solutions and it increases with time. The leaching behavior is predictable by thermodynamic stability considerations. These predictions are in good agreement with the experimental results.

1. Introduction

Many different elution tests for waste characterization exist worldwide to quantify leached elements out of different wastes and to classify them into risk groups.[1–4] All these tests have different requirements regarding sample size, leaching solution and treatment method. For example, the European Standard EN 12457-4 for the characterization of granular waste materials demands distilled water as leaching solution.[1] In contrast, the Toxicity Characterization Leaching Procedure (TCLP), used in the United States, requires acetic acid and sodium hydroxide as solution with a pH = 4.93 ± 0.05.[2] For all these tests, leaching is only applied for 18 to 48 h. Therefore, the tests have to apply conditions (e.g., orbital shaking or end-over-end agitation) which simulate accelerated aging.

Nevertheless, it is not clear if these short leaching times allow meaningful predictions for the long-term leaching behavior. For example, leaching tests on copper indium diselenide (CIS), cadmium telluride (CdTe) and module pieces from crystalline silicon (c-Si), amorphous silicon (a-Si), and copper indium gallium diselenide (CIGS) also occurred only over a maximum of 48 h and the leaching results are low.[5–9] In these studies, the eluted amount of cadmium reached only 5.3 to 6.4%[6] and 0.6%.[9] Considerably higher amounts were achieved in our recent worst-case study which investigated leaching of milled module powder instead of whole module pieces.[10]

However, some studies reported also leaching results which are very close to the TCLP limits or even exceed them especially for lead from c-Si modules and cadmium from CdTe modules.[11–15] Steinberger showed also leached elements from broken and unbroken CIS and CdTe modules by natural rainwater.[16] In case of leaching broken modules, the limit of the German drinking water regulation is exceeded.[17]

Zimmermann et al. reported long-term leaching tests on CIGS and organic photovoltaic cells (OPV).[18] After four months of exposure, the authors measured substantial amounts of leached elements.

The potential risks of environmental pollution due to improperly discarded photovoltaic (PV) modules are addressed by so-called ecotoxical tests where bioassays with different species are conducted by using the leaching solutions from standard leaching tests.[19–22]

Numerous studies dealt with life cycle analyses of PV modules starting with mining the raw materials, continuing with their processing, the actual manufacturing and operation of PV modules and ending with disposal or recycling.[23–27] According to the authors there are only few emissions during production and operation, but they did not consider in detail the potential risks posed by the disposal of used PV modules into landfills. Only the study by Cyrs et al. faced this important issue.[28] The authors stated that the health risk due to disposing CdTe modules in landfills is remote at current disposal rates. But if the rates increase markedly they suggested to revisit this question. However, all their evaluations of the potential risks were based on disposal into official lined landfills. They did not consider the possibility that PV modules could get disposed somewhere else in the environment.

Standard leaching tests are only performed over one to several days. In comparison, if modules or module pieces are — legally or illegally — dumped or landfilled somewhere, they certainly remain there for weeks, months, years, or, forever. Therefore, it is important to know if leaching occurs or not, what will be leached out, and how fast. Nevertheless, no studies are available about leaching tests of PV modules over a long period.

The present study reports on leaching of 5 × 5 cm^2 module pieces, cut out from commercial modules using either c-Si, a-Si, CdTe, or CIGS. So far, the experiments have lasted over 360 days without applying accelerating agitation. Even under these conditions, substantial leaching of toxic substances is observed. Thus, it is only a question of time until hazardous elements release into the environment if broken modules are improperly disposed.

2. Experimental methods

In order to identify the leaching mechanisms as well as potential weak spots in the modules, we analyze not only leaching of toxic substances like cadmium (Cd), lead (Pb), and selenium (Se), but also other elements: silver (Ag), zinc (Zn), tellurium (Te), indium (In), gallium (Ga), aluminum (Al), molybdenum (Mo), nickel (Ni), and copper (Cu). To obtain module pieces with well-defined sizes and edges, we

Table I. Composition of leaching solutions with pH values 3, 7, and 11 used in the experiments.

pH	E_H (V)	Chemical composition	Simulated environmental condition
3	0.62	15.4 g/l $C_6H_8O_7$, 2.8 g/l Na_2HPO_4, DI water	Acid rain[29]
7	0.56	3.7 g/l KH_2PO_4, 5 g/l Na_2HPO_4, DI water	Groundwater
11	0.33	0.04 g/l NaOH, DI water	Alkaline percolating water on waste disposal sites[30]

apply water jet cutting to the following PV technologies: c-Si, a-Si, CdTe, and CIGS. All module pieces contain at least one solder ribbon, but no parts of the frame, module boxes or cables. In many cases, these solder ribbons contain the toxic heavy metal lead. In fact, even the thin film modules (a-Si, CdTe, CIGS) contain such solder ribbons in order to connect the first and last cell of the module with the module box. However, the analyzed thin film modules in this study do not contain any Pb.

All leaching experiments occur at room temperature using high-density polyethylene (HDPE) bottles supplied with the leaching solution with a volume of 1000 ml and two module pieces from the same technology. All experiments are conducted in triplicate. In order to create realistic conditions comparable to field conditions, the bottles are not agitated in this study.

Table I shows the chemical composition of the three different leaching solutions used in the experiments to simulate different environmental conditions. All of them contain deionized (DI) water. The measured pH values as well as the oxidation–reduction potential E_H of the leaching solutions, remain almost constant for the experimental duration of nearly one year. The E_H is measured with a platinum electrode against a silver/silver chloride reference electrode (Ag/AgCl) with a concentration of potassium chloride $c_{KCl} = 3$ mol/l at $T = 25$ °C according to DIN 38404-6 and converted to a potential against a standard hydrogen electrode.[31]

During the experiments, we periodically take samples with a volume of 15 ml from the liquids in the bottles to observe the time-dependent leaching behavior. To keep the initial volume of the leaching solution constant at 1000 ml, the volume is corrected after each sampling. These corrections are included in the measurement data by a factor which takes into account the amount of leached elements missing in the solution because of sampling. With inductively coupled plasma mass spectrometry (ICP-MS) the amount of eluted elements is determined according to ISO 17294-2.[32] Only dissolved substances are analyzed, precipitations in the solution are not measured as leached.

The leaching tests are still in progress and will continue until either the final test duration of two years is accomplished, or, alternatively, 100% of the elements are leached out.

Table II shows the total mass of measured elements contained in one module piece for each PV technology. To determine the mass, we mill the module pieces to a powder; digest it by adding acid and oxidizing agents and applying microwave irradiation. The digested samples are then analyzed by ICP-MS (PerkinElmer NexION 350X). For example, in the c-Si module piece, we find 15 mg of lead, which stem from the solder of the ribbons which connect the solar cell to the next one in the module.

Table II. Total mass of elements in one module piece for c-Si, a-Si, CdTe, and CIGS.

