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Environmental Monitoring Report January 2016-June 2017

Tennessee. Department of Environment and Conservation.

TENNESSEE DEPARTMENT OF
ENVIRONMENT AND CONSERVATION

DIVISION OF REMEDIATION
OAK RIDGE OFFICE

ENVIRONMENTAL MONITORING REPORT

January 2016 – June 2017

January 2018

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Table of Contents

List of Tables

List of Figures

List of Acronyms and Common Abbreviations

ALARA	As Low As Reasonably Achievable
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
asl	above sea level
AWQC	Ambient Water Quality Criteria
BCBG	Bear Creek Burial Ground
BCID	Bat Call Identification
BCK	Bear Creek or Bear Creek Kilometer (station location)
BFK	Brushy Fork Creek Kilometer (station location)
BOD	Biological Oxygen Demand
BTEX	Benzene Toluene Ethylbenzene Xylene
CAA	Clean Air Act
CBSQGs	Consensus-based Sediment Quality Guidelines
cc	cubic centimeter
CCK	Clear Creek Kilometer (station location)
Ce-144	Cerium-144
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
Co-60	Cobalt-60
COC	Contaminants of Concern
CRBR	Clinch River Breeder Reactor
CRK	Clinch River KM (station location)
CRM	Clinch River Mile (station location)
Cs-137	Cesium-137
CWP	Contact Water Pond
CWT	Contact Water Tank
D&D	Decontamination and Decommissioning
DCG	Derived Concentration Guide
DIL	Derived Intervention Levels
DO	dissolved oxygen
DOE	Department of Energy
DoR-OR	Division of Remediation, Oak Ridge Office

EFK	East Fork Poplar Creek Kilometer (station location)
EFPC	East Fork Poplar Creek
EMDF	Environmental Management Disposal Facility
EMP	Environmental Monitoring Plan
EMR	Environmental Monitoring Report
EMWMF	Environmental Management Waste Management Facility
EPA	Environmental Protection Agency
EPT	*Ephemeroptera*, *Plecoptera*, *Trichoptera* (mayflies, stoneflies, caddisflies)
ETTP	East Tennessee Technology Park
FB	Freels Bend
FDA	U. S. Food and Drug Administration
FFA	Federal Facility Agreement
FRMAC	Federal Radiation Monitoring and Assessment Center
FWS	U. S. Fish and Wildlife Service
g	gram
GHK	Gum Hollow Branch Kilometer (station location)
GIS	Geographic Information Systems
GPS	Global Positioning System
GW	Ground Water
GWQC	Ground Water Quality Criteria
H-3	Tritium
HAP	Hazardous Air Pollutant
HCK	Hinds Creek Kilometer (station location)
HFIR	High Flux Isotope Reactor
Hg	Mercury
HRE	Homogeneous Reactor Experiment
HWY	Highway
I-131	Iodine-131
IBI	Index of Biotic Integrity
K-####	Facility at K-25 (ETTP)
K-25	Oak Ridge Gaseous Diffusion Plant (now called ETTP)
KDOW	Kentucky Department of Water
KFO	Knoxville Field Office
kg	kilogram

km	kilometer
l, L	liter
LEFPC	Lower East Fork Poplar Creek
LLW	Low Level Waste
LHAV	Lifetime Health Advisory Value
LSP	Lovely Spring
m	meter
m^3	cubic meter
MBK	Mill Branch Kilometer (station location)
MCL	Maximum Contaminant Level (for drinking water)
MDC	Minimum Detectable Concentration
MDL	Method Detection Limit
MQL	Maximum Quantification Level
MEK	Melton Branch Kilometer (station location)
MV	Melton Valley
MeHg	methylmercury
mg	milligram
MIK	Mitchell Branch Kilometer (station location)
ml	milliliter
mrem	1/1000 of a rem – millirem
MSRE	Molten Salt Reactor Experiment
MV	Melton Valley
mv	millivolt
N, S, E, W	North, South, East, West
NAREL	National Air and Radiation Environmental Laboratory
NAWQA	National Water-Quality Assessment Program
Nb-95	Niobium-95
NCBI	North Carolina Biotic Index
NESHAPs	National Emissions Standards for HAPs
ng	nanogram
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site (formerly the Nevada Test Site, NTS)
NORM	naturally occurring radioactive material
Np-237	Neptunium-237

NPDES	National Pollution Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NPL	National Priorities List
NRWQC	Nationally Recommended Water Quality Criteria
NSDWR	National Secondary Drinking Water Regulation
NT#	Northern Tributary of Bear Creek in Bear Creek Valley
NTU	Nephelometric Turbidity Unit
OC	oligochaetes and chironomids
OPW	organ pipe wasps
ORAU	Oak Ridge Associated Universities
OREIS	Oak Ridge Environmental Information System
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
ORP	Oxidation-Reduction Potential
ORR	Oak Ridge Reservation
OSL	Optically Stimulated Luminescent (dosimeter)
OWS	orb weaver spiders
P#	Pond Number
PCB	polychlorinated biphenyls
pCi	1x10-12 Curie (picoCurie)
pCi/L	picoCuries per liter
pCi/m3	picoCuries per cubic meter
PCE	Perchloroethene/Tetrachloroethene
PCK	Poplar Creek Kilometer (station location)
PEC	Probable Effect Concentration
pH	Proportion of Hydrogen Ions (acid vs. base)
ppb	parts per billion
ppm	parts per million
PRG	Preliminary Remediation Goals
PVC	polyvinyl chloride
QA	Quality Assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
QC	Quality Control

RadNet	Nationwide Environmental Radiation Monitoring Program
RCK	Raccoon Creek Mile (station location)
RCRA	Resource Conservation and Recovery Act
REM (rem)	Roentgen Equivalent Man (unit)
RER	Remediation Effectiveness Report
ROD	Record of Decision
RPM	Radiation Portal Monitor
RSL	Regional Screening Levels
RSPs	radiation sensor panels
Ru-106	Ruthenium-106
RWA#	Residential Well Number
SAP	Sampling and Analysis Plan
SD	Storm Drain
SMCL	Secondary MCLs (non-regulatory)
SNS	Spallation Neutron Source
SOF	Sum of Fractions
SOP	Standard Operating Procedure
SQKICK	Semi-Quantitative Kick
Sr-90	Strontium-90
SW	Surface Water
SWSA#	Solid Waste Storage Area
Tc-99	Technetium-99
TCE	Trichloroethene
TDEC	Tennessee Department of Environment and Conservation
TDH	Tennessee Department of Health
TEC	Threshold Effects Concentration
Th-232	Thorium-232
THg	Total Mercury
TMI	Tennessee Macroinvertebrate Index
TNUTOL	% nutrient tolerant organisms
TOA	Tennessee Oversight Agreement
TSCA	Toxic Substance Control Act
TWQC	Tennessee Water Quality Criteria
U.S.	United States

U-234	Uranium-234
U-235	Uranium-235
U-236	Uranium-236
U-238	Uranium-238
UCOR	URS/CH2M Oak Ridge LLC (Current EM Prime Contractor)
UEFK	Upper East Fork Poplar Creek Kilometer (station location)
UEFPC	Upper East Fork Poplar Creek
USFWS	U. S. Fish and Wildlife Service
USGS	United State Geological Survey
VOC	Volatile Organic Compound
Vol.	volume
WAC	Waste Acceptance Criteria
WCK	White Oak Creek Kilometer (station location)
WNS	White-nose Syndrome
WOC	White Oak Creek
X-####	Facility at X-10 (ORNL)
X-10	Oak Ridge National Laboratory
Y-####	Facility at Y-12
Y-12	U.S. Department of Energy Y-12 National Security Complex
Zr-95	Zirconium-95
µS	microSiemens
µg	microgram
µmho	micro ohm (ohm=1/ohm)
µR	microroentgen
µrem	micro rem

1.0 Introduction

The Tennessee Department of Environment and Conservation (TDEC), Division of Remediation, Oak Ridge Office (DoR-OR), submits its annual Environmental Monitoring Report for the period January 1, 2016 through June 30, 2017, under the terms of the Tennessee Oversight Agreement (TOA) between the state of Tennessee and the United States Department of Energy (DOE), Section A.6.1.2. This monitoring report focuses on the following media-specific focus areas:

- radiological emissions and releases
- mercury monitoring and releases
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) landfill
- oversight of impacts to regional groundwater
- general site monitoring on the Oak Ridge Reservation and environs

The TDEC DoR-OR media-specific sampling programs are coordinated to apply the full effect of DoR-OR's resources to the above focus areas to ensure that DOE's Oak Ridge Operations (ORO) have no adverse impacts to public health, safety, or the environment from past or present activities. If adverse effects are identified or suspected, then, TDEC DoR-OR communicates those effects to DOE, the responsible regulatory state agency, the Tennessee Department of Health (TDH), and affected members of the public, when appropriate. Results from monitoring and findings of the adequacy and effectiveness of DOE's environmental programs are reported in TDEC DoR-OR's quarterly and annual status reports. This Environmental Monitoring Report provides the technical results of studies from January 1, 2016 through June 30, 2017.

1.1 Oak Ridge Reservation Background Information

The ORR is owned by the United States (US) federal government and consists of the following three major operating sites:

1. East Tennessee Technology Park (ETTP), formerly K-25
2. Oak Ridge National Lab (ORNL), formerly X-10
3. Y-12 National Security Complex (Y-12)

Facilities at these sites were constructed as part of the Manhattan Project. Their primary missions have evolved over the years and continue to adapt to meet the changing research, defense, and environmental restoration needs of the United States. From the 1940s through 1987, various site operations released radionuclides into the air and surface water and generated land disposals of radionuclides and hazardous waste on the ORR. Historical radionuclide releases from the Oak Ridge facilities have been summarized from existing data, and the estimated annual liquid release from the ORO includes:

- tritium (H-3) , cobalt-60 (Co-60), strontium-90 (Sr-90), niobium-95 (Nb-95), zirconium-95 (Zr-95), ruthenium-106 (Ru-106), iodine-131 (I-131), cesium-137 (Cs-137), and cerium (Ce-144)

- transuranics from ORNL
- thorium-232 (Th-232) and uranium-238 (U-238) from the Y-12 Plant
- technetium-99 (Tc-99), neptunium-237 (Np-237), and U-238 from the former K-25 facility at ETTP

At ORNL, the activities of fuel reprocessing, isotope production, waste management, radioisotope applications, reactor developments, and multi-program laboratory operations produced waste streams resulting in environmental releases that contain both radionuclides and hazardous chemicals. In addition, low-level radioactive waste generated by other sites has been disposed of at ORNL.

The Y-12 plant continues to produce components for various nuclear weapons systems. A portion of that effort involves converting uranium-235 (U-235) compounds to metal. The associated waste streams have resulted in environmental releases that contain both radionuclides and hazardous chemicals.

Although the gaseous diffusion activities at ETTP have concluded, past environmental waste streams and current decommissioning activities have resulted in environmental releases that contain both radionuclides and hazardous chemicals.

The largest quantity of mercury released in the environment was from Y-12 operations during the 1950s and early 1960s. East Fork Poplar Creek (EFPC) is contaminated with average aqueous mercury concentrations exceeding those in reference streams by several hundred-fold. Remedial actions over the past 20 years have decreased aqueous mercury concentrations in East Fork Poplar Creek by 85% [from >1600 nanograms per liter [(ng/L) to <400 ng/L]. The water quality criterion for mercury in recreational waters for organisms only is 51 ng/L [TDEC Rule 0400-40-03-.03 (4)]. Fish fillet concentrations, however, have not responded to the decrease in aqueous mercury. They remain above the United States (US) Environmental Protection Agency (EPA) National Recommended Water Quality Criteria (NRWQC) of 0.3 milligrams per kilogram (mg/kg).

As a consequence of past mission activity, groundwater beneath the ORR has become contaminated. DOE has outlined areas of groundwater contamination on the ORR as seen in the Remediation Effectiveness Reports (RER). Extensive measures, as noted in the RERs, have been implemented attempting to isolate remaining contaminant sources from groundwater. However, additional efforts are necessary to understand and respond to legacy groundwater challenges.

Each project designed and implemented for each focus area used three criteria to communicate results:

1. Are contaminants detected?
2. Do they exceed health-based criteria, e.g., National Primary Drinking Water Regulations (NPDWR) or National Secondary Drinking Regulations (NSDWR)?
3. Can the contaminants be attributed to DOE activities?

The TDEC DoR-OR Environmental Monitoring Plan supports identifying and determining the level and risk of historic and ongoing releases to public health and to the environment. This report focuses on potential pathways of air, surface water, ground water, sediment, soil, and ecological effects in areas of known contamination, active remediation, or ongoing activities. It reports the results of those activities outlined in the TDEC DoR-OR Environmental Monitoring Plans (2016, 2017).

1.2 Site Description

The ORR is located in the counties of Anderson and Roane within the corporate boundaries of the city of Oak Ridge, Tennessee. The reservation is bound on the north and east by residential areas of the city of Oak Ridge and on the south and west by the Clinch River. Counties adjacent to the reservation include Knox to the east, Loudon to the southeast, and Morgan to the northwest. Portions of Meigs and Rhea counties are immediately downstream from the ORR on the Tennessee River. The nearest cities are Oak Ridge, Oliver Springs, Clinton, Kingston, Harriman, Farragut, and Lenoir City. The nearest metropolitan area, Knoxville, lies approximately 20 miles to the east. Figure 1.1.1 shows the general location of the ORR relative to nearby cities and surrounding counties.

The ORR, as shown in Figure 1.1.2, encompasses approximately 32,500 acres and three major operational DOE program sites: ETTP, ORNL, and Y-12. The initial objectives of the ORO were the production of plutonium and the enrichment of uranium for nuclear weapons components. In the 70 years since the ORR was established, a variety of production and research activities have generated numerous radioactive hazardous, and mixed wastes. These wastes, along with wastes from other locations, were disposed of on the ORR. Earlier waste disposal methods on the ORR were rudimentary compared to today's standards.

The ORR lies in the Valley and Ridge Physiographic Province of East Tennessee. This province consists of alternating ridges and valleys of southwest-to-northeast orientation. The Valley and Ridge Province is a zone of complex geologic structures dominated by a series of thrust faults. It is characterized by a succession of elongated southwest-to-northeast trending valleys and ridges. In general, sandstones, limestones, and dolomites underlie the ridges that are relatively resistant to erosion. Weaker shales and more soluble carbonate rock units underlie the valleys.

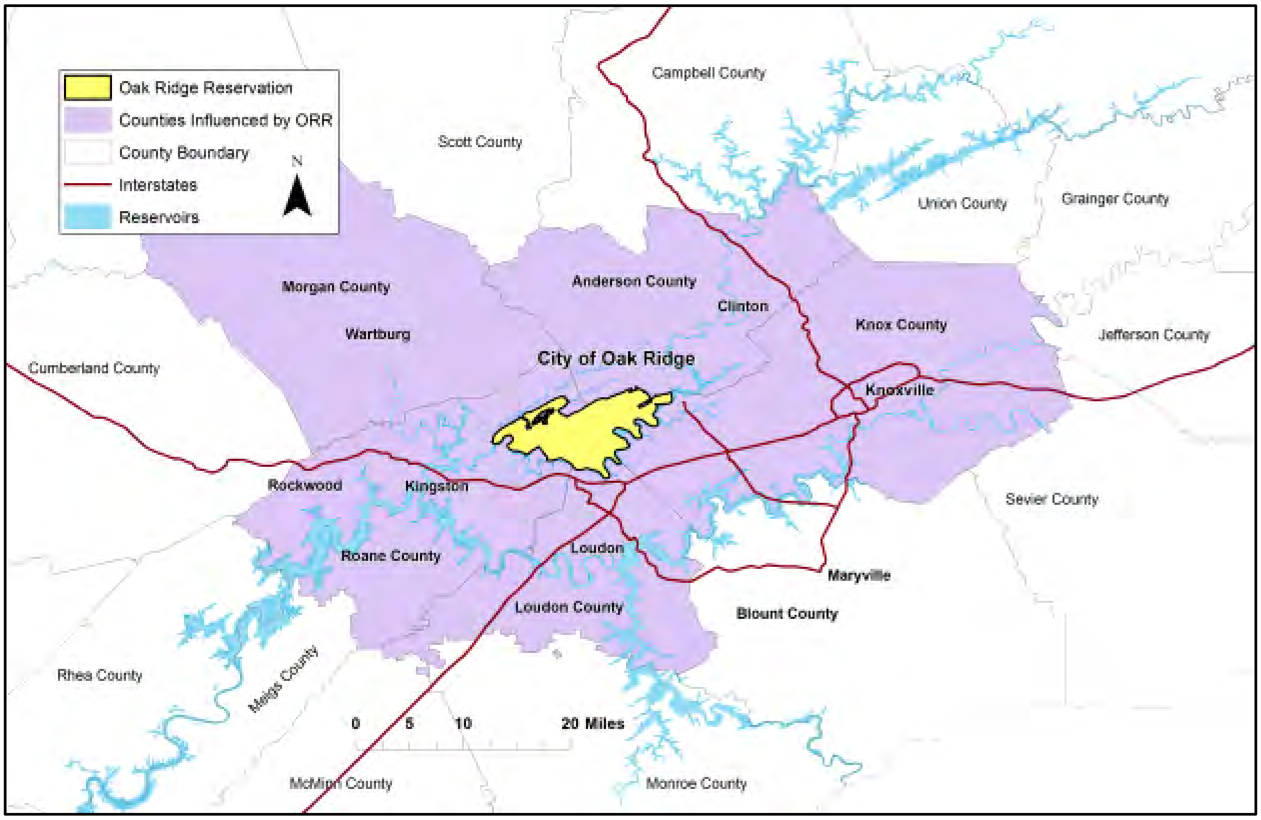


Figure 1.1.1: Location of the Oak Ridge Reservation in Relation to Surrounding Counties

The hydrogeology of the ORR is complex with a number of variables influencing the direction, quantity, and velocity of groundwater flow that may or may not be evident from surface topography. In many areas of the ORR, groundwater appears to travel primarily along short flow paths in the storm flow zone to nearby streams. In other areas, evidence indicates substantial groundwater flow paths, possibly causing the preferential transport of contaminants in fractures and solution cavities in the bedrock for relatively long distances and at considerable depths increasing the probability for off-site migration of those contaminants to areas accessible by the public.

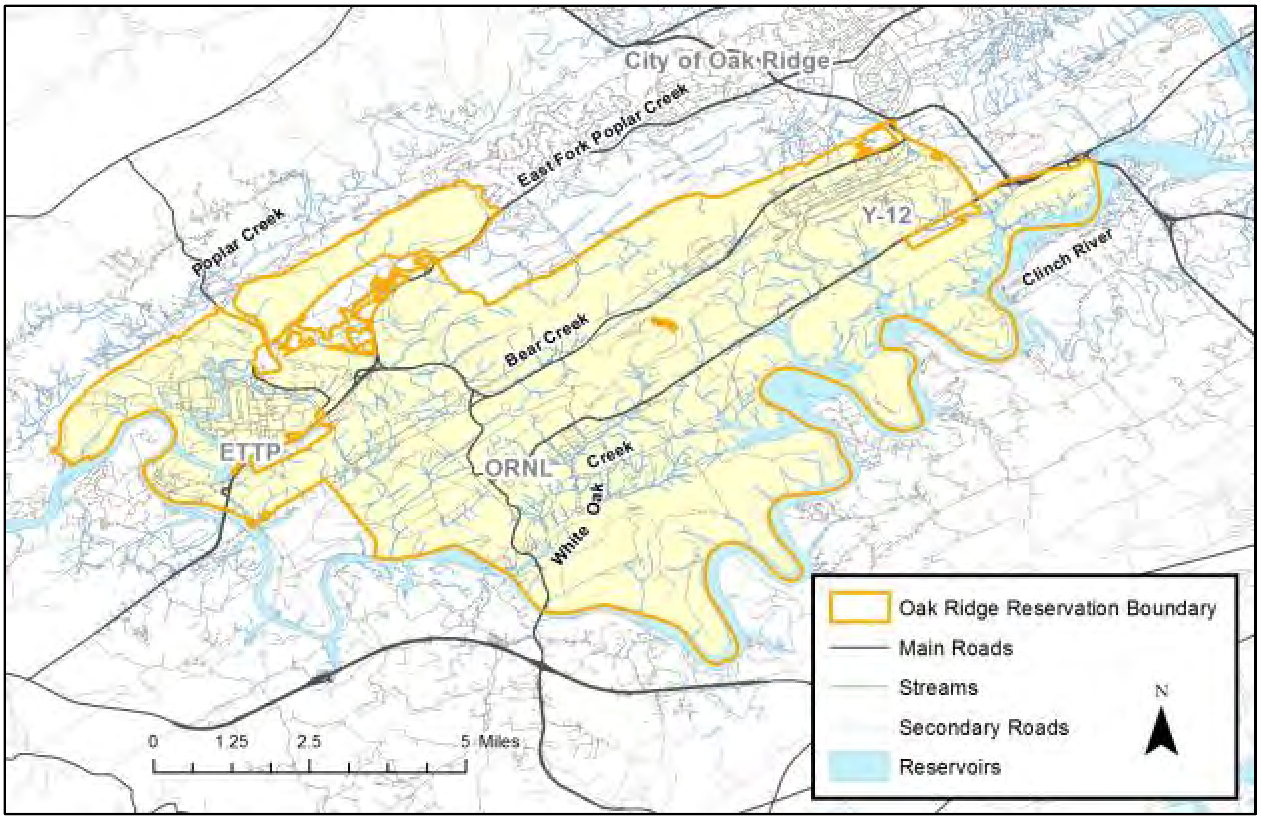


Figure 1.1.2: The Oak Ridge Reservation

2.0 Sampling and Monitoring Programs

2.1 Radiological Monitoring

2.1.1 Environmental Dosimeters

Introduction

Gamma radiation is emitted by various radionuclides that have been produced, stored, and disposed of on the ORR. Associated radionuclides are evident in ORR facilities and in the surrounding soils, sediment, and water. In order to assess the risk posed by these contaminants, DoR-OR began monitoring ambient gamma radiation levels on and in the vicinity the ORR in 1995. DoR-OR uses environmental dosimeters to measure the radiation dose attributable to external radiation at more than one hundred locations on or near the ORR.

Each quarter, dosimeters are staged, collected, returned to the vendor, and the data processed to determine radiation levels at the locations. This program, in conjunction with the Real Time Gamma Radiation monitoring program, provides:

- conservative estimates of the potential dose and risk to members of the public from exposure to radiation attributable to DOE activities or ORR facilities
- baseline values to assess the need for and effectiveness of remedial actions
- information necessary to establish trends in radioactive emissions
- information relative to the unplanned releases of radioactive contaminants on the ORR

Methods and Materials

The dosimeters used in this program were obtained from Landauer, Inc., of Glenwood, Illinois. Each dosimeter used an aluminum oxide photon detector to measure the dose from gamma radiation [minimum reporting value equals one millirem (mrem)]. At locations where a potential for the release of neutron radiation exists, dosimeters also contain an allyl diglycol carbonate-based neutron detector (minimum reporting value equals 10 mrem). The dosimeters, staged and collected quarterly, are returned to Landauer for processing.

To account for exposures received in transit, control dosimeters are provided with each shipment of dosimeters received from the Landauer Company. Each control dosimeter is stored in a lead container at the DoR-OR during the monitoring period and returned to Landauer for processing along with field deployed dosimeters. Scores are adjusted to ensure that control dosimeter results are subtracted from field-deployed dosimeter results prior reporting.

As quarterly data are received from the vendor, DoR-OR reviews, compiles, and distributes a quarterly report to DOE and other interested parties. Quarterly results (for each location) are summed and the annual dose is determined and compared to background values and to the state's primary dose limit for members of the public (100 mrem/year above background concentrations and medical applications).

Results and Discussion

The Atomic Energy Act exempts DOE from outside regulation of radiological materials at its facilities, but requires DOE to manage these materials in a manner protective of the public health and the environment. Since access to the reservation has been predominately restricted to DOE employees or DOE contractors, locations within the fenced areas of the reservation have been inaccessible to the public. With the reindustrialization and revitalization of portions of the reservation, there has been an influx of workers employed by businesses not directly associated with DOE operations and, in some cases, property within the reservation boundaries has been deeded to private entities.

Under state regulations, a member of the public is any individual not employed to perform duties that involve exposures to radiation. State regulations limit public exposures to radiation to a dose of 100 mrem/year (above background and medical applications) and the release of radiation to unrestricted areas to a dose of two mrem in any one-hour period. In this context, a restricted area is an area with limited access to protect individuals against undue risks from exposure to radiation and radioactive materials.

The dose of radiation an individual receives at any given location is dependent on the intensity and the duration of the exposure. For example, an individual standing at a site where the dose rate is one mrem/hour would receive a dose of two mrem if he or she stayed at the same spot for two hours. If that person were exposed to the same level of radiation for eight hours a day for the approximately 220 working days in a year (1,760 hours), the individual would receive a dose of 1,760 mrem in that year. It is important to note that the doses reported in the program are based on an individual's exposure that would remain at the monitoring station twenty-four hours a day for one year (8,760 hours). Since this is unlikely, the doses reported are conservative estimates of the maximum dose an individual could receive at each location.

None of the neutron dosimeters recorded a dose during 2016. Results are organized according to location and provide a comparative analysis for 2015 and 2016 data:

- Table 2.1.1.1and Figure 2.1.1.1: Offsite Dosimeter Stations
- Table 2.1.1.2 and Figure 2.1.1.2: ETTP Dosimeter Stations
- Table 2.1.1.3 and Figure 2.1.1.3: Y-12 Dosimeter Stations
- Table 2.1.1.4 and Figure 2.1.1.4: EMWMF Contact Water Pond Dosimeters
- Table 2.1.1.5 and Figure 2.1.1.5 (A and B): EMWMF Waste Cell Dosimeters
- Table 2.1.1.12 provides descriptive notes for Tables 2.1.1.1 through 2.1.1.11

Table 2.1.1.1: Offsite Dosimeter Stations

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
A-11 (9)	Norris Dam Air Monitoring Station (Background)	Gamma	2	2	5	4	13	14
A-12 (86)	Loudoun Dam Air Monitoring Station (Background)	Gamma	2	2	4	2	10	15
A-13 (86a)	Loudoun Dam Air Monitoring Station (Background)	Gamma	2	3	3	3	11	12
A-13 (86a)	Loudoun Dam Air Monitoring Station (Background)	Neutron	M	M	M	M	0	0
A-14 (66)	Emory Valley Greenway	Gamma	10	11	16	12	49	51
A-15 (80)	Elza Gate	Gamma	M	2	3	2	7	9
A-16 (65)	California Avenue	Gamma	M	M	3	1	4	8
A-17 (64)	Cedar Hill Greenway	Gamma	M	M	3	3	6	13
A-18 (63)	Key Springs Road	Gamma	M	M	3	1	4	3
A-19 (62)	East Pawley	Gamma	2	4	6	5	17	17
A-21 (67)	West Vanderbilt	Gamma	5	6	10	6	27	23
A-22 (70)	Scarboro Perimeter Air Monitoring Station	Gamma	5	6	8	6	25	24
A-23 (91)	Emory Valley Pump House	Gamma	13	19	20	15	67	65

Since data is based on a year-long estimate of exposure, extrapolations were made to estimate a full year's data for any situation where data was incomplete due to missing dosimeters, deployment periods less than one-year, and instances where certain quarters of data were eliminated because of extreme differences from the expected norm for a station. Monitoring results that varied extremely from the norm were usually found to possess elevated dosage levels for the control (theoretically unexposed) dosimeters. In instances where the result for a given dosimeter was returned as "M" (<1 mrem), the value for that quarter was assumed to be zero.

Stations Off the Oak Ridge Reservation

In 2016, the results for offsite locations ranged from four to 67 mrem/year. The highest results reported for offsite locations were for the Emory Valley Pump House station A-23 (67 mrem) and station A-14 the Emory Valley Greenway (49 mrem). Station A-14, adjacent to the Emory Valley Greenway, is approximately one hundred feet from Station A-23, the Emory Valley pump station. The slightly elevated results (compared to other offsite locations) may be an artifact of the use of sediment from the East Fork Poplar Creek flood plain downstream from Y-12 and from fill during the construction of portions of the Oak Ridge sewer system (1982, MMES). For the majority, stations' results were lower in 2016 than they were in 2015. Only a few were higher in 2016 than in 2015.

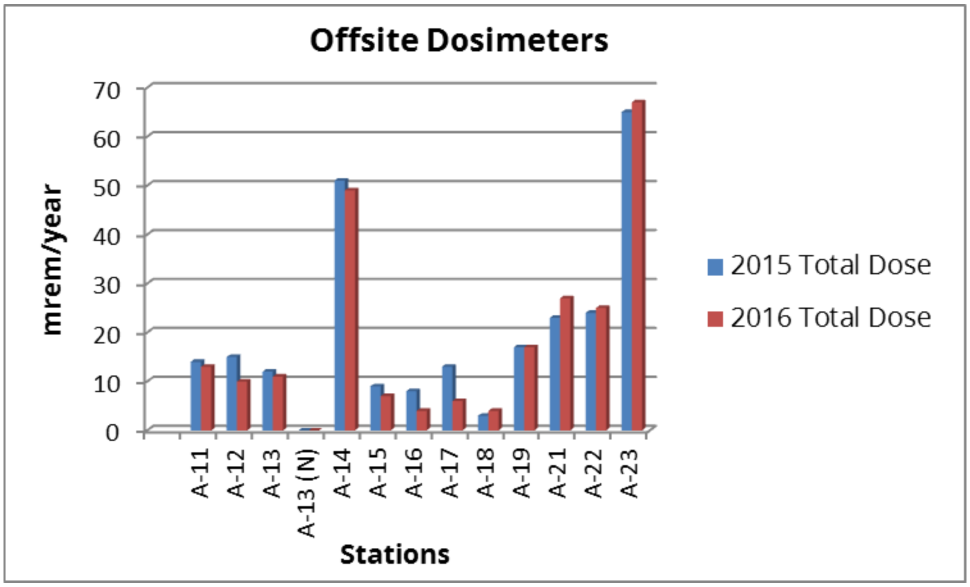


Figure 2.1.1.1: Offsite Dosimeter Stations

<u>East Tennessee Technology Park</u>

The K-25 Gaseous Diffusion Plant, now known as ETTP, was constructed during World War II to produce enriched uranium for use in the first atomic weapons and later to fuel commercial- and government-owned reactors. Other site activities included uranium enrichment by liquid thermal diffusion; development and testing of the gas centrifuge method of uranium enrichment; laser isotope separation research and development; and the incineration of 35 million pounds of hazardous and radioactive waste at the Toxic Substance Control Act (TSCA) Incinerator (1991-2012).

The original gaseous diffusion facilities were put in stand-by mode in 1967 and the plant permanently closed in 1987, when the focus turned to site remediation and reindustrialization, with a long-term goal of transitioning ETTP into an industrial park. Under the reindustrialization program, portions of ETTP may be transitioned to private entities for use or development.

During 2016, the results for dosimeters stationed at ETTP ranged from two to 90 mrem/year. The highest results were at stations C-42 (90 mrem/year), C-53 (45 mrem/year), C-51 (42 mrem/year), C-52 (37 mrem/year), and C-21 (30 mrem/year). Station C-42 (with the highest reading) is located just off the ETTP reservation on Bear Creek Road across from an active waste handling business. Other results were similar to background values. The majority of the ETTP dosimeters showed slightly higher values in 2016 than in 2015.

Although the readings may appear high, an individual would have to remain at the given station for 24 hours a day for an entire year to receive the measured dose. Table 2.1.1.2 provides the identity of the ETTP dosimeter stations. Figure 2.1.1.2 depicts the results for dosimeter data for 2015 and 2016.

Table 2.1.1.2: ETTP (Horizon Center) Dosimeter Stations

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem				2016 Total Dose **	2015 Total Dose **
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
C-10(43)	K-1401 Building (West side)	Gamma	4	5	8	6	23	23
C-12(48)	K-1420 Building	Gamma	M	M	2	M	2	1
C-17(44)	K-25 Building	Gamma	M	2	2	M	4	5
C-18(160)	K-27 Building (SW Corner)	Gamma	3	6	6	7	22	5
C-19(159)	K-27 Building (South Side)	Gamma	5	7	8	7	27	5
C-20(158)	K-27 Building (SE Corner)	Gamma	3	4	3	3	13	4
C-21(155)	K-27 Building (NW Corner)	Gamma	6	8	8	8	30	20
C-22(156)	K-27 Building (North Side)	Gamma	5	7	8	6	26	12
C-23(157)	K-27 Building (NE Corner)	Gamma	1	1	2	M	4	4
C-24(16)	K-901 Pond	Gamma	M	2	4	2	8	7
C-25(15)	K-1070-A Burial Ground	Gamma	M	2	4	3	9	12
C-27(79)	ED1 On Pole	Gamma	4	7	7	6	24	21
C-28(58)	K-25 Portal 5	Gamma	2	4	6	M	12	13
C-29(177)	TSCA West Gate	Gamma	M	M	2	M	2	0
C-30(178)	TSCA North Gate	Gamma	M	1	1	2	4	4
C-40(72)	ETTP Visitors Overlook	Gamma	6	10	Absent	10	26	25
C-41(45)	K-770 Scrap Yard	Gamma	M	M	2	1	3	0
C-42(47)	Bear Creek Road ~ 2800 Feet From Clinch River	Gamma	18	25	26	21	90	83
C-43(11)	Grassy Creek Embayment On The Clinch River	Gamma	2	2	2	3	9	16
C-44(21)	White Wing Scrap Yard	Gamma	5	7	8	8	28	28
C-50(179)	ETTP Uranium Storage Yard (East)	Gamma	2	4	3	3	12	19
C-51(180)	ETTP Uranium Storage Yard (South)	Gamma	11	12	11	8	42	51
C-52(181)	ETTP Uranium Storage Yard (South)	Gamma	9	12	9	7	37	52
C-53(182)	ETTP Uranium Storage Yard (West)	Gamma	8	10	22	5	45	36

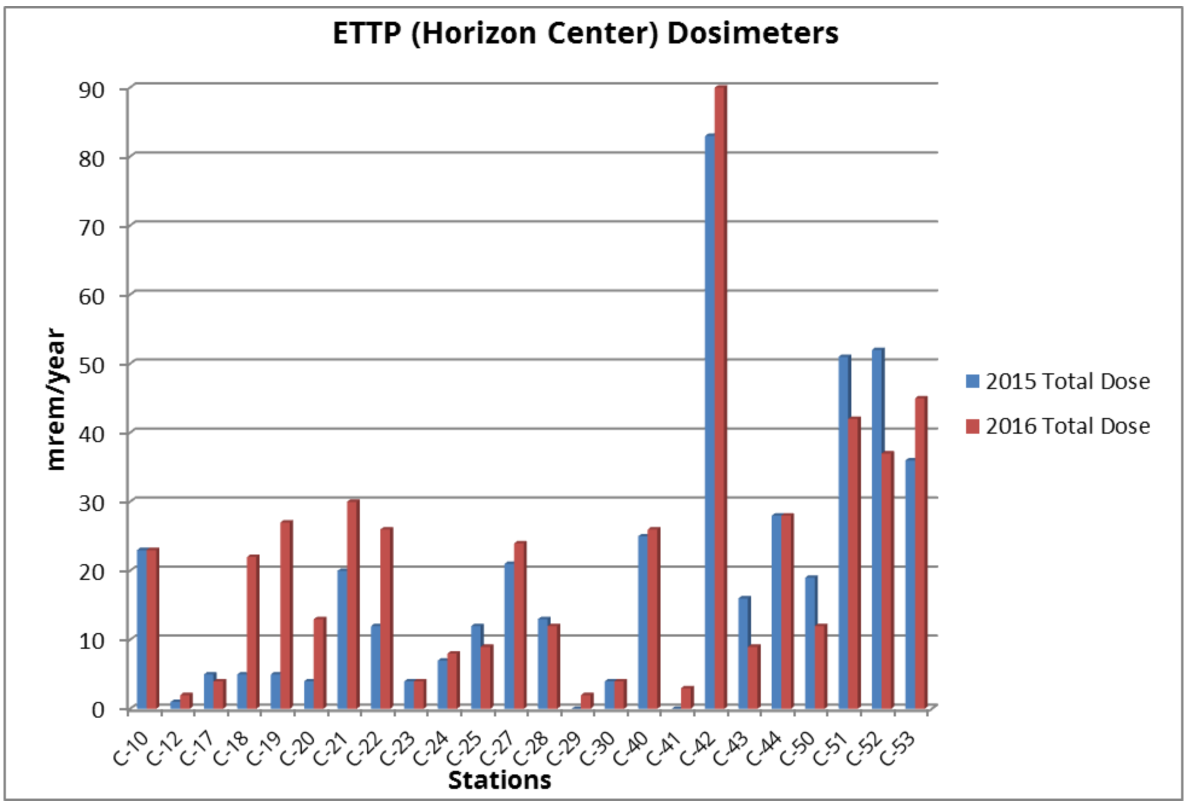


Figure 2.1.1.2: ETTP (Horizon Center) Dosimeter Stations

The Y-12 National Security Complex

Similar to K-25, Y-12 was constructed during World War II to produce enriched uranium by the electromagnetic separation process. In ensuing years, the facility produced fuel for naval reactors, conducted lithium/mercury enrichment operations, manufactured components for nuclear weapons, dismantled nuclear weapons, and stored enriched uranium. A number of Y-12 buildings were used by ORNL for various pursuits: animal studies, Molten Salt Reactor Experiment (MSRE) research, radioactive isotope production, and the Aircraft Nuclear Propulsion Program. Y-12 is the least accessible of the three DOE Oak Ridge facilities to the public.

Three locations within the Y-12 complex are currently being monitored: 1.) the Uranium Oxide Storage Vaults, 2.) the Walk-In Pits, and 3.) the East Perimeter air monitoring station. Table 2.1.1.3 provides the locations of the Y-12 dosimeter stations and Figure 2.1.1.3 depicts the Y-12 dosimeter station results for the period 2015-2016.

Table 2.1.1.3: Y-12 Dosimeter Stations

Dosimeter Designation (Dosimeter number)	**Location** *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	**Type of Radiation**	**Dose Reported for 2016 in mrem** *M = Below Minimum Reportable Quantity*				**2016 Total Dose**	**2015 Total Dose**
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
B-10 (71)	Y-12 East Perimeter Air Monitoring	Gamma	M	2	4	4	10	17
B-11 (39)	Y-12 at back side of Walk In Pits	Gamma	2	4	6	4	16	15
B-12 (38)	Y-12 Uranium Oxide Storage Vaults	Gamma	3	2	5	3	13	13

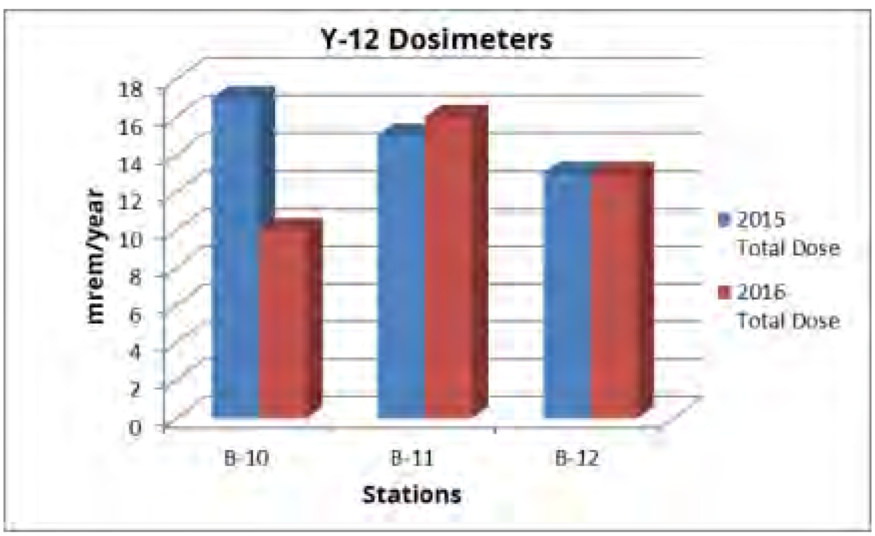


Figure 2.1.1.3: Y-12 Dosimeter Stations

The results for the Y-12 locations ranged from 10 to 16 mrem/year. These low levels are expected because the majority of the material handled at Y-12 emits primarily alpha and beta (not gamma) radiation. Results for 2016 and 2015 were roughly comparable.

Environmental Management Waste Management Facility

The EMWMF was constructed in 2002 to dispose of radioactive and hazardous wastes generated by remedial activities from all three plants on the ORR. The facility operates under the authority of CERCLA, and waste approved for disposal is limited by the waste acceptance criteria agreed upon by DOE, EPA, and the state. EMWMF is located immediately to the west of the Y-12 complex (in Bear Creek Valley). Monitoring stations have been established at the boundary of the waste disposal cells and at secondary waste management systems (contact water ponds). For this report, the dosimeters surrounding the EMWMF waste cell and those surrounding the contact water ponds are discussed separately. During 2016, the results for the contact water pond dosimeters ranged from nine to 44 mrem/year. Dosimeters surrounding the EMWMF waste cell ranged from 13 to 48 mrem/year. The results for the contact water ponds were slightly higher in 2016 than they were in 2015. This is also true for the majority of the stations for the EMWMF waste cell.

Figure 2.1.1.4 depicts the results for EMWMF dosimeter data for the contact water ponds and Table 2.1.1.4 provides the identity of the EMWMF stations for 2015-2016. Table 2.1.1.5 identifies the monitoring stations and Figure 2.1.1.5 (A&B) depicts the results for dosimeter data for the EMWMF waste cell for the period 2015-2016.