Element	Total mass per 1 module piece ($5 \times 5\,cm^2$) (mg)			
	c-Si	a-Si	CdTe	CIGS
Ag	7.8 ± 0.9	2.2 ± 0.3	0.05 ± 0.005	1.2 ± 0.4
Sn	21.3 ± 1.1	31.0 ± 1.7	12.5 ± 3.9	19.1 ± 0.4
Zn				16.1 ± 1.6
Cd			14.9 ± 1.6	0.2 ± 0.001
Te			15.9 ± 1.1	
In				19.2 ± 0.7
Ga				0.7 ± 0.2
Se				8.2 ± 0.8
Al	167.2 ± 49.9			
Mo			13.0 ± 1.8	5.0 ± 0.2
Cu	254.2 ± 18.4	130.4 ± 16.7	74.5 ± 4.7	146.2 ± 5.7
Ni		1.0 ± 0.2		
Pb	15.9 ± 1.2			

3. Results

Figures 1(a)–1(d) give results of eluted elements after a time $t = 360$ days. Data are given with respect to the total mass (see Table II). The absolute concentrations of the eluted elements measured in the solutions given in mg/L are shown in Table III.

The results of Fig. 1(a) stem from leaching c-Si module pieces: Pb, Cu and Al are dissolved. Eluted Al from the back contact reaches 22% in acidic solutions. With around 0.1% level, Cu shows a low leaching. The amount of eluted Pb is 1.4%. Ag and Sn are not detected in the leachate. Figure 1(b) shows only leached Cu and Ni released from a-Si module pieces with a maximum value of $Cu_{a\text{-}Si} \approx 6.5\%$ and $Ni_{a\text{-}Si} \approx 55\%$ in acidic solutions.

Figure 1(c) shows the eluted elements from CdTe module pieces. In solutions with pH 3, 62% of Cd_{CdTe} is leached out after 360 days. In neutral solutions, the leaching is lower with $Cd_{CdTe} \approx 4\%$. Under alkaline conditions, Cd forms insoluble solid cadmium hydroxide [$Cd(OH)_2$] and therefore only low concentrations are found in the leachate by ICP-MS.

For pH 3, the amount of eluted Te with $Te_{CdTe} \approx 9\%$ is much lower than the amount of $Cd_{CdTe} \approx 62\%$. The back contact, molybdenum, in CdTe modules also shows substantial leaching: $Mo_{CdTe} \approx 71\%$ in acidic solution, $Mo_{CdTe} \approx 19\%$ in neutral solution, and $Mo_{CdTe} \approx 29\%$ in alkaline solution.

Figure 1(d) illustrates the elements detected in the solutions from leached CIGS module pieces. In acidic solution, eluted Zn (used in the ZnO front contact) reaches $Zn_{CIGS} \approx 43\%$ after $t = 360$ days. Cd from the cadmium sulfide (CdS) buffer layer shows lower leaching values than from CdTe module pieces. This lower leaching of Cd indicates that CdS is more stable than CdTe. Mo from the back contact shows similar leaching behavior like Mo from CdTe module pieces.

Table III. Concentration of eluted elements after $t = 360$ days in three different solutions with pH 3, 7, and 11. The given concentrations are based on two module pieces of the same module type per 1000 ml leaching solution.

Element	Concentration (mg/L)					
	c-Si			a-Si		
	pH 3	pH 7	pH 11	pH 3	pH 7	pH 11
Ag						
Zn						
Cd						
Te						
In						
Ga						
Se						
Al	71.96 ± 5.01		8.49 ± 0.42			
Mo						
Cu	0.27 ± 0.18	0.37 ± 0.08		16.1 ± 0.96	0.52 ± 0.05	
Ni				1.02 ± 0.16	0.07 ± 0.02	
Pb	0.45 ± 0.27		0.07 ± 0.04			

Element	Concentration (mg/L)					
	CdTe			CIGS		
	pH 3	pH 7	pH 11	pH 3	pH 7	pH 11
Ag						
Zn				13.20 ± 0.57	0.58 ± 0.07	
Cd	18.61 ± 0.94	1.25 ± 0.90	0.02 ± 0.008	0.08 ± 0.01	0.006 ± 0.003	
Te	2.92 ± 0.91	2.75 ± 2.58	0.10 ± 0.06			
In				0.21 ± 0.05		
Ga				0.05 ± 0.01	0.02 ± 0.001	0.01 ± 0.001
Se					0.02 ± 0.015	0.10 ± 0.05
Al						
Mo	18.62 ± 2.58	4.98 ± 2.92	7.69 ± 4.95	1.44 ± 0.36	1.39 ± 0.13	1.09 ± 0.36
Cu	4.59 ± 0.69	0.53 ± 0.06		8.93 ± 4.55	0.25 ± 0.04	
Ni						
Pb						

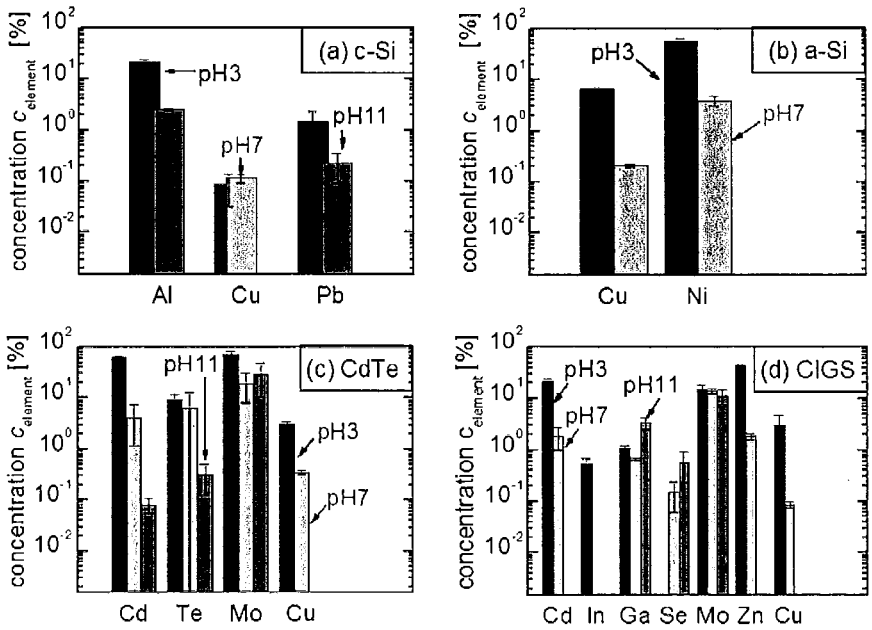

Fig. 1. (Color online) Amount of eluted elements after $t = 360$ days in three different solutions with pH 3, 7, and 11. (a) Al, Cu, and Pb from c-Si module pieces. (b) Cu and Ni from a-Si module pieces. (c) Cd, Te, Mo, and Cu from CdTe module pieces. (d) Cd, In, Ga, Se, Mo, Zn, and Cu from CIGS module pieces. The error bars stem from three identical experiments. The element Ag is not detected in the solutions.

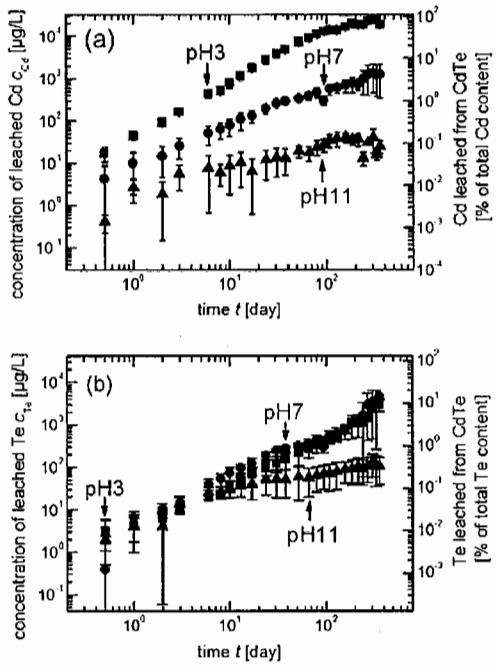

Fig. 2. (Color online) Time-dependent leaching of Cd (a) and Te (b) from CdTe module pieces within different pH solutions. Values are given as absolute concentrations in µg/L and as percentage of total content of the particular element.

The elements In, Ga, and Se from CIGS module pieces leach only in minor amounts.

Most of the analysed metals follow a cationic leaching pattern, which means that leachate concentrations decrease with increasing pH. In this study, the following elements show cationic behavior: Cu, Cd, Te, Mo, and Zn. The elements Al and Pb follow an amphoteric leaching pattern where leaching under neutral conditions is minimal but increases at acidic and alkaline conditions. The elements Ga and Se are the only metals where an oxyanionic leaching behavior is observed with considerable amounts measured only in alkaline solutions. With decreasing pH, the eluted amount of Ga and Se detected in the solutions also decreases.

As an example for the time-dependent leaching of the elements, Fig. 2(a) shows the leaching results of Cd from CdTe module pieces in the three different solutions. The percentage of eluted Cd is given with respect to the total Cd content as well as the absolute concentration measured in the solution. In all solutions, the amount of leached Cd increases with time. Under acid rain conditions with pH 3, almost 500 times stronger leaching is observed after one year when compared to the leaching after one day. Still, under groundwater conditions the leached Cd after 360 days is 100 times higher than after one day. These data show that experiments lasting only one or a few days, are by no means representative for dumped modules.

Even only one day of leaching of two module pieces in 1 l of acid rain and neutral solution is sufficient to exceed the World Health Organization (WHO) drinking water limit: for Cd the threshold limit is 3 µg/L.[33] Even under alkaline conditions (pH 11), it takes only three days to exceed this limit. After nearly one year, the Cd concentration c_{Cd} in acidic solutions is almost 20000 µg/L (62%), in neutral solutions

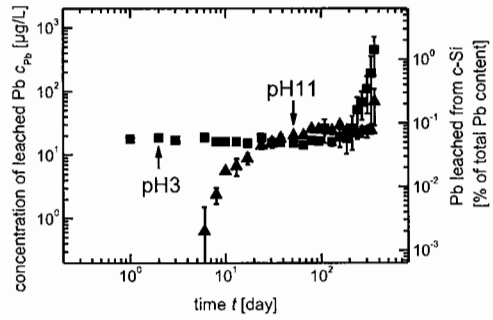

Fig. 3. (Color online) Time-dependent leaching of Pb from c-Si module pieces within different pH solutions. Values are given as absolute concentrations in µg/L and as percentage amount regarding the total content of the particular element.

$c_{Cd} \approx 1200$ µg/L (4%) and in basic solutions $c_{Cd} \approx 25$ µg/L (0.1%). After three days in acidic solutions, the CdTe modules pieces exceed the limit of the German legislation, which is set to 100 µg/L, for classification of hazardous waste.[1]

Figure 2(b) shows the leaching of Te released from CdTe module pieces within nearly one year. Under alkaline and groundwater conditions Te shows slightly higher concentrations than Cd. In acidic solutions, Te also behaves differently. Here, the measured amount is almost one order of magnitude lower than the Cd amount and it is in the same range as the leached Te under groundwater conditions.

Figure 3 shows the time-dependent leaching amounts of the toxic heavy metal Pb, which is released from the solder ribbons in c-Si module pieces. Only under acid rain and alkaline conditions, considerable amounts of Pb are detected in the leachate. Until day 241, the Pb concentration $c_{Pb} \approx 18$ µg/L (0.06%) is almost constant in acid solutions. After this time, the concentration increases dramatically up to $c_{Pb} \approx 446$ µg/L (1.4%). It seems that it takes nearly one year before considerable leaching starts to occur. We assume that the reason for this behavior could be related to the presence of Pb in an alloy with Sn. Studies showed that in the case of Pb–Sn alloys, tin is oxidized and enriched at the surface.[34–36] Therefore we presume that the tin oxide at the surface has to be leached first to uncover the Pb. Unfortunately, Sn is currently not measurable. We suppose that Sn precipitates in the solutions and further investigations are in progress.

Nevertheless, the Pb concentration exceeds the WHO limit of 10 µg/L for drinking water[33] from the first day in acid solutions. In alkaline solutions, a similar behavior is observed only with a slight delay in the increase in concentration and a slower increase at the beginning.

4. Discussion

Our study compares the four major commercial photovoltaic technologies c-Si, a-Si, CdTe, and CIGS for their long-term leaching behavior in three environmentally relevant aqueous solutions. The results show high leaching of toxic elements like Cd, released from CdTe module pieces. Two further hazardous elements, Te and Pb, are leached only in minor amounts, but Pb shows a considerable increase after 241 days of leaching. Nevertheless, also low- or non-toxic metals like Mo, Zn, and Al are detected in high amounts in the leachate.

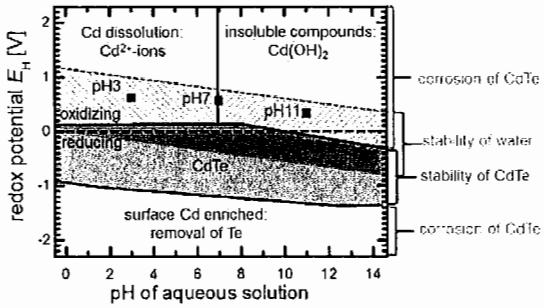

Fig. 4. (Color online) Highly simplified potential-pH (Pourbaix) diagram for CdTe in aqueous solutions at $T = 25\,°C$ showing only predominant Cd species.[6] Stability and corrosive regions of CdTe are shown. Measured redox potentials in solutions with pH 3, 7, and 11, which are used in the leaching experiments, are located at oxidizing redox potentials E_H.

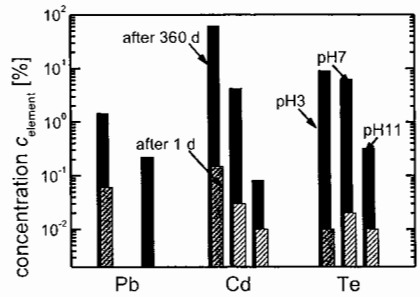

Fig. 5. (Color online) Amount of eluted toxic elements as Pb, released from c-Si module pieces, and Cd and Te out of CdTe module pieces after $t = 1$ day (hatched bars) and after $t = 360$ days (solid bars) in different solutions.

Table IV. Typical E_H values (in mV) of waters in various environments.[37]

Environment	E_H range
Rain water	+400 to +600
Freshwater lakes, ocean water	+300 to +500
Oilfield brines	−300 to −600
Water in wetlands	+100 to −100

4.1 Stability of CdTe

The leaching results for CdTe are in good agreement with thermodynamic calculations. To explain the leaching behavior of elements, not only the pH of the aqueous solutions is important, but also the redox potential E_H highly affects the leaching.