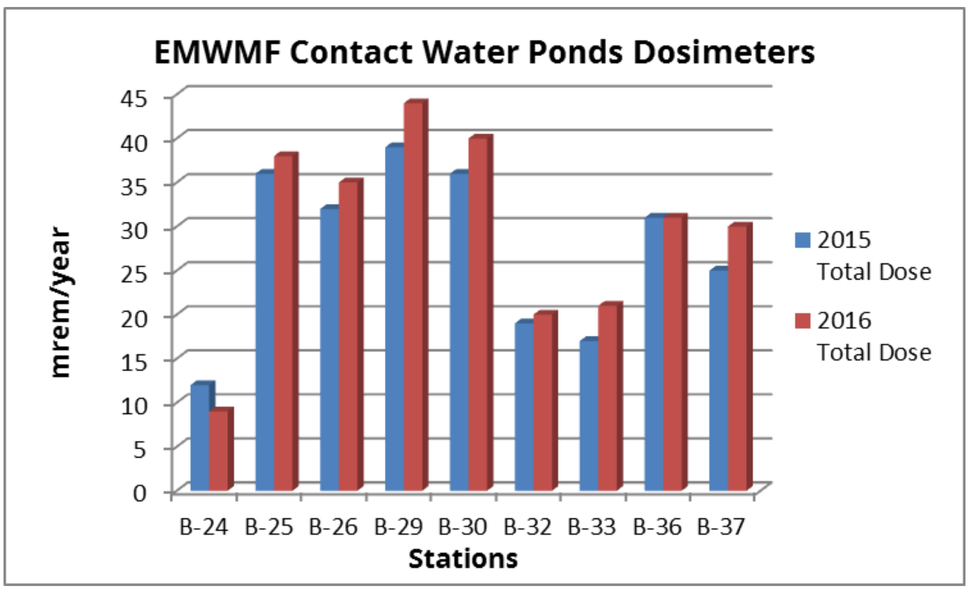


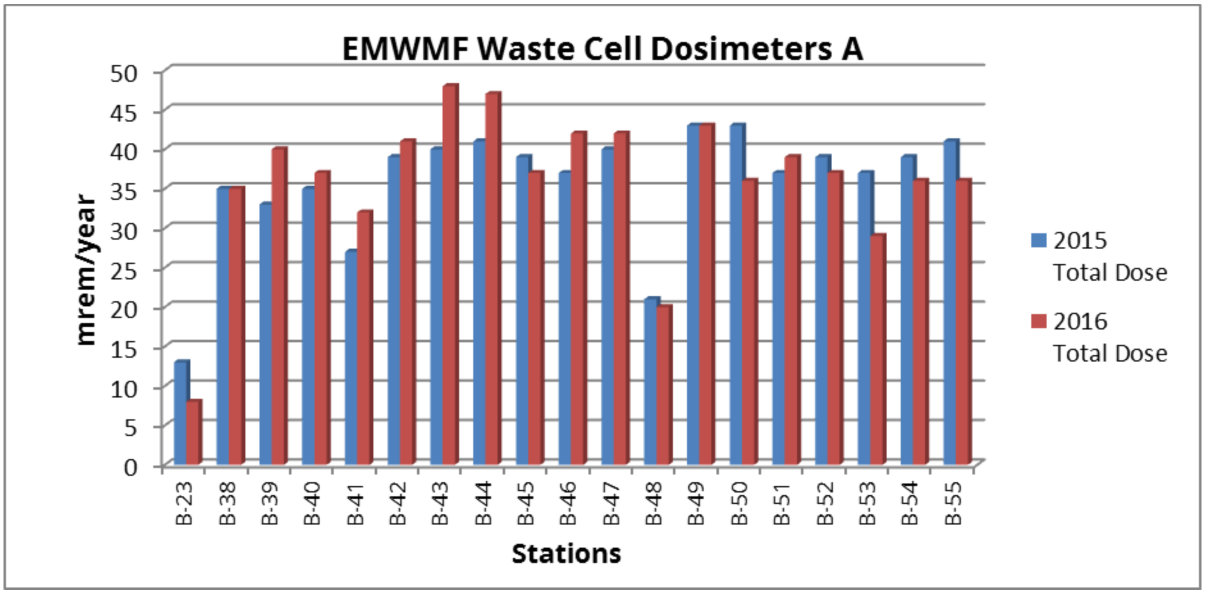
Figure 2.1.1.4: EMWMF Contact Water Ponds Dosimeters

Table 2.1.1.4: EMWMF Contact Water Ponds Dosimeters

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
B-24 (92)	Leachate Collection Tanks at Gate	Gamma	2	2	3	2	9	12
B-25 (105)	Contact Water Ponds Fence (NW Side)	Gamma	6	10	12	10	38	36
B-26 (106)	Contact Water Ponds Fence (NE Side)	Gamma	7	8	10	10	35	32
B-29 (109)	Contact Water Ponds Fence (SE Side)	Gamma	8	11	12	13	44	39
B-30 (110)	Contact Water Ponds Fence (SW Side)	Gamma	7	12	11	10	40	36
B-32 (112)	Contact Water Tanks Fence (NE Side)	Gamma	3	4	7	6	20	19
B-33 (113)	Contact Water Tanks Fence (NW Side)	Gamma	2	5	7	7	21	17
B-36 (116)	Contact Water Tanks Fence (SW Side)	Gamma	5	8	9	9	31	31
B-37 (117)	Contact Water Tanks Fence (SE Side)	Gamma	5	7	9	9	30	25

Table 2.1.1.5: EMWMF Waste Cell Dosimeters

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
B-23 (90)	Waste Cell Perimeter Fence @ Gate	Gamma	4	5	8	6	23	23
B-38 (118)	Waste Cell Perimeter Fence (SE Corner)	Gamma	6	9	10	10	35	35
B-39 (119)	Waste Cell Perimeter Fence (South Side)	Gamma	8	11	10	11	40	33
B-40 (120)	Waste Cell Perimeter Fence (South Side)	Gamma	6	10	11	10	37	35
B-41 (121)	Waste Cell Perimeter Fence (South Side)	Gamma	5	10	8	9	32	27
B-42 (122)	Waste Cell Perimeter Fence (South Side)	Gamma	8	10	12	11	41	39
B-43 (123)	Waste Cell Perimeter Fence (South Side)	Gamma	8	12	14	14	48	40
B-44 (124)	Waste Cell Perimeter Fence (South Side)	Gamma	8	12	14	13	47	41
B-45 (125)	Waste Cell Perimeter Fence (South Side)	Gamma	7	9	10	11	37	39
B-46 (126)	Waste Cell Perimeter Fence (South Side)	Gamma	6	12	11	13	42	37
B-47 (127)	Waste Cell Perimeter Fence (South Side)	Gamma	7	11	11	13	42	40
B-48 (128)	Waste Cell Perimeter Fence (South Side)	Gamma	3	6	5	6	20	21
B-49 (129)	Waste Cell Perimeter Fence (SW Corner)	Gamma	7	11	13	12	43	43
B-50 (130)	Waste Cell Perimeter Fence (West Side)	Gamma	7	12	12	5	36	43
B-51 (131)	Waste Cell Perimeter Fence (West Side)	Gamma	8	11	12	8	39	37
B-52 (132)	Waste Cell Perimeter Fence (West Side)	Gamma	7	10	12	8	37	39
B-53 (133)	Waste Cell Perimeter Fence (West Side)	Gamma	7	10	12	M	29	37
B-54 (134)	Waste Cell Perimeter Fence (West Side)	Gamma	6	10	11	9	36	39
B-55 (135)	Waste Cell Perimeter Fence (West Side)	Gamma	6	10	13	7	36	41
B-56 (136)	Waste Cell Perimeter Fence (NW Corner)	Gamma	7	11	11	11	40	39
B-57 (137)	Waste Cell Perimeter Fence (North Side)	Gamma	7	10	11	13	41	36
B-58 (138)	Waste Cell Perimeter Fence (North Side)	Gamma	9	12	11	12	44	44
B-59 (139)	Waste Cell Perimeter Fence (North Side)	Gamma	7	10	10	9	36	36
B-60 (140)	Waste Cell Perimeter Fence (North Side)	Gamma	8	12	12	6	38	43
B-61 (141)	Waste Cell Perimeter Fence (North Side)	Gamma	9	12	12	13	46	43
B-62 (142)	Waste Cell Perimeter Fence (North Side)	Gamma	5	7	9	8	29	32
B-63 (143)	Waste Cell Perimeter Fence (North Side)	Gamma	6	11	11	12	40	36
B-64 (144)	Waste Cell Perimeter Fence (North Side)	Gamma	7	10	11	11	39	35
B-65 (145)	Waste Cell Perimeter Fence (North Side)	Gamma	8	13	11	12	44	45
B-66 (146)	Waste Cell Perimeter Fence (North Side)	Gamma	6	11	10	10	37	36
B-67 (147)	Waste Cell Perimeter Fence (NE Corner)	Gamma	7	10	11	10	38	37
B-68 (148)	Waste Cell Perimeter Fence (East side)	Gamma	3	5	5	M	13	21
B-69 (149)	Waste Cell Perimeter Fence (East side)	Gamma	6	10	9	9	34	35
B-70 (150)	Waste Cell Perimeter Fence (East side)	Gamma	6	9	10	9	34	35
B-71 (151)	Waste Cell Perimeter Fence (East side)	Gamma	6	7	9	8	30	35
B-72 (152)	Waste Cell Perimeter Fence (East side)	Gamma	4	6	8	9	27	33
B-73 (153)	Waste Cell Perimeter Fence (East side)	Gamma	6	9	7	9	31	29
B-74 (154)	Waste Cell Perimeter Fence (East side)	Gamma	5	8	7	9	29	33



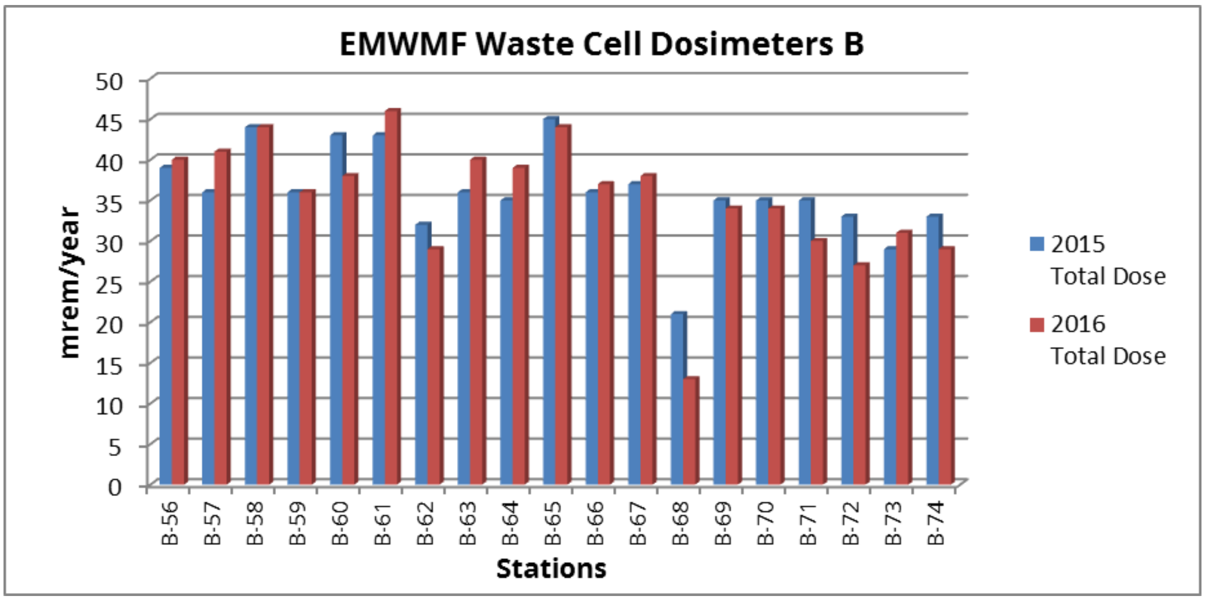


Figure 2.1.1.5: EMWMF Waste Cell Dosimeters:
A (Stations B-23 to B-55)
B (Stations B-56to B-74)

Oak Ridge National Laboratory

ORNL was established during the World War II Manhattan Project Era. Its wartime mission focused on reactor research and the production of plutonium and other radionuclides that were chemically extracted from uranium irradiated in ORNL's Graphite Reactor and other ORNL and Hanford reactors. Throughout the years, thirteen reactors were constructed and operated at the ORNL site, including the currently active High Flux Isotope Reactor (HFIR). Since its inception, ORNL has evolved into DOE's largest multi-program national science and energy laboratory hosting thousands of visitors each year. Land adjacent to ORNL's main campus has been deeded to organizations outside of DOE, buildings have been constructed using private funds, and non-DOE contractor facilities now occupy that land adjacent to ORNL (ORAU, 2003).

Many of the remaining facilities (constructed during World War II and the cold war era) are contaminated, have fallen into disrepair, and complicate remediation. Access to the site is controlled for security; however, admittance is allowed with an appropriate visitor's pass and the appropriate training. Within the access-controlled areas, certain locations have been designated as radiation areas. Access to these locations, legacy burial grounds, and associated facilities is restricted for safety reasons.

Due to the nature of some radioactive contaminants at ORNL (high-energy gamma emitters), the highest dose rates in the dosimetry program are typically associated with stations at ORNL. The dose rates measured at ORNL in 2016 ranged from zero to 11,651 mrem for the year. The dose rates reported reflect the dose that a person could receive if a person remained at the monitoring station for 365 days a year, 24 hours a day. The actual dose any individual would receive depends on the time spent at the location, which in all cases would be a fraction of that assumed for the dose estimates. These estimates are conservative, but they identify locations that merit further evaluation. A complete listing of all stations related to ORNL (except SNS) is included in Table 2.1.1.6.

Table 2.1.1.6: Complete List of ORNL Related Dosimeters (Except SNS)

Dosimeter Designation (Dosimeter	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
D-10 (20)	Freels Bend Entrance	Gamma	2	2	5	3	12	15
D-12 (69)	Graphite Reactor	Gamma	6	6	9	5	26	29
D-13 (167)	South Side Of Central Ave.	Gamma	14	19	15	14	62	63
D-14 (166)	North Side Of Central Ave.	Gamma	51	64	56	58	229	220
D-16 (30)	Old X-3513 Impoundment	Gamma	3	4	7	3	17	26
D-17 (28)	White Oak Dam @ Highway 95	Gamma	M	M	2	M	2	7
D-18 (34)	SWSA 6 On Fence @ Highway 95	Gamma	2	3	5	6	16	19
D-19 (75)	Haw Ridge @ Melton Valley Access Rd.	Gamma	33	29	42	41	145	148
D-20 (25)	Molten Salt Reactor Experiment	Gamma	16	22	21	29	88	113
D-21 (27)	White Oak Creek Weir @ Lagoon Rd	Gamma	25	31	28	31	115	127
D-22 (24)	Building X-7819	Gamma	4	5	7	7	23	29
D-23 (35)	Confluence of White Oak Ck & Melton Branch	Gamma	96	89	109	97	391	444
D-24 (56)	Old Hydrofracture Pond	Gamma	10	13	16	13	52	49
D-26 (23)	SWSA 5 (South 7828)	Gamma	M	2	3	4	9	9
D-27 (46)	Homogeneous Reactor Experiment Site	Gamma	2	M	5	2	9	9
D-28 (22)	High Flux Isotope Reactor	Gamma	5	6	10	6	27	31
D-30 (55)	SWSA 5 TRU Waste Trench	Gamma	22	39	34	47	142	125
D-31 (87)	SWSA 5 Near Storage Tank Area	Gamma	19	20	19	19	77	91
D-32 (168)	New Hydrofracture Facility	Gamma	99	111	108	114	432	404
D-33 (169)	Melton Valley Haul Road Near Creek	Gamma	135	154	161	156	606	600
D-34 (170)	Cask Storage Containment Area	Gamma	1188	1326	1293	1329	5136	5183
D-35 (171)	Building 3038 N	Gamma	97	117	93	103	410	408
D-36 (172)	Building 3607 Material Storage Area	Gamma	2576	1786	829	774	5965	12401
D-37 (173)	TH4 Tank	Gamma	86	56	15	12	169	595
D-38 (174)	Hot Storage Garden (3597)	Gamma	1029	1187	1072	1243	4531	4449
D-39 (175)	Building 3618	Gamma	50	73	64	52	239	296
D-40 (84)	Tower Shielding Facility @ West Gate	Gamma	3	4	6	4	17	17
D-41 (85)	Tower Shielding Facility @ North Gate	Gamma	3	3	4	2	12	15
D-42 (176)	Neutralization Plant	Gamma	593	34	31	33	691	6000
D-50 (68)	White Oak Creek @ Coffer Dam	Gamma	M	M	M	M	0	1
D-51 (26)	Cesium Fields @ Clinch River	Gamma	5	6	7	8	26	24
D-52 (31)	Cesium Forest Boundary	Gamma	12	14	19	13	58	61
D-53 (31a)	Cesium Forest Boundary (Duplicate)	Gamma	10	15	19	14	58	53
D-54 (32)	Cesium Forest @ Base Of Tree	Gamma	2629	3076	2902	3044	11651	11172
D-55 (33)	Cesium Forest Satellite Plot	Gamma	70	84	95	82	331	343
D-60 (183)	ORNL Melton Valley Trench 7	Gamma	11	11	14	14	50	48
D-61(184)	New Hydrofracture Facility	Gamma	88	114	115	129	446	8
D-61(184)	New Hydrofracture Facility	Neutron	M	M	M	M	0	0
D-62 (185)	ORAU Pumphouse Road	Gamma	4	4	3	7	18	24
D-62 (185)	ORAU Pumphouse Road	Neutron	M	M	M	M	0	0

Three stations (D-36, D-37, and D-42) showed substantial decreases in exposure during 2016. Station D-36 was 12,401 mrem/year in 2015 and only 5965 mrem/year in 2016; station D-37 was 595 mrem/year in 2015 and only 169 mrem/year in 2016; station D-42 was 6000 mrem/year in 2015 and only 691 mrem/year in 2016. The differences at D-36 and D-37 are likely due to changes in what is being stored; the difference at D-42 is likely due to activities leading to facility shutdown.

For this report, discussions of dosimeters at ORNL are grouped, as follows:

- ORNL Main Campus [dosimeters on the main campus of ORNL as well as all other dosimeters not in Melton Valley, at the Spallation Neutron Source (SNS), or South of Melton Valley] See Table 2.1.1.7, Figure 2.1.1.6.
- ORNL Melton Valley (dosimeters in the waste areas of Melton Valley) See Table 2.1.1.8, Figure 2.1.1.7.
- ORNL south of Melton Valley (dosimeters at Tower Shielding and Cesium Forest) See Table 2.1.1.9, Figure 2.1.1.8.
- ORNL SNS See Table 2.1.1.11, Figure 2.1.1.10.

During 2016, seventeen monitoring stations at ORNL reported results that exceeded 100 mrem over the span of the year. Seven of the monitoring stations are located on the main campus of ORNL, away from the most heavily traveled areas of the facility except for station D-14 (Table 2.1.1.7; Figure 2.1.1.6). Eight of the sites are located in the considerably less traveled ORNL Melton Valley Area (Table 2.1.1.8; Figure 2.1.1.7; Note: Duplicate dosimeter is at New Hydrofracture Facility). Two of the sites are in the Cesium Forest located south of the Melton Valley (Table 2.1.1.9; Figure 2.1.1.8). One site is at the SNS.

Table 2.1.1.7: ORNL Campus Dosimeters >100 mrem/year

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
D-14 (166)	North Side Of Central Ave.	Gamma	51	64	56	58	229	220
D-35 (171)	Building 3038 N	Gamma	97	117	93	103	410	408
D-36 (172)	Building 3607 Material Storage Area	Gamma	2576	1786	829	774	5965	12401
D-37 (173)	TH4 Tank	Gamma	86	56	15	12	169	595
D-38 (174)	Hot Storage Garden (3597)	Gamma	1029	1187	1072	1243	4531	4449
D-39 (175)	Building 3618	Gamma	50	73	64	52	239	296
D-42 (176)	Neutralization Plant	Gamma	593	34	31	33	691	6000

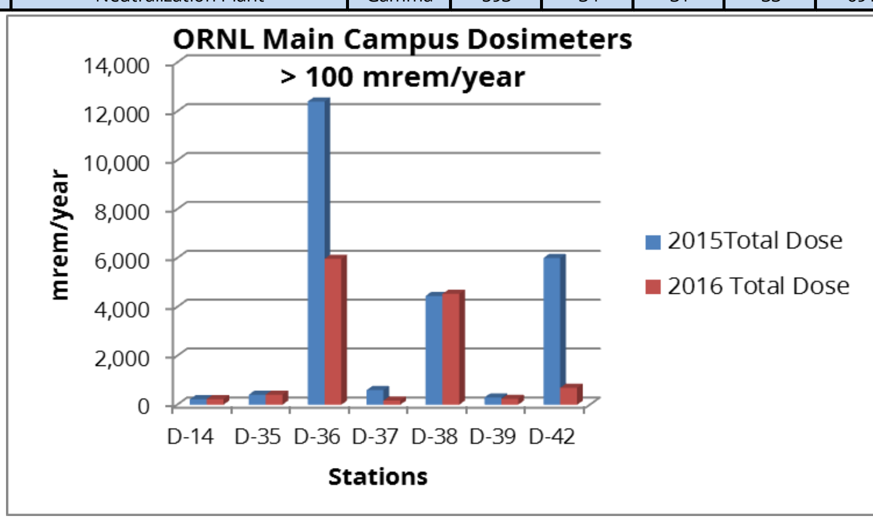


Figure 2.1.1.6: ORNL Main Campus Dosimeters >100 mrem/year

Table 2.1.1.8: ORNL Melton Valley Dosimeters >100 mrem/year

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
D-19 (75)	Haw Ridge @ Melton Valley Access Rd.	Gamma	33	29	42	41	145	148
D-21 (27)	White Oak Creek Weir @ Lagoon Rd	Gamma	25	31	28	31	115	127
D-23 (35)	Confluence of White Oak Ck & Melton Branch	Gamma	96	89	109	97	391	444
D-30 (55)	SWSA 5 TRU Waste Trench	Gamma	22	39	34	47	142	125
D-32 (168)	New Hydrofracture Facility	Gamma	99	111	108	114	432	404
D-33 (169)	Melton Valley Haul Road Near Creek	Gamma	135	154	161	156	606	600
D-34 (170)	Cask Storage Containment Area	Gamma	1188	1326	1293	1329	5136	5183
D-61(184)	New Hydrofracture Facility	Gamma	88	114	115	129	446	N/A

N/A - not available

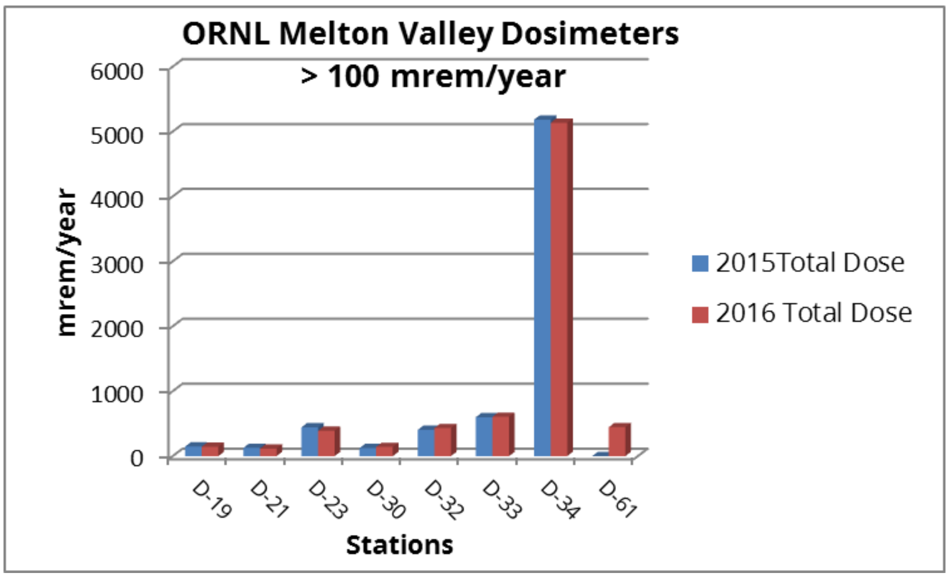


Figure 2.1.1.7: ORNL Melton Valley Dosimeters >100 mrem/year

The Cesium Forest is located in a remote, gated area of the reservation posted as a radiation area. A dosimeter was secured near the trunk of one tree and was exchanged remotely with assistance from ORNL personnel. The variability in the results, as noted in the TDEC Quarterly report and shown in Table 2.1.1.9, is due primarily to the inexact nature of the remote apparatus in placing the dosimeter near the tree. The higher readings (for 2016 compared to 2015) may be due (in part) to a more secure placement of the dosimeter at the base of the sample tree. The highest dose reported in the program for 2016 (11,651 mrem) was at station D-54 (station 32 in 2013 report), which is located at the base of a tree at the Cesium Forest. However, in 2015, the highest dose was at Station D-36 (Building 3607, Material Storage Area), a dosimeter located on a rad chain surrounding the storage area (Table 2.1.1.7). In 2016, this site displayed less than half the dose of 2015, likely due to a reduction in the materials stored at the facility. For 2015, the second highest dose was at the location in the Cesium Forest (D-54).

In 1962, trees in the Cesium Forest were injected with a total of 360 millicuries of cesium-137 as part of a study on the isotope's behavior in a forest ecosystem (Witkamp, 1964). Overall, the dose rates at the ORNL locations decreased in 2016 when compared to 2015 results. Most of these locations are associated with legacy facilities that are either undergoing or are scheduled for remediation. As the cleanup continues, the dose rate measurements are expected to be further reduced. Exceptions may be found where activities continue.

Table 2.1.1.9: ORNL Dosimeters >100 mrem/year South of Melton Valley

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
D-54 (32)	Cesium Forest onTree	Gamma	2629	3076	2902	3044	11651	11172
D-55 (33)	Cesium Forest Satellite Plot	Gamma	70	84	95	82	331	343

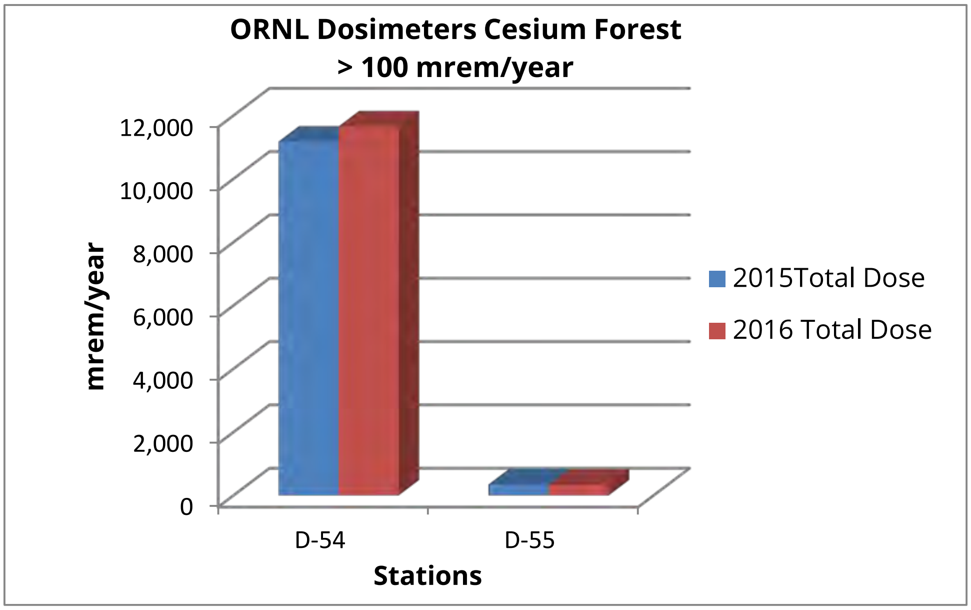


Figure 2.1.1.8: ORNL Dosimeters South of Melton Valley >100 mrem/year

Table 2.1.1.10: ORNL Stations (Except SNS) with Annual Readings <100 mrem/year

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
D-10 (20)	Freels Bend Entrance	Gamma	2	2	5	3	12	15
D-12 (69)	Graphite Reactor	Gamma	6	6	9	5	26	29
D-13 (167)	South Side Of Central Ave.	Gamma	14	19	15	14	62	63
D-16 (30)	Southside Ave. Parking Lot (Old X-3513 Impoundment)	Gamma	3	4	7	3	17	26
D-17 (28)	White Oak Dam @ Highway 95	Gamma	M	M	2	M	2	7
D-18 (34)	SWSA 6 On Fence @ Highway 95	Gamma	2	3	5	6	16	19
D-20 (25)	Molten Salt Reactor Experiment	Gamma	16	22	21	29	88	113
D-22 (24)	Building X-7819	Gamma	4	5	7	7	23	29
D-24 (56)	Old Hydrofracture Pond	Gamma	10	13	16	13	52	49
D-26 (23)	SWSA 5 (South 7828)	Gamma	M	2	3	4	9	9
D-27 (46)	Homogeneous Reactor Experiment Site	Gamma	2	M	5	2	9	9
D-28 (22)	High Flux Isotope Reactor	Gamma	5	6	10	6	27	31
D-31 (87)	SWSA 5 Near Storage Tank Area	Gamma	19	20	19	19	77	91
D-40 (84)	Tower Shielding Facility @ West Gate	Gamma	3	4	6	4	17	17
D-41 (85)	Tower Shielding Facility @ North Gate	Gamma	3	3	4	2	12	15
D-50 (68)	White Oak Creek @ Coffer Dam	Gamma	M	M	M	M	0	1
D-51 (26)	Cesium Fields @ Clinch River	Gamma	5	6	7	8	26	24
D-53 (31a)	Cesium Forest Boundary (Duplicate)	Gamma	10	15	19	14	58	53
D-60 (183)	ORNL Melton Valley Trench 7	Gamma	11	11	14	14	50	48
D-62 (185)	ORAU Pumphouse Road	Gamma	4	4	3	7	18	24
D-62 (185)	ORAU Pumphouse Road	Neutron	M	M	M	M	0	0

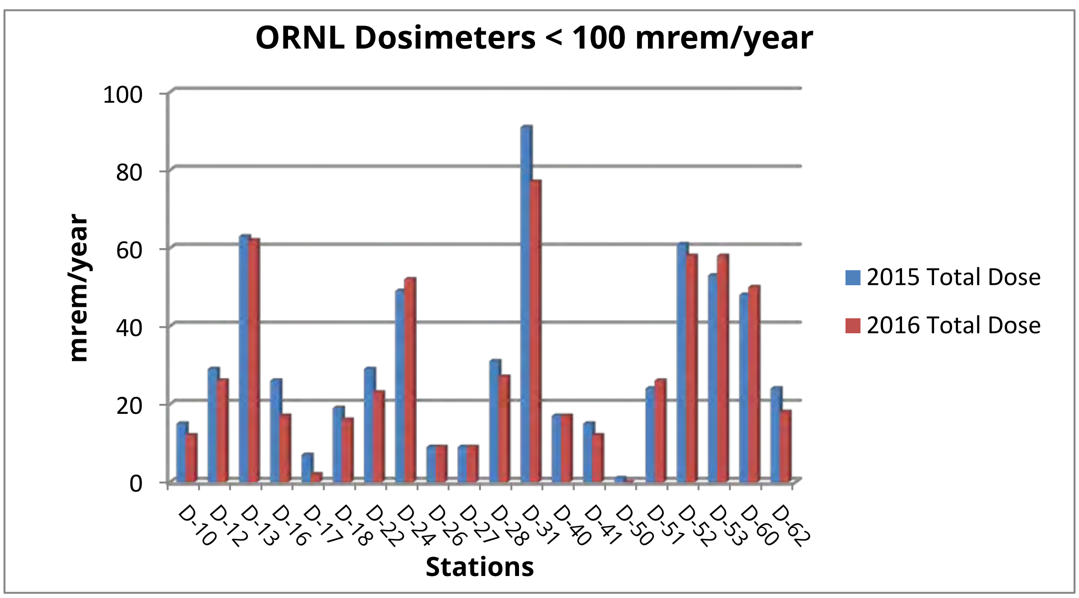


Figure 2.1.1.9: ORNL (Except SNS) Dosimeters with Annual Readings <100 mrem/year

All locations exceeding 100 mrem (Table 2.1.1.7, 2.1.1.8 and 2.1.1.9) warrant continued monitoring.

Spallation Neutron Source

The SNS is a research facility that produces the most intense pulsed-neutron beams in the world. The SNS was designed and built in partnership with six DOE national laboratories: 1.) Lawrence Berkeley in California, 2.) Los Alamos in New Mexico, 3.) Argonne in Illinois, 4.) Brookhaven in New York, 5.) Thomas Jefferson in Virginia, and 6.) ORNL in Tennessee.

The production process begins with a source that produces negatively-charged hydrogen ions, consisting of one proton and two electrons. The hydrogen ions are injected into a linear-particle accelerator (linac) where they are accelerated to high energies and passed through a magnetic foil that strips off the electrons, converting the ions to protons. The protons pass into an accumulator ring, which releases them in high-energy pulses directed toward a liquid mercury target. When the protons strike the nucleus of the mercury atoms in the target, neutrons are "spalled" or “thrown off” along with other spallation products.

The neutrons released by the spallation process are guided through beam lines to areas containing specialized instruments for conducting experiments. During the process, high-energy protons interact with nuclei of the accelerator components and materials in the air inside the facility, converting the struck nucleus to that of a different isotope, which is often radioactive.

Air evacuated from the facility is:

- held to allow short-lived, radioisotopes to decay
- filtered to remove particulates
- released to the atmosphere through the central exhaust stack

DoR-OR has placed dosimeters at the SNS near the linac, accumulator ring, target building, central exhaust stack, and other locations of interest (Table 2.1.1.11; Figure 2.1.1.10).

Table 2.1.1.11: SNS Dosimeters

Dosimeter Designation (Dosimeter number)	Location *Optically Stimulated Luminescent Dosimeter (OSLs) & neutron dosimeters are reported quarterly.*	Type of Radiation	Dose Reported for 2016 in mrem *M = Below Minimum Reportable Quantity*				2016 Total Dose	2015 Total Dose
			1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
D-70 (53)	Central Exhaust Facility	Gamma	248	280	440	282	1250	543
D-70 (53)	Central Exhaust Facility	Neutron	M	M	M	M	0	0
D-71 (93)	Ring Building Perimeter Fence	Gamma	4	5	12	9	30	20
D-71 (93)	Ring Building Perimeter Fence	Neutron	M	M	M	M	0	0
D-72 (17)	Beam-dump Bldg # 8520	Gamma	2	4	5	7	18	23
D-72 (17)	Beam-dump Bldg # 8520	Neutron	M	M	M	M	0	0
D-73(73)	SNS Water Tower (overlook) North	Gamma	8	9	19	15	51	31
D-74 (101)	LINAC Beam Tunnel Berm West (#1)	Gamma	5	8	10	7	30	25
D-74 (101)	LINAC Beam Tunnel Berm West (#1)	Neutron	M	M	M	M	0	0
D-75 (102)	LINAC Beam Tunnel Berm (#2)	Gamma	7	8	15	13	43	35
D-75 (102)	LINAC Beam Tunnel Berm (#2)	Neutron	M	M	M	M	0	0
D-76 (103)	LINAC Beam Tunnel Berm (#3)	Gamma	5	7	13	9	34	27
D-76 (103)	LINAC Beam Tunnel Berm (#3)	Neutron	M	M	M	M	0	0
D-77 (100)	LINAC Beam Tunnel Berm (#4)	Gamma	7	10	19	14	50	39
D-77 (100)	LINAC Beam Tunnel Berm (#4)	Neutron	M	M	M	M	0	0
D-78 (99)	LINAC Beam Tunnel Berm (#5)	Gamma	5	9	14	4	32	25
D-78 (99)	LINAC Beam Tunnel Berm (#5)	Neutron	M	M	M	M	0	0
D-79 (98)	LINAC Beam Tunnel Berm (#6)	Gamma	9	12	21	16	58	41
D-79 (98)	LINAC Beam Tunnel Berm (#6)	Neutron	M	M	M	M	0	0
D-80 (97)	LINAC Beam Tunnel Berm East (#7)	Gamma	5	9	15	11	40	27
D-80 (97)	LINAC Beam Tunnel Berm East (#7)	Neutron	M	M	M	M	0	0
D-81 (74)	SNS Cooling Tower South	Gamma	4	2	9	6	21	15
D-82 (52)	Target Bldg West	Gamma	2	2	4	4	12	24
D-82 (52)	Target Bldg West	Neutron	M	M	M	M	0	0
D-83 (51)	Target Bldg South	Gamma	2	M	3	3	8	3
D-83 (51)	Target Bldg South	Neutron	M		M	M	0	0
D-84 (12)	Target Bldg East	Gamma	4	5	7	7	23	15
D-84 (12)	Target Bldg East	Neutron	M	M	M	M	0	0
D-85 (104)	SNS Administrative Building	Gamma	M	M	M	1	1	8
D-85 (104)	SNS Administrative Building	Neutron	M		M	M	0	0

During 2016, the results ranged from one to 1250 mrem/year. The only result to exceed 100 mrem in 2016 was for one dosimeter located on the central exhaust stack (1250 mrem/year). This reading was two times greater than the reading obtained in 2015 (543 mrem/year). During 2016, the beam line ran at much higher power levels than it had previously.

Table 2.1.1.12 provides additional descriptive information to aid in the understanding of Tables 2.1.1.1 through 2.1.1.11 for the environmental dosimeter program.

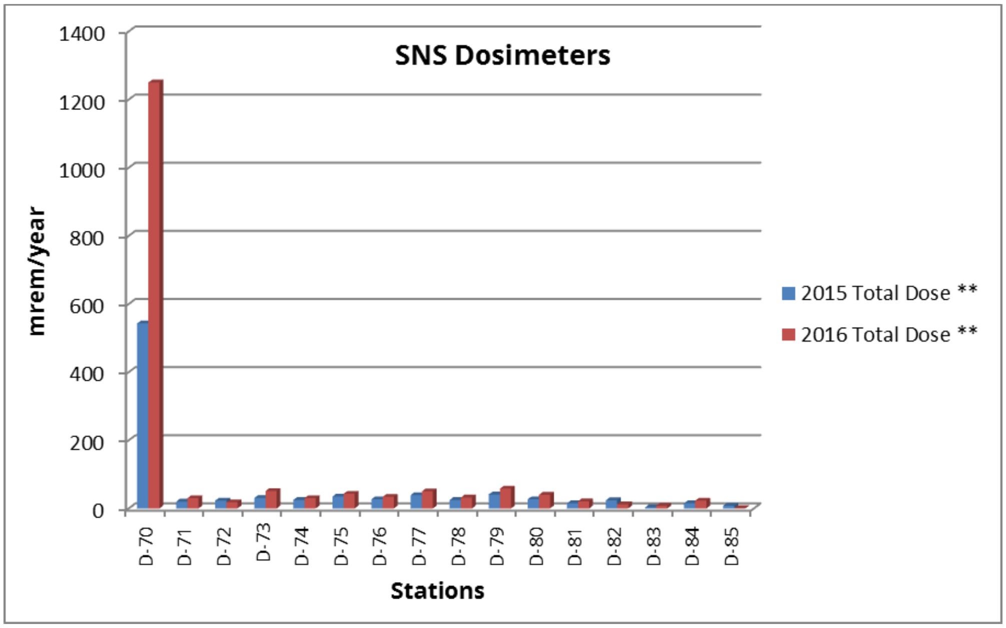


Figure 2.1.1.10: SNS Dosimeters

Table 2.1.1.12: Descriptive Notes for Tables 2.1.1.1 through 2.1.1.11

Notes: Two types of dosimeters are used in the program: optically stimulated luminescent dosimeters (OSLs) and neutron dosimeters. The OSLs measure the dose from gamma radiation, which is considered sufficient for most of the monitoring stations. The neutron dosimeters, which have been placed at selected locations, measure the dose from neutrons in addition to the gamma radiation. At the locations where the neutron dosimeters have been deployed, the total dose is the sum of the doses reported for neutrons and the dose reported for gamma radiation
The primary dose limit for members of the public specified in both DOE Orders and 10 CFR Part 20 (Standards for Protection Against Radiation) is 100 mrem total effective dose equivalent in a year, exclusive of the dose contributions from background radiation, any medical administration the individual has received, or voluntary participation in medical research programs. The Nuclear Regulatory Commission limit for a decommissioned facility
NEW = Data for the period does not exist for this station because it is new.
M = Below minimum reportable quantity (one mrem for gamma, 10 mrem for thermal neutrons)
NA = Not analyzed or not deployed at location.
Absent = The dosimeter was not found at the time of collection.
Damaged = The dosimeter was physically damaged and the results were not consistent with historical values.
** A control dosimeter is provided with each batch of dosimeters received from the vender. The control dosimeters are used to identify the portion of the dose reported due to radiation exposures received in storage and transit. The dose reported for the control dosimeter is subtracted from the dose reported for each field deployed dosimeter.
# (#) = 2016 reading (2015 reading)

Conclusions

Overall, the radiation doses measured in the environmental dosimetry program in 2016 decreased or remained statistically the same as in 2015. Seventeen locations exceeded the 100 mrem screening level during the year: sixteen at ORNL and one at SNS. Seven of these sites are located on the main campus of ORNL. Six of those seven are away from the most heavily traveled areas of the facility. One station (D-14) is within the more heavily traveled area of the facility. (Refer to Table 2.1.1.7 and Figure 2.1.1.6.). Three of these stations at ORNL (D-36, D-37, and D-42) showed substantial decreases in exposures during 2016.

2.1.2 Gamma Exposure Rate Monitoring

Introduction

DoR-OR has deployed gamma-radiation exposure-rate monitors equipped with microprocessor-controlled data-loggers on the ORR since 1996. While the environmental dosimeters used in DoR-OR's ambient radiation monitoring program provide the cumulative dose for the time period monitored, the results cannot account for the specific time, duration, and magnitude of fluctuations in the dose rates. Consequently, when using only dosimeters, one cannot distinguish a series of small releases from a single, large release. Exposure-rate-monitors measure and record gamma radiation levels at predetermined intervals (e.g., minutes) over extended periods of time, providing an exposure rate profile that can be correlated with activities and/or changing conditions. Primarily, the dosimeters have been used to record exposure rates during remedial and waste management activities to supplement the integrated dose rates provided by DoR-OR's environmental dosimetry program.

Methods and Materials

The amount of radiation to which an individual can be exposed is limited by state and federal regulations. The primary dose limit for members of the public (specified by these regulations) is a total effective dose equivalent of 100 mrem in a year. Since there are no agreed-upon levels where exposures to radiation constitute zero risk, radiological facilities are also required to maintain exposures as low as reasonably achievable (ALARA). Table 2.1.2.1 provides some of the more commonly encountered dose limits.

The unit used to express the limits (rem) refers to the dose of radiation an individual receives (the amount of radiation absorbed by the individual). For alpha and neutron radiation, the measured quantity of exposure, roentgen (R), is multiplied by a quality factor to derive the dose. For gamma radiation, the roentgen and the rem units of measure are generally considered equivalent. The more familiar unit, rem, is used in this report to avoid confusion. The monitors used in this program only account for the doses attributable to external exposures from gamma radiation. Any dose contribution from alpha, beta, or neutron radiation would be in addition to the measurements reported.

Table 2.1.2.1: Commonly Encountered Dose Limits for Exposures to Radiation

Dose Limit	Application
5,000 mrem/year	Maximum annual dose for radiation workers
100 mrem/year	Maximum dose to a member of the general public
25 mrem/year	Limit required by state regulations for free release of facilities that have been decommissioned
2 mrem in any one hour period	The state limit for the maximum dose in an unrestricted area in any one hour period

Results and Discussion

Fort Loudoun Dam Background Station

On average, individuals in the United States receive a dose of approximately 300 mrem in a year from naturally occurring radiation. Most of this dose is from internal exposures received from breathing radon and associated daughter radionuclides. Background exposure rates fluctuate over time due to various phenomena that alter the quantity of radionuclides in the environment and/or the intensity of radiation emitted by these radionuclides. For example, the gamma exposure rate above soils saturated with water after a rain are expected to be lower than the gamma exposure rate over dry soils, because the moisture shields radiation released by terrestrial radionuclides.

To better assess exposure rates measured on the Reservation and the influence that natural conditions have on these rates, DoR-OR maintains one gamma monitor at Fort Loudoun Dam in Loudon County to collect background information. The background results are provided on Figures 2.1.2.1 through 2.1.2.4. During the period January 1, 2016 through June 30, 2017, exposure rates averaged 8.8 μrem/hour and ranged from seven to 17 μrem/hour, which is equivalent to a dose of approximately 77 mrem/year.

Environmental Management Waste Management Facility

The EMWMF was constructed in Bear Creek Valley (near Y-12) to dispose of wastes generated by CERCLA activities on the ORR. The EMWMF relies on a waste profile provided by the generator to characterize waste disposed of on the facility. This profile is based on an average of the contaminants in a waste lot. Since the size of waste lots can vary from a single package to many truckloads of waste, the averages reported are not necessarily representative of each load of waste transported to the facility. Some loads may have highly contaminated wastes, while other loads may contain smaller concentrations.

Historically, the exposure rate monitors used were to identify waste potentially exceeding waste acceptance criteria (WAC) as the waste is transported into the waste disposal cells. In 2011, DoR-OR replaced the unit with a radiation portal monitor (RPM). One of the exposure rate monitors was returned to the site and placed alongside the RPM to assess the performance of each and confirm associated results.

Measurements taken during the period January 1, 2016 through June 30, 2017 averaged 7.1 μrem/hour and ranged from five to 12 μrem/hour, which was similar to the background measurements collected during the period (Figure 2.1.2.1).

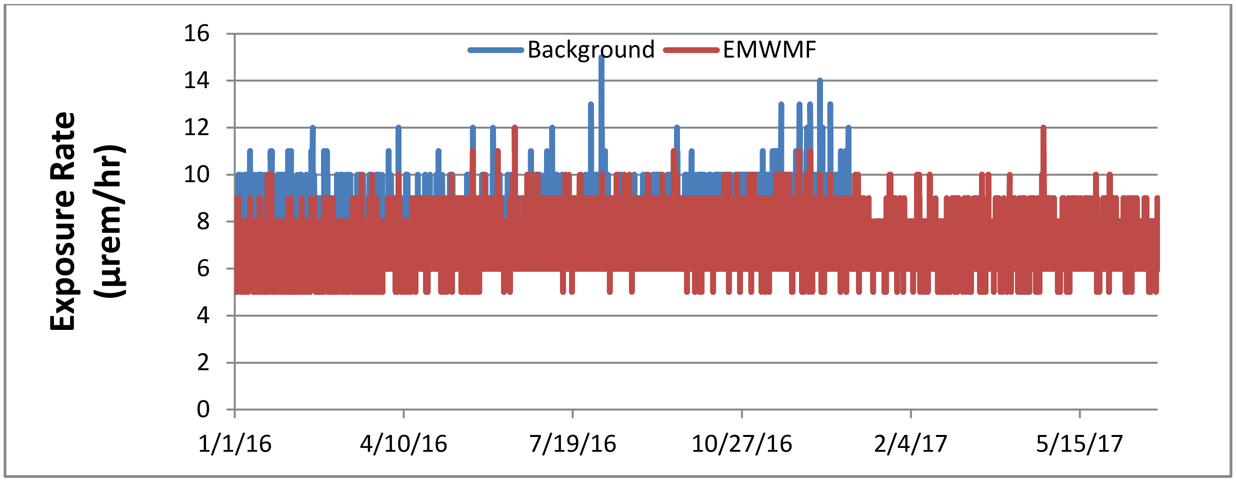


Figure 2.1.2.1: Results of Gamma Exposure Rate Monitoring at the Weigh-in Station for EMWMF and at the Background Station

The state dose limit in an unrestricted area is two mrem (2,000 µrem) in any one-hour period.
The state dose limit for members of the public is 100 mrem (100,000 µrem) in a year.