Figure 4 shows a simplified redox potential E_H–pH diagram for CdTe in aqueous solutions according to Zeng et al.[6] This diagram shows the stability limits of CdTe according to pH and E_H and the corrosion regions with the predominant species. The measured redox potentials E_H of our leaching solutions are all in the oxidizing regime. These values lie in the range of reported E_H values of different types of water in various environments (see Table IV).

Under reductive conditions, CdTe is thermodynamically stable in aqueous solutions within the whole pH range of the stability regime of water. In contrast, under oxidative conditions occurring naturally in any freshwaters, the compound CdTe is no longer stable. Under oxidative and acid conditions, Cd^{2+} ions are formed and can be measured in the solutions. For Te, the predicted species are insoluble Te and tellurium dioxide (TeO_2) within the stability region of water (not shown in the figure). These insoluble tellurium species explain the difference between the high Cd amount and the lower Te amount measured as dissolved in the leachate. Under oxidative and alkaline conditions, the predominant species of Cd are insoluble cadmium hydroxide [$Cd(OH)_2$] and for Te the predominant species are different tellurite ions for example hydrogen tellurite ion ($HTeO_3^-$), hydrogen tellurate ($HTeO_4^-$) and TeO_3^{2-}. Therefore, a higher amount of Te than Cd is measured in alkaline solutions.

4.2 Environmental poisoning

If broken PV modules are dumped in the environment where they may get in contact with water, metals or metal compounds which are supposed to be stable can elute from these modules. Our leaching study indicates that the highest risk for a contamination with metals released from PV modules occur under acidic and oxidizing conditions. It is presumed that most metals are present in their ionic form with an increased mobility. But even under groundwater conditions, considerable amounts of leached metals are measured after nearly one year. For Cd and Pb, the leaching amounts still lie above the WHO limits for drinking water. Only under alkaline conditions the results show a lower risk for leaching toxic substances, because the toxic substances are in their immobilized forms and precipitate for example as $Cd(OH)_2$. But nevertheless it is not negligible that small amounts of Cd can be also detected in alkaline solutions and these values exceed the WHO limits. Metals which show also higher leaching amounts in alkaline solutions are Al, Ga, and Mo, but they are considered being low or non-toxic. Molybdenum for example is actually a trace element and essential for human health.

4.3 Short-term versus long-term leaching

Figure 5 reveals a substantial difference between short- and long-term leaching: We show the amounts of eluted toxic elements as Pb, Cd, and Te out of PV module pieces after one day and after nearly one year in the analysed solutions. Under all conditions, acid rain, groundwater and alkaline landfilling, the leached amounts increase clearly after one year. For Cd and Te under acid rain conditions, the difference between short- and long-term is almost three orders of magnitude. In neutral solutions, the long-term results show an increase of nearly two orders of magnitude and for alkaline conditions an increase of more than one order of magnitude is reported.

For the leaching of Pb out of c-Si module pieces under acid rain conditions, a percentage increase of more than 2000% is obtained. After one day, no Pb is detected in alkaline solutions, but after nearly one year a concentration of $c_{Pb} \approx 70\,\mu g/L$ is reached, which is equivalent to 0.2% regarding the total mass of Pb.

Compared to the TCLP leaching test from Zeng et al. on pure CdTe powder, where 6.4% of the total Cd amount was leached after 18 h in acid solutions,[6] our measured Cd amount after one day is lower. This result is understandable: Our present study uses module pieces with an intact layer construction, they are not milled to a powder and we do not apply any agitation.

Compared to the leaching test results according to EN 12457-4, where 0.1% Pb, 0.6% Cd, and 0.5% Te was measured after 24 h in neutral solutions,[9] our results are also

slightly lower. This is due to the smaller size (<40 mm) of the leached module pieces in this standard test and the end-over-end agitation for an accelerated aging parameter.

Nevertheless, if the leaching amounts of the toxic substances Pb, Cd, and Te from PV modules are low at the first day of leaching or lower than the regulatory limits according to standard tests, it is not likely that these values stay constant with ongoing leaching. Our study clearly proves that it is important to consider the long-term behavior of leaching and the possibility that after a certain time 100% of the toxic material will be leached out. To prevent environmental pollution due to a release of toxic heavy metals by dumping or landfilling broken PV modules, strict recycling policies and regulations are needed worldwide. Alternatively, toxic materials in PV modules simply could be omitted.

5. Conclusions

This study proves substantial leaching of toxic elements out of pieces cut from commercial photovoltaic modules. After 360 days, around 1.4% of lead from c-Si module pieces and 62% of cadmium from CdTe module pieces are leached out and found in water-based solutions. A substantial difference between short- and long-term leaching exists: for CdTe modules, for example, the eluted Cd amount after 360 days is 500 times higher than the amount measured after one day. Therefore, we challenge the meaningfulness of short-term leaching tests of 18 to 24 h with respect to environmental issues. In addition to toxic elements, other substances also are strongly leached out: Al from c-Si module pieces, Mo from CdTe module pieces, and Zn from of CIGS module pieces. Therefore, the layers containing these elements represent weak spots in the modules and indicate penetration paths for the water-based solutions. The leaching results not only show a strong influence of the pH of the leaching solutions on the leaching behavior, but also indicate that the redox potential has a considerable effect. Regarding these parameters, pH and redox potential, the leaching behavior can be predicted by thermodynamic stability calculations, which are in good agreement with our experimental results for the compound CdTe.

So far, our study has used leaching *without* applying any accelerated aging parameter — for example agitation, increased temperatures, applied voltages or illumination.

Nevertheless, high amounts of toxic heavy metals are measured in the leaching solutions. Two module pieces with a size of $5 \times 5\,\mathrm{cm}^2$ are enough to exceed the WHO limits of drinking water for Cd after only one day of leaching in acid as well as neutral solutions. For Pb it takes also only one day of leaching in acid solutions to exceed the WHO limit.

In future, we will investigate what will happen to dumped modules or module pieces under more stressful conditions: For example, increased temperatures and illumination — which are natural conditions for any photovoltaic module — will probably lead to even higher leaching and even faster emission of toxic materials from photovoltaic modules into the environment according to studies on leaching kinetics regarding heavy metals.[38,39]

Acknowledgments

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EXHIBIT N

#02

DRS DELAWARE RIVER SOLAR

June 29, 2018

Town of Farmington
Planning Board
1000 County Road 8
Farmington, NY 14425

Re: Proposed Solar Projects Yellow Mills Road ("Solar Project") – Decommissioning

Dear Members of the Planning Board,

Please find enclosed the following regarding the proposed decommissioning for the Solar Project. Please note, the information provided herein relates to a 2MW ac solar facility as the decommissioning agreements executed by Delaware River Solar, LLC ("**DRS**") in other towns are shown as a comparison and such projects were primarily 2 MW projects. As the proposed project progresses through the town approval process, the information will be updated and provided to the town.

APPENDIX I: Draft Decommissioning Plan

APPENDIX II: Draft Decommissioning Agreement

APPENDIX III: List of Decommissioning Agreements DRS has executed with other Towns in New York State.

If there are any questions or additional information required, I can be contacted at 646-998-6495 or at peter.dolgos@delawareriversolar.com.