ORNL Central Campus Remediation / Building 3026 Radioisotope Development Lab

Monitoring of the ORNL Central Campus remediation began September 1, 2011 and continued through June 2017. Concerns include potential releases during the demolition of high-risk facilities centrally located on ORNL's main campus in close proximity to pedestrian and vehicular traffic, privately funded facilities, and active ORNL facilities. Many of these facilities, constructed during the Manhattan Project Era, produced radioisotopes, supported the development of the first nuclear weapons, and were later used in medical research and commercial applications.

Among these facilities is the Radioisotope Development Laboratory, a wooden structure comprised of the 3026-C and 3026-D facilities, which is being addressed as a CERCLA time-critical removal action. The 3026 facilities, constructed in the 1940s, housed operations for the separation of barium-140 from uranium fuel slugs irradiated in ORNL's Graphite Reactor and later Hanford reactors. Over the years, the facilities changed for various uses, including the separation of radioisotopes from liquid wastes generated by the processing of irradiated fuel elements for uranium and plutonium in the 3019 Radiochemical Chemical Development Laboratory.

In the 1960s, 3026-C was equipped to enrich krypton-85 by thermal diffusion and in the 1970s, the addition of a tritium lab facilitated the packaging, storage, and testing of radio-luminescent lights. Later in the 1960s, 3026-D supported the processing of fuel from the Sodium Reactor Experiment and the examination of irradiated metallurgical reactor components. Both facilities shut down in the late 1980s. In the interim, the wooden-framed structures experienced significant physical deterioration, to the point of failure. In 2009, a time-critical removal action was initiated because of the hazards presented by the presence of radioactive contamination and the facilities' conditions and locations. This included the demolition of the 3026 wooden-frame structure and the stabilization of the hot cells contained in each of the two facilities.

The 3026 wooden superstructure was demolished in 2010; the 3026-C hot cells were demolished in 2012; but, 3026-D hot cell was not demolished until 2013 because higher than expected radiation levels hindered the project. Due to historical operations in each of the facilities, potential contaminants included cesium-137, strontium-90, carbon-14, nickels-59 and 63, irons-55 and 59, krypton-85, promethium-147, silver-110m, tritium, technetium-99, zinc-65, americium-241, and neptunium-239, along with isotopes of europium (153, 154, and 155), plutonium (239, 240, and 241), and uranium (233, 234, 235, 236, and 238).

One of DoR-OR's exposure rate monitors was placed at the 3026 demolition site on January 11, 2012 (prior to the demolition of the 3026-C hot cell) and remained at that site through June 2017. In 2012, the levels of gamma radiation measured ranged from 12 to 88 µrem/hour and averaged 24.7 µrem/hour. As the removal action turned to the more contaminated 3026-D hot cells in 2013, the exposure rates increased, substantially, then declined near the end of the year as the waste was removed for disposal. The exposure rate spike seen in October of 2016 was apparently due to movement of some elevated radioactive material. During the period January 1, 2016 through June 30, 2017, gamma radiation measured at the site ranged from 11 to 52 µrem/hour and averaged 16.1 µrem/hour. As can be seen from Figure 2.1.2.2 below, measurements were pretty much constant except for a peak in October 2016. That peak reading is most probably due to .

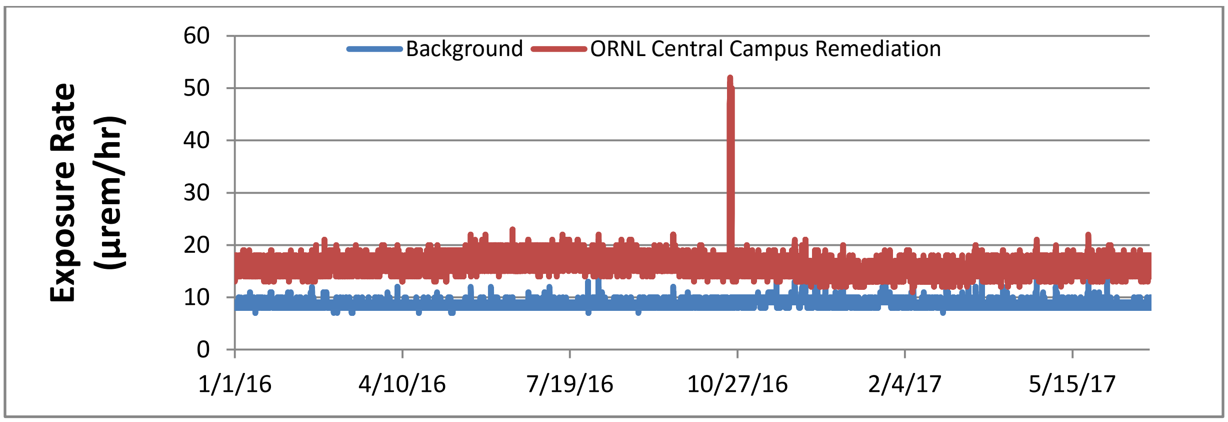


Figure 2.1.2.2: Results of Gamma Exposure Rate Monitoring at the ORNL Central Campus Removal Action and at the Background Station

The state dose limit in an unrestricted area is two mrem (2,000 µrem) in any one-hour period.
The state dose limit for members of the public is 100 mrem (100,000 µrem) in a year.

The Molten Salt Reactor Experiment

The concept of a molten salt reactor experiment (MSRE) was first experimented with at ORNL in association with a 1950s campaign to design a nuclear-powered airplane. After interest in an atomic airplane subsided, the MSRE was constructed to evaluate the feasibility of applying the technology to commercial powered applications. The concept called for circulating uranium fluoride (the fuel) dissolved in a molten salt mixture through the reactor vessel. The MSRE achieved criticality (a chain reaction resulting in a release of radiation) in1965 and was used for research until 1969.

When the reactor was shut down, molten fuel salts and flush salts were transferred to drain tanks and allowed to solidify. In 1994, an investigation of the MSRE revealed elevated levels of uranium hexafluoride and fluorine gases throughout the off-gas piping connected to the drain tanks. Among other problems, uranium had migrated through the system to the auxiliary charcoal bed, creating criticality concerns. Actions were taken to stabilize the facility and a CERCLA Record of Decision (ROD) was issued in July 1998 requiring the removal, treatment, and the safe disposition of the fuel and the flushing of salts from the drain tanks.

From November 1, 2012 through June 30, 2017, DoR-OR has recorded gamma exposure rates with a gamma monitor placed near the gate where trucks containing radioactive materials (fuel removed from the drain tanks) exit the MSRE. The location is near a radiation area established to store equipment used in the remediation. During the January 1, 2016 through June 30, 2017 monitoring period, the average exposure rate ranged from 37 to 54 μrem/hour and averaged 47.3 μrem/hour (Figure 2.1.2.3). The major source of the radiation measured appears to be a salt probe stored in the radiation area adjacent to the monitoring station.

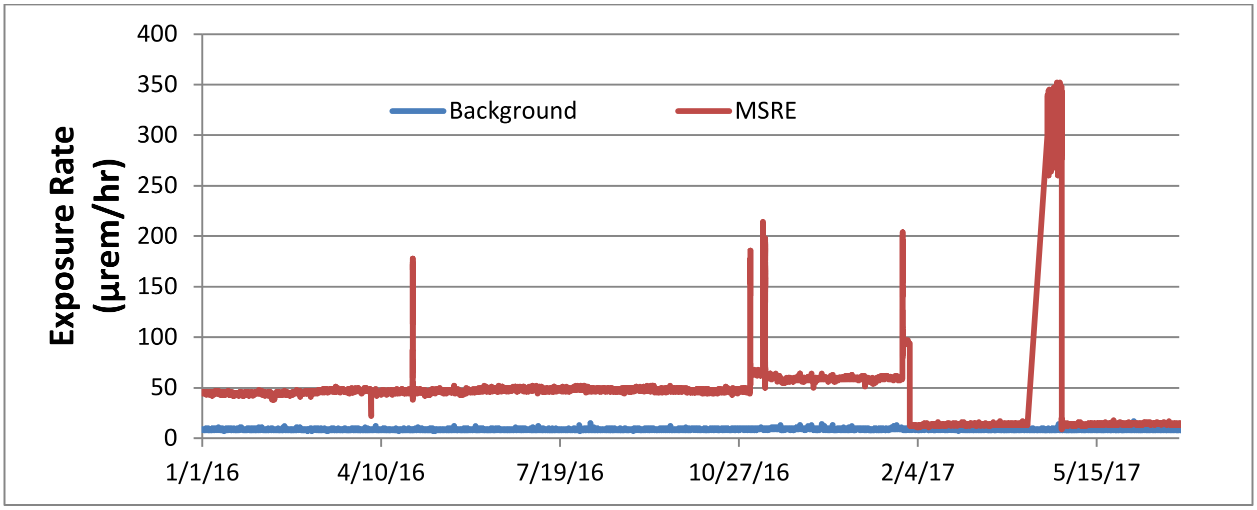


Figure 2.1.2.3: Results of Gamma Exposure Rate Monitoring at the ORNL MSRE and at the Background Station

The state dose limit in an unrestricted area is two mrem (2,000 μrem) in any one-hour period.
The state dose limit for members of the public is 100 mrem (100,000 μrem) in a year.

Spallation Neutron Source

To assess the gamma component of air releases from the SNS, one of DoR-OR's exposure rate monitors has been located on the central exhaust stack used to vent air from process areas inside the linac and target building. The exposure rates vary with the operational status of the accelerator. During periods when the accelerator is not on line, the rate is similar to background measurements, with much higher levels recorded during operational periods. The exposure rates measured between January 1, 2016 and June 30, 2017 ranged from six to 966 μrem/hour and averaged 45 μrem/hour (Figure 2.1.2.4).

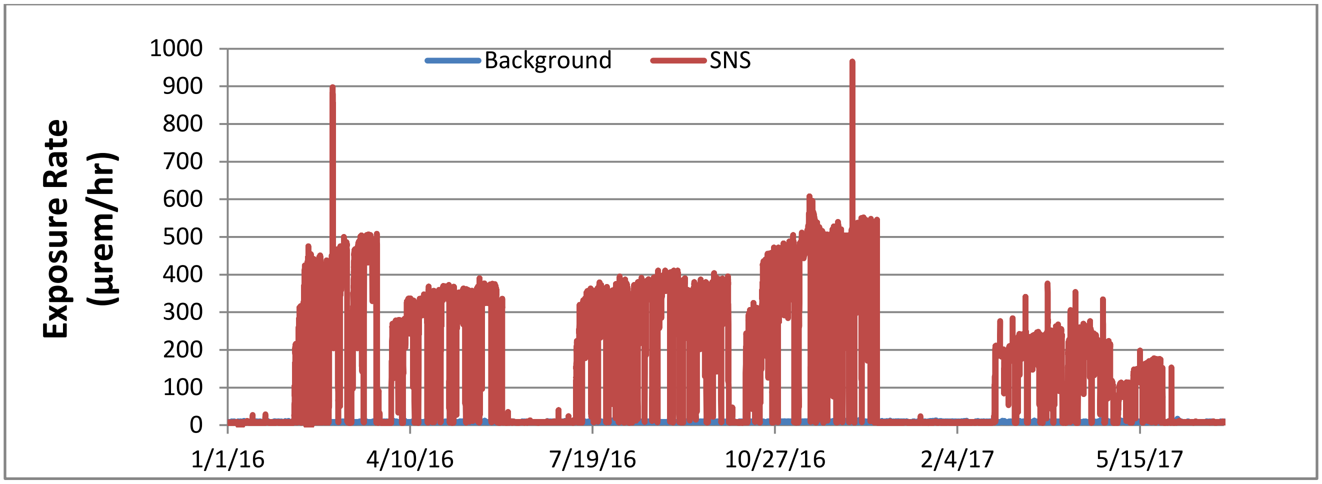


Figure 2.1.2.4: Results of Gamma Exposure Rate Monitoring at the SNS Stack and at the Background Station

The state dose limit in an unrestricted area is two mrem (2,000 µrem) in any one-hour period.
The state dose limit for members of the public is 100 mrem (100,000 µrem) in a year.

Conclusions

- The following conclusions are drawn, based on the data collected January 1, 2016-June 30, 2017:
- EMWMF gamma levels were consistent with background measurements
- ORNL Central Campus D&D (3000 Area) gamma levels were consistent with background measurements
- Measurements taken at the MSRE did not indicate any releases during the period. Exposure levels measured during the year were attributed to a contaminated salt probe stored near the monitor
- Gamma levels at SNS varied substantially depending on the power level at which the accelerator was operating. During periods when the accelerator was shut down, gamma rates approximated background levels, which would tend to indicate that radioactive materials are not adhering to the interior of the stack and that during operation, gamma rates are attributed to noble gases being expelled.

2.1.3 Portal Monitor

Introduction

The EMWMF was constructed for and is dedicated to the disposal of low-level radioactive waste (LLW) and hazardous waste generated by remedial activities on the ORR. Operated under the authority of CERCLA, the facility is required to comply with regulations contained in the Record of Decision authorizing the construction of the facility (DOE, 1999). Hazardous waste, TSCA waste and low-level radioactive waste, as defined in TDEC 0400-20-11-.03 (TDEC, 2012), with concentrations below limits imposed by waste acceptance criteria (WAC), are approved for disposal in EMWMF. The DOE is accountable for compliance with the WAC and has delegated responsibility to make WAC attainment decisions to its prime contractors (which it oversees). These responsibilities include waste characterization and approval of waste for disposal in the EMWMF (DOE, 2001). The state and

EPA oversee and audit associated activities, including decisions authorizing waste lots for disposal. To help ensure compliance with the WAC, DoR-OR placed a radiation portal monitor (RPM) at the check-in station to scan trucks transporting waste for disposal into the EMWMF. As trucks pass through the portal monitor, gamma radiation levels are measured, recorded for later retrieval by DoR-OR personnel, and made available to DOE and its authorized contractors, upon request. When anomalous measurements are observed, DOE is notified. Basic information, such as the nature and source of the waste passing through the portal at the time of the anomaly, is obtained from EMWMF personnel. If preliminary information suggests the facility's WAC may have been violated, DoR-OR reviews the information and monitors the disposition.

Methods and Materials

A Canberra© RadSentry Model S585 portal monitor comprised of two large area gamma-ray scintillators, an occupancy sensor, a control box, a computer, and appropriate software is used at the EMWMF. The gamma-ray scintillators and instrumentation are contained in radiation sensor panels (RSPs). The panels are mounted on stands on each side of the road at the check-in station for trucks hauling waste into the disposal area (Figure 2.1.3). The occupancy sensor initiates measurements (one per 200 milliseconds) when a truck enters the portal. Results are transmitted from the RSPs to the control box, where they are stored, along with pertinent information date, time, and background measurements. Data retrieved by DoR-OR is made available for review by DOE and authorized contractors upon request.

Figure 2.1.3: Truck Hauling Waste through the Portal Monitor

Results and Discussion

During the 70 years since the ORR was established, a variety of production and research activities have generated numerous radioactive wastes, most of which are eligible for disposal at EMWMF.

Contaminants include activation and fission products from isotope production facilities, reactor operations, and nuclear research at the ORNL: uranium (U), technetium-99 (Tc-99), and associated radionuclides generated by uranium enrichment operations and the manufacturing of nuclear weapons components at K-25 and Y-12. As these radionuclides decay, they emit one or more types of ionizing radiation, which is any form of radiation that has enough energy to free electrons from atoms or molecules, creating ions. The three most often considered of concern at EMWMF are alpha (large positively charged particles), beta (smaller negatively charged electrons), and gamma/x-rays (small packets of energy called photons). Due to their size, weight, and charge, alpha and beta particles tend to interact with nearby atoms over short distances. Consequently, alpha and beta radiation are easily shielded and would not be expected to penetrate the steel sidewalls of truck beds carrying waste into EMWMF for disposal or, to a large degree, the waste itself. Gamma radiation is pure electromagnetic energy with no mass or charge, capable of traveling long distances through various materials before depleting its energy. The radiation portal monitor is only capable of measuring gamma radiation.

Most radionuclides emit gamma radiation, although the frequency of emissions and associated energies vary, depending on the nuclear characteristics of the particular radionuclide. Radionuclides that are predominately alpha emitters emit gamma less frequently than do beta emitters and radionuclides considered pure alpha or beta emitters only emit gamma radiation a small percentage of the time, or not at all. The waste lots disposed of in EMWMF contain mixtures of radionuclides that, as a whole, emit all three kinds of radiation. Since there are no pure gamma emitters, it is assumed for screening that anomalous increases in gamma measurements are accompanied by increased alpha/beta radiation and concentrations of associated radionuclides. The higher the energy of the gamma emissions, the more likely the gamma photons of any given radioisotope will penetrate through the waste and truck bed to be counted by the portal monitor's detectors. The higher the frequency of emissions and concentrations of gamma emitting radioisotopes in the waste, the greater the number of counts measured (the count rate).

To a large degree, the mixtures of radionuclides in wastes from the different ORR facilities are characteristic of the primary mission at each site. For example, wastes from ORNL typically include a long list of synthetic radionuclides produced by irradiating uranium in reactors, along with their progeny (radionuclides to which they decay). Included in this mix are the most prolific gamma emitters typically found on the ORR (cesium-137, cobolt-60), along with many other radionuclides produced during nuclear reactions. Consequently, ORNL wastes are expected to have higher count rates than the other sites and typically a larger variety of isotopes in the mix. Conversely, uranium isotopes and technetium-99 are the dominate radionuclides in waste from ETTP and Y-12. Uranium isotopes are primarily alpha emitters and technetium-99 is a pure beta emitter. Decay products of uranium are removed during the processing of the ore, so only the immediate progeny of the uranium isotopes that grow over relatively short time periods are generally present in ETTP and Y-12 wastes (thorium-231, thorium-234, and protactinium-234m). As a result, the count rates are expected to be much lower and anomalies more difficult to detect. When reviewing the results generated by the RPM, DoR-OR attempts to identify deviations from the norm, which, for the reasons stated above, change from site to site and from waste lot to waste lot. In most cases, the anomalous results can be resolved based on preliminary information, while in others, it cannot. In such instances, the results and preliminary information are submitted to DoR-OR for disposition.

Conclusions

Most of the waste delivered to EMWMF for disposal was derived from the demolition of uranium enrichment facilities at ETTP. Associated contaminants were primarily uranium isotopes (predominately alpha emitters) and Tc-99 (a pure beta emitter). When measured, the radiation levels were low. The only observed elevated results were due to the interaction of a nuclear density gauge that contains sealed and shielded cesium-137 and americium-241 sources used to measure compaction of the waste. The density gauge is not a waste, but a tool transported to the EMWMF disposal cells as needed and otherwise stored outside the facility.

2.1.4 Surplus Material Verification

Introduction

Since 2002, DoR-OR, in cooperation with DOE and its contractors, conducted random surface radiological surveys of surplus materials that are destined for sale to the public on the ORR. DOE releases items containing residual surface contamination based on a set of administrative criteria (DOE O 458.1, change 3; CFR-2016-title10-vol4-part835-appD). Standard radiological survey protocols and instrumentation are used for these surveys. In addition to performing the surveys, DoR-OR reviews the procedures used for release of materials under DOE radiological regulations. The overall goal of the program is to ensure that DOE radiation controls are adequately preventing radiological contamination from reaching the public. Pre-auction surveys are performed for every auction where adequate time and staff are available for the survey.

In the event that radiological activity is detected, DoR-OR will immediately report that detection to the responsible supervisory personnel of the surplus sales program. DoR-OR will follow the response to the notification, ensuring that the appropriate steps are taken to protect the public (removal of items from sale, re-surveys, etc.). DoR-OR reviews any occurrence reports, procedural changes, and removal of items from sales inventories.

Although auctions no longer sell items directly to the individual members of the public in Oak Ridge, items do continue to be auctioned to a select list of approved public bidders. Items are sold in truckload lots. Any items purchased by these bidders may still eventually reach the public.

Methods and Materials

Staff members make biased surveys of items using standard radiological monitoring meters and techniques: sodium iodide meters are used for gamma radiation detection; zinc sulfide scintillators (for alpha) and plastic scintillators (for beta) are used for dual detection, or equivalent scintillators are used for alpha/beta detection. The alpha/beta scintillator dual detection meters have been found to be the most likely to find increased activity (i.e., most increased activity found is either alpha or beta radiation). Inspections are scheduled just prior to sales after the material has been staged. Items range from furniture and equipment (shop, laboratory, and computer) to vehicles and construction materials. Particular attention is paid to items originating from shops and laboratories. Where radiological release tags are attached, radiation clearance information is compared to procedural requirements. If any contamination is detected during the on-site survey, the surplus materials manager is notified immediately.

Results and Discussion

Twelve inspections were conducted from January 1, 2016 through June 30, 2017 at ORNL. No sales were held at Y-12 or at ETTP. Occasional items with elevated levels of alpha and beta radiological contamination requiring further evaluation were discovered during the surveys; however, no items exceeding DOE release criteria were discovered during this period. Some items containing NORM (naturally occurring radioactive material) may be included among the auction items. These include old cathode ray tube televisions, electronic insulators, ceramic sinks, and other items made from ceramics. When found, these items are noted and that information is provided to auction personnel.

When items of concern were found, they were re-evaluated by ORNL to ensure they met the appropriate ORNL release criteria for release of items to the public. The elevated levels of activity are often determined to be due to an accumulation of radon.

Conclusions

During the period January 1, 2016 through June 30, 2017, no items with elevated levels of alpha and beta radiological contamination exceeded the DOE release criteria during the surveys. However, occasional items requiring further evaluation were found.

2.1.5 Haul Road Surveys

Introduction

TDEC's Division of Remediation Oak Ridge Office, with the cooperation of DOE and its contractors, perform weekly surveys of the Haul Road and other waste transportation routes on the Oak Ridge Reservation (ORR). The Haul Road was constructed for and is dedicated to trucks transporting CERCLA radioactive and hazardous waste from remedial activities on the ORR for disposal at EMWMF in Bear Creek Valley. To account for wastes that may fall or be blown from the trucks in transit, DoR-OR personnel perform walk-over inspections of different segments of the nine-mile long Haul Road and associated access roads on a biweekly basis (weather permitting). Anomalous items are scanned for radiological contamination, marked with contractor's ribbon, fully documented, and their description and location submitted to DOE for disposition. If anomalous items remain from previous surveys, they are included in subsequent reports until they are removed or DOE advises that the items have been found to be free of radioactive or hazardous contamination.

Methods and Materials

As previously noted, the nine-mile long Haul Road is surveyed in segments typically consisting of one to two miles on a biweekly basis (weather permitting). For safety and by agreement with DOE and its contractors, staff members performing the inspections sign in at the ETTP transportation hub and advise site personnel that they intend to enter the road to perform the survey. The DOE contractor responsible for the road briefs staff members on any known conditions that could present a safety hazard and provides a two-way radio to DoR-OR staff to maintain communication should unforeseen conditions arise that could present a safety hazard while on the road. When the DOE contractor is not working, staff members call into the designated DOE site safety office for the segment being surveyed. Should excessive traffic present a safety concern, the survey is postponed to a later date. Alternate entrances are sometimes used to access the road with DOE approval, but the basic requirements remain in effect.

When staff members arrive at the segment of the road to be surveyed, their vehicle is parked completely off the road, as far away from vehicular traffic as possible. No fewer than two people perform the surveys, each walking in a serpentine pattern along opposite sides of the road being surveyed or one person walking in a serpentine pattern across the entire road accompanied by an approved safety buddy. Typically, a Ludlum Model 2221 Scaler Ratemeter with a Model 44-10 2"X2" NaI Gamma Scintillator probe held approximately six inches above the ground surface is used to scan for radioactive contaminants as the walkover proceeds. A Ludlum 2224 Scaler with a Model 43-

93 Alpha/Beta dual detector is used to investigate potential contamination on the road surfaces or anomalous items along the road that may be associated with waste shipments. Other radiological instruments available to staff are used as warranted (Table 2.1.5.1).

Any areas or items, with contamination levels exceeding 200 disintegrations per minute (dpm), dpm per 100 cm^2 removable beta, 1000 dpm/100 cm^2 total beta, 20 dpm/100 cm^2 removable alpha, and/or 100 dpm/100 cm^2 total alpha, require further investigation. Anomalous items found during the survey are marked with contractor's ribbon at the side of the road, a description of that item and its location logged, and pertinent findings reported to DOE and its contractors for disposition. A survey form or the equivalent is maintained for each walk-over survey and is retained at the DoR-OR. When staff members return to the road for the next weekly inspection, they perform a follow-up inspection of items found and reported in previous weeks. If any items remain, they are included in subsequent reports until removed or until staff members are advised that the items have been determined to be free of radioactive and hazardous constituents.

Table 2.1.5.1: DoR-OR Portable Radiation Detection Equipment

DoR-OR Portable Radiation Detection Equipment		
Detection Equipment	**Detection Probes**	**Radioactivity Measured**
Ludlum Model 2221 Scaler/Ratemeter	Ludlum Model 44-10 2"x2" NaI Gamma Scintillator	Gamma
Ludlum Model 2224 Scaler/Ratemeter	Ludlum 43-93 Alpha/Beta Scintillation Detector	Alpha, Beta
Ludlum Model 3 Survey Meter	Ludlum Model 44-9 Pancake G-M Detector	Alpha, Beta, Gamma
Ludlum Model 3 Survey Meter	Ludlum Model 43-65 50 cm^2 Alpha Scintillator	Alpha
Ludlum Model 48-2748	Gas Proportional Detector Floor Monitor	Alpha, Beta
Bicron Micro Rem	Internal 1"x1" NaI Gamma Scintillator	Tissue Dose Equivalent, Gamma (µrem/hr)
Identifinder-NGH	Isotopic Identifinder and Ratemeter	Gamma Spectroscopy and Dose Rate Meter

µrem/hr - microrem per hour

Results and Discussion

During the period January 2016 through June 2017, the Haul Road walk-over surveys identified six items potentially originating from hazardous and/or radioactive waste being transported to the EMWMF. No surface contamination readings exceeded free release limits and all ambient high-energy gamma readings were within the range of normal background for the area. The items were marked as previously described; DOE was notified of the findings, and the items were removed.

Conclusions

The weekly inspections of the roads used to haul waste to the EMWMF, indicate waste items fall or are blown from trucks transporting the waste. Based on the continued findings of anomalous items, the Haul Road Survey Program is planned to continue throughout 2017 and 2018.

2.2 Biological Monitoring

2.2.1 Bat Monitoring

Introduction

Acoustic monitoring of Tennessee bat species (Order *Chiroptera*) continued on the ORR during 2016. Of particular interest are the three bat species that are federally listed as threatened or endangered. North American bats have the ability to use ultrasonic echolocation as a navigation tool in obstacle avoidance and for the location of prey items (Simmons and Conway 2003, Britzke 2003). Ultrasonic detectors are widely used for bat censuses (inventory) and have improved conservation efforts by

(1) providing increased knowledge of bat ecology, (2) documenting cases of white nose syndrome, (3) providing an inventory of bat species presence, and (4) characterizing bat communities (Vaughn et al. 1997, Barataud 1998, Pauza and Pauziene 1998, Avila-Flores and Fenton 2005, Britzke et al. 2011).

Echolocating bats typically emit an ultrasonic pulse (>20 kilohertz) while searching for insect food, and, in turn, analyze the returning echo with specialized ear and brain functions to determine the distance to the object as well as the type of object (Fenton 1992). Some researchers support the theory that echolocation calls of most bats are species-specific (Fenton and Bell 1981, O'Farrell et al. 1999, O'Farrell and Gannon 1999), whereas, others suggest caution using these calls to identify bats (Barclay 1999). The bat detectors record and save recorded bat echolocation search calls for later species analysis using specialized software programs.

Tennessee bat species are nocturnal and feed exclusively on insects such as crop-damaging pests. Bats roost in a variety of naturally occurring and anthropogenic structures such as abandoned buildings, caves, rock bluffs, rock crevices, dead tree snags, trees with exfoliating bark, tree leaves/branches, tree cavities, bridges, abandoned mines, railroad tunnels, forest/field edge, wetlands, utility right-of-ways, ponds, stream riparian zones, lakes, and spring houses (Ammerman et al. 2012). In the summer, bats emerge each evening, and activity commonly peaks immediately after sunset and can continue for several hours (Kunz 1973, Barclay 1982). Typically, another activity peak occurs before sunrise as bats return to their diurnal roosts after foraging (Kunz 1973). During the night, bats roost at intervals, either at diurnal roosts or at night-roosts nearer their foraging areas (Adam and Hayes 2000, Johnson 2002, Daniel et al. 2008). Unusual daytime flights may be symptomatic of white-nose syndrome-infected bats.

White-nose syndrome (WNS) is an emergent disease of hibernating bats that has spread from the northeastern to the central United States at an alarming rate. Since the winter of 2007-2008, millions of insect-eating bats in 31 states and five Canadian provinces have died from this disease (as of September 2017). The disease is named for the white fungus, *Pseudogymnoascus destructans*, that infects the skin of the muzzle, ears, and wings of hibernating bats. Field signs of WNS-infected bats include abnormal behaviors in their hibernation sites (hibernacula), such as movement toward the mouth of caves and daytime flights. These abnormal behaviors may contribute to the untimely consumption of stored fat reserves causing dehydration and emaciation, characteristics documented in a portion of the bats that die from WNS (USGS 2017).

In the United States, about 45 bat species are known with 16 of the 45 species in Tennessee including the federally threatened northern long-eared bat, the endangered Indiana bat and the gray bat. However, there is a paucity of information regarding the distribution and occurrence of these bats in the Southern Appalachians and Tennessee.

Methods and Materials

The application of bat ultrasonic monitoring devices at field habitats has allowed ecologists to quickly and efficiently characterize and inventory bat communities at multiple areas (O'Farrell and Gannon 1999, Owen et al. 2004). Bats were monitored on the ORR with acoustic detectors such as the Anabat™ Express and the Anabat™ SD-2 (Titley Scientific, Columbia, MO). These detectors record the ultra-high frequencies emitted by bats in flight (echolocation) while they are foraging for insects at night. Bat habitat survey sites were selected carefully, based upon satellite imagery, topographic maps, and field investigations to maximize potential bat usage and foraging of the ORR landscape.

For example, bats roost in trees such as shagbark hickory, white oaks, and dead standing snags (targeted as high potential bat habitats). Water features such as wetlands, stream riparian zones, and river shorelines were also prioritized bat study habitats. Karst features such as caves and rocky bluffs were monitored with acoustic detectors to determine if there was abnormal bat activity recorded during daylight hours. Daytime flight activity would suggest the possibility of WNS-infected bats. Field and laboratory safety methods followed the DoR-OR Life Safety Plan (2017). Project methods followed the bat monitoring guidance and protocols of Britzke (2003), Ford et al. (2005), Manley et al. (2006), Martin and Britzke (2010), Menzel et al. (2005), Mitchell and Martin (2002), O'Farrell et al. (1999), Schirmacher et al. (2007), Timpone et al. (2010), the U.S. Fish and Wildlife Service (USFWS 2011, 2014), and Weller and Zabel (2002).

Bat data was collected from dusk until dawn at all ORR monitoring sites from two to 16 consecutive nights, except caves where the detectors were running 24 hours a day, seven days a week. Data downloads from the detectors were then processed using specialized bat identification software programs that compare the unknown recorded bat calls to a built-in library of bat calls. These programs include Kaleidoscope PRO (Wildlife Acoustics, Maynard, MA), and BCID-East (Bat Call Identification, Inc., Kansas City, MO). The software output produces a Microsoft® Excel file with a list of bat species that were recorded during an acoustic monitoring survey event. However, the number of calls reported herein does not equate with the number of bats, as each bat makes multiple calls while foraging and may pass through the same area several times, thus the number of bats per species recorded at each site cannot be quantified (McCracken et al. 2015).

Bats may alter their calls due to variations in the habitat where they are flying, such as reflections off water surfaces, foraging in open fields, in a heavy clutter of forests, or avoiding obstacles during flight. These factors can result in an inability of software to accurately categorize each unknown call (McCracken et al. 2015). Some bat species such as the little brown bat and the Indiana bat have overlapping acoustical characteristics that software programs cannot always accurately distinguish. All of these factors can contribute to call misidentification or rejection from identification altogether (Anthony 1981, Agranat 2012, Allen et al. 2015). Accordingly, software-based species decisions on unknown calls should be considered as suggested classifications only (Lausen 2015). Given these limitations, acoustic surveys provide a good baseline for monitoring the presence of bat species populations in a given area. Mist-net surveys are often required to confirm the presence of an actual presence. For oversight, DoR-OR co-deployed bat detectors with the ORNL Environmental Sciences Division bat ecology staff at several locations during the course of the 2016 bat monitoring season including limestone caves and a proposed waste cell site.

Results and Discussion

Acoustic bat surveys were conducted at four major ORR areas during 2016: (1) Freels Bend (ORR wildlife management area), (2) East Fork Poplar Creek floodplain, (3) Bear Creek floodplain, and (4) the proposed EMDF 7a/7c site in Bear Creek Valley. Bat habitats surveyed included karst features and caves, riparian zones along streams, trees with loose and exfoliating bark, utility right-of-ways, river shorelines, and a proposed landfill site in Bear Creek valley. During these 2016 surveys, fourteen bat species were detected on the ORR.

<u>Freels Bend (ORR Wildlife Management Area) Acoustic Monitoring Results</u>

The Freels Bend site on the ORR is part of the Three Bends Wildlife Management Area characterized by karst topography underlain by Cambro-Ordovician limestone, shale, and dolomite rocks. An estimated 70% of the site is covered with oak-hickory forest and bounded on three sides by the Clinch River. Because the Freels Bend site is dominated by limestone, karst topography, and cave-like openings, all bat detector deployments were operating twenty-four hours a day, seven days a week to evaluate the general area for indications of WNS-infected bats (i.e., unusual daytime flight activity). During 255 combined survey nights (and days) using multiple bat detectors, DoR-OR recorded 95,780 files of bat acoustic data at 22 field survey sites (Table 2.2.1.1, Figure 2.2.1.1).

Table 2.2.1.1: Freels Bend (ORR Wildlife Management Area) Survey Sites

Freels Bend (ORR Wildlife Management Area) Survey Sites					
SITE ID	Latitude	Longitude	Survey Nights	Detector	Acoustic Monitoring Site Description
FB-01	*	*	8	Anabat Express	Freels Bend Cave (survey 1) / large limestone sinkhole / forested
FB-02	35.96224	-84.22437	8	Anabat Express	Freels Bend access road (north causeway)
FB-03	35.96079	-84.22459	14	Anabat Express	South causeway backwater shoreline
FB-04	35.96036	-84.22574	14	Anabat Express	Limestone bluff (karst features) overlooking backwater area
FB-05	*	*	9	Anabat Express	Larry's Cave (survey 1) / entance at bottom of sinkhole / forested
FB-06	*	*	9	Anabat Express	Maple Tree Cave (survey 1) /limestone karst outcrops / forested
FB-07	35.95926	-84.22793	8	Anabat Express	Twin limestone chasms with cave-like fissures & karst features / forested
FB-08	35.95622	-84.22995	7	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-09	35.95488	-84.23166	10	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-10	35.61160	-84.22428	15	Anabat Express	Freels Bend access road (south causeway)
FB-11	35.65196	-84.23015	13	Anabat Express	South Freels Bend / shoreline of Clinch River at small cove
FB-12	35.95296	-84.22835	17	Anabat Express	South Freels Bend / drainage ditch in old agricultural experimental area
FB-13	*	*	7	Anabat Express	Freels Bend Cave (survey 2) / large limestone sinkhole / forested
FB-14	*	*	13	Anabat Express	Larry's Cave (survey) / entance at bottom of sinkhole / forested
FB-15	35.95624	-84.23103	14	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-16	35.9562	-84.23164	7	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-17	35.95598	-84.23183	15	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-18	35.95531	-84.23132	6	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-19	35.95694	-84.22967	14	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-20	*	*	15	Anabat Express	Maple Tree Cave (survey 2) /limestone karst outcrops / forested
FB-21	35.95775	-84.22851	16	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
FB-22	35.95810	-84.22924	16	Anabat Express	Limestone outcrops with cave-like fissures & karst features / forested
			255	Total Survey Nights	

* Because caves are environmentally sensitive ORR natural resources, GPS coordinates are not shown.

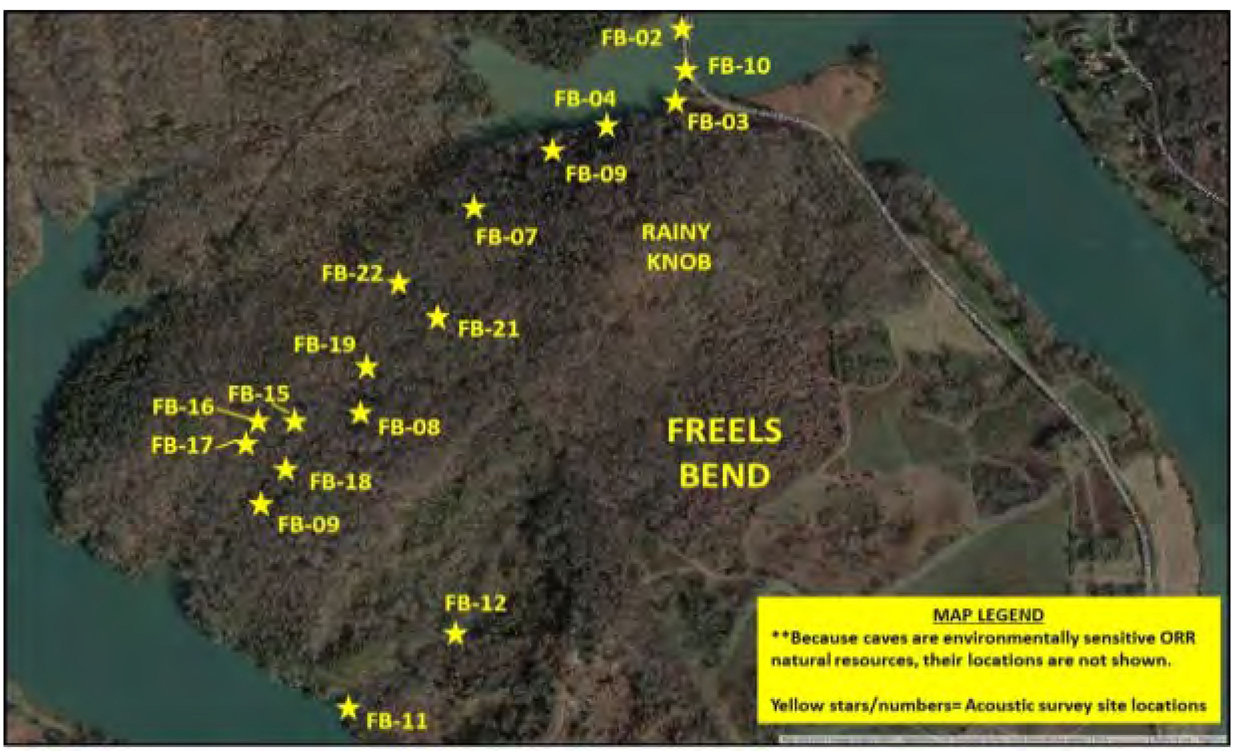


Figure 2.2.1.1: Freels Bend (ORR Wildlife Management Area) Survey Sites

The bat acoustic data files were processed with specialized, automated bat identification software (Kaleidoscope PRO) yielding 7,302 bat identifications. An additional 1,375 bat calls were detected but could not be identified to species by the software program due to poor call quality, noise, inclement weather conditions, or field clutter. It is important to note that the data represents the number of bat calls, not the number of bats present. Approximately 87,103 noise files were recorded. Noise files are not bat calls. Noise calls represent natural and anthropogenic noises recorded by the detector.

In general, but not always so, the *Myotis* species, the tri-colored bat, the Brazilian free-tailed bat, and the big brown bat are cave-obligate bats. An example of a variant would be the eastern, small-footed bat (*Myotis* leibii) which is sometimes found roosting in rock crevices and expansion joints in bridges. The big brown bat sometimes forms colonies in abandoned buildings. The *Myotis* species group is important because it includes the three federally threatened and endangered bat species that occur in Tennessee (endangered Indiana and gray bats; threatened northern long-eared bat).

Figure 2.2.1.2 compares the *Myotis* species to Non-*Myotis* species detected at Freels Bend; Non-*Myotis* species calls are 11 times more frequent than *Myotis* species. Species indicated by the Freels Bend survey data included a mixture of tree bats and cave bats: Townsend's big-eared bat, big brown bat, eastern red bat, hoary bat, silver-haired bat, southeastern bat, eastern small-footed bat, little brown bat, northern long-eared bat, Indiana bat, gray bat, evening bat, tri-colored bat (eastern pipistrelle), and the Brazilian free-tailed bat (Table 2.2.1.2).

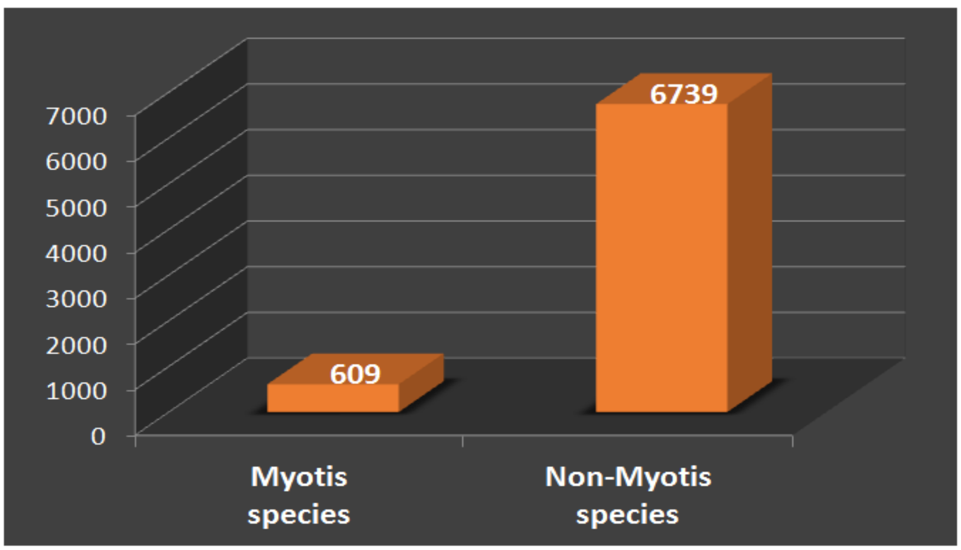


Figure 2.2.1.2: Freels Bend *Myotis* Species vs. Non-*Myotis* Composition

Table 2.2.1.2: Freels Bend Acoustic Survey Results

	COMBINED TOTAL BAT CALLS DETECTED PER SPECIES														ADDITIONAL SOFTWARE OUTPUT	
BAT SPECIES→	**COTO**	**EPFU**	**LABO**	**LACI**	**LANO**	**MYAU**	**MYGR**	**MYLE**	**MYLU**	**MYSE**	**MYSO**	**NYHU**	**PESU**	**TABR**	**NOID**	**NOISE**
SITE ID↓																
FB-01	26	198	25	9	2	1	10	1		2	2		6	1	11	61
FB-02		50	92	97	89	2	118		35	1		31	75	26	65	879
FB-03	2	4	30	17	9	1		3	9	2	2	4	12	51	44	191
FB-04		15	4	868	99	5				1		1		72	161	870
FB-05	1	262	3	163	706	4	2			1	1		2	67	251	740
FB-06	3	61	5	2	378		1			1	2			35	156	1502
FB-07	1	4	8	5	30			1						9	14	97
FB-08		6	1	1	45	1	4				2			4	16	75
FB-09	8	42	16	2	12	3	29	1	22	4	5		3	4	27	33948
FB-10		5	87	94	214		27		16	2		50	37	52	71	388
FB-11			5	19	23							1	1	3	11	16512
FB-12	9	84	83	3	32		6		5		1	4	29	21	86	1087
FB-13		6	21	50	179		5		11			3	11	54	15	158
FB-14	1	63	7	2	174				1	2	1	1	2	10	57	175
FB-15	2	4	30	17	9	1		3	9	2	2	4	12	51	44	191
FB-16	5	18	16	4	25		4	1	14	2	4		1	4	25	26433
FB-17	1	57	3	25	119	1	1					1		12	76	519
FB-18		9	1	3	34	1							3	8	26	523
FB-19		60	25	12	221							3	6	29	33	177
FB-20	4	33	7	3	147	2	1			1			4	5	54	613
FB-21	9	84	83	3	32		6		5		1	4	29	21	86	1087
FB-22	4	19	71	1	10	10	107	4	36	12	23	9	33		46	877
TOTALS	76	1084	623	1400	2589	32	321	14	163	33	46	116	266	539	1375	87103

•Notes: The numbers in each bat species column represent the number of bat calls recorded per species, ***not*** the number of bats present. A call is the series of frequency sweeps which a bat emits (i.e., biosonar) for navigation or location of a prey item (McCracken et al. 2013). NOISE files include insect noise, wind, rain, and anthropogenic noise. NOID: Bat calls were recorded but not identified to species.

•Bat species codes: CORA = *Corynorhinus rafinesquii* (Rafinesque's big-eared bat), COTO = *Corynorhinus townsendii* (Townsend's big-eared bat), EPFU = *Eptesicus fuscus* (big brown bat), LABO = *Lasiurus borealis* (eastern red bat), LACI = *Lasiurus cinereus* (hoary bat), LANO = *Lasionycteris noctivagans* (silver-haired bat), MYAU = *Myotis austroriparius* (southeastern myotis), MYGR = *Myotis grisescens* (gray bat, endangered species), MYLE = *Myotis leibii* (eastern small-footed bat), MYLU = *Myotis lucifugus* (little brown bat), MYSE = *Myotis septentrionalis* (northern long-eared bat, threatened species), MYSO = *Myotis sodalis* (indiana bat, endangered species), NYHU = *Nycticeius humeralis* (evening bat), PESU = *Perimyotis subflavus* (tricolored bat; eastern pipistrelle), TABR = *Tadarida brasiliensis* (brazilian free-tailed bat). {Threatened and endangered bat species codes are shaded in green at top of the table.}

A greater number of tree bats species were detected than cave bat species. Obligate tree bats include the eastern red bat, the hoary bat, the silver-haired bat, and the evening bat. Of all species detected, LANO [the silver-haired bat (36%)], LACI [the hoary bat (19%)], EPFU [the big brown bat (15%)], LABO [the eastern red bat (9%)] and TABR [the Brazilian free-tailed bat (7%)] dominated the bat species composition at Freels Bend (Figure 2.2.1.3).

Two sites recorded the highest number of bat calls: (1) survey site FB-04 (limestone bluff overlooking causeway backwater area) = 1,226 bat calls and (2) survey site FB-05 (Larry's Cave) = 1,463 bat calls. Threatened and endangered species detected at Freels Bend included the gray bat (4% of all species; federally listed endangered species), Indiana bat (<1% of all species; federally listed endangered species), and northern long-eared bat (<1% of all species; federally listed threatened species).

The largest number of threatened and endangered species calls was detected at two survey sites:

1. FB-02 (Freels Bend causeway access road) = 118 gray bat calls

2. FB-22 (open canopy area with limestone karst features)
   = 107 gray bat calls, 12 northern long-eared bat calls, and 23 Indiana bat calls

Overall, a low number of *Myotis* bat calls were detected at the three caves that were monitored. However, DoR-OR recorded acoustic hits of threatened and endangered bats at 18 of 22 survey sites

(Figure 2.2.1.3). Given the proportionally large area of karst topography at Freels Bend, the approximated composition was 40% were cave bats and 60% were tree bats. Nevertheless, DoR-OR confirmed that *Myotis* bats are roosting in the caves, in the numerous limestone fissures, and in the cave-like openings on Freels Bend. It is important to note that the recorded call data processed with

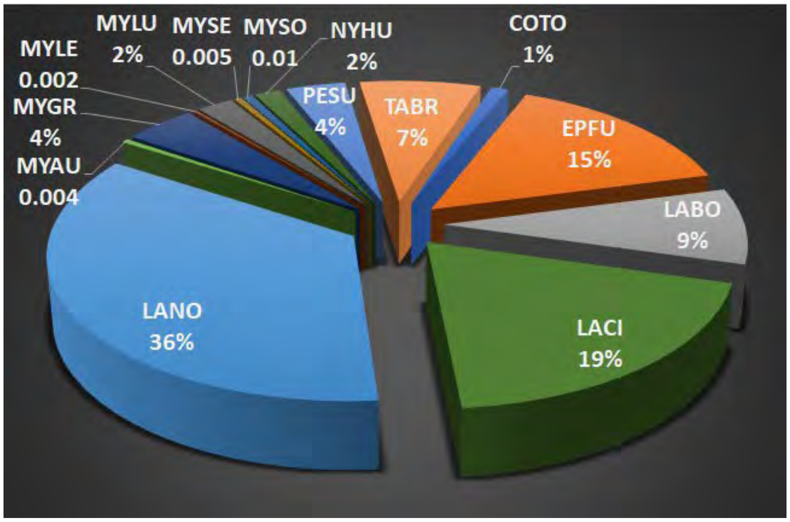


Figure 2.2.1.3: Freels Bend Bat Species Composition

the Kaleidoscope PRO software program revealed no daytime bat activity at Freels Bend. This is evidence of little or no WNS-infected bats being present on the site. Although Townsend's big-eared bat's known range does not include the ORR, DoR-OR recorded acoustic hits for this species at 14 of 22 Freels Bend sites. McCracken et al. (2015) reported that the southeastern bat, *Myotis austroriparius*, whose range includes some counties in southern Tennessee, has not been trapped or recorded acoustically on the ORR. However, the 2016 Freels Bend results suggest acoustic hits on the southeastern bat at 12 of 22 sites. This survey information will be provided to the Tennessee Wildlife Resources Agency, the TDEC Division of Natural Areas, the US Department of Energy, and the US Fish and Wildlife Service.

East Fork Poplar Creek Floodplain Acoustic Monitoring Results

East Fork Poplar Creek (EFPC) originates within the Y-12 plant as a drainage ditch, which primarily receives contaminated process water from the plant. From its origin at the Y-12 plant to its confluence with Poplar Creek, EFPC falls approximately 200 feet, having an average fall of about 3.9 meters per kilometer over 25.5 kilometers (Carmichael 1989). In parts of the study area, coal particles that washed into EFPC from the Y-12 plant have been deposited, along with mercury and other contaminants, in a dark-colored layer several inches thick in the upper 18" of the flood-plain alluvium (Carmichael 1989).

The EFPC floodplain study area is located in the Valley and Ridge physiographic province, an area characterized by thrust-faulting and northeast-southwest trending ridges and valleys underlain by Cambro-Ordovician limestones, dolomites, shales, and siltstones. A well-developed riparian zone and forest make up the course of EFPC except where disturbed by industrial activities. The riparian zone includes trees with loose, exfoliating bark and dead snags that provide habitat for federally endangered Indiana bat females during the summer reproduction months.

During 104 combined survey nights and using multiple bat detectors deployments, TDEC recorded 252,500 files of bat acoustic data at ten EFPC field survey sites (Table 2.2.1.3, Figure 2.2.1.4, Figure 2.2.1.5) processed with specialized, automated bat identification software (Kaleidoscope PRO) that yielded 10,404 bat identifications. Bat detectors were programmed to record bat calls only from dusk until dawn. An additional 1,192 bat calls were detected but they were not identified to species by the software program due to either poor call quality, noise, inclement weather conditions, or field clutter. It is important to note that these are the number of bat calls, not the number of bats present. Approximately 240,904 noise files were also recorded. Noise files are not bat calls: they represent natural and anthropogenic noises recorded by the detector.

In general, but not always so, the *Myotis* species, the tri-colored bat, Brazilian free-tailed bat, and the big brown bat are cave-obligate bats. An example of a variant would be the eastern small-footed bat (*Myotis leibii*) which is sometimes found roosting in rock crevices and expansion joints in bridges. The big brown bat sometimes forms colonies in abandoned buildings. The *Myotis* species group includes the three federally threatened and endangered bat species that occur in Tennessee (endangered Indiana bats, gray bats, and threatened northern long-eared bat). Figure 2.2.1.6 compares the *Myotis* species to Non-*Myotis* species detected at EFPC; Non-*Myotis* species calls are 17X greater than *Myotis* species calls.

Table 2.2.1.3: East Fork Poplar Creek Survey Sites

East Fork Poplar Creek Survey Sites					
SITE ID	**Latitude**	**Longitude**	**Survey Nights**	**Detector**	**Acoustic Monitoring Site Description**
EFK-01	36.00100	-84.24707	9	Anabat Express	East Fork Poplar Creek Floodplain / south of Ole Ben Franklin Motors (Oak Ridge)
EFK-02	36.00532	-84.26087	9	Anabat Express	East Fork Poplar Creek Floodplain / west of Big Lots (Oak Ridge)
EFK-03	35.99722	-84.30376	6	Anabat Express	East Fork Poplar Creek Floodplain / south of electric substation
EFK-04	35.99129	-84.3151	6	Anabat Express	East Fork Poplar Creek Floodplain / EFK 13.8 (upstream of Monterey Road Bridge)
EFK-05	35.97537	-84.33781	12	Anabat Express	East Fork Poplar Creek Floodplain / At bridge leading into abandoned development
EFK-06	35.96347	-84.35966	14	Anabat Express	East Fork Poplar Creek Floodplain / Horizon Center / EFK 6.3 bridge
EFK-07	35.95633	-84.36942	13	Anabat Express	East Fork Poplar Creek Floodplain / Horizon Center / record-size sycamore
EFK-08	35.94906	-84.37507	16	Anabat Express	Poplar Creek greenway / embankment above EFPC
EFK-09	35.95318	-84.38313	11	Anabat Express	East Fork Poplar Creek Floodplain / East Fork Road at spring outfall from wetlands
EFK-10	35.94960	-84.38594	8	Anabat Express	East Fork Poplar Creek Floodplain / Upstream of Poplar Creek bridge (EFPC mouth)
			104	Total Survey Nights	

Figure 2.2.1.4: East Fork Poplar Creek Survey Sites (Northern Section)

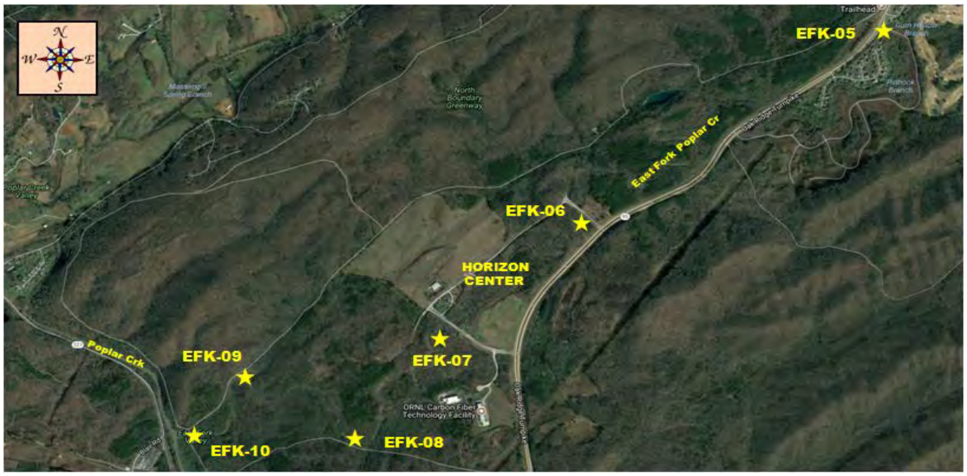


Figure 2.2.1.5: East Fork Poplar Creek Survey Sites (Southern Section)

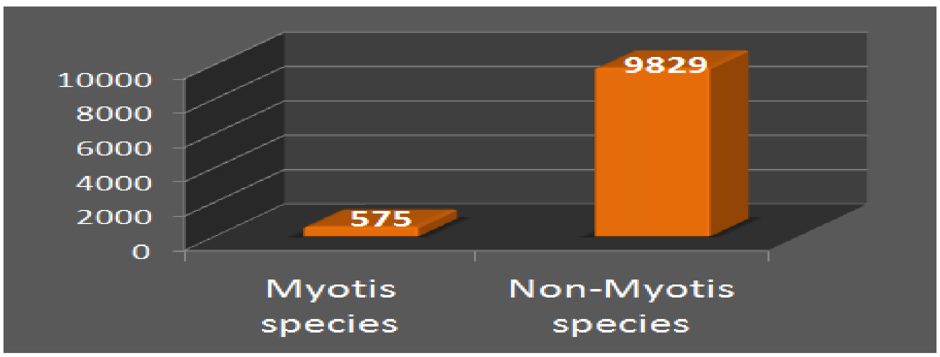


Figure 2.2.1.6: East Fork Poplar Creek *Myotis* Species vs. Non-*Myotis* Composition

Species indicated by the EFPC survey data include a mixture of tree bats and cave bats: Townsend's big-eared bat, big brown bat, eastern red bat, hoary bat, silver-haired bat, southeastern bat, eastern small-footed bat, little brown bat, northern long-eared bat, Indiana bat, gray bat, evening bat, tri-colored bat (eastern pipistrelle), and the Brazilian free-tailed bat (Table 2.2.1.4). Considerably more cave bat species were detected than tree bat species. Obligate tree bats include the eastern red bat, the hoary bat, the silver-haired bat, and the evening bat. Of all species detected, EPFU [the big brown bat (43%)], LABO [the eastern red bat (17%)], and LANO [the silver-haired bat (12%)] dominated the EFPC bat species composition (Figure 2.2.1.7).

Table 2.2.1.4: East Fork Poplar Creek Acoustic Survey Results

East Fork Poplar Creek Acoustic Survey Results																	
	NUMBER OF BAT CALLS PER SPECIES															ADDITIONAL SOFTWARE OUTPUT	
Bat Species→	**COTO**	**EPFU**	**LABO**	**LACI**	**LANO**	**MYAU**	**MYGR**	**MYLE**	**MYLU**	**MYSE**	**MYSO**	**NYHU**	**PESU**	**TABR**		**NOID**	**NOISE**
Site ID ↓																	
EFK-01	446	2639	471	44	513		1		112	2	5	154	190	37		467	49546
EFK-02	95	394	87	5	152	5	52	4	74	7	22	2	12	10		143	42385
EFK-03	46	167	112	75	98	1	9		26	2		25	42	17		107	52464
EFK-04	80	812	143	18	80	1	9		32		1	47	60	16		105	16701
EFK-05	9	68	59	26	171		2		10		4	6	10	22		87	32507
EFK-06	5	10	12	2	1		11		5				9	2		20	9961
EFK-07	33	248	243	7	100	1	38	2	42	3	6	60	145	6		86	6731
EFK-08	6	21	65	3	22	1	5		14			29	95	5		78	29493
EFK-09	13	46	134	2	68		2		19		5	25	86	20		70	522
EFK-10		40	415	18	38		16		23	1		227	92	16		29	594
Totals	*733*	*4445*	*1741*	*200*	*1243*	*9*	*145*	*6*	*357*	*15*	*43*	*575*	*741*	*151*		*1192*	*240904*

•Notes: The numbers in each bat species column represent the number of bat calls recorded per species, ***not*** the number of bats present. A call is the series of frequency sweeps which a bat emits (i.e., biosonar) for navigation or location of a prey item (McCracken et al. 2013). NOISE files include insect noise, wind, rain, and anthropogenic noise. NOID: Bat calls were recorded but not identified to species.

•Bat species codes: CORA = *Corynorhinus rafinesquii* (Rafinesque's big-eared bat), COTO = *Corynorhinus townsendii* (Townsend's big-eared bat), EPFU = *Eptesicus fuscus* (big brown bat), LABO = *Lasiurus borealis* (eastern red bat), LACI = *Lasiurus cinereus* (hoary bat), LANO = *Lasionycteris noctivagans* (silver-haired bat), MYAU = *Myotis austroriparius* (southeastern myotis), MYGR = *Myotis grisescens* (gray bat, endangered species), MYLE = *Myotis leibii* (eastern small-footed bat), MYLU = *Myotis lucifugus* (little brown bat), MYSE = *Myotis septentrionalis* (northern long-eared bat, threatened species), MYSO = *Myotis sodalis* (Indiana bat, endangered species), NYHU = *Nycticeius humeralis* (evening bat), PESU = *Perimyotis subflavus* (tricolored bat; eastern pipistrelle), TABR = *Tadarida brasiliensis* (Brazilian free-tailed bat). {Threatened and endangered bat species codes are shaded in green at top of the table.}

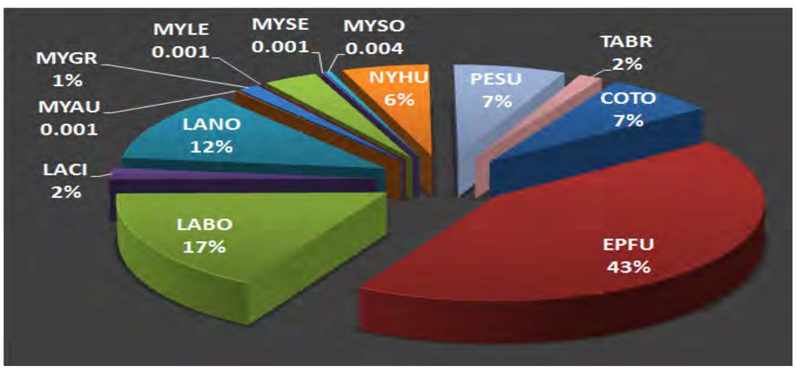


Figure 2.2.1.7: East Fork Poplar Creek Bat Species Composition

Table 2.2.1.4 depicts the four sites where the highest number of bat calls were recorded:

1. EFK-01 (EFPK floodplain behind Ole Ben Franklin Motors, Oak Ridge) = 5,081 bat calls.
2. EFK-02 (EFPK floodplain near Big Lots, Oak Ridge) = 1,064 bat calls.
3. EFK-04 (EFPK floodplain upstream of Monterrey Road bridge, Oak Ridge) = 1,404 bat calls.
4. EFK-07 (EFPK floodplain, Horizon Center near record-size sycamore tree) = 1,020 bat calls.

Threatened and endangered species detected at EFPC included the gray bat (1% of all species; federally listed endangered species), the Indiana bat (<1% of all species; federally listed endangered species), and northern long-eared bat (<1% of all species; federally listed threatened species). The largest number of threatened and endangered species calls was detected at survey sites: (1) EFK-02 (EFPC floodplain, near Big Lots, Oak Ridge) = 52 gray bat calls, seven northern long-eared bat calls, 22 Indiana bat calls, and (2) EFK-07 (EFPC floodplain, Horizon Center, near record-size sycamore tree)

= 38 gray bat calls, three northern long-eared bat calls, and six Indiana bat calls. Overall, DoR-OR had low numbers of *Myotis* bat calls detected; however, DoR-OR had acoustic hits of threatened and endangered bats at ten of the ten survey sites.

Along the course of the EFPC floodplain riparian zone, the bat composition consists of approximately 64% of cave bats and approximately 36% of tree bats. DoR-OR confirmed that *Myotis* bats are roosting in the riparian zone of the EFPC floodplain. The *Myotis* bats are likely coming from several nearby ORR caves to forage for insects after dusk.

Although the known range for Townsend's big-eared bat does not include the ORR, DoR-OR had acoustic hits for this species at nine of ten EFPC sites; 446 bat calls were recorded for Townsend's big-eared bat at EFK-01. McCracken et al. (2015) reported that the southeastern bat, *Myotis austroriparius*, whose range includes some counties in southern Tennessee, has not been trapped or recorded acoustically on the ORR. However, the 2016 results suggest acoustic hits on the southeastern bat at five of ten EFPC sites. The results of this survey will be provided to the Tennessee Wildlife Resources Agency, the TDEC Division of Natural Areas, the US Department of Energy, and the US Fish and Wildlife Service.

<u>Bear Creek Floodplain Acoustic Monitoring Results</u>

Bear Creek (BCK) originates within the western section of the Y-12 plant (Bear Creek valley) as a drainage outfall from the former S-3 ponds site and springs. Bear Creek flows southwesterly for about 12.5 kilometers along the axis of the valley through Pine Ridge, and drains into East Fork Poplar Creek (Bailey and Lee 1991). The BCK floodplain study area is located in the Valley and Ridge physiographic province, an area characterized by northeast-southwest trending ridges and valleys underlain by thrust-faulted Cambro-Ordovician rock formations (i.e., limestones, dolomites, shales, and siltstones). Except where disturbed by industrial activities, a well-developed riparian zone and forest along the course of BCK exist. The riparian zone includes trees with loose, exfoliating bark and dead snags that provide habitat for federally endangered Indiana bat females during the summer reproduction months. During 14 combined survey nights using multiple bat detector deployments, DoR-OR recorded 3,825 files of bat acoustic data at four BCK field survey sites (Table 2.2.1.5, Figure 2.2.1.8).

The recordings were processed with specialized, automated bat identification software (Kaleidoscope PRO) yielding 3,632 bat identifications. Bat detectors only operated from dusk until dawn during the BCK surveys. An additional 193 bat calls were detected, but could not be identified to species by the software program due to poor call quality, noise, inclement weather conditions, or field clutter. Note that these are the number of bat calls, not the number of bats present. Approximately 15,296 noise files were recorded. Noise files are not bat calls; they represent natural and anthropogenic noises recorded by the detector.

Table 2.2.1.5: Bear Creek Survey Sites

Bear Creek Survey Sites					
SITE ID	**Latitude**	**Longitude**	**Survey Nights**	**Detector**	**Acoustic Monitoring Site Description**
BCK-01	36.00100	-84.24707	4	Anabat Express	Bear Creek Floodplain / upstream of BCK 9.6
BCK-02	36.00532	-84.26087	4	Anabat Express	Bear Creek Floodplain / Reeves Road at Bear Creek bridge (Haul Road access)
BCK-03	35.99722	-84.30376	2	Anabat Express	Bear Creek Floodplain / Constructed wetlands at HWY 95 "triangle" (BCK 4.55)
BCK-04	35.99129	-84.3151	6	Anabat Express	Bear Creek Floodplain / 2nd bridge along Poplar Creek greenway (BCK 0.63)
			14	Total Survey Nights	

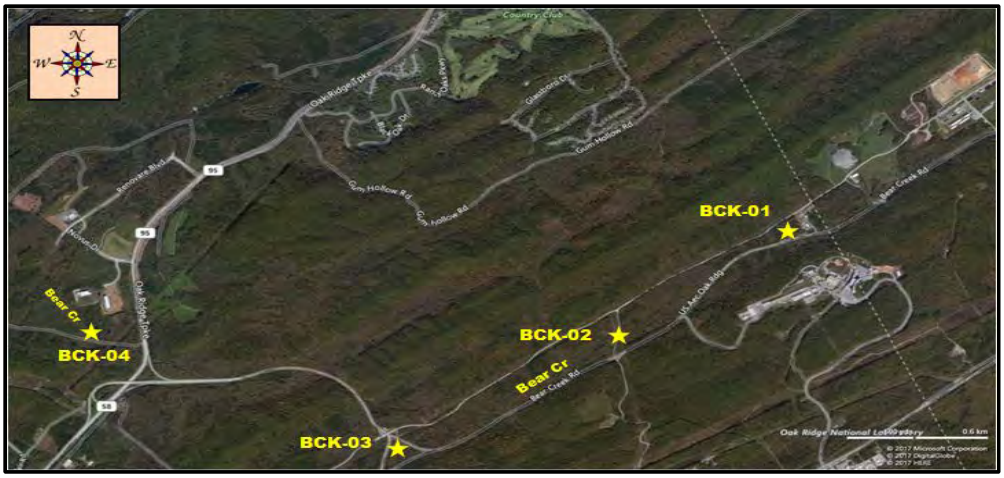


Figure 2.2.1.8: Bear Creek Survey Sites

In general, but not always so, the *Myotis* species, the tri-colored bat, the Brazilian free-tailed bat, and the big brown bat are cave-obligate bats. An example of a variant would be the eastern small-footed bat (*Myotis leibii*) sometimes found roosting in rock crevices and expansion joints in bridges. The big brown bat sometimes forms colonies in abandoned buildings. The *Myotis* species group is important because it includes the three federally threatened and endangered bat species that occur in Tennessee (endangered Indiana bats and gray bats; threatened northern long-eared bat). Figure 2.2.1.9 compares the *Myotis* species to Non-*Myotis* species detected at BCK; Non-*Myotis* species calls are 2.3X greater than *Myotis* species calls.

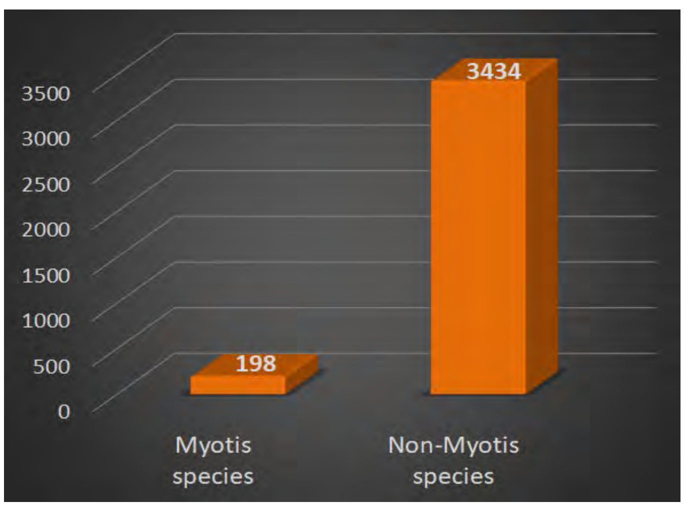


Figure 2.2.1.9: Bear Creek *Myotis* Species vs. Non-*Myotis* Composition

Species indicated by the ORR survey data includes a mixture of tree bats and cave bats: Townsend's big-eared bat, big brown bat, eastern red bat, hoary bat, silver-haired bat, southeastern bat, eastern small-footed bat, little brown bat, northern long-eared bat, Indiana bat, gray bat, evening bat, tri-colored bat (eastern pipistrelle), and the Brazilian free-tailed bat (Table 2.2.1.6). More tree bats than cave bat species were detected. Obligate tree bats include the eastern red bat, the hoary bat, the silver-haired bat and the evening bat. Of all species detected, LABO [the eastern red bat (37%)], PESU [the tri-colored bat (30%)], and LANO [the silver-haired bat (12%)] dominated the BCK bat species composition (Figure 2.2.1.10). The two sites where the highest number of bat calls were recorded follow: (1) Survey site BCK-02 (BCK floodplain, Reeves Road-Haul Road at BCK bridge) = 2,025 bat calls. (2) Survey site BCK-03 (BCK floodplain at constructed wetlands, HWY 95/Bear Creek Road triangle) = 1,414 bat calls.

Table 2.2.1.6: Bear Creek Acoustic Survey Results

Bear Creek Acoustic Survey Results																	
	NUMBER OF BAT CALLS PER SPECIES															ADDITIONAL	
Bat Species→	**COTO**	**EPFU**	**LABO**	**LACI**	**LANO**	**MYAU**	**MYGR**	**MYLE**	**MYLU**	**MYSE**	**MYSO**	**NYHU**	**PESU**	**TABR**		**NOID**	**NOISE**
Site ID ↓																	
BCK-01		4	25	18	18				8			13	2	5		15	7386
BCK-02	10	162	575	10	328	1	40	1	20			130	622	26		100	2385
BCK-03	1	51	581	9	94		68		26	1	1	110	394	21		57	3917
BCK-04		12	144	1	4		2		28		2	9	54	1		21	1608
Totals	*11*	*229*	*1325*	*38*	*444*	*1*	*110*	*1*	*82*	*1*	*3*	*262*	*1072*	*53*		*193*	*15296*

•Notes: The numbers in each bat species column represent the number of bat calls recorded per species, ***not*** the number of bats present. A call is the series of frequency sweeps which a bat emits (i.e., biosonar) for navigation or location of a prey item (McCracken et al. 2013). NOISE files include insect noise, wind, rain, and anthropogenic noise. NOID: Bat calls were recorded but not identified to species.

•Bat species codes: CORA = *Corynorhinus rafinesquii* (Rafinesque's big-eared bat), COTO = *Corynorhinus townsendii* (Townsend's big-eared bat), EPFU = *Eptesicus fuscus* (big brown bat), LABO = *Lasiurus borealis* (eastern red bat), LACI = *Lasiurus cinereus* (hoary bat), LANO = *Lasionycteris noctivagans* (silver-haired bat), MYAU = *Myotis austroriparius* (southeastern myotis), MYGR = *Myotis grisescens* (gray bat, endangered species), MYLE = *Myotis leibii* (eastern small-footed bat), MYLU = *Myotis lucifugus* (little brown bat), MYSE = *Myotis septentrionalis* (northern long-eared bat, threatened species), MYSO = *Myotis sodalis* (Indiana bat, endangered species), NYHU = *Nycticeius humeralis* (evening bat), PESU = *Perimyotis subflavus* (tricolored bat; eastern pipistrelle), TABR = *Tadarida brasiliensis* (Brazilian free-tailed bat). {Threatened and endangered bat species codes are shaded in green at top of the table.}

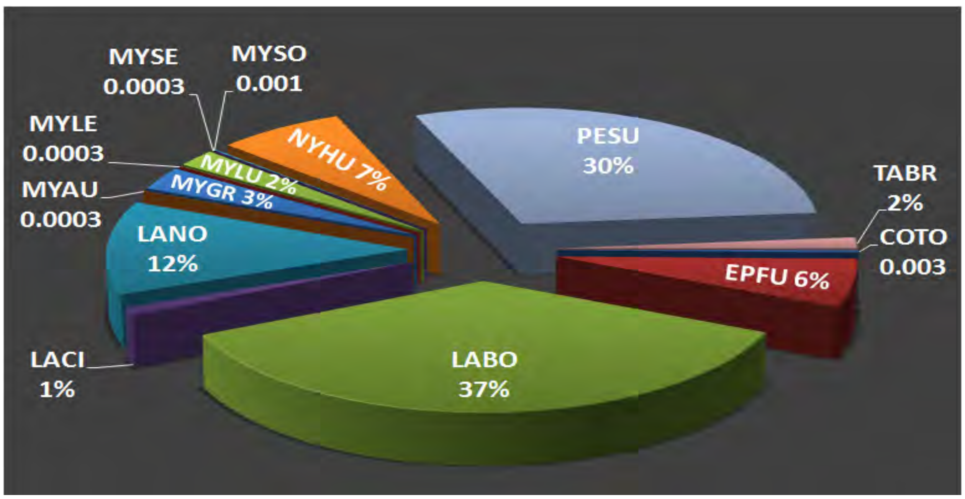


Figure 2.2.1.10: Bear Creek Bat Species Composition

Threatened and endangered species detected at BCK included the gray bat (3% of all species; federally listed endangered species), Indiana bat (<1% of all species; federally listed endangered species), and northern Long-eared bat (<1% of all species; federally listed threatened species). The largest number of threatened and endangered species calls was detected at survey sites: (1) BCK-02 (BCK floodplain, Reeves Road-Haul Road at BCK bridge) = 40 gray bat calls, and (2) BCK-03 (BCK floodplain, constructed wetlands at HWY 95/Bear Creek Road triangle) = 68 gray bat calls. Overall, low numbers of *Myotis* bat calls were detected; however, DoR-OR experienced acoustic hits of threatened and endangered bats at three of four survey sites.

Along the course of the BCK floodplain riparian zone, tree bats comprised approximately 57% of the total composition of bats detected; the remaining approximately 43% were largely cave bats. Nevertheless, DoR-OR confirmed that *Myotis* bats are roosting in the riparian zone of the BCK floodplain. All these *Myotis* bats are likely coming from several nearby ORR caves to forage for insects after dusk.

Although the Townsend's big-eared bats known range does not include the ORR, DoR-OR had acoustic hits for this species at two of four BCK sites. McCracken et al. (2015) reported that the southeastern bat, *Myotis austroriparius*, whose range includes some counties in southern Tennessee, has not been trapped or recorded acoustically on the ORR. However, the 2016 results suggest acoustic hits on the Southeastern bat at one of four BCK sites. This survey information will be provided to the Tennessee Wildlife Resources Agency, the TDEC Division of Natural Areas, the US Department of Energy, and the US Fish and Wildlife Service.

Proposed EMDF Site 7a/7c Acoustic Monitoring Results

The location of the proposed CERCLA Environmental Management Disposal Facility site 7a/7c (EMDF) is situated in the western section of Bear Creek Valley near the base of Pine Ridge. The proposed site of dissected hilly terrain is forested and consists of ≥100 acres. The site includes trees with loose, exfoliating bark and dead snags that provide habitat for federally endangered Indiana bat females during the summer reproduction months. There are natural drainages with wetlands flanking the east and west sides of the site. The drainages are tributary to Bear Creek, which flows southwesterly for about 12.5 kilometers along the axis of the valley through Pine Ridge and drains into East Fork Poplar Creek (Bailey and Lee 1991). The EMDF study area is located in the Valley and Ridge physiographic province, an area characterized by northeast-southwest trending ridges and valleys underlain by thrust-faulted Cambro-Ordovician rock formations (i.e., limestones, dolomites, shales, and siltstones.

During 205 combined survey nights using multiple bat detector deployments, DoR-OR recorded 185,899 files of bat acoustic data at 26 EMDF field survey sites (Table 2.2.1.7, Figure 2.2.1.11) that were processed with specialized, automated bat identification software (Kaleidoscope PRO) yielding 16,155 bat identifications. Bat detectors were operating only from dusk until dawn during the EMDF surveys. An additional 2,409 bat calls were detected but could not identified to species by the software program due to poor call quality, noise, inclement weather conditions, or field clutter.

Table 2.2.1.7: Proposed EMDF Site 7a/7c Survey Sites

Proposed EMDF Site 7a/7c Survey Sites				
SITE ID	**Latitude**	**Longitude**	**Survey Nights**	**Acoustic Monitoring Site Description**
EMDF-01	35.95770	-84.30965	4	Douglas Chapel Cemetery
EMDF-02	35.95655	-84.30894	4	Small wetland, north of Haul Road
EMDF-03	35.95542	-84.30984	5	Constructed wetland (west side), laydown area
EMDF-04	35.95299	-84.31266	5	Catchment pond, laydown area
EMDF-05	35.95818	-84.31096	5	Small stream drainage hollow; forest west of cemetery
EMDF-06	35.95713	-84.31106	5	Ridgetop, white oak / hickory forest
EMDF-07	35.95679	-84.3121	9	Ridgetop, white oak / hickory forest
EMDF-08	35.95544	-84.30891	5	Constructed wetland (east side), laydown area
EMDF-09	35.95763	-84.31063	13	Small stream drainage hollow; forest southwest of cemetery
EMDF-10	35.95700	-84.30995	12	Small stream drainage hollow; forest southwest of cemetery
EMDF-11	35.95794	-81.31164	13	Forested topographic saddle, north fringe of EMDF footprint
EMDF-12	35.95523	-84.31095	13	Haul Road near laydown area (open)
EMDF-13	35.95585	-84.31162	11	Ridgetop, white oak / hickory forest
EMDF-14	35.95684	-84.30967	9	Small stream drainage hollow; forested wetland area
EMDF-15	35.95768	-84.31406	8	Large forested drainage hollow, northwest of EMDF footprint
EMDF-16	35.95729	-84.31309	7	Large white oaks, northwest section of EMDF footprint
EMDF-17	35.95515	-84.31342	10	Forested stream drainage hollow, west of site
EMDF-18	35.95609	-84.31205	10	Small forested hollow between two ridges, west side
EMDF-19	35.95025	-84.31344	7	Bear Creek Road bridge at forest edge (open), west of EMDF footprint
EMDF-20	35.95421	-84.31016	7	South side of laydown area (open), adjacent to Bear Creek Road
EMDF-21	35.95634	-84.30516	8	Bear Creek Road at forest edge (open), east of EMDF footprint
EMDF-22	35.95516	-84.31181	7	West side of parcel overlooking NT11
EMDF-23	35.95459	-84.31185	7	West side of parcel overlooking NT11
EMDF-24	35.95142	-84.31128	7	Bear Creek Floodplain / utility right-of-way beside creek
EMDF-25	35.95218	-84.30988	7	Bear Creek Floodplain / stream embankment
EMDF-26	35.95256	-84.30879	7	Bear Creek Floodplain / large beaver dam area
			205	Total Survey Nights

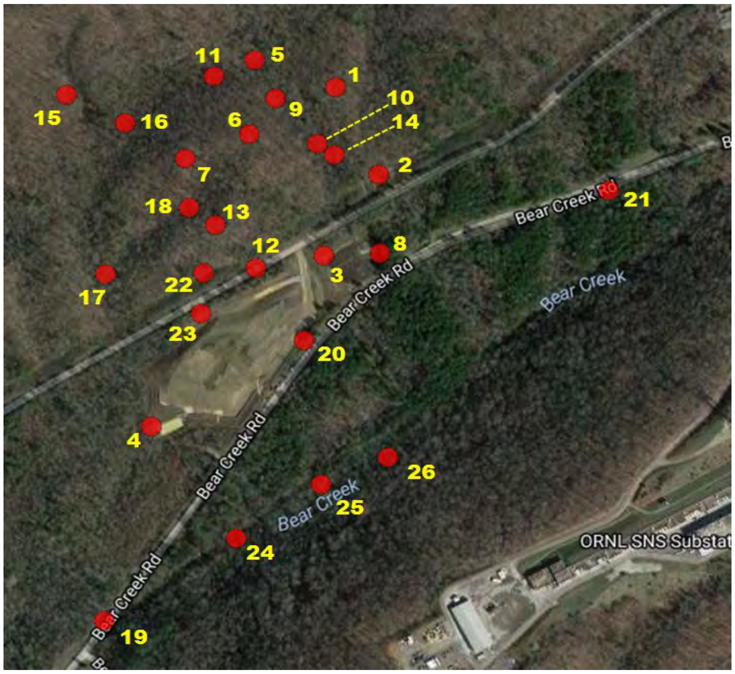


Figure 2.2.1.11: Proposed EMDF Site 7a/7c Survey Sites

Approximately 167,238 noise files were also recorded; noise files are not bat calls but represent natural and anthropogenic noises recorded by the detector. In general, but not always so, the *Myotis* species, the tri-colored bat, Brazilian free-tailed bat and the big brown bat are cave-obligate bats. An example of a variant would be the eastern small-footed bat (*Myotis leibii*) which is sometimes found roosting in rock crevices and expansion joints in bridges. The big brown bat sometimes forms colonies in abandoned buildings. The *Myotis* species group is important because it includes the three federally threatened and endangered bat species that occur in Tennessee (endangered Indiana bats and gray bats, and threatened northern Long-eared bat). Figure 2.2.1.12 compares the *Myotis*

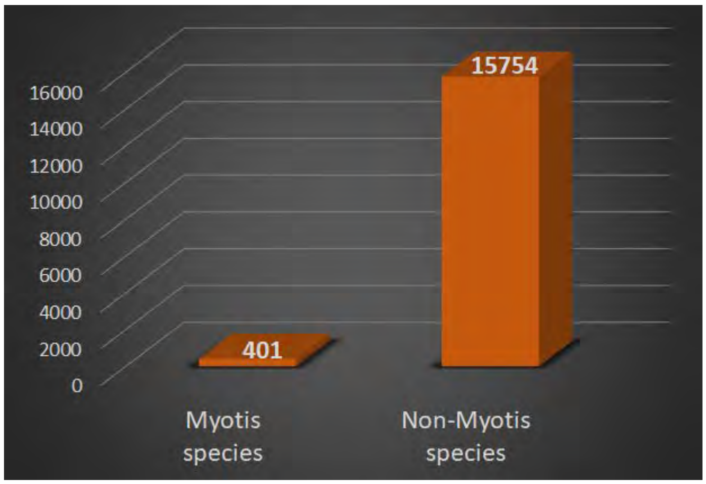


Figure 2.2.1.12: Proposed EMDF Site 7a/7c *Myotis* Species vs. Non-*Myotis* Composition

species to Non-*Myotis* species detected at EMDF; Non-*Myotis* species calls are 39X greater than *Myotis* species calls. Species indicated by the ORR survey data includes a mixture of tree bats and cave bats: Townsend's big-eared bat, big brown bat, eastern red bat, hoary bat, silver-haired bat, southeastern bat, eastern small-footed bat, little brown bat, northern long-eared bat, Indiana bat, gray bat, evening bat, tri-colored bat (eastern pipistrelle), and the Brazilian free-tailed bat (Table 2.2.1.8).

Table 2.2.1.8: Proposed EMDF Site 7a/7c Acoustic Survey Results

Proposed EMDF Site 7a/7c Survey Sites																	
	NUMBER OF BAT CALLS PER SPECIES															ADDITIONAL OUTPUT	
BAT SPECIES→	COTO	EPFU	LABO	LACI	LANO	MYAU	MYGR	MYLE	MYLU	MYSE	MYSO	NYHU	PESU	TABR		NOID	NOISE
SITE ID # ↓																	
EMDF-01			27	3	4		1		3			1	3	2		4	2327
EMDF-02		94		323	18								3	2		108	33304
EMDF-03		322	156	877	74	3	2	2	34			27	27	6		277	13732
EMDF-04	1	721	90	1122	176	7	1		23	1		18	52	9		607	21829
EMDF-05			1	1	4									6		2	91
EMDF-06			2			1							1			3	5596
EMDF-07			1	1	1	2										0	4858
EMDF-08	1	171	61	215	72	3	3		6			12	32	3		103	22708
EMDF-09		4	10	110		1						1				35	12099
EMDF-10		1	26	40	14	3								21		121	839
EMDF-11			1	5	3	3								1		7	1786
EMDF-12		203	154	280	237	4	9		12		2	95	141	13		232	9169
EMDF-13			1	1	11							1		2		3	4250
EMDF-14		24	5	156	17	1								4		32	14742
EMDF-15	2	454	62	6	289		1		1			71	45	15		25	641
EMDF-16				2												1	10
EMDF-17		1	3	14	6	4								1		9	1138
EMDF-18		1	6	5	5	1			1				3	2		3	809
EMDF-19	3	146	184	124	522		7		2			79	37	32		120	1019
EMDF-20		249	88	381	93	2	4	2	2	1	1	24	25	8		161	10013
EMDF-21		38	87	38	52	5	4		5	1		40	60	5		82	3281
EMDF-22		71	265	31	329	4	36	1	12	1		29	38	91		115	955
EMDF-23	1	1230	204	18	1611	4	1	1	2	1	1	183	12	42		59	163
EMDF-24		19	805	28	82	5	106	2	14			74	103	24		220	1193
EMDF-25	1	28	100	10	130	9	3	1	22			4	5	28		59	585
EMDF-26	7	8	29	1	42	2	1		1				524	11		21	101
TOTALS	16	3785	2368	3695	3792	64	179	9	140	5	4	659	1111	328		2409	167238

•Notes: The numbers in each bat species column represent the number of bat calls recorded per species, *not* the number of bats present. A call is the series of frequency sweeps which a bat emits (i.e., biosonar) for navigation or location of a prey item (McCracken et al. 2013). NOISE files include insect noise, wind, rain, and anthropogenic noise. NOID: Bat calls were recorded but not identified to species.

•Bat species codes: CORA = *Corynorhinus rafinesquii* (Rafinesque's big-eared bat), COTO = *Corynorhinus townsendii* (Townsend's big-eared bat), EPFU = *Eptesicus fuscus* (big brown bat), LABO = *Lasiurus borealis* (eastern red bat), LACI = *Lasiurus cinereus* (hoary bat), LANO = *Lasionycteris noctivagans* (silver-haired bat), MYAU = *Myotis austroriparius* (southeastern myotis), MYGR = *Myotis grisescens* (gray bat, endangered species), MYLE = *Myotis leibii* (eastern small-footed bat), MYLU = *Myotis lucifugus* (little brown bat), MYSE = *Myotis septentrionalis* (northern long-eared bat, threatened species), MYSO = *Myotis sodalis* (Indiana bat, endangered species), NYHU = *Nycticeius humeralis* (evening bat), PESU = *Perimyotis subflavus* (tricolored bat; eastern pipistrelle), TABR = *Tadarida brasiliensis* (Brazilian free-tailed bat). {Threatened and endangered bat species codes are shaded in green at top of the table.}

There were more tree bat species detected than cave bat species. Obligate tree bats include the eastern red bat, the hoary bat, the silver-haired bat, and the evening bat. Of all species detected, LANO [the silver-haired bat (24%)], LACI [the hoary bat (23%)], EPFU [the big brown bat (23%)], and LABO [the eastern red bat (15%)] dominated the EMDF bat species composition (Figure 2.2.1.13).