Sincerely,

Peter Dolgos

Peter Dolgos
Senior Vice President
Delaware River Solar, LLC

DRS | DELAWARE RIVER SOLAR

APPENDIX I

Draft Decommissioning Plan

New York Community Solar Facility Decommissioning Plan

JUNE 2018

Prepared For:

Town of Farmington

Delaware River Solar, LLC
33 Irving Place, Suite 1090
New York, NY 10003

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1. Introduction

Delaware River Solar ("**DRS**") proposes to build a photovoltaic (PV) solar facility ("**Solar Facility**") at 466 Yellow Mills Road in the Town of Farmington ("**Town**") under New York State's Community Solar initiative. The Solar Facility is planned to have a nameplate capacity of approximately 7.0 megawatts (MW) alternating current (AC) and be built on private land ("**Project Site**") leased by an affiliate of DRS from the property owner ("**Property Owner**").

This Decommissioning Plan ("**Plan**") provides an overview of activities that will occur during the decommissioning phase of the Solar Facility, including; activities related to the restoration of land, the management of materials and waste, projected costs, and a proposed decommissioning fund agreement overview.

The Solar Facility will have a useful life of thirty (30) years and the lease agreement between DRS and the Property Owner will have a thirty (30) year lease term, subject to five (5) year extensions. This Plan assumes that the Solar Facility will be dismantled, and the Project Site restored to a state similar to its pre-construction condition, at the thirty (30) year anniversary of the Solar Facility's commercial operation date ("**Expected Decommissioning Date**"). This Plan also covers the case of the abandonment of the Solar Facility, for any reason, prior to the Expected Decommissioning Date.

Decommissioning of the Solar Facility will include the disconnection of the Solar Facility from the electrical grid and the removal of all Solar Facility components, including:

- Photovoltaic (PV) modules, panel racking and supports;
- Inverter units, substation, transformers, and other electrical equipment;
- Access roads, wiring cables, communication tower, perimeter fence; and,
- Concrete foundations.

This Plan is based on current best management practices and procedures. This Plan may be subject to revision based on new standards and emergent best management practices at the time of decommissioning. Permits will be obtained as required and notification will be given to stakeholders prior to decommissioning.

2. Conditions to the Issuance of A Special Use Permit

The conditions of the decommissioning plan for the issuance of a Special Use Permit granted by the Town of Farmington Planning Board shall include:

1. A licensed engineer's estimate of the anticipated operational life of the Solar Facility
   - DRS will provide this.
2. Identification of the party responsible for the decommissioning.
   - DRS will create project specific entities (i.e. NY Farmington I, LLC, NY Farmington II, LLC and NY Farmington III, LLC) for each of the individual projects. The project specific entities, affiliates of DRS, will be the entity responsible for decommissioning, and will enter decommissioning agreements with the Town.
3. A description of any decommissioning agreement between the responsible party and the landowner.
   - Attached as Appendix II is a draft decommissioning agreement that DRS would typically execute with the applicable town. The lease agreement that DRS has in place with the Property Owner also contains conditions regarding the removal of the Solar Facility and restoration of the Project Site.
4. A schedule showing the time frame for the decommissioning and restoration work to occur.
   - The decommissioning and restoration work will be completed within 180 days of the 30 year anniversary of the commercial operation date (or within 180 days of abandonment). The "Decommissioning of the Solar Facility" section herein contains details on work to be performed.
5. A cost estimate prepared by a licensed engineer estimating the full cost of the decommissioning and removal of the Solar Facility
   - The "Cost of Decommissioning" section herein contains the estimate costs of the decommissioning the Solar Facility. Prior to any Site Plan Approval or issuance of any Special Use Permit, DRS will provide a "final" estimate of the decommissioning cost from a licensed engineer based on the site plan considered for approval.
6. A financial plan to ensure that financial resources will be available to fully decommission the Solar Facility.
   - The financial plan is set forth herein and is similar to decommissioning agreements that DRS has executed with other towns in the State of New York. See Appendix III for a list of other towns for which a substantially similar decommissioning plan has been executed.
7. An acceptable form of surety to be approved by the Planning Board, accepted by the Town Board and filed with the Town Clerk in an amount specified in the financial plan.
   - DRS is proposing the financial plan set forth herein which entails an upfront deposit to the town and annual contributions thereafter. As indicated above, this is similar to decommissioning agreements DRS has executed with other towns, however, DRS is open to discuss other recommendations of the Town.

8. Before obtaining a Building Permit and every 3 years thereafter the Solar Facility owner is required to file with the Town Clerk evidence of financial surety to provide for the full cost of decommissioning and removal of the Solar Facility.
   - As indicated above, DRS is proposing the financial plan set forth herein. If this financial plan is acceptable, the Town would be the controlling party of the "decommissioning account" and DRS can attest to the schedule set forth herein for payments.
9. The amount of surety is determined by the Town Engineer based upon a current estimate of the decommissioning and removal costs as provided by the Solar Facility owner in the Decommissioning Plan.
   - As indicated above, DRS is proposing the financial plan set forth herein. It is assumed that in the event the estimate of the decommissioning and removal costs increases, based on the annual report described in the following item, DRS will contribute an additional deposit to the decommissioning account to ensure that such additional amount, plus the annual deposits, will be sufficient to cover the revised decommissioning cost.
10. The Solar Facility owner is required to provide, on a yearly basis, to the Code Enforcement Officer a written report showing the rate capacity of the Solar Facility and the amount of electricity that was generated by the Solar Facility and transmitted to the grid in the most recent 12 month period. Every third year the annual report shall also include a recalculation of the estimated cost of decommissioning and removal of the system. The Town Boad may then require the amount of surety to be changed to reflect any changes in the decommissioning costs.
    - DRS will provide the required reports.

3. The Proponent

Delaware River Solar LLC ("**DRS**") will manage and coordinate the approvals process during decommissioning. DRS will obtain all necessary regulatory approvals that vary depending on the jurisdiction, project capacity, and site location. DRS will build a long-term relationship with the community hosting the Solar Facility and DRS will be committed to the safety, health, and welfare of the townships.

Contact information for the proponent is as follows:

Full Name of Company: Delaware River Solar, LLC

Contact: Peter Dolgos

Address: 33 Irving Place Suite 1090, New York, NY 10003

Telephone: (646) 998-6495

Email: peter.dolgos@delawareriversolar.com

3.1 Project Information

Address: 466 Yellow Mills Road, Farmington NY 14522

Tax ID: 10.00-1.37.110

Project Size (estimated): Three Projects totaling approximately 7.0 MW ac

Landowner: Roger Smith and Carol Smith

Own / Lease: Lease

4. Decommissioning of the Solar Facility

At the time of decommissioning, the installed components will be removed, reused, disposed of, and recycled, where possible. The Project Site will be restored to a state similar to its pre- construction condition. All removal of equipment will be done in accordance with any applicable regulations and manufacturer recommendations. All applicable permits will be acquired.

4.1 Equipment Dismantling and Removal

Generally, the decommissioning of a Solar Facility proceeds in the reverse order of the installation.