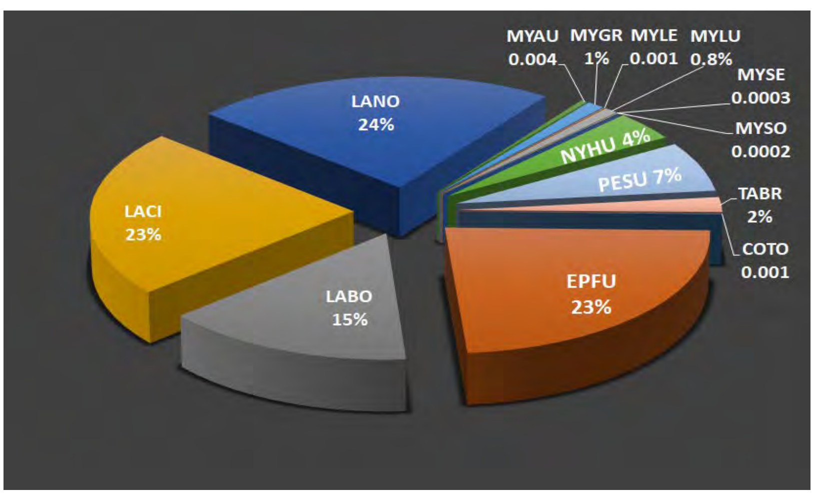


Figure 2.2.1.13: Proposed EMDF 7a/7c Site Bat Species Composition

The four sites where the highest number of bat calls were recorded follow: (1) Survey site EMDF-03 (constructed wetland, laydown area) = 1,807 bat calls. (2) Survey site EMDF-04 (catchment pond, west side of laydown area) = 2,828 bat calls. (3) Survey site EMDF-23 (west side of laydown area at location of pre-Manhattan Project home site near Haul Road) = 3,370 bat calls. (4) Survey site EMDF-24 (BCK floodplain south of footprint at utility right-of-way at creek bank) = 1,482 bat calls.

Threatened and endangered species detected at EMDF included the gray bat (1% of all species; federally listed endangered species), Indiana bat (<1% of all species; federally listed endangered species), and northern long-eared bat (<1% of all species; federally listed threatened species). The largest number of threatened and endangered species calls was detected at survey sites: (1) EMDF-22 (west side of EMDF at drainage wetland area, north tributary 11) = 36 gray bat calls, and (2) EMDF-24 (BCK floodplain, constructed wetlands at HWY 95/Bear Creek Road triangle) = 106 gray bat calls. Overall, DoR-OR only had low numbers of *Myotis* bat calls detected; however, DoR-OR had acoustic hits of threatened and endangered bats at 15 of 26 survey sites. This proposed EMDF site, if selected, supports all three federally listed threatened and endangered bat species known to occur in Tennessee. Within the footprint of the EMDF site, tree bats comprised approximately 65% of the total composition of bats detected; the remaining approximately 35% were largely cave bats. Nevertheless, DoR-OR confirmed that *Myotis* bats are roosting in the EMDF site. All these *Myotis* bats are likely coming from several nearby ORR caves to forage for insects after dusk.

Although the known range for Townsend's big-eared bat does not include the ORR, DoR-OR had acoustic hits for this species at seven of 26 EMDF survey sites. McCracken, et al. (2015) reported that the southeastern bat, *Myotis austroriparius*, whose range includes some counties in southern Tennessee, has not been trapped or recorded acoustically on the ORR. However, the 2016 results suggest acoustic hits on the southeastern bat at 19 of 26 EMDF survey sites. This survey information will be provided to the Tennessee Wildlife Resources Agency, the TDEC Division of Natural Areas, the US Department of Energy and the US Fish and Wildlife Service.

Conclusions

- Sixty-two ORR field sites were surveyed with multiple Anabat™ detectors spanning 578 survey nights
- Detectors were programmed to operate dusk-dawn except at Freels Bend caves (24 hours a day 7 days a week)
- Kaleidoscope PRO software processed 538,000 files and identified 37,493 bat calls to species
- Fourteen different bat species were detected on the ORR
- Threatened and endangered bats were detected at 46 of 62 combined ORR survey sites
    - gray bat (endangered)
    - Indiana bat (endangered)
    - northern long-eared bat (threatened)
- Tree bat calls were considerably more numerous than cave bat calls (except at East Fork Poplar Creek sites)
- Most dominant bats recorded (greatest number of calls) = big brown bat, hoary bat, eastern red bat, silver-haired bat, and tri-colored bat
- Townsend's big-eared bat range does not include the ORR; however, DoR-OR recorded acoustic hits at 32 of 62 of the total 2016 survey sites
- Southeastern bat (which has not been previously trapped or acoustically recorded on the ORR) was detected at 37 of 62 of the total 2016 survey sites
- No daytime bat flight activity was recorded at the three caves surveyed (which likely indicates that there is likely no white nose syndrome disease)
- This study provides valuable baseline information for management of natural resources on federal-owned lands
- Future acoustic surveys are recommended to fill data gaps where there is little, no, or un-organized bat species data on additional ORR areas

2.2.2 Mercury Uptake in Biota

Introduction

Between 1950 and 1963, an estimated 108,000-212,000 pounds of mercury (Hg) was released into the environment at the Y-12 National Security Complex, located on the ORR (US DOE 2014). The East Fork Poplar Creek drainage basin is located near the northern boundary of the DOE ORR and has an area of 77.2 square kilometers (km^2) from its headwaters to its mouth at Poplar Creek. East Fork Poplar Creek originates within the Y-12 Complex with a total length of nearly 26 kilometers (km). Coal particles that washed into EFPC from the Y-12 Complex have been deposited, along with mercury and other contaminants, in a dark-colored layer several inches thick in the upper 18 inches of the flood-plain alluvium (Carmichael 1989). The EFPC floodplain study area is located in the Valley and Ridge physiographic province, an area characterized by thrust-faulting and northeast-southwest trending ridges and valleys underlain by Cambro-Ordovician limestones, dolomites, shales, and siltstones. In the EFPC floodplain, mercury is dispersed in a wide range of concentrations extensively in the top three meters of the floodplain soil and distributed in EFPC sediment (Pant et al. 2010, Han et al. 2012).

Another impacted watershed, Bear Creek (BCK), also received environmental impacts from Y-12

Complex operations. The BCK watershed contains closed and active waste disposal facilities, including EMWMF and the Bear Creek Burial Grounds (BCBG), and is the proposed location for the environmental management disposal facility (EMDF, US DOE 2015). Bear Creek is designated by DoR-OR as an impacted stream due to nitrates (TDEC 2014a). Bear Creek contains cadmium (Cd) and mercury (Hg) concentrations that exceed Tennessee ambient water quality criteria (AWQC) and is adversely affected by polychlorinated biphenyls (PCBs) and uranium (TDEC 2014b). Bear Creek Valley is located between two ridges (Pine Ridge to the northwest and Chestnut Ridge to the southeast). The headwaters of BCK originate near the surface water divide at the S-3 Ponds site in the upper reaches of Bear Creek Valley. Springs and the north tributaries draining Pine Ridge provide flow volume to the creek. Bear Creek flows southwesterly for approximately 13 kilometers along the axis of the valley through Pine Ridge and drains into EFPC. Few surface tributaries drain Chestnut Ridge; the drainage is primarily subsurface and runoff reaches Bear Creek through numerous springs along the base of the ridge (Bailey and Lee 1991). Bear Creek Valley is underlain by calcareous shale and limestone of the Conasauga Group. Rome Formation siltstones, shales, sandstones, and thin limestone beds underlie Pine Ridge. Chestnut Ridge is underlain by massive, siliceous dolomite of the Knox Group and contains solutions and karst features (McMaster 1963). Discharges to surface water from a plume of contaminated groundwater at the S-3 Ponds site are the primary causes of current impacts on the aquatic ecology in BCK (USDOE 2015).

Industrial releases of mercury to the environment often finds its way into aquatic systems where it has long residence times and can bioaccumulate in aquatic food webs (Evers et al. 2005). Mercury and especially the toxic methylmercury (MeHg) present environmental concerns due to their abilities to cause neurological, reproductive, and other physical damage to wildlife (Standish 2016) and in humans. For example, researchers have demonstrated methylmercury concentrations in fish tissue range from 73.1-99% of the Total Mercury (THg) in fish (May et al. 1987). River and stream floodplains may be prime locations for mercury methylation for the same reasons that methylation occurs in wetlands (Wiener et al. 2003). Micro-organisms, found in sediment, naturally convert anthropogenic mercury deposited in wetlands and sediment into the more bioavailable and toxic form of methylmercury (UNEP 2002). Mercury can bioaccumulate to high levels in biota as it moves up the food chain (Bell and Scudder 2007), especially in areas where mercury exists as a point-source contaminant (Bergeron et al. 2011; Hothem et al. 2010). Recent research has shown that mercury is not only a problem for piscivorous and aquatic wildlife inhabiting contaminated rivers, but also for terrestrial songbirds (Cristol et al. 2008) and amphibians (Bergeron et al. 2011) in floodplain habitats.

Periphyton (primary production) is also known to provide a mechanism for methylation of mercury in stream sediment and floodplain soils. Some aquatic invertebrates graze and feed on *periphyton*, which are predated upon by higher organisms. Accordingly, methylmercury is likely to move from aquatic systems via emigrating amphibians and invertebrates entering terrestrial food webs and bioaccumulating in higher trophic levels through predation (Wolfe et al. 2007).

The reference stream for the project was Brushy Fork near the Key Springs Road Bridge (Marlow community). Brushy Fork is a rural watershed dominated by low-density housing and agricultural fields (primarily livestock grazing) interspersed among stands of second-growth hardwood forests (Loar et al. 2011). The Brushy Fork watershed is geologically similar to the EFPC watershed with the Knox Dolomite as one of the principal aquifers.

Methods and Materials

Given that biota are known to bioaccumulate contaminants, DoR-OR wanted to determine if the toxic methylmercury is being transferred from stream biota to terrestrial biota (i.e., moving up the food web) in BCK and EFPC floodplain ecosystems. To this end, the following groups have been sampled, eventually will be sampled, and all samples will be evaluated for methylmercury uptake (i.e., "target organisms"):

- periphyton (Diatoms; Primary production in aquatic systems; Class: *Bacillariophyceae*)
- salamanders (Class: *Amphibia*, Order: *Urodela*)
- flying insects (beetles, Order: *Coleoptera*)
- flying insects (moths, Order: *Lepidoptera*)
- small mammals
- mayflies, stoneflies, caddisflies (detritivores, carnivores, omnivores, algivores; Orders: *ephemeroptera/plecoptera/trichoptera*)
- odonates (carnivores, dragonflies/damselflies, Infraorder: *anisoptera/zygoptera*)
- fishing spiders (carnivore, Class: *arachnida*, Order: *araneae*)
- crawfish (omnivores, Order: *Decapoda*)
- "rolly-bugs" (detritivore, Order: *Isopoda*)
- earthworms (detritivore, Class: *Oligochaete*, Order: *Megadrilacea*)
- snails (omnivores, Class: *Gastropoda*)
- mud dauber wasps
- Bat guano

Due to the diverse nature of these organisms and the complicated field logistics to sample all biota in one field season, sampling activities are completed in phases over a period of several field seasons. Care was taken to avoid sampling any state- or federally listed threatened and endangered species. Field and laboratory safety methods followed the TDEC Life Safety Plan (2017).

Snails and crayfish were collected with D-frame aquatic dip nets. On a few occasions, a 1-meter kick net was used to collect the crayfish. Sample material was immediately placed in a clean plastic cup, sealed with lid, labeled, placed into an ice cooler, and transported to the DoR-OR office laboratory. All samples were kept frozen until their shipment to the analytical laboratory. Invertebrate sampling protocols followed the procedures of Barbour et al. (1999), Moulton et al. (2002), Mathews et al. (2011), and TDEC (2011). Snails and crayfish were run whole-body for the THg and MeHg assays. The rationale for the whole-body assays is that snails and crayfish are consumed in whole by predators (i.e., fish, mammals, salamanders, birds of prey, etc.).

Specialized beetle traps were deployed in the field for two weeks to collect adult flying insects. Samples were placed in plastic containers and packed in an ice cooler for transport to the DoR-OR office laboratory for further processing. Sample materials collected were predominantly beetles and butterflies with a few moths. Since two to three weeks passed before checking traps, some of the organisms were matted together and not separable, so collected material from each site was lumped together as one sample. Organisms were identified by genus (or family); sealed in labeled containers, and kept frozen until shipment to the analytical laboratory for THg and MeHg assays.

To collect bat guano samples for laboratory analysis, bat houses were deployed to attract bats. After bats occupancy was verified, a small bucket was installed directly beneath each bat house to catch bat guano droppings. Each collection of the guano droppings then became a surrogate sample for potential Hg uptake within the bat body. Bat houses were semi-permanently deployed at 14 locations in EFPC and BCK floodplains.

Results and Discussion

During 2016, there were three rounds of sampling activity to collect terrestrial and aquatic samples to test for uptake of THg and MeHg in biota. First, insect traps were deployed at 14 EFPC/BCK sites (Figure 2.2.2.1). Traps were installed at the location of the bat houses as a redundant or backup sampling system in the event the bat houses were not colonized. Second, snails and crayfish were collected from three EFPC locations (upstream, midstream, and downstream) and the Brushy Fork reference site (Figure 2.2.2.2). Third, bat houses were inspected with a high-intensity light and/or a flexible inspection camera for bat occupancy. During the course of two inspections (three-month intervals), no bats were observed living in any of the 14 bat houses and as a consequence, no bat guano samples were collected. However, we discovered that most of the bat houses were occupied with organ pipe mud dauber wasp nests. The nests were collected; the wasps and their spider prey were separated from the nest material, used as proxy samples, and assayed for mercury because wasps are potential bat food. In lieu of being able to collect bat guano for mercury assays during the 2016 field season, the focus shifted to the collection of bat prey (insects). If the insects where bats are foraging have significant body burdens of mercury, then it is reasonable to assume the bats are likely bioaccumulating concentrations of mercury from the consumption of their prey.

Figure 2.2.2.1: Insect Sampling Sites

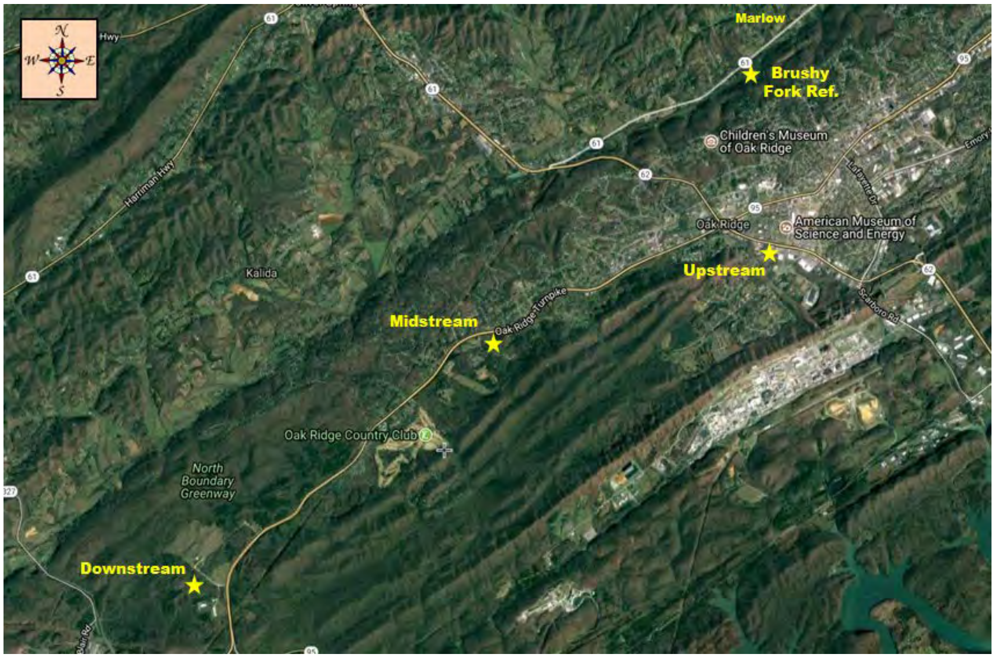


Figure 2.2.2.2: Crayfish and Snail Sampling Sites

Insect Trap Biota Results

DoR-OR attempted to collect flying insects from traps deployed at 14 ORR stream sites (Figure 2.2.2.1). BIOTA-01 through BIOTA-10 represent samples collected from EFPC floodplain and BIOTA-11 through BIOTA-14 represent samples collected from BCK floodplain. However, for the purposes of this report, EFPC and BCK data were clustered together as ORR watershed data.

Over a period of several weeks, beetles (*Coleoptera*) and butterflies (*Lepidoptera*) were trapped and retrieved as samples for the THg and MeHg assays. Due to several rainstorms and subsequent desiccation of the traps and contents, the insect material in all traps became matted and it was not possible to effectively separate the taxa into groups. As a result, the entire sample mass (beetles and butterflies) from each trap was analyzed as one composite sample. No insects were trapped at six of the 14 sites; three traps were damaged and emptied of contents by either raccoons or other mammals.

Table 2.2.2.1 and Figure 2.2.2.3 present the raw beetle/butterfly THg and MeHg analytical data for eight of the 14 sites. Note that the zeros shown in Figure 2.2.2.3 for BIOTA-01 through BIOTA-04, BIOTA-06 and BIOTA-13 represent "no sample collected" and do not represent analytical data. Figure 2.2.2.4 is a bar graph comparing the THg and MeHg of only the eight sites where sample material was actually collected. The percent MeHg component of the THg for each reported sample result varied from 0.54% to 23.43% in beetle/butterfly tissue (Table 2.2.2.1). In contrast, May et al. (1987) reported MeHg concentrations in fish tissue ranged from 73.1-99% of the THg. Although there are no mercury advisories listed for beetles and butterflies, five of our beetle/butterfly sample results exceeded the TDEC precautionary advisory levels (fish flesh criterion) of 0.3 parts per million (ppm) (300 ng/g) total mercury as the appropriate protective level for mercury for consumption of fish (Denton 2007).

Table 2.2.2.1: Mercury and Methylmercury Results: ORR Watershed Beetles/*Lepidopterans*

ORR Watershed Beetles and *Lepidopterans* Results				
Site	**THg (ng/g)**	**MeHg (ng/g)**	**%MeHg of THg**	**Biota**
BIOTA-01	*	*	*	No Sample
BIOTA-02	*	*	*	No Sample
BIOTA-03	*	*	*	No Sample
BIOTA-04	*	*	*	No Sample
BIOTA-05	1500	24.6	1.64	Beetles/*Lepidopterans*
BIOTA-06	*	*	*	No Sample
BIOTA-07	160	9.5	5.93	Beetles/*Lepidopterans*
BIOTA-08	1200	17.9	1.49	Beetles/*Lepidopterans*
BIOTA-09	1320	28.3	2.14	Beetles/*Lepidopterans*
BIOTA-10	1130	6.2	0.54	Beetles/*Lepidopterans*
BIOTA-11	230	53.9	23.43	Beetles/*Lepidopterans*
BIOTA-12	299	5.7	1.91	Beetles/*Lepidopterans*
BIOTA-13	*	*	*	No Sample
BIOTA-14	418	4.6	1.10	Beetles/*Lepidopterans*

THg - Total Mercury ng/g - nanograms per gram

MeHg - Methyl Mercury % - per cent

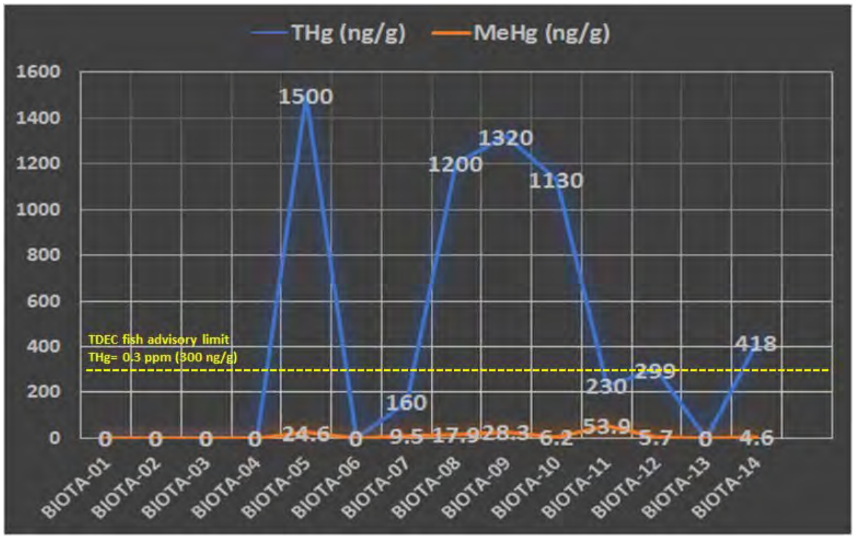


Figure 2.2.2.3: Mercury and Methylmercury Results: ORR Watershed Beetles/*Lepidopterans*

(zeros represent "no sample collected" and are not analytical data)

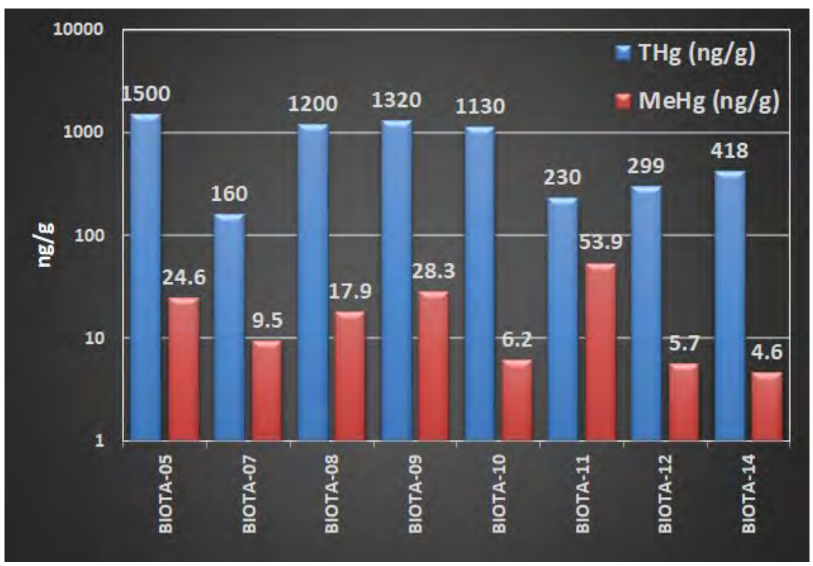


Figure 2.2.2.4: Mercury and Methylmercury Results: ORR Watershed Beetles/*Lepidopterans*

Table 2.2.2.2 presents the combined descriptive statistics results for the eight trap sites that produced beetle/butterfly sample material. The maximum THg result = 1,500 ng/g and the minimum THg result = 160 ng/g; the maximum MeHg result = 53.9 ng/g and the minimum MeHg result = 4.60 ng/g; The mean THg results = 782.13 ng/g and the mean MeHg = 18.84 ng/g.

Figures 2.2.2.5 and 2.2.2.6 are histogram statistical plots representing the underlying frequency distribution (shape) of the eight THg and MeHg data sets which are organized into bins in each plot.

The dot plot below the respective frequency graphic illustrates the eight laboratory data sets (analytical data) for THg and MeHg for each sampling site, and shows data by respective bins (i.e., orange boxes for THg and green boxes for MeHg). The histograms offer an alternative view of the data.

Table 2.2.2.2: Mercury and Methylmercury Results: Descriptive Statistics

Beetles/*Lepidopterans*		
Descriptive Statistics	**Total Hg (ng/g)**	**MeHg (ng/g)**
Mean	782.13	18.84
Standard Error	196.31	5.94
Median	774.00	13.70
Standard Deviation	555.26	16.80
Kurtosis	-2.34	2.10
Skewness	0.08	1.45
Range	1340.00	49.30
Minimum	160.00	4.60
Maximum	1500.00	53.90
Sum	6257.00	150.70
Count	8	8

THg - Total Mercury ng/g - nanograms per gram

MeHg - Methyl Mercury

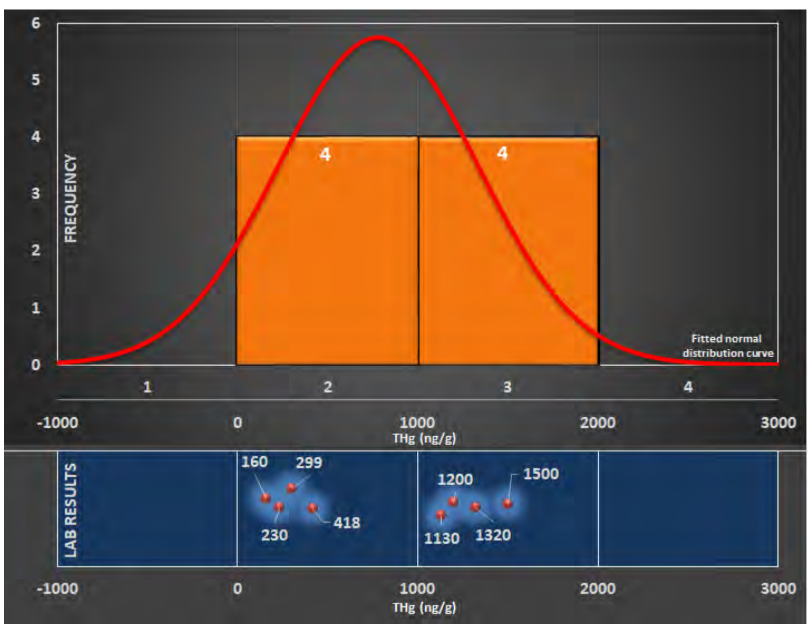


Figure 2.2.2.5: Total Mercury Histogram Plot: ORR Watershed Beetles/*Lepidopterans*

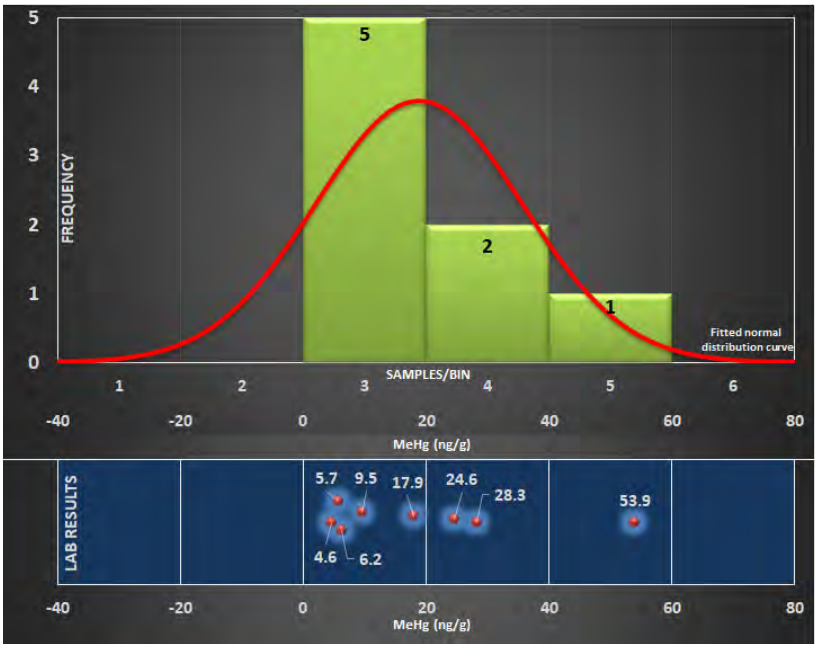


Figure 2.2.2.6: Methylmercury Histogram Plot: ORR Watershed Beetles/*Lepidopterans*

A brief literature review revealed little information regarding bioaccumulation of THg or MeHg in beetles and butterflies. However, results are important because beetles and butterflies are important prey for songbirds in the EFPC floodplain. In particular, biota research elsewhere showed that spiders and predatory and scavenger beetles, positioned at high trophic levels, demonstrate elevated Hg levels and may represent strong pathways of Hg bioaccumulation for songbirds foraging on these invertebrate prey (Driscoll and Sauer 2015).

Keller et al. (2014) found that Hg is biomagnifying within insectivorous birds in the southern Appalachians. Songbirds may bioaccumulate even greater THg and MeHg body burdens than the concentrations detected in our beetle and butterfly results, herein. Along with a decrease in the number of fertilized eggs, high concentrations of MeHg bioaccumulated by birds can cause spinal cord degeneration, a reduction of food intake resulting in weight loss, and a weakness in wings and legs; this weakness is due (overall) to an inability to coordinate muscle movement (Landrum et al. 1993).

Bird depurations of mercury from their bodies during feather molting and egg deposition but may retain Hg in other body tissues (Scheuhammer et al. 2001, 2007; Whitney and Cristol 2017). However, through continued ingestion of prey species high in Hg content, birds may accumulate Hg (and retain it in their body tissues) faster than they depurate excess body burdens through molting and reproduction (Driscoll and Sauer 2015). Cristol et al. (2008) reported the most prevalent items in a songbird species' diet are members of the orders *Araneae* (spiders), *Lepidoptera* (moths or caterpillars), and *Orthopterae* (grasshoppers) comprising >80% of the biomass (freshweight) delivered to nestlings. Their study found that wrens averaged 8.76 ± 6.46 (standard deviation) ppm (n=6), compared with 5.63 ± 2.12 ppm for owls (n=5) and 2.38±1.31 ppm for woodpeckers (n=10), all about twice the level of blood-mercury (Cristol et al. 2008).

Driscoll and Sauer (2015) reported invertebrates categorized within scavenger and predatory foraging guilds in northern hardwood forests exhibited the highest mean Hg concentrations, including the *Oodes amaroides* beetle (Hg=27.16 ng/g), the burying beetle (Hg=110.7 ng/g), and the American carrion beetle larvae (Hg=216.1 ng/g). They also reported mean Hg concentrations were found in predatory and scavenger beetles in sphagnum bogs, including the American carrion beetle (Hg=1221.83 ng/g), burying beetle (Hg=331.3 ng/g), and the *Oodes amaroides* beetle (Hg=761.4 ng/g). Caterpillars (*Lepidoptera*), classified within the herbivore foraging guild, exhibited the lowest mean Hg values =25.2 ng/g (Driscoll and Sauer 2015). These reported Hg values are consistent with Hg results for the combined beetle/butterfly samples from EFPC.

Songbird sampling should receive priority-sampling status on impacted ORR watersheds in the next few seasons to determine if they are bioaccumulating toxic MeHg concentrations. Target species should have small home ranges. Future sampling efforts will also include songbird prey item sampling. These studies should help elucidate the effectiveness of recent remedial actions on the ORR.

Aquatic Biota (Crayfish and Snails) Results

During 2016, DoR-OR collected aquatic biota with dip nets at three EFPC stream locations plus a reference site (Figure 2.2.2.2). DoR-OR selected one upstream site (EFK 22), one midstream location (EFK 13.8), one downstream location (EFK 5), and the Brushy Fork reference stream (Marlow community). Crayfish and snails were the target organisms for the THg and MeHg assays. Table 2.2.2.3 and Figures 2.2.2.7 to 2.2.2.13 present the raw THg and MeHg analytical data for all sites sampled. Figure 2.2.2.7 provides the results for EFPC Watershed crayfish for THg and MeHg. Figure 2.2.2.8: provides the results for mercury and methylmercury for EFPC watershed snails.

Table 2.2.2.3: Mercury and Methylmercury Results: EFPC Watershed Crayfish and Snails

EFPC Watershed Crayfish and Snails Mercury and Methyl Mercury Results						
Sites	THg (ng/g) crayfish	MeHg (ng/g) crayfish	%MeHg of THg crayfish	THg (ng/g) snails	MeHg (ng/g) snails	%MeHg of THg snails
Upstream EFPC	226	88.7	39.25	218	47.1	21.6
Midstream EFPC	189	102	53.96	248	72.3	29.15
Downstream EFPC	98.6	91.4	92.69	188	58.3	31.01
Brushy Fork Reference	4.12	1.8	43.68	4.87	4.1	84.18

THg - Total Mercury
MeHg - Methyl Mercury
EFPC - East Fork Poplar Creek
ng/g - nanograms per gram
% - per cent

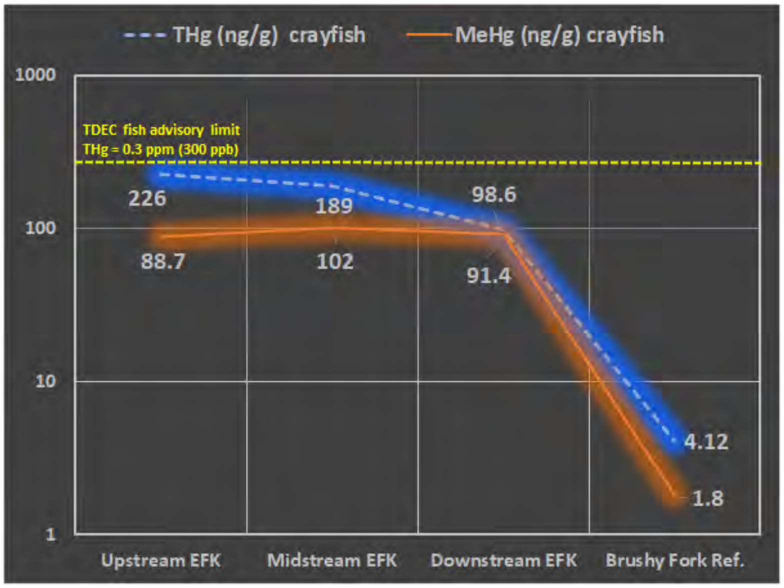


Figure 2.2.2.7: Mercury and Methylmercury Results: EFPC Watershed Crayfish

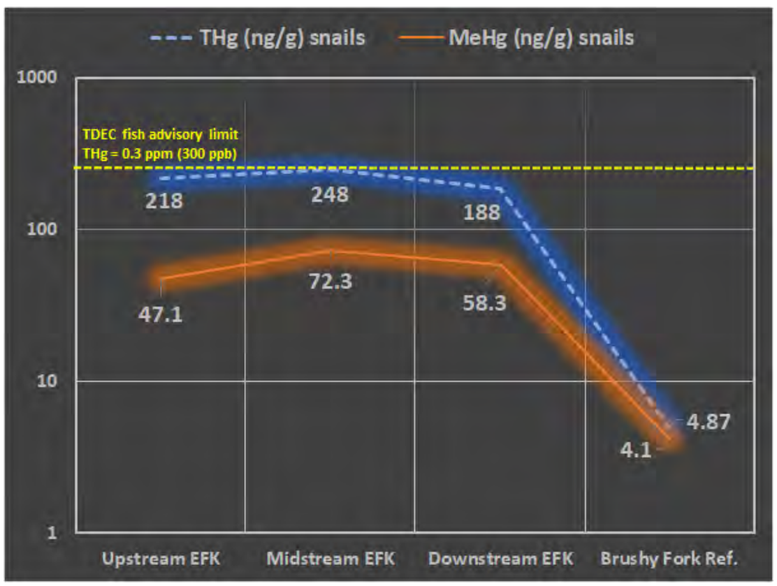


Figure 2.2.2.8: Mercury and Methylmercury Results: EFPC Watershed Snails

Figure 2.2.2.9 is a bar graph comparing the THg and MeHg results of crayfish and snail assays for all four locations. Some trends observed, include: (1) Total Hg progressively decreased downstream in EFPC crayfish, but MeHg in crayfish increased slightly at midstream compared to the upstream result, but then decreased again at the downstream site. (2) Both total Hg and MeHg concentrations in EFPC snails increased slightly at the midstream site compared to the upstream concentrations, but both Hg and MeHg decreased again at the downstream site. (3) As expected, concentrations of both THg and MeHg in crayfish and snails at the Brushy Fork reference site were several orders of magnitude lower than the corresponding EFPC THg and MeHg concentrations.

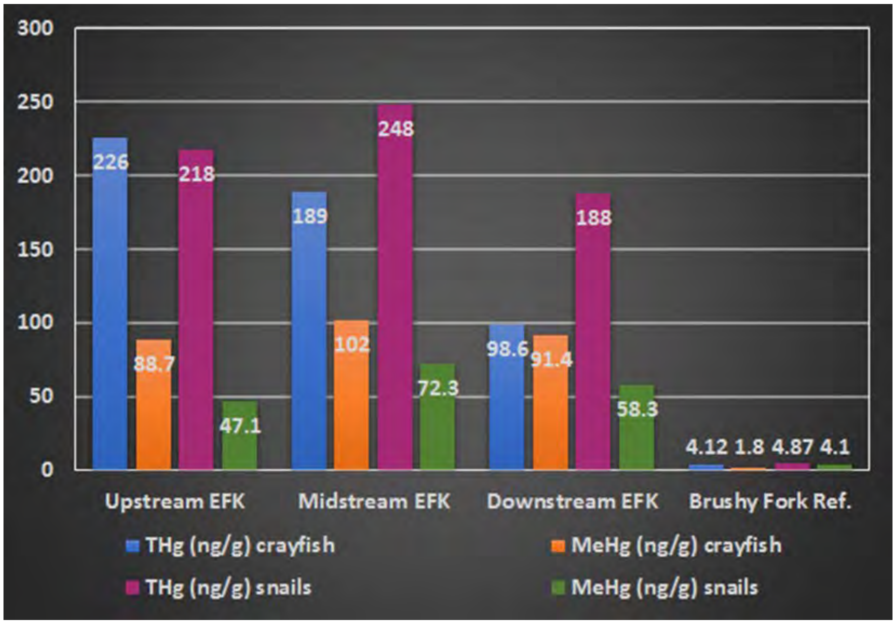


Figure 2.2.2.9: Mercury and Methylmercury Results: EFPC Watershed Crayfish/Snails

Table 2.2.2.4 presents the combined descriptive statistics results for the three EFPC sites and the Brushy Fork reference site. The maximum crayfish THg result = 226 ng/g and the minimum THg result = 4.12 ng/g; the maximum MeHg result = 102 ng/g and the minimum MeHg result = 1.80 ng/g. The maximum snail THg result = 248 ng/g and the minimum THg result = 4.87 ng/g; the maximum MeHg result = 72.30 ng/g and the minimum MeHg result = 4.10 ng/g. The mean THg results = 164.72 ng/g and the mean MeHg = 45.45 ng/g.

Figures 2.2.2.10 to 2.2.2.13 are histogram statistical plots representing the underlying frequency distribution (shape) of the THg and MeHg data sets which are organized into bins in each plot. Reference the following callouts.

- Figure 2.2.2.10 histogram shows the total mercury for EFPC watershed snails
- Figure 2.2.2.11 histogram shows the methylmercury for EFPC watershed snails
- Figure 2.2.2.12 histogram shows the total mercury for EFPC watershed crayfish
- Figure 2.2.2.13 histogram shows the methylmercury for EFPC watershed crayfish

The dot plot below the respective frequency graphics illustrate: laboratory data sets (analytical data) for THg and MeHg for each sampling site; where they fit into their respective bins (i.e., orange boxes for THg and green boxes for MeHg). The histograms merely provide another way to view and self-evaluate the data. The percent MeHg component of the THg varied from 28.19-48.11% (mean = 37.12%) in EFPC crayfish and 17.77-23.67% (mean = 21.34%) in EFPC snails (Table 2.2.2.3). For the Brushy Fork reference site, the percent MeHg component of the THg was 30.41% for crayfish and 45.71% for snails. May et al. (1987) reported MeHg concentrations in fish tissue ranged from 73.1-99% of the THg. None of the MeHg results for crayfish and snails exceeded the TDEC precautionary advisory levels (fish flesh criterion) of 0.3 ppm (300 ng/g) as the appropriately protective level for mercury for consumption of fish (Denton 2007). In a Colorado study, crayfish THg concentrations ranged from 0.020 to 0.057 ppm and MeHg ranged from 0.001 ppm to 0.045 ppm (mean 0.017

ppm). The percent of THgG as MeHg was highly variable, ranging from five to 100%, with a mean of 48% (Nydick and Williams 2010). Their reported mean (48% of THg as MeHg) is not consistent with our downstream EFPC crayfish result of 92.69% (percent of THg as MeHg). Crayfish have been used as bioindicators of Hg in the environment because they accumulate Hg, primarily as MeHg (Eisemann et al. 1997, Scheuhammer and Graham 1999, Simon and Boudou 2001).