1. The Solar Facility shall be disconnected from the utility power grid.
2. PV modules shall be disconnected, collected, and disposed at an approved solar module recycler or reused / resold on the market..
3. All aboveground and underground electrical interconnection and distribution cables shall be removed and disposed off-site by an approved facility.
4. Galvanized steel PV module support and racking system support posts shall be removed and disposed off-site by an approved facility.
5. Electrical and electronic devices, including transformers and inverters shall be removed and disposed off-site by an approved facility.
6. Concrete foundations shall be removed and disposed off-site by an approved facility.
7. Fencing shall be removed and will be disposed off-site by an approved facility.

4.2 Environmental Effects

Decommissioning activities, particularly the removal of project components could result in environmental effects similar to those of the construction phase. For example, there is the potential for disturbance (erosion/sedimentation) to adjacent watercourses or significant natural features. Mitigation measures similar to those employed during the construction phase of the Solar Facility will be implemented. These will remain in place until the site is stabilized in order to mitigate erosion and silt/sediment runoff and any impacts on the significant natural features or water bodies located adjacent to the Project Site.

Road traffic will temporarily increase due to the movement of decommissioning crews and equipment. There may be an increase in particulate matter (dust) in adjacent areas during the decommissioning phase. Decommissioning activities may lead to temporary elevated noise levels from machinery and an increase in trips to the Project Site. Work will be undertaken during daylight hours and conform to any applicable restrictions.

4.3 Site Restoration

Through the decommissioning phase, the Project Site will be restored to a state similar to its pre-construction condition.

All project components (discussed in **Table 1**) will be removed. Rehabilitated lands may be seeded with a low-growing species such as clover to help stabilize soil conditions, enhance soil structure, and increase soil fertility.

4.4 Managing Materials and Waste

During the decommissioning phase a variety of excess materials and wastes (listed in **Table 1**) will be generated. Most of the materials used in a Solar Facility are reusable or recyclable and some equipment may have manufacturer take-back and recycling requirements. Any remaining materials will be removed and disposed of off-site at an appropriate facility. DRS will establish policies and procedures to maximize recycling and reuse and will work with manufacturers, local subcontractors, and waste firms to segregate material to be disposed of, recycled, or reused.

DRS will be responsible for the logistics of collecting and recycling the PV modules and to minimize the potential for modules to be discarded in the municipal waste stream. Currently, some manufacturers and new companies are looking for ways to recycle and/or reuse solar modules when they have reached the end of their lifespan. Due to a recent increase in the use of solar energy technology, a large number of panels from a variety of projects will be nearing the end of their lifespan in 25-30 years. It is anticipated there will be more recycling options available for solar modules at that time. DRS will dispose of the solar modules using best management practices at the time of decommissioning.

Table 1: Management of Excess Materials and Waste

Material / Waste	Means of Managing Excess Materials and Waste
PV panels	If there is no possibility for reuse, the panels will either be returned to the manufacturer for appropriate disposal or will be transported to a recycling facility where the glass, metal and semiconductor materials will be separated and recycled.
Metal array mounting racks and steel supports	These materials will be disposed off-site at an approved facility.
Transformers and substation components	The small amount of oil from the transformers will be removed on-site to reduce the potential for spills and will be transported to an approved facility for disposal. The substation transformer and step-up transformers in the inverter units will be transported off-site to be sent back to the manufacturer, recycled, reused, or safely disposed off-site in accordance with current standards and best practices.
Inverters, fans, fixtures	The metal components of the inverters, fans and fixtures will be disposed of or recycled, where possible. Remaining components will be Disposed of in accordance with the standards of the day.
Gravel (or other granular)	It is possible that the municipality may accept uncontaminated material without processing for use on local roads, however, for the purpose of this report it is assumed that the material will be removed from the project location by truck to a location where The aggregate can be processed for salvage. It will then be reused As fill for construction. It is not expected that any such material will be contaminated.
Geotextile fabric	It is assumed that during excavation of the aggregate, a large portion of the geotextile will be "picked up" and sorted out of The aggregate at the aggregate reprocessing site. Geotextile fabric that is remaining or large pieces that can be readily removed from the excavated aggregate will be disposed of off-site at an approved disposal facility.
Concrete inverter/transformer Foundations	Concrete foundations will be broken down and transported by certified and licensed contractor to a recycling or approved disposal facility.
Cables and wiring	The electrical line that connects the substation to the point of common coupling will be disconnected and disposed of at an approved facility. Support poles, if made of untreated wood, will be chipped for reuse. Associated electronic equipment (isolation switches, fuses, metering) will be transported off-site to be sent back to the manufacturer, recycled, reused, or safely disposed off-site in accordance with current standards and best practices.
Fencing	Fencing will be removed and recycled at a metal recycling facility.
Debris	Any remaining debris on the site will be separated into recyclables/residual wastes and will be transported from the site and managed as appropriate.

4.5 Decommissioning During Construction or Abandonment Before Maturity

In case of abandonment of the Solar Facility during construction or before its 30 year maturity, the same decommissioning procedures as for decommissioning after ceasing operation will be undertaken and the same decommissioning and restoration program will be honored, in as far as construction proceeded before abandonment. The Solar Facility will be dismantled, materials removed and disposed, the soil that was removed will be graded and the site restored to a state similar to its preconstruction condition.

4.6 Decommissioning Notification

Decommissioning activities may require the notification of stakeholders given the nature of the works at the Facility Site. The local municipality in particular will be notified prior to commencement of any decommissioning activities. Six months prior to decommissioning, DRS will update their list of stakeholders and notify appropriate municipalities of decommissioning activities. Federal, county, and local authorities will be notified as needed to discuss the potential approvals required to engage in decommissioning activities.

4.7 Approvals

Well-planned and well-managed renewable energy facilities are not expected to pose environmental risks at the time of decommissioning. Decommissioning of a Solar Facility will follow standards of the day. DRS will ensure that any required permits are obtained prior to decommissioning.

This Decommissioning Report will be updated as necessary in the future to ensure that changes in technology and site restoration methods are taken into consideration.

5. Cost of Decommissioning

The costs below are the current estimated costs to decommission a 2 MWac Solar Facility, based on guidance from NYSERDA and estimates from the Massachusetts solar market, a mature solar market with experience decommissioning projects. The salvage values of valuable recyclable materials (aluminum, steel, copper, etc) are not factored into the below costs. The scrap value will be determined on current market rates at the time of salvage.

Tasks	Estimated Cost ($)
Remove Panels	$2,450
Remove Rack Wiring	$2,459
Dismantle Racks	$17,350
Remove and Load Electrical Equipment	$1,850
Break up Concrete Pads	$1,500
Remove Racks	$7,800
Remove Cable	$6,500
Remove Ground Screws and Power Poles	$13,850
Remove Fence	$4,950
Grading	$4,000
Seed Disturbed Area	$250
Truck to Recycling Center	$2,250
Custom Fees	$6,200
Total After 30 Years (2.5% inflation rate)	**$126,000**

NY PVTN Decommissioning Fact Sheet.pdf

6. Decommissioning Fund

DRS will create a decommissioning fund to guarantee that monies are available to perform the facility decommissioning. Although DRS intends to perform the decommissioning, unforeseen circumstances such DRS selling the project to another party or DRS going out of business are possible. The funds will be held in a 3rd party escrow account, and they will remain available to any party performing the decommissioning such as a municipality or a landowner.

At the completion of construction, DRS will deposit $60,000 into the fund (prorated for the actual facility size). After every year of operation, DRS will deposit an additional 2.5% of the previous balance to keep up with inflation and expected decommissioning costs.

Decommissioning Fund (Deposits)		
Timeframe	Amount	Cumulative
Construction	60,000	60,000
Year 1	1,500	61,500
Year 2	1,538	63,038
Year 3	1,576	64,613
Year 4	1,615	66,229
Year 5	1,656	67,884
Year 6	1,697	69,582
Year 7	1,740	71,321
Year 8	1,783	73,104
Year 9	1,828	74,932
Year 10	1,873	76,805
Year 11	1,920	78,725
Year 12	1,968	80,693
Year 13	2,017	82,711
Year 14	2,068	84,778
Year 15	2,119	86,898
Year 16	2,172	89,070
Year 17	2,227	91,297
Year 18	2,282	93,580
Year 19	2,339	95,919
Year 20	2,398	98,317
Year 21	2,458	100,775
Year 22	2,519	103,294
Year 23	2,582	105,877
Year 24	2,647	108,524
Year 25	2,713	111,237
Year 26	2,781	114,018
Year 27	2,850	116,868
Year 28	2,922	119,790
Year 29	2,995	122,784
Year 30	3,070	125,854

Assumed 2MWac Facility

APPENDIX II

[DRAFT] DECOMMISSIONING AGREEMENT

This DECOMMISSIONING AGREEMENT (this "Agreement") dated as of_____, 2018 (the "Effective Date") is made by and among the Town of Farmington ("Town") and [Delaware River Solar, LLC] ("Owner", together with the Town, the "Parties").

WHEREAS, Owner intends to build a solar energy generation project on 466 Yellow Mills Road in the Town (the "Project");

WHEREAS, the Parties wish to enter into this Agreement to set forth terms and conditions of having funds available to pay for the costs of any decommissioning of the Project; and

NOW, THEREFORE, in consideration of the premises and for other good and valuable consideration, the receipt and sufficiency of which are hereby acknowledged, the Parties agree as follows:

1. Prior to the commencement of construction of the Project, Owner agrees to deposit [sixty-thousand dollars ($60,000)] in a special purpose account designated in writing by the Town (the "Decommissioning Account"). At the end of each anniversary year of operation of the Project (the "Anniversary Date"), Owner agrees to deposit an additional 2.5% of the then existing amount in the Decommissioning Account on the Anniversary Date, as described in greater detail on Schedule I attached hereto. The Parties agree that the amount in the Decommissioning Account shall be used solely to pay for any decommissioning costs of the Project. Provided Owner complies with its obligations to deposit funds into the Decommissioning Account in accordance with this Agreement, Owner shall have no further payment obligations in connection with funding the Decommissioning Account during the operation of the Project; provided, however, in the event the actual decommissioning costs exceed the amount in the Decommissioning Account, Owner shall be responsible for any such excess costs, provided such excess costs are not as a result of the Town using any amount in the Decommissioning Account for any reason other than to pay for decommissioning costs of the Project in accordance with this Agreement. In the event the Town uses any amount in the Decommissioning Account for any reason other than to pay for decommissioning costs in accordance with this Agreement, the Town shall be responsible to pay for such amount used and shall indemnify and hold harmless Owner and the landowner of the Project, if different from Owner, from any claim, loss, damage, liability or costs (including any reasonable attorney costs) arising from such use of funds for reasons other than to pay for decommissioning costs in accordance with this Agreement.

2. The Parties agree that the decommissioning process of the Project may commence (and the funds to pay for the cost of any such decommissioning from the Decommissioning Account may be used) for the following reasons: (a) Owner provides written notice to the Town of its intent to retire or decommission the Project (the "Owner Decommissioning Notice"), (b) construction of the Project has not started within eighteen (18) months of site plan being approved by the Town, or (c) the Project ceases to be operational for more than twelve (12) consecutive months. The Town shall provide Owner thirty (30) days written notice (the "Town Decommissioning Notice") prior to the commencement of any decommissioning of the Project by

the Town. In event the Owner fails to decommission the Project within ninety (90) days after providing Owner Decommissioning Notice or fails to respond with a reasonable explanation for the delay in the construction or cessation of operation of the Project within 30 days of the Town Decommissioning Notice, the Town may commence the decommissioning of the Project. For the purposes of this Agreement, "ceases to be operational" shall mean no generation of electricity, other than due to repairs to the Project or causes beyond the reasonable control of Owner.Upon removal of the infrastructure and disposal of any component of the Project from the site on which the Project is built, or in the event the Town becomes owner of the Project, any and all amount remaining in the Decommissioning Account shall be returned to Owner.

3. This Agreement may not be amended or modified except by written instrument signed and delivered by the Parties. This Agreement is binding upon and shall inure to the benefit of the Parties and their respective heirs, executors, administrators, successors and assigns. Owner may assign this Agreement to any subsidiary, or purchaser or transferee of the Project. The Parties agree to execute and deliver any additional document or take any further action as reasonably requested by the other party to effectuate the purpose of this Agreement. The Parties agree that Owner shall have the option to replace the funds in the Decommissioning Account with a commercially reasonable decommissioning bond.

4. The Parties agree that this Agreement shall be construed and enforced in accordance with and governed by the laws of New York.

5. This Agreement may be executed through separate signature pages or in any number of counterparts, and each of such counterparts shall, for all purposes, constitute one agreement binding on all parties.

[Signature Page Follows]

IN WITNESS WHEREOF, the Parties have caused their names to be signed hereto by their respective representatives thereunto duly authorized as of the date first above written.

TOWN OF FARMINGTON

By: _____

Name: _____

Title: _____

[DELAWARE RIVER SOLAR, LLC]

By: _____

Name: _____

Title: _____

SCHEDULE I

Decommissioning Fund (Deposits)		
Timeframe	Amount	Cumulative
Construction	60,000	60,000
Year 1	1,500	61,500
Year 2	1,538	63,038
Year 3	1,576	64,613
Year 4	1,615	66,229
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Year 13	2,017	82,711
Year 14	2,068	84,778
Year 15	2,119	86,898
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Year 18	2,282	93,580
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Year 23	2,582	105,877
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Year 25	2,713	111,237
Year 26	2,781	114,018
Year 27	2,850	116,868
Year 28	2,922	119,790
Year 29	2,995	122,784
Year 30	3,070	125,854