Table 2.2.2.4: Mercury and Methylmercury Results: Descriptive Statistics

Crayfish / Snails				
Descriptive Statistics	**Total Hg (ng/g)**	**MeHg (ng/g)**	**Total Hg (ng/g)**	**MeHg (ng/g)**
	crayfish		**Snails**	
Mean	129.43	70.89	164.72	45.45
Standard Error	49.60	23.24	54.67	14.72
Median	143.80	90.05	203.00	52.70
Standard Deviation	99.21	46.47	109.34	29.43
Kurtosis	-1.56	3.72	3.04	1.92
Skewness	-0.60	-1.91	-1.70	-1.29
Range	221.88	100.20	243.13	68.20
Minimum	4.12	1.80	4.87	4.10
Maximum	226.00	102.00	248.00	72.30
Sum	517.72	283.90	658.87	181.80
Count	4	4	4	4

THg - Total Mercury   ng/g - nanograms per gram
MeHg - Methyl Mercury

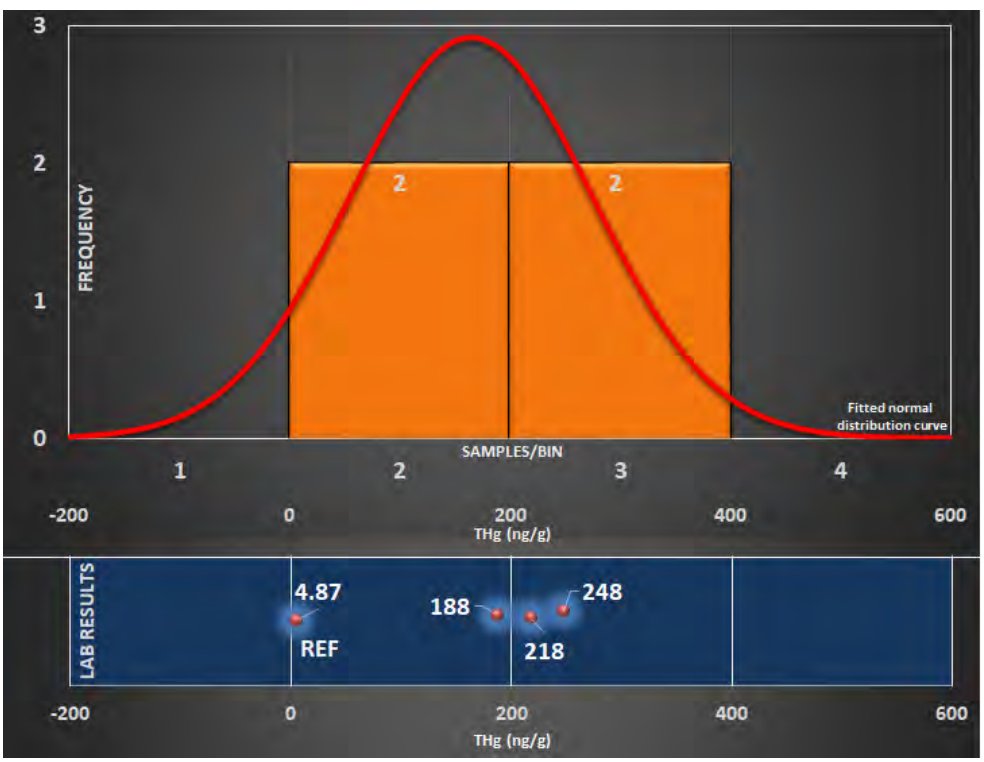


Figure 2.2.2.10: Total Mercury Histogram Plot: EFPC Watershed Snails

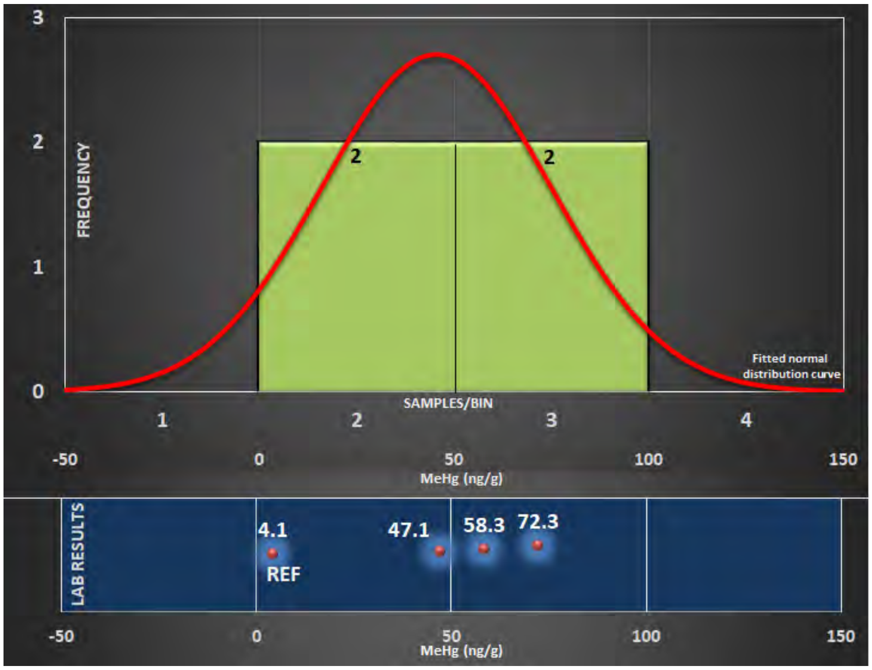


Figure 2.2.2.11: Methylmercury Histogram Plot: EFPC Watershed Snails

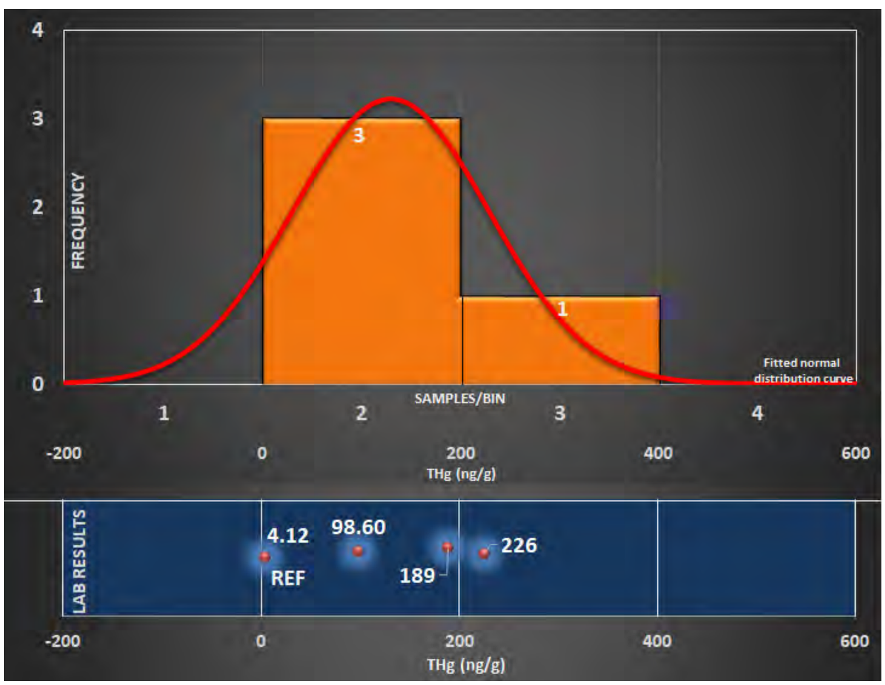


Figure 2.2.2.12: Total Mercury Histogram Plot: EFPC Watershed Crayfish

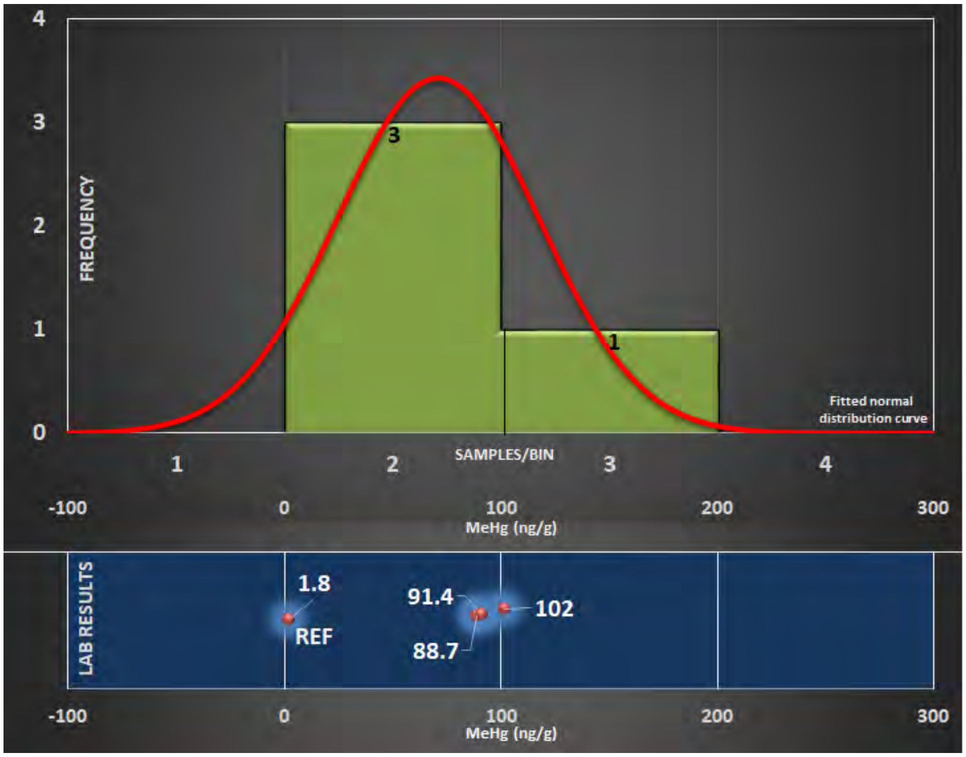


Figure 2.2.2.13: Methylmercury Histogram Plot: EFPC Watershed Crayfish

Crayfish are among the largest, longest-lived benthic invertebrates [two to three years in northern climates (Martin 1997)], are intimately associated with the substrate, have a ubiquitous distribution, and are an important food item for many organisms (Pennuto et al. 2005). Therefore, they represent an important trophic link between benthic and water-column food webs in lakes and streams and have been suggested as excellent indicator species for Hg bioavailability studies (Verneer 1972, Armstrong and Hamilton 1973, Allard and Stokes 1989, Parks 1988, Parks et al. 1991). Methylmercury concentrations may represent ≥90% of THg in fish and crayfish (Lafrancois and Carlisle 2004). The omnivorous diet of the crayfish commonly includes algae and other plant material, aquatic insects, snails and detritus. Crayfish are eaten by fish, mammals, birds, and humans.

Allah et al. (2003) demonstrated that snails experienced decreased growth and high mortality (within two days to two weeks) from exposures to high Hg concentrations (>600 ppb) in aquatic systems. More specifically, Hg causes protein denaturation in the foot, gill, and digestive tract of freshwater mussels and snails (Arunee 1986). However, studies have demonstrated that total Hg analyses in snails exposed to contaminated matrices revealed important bioaccumulation capacities up to 2,000 ppm in tissues (Gimbert et al. 2016).

Bat House Biota Results

Due to the lack of occupancy (in the 14 deployed bat houses) and to supplement the insect trap collections, a decision was made to take advantage of established dirt dauber nests in the houses. Organ pipe wasps (OPW, *Crabronidae*) and their prey items, orb weaver spiders (OWS, *Araneidae*), were collected from eight of the 14 houses as there were no nests in the remaining houses (Figure 2.2.2.1). Overall, sample biomass collected at each bat house was low, so the OPW/OWS were combined and assayed as composites for each site.

Table 2.2.2.5 and Figure 2.2.2.14 present the raw OPW/OWS THg and MeHg analytical data for eight of the 14 sites. Note that the zeros shown in Figure 2.2.2.14 for BIOTA-01, BIOTA-03 through BIOTA-05, BIOTA-12, and BIOTA-14 represent “no sample collected” and are not analytical data. Figure 2.2.2.15 is a bar graph comparing the raw THg and MeHg data of only the eight sites where DoR-OR actually collected sample material.

Table 2.2.2.6 presents the combined descriptive statistics results for the eight trap sites that produced OPW/OWS sample material. The maximum THg result = 720 ng/g and the minimum THg result = 262 ng/g; the maximum MeHg result = 203 ng/g and the minimum MeHg result = 4.64 ng/g. The mean THg results = 518.50 ng/g and the mean MeHg = 122.73 ng/g. Figures 2.2.2.16 and 2.2.2.17 are histogram statistical plots representing the underlying frequency distribution (shape) of the eight THg and MeHg data sets which are organized into bins in each plot. The dot plot below the respective frequency graphics illustrate the eight laboratory data sets (analytical data) for THg and MeHg for each sampling site and where they fit into their respective bins (i.e., orange boxes for THg and green boxes for MeHg). The histograms merely provide another way to view and evaluate the data.

Table 2.2.2.5: Mercury and Methylmercury Results: Organ Pipe Wasps/Orb Weaver Spiders

Organ Pipe Wasps / Orb Weaver Spiders Results				
Site	**THg (ng/g)**	**MeHg (ng/g)**	**%MeHg of THg**	**Biota**
BIOTA-01	*	*	*	No Sample
BIOTA-02	474	4.64	0.98	Organ pipe wasps/Orb weaver spiders
BIOTA-03	*	*	*	No Sample
BIOTA-04	*	*	*	No Sample
BIOTA-05	*	*	*	No Sample
BIOTA-06	491	165	33.60	Organ pipe wasps/Orb weaver spiders
BIOTA-07	720	153	21.25	Organ pipe wasps/Orb weaver spiders
BIOTA-08	318	128	40.25	Organ pipe wasps/Orb weaver spiders
BIOTA-09	686	133	19.38	Organ pipe wasps/Orb weaver spiders
BIOTA-10	701	190	27.10	Organ pipe wasps/Orb weaver spiders
BIOTA-11	496	5.16	1.04	Organ pipe wasps/Orb weaver spiders
BIOTA-12	*	*	*	No Sample
BIOTA-13	262	203	77.48	Organ pipe wasps/Orb weaver spiders
BIOTA-14	*	*	*	No Sample

THg - Total Mercury ng/g - nanograms per gram
MeHg - Methyl Mercury % - per cent

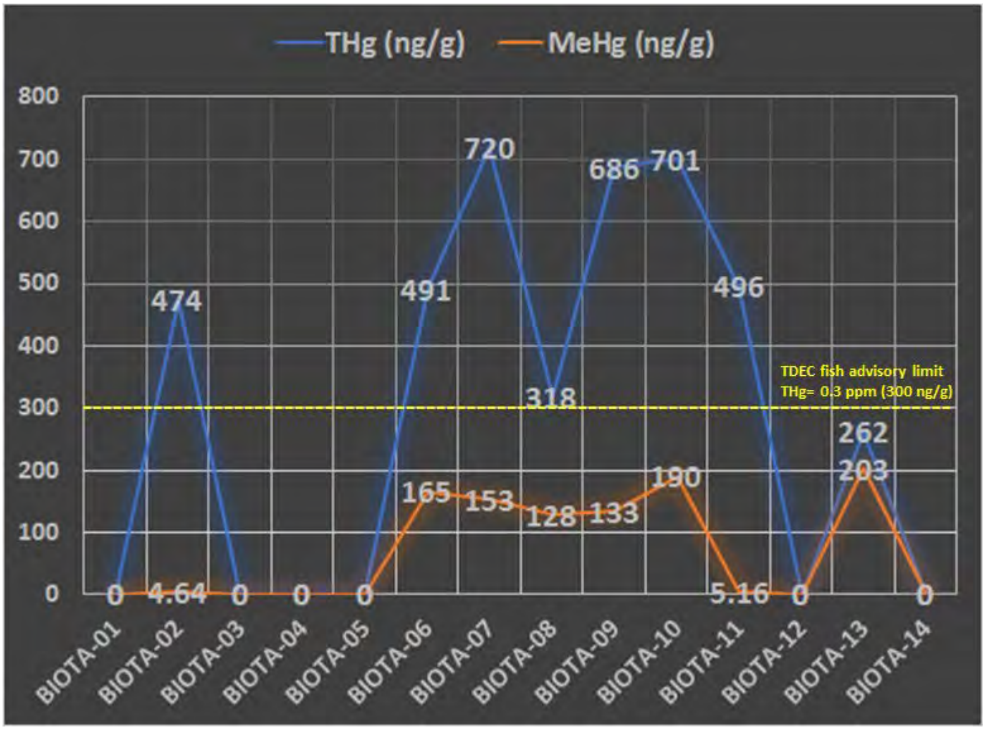


Figure 2.2.2.14: Mercury and Methylmercury Results: Organ Pipe Wasps/Orb Weaver Spiders

(zeros represent "no sample collected" and are not analytical data)

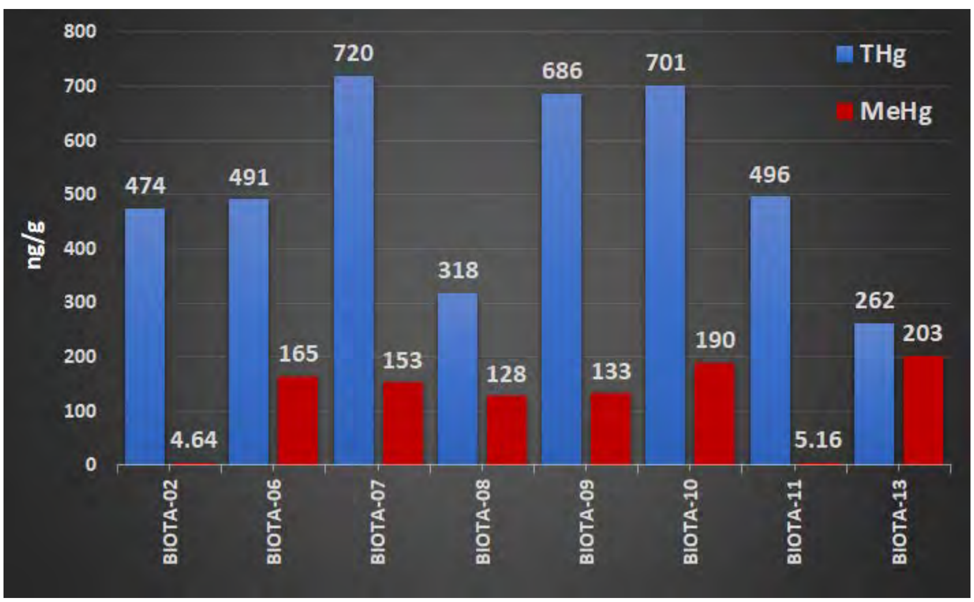


Figure 2.2.2.15: Mercury and Methylmercury Results: Organ Pipe Wasps/Orb Weaver Spiders

Table 2.2.2.6: Mercury and Methylmercury Results: Descriptive Statistics

Organ Pipe Wasps /Orb Weaver Spiders		
Descriptive Statistics	**Total Hg (ng/g)**	**MeHg (ng/g)**
Mean	518.50	122.73
Standard Error	61.41	27.25
Median	493.50	143
Standard Deviation	173.70	77.06
Kurtosis	-1.32	-0.51
Skewness	-0.22	-0.98
Range	458	198.36
Minimum	262	4.64
Maximum	720	203
Sum	4148	981.80
Count	8	8

THg - Total Mercury ng/g - nanograms per gram
MeHg - Methyl Mercury

Figure 2.2.2.16 histogram box plot depicts the results for total mercury for organ pipe wasps/orb weaver spiders. Figure 2.2.2.17 histogram box plot depicts the results for methylmercury for organ pipe wasps/orb weaver spiders.

The percent MeHg component of the THg for each reported sample result varied from 0.98% to 72.48% in OPW/OWS tissues (Table 2.2.2.5). In contrast, May et al. (1987) reported MeHg concentrations in fish tissue ranged from 73.1-99% of the THg. The study shows that seven of eight THg sample results exceeded the TDEC precautionary advisory levels (fish flesh criterion) of 0.3 ppm (300 ng/g) as the appropriately protective level for mercury for consumption of fish (Denton 2007).

Recent studies have shown that predatory invertebrates within the *Araneae* (spider: N=160; Hg=246.2 ng/g) order exhibited some the highest mean Hg uptake values representing strong pathways of Hg bioaccumulation for songbirds foraging on these invertebrate prey items (Driscoll and Sauer 2015). Hannappel (2017) found that mud dauber nests could act as a source of spiders that can be used as biosentinels of MeHg contamination in the environment. The concentrations of Hg in the spiders in the Hannappel study were high enough to pose a risk to nestling songbirds. A 2011 ecological assessment in EFPC reported total mercury concentrations of 0.10 ppm, 2.33 ppm, 3.92 ppm, 7.80 ppm for leafhoppers, wolf spiders, isopods, and earthworms, respectively, whereas MeHg concentrations averaged 0.02 ppm, 0.18 ppm, 1.18 ppm, 1.29 ppm for leafhoppers, earthworms, isopods, and wolf spiders, respectively (Standish 2016). Elsewhere, Corbicula (clam species) is known to accumulate bioavailable methylmercury (Doherty 1990, Halverson et al. 2008).

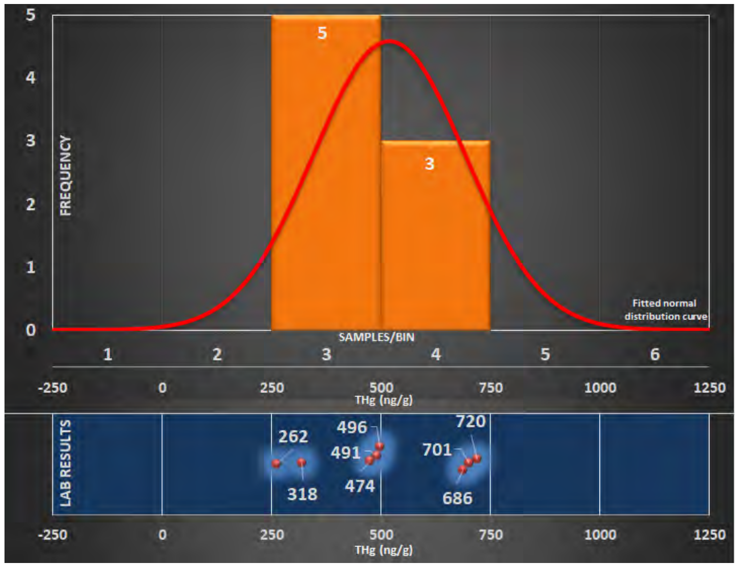


Figure 2.2.2.16: Total Mercury Histogram Plot: Organ Pipe Wasps/Orb Weaver Spiders

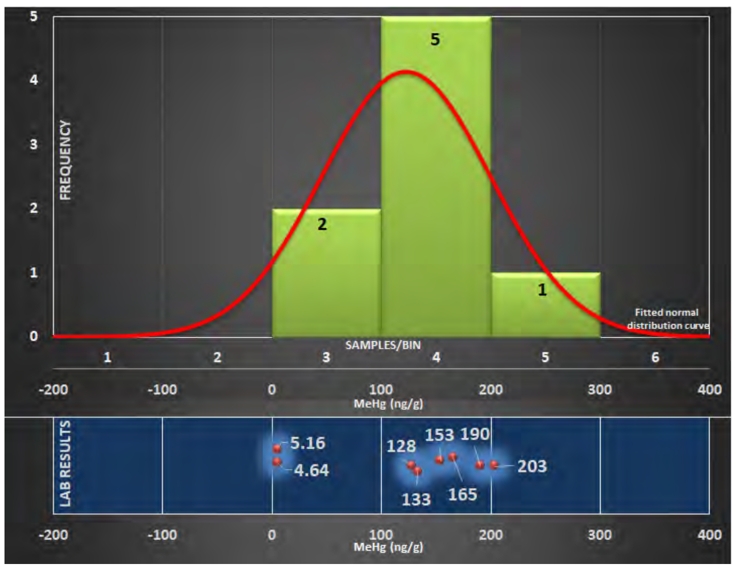


Figure 2.2.2.17: Methylmercury Histogram Plot: Organ Pipe Wasps/ORB Weaver Spiders

For instance, in a study of tributaries of the Savannah River, mercury levels in Corbicula were highest downstream from wetlands where it is likely that higher methylation rates increase its bioavailability (Paller et al. 2004, Neufeld 2010). Future DoR-OR mercury bioaccumulation investigations of ORR floodplains should include spiders, earthworms, isopods, beetles, and other biota.

Conclusions

- The results of this study provide evidence of the varying extent and magnitude of mercury contamination within several groups of ORR aquatic and terrestrial biota in the EFPC and BCK floodplains.
- Beetle and butterfly samples exhibited the highest THG concentrations (THg maximum= 1500 ng/g, THg minimum=230 ng/g) of any biota examined during 2016. Although there are

no mercury advisory limits for beetles and butterflies, five samples exceeded the TDEC advisory of 0.3 ppm (300 ng/g) for consumption of fish tissue.

- The percent MeHg component of THg in beetle/butterfly samples was highest at the downstream BCK site (23.43% of THg is MeHg, BIOTA-11 sampling site) and at the downstream EFPC Site (5.93% of THg is MeHg, BIOTA-07 sampling site).
- Analysis of EFPC crayfish samples yielded THg concentrations ranging from 98.6 ng/g (down-stream site) to 226 ng/g (up-stream site) and MeHg concentrations ranging from 88.7 ng/g (upstream site) to 102 ng/g (midstream site).
- Analysis of EFPC snail samples yielded THg concentrations ranging from 188 ng/g (down-stream site) to 248 ng/g (mid-stream site) and MeHg concentrations ranging from 47.1 ng/g (up-stream site) to 72.3 ng/g (mid-stream site).
- The percent MeHg component of THg was highest at the downstream site for both crayfish (92.69% of THg is MeHg) and snails (31.01% of THg is MeHg) at EFPC
- Concentrations of both THg and MeHg in crayfish and snails at the Brushy Fork reference site were several orders of magnitude lower than the corresponding EFPC THg and MeHg concentrations.
- THg results of the OPW/OWS biota from bat houses at EFPC and BCK revealed seven of eight samples exceeded the TDEC advisory of 0.3 ppm (300 ng/g) for consumption of fish tissue.
- THg concentrations in OPW/OWS samples yielded a maximum of 720 ng/g and a minimum of 318 ng/g (mean= 518.50 ng/g) at EFPC and BCK.
- MeHg concentrations in OPW/OWS samples yielded a maximum of 203 ng/g and a minimum of 4.64 ng/g (mean= 122.73 ng/g) at EFPC and BCK.
- The percent MeHg component of THg in OPW/OWS samples was highest at the midstream BCK site (72.48% of THg is MeHg, BIOTA-13 sampling site) and at the downstream EFPC site (40.25% of THg is MeHg, BIOTA-08 sampling site).
- This study can serve to supplement and inform future research efforts, contribute valuable scientific information on mercury dynamics in biota of stream riparian areas on the ORR, and advance understanding of the ecological links between mercury bioaccumulation and wildlife communities.
- DoR-OR recommends future multi-year studies incorporating annual sampling efforts for both targeted (small home ranges) and generalized capture of songbird species in ORR floodplain ecosystems to further identify and monitor mercury exposure patterns within at-risk songbirds and sensitive habitat types.

2.2.3 Radiological Uptake in Vegetation

Introduction

DoR-OR conducts vegetation sampling for radiological contaminant uptake on and near the ORR. In this program, DoR-OR collects vegetation at locations near or in water with the potential for radiological contamination. If surface water bodies have been impacted by radioactivity, vegetation in the immediate vicinity may uptake radionuclides, bioaccumulating radiological contaminants. The vegetation is analyzed for gross alpha, gross beta, gamma radionuclides and it is compared to the radiological analysis of vegetation taken from a background location. The sampling conducted during 2016 suggests limited areas of elevated radionuclide concentrations in the vegetation associated with surface water on the ORR.

Methods and Materials

Twenty vegetation samples were collected in 2016 in areas where there was thought to be a greater potential for radiological contamination. Samples consisted of at least one gallon of vegetation, including minimal other debris, and minimal or no roots. Samples were then scanned with a radiological instrument for beta and gamma radiation, double-bagged in re-sealable plastic bags, labeled, and transported back to DoR-OR. When enough samples were collected, they were processed and sent to the State Tennessee Department of Health (TDH) environmental laboratory in Nashville for analysis.

Twenty samples, which included a background sample, were collected and analyzed for general radiological contamination. Samples were analyzed for gross alpha, gross beta and gamma radionuclides. Samples were collected near ORR surface water sites, including springs, creeks, and wetlands, to determine if radioactive contaminants had accumulated in the associated vegetation. The species sampled were determined based on what was available at the desired sampling locations. Cattails (*Typha* spp.), watercress (*Nasturtium officinale)*, and willow (*Salix* spp.) are especially good at bioaccumulating radiological contaminants. In locations where radiological contamination seemed possible or even likely, but where cattails, watercress, and willow were not available or not in large enough quantities, mixed floodplain vegetation was collected, instead. The mixed floodplain vegetation samples were collected near the edges of water sources, mainly creeks. A similar method used by the Federal Radiation Monitoring and Assessment Center (FRMAC) for vegetation sampling was utilized (NNSA 2012). Only areas large enough to fill at least a gallon bag were sampled. Sampling mixed floodplain vegetation allowed for a wider variety of locations of potential interest to be sampled by not limiting location to certain vegetation types. In general, samples were taken at locations thought to potentially contain elevated levels of radiological contamination that could be taken up by the nearby vegetation, or at sites with previously elevated results. At one location previously sampled with increased levels of gross beta, two samples were collected, both consisting of cattails from about the same area. In addition, more locations along White Oak Creek were sampled in 2016. The locations of the samples collected and analyzed for radiological contaminants in 2016 are shown and listed in Figure 2.2.3.1 and Table 2.2.3.1.

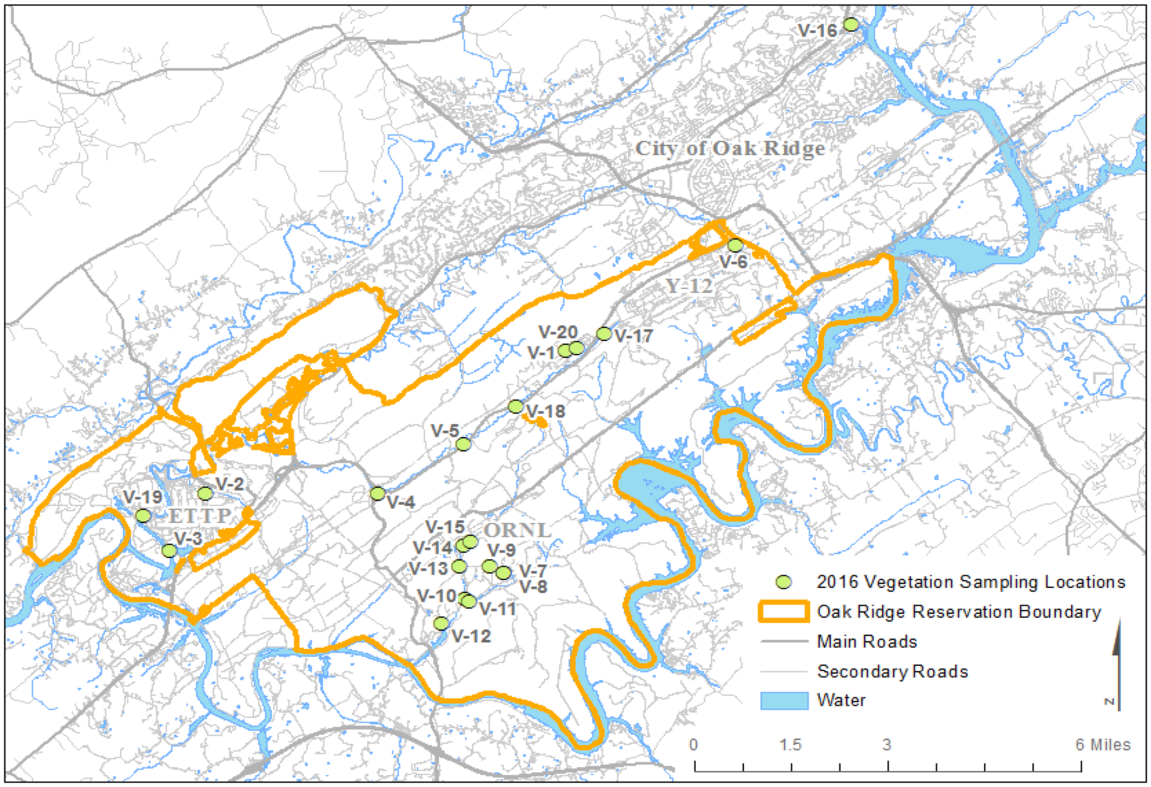


Figure 2.2.3.1: 2016 Vegetation Sampling Locations

Table 2.2.3.1: 2016 Vegetation Sampling Locations

Site	Location	Vegetation Type
V-1	EMWMF Underdrain	cattails
V-2	ETTP (K-25) - Mitchell Branch	mixed
V-3	K-1007 P-1 Pond West	cattails
V-4	Bear Creek - SS-8 Spring	cattails
V-5	Bear Creek - SS-6 Spring	mixed
V-6	East Fork Poplar Creek - New Hope	mixed
V-7	HFIR drainage A	cattails
V-8	HFIR drainage B	cattails
V-9	HRE wetland	cattails
V-10	White Oak Creek Weir - Melton Valley	cattails
V-11	Melton Branch Weir - Melton Valley	mixed
V-12	White Oak Lake wetland - Melton Valley	cattails
V-13	White Oak Creek @ Melton Valley Road	cattails
V-14	White Oak Creek - Bethel Valley 3rd Street	mixed
V-15	White Oak Creek - Bethel Valley, upstream	mixed
V-16	Offsite Background - Worthington Cemetery Trail	cattails
V-17	Y-12 - Bear Creek below S-2	cattails
V-18	Y-12 - Bear Creek below SS-5 Spring	watercress
V-19	ETTP (K-25) - Poplar Creek wetland	cattails
V-20	Y-12 - NT-3 Near Boneyard Burnyard (BYBY)	cattails

Results and Discussion

The Environmental Protection Agency (EPA) does not currently regulate radionuclide levels in vegetation. The U.S. Food and Drug Administration (FDA) has established guidelines called Derived Intervention Levels (DILs) to describe radionuclide concentrations at which the introduction to protective measures should be considered (FDA 1998, FDA 2005). These values are meant to be protective in the event a nuclear incident occurs and food is radioactively contaminated. They are specific to certain radionuclides and are not directly comparable to gross alpha, gross beta, and gamma activity, that were the analyses run on the vegetation samples for this project. A potentially more useful comparison is of the levels of alpha, beta, and gamma seen at a background location or other samples with low levels of radionuclide contamination. Generally, this is done by determining where results of more than twice the background levels are considered elevated, at least at environmental levels.

DoR-OR gathered 20 vegetation samples for radiological analysis during June 2016. One background sample was taken (V-16). Two samples (both cattails) were taken at HFIR at approximately the same sampling location (V-7 and V-8). A variety of samples were taken along White Oak Creek down to the wetland at the edge of White Oak Lake (V-15, V-14, V-13, V-10, V-12). Other samples were taken at locations thought to potentially contain elevated levels of radiological contamination that could be taken up by the nearby vegetation, or at sites with previously elevated results. Table 2.2.3.2 provides the results of the radiochemical analysis of the 20 vegetation samples collected in 2016.

Table 2.2.3.2: Results for Radiochemical Analysis of 2016 Vegetation Samples (pCi/g)

vegetation type	site	location	gross alpha	gross beta	gamma				
					Cs-137	K-40	Be-7	Bi-214	Others
cattails	V-9	HRE Wetland	5.40	151		3.43			
cattails	V-7	HFIR drainage A	3.33	8.6		6.09		0.135	Ac,Pb, Tl
mixed	V-6	East Fork Poplar Creek - New Hope	1.40	33.8		3.62			
cattails	V-8	HFIR drainage B	0.8	20.6		3.51			
cattails	V-13	White Oak Creek @ MV road	0.72	15.4					
cattails	V-10	White Oak Creek Weir- MV	0.54	9.9		2.91			
mixed	V-14	White Oak Creek Bethel Valley, 3rd St	0.45	4.8	4.96	5.14	1.08		
mixed	V-11	Melton Branch Weir- MV	0.45	4.7			0.60		
cattails	V-1	EMWMF Underdrain	0.44	4.6		4.44			
cattails	V-12	White Oak Lake wetland- MV	0.43	4.0		3.84			
mixed	V-15	White Oak Creek Bethel Valley, upstream	0.41	3.9			1.20		
cattails	V-17	Y-12 Bear Creek below S-2	0.41	3.8			0.32		
cattails	V-20	NT-3 Near Bone Yard Burn Yard (BYBY)	0.38	3.6		3.90	0.24	0.094	
mixed	V-2	ETTP Mitchell Branch	0.36	3.3		4.08			
mixed	V-5	Bear Creek SS-6 Spring	0.36	3.1		4.66	1.38		
cattails	V-3	K-1007 P-1 Pond west	0.24	2.4		3.50			
cattails	V-4	Bear Creek SS-8 Spring	0.23	2.3		3.70			
cattails	V-19	ETTP (K-25) Poplar Creek Wetland	0.22	1.8		3.77			
cattails	V-16	Offsite Background- Worthington Cemetery Trail	0.19	1.6		5.80			
watercress	V-18	Y-12 Bear Creek SS-5 Spring	0.16	1.3		1.67			
		2X BG:	0.38	3.2					

Bold# above sample specific detection limit

gray# less than sample specific detection limit

more than 2x background (if greater than detection limit)

The data have been arranged based on the levels of gross alpha, with the most elevated gross alpha results at the top of the table. The yellow and blue bars shown in Table 2.2.3.2 for gross alpha and gross beta, respectively, are to visually highlight which values are higher and which are lower; the longer the bar, the higher the result. The values representing two times those seen at the background location are shown at the bottom of the table for further comparison, but since they are not actual results, they are not compared using the blue and yellow bars. Values greater than twice background have a light yellow background to make them easier to identify in the tables that follow. Data shown in bold black type are results with values greater than the sample-specific detection limit for that analysis. Results shown in gray were less than the sample-specific detection limit for that analysis.

The data suggest limited areas of elevated radionuclide concentrations in the vegetation near surface water on the ORR. The highest levels of gross alpha and gross beta activity for the 2016 samples were from the sample collected at V-9. The V-9 sample was collected at the edge of the wetland area behind the old Homogeneous Reactor Experiment (HRE) site in ORNL's Melton Valley and had elevated gross alpha (5.40 pCi/g) and gross beta (151 pCi/g) levels. Samples have been collected at the HRE area since 2012, although not all of them have been the exact same location or media. The HRE area has yielded the highest gross beta result each year it has been sampled. In Table 2.2.3.3, the highest gross alpha and gross beta values for HRE are listed for 2012 through 2016. Gross alpha levels were similar for all years except 2016, where it was higher. The highest levels of gross beta seen at HRE were from the 2012, 2013, and 2016 samples.

Table 2.2.3.3: Highest Gross Beta Analyses at HRE Wetland 2012-2016

Station	Year	Gross Alpha	Gross Beta	Units
HRE Wetland	2012	2.5	189	pCi/g
HRE Wetland	2013	3.2	213	pCi/g
HRE Wetland	2014	3	53.9	pCi/g
HRE Wetland	2015	2	69.1	pCi/g
HRE Wetland	2016	5.4	151	pCi/g

HRE – Homogeneous Reactor Experiment
pCi/g – picoCuries per gram

The V-7 and V-8 samples were collected from a roadside wetland with cattails downhill from the HFIR experiment buildings. It was sampled in 2016 as it had shown elevated gross beta levels in 2014 and 2015 (Table 2.2.3.4). In 2016, two samples of vegetation, both cattails, were taken at HFIR in approximately the same area in 2016. The V-7 sample had elevated gross alpha (3.33 pCi/g) and gross beta (8.6 pCi/g) levels. The V-7 HFIR sample also showed gamma radionuclides not seen at the background location, including 0.093 pCi/g of Tl-208 (thallium), 0.224 pCi/g of Pb-212 (lead), 0.135 pCi/g of Bi-214 (bismuth), and 0.297 pCi/g of Ac-228 (actinium). The V-8 sample was taken at nearly the same location and showed 0.8 pCi/g of gross alpha and elevated gross beta (20.6 pCi/g). While one might have expected the two samples to show more similar levels, there is a lot of variability in vegetation sampling and some variation due to the nature of radionuclides and their analyses. In addition, while both samples did consist of cattails, different cattails were collected for each sample, each with varying size and proximity to the presumed source of contamination. The V-7 sample, with the suite of gamma radionuclides detected, ended up being a larger sample by weight, though both samples filled the same size bag. Having a larger sample makes it easier to detect small levels of contaminants, which is likely why that particular sample showed more gamma radionuclides when analyzed.

Table 2.2.3.4: HFIR Sampling Results 2014-2016

Station	Year	Gross Alpha	Gross Beta	Sr-90	Units
HFIR	2014	0.4	6.3	-	pCi/g wet weight
HFIR	2015	0.7	29.8	10.3	pCi/g wet weight
HFIR-A	2016	3.33	8.6	-	pCi/g wet weight
HFIR-B	2016	0.8	20.6	-	pCi/g wet weight

HFIR - High Flux Isotope Reactor
pCi/g – picoCuries per gram

The second highest gross beta value (33.8 pCi/g) and the only other gross alpha value more than twice background (1.40 pCi/g) was seen from a vegetation sample collected on East Fork Poplar Creek, behind the Y-12 New Hope Center. This location was a new sampling location. Many of the other locations with elevated gross beta were collected along WOC at ORNL. The highest of these was at a location near where Melton Valley Road crosses the creek (gross beta 15.4 pCi/g) and at the WOC Weir, in Melton Valley (gross beta 9.9 pCi/g). Other samples taken along WOC (V-14, V-11, V-12, V-15) all had gross beta results greater than twice background as did the sample from below the Melton Branch weir (V-11). WOC and Melton Branch have radiological contamination. The V-14 sample collected along WOC at the Third Street bridge (gross beta 4.8 pCi/g) was the only sample to show Cs-137 (4.96 pCi/g) in 2016.

The other sites with gross beta levels greater than two times background were stations V-1, V-17, V-20, and V-2 (Table 2.2.3.1 and 2.2.3.2). Three of these locations are in Bear Creek Valley and one at ETTP. The V-1 sample was from the underdrain at EMWMF in Bear Creek Valley (gross beta 4.6 pCi/g). The sample from V-17 was from Y-12, along Bear Creek near the S-2 site (gross beta 3.8 pCi/g). The V-20 sample (gross beta 3.6 pCi/g) was taken along the stream NT-3 near the Bone Yard Burn Yard, an area known to have contamination. The lowest vegetation sampling result with a level greater than twice gross beta background was from the ETTP site along Mitchell Branch (3.3 pCi/g). Areas with both gross alpha and gross beta results less than twice background for 2016 (Table 2.2.3.1) include the SS-6 spring in Bear Creek Valley (V-5), the K-1007 P-1 Pond at ETTP (V-3), the SS-8 spring (V-4), a wetland along Poplar Creek at ETTP (V-19), and the SS-5 spring (V-18).

Conclusions

The data from the samples collected in 2016 for the radiological contaminant uptake in vegetation project suggest limited areas of elevated radionuclide concentrations in the vegetation associated with surface water on the ORR. Areas with elevated sampling results will likely continue to be monitored by this program. Areas with elevated results may indicate locations where further sampling and potential remediation efforts may be warranted.

2.2.4 Benthic Macroinvertebrates

Introduction

Benthic macroinvertebrates include insects, crustaceans, annelids, mollusks, and other organisms with long aquatic life cycles (multiple stages of larval instars: typically requiring one or more years for egg to adult generation) that inhabit the bottom substrates of aquatic systems and can be easily collected using aquatic sampling nets of ≤500 μm (Hauer and Resh 1996). Occupying the primary consumer trophic level in aquatic ecosystems, macroinvertebrates serve as a link between producers (e.g., algae) and decomposers (e.g., microorganisms) in a food chain, provide a major food source for fisheries, and maintain a diverse spectrum in species composition (Song 2007). Because they are ubiquitous, sedentary, and sensitive in varying degrees to anthropogenic pollutants and other stressors, macroinvertebrate communities can provide considerable information regarding the biological condition of water bodies (Davis and Simons 1995, Karr and Chu 1998). Aquatic macroinvertebrate assemblages provide a surrogate measure of water chemistry and physical stream conditions (Cummins 1974, Vannote et al. 1980, Rosenberg and Resh 1993, Weigel et al. 2002) to indicate the overall health of the aquatic system (Meyer 1997, Karr 1999).

Introduction of nutrients (organic pollution) and heavy metals into a stream, dilution by tributaries, uptake of contaminants by aquatic organisms, and changes in stream structure/function create a pollution gradient from upstream to downstream, superimposed on the natural longitudinal gradient of the stream (Vannote et al. 1980, Clements 1994, Clements and Kiffney 1995, Medley and Clements 1998). Anthropogenic impacts inducing eutrophication (organic pollution) in aquatic systems are known to have dramatic effects on stream invertebrates (Hynes 1978; Wiederholm 1984; Rosenberg and Resh 1993; Suren 2000). Thus, nutrient enrichment can decrease species richness (Paul and Meyer 2001) by the elimination of sensitive taxa, most often represented by the insect orders *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT); mayflies, stoneflies, caddisflies, Lenat 1983). A healthy stream will have a larger number (higher EPT) of the sensitive taxa, whereas streams impacted by pollution will have a lower EPT due to the presence of fewer sensitive taxa. Simultaneously, taxa considered resistant to pollution and adapted to unstable habitats, such as midges (chironomids) and worms (oligochaetes), are enhanced (Hynes 1978).

In streams where metal concentrations are sufficiently high, benthic macroinvertebrates may be entirely absent or their abundance greatly reduced (Clements 1991). Where metals and organic pollutants do not entirely eliminate the community, however, measures of taxa richness (e.g., total number of species present) or abundance of metals-sensitive taxa provide the most sensitive and reliable measures of community level effects (Barbour et al. 1992, Clements and Kiffney 1995, Kiffney 1996, Carlisle and Clements 1999). Many mayfly species are sensitive to metals contamination (Warnick and Bell 1969) and a reduction in the number of mayfly species present is an effective and reliable measure of metals impacts on benthic macroinvertebrate communities (Ramusino et al. 1981, Specht et al. 1984, Van Hassel and Gaulke 1986, Clements 1991, Clements et al. 1992, Kiffney and Clements 1994). For example, heptageniids (flatheaded mayflies) are highly sensitive to heavy metals and are usually absent in metal-polluted streams (Clements 1994, Clements and Kiffney 1995). Macroinvertebrate biomonitoring is a proven method of assessing and documenting stressors and any community and population changes that may occur within the impacted ecosystem.

Semi-quantitative kick net samples (SQKICK) provide a snapshot of the benthic community population at a particular stream location and the respective taxonomic identifications and taxa counts present at this site to calculate the Tennessee Macroinvertebrate Index (TMI) (TDEC 2011). Several quantifiable attributes of the biotic assemblage (metrics) that assess macroinvertebrate assemblage structure, composition, and function comprise these indices (Hilsenhoff 1982, 1987, 1988, Fore et al. 1996, Karr and Chu 1998). These metrics are used to measure and calculate an overall score to represent the ecological condition and integrity of stream health. This multimetric index approach is effective for evaluating anthropogenic disturbance and pollution, for standardizing assessment, and for communicating the biotic condition of streams (Barbour et al. 1999), because susceptibility to toxic agents varies with the response of individual genera and species (Resh et al. 1988, 1996). Historically, four aquatic systems originating on the ORR (East Fork Poplar Creek, Bear Creek, Mitchell Branch, and the White Oak Creek/Melton Branch watershed) have been impacted by DOE-related activities. EFPC and BCK have received inputs from Y-12, MB from ETTP, and the WOC/Melton Branch watershed from ORNL. Contaminant releases to surface water and groundwater vary among industrial sites, but generally include organic pollutants, heavy metals, and radionuclides.

Benthic macroinvertebrate samples were collected from various locations on these streams for semi-quantitative analysis. Surface water samples were collected at the sites and analyzed for various constituents in support of the biomonitoring. Parameters analyzed included nutrients, mercury, metals, hardness, residue, and radiological constituents. The objectives of this study were to quantify benthic macroinvertebrate communities and to assess the degree of impact compared to reference conditions.

Methods and Materials

Benthic macroinvertebrate communities were semi-quantitatively sampled (i.e., kick sampled, "SQKICK") between May 9, 2016 and June 14, 2016 using the current US EPA, USGS, and TDEC, Division of Water Pollution Control SOPs for macroinvertebrates (Barbour et al. 1999, Moulton et al. 2000, TDEC 2006, 2011). Fourteen stream stations sampled during 2016 on the ORR from the four main watersheds (EFPC, BCK, MIK, and WOC). Melton Branch (MEK) is a tributary to WOC. Six other reference streams were sampled Table 2.2.4.1 depicts the Oak Ridge Reservation Benthic Monitoring Sites.

Figures 2.2.4.1-2.2.4.5 provide aerial views of 2016 benthic site locations:

- Figure 2.2.4.1: ORNL (White Oak Creek/Melton Branch)
- Figure 2.2.4.2: Upper East Fork Poplar Creek
- Figure 2.2.4.3: Hinds Creek and Clear Creek reference streams
- Figure 2.2.4.4: Bear Creek, Mill Branch, Gum Hollow Branch, and Lower East Fork Poplar Creek
- Figure 2.2.4.5: Bear Creek: Mill Branch, Gum Hollow Branch and Lower EFPC

Table 2.2.4.1: Oak Ridge Reservation Benthic Monitoring Sites

Station	Description	Cover	TDEC DWR Designation
EFK 25.1	East Fork Poplar Creek km 25.1	thin canopy	EFPOP015.6AN
EFK 24.4	East Fork Poplar Creek km 24.4	canopy	EFPOP015.2AN
EFK 23.4	East Fork Poplar Creek km 23.4	open	EFPOP014.5AN
EFK 13.8	East Fork Poplar Creek km 13.8	open	EFPOP008.6AN
EFK 6.3	East Fork Poplar Creek km 6.3	canopy	EFPOP003.9RO
HCK 20.6	Hinds Creek km 20.6 Reference	canopy	HINDS012.8AN
CCK 1.45	Clear Creek km 1.45 Reference	thin canopy	ECO67F06
GHK 2.9	Gum Hollow Branch km 2.9 Reference	canopy	GHOLL001.8RO
MIK 1.43	Mitchell Branch km 1.43 Reference	canopy	MITCH000.9RO
MIK 0.71	Mitchell Branch km 0.71	open	MITCH000.4RO
MIK 0.45	Mitchell Branch km 0.45	thin canopy	MITCH000.3RO
BCK 12.3	Bear Creek km 12.3	canopy	BEAR007.6AN
BCK 9.6	Bear Creek km 9.6	canopy	BEAR006.0AN
BCK 3.3	Bear Creek km 3.3	canopy	BEAR002.0RO
MBK 1.6	Mill Branch km 1.6 Reference	canopy	FECO67I12
WCK 6.8	White Oak Creek km 6.8 Reference	thin canopy	WHITE004.2RO
WCK 3.9	White Oak Creek km 3.9	thin canopy	WHITE002.4RO
WCK 3.4	White Oak Creek km 3.4	canopy	WHITE002.1RO
WCK 2.3	White Oak Creek km 2.3	canopy	WHITE001.4RO
MEK 0.3	Melton Branch km 0.3	thin canopy	MELTO000.2RO

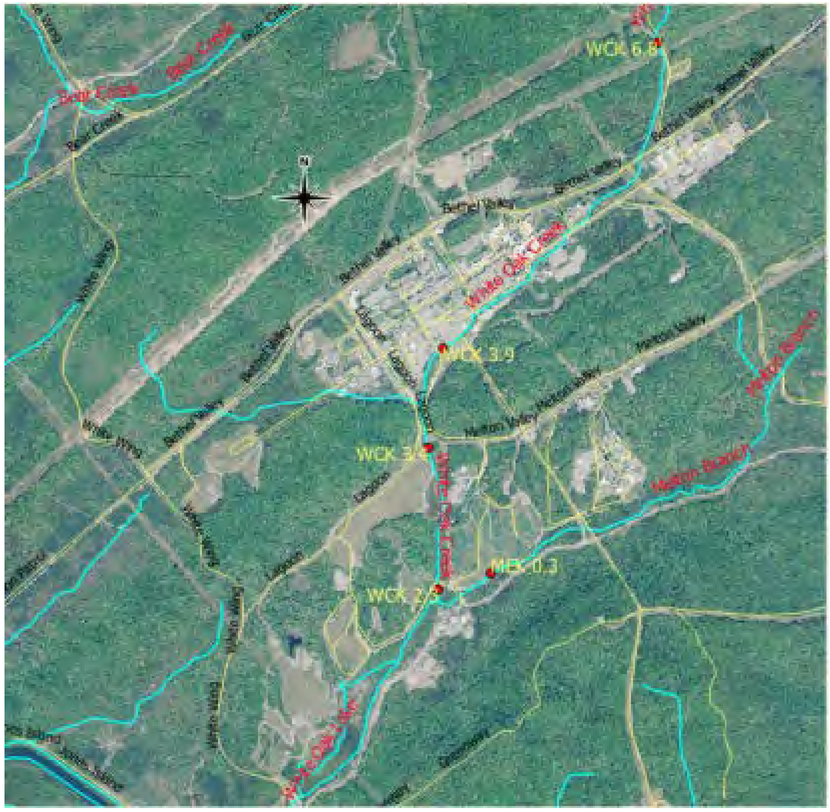


Figure 2.2.4.1: 2016 Benthic Sites at ORNL (White Oak Creek/Melton Branch)

Figure 2.2.4.2: 2016 Benthic Sites at Upper East Fork Poplar Creek

Figure 2.2.4.3: 2016 Benthic Sites at the Hinds Creek and Clear Creek Reference Streams

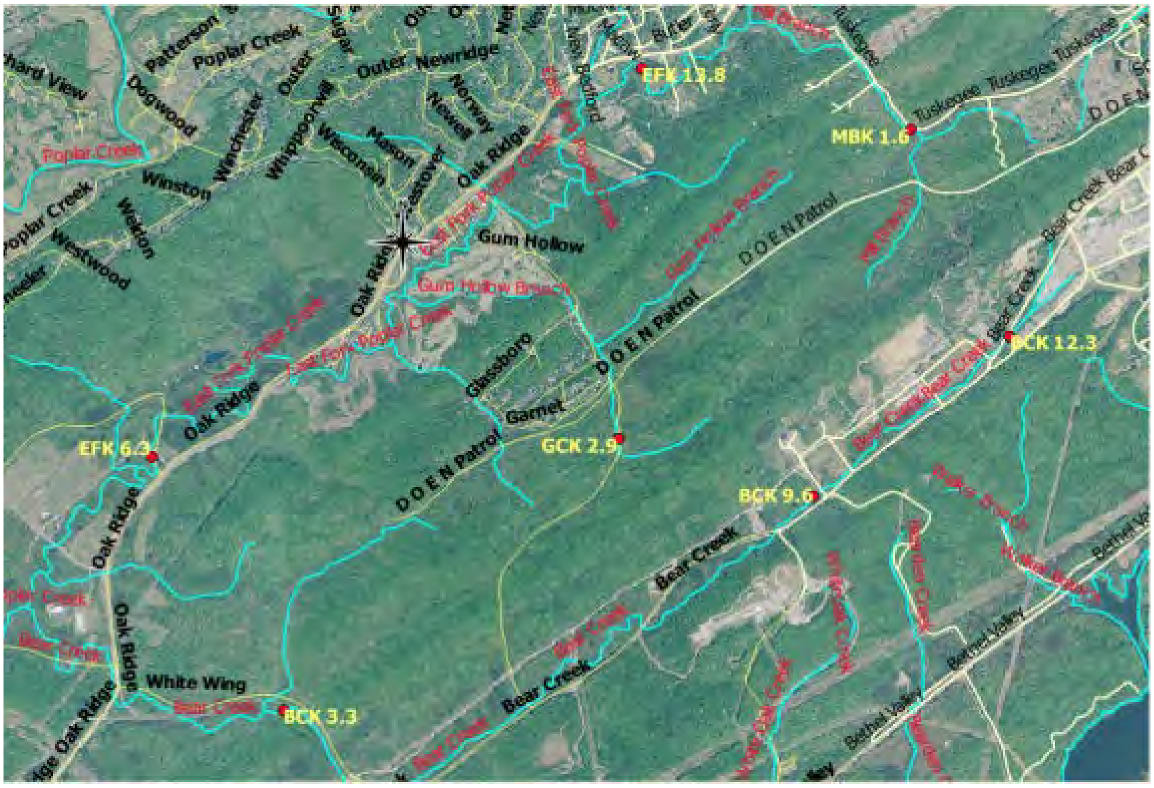


Figure 2.2.4.4: 2016 Benthic Sites at Bear Creek, Mill Branch, Gum Hollow Branch, and Lower East Fork Poplar Creek

Figure 2.2.4.5: 2016 Benthic Sites at Bear Creek, Mill Branch, Gum Hollow Branch, and Lower East Fork Poplar Creek

Benthic organisms (typically larvae) were collected at each site by combining samples from two similar riffles using a one-square meter kick net (Figures 2.2.4.6 through 2.2.4.8 depict sample collection, rinsing, and cleansing.).

- Figure 2.2.4.6 is a photograph of kick sampling
- Figure 2.2.4.7 is photograph of rinsing collected organisms from net
- Figure 2.2.4.8 is a photograph of removing residual organisms from net after rinsing

At all sites, with the exception of contaminated sites on White Oak Creek (WCK 3.9, WCK 3.4, WCK 2.3) and Melton Branch (MEK 0.3), samples were transferred into labeled sample jars as a composite sample. Benthic macroinvertebrate samples were preserved in 95% ethanol with internal and external site-specific labels. Labeling information included site name, sampling date, and samplers' initials. If more than one sample container was needed at a site, the debris was split evenly with internal and external labels completed for each container. In the case of WCK 3.9, WCK 3.4, WCK 2.3, and MEK 0.3, all samples were laboratory processed in the field to avoid bringing any contaminated sediment back to the DoR-OR lab.

Surface water samples were collected from each 2016 benthic sampling location. Laboratory results are presented in Section 3.1. Personnel safety while conducting field and laboratory work followed the guidelines of the DoR-OR Life Safety Plan (TDEC 2017).

Figure 2.2.4.6: Example of Kick Sampling

Figure 2.2.4.7: Rinsing Collected Organisms from Net

Figure 2.2.4.8: Removing Residual Organisms from Net After Rinsing

Due to the potential for radioactive contamination associated with the lower White Oak Creek / Melton Branch sediment (WCK 3.9, WCK 3.4, WCK 2.3, MEK 0.3), benthic samples were picked and sorted in the field. Benthic material was separated from the detritus for the entire sample. The picked organisms were then transferred to sealable plastic vials, labeled, and preserved in 95% ethanol. The remaining benthic samples (BCK, EFPK, MIK, and reference stations) were stored and later processed following sub-sampling procedures (picking and sorting) at the DoR-OR laboratory.

In the laboratory, samples were picked and benthic macroinvertebrates were enumerated and microscopically identified (by certified DoR-OR taxonomist in-house) to the genus and species (where possible) level, thus, producing raw taxonomic data for each stream station. TDEC Division of Water Pollution Control Rev 5 of the Macroinvertebrate SOP (TDEC 2011) was used to calculate the metrics and interpret the results. Macroinvertebrate larvae were identified using various taxonomic keys (Edmunds et al. 1976; Simpson and Bode 1980; Brigham et al. 1982; Oliver and Roussel 1983; Stewart and Stark 1988; McAlpine et al. 1981, 1987; Pennak 1989; Wiggins 1996; Needham et al. 2000; Epler 2001, 2006, 2010; Gelhaus 2002; Westfall and May 2006; Merritt et al. 2008; Pfeiffer et al. 2008).

Biological metrics were calculated from the raw data to develop an overall site-assessment rating. Eight calculated metrics included taxa richness, EPT richness [*Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies)], % EPT-*Cheumatopsyche* (% EPT-Cheum), % OC (oligochaetes and chironomids), NCBI (North Carolina Biotic Index), % clingers, % nutrient tolerant organisms (%TNUTOL) and intolerant taxa [Hilsenhoff 1982, 1987, 1988, Kentucky Department of Wildlife (KDOW) 2009, TDEC 2006, 2011]. The EPTs are pollution-sensitive to environmental contamination and the OCs are pollution-tolerant. The biometrics used to generate stream ratings and the expected response of each metric to stress introduced to the system are given in Table 2.2.4.2.

Table 2.2.4.2: Description of Metrics and Expected Responses to Stressors

Category	Metric	Description	Response to Stress
Richness Metrics	Taxa Richness	Measures the overall variety of the macroinvertebrate assemblage	Number decreases
	EPT Richness	Number of taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)	Number decreases
	Intolerant Taxa	Number of taxa in sample that display a tolerance rating of <3.0	Number decreases
Composition Metrics	% EPT-Cheum	% of EPT abundance excluding Cheumatopsyche taxa	% decreases
	% OC	% of oligochaetes (worms) and chironomids (midges) present in sample	% increases
Tolerance Metrics	NCBI	North Carolina Biotic Index which incorporates richness and abundance with a numerical rating of tolerance	Number increases
	% Total Nutrient Tolerant (%TNUTOL)	% of organisms present in sample that are considered tolerant of nutrients	% increases
Habit Metric	% Clingers	% of macroinvertebrates present in sample w/ fixed retreats or attach themselves to substrates	% decreases

Because some of the streams being monitored on the ORR did not meet the conditions necessary for comparison of results to bioregion biocriteria, an alternative reference stream method cited in the 2011 Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys (TDEC 2011) (with some modifications) was used to evaluate the study's results. The primary condition not met was that certain streams in the study were headwater streams (< 2 square miles of drainage area). The description of the alternative reference stream method is provided in Section 1.I, Protocol K: Pages 3 and 4 of the Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys (TDEC 2011).

In order to generate a table of values for comparison of reference stations to potentially impacted stream stations, eight metrics were first calculated for all of the reference stations (CCK 1.45, GHK 2.9, HCK 20.6, MBK 1.6, MIK 1.43, and WCK 6.8). Based on the average value of each metric and using the calculations provided in Section 1.I, Protocol K: Pages 3 and 4 of the Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys (TDEC 2011), ranges of values for ratings of 6, 4, 2, and 0 for each metric were further determined. Because this report compares the data obtained for 2015 vs. 2016, separate alternate reference stream tables were generated for each year. The results of these calculations are found in Tables 2.2.4.3 and Table 2.2.4.4.

Table 2.2.4.3: Alternative Reference Stream Metrics 2016

Alternative Reference Steam Metrics				
Metric	**6**	**4**	**2**	**0**
Taxa Richness	>50	38-49	29-37	< 29
EPT Richness	>18	14-17	11-13	<11
% EPT- Cheum	>33.44	25.08-33.43	18.81-25.07	<18.81
% OC	≤54.2	54.3-65.5	65.6-74.5	>74.5
NCBI	<4.97	4.98-6.23	6.24-7.17	>7.17
% Clingers	>29.47	22.10-29.46	16.57-22.09	<16.57
% TNutol	<38.41	38.42-53.81	53.82-65.35	>65.35
% Intolerant Taxa	>15	11-14	8-10	<8

Table 2.2.4.4: Alternative Reference Stream Metrics 2015

Alternative Reference Steam Metrics				
Metric	**6**	**4**	**2**	**0**
Taxa Richness	> 43	32-42	24-31	<24
EPT Richness	>16	12-15	9-11	<9
% EPT- Cheum	>32.5	24.4-32.5	18.3-24.3	<18.3
% OC	<40.7	40.8-55.8	55.9-67	>67
NCBI	<5.16	5.17-6.4	6.5-7.3	>7.3
% Clingers	>31.1	23.3-31.0	17.5-23.2	<17.5
% TNutol	<42.7	42.8-57.0	57.1-67.8	>67.8
% Intolerant Taxa	>13	10-12	7-9	<7

Because some of the streams and stations in the study did not meet the bioregion comparison criteria, some modifications were made to procedures in order to differentiate among the benthic communities in the streams. Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys (TDEC 2011) requires identification of taxa to only the genus-level. Taking certain taxa to the species level, where possible, allows for a clearer picture of the health of a site to be developed. Certain genera of mayflies (*Ephemeroptera*) may have more than one species occurring at a sample site. This is particularly true of the genera Baetis and Maccaffertium. Reference sites may contain as many as five species in these combined genera, whereas an impacted site may only have two of these species, if any. Because of this difference, the numbers generated for EPT taxa richness and total taxa richness could vary (increase) when using species level identification versus genus-level identification. Species-level identification could also be important in other genera including the caddisflies Pycnopsyche and Neophylax. Calculations of all metrics for this study were determined using the species-level identifications.

Results and Discussion

Semi-quantitative Assessments (SQKICK Sample Results)

East Fork Poplar Creek

Benthic laboratory results, i.e., metric values, metric scores, overall TMI scores (alternative reference stream method), and biological condition ratings are presented in Table 2.2.4.5 for the EFPC watershed. For monitoring purposes, the watershed is herein considered the upper EFPC (UEFPC) with three sampling stations within Y-12, (EFK 25.1, EFK 24.4, EFK 23.4) and lower EFPC (LEFPC) with two sampling stations (EFK 13.8, EFK 6.3) (Figures 2.2.4.2 and 2.2.4.4). The stream numbers represent distances in kilometers that decrease from headwaters (EFK 25.1) toward the mouth downstream (EFK 0.0). The reference streams for the EFPC watershed include Hinds Creek (HCK 20.6) and Clear Creek (CCK 1.45). Generally, stream biotic integrity in EFPC appeared to be slightly better in the LEFPC than in UEFPC.

The East Fork Poplar Creek is one of the streams on the ORR where impacts occur from the headwaters of the stream to a considerable distance downstream in the watershed. The headwaters of the stream originate from tributaries that flow through storm water conduits in the main industrialized portion of Y-12. Downstream, the stream flows through urbanized and suburbanized sections of Oak Ridge before flowing through less developed areas prior to its confluence with Poplar Creek. Near its origin, EFPC receives inputs of contaminants such as mercury, uranium, volatile organic compounds (VOCs), and other metals and organics. Once leaving the Y-12 boundary, EFPC receives further contaminant loading from urban and suburban runoff as well as discharges from a sewage treatment plant. Only near its mouth, does East Fork Poplar Creek flow through relatively undisturbed terrain. During 2015 and 2016, no flow augmentation from the Clinch River was provided in EFPC. Flows in the creek were reduced from years prior to 2015 due to lack of this augmentation. Metrics from 2015 and 2016 benthic sampling are compared to see if there are any changes (negative or positive) that can possibly be related to the halting of flow augmentation in 2014.

In order to determine the condition of the sampling stations in East Fork Poplar Creek, the following series of nine graphs for the years 2015 and 2016 are provided (Figures 2.2.4.9 through 2.2.4.17):

- Figure 2.2.4.9: Total Scores EFPC 2015 vs 2016
- Figure 2.2.4.10: Taxa Richness EFPC
- Figure 2.2.4.11: EPT Richness EFPC
- Figure 2.2.4.12: % EPT-Cheum EFPC
- Figure 2.2.4.13: % OC EFPC
- Figure 2.2.4.14: NCBI at EFPC
- Figure 2.2.4.15: % Clingers EFPC
- Figure 2.2.4.16: % TNUTOL EFPC
- Figure 2.2.4.17: Intolerant Taxa EFPC

Table 2.2.4.2 depicts these metrics. For the impacted stations in East Fork Poplar Creek, values are in Table 2.2.4.5. For reference stations, values are in Table 2.2.4.6. Their discussions follow the figures below.

Table 2.2.4.5: Metric Values, Scores, and Biological Condition Ratings for East Fork Poplar Creek

2016 RESULTS	EAST FORK POPLAR CREEK									
Stream station	EFK 25.1		EFK 24.4		EFK 23.4		EFK 13.8		EFK 6.3	
METRIC	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
Taxa Richness	27	0	36	2	47	4	52	6	59	6
EPT Richness	3	0	3	0	6	0	11	2	12	2
% EPT-Cheum	0.49	0	3.84	0	5.67	0	34.37	6	8.79	0
% OC	72.78	2	63.07	6	70.09	2	35.92	6	52.36	6
NCBI	5.27	4	5.55	4	5.67	4	4.89	6	5.35	4
% Clingers	78.65	6	56.35	4	52.65	6	47.49	6	60.68	6
%TNUTOL	77.18	0	54.20	2	45.67	4	23.52	6	24.40	6
Intolerant Taxa	0		1		1		6		6	
INDEX SCORE (Tenn. Macro. Index)		12		18		20		38		30
RATING		C		C		C		A		B

TMI = Tennessee Macroinvertebrate Index

A = Supporting / Non Impaired (Tenn. Macro. Index Scores ≥32)

B = Partially Supporting / Slightly Impaired (TMI Scores 21-31)

C = Partially Supporting / Moderately Impaired (TMI Scores 10-20)

D = Non Supporting / Severely Impaired (TMI Scores <10)

Table 2.2.4.6: Metric Values, Scores, and Biological Condition Ratings for Reference Stations

2016 RESULTS	Benthic Macroinvertebrate Reference Stations															
Stream station	CCK 1.45		CCK 1.45 DUP		HCK 20.6		MIK 1.43		GHK 2.9		MBK 1.6		MBK 1.6 DUP		WCK 6.8	
METRIC	VAL	SCR	VAL	SCR	VAL	SCR	VAL	SCR	VAL	SCR	VAL	SCR	VAL	SCR	VAL	SCR
Taxa Richness	50	6	61	6	66	6	61	6	79	6	69	6	76	6	71	6
EPT Richness	23	6	26	6	28	6	15	4	25	6	26	6	27	6	25	6
% EPT-Cheum	47.88	6	34.31	6	53.62	6	20.2	2	45.89	6	48.15	6	54.6	6	52.04	6
% OC	7.01	6	13.38	6	16.71	6	64.98	4	35.48	6	8.71	6	18.66	6	26.61	6
NCBI	2.39	6	2.61	6	4.63	6	4.62	6	3.12	6	3.03	6	2.83	6	3.16	6
% Clingers	40.66	6	52.3	6	44.85	6	13.55	0	24.3	4	63.26	6	42.11	6	33.35	6
%TNUTOL	9.87	6	4.99	6	29.25	6	48.5	4	17.24	6	19.13	6	5.01	6	9	6
Intolerant Taxa	20	0	20	0	17	0	20	0	20	0	19	0	21	0	18	0
INDEX SCORE (Tenn. Macro. Index)		42		42		42		26		40		42		42		42
RATING		A		A		A		B		A		A		A		A

TMI = Tennessee

A = Supporting / Non Impaired (Tenn. Macro. Index Scores ≥32)

B = Partially Supporting / Slightly Impaired (TMI Scores 21-31)

C = Partially Supporting / Moderately Impaired (TMI Scores 10-20)

D = Non Supporting / Severely Impaired (TMI Scores <10)

DUP = duplicate

SCR = score

VAL = value

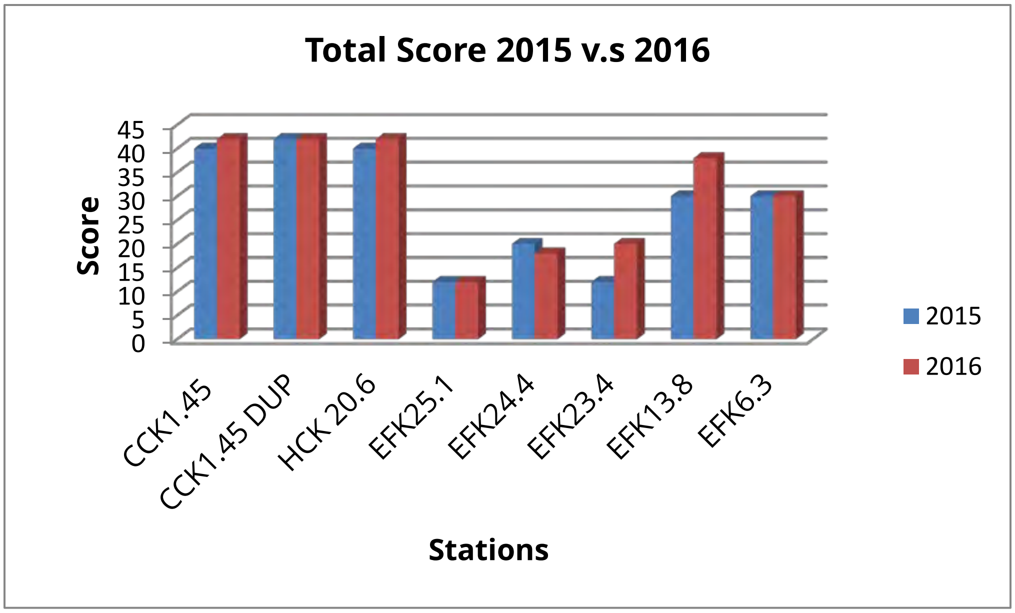


Figure 2.2.4.9: Total Scores East Fork Poplar Creek 2015 vs. 2016

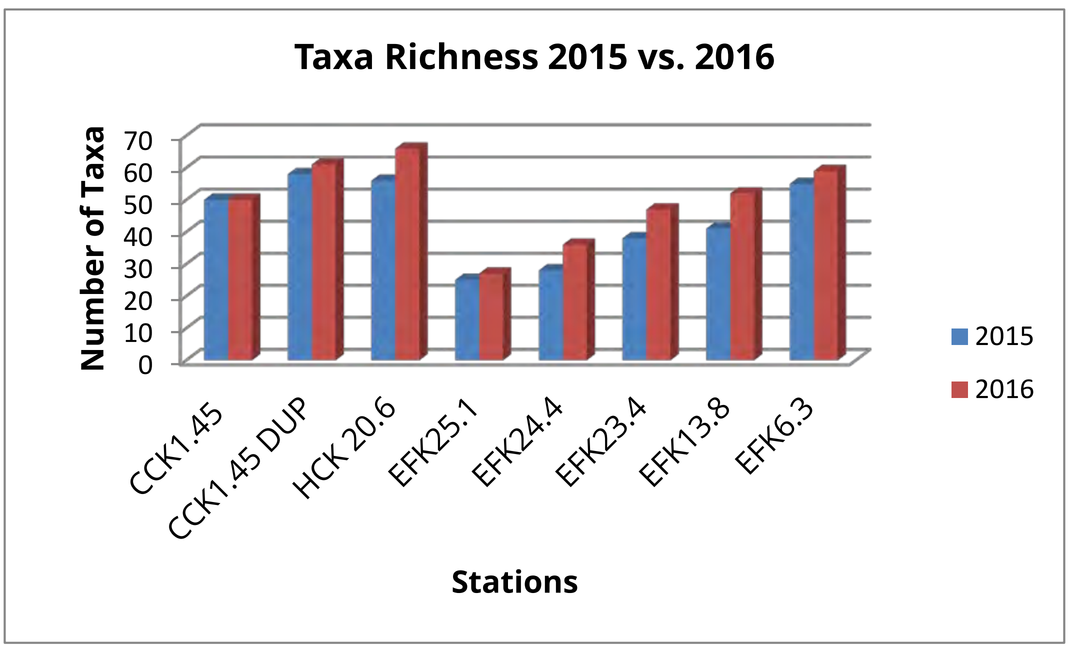


Figure 2.2.4.10: Taxa Richness East Fork Poplar Creek

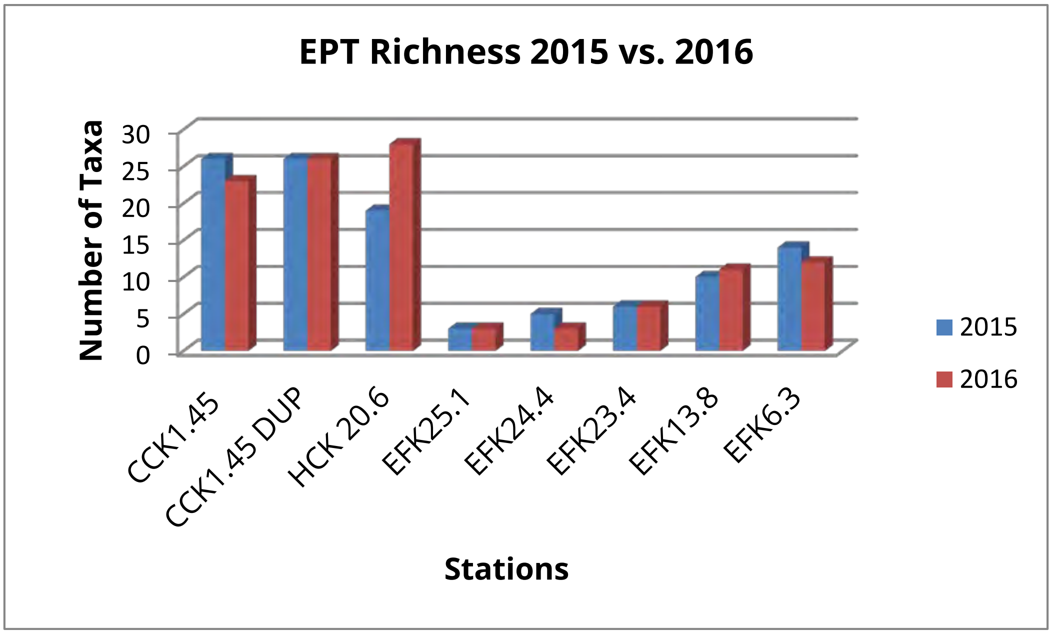


Figure 2.2.4.11: EPT Richness East Fork Poplar Creek

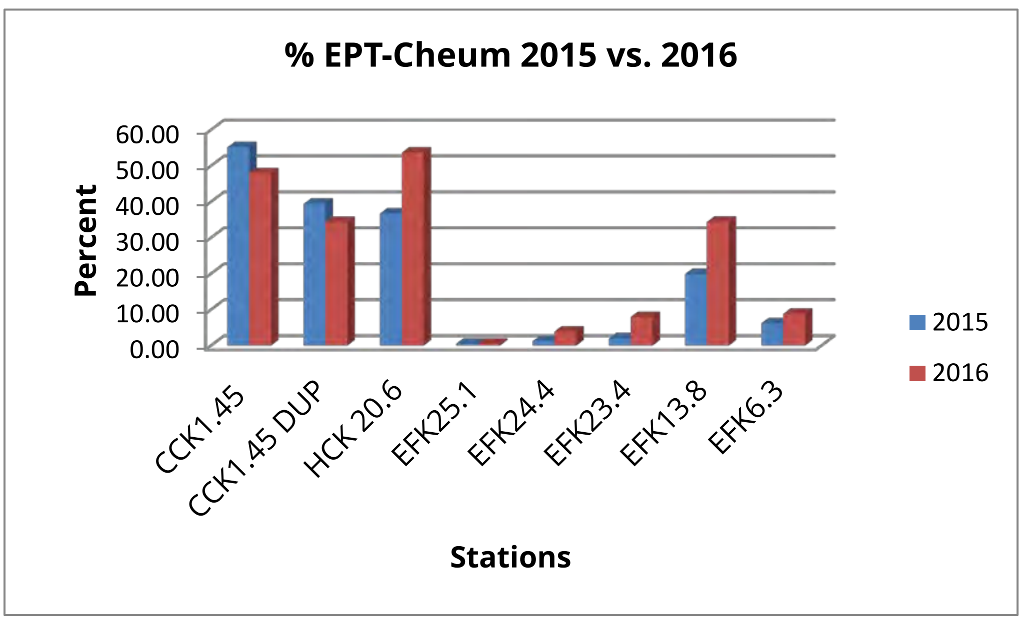


Figure 2.2.4.12: % EPT-Cheum East Fork Poplar Creek

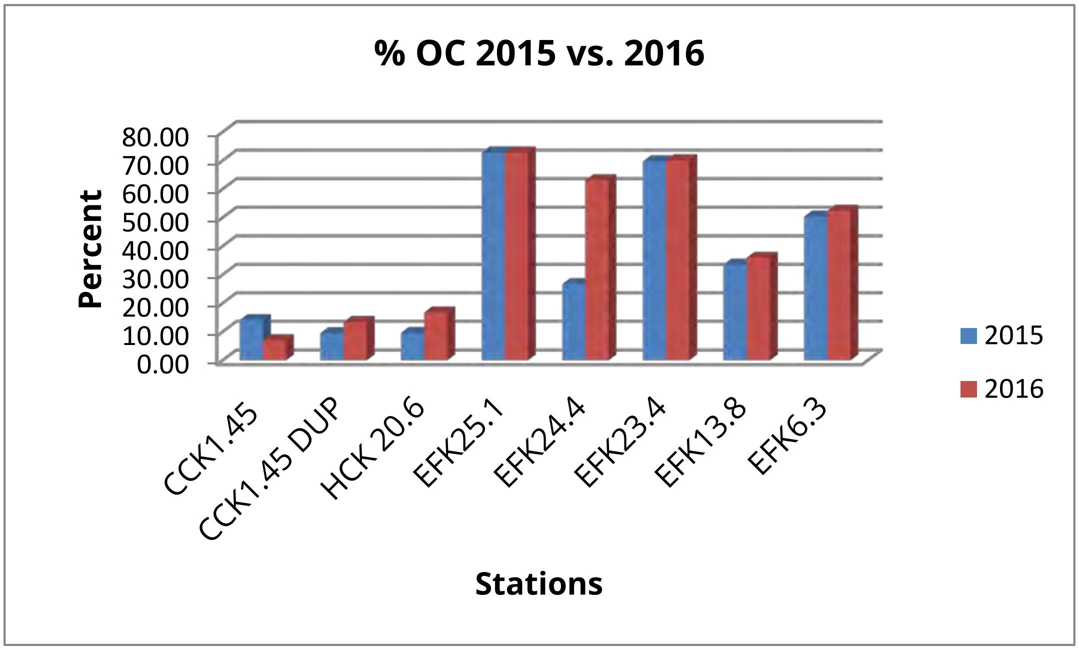


Figure 2.2.4.13: % OC East Fork Poplar Creek

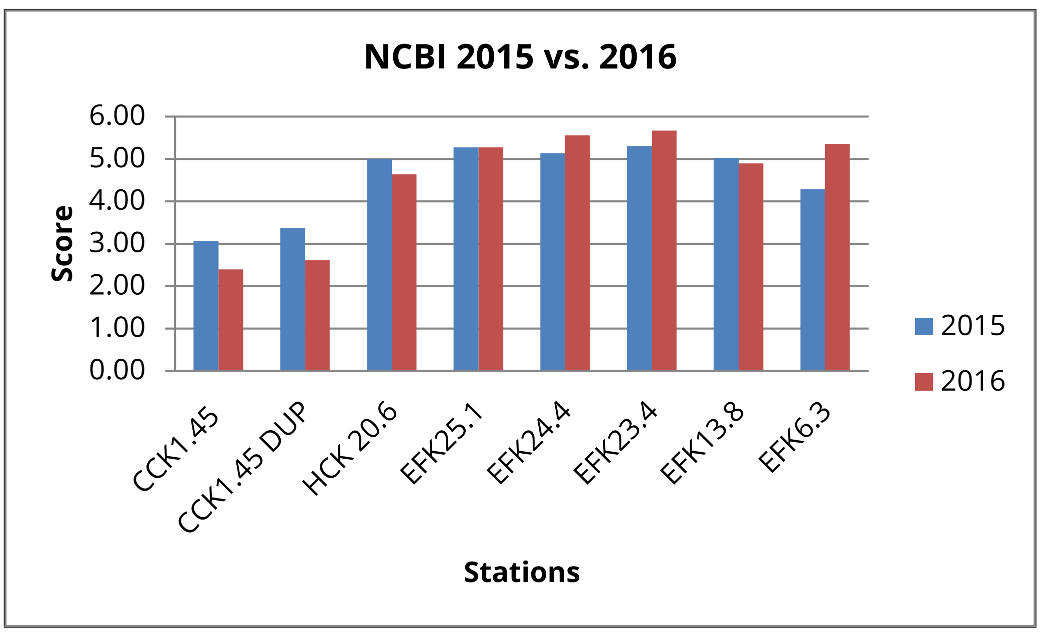


Figure 2.2.4.14: NCBI East Fork Poplar Creek

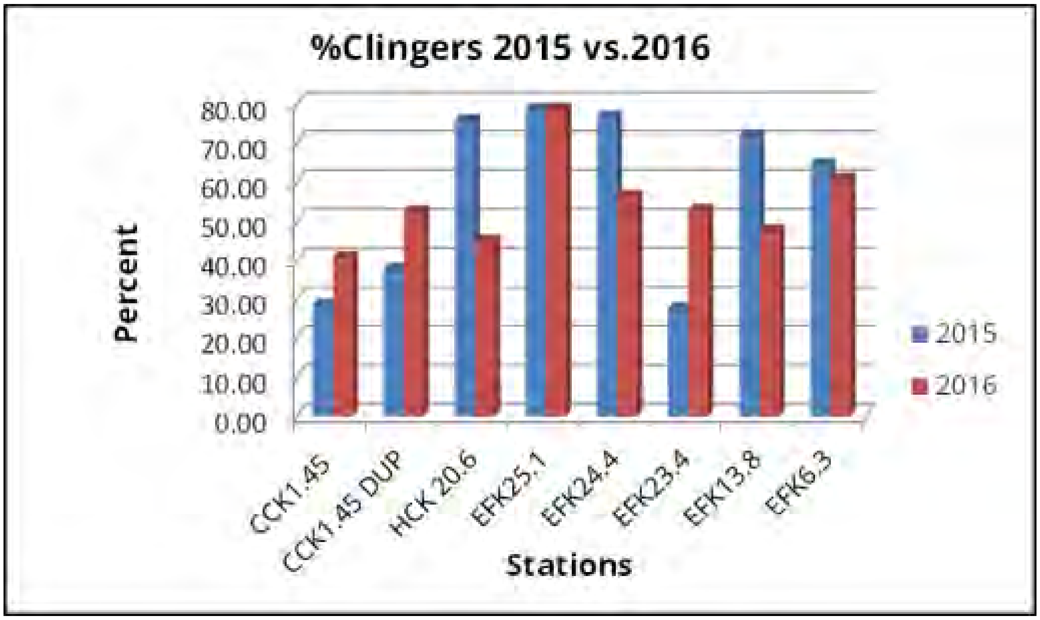


Figure 2.2.4.15: % Clingers East Fork Poplar Creek

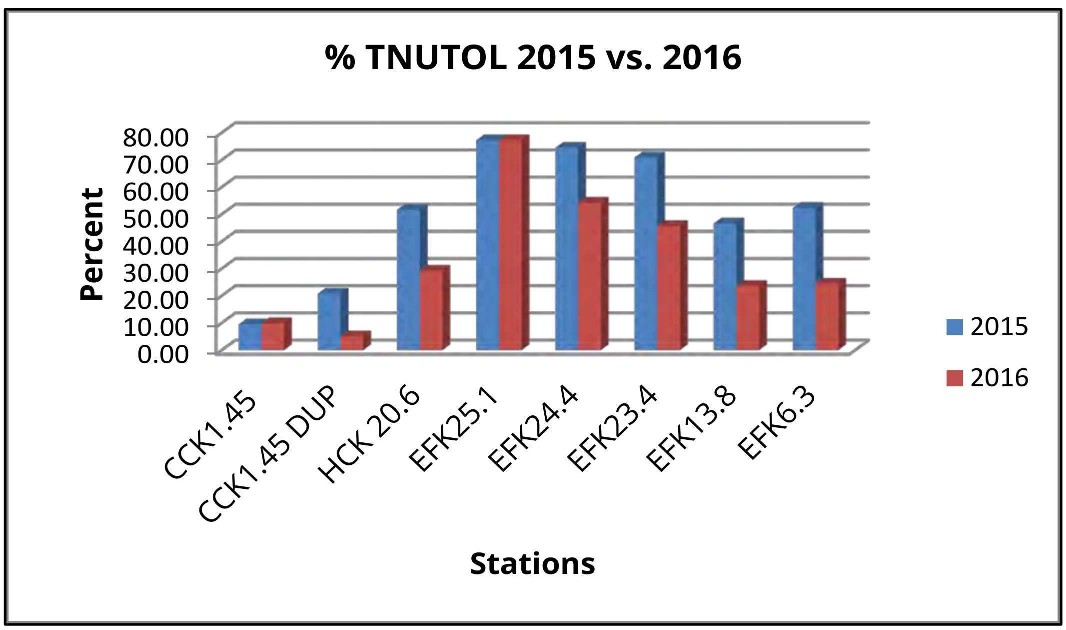


Figure 2.2.4.16: % TNUTOL East Fork Poplar Creek

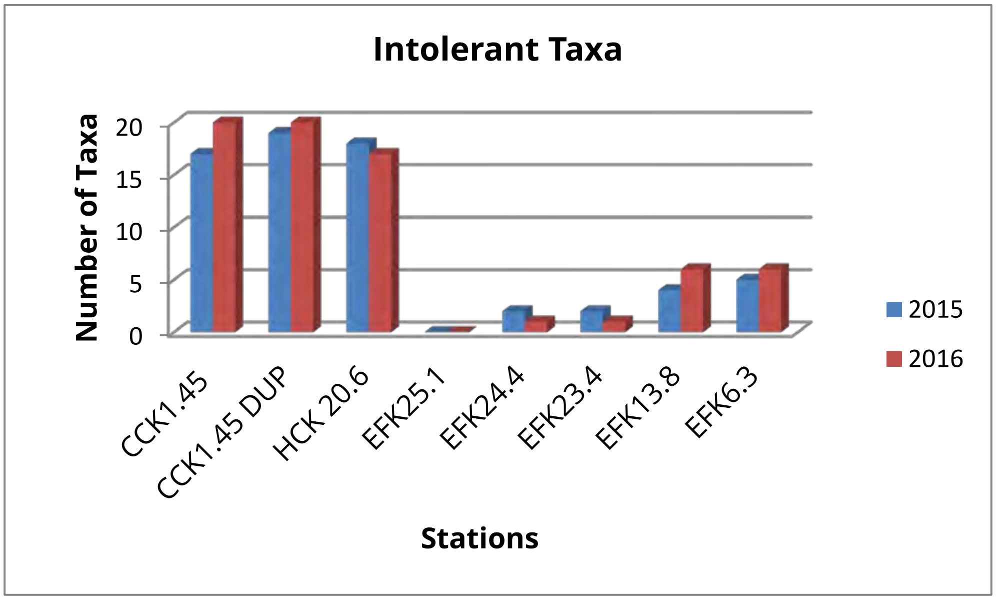


Figure 2.2.4.17: Intolerant Taxa East Fork Poplar Creek

Figure 2.2.4.9 compares the TMI Total Score results for the two reference sites (CCK 1.45 and HCK 20.6) with the five sampling stations in East Fork Poplar Creek for both 2015 and 2016. The scores for the two reference stations (including a duplicate sample taken on Clear Creek) exceed those for all stations of EFPC with only EFK 13.8 approaching the controls in 2016 but not in 2015. The metric taxa richness (Figure 2.2.4.10) shows that the reference stations (CCK and HCK) displayed a higher number of total taxa than any of the East Fork Poplar Creek stations with the exception of EFK 13.8 in 2016 and EFK 6.3 in both 2015 and 2016. A trend may be seen for both the 2015 and 2016 data with the number of taxa increasing incrementally in a downstream direction. EPT richness (Figure 2.2.4.11) shows a distinct difference between the reference stations and the East Fork Poplar Creek stations with the best East Fork Poplar Creek station (EFK 13.8) possessing approximately five fewer EPT taxa in 2015 and seven fewer EPT taxa in 2016 than the lowest number for the reference stations (HCK 20.6) in 2015. The same trend as with total taxa richness may be seen here with the number of EPT taxa increasing in a downstream direction.

The % EPT-*Cheumatopsyche* (Cheum) (Figure 2.2.4.12) shows a slight increase in 2016 after suffering a dramatic decrease in the upper stations of EFPC (EFK 25.1, EFK 24.4, and EFK 23.4) during 2015. The % OC metric (Figure 2.2.4.13) shows a distinction between the reference stations and all stations in East Fork Poplar Creek. All East Fork Poplar Creek sites display a higher proportion of oligochaetes and midges, often a sign of degraded conditions. Data for 2015 and 2016 are similar except at station EFK 24.4. The metrics for NCBI (Figure 2.2.4.14), % clingers (Figure 2.2.4.15), and % TNUTOL (Figure 2.2.4.16) do not distinguish clearly between the reference streams and impacted sites. The reference station HCK 20.6 displays NCBI (Figure 2.2.4.14) value that is indistinguishable from those of the EFPC stations. The metric for % clingers (Figure 2.2.4.15) also does not distinguish between the reference stations and stations in EFPC.