Assumed 2MWac Facility

APPENDIX III

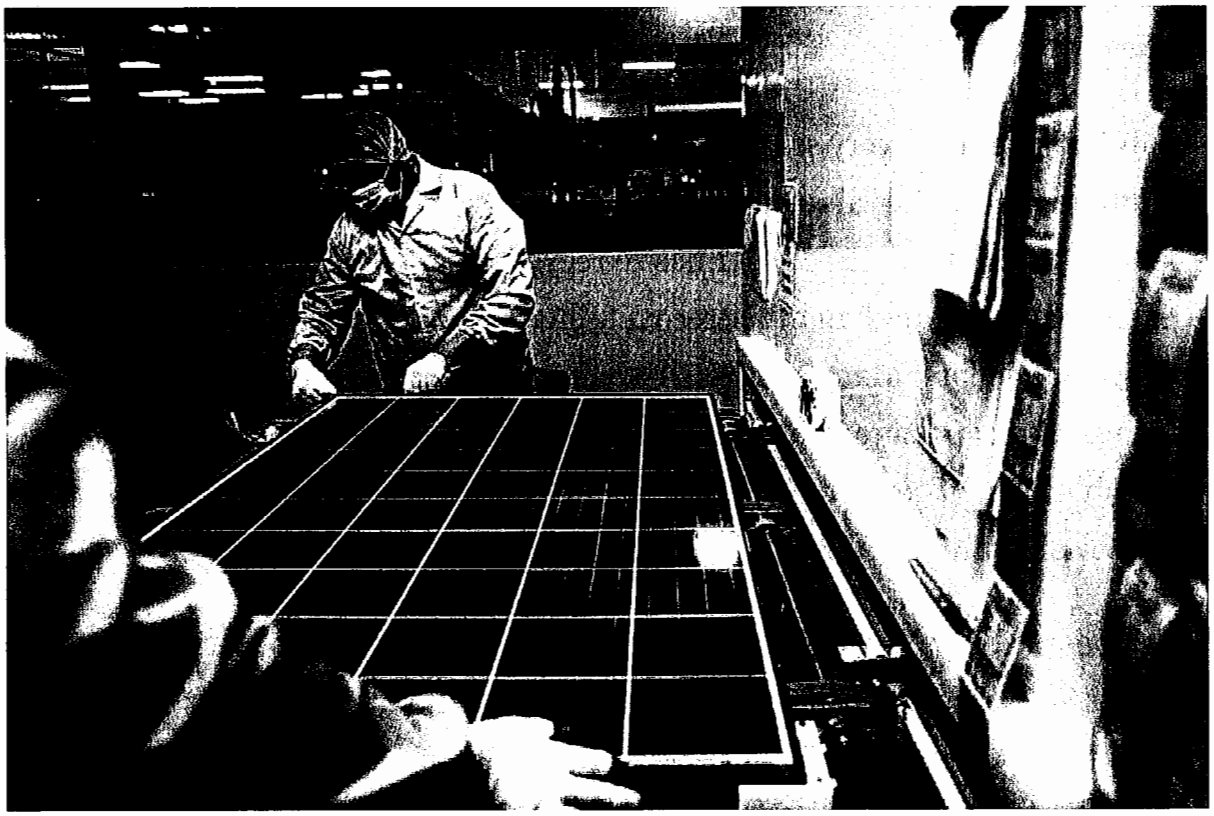
DRS Executed Decommissioning Agreements

Town / County	System Size MW (AC)	Decommissioning Amount (Deposit)	Annual Deposit	Payable
Delaware / Sullivan	2.00	$76,000	2.50%	Issuance of Building Permit
Delaware / Sullivan	1.75	$61,000	2.50%	Issuance of Building Permit
Thompson / Sullivan	2.00	$60,000	2.50%	Start of Construction
Thompson / Sullivan	1.75	$52,500	2.50%	Start of Construction
Liberty / Sullivan	2.00	$108,000	2.50%	Issuance of Building Permit
Mooers / Clinton	2.00	$60,000	$2,500	Start of Construction
Mooers / Clinton	2.00	$60,000	$2,500	Start of Construction
Mooers / Clinton	2.00	$60,000	$2,500	Start of Construction
Baldwin / Chemung	2.00	$60,000	2.50%	Start of Construction
Baldwin / Chemung	2.00	$60,000	2.50%	Start of Construction
Newfield / Tompkins	2.00	$60,000	2.50%	Start of Construction
Newfield / Tompkins	2.00	$60,000	2.50%	Start of Construction
Newfield / Tompkins	2.00	$60,000	2.50%	Start of Construction

EXHIBIT O

Innovation Is Making Solar Panels Harder To Recycle

Jeff McMahon Contributor
Green Tech
From Chicago, I write about climate change, green technology, energy.



Workers prepare a solar panel for packaging during production at the SunSpark Technology Inc. manufacturing facility in Riverside, California. Photographer: Patrick T. Fallon/Bloomberg

Solar panels are becoming less and less recyclable as the need for recycling them looms more and more.

The United States installs 7 million pounds per day of solar panels, according to the National Renewable Energy Laboratory, a pace that secures only fourth place among countries for installed capacity. Those panels are built to last 30 years, which foretells a huge demand for recycling decades ahead and an

increasing demand sooner, as some panels succumb to damage or fall short of their warrantied performance.

Two months ago you read in this column that innovation is making lithium-ion batteries harder to recycle. Just as lithium-ion manufacturers have learned to cut down on expensive cobalt, solar-panel manufacturers have gotten very good at omitting their most expensive ingredient: silver.

"The manufacturers themselves are quite inclined to reduce the silver content in their modules," said Garvin Heath, a senior scientist with the National Renewable Energy Laboratory, "because that can help to manage and lower the cost for their manufactured product."

Silver makes up a very small fraction of the mass of a solar panel, but a very high fraction of its value—about 47 percent. We might think of that as almost half of the incentive a recycler has to recycle a panel. Silver is worth significantly more than other recoverable components—aluminum, copper, silicon and glass. Manufacturers have been able to reduce silver content by using inkjet and screen printing technologies to replace silver with a combination of copper, nickel and aluminum, according to the International Renewable Energy Agency.

"Copper is one element that's being looked at as a replacement for silver," Heath said during a webinar hosted by the Clean Energy States Alliance. "Also, just simply smarter manufacturing techniques that are more precise about just the absolute minimum amount of silver that's required. So it's a dematerialization. Some of it is substitution but I think most of this trend is driven by dematerialization. Just using less."

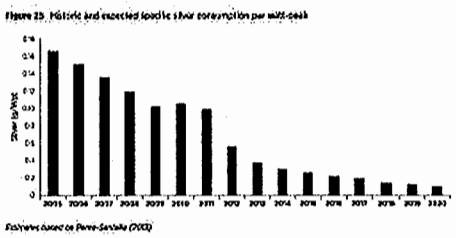
There's been about a tenfold decrease in silver content in panels since 2005, according to IRENA. ***More after the jump...***>

"It's a pretty significant decrease in silver which makes recycling more of a challenge from a value perspective, because you have less and less silver to

recover from those modules," Heath said.

That raises the prospect that aging panels could end up in landfills.

"Currently the cost to recycle is high, especially relative to landfilling or other options," he said.



The historic and expected levels of silver consumption in the manufacturing of silicon photovoltaic panels. (International Renewable Energy Agency) IRENA

No comprehensive studies have been done on the cost of different end-of-life scenarios for solar panels, Heath said, but anecdotally he said he believes they cost $10-$20 per module to recycle, an expense the owner would have to pay. The cost of landfill disposal is much less, but it varies from state to state, and landfilling is not an option everywhere. "In some states landfilling is illegal; in others, it is still legal. PV panels could be classified as hazardous waste in some places and not in others."

At least one state is on top of the problem. The State of Washington's Department of Ecology is drafting a regulation that would prohibit manufacturers from selling modules in Washington unless they provide a recycling option.

"That's a pretty significant mandate," Heath said.

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Jeff McMahon Contributor

I've covered the energy and environment beat since 1985, when I discovered my college was discarding radioactive waste in a dumpster. That story ran in the Arizona Repu...
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