The % TNUTOL metric (Figure 2.2.4.16) does not distinguish between reference and impacted stations with the values for the majority of the East Fork Poplar Creek stations for both 2015 and 2016. This is particularly evident for HCK 20.6. A trend may be seen in both the 2015 and 2016 East Fork Poplar Creek data with % TNUTOL trending downward in a downstream direction. The comparison of the number of intolerant taxa between reference and impacted streams (Figure 2.2.4.17) shows a distinct difference between reference and impacted stations with impacted stations displaying few sensitive taxa. Both the 2015 and 2016 data shows a gradual increase in the number of sensitive taxa in a downstream direction.

Although East Fork Poplar Creek has shown improvement over time since the 1980s when sampling initially began, improvements have leveled off somewhat in the past few years. There is some indication that due to lower flows (related to halting of flow augmentation) East Fork Poplar Creek (particularly upstream East Fork Poplar Creek) may be adjusting toward a less healthy condition.

Mitchell Branch

Mitchell Branch is a small headwater tributary to Poplar Creek at ETTP. The highest upstream station, which serves as the reference station (MIK 1.43), does not meet the criteria for rating, according to the bioregion concept, due to the size of the watershed above it (<two square miles). Because of the small upstream watershed and variable flow conditions depending on annual rainfall, MIK 1.43 does not always provide a clear picture of the impacted condition of the downstream stations (MIK 0.71 and MIK 0.45). Historically, MIK 1.43 has been relatively unimpacted by the presence of ETTP. The lower stations (MIK 0.71 and MIK 0.45) have, however, been impacted not only from former industrial activities at ETTP and waste areas; they have also been channelized with much of the channel being replaced with unnatural substrate.

In order to determine the condition of the sampling stations in Mitchell Branch, the following series of nine graphs comparing total score, taxa richness, EPT richness, % EPT-Cheum, % OC, NCBI, % clingers, % TNUTOL, and intolerant taxa have been provided (Figures 2.2.4.18 – 2.2.4.26). Metric data for all stations, including the reference station (MIK 1.43), are found in Table 2.2.4.7. The discussion of the data follows.

Table 2.2.4.7: Metric Values, Scores, and Biological Condition Ratings for Mitchell Branch

2016 RESULTS	MITCHELL BRANCH					
Stream station	**MIK 1.43**		**MIK 0.71**		**MIK 0.45**	
METRIC	**VALUE**	**SCORE**	**VALUE**	**SCORE**	**VALUE**	**SCORE**
Taxa Richness	61	6	57	6	54	6
EPT Richness	15	4	14	4	9	0
% EPT-Cheum	20.20	2	5.28	0	7.10	0
% OC	64.98	4	76.86	0	68.14	2
NCBI	4.62	6	5.13	4	5.37	4
% Clingers	13.55	0	37.40	6	29.65	6
%TNUTOL	48.50	4	31.09	6	15.62	6
Intolerant Taxa	20	0	8	0	5	0
INDEX SCORE (Tenn. Macro. Index)		26		26		24
RATING		B		B		B

TMI = Tennessee Macroinvertebrate Index

A = Supporting / Non Impaired (Tenn. Macro. Index Scores ≥32)

B = Partially Supporting / Slightly Impaired (TMI Scores 21-31)

C = Partially Supporting / Moderately Impaired (TMI Scores 10-20)

D = Non Supporting / Severely Impaired (TMI Scores <10)

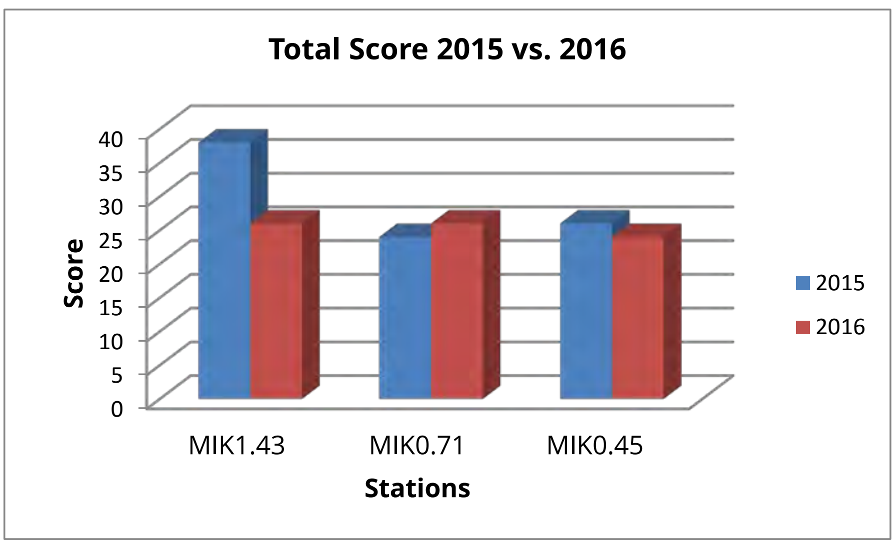


Figure 2.2.4.18: Total Score Mitchell Branch

The Total Score for the Mitchell Branch stations (Figure 2.2.4.18) shows the overall better condition of MIK 1.43 compared to the lower two Mitchell Branch stations (MIK 0.71 and MIK 0.45) in 2015, but not so much in 2016. The total score for MIK 1.43 for 2016 rates as partially supporting/slightly impaired. Historically, this is unusual and may be an artifact of the variability from sample to sample.

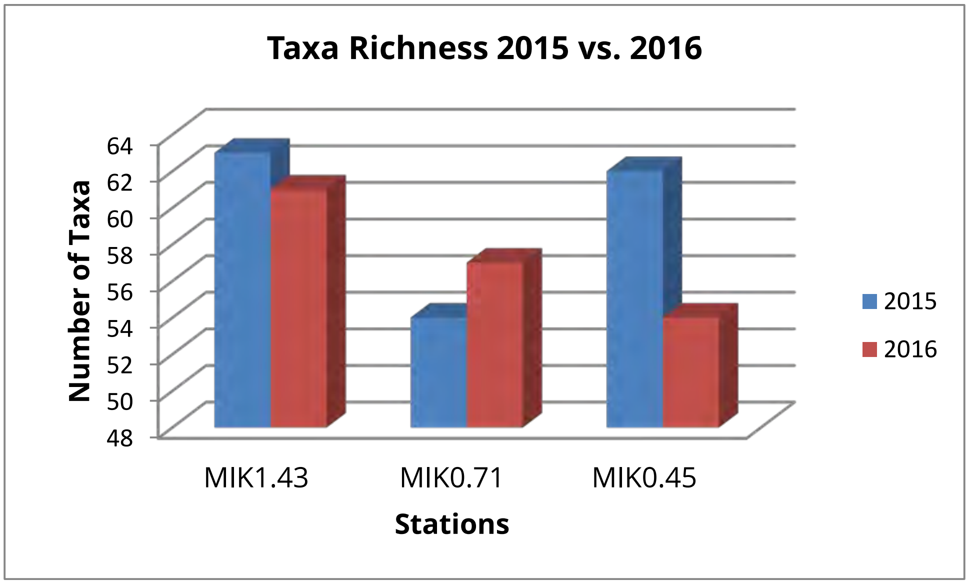


Figure 2.2.4.19: Taxa Richness Mitchell Branch

Taxa richness (Figure 2.2.4.19) provides a less clear picture in the 2015 data with MIK 1.43 and MIK 0.45 quite similar, but a clearer picture in the 2016 data with values dropping for each station in a downstream direction.

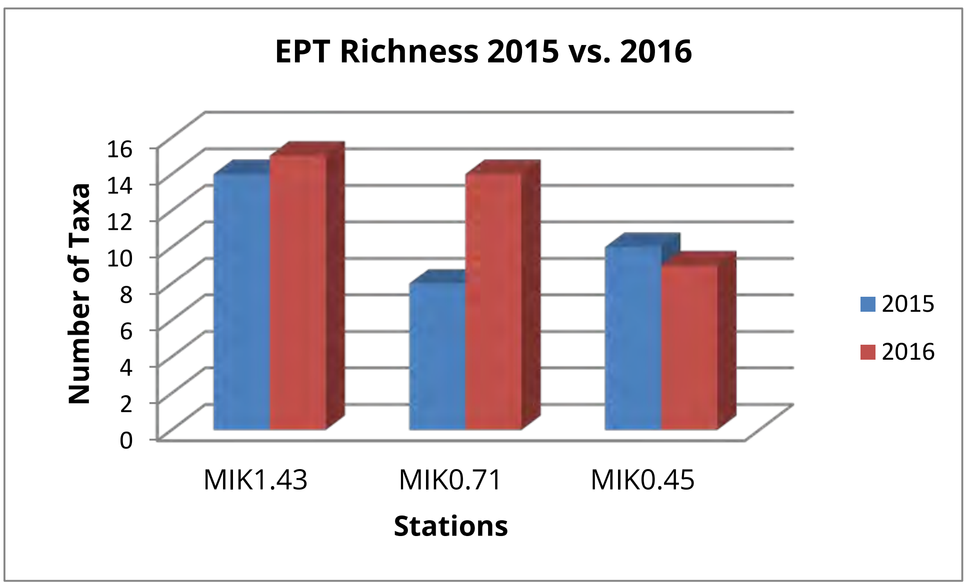


Figure 2.2.4.20: EPT Richness Mitchell Branch

EPT richness (Figure2.2.4.20) shows a clear superiority for MIK 1.43 in the 2015 data with a larger number of these sensitive taxa occurring at that station; however, the metric shows more similarity between stations MIK 1.43 and MIK 071 in the 2016 data.

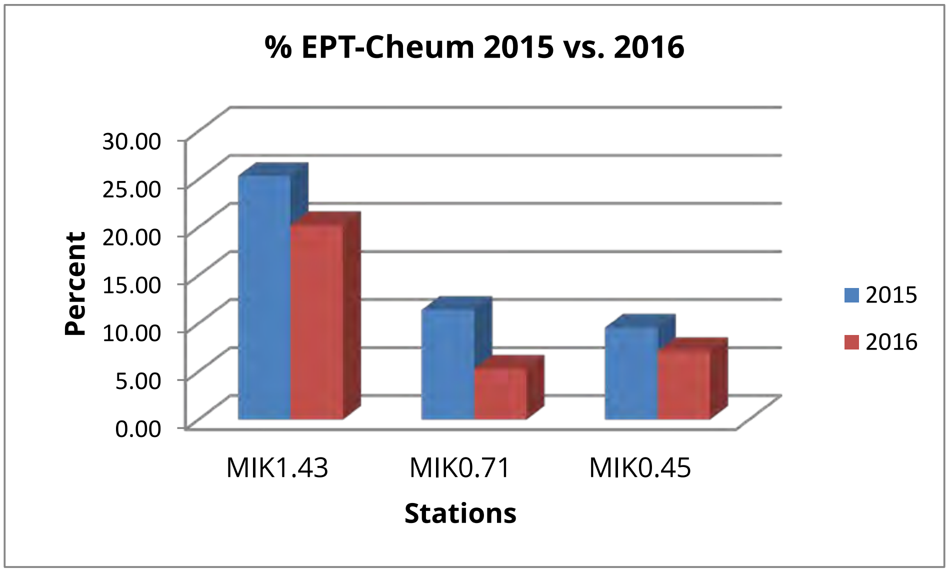


Figure 2.2.4.21: % EPT-Cheum Mitchell Branch

The % EPT-Cheum (Figure2.2.4.21) is indicative of somewhat more stressful conditions at MIK 0.71 and MIK 0.45. This stress is shown in the more tolerant EPT community at these stations.

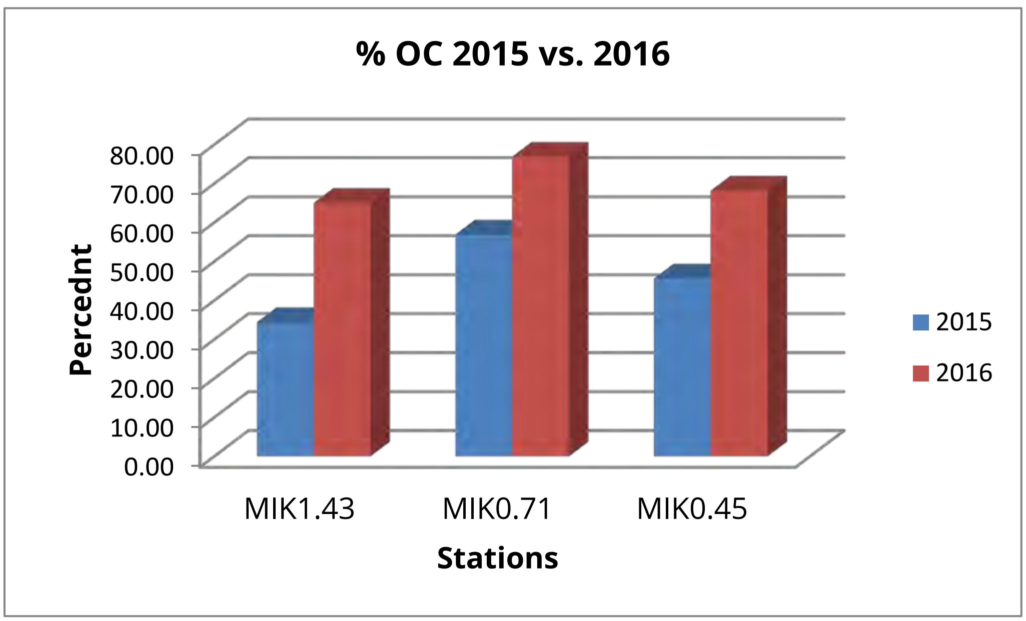


Figure 2.2.4.22: % OC Mitchell Branch

The % OC (Figure 2.2.4.22) metric shows a clear difference between the reference (MIK 1.43) and impacted stations (MIK 0.71, MIK 0.45) in the 2015 data, but a more similar situation among stations in the 2016 data. Generally, the lower the value for the % OC metric, the better the condition of the stream.

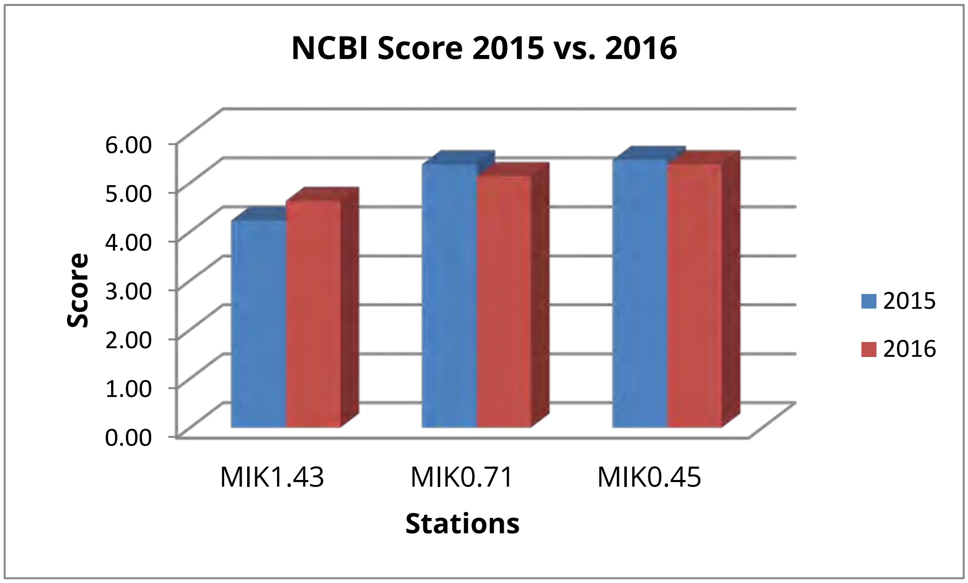


Figure 2.2.4.23: NCBI Mitchell Branch

In line with the less stressful conditions at MIK 1.43, this site shows a lower (better) score for the NCBI (biotic integrity) metric (Figure 2.2.4.23) for both the 2015 and 2016 data

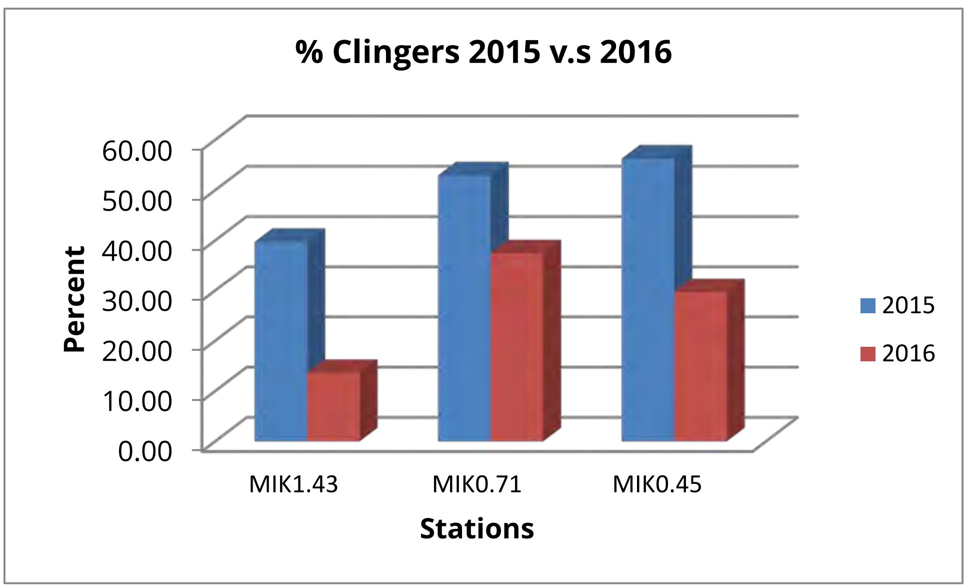


Figure 2.2.4.24: % Clingers Mitchell Branch

The % clingers (Figure 2.2.4.24) (higher values indicating better stream conditions) is better for the downstream stations than for the MIK 1.43 reference station. Generally, the greater the proportion of clingers present, the better the health of the community. A clear reason for this difference is not obvious.

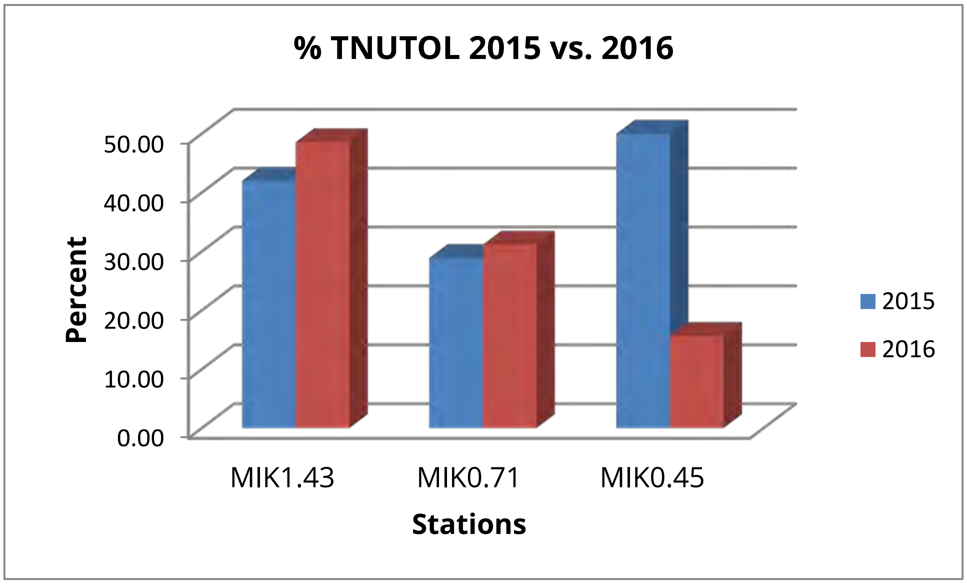


Figure 2.2.4.25: % TNUTOL Mitchell Branch

The % TNUTOL (Figure2.2.4.25) shows higher nutrient levels for MIK 1.43 (reference station) for both 2015 and 2016, than for the downstream stations (except for MIK 0.45 in 2015). A higher proportion (of nutrient-tolerant organisms at a site) is indicative of a less healthy community. Again, the reason for this difference is not obvious.

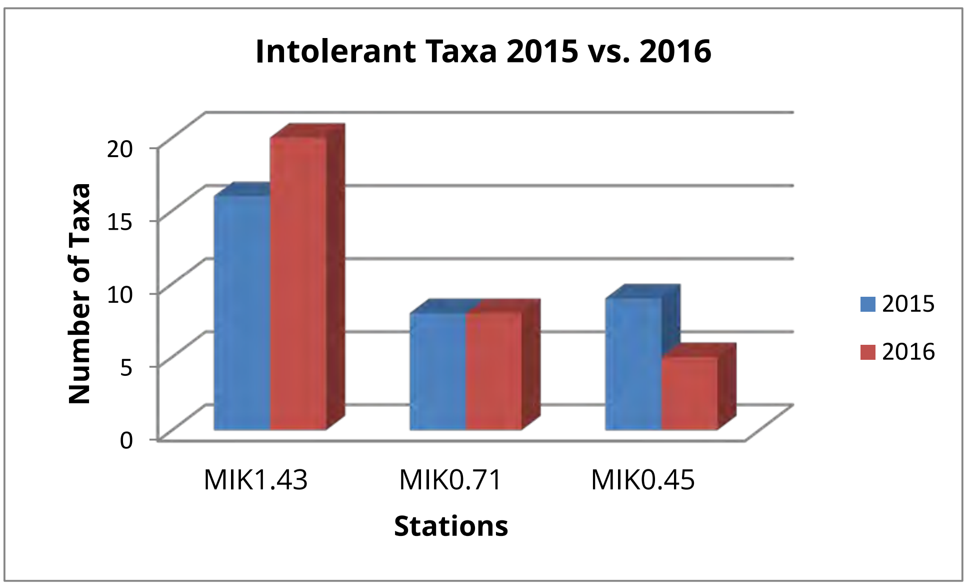


Figure 2.2.4.26: Intolerant Taxa Mitchell Branch

The number of intolerant taxa (Figure2.2.4.26) at MIK 1.43 is nearly twice that found at either of the lower MIK stations. This further highlights the better condition of this headwater reference site.

The lower stations of Mitchell Branch appear to be maintaining, if not slightly improving, in condition. Over time, the substrate (stream bottom) is becoming more natural at the lower stations (MIK 0.71 and MIK 0.45) of Mitchell Branch allowing a more diverse community to inhabit those stations. Further improvements in substrate as well as water quality improvements due to remedial activities should allow Mitchell Branch to continue to slowly improve. Perhaps more significant than these improvements is the protection from degradation of the upstream portions of Mitchell Branch which currently continue to provide communities of healthy organisms which may eventually establish themselves in the lower reaches of the stream.

Bear Creek

Alternative Reference Stream Method Total Scores increase considerably from BCK 12.3 (with a score of 24) downstream to BCK 3.3 (with a score of 42). Bear Creek is a small- to moderate-sized stream whose headwaters begin partly in the west end of the industrialized complex at Y-12. Historically, Bear Creek has received pollution from industrial activities, as well as waste disposal activities at Y-12. Former waste sites such as the S3 ponds (at its headwaters) negatively influence the water quality of the stream. Heading downstream from its source, Bear Creek continues to be impacted by inputs from various former and current waste sites. Bear Creek is also a stream where shallow groundwater and surface waters mingle freely throughout its length to its confluence with East Fork Poplar Creek. Because Bear Creek is impacted from its headwaters, two small tributaries to East Fork Polar Creek are utilized as its references (Mill Branch, MBK 1.6; and Gum Hollow Branch, GHK 2.9). Metric data for both Bear Creek stations are found along with the two reference stations in Table 2.2.4.8.

Table 2.2.4.8: Metric Values, Scores, and Biological Condition Ratings for Bear Creek

2016 RESULTS	Benthic Macroinvertebrates Bear Creek											
Stream station	GHK 2.9		MBK 1.6		MBK 1.6 DUP		BCK 12.3		BCK 9.6		BCK 3.3	
METRIC	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
Taxa Richness	79	6	69	6	76	6	62	6	57	6	59	6
EPT Richness	25	6	26	6	27	6	14	4	19	6	18	6
% EPT-Cheum	45.89	6	48.15	6	54.6	6	10.70	0	14.21	0	44.56	6
% OC	35.48	6	8.71	6	18.66	6	25.11	6	11.33	6	10.33	6
NCBI	3.12	6	3.03	6	2.83	6	6.45	2	4.71	6	3.61	6
% Clingers	24.30	4	63.26	6	42.11	6	24.86	4	72.97	6	57.4	6
%TNUTOL	17.24	6	19.13	6	5.01	6	61.81	2	50.19	4	28.19	6
Intolerant Taxa	20		19		21		5		14		14	
INDEX SCORE (Tenn. Macro. Index)		40		42		42		24		34		42
RATING		A		A		A		B		A		A

TMI = Tennessee Macroinvertebrate Index

A = Supporting / Non Impaired (Tenn. Macro. Index Scores ≥32)

B = Partially Supporting / Slightly Impaired (TMI Scores 21-31)

C = Partially Supporting / Moderately Impaired (TMI Scores 10-20)

D = Non Supporting / Severely Impaired (TMI Scores <10)

DUP = duplicate sample

In order to determine the condition of the sampling stations in Bear Creek, Figures 2.2.4.27 through 2.2.4.35 compare the total score, taxa richness, EPT richness, % EPT-Cheum, % OC, NCBI, % clingers, % TNUTOL, and intolerant taxa, as listed below and are discussed in the following sections.

- Figure 2.2.4.27: 2015 and 2016 Total Score Bear Creek
- Figure 2.2.4.28: 2015 and 2016 Taxa Richness Bear Creek
- Figure 2.2.4.29: 2015 to 2016 EPT Richness Bear Creek
- Figure 2.2.4.30: 2015 to 2016 EPT-Cheum Bear Creek
- Figure 2.2.4.31: 2015 to 2016 % OC Bear Creek
- Figure 2.2.4.32: 2015 to 2016 NCBI Bear Creek
- Figure 2.2.4.33: 2015 and 2016 % Clingers Bear Creek

- Figure 2.2.4.34: 2015 to 2016 TNUTOL Bear Creek
- Figure 2.2.4.35: 2015 to 2016 Intolerant Taxa Bear Creek

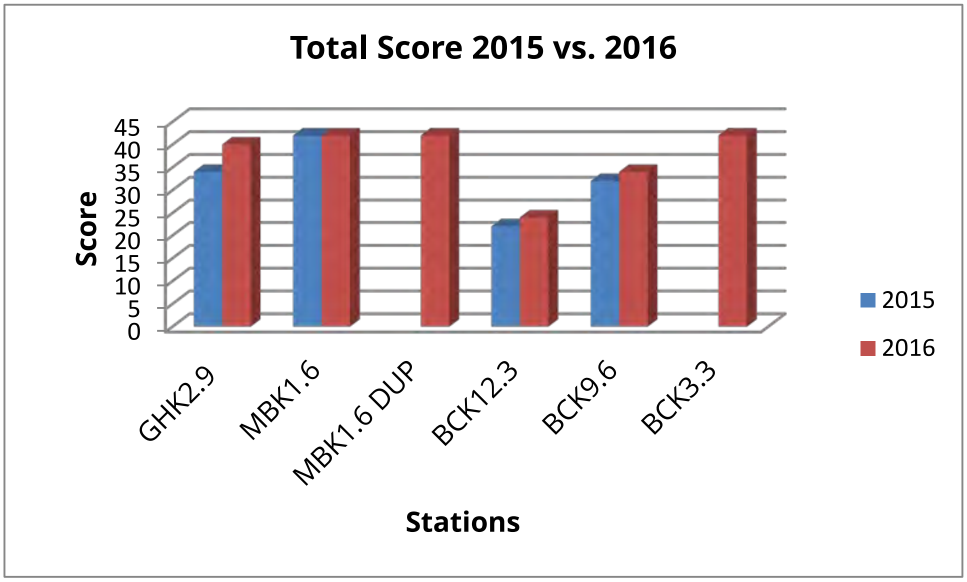


Figure 2.2.4.27: Total Score Bear Creek

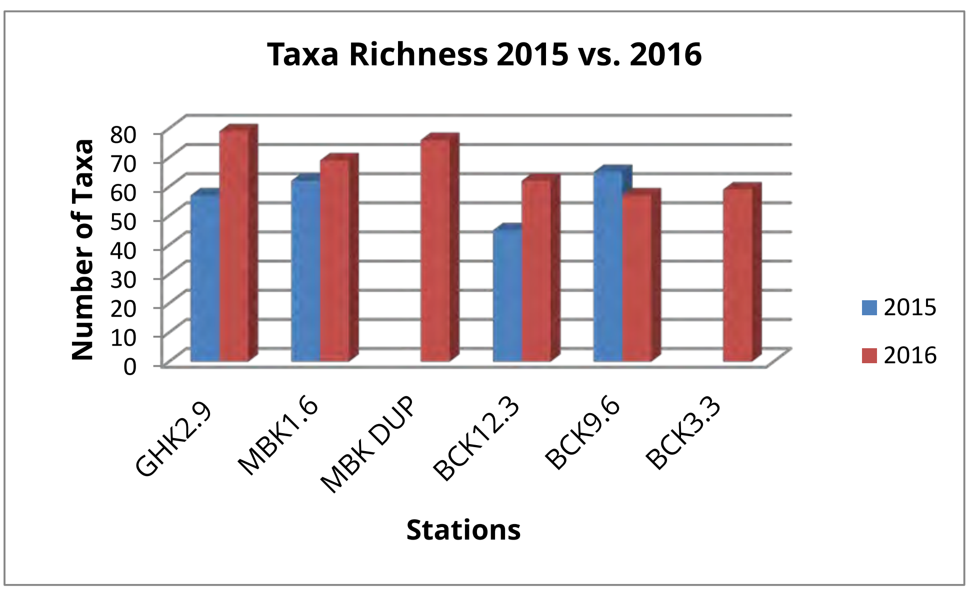


Figure 2.2.4.28: Taxa Richness Bear Creek

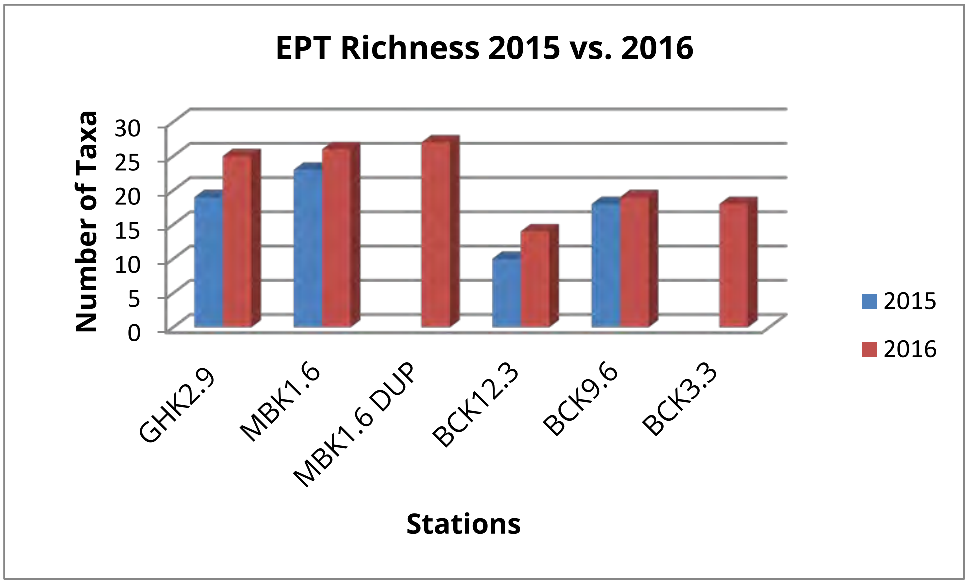


Figure 2.2.4.29: EPT Richness Bear Creek

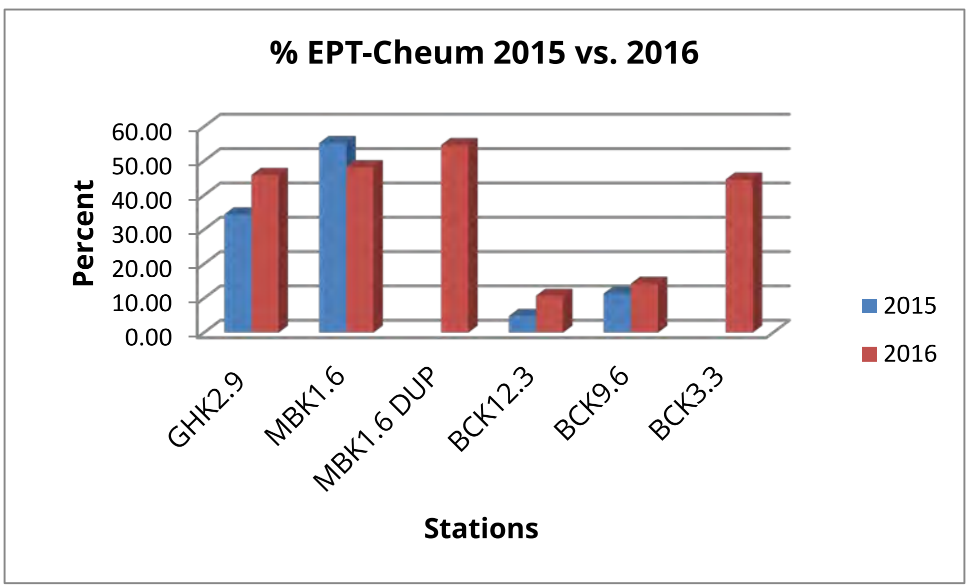


Figure 2.2.4.30: % EPT-Cheum Bear Creek

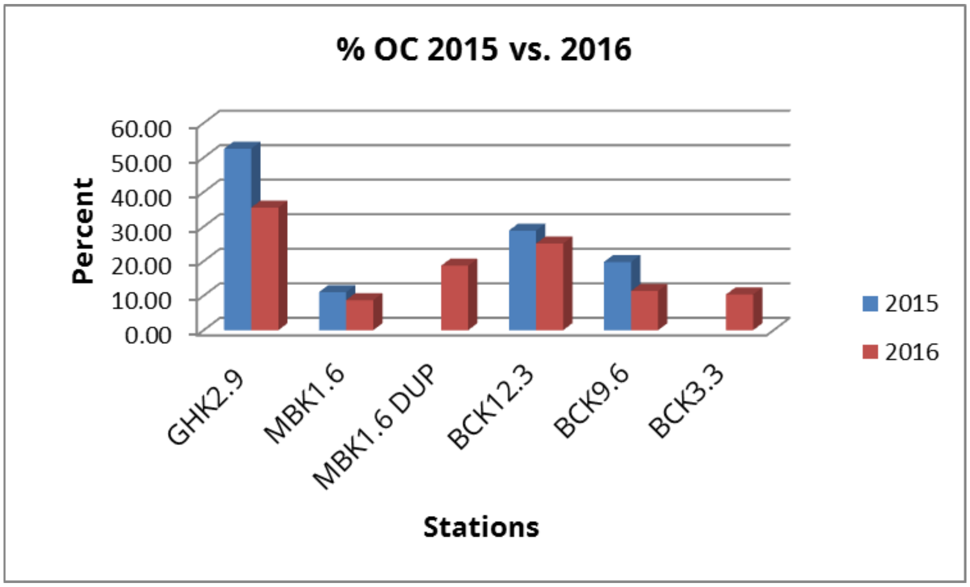


Figure 2.2.4.31: % OC Bear Creek

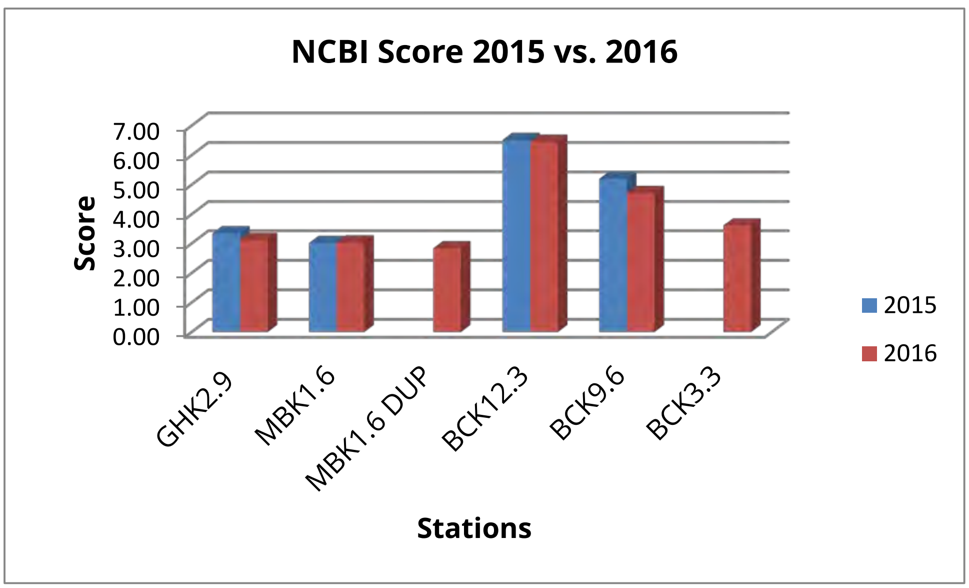


Figure 2.2.4.32: NCBI Bear Creek

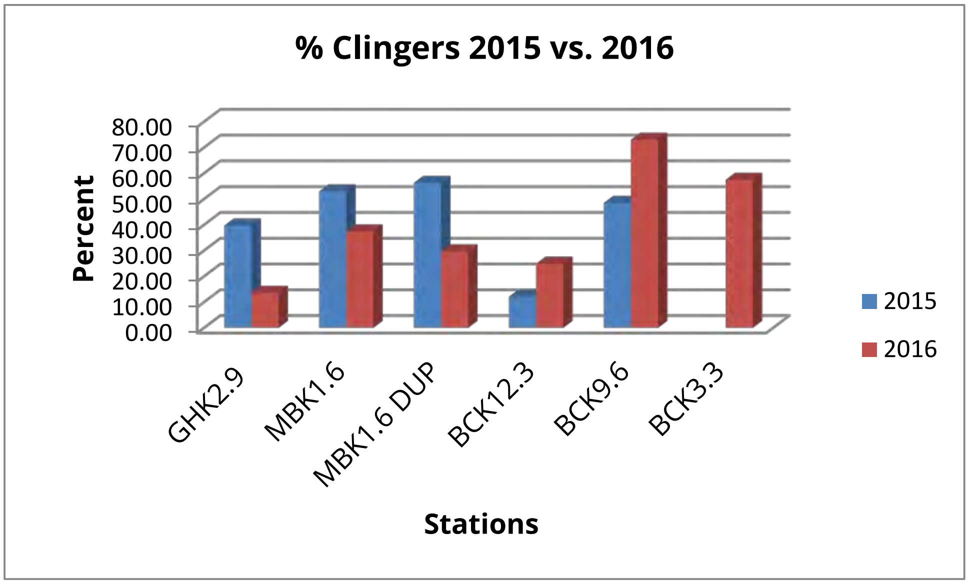


Figure 2.2.4.33: % Clingers Bear Creek

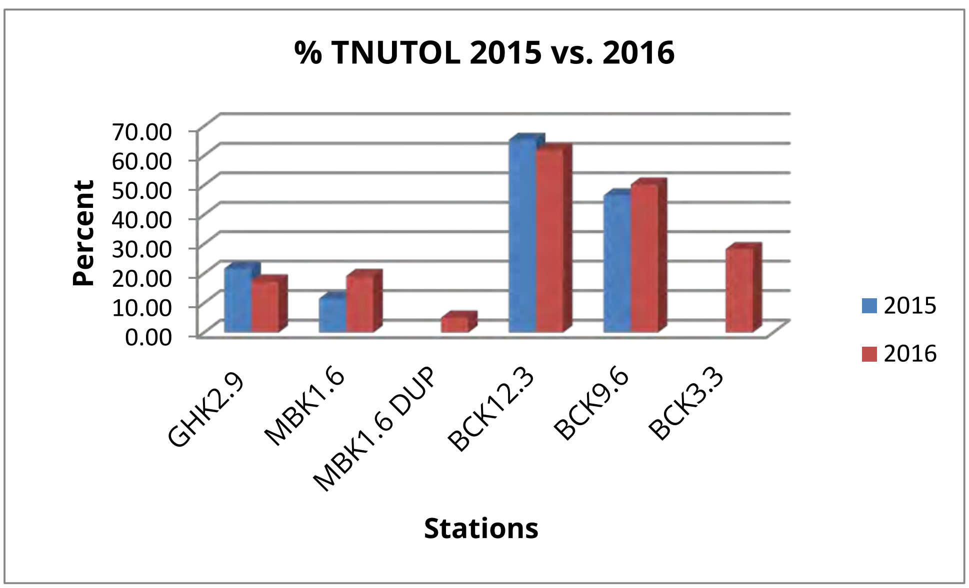


Figure 2.2.4.34: % TNUTOL Bear Creek

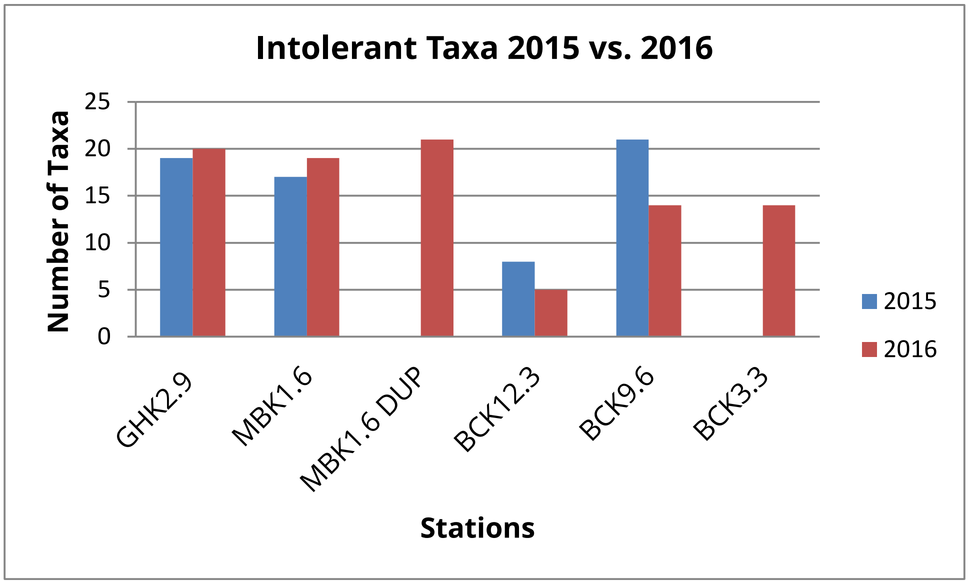


Figure 2.2.4.35: Intolerant Taxa Bear Creek

Bear Creek 12.3 displays a reduced benthic macroinvertebrate community, although BCK 12.3 was at one time the station in this study with the lowest TMI score. Its score increased (Figure 2.2.4.27) in 2015 ranking it above two stations in Upper East Fork Poplar Creek (EFK 25.1 and EFK 23.4). In 2016, BCK 12.3 displayed a TMI score above not only EFK 25.1 and EFK 23.4, but also EFK 24.4 and WCK 3.9. In the metric taxa richness, BCK 12.3 lags only slightly behind the reference stations. However, BCK 12.3 also continues to score low on the majority of the metrics compared to other healthier stream stations (Figures 2.2.4.29 through 2.2.4.35). Conditions have improved as shown in both the 2015 and 2016 sampling. This improvement is evident in a number of metrics including total score (Figure 2.2.4.27), taxa richness (Figure 2.2.4.28), EPT richness (Figure 2.2.4.29), NCBI Score (Figure 2.2.4.32).

At station BCK 12.3, a number of the intolerant taxa are successfully reproducing at the site. This is illustrated by the large number (34 were found in the subsample) of the "young of year" (first instar) caddisfly *Psilotreta* sp. The successful reproduction of this sensitive caddisfly indicates constant, good water quality conditions at the site throughout the year. Several intolerant taxa (Figure 2.2.4.35) continue to hold on at this station. Eight intolerant taxa were found at BCK 12.3 during the 2015 sampling and five during the 2016 sampling. Bear Creek 12.3 continues to receive inputs from industry and former and current waste sites. BCK 12.3 lacks adequate substrate for colonization by aquatic organisms. The watershed upstream of BCK 12.3 is limited in size, affecting the amount of flow at the station, particularly in the summer. BCK 12.3 suffers from a paucity of aquatic macroinvertebrate refuges in its vicinity from which recolonization of the station can occur. Little is currently known of the condition of Bear Creek property between BCK 12.3 and BCK 9.6; however, a number of the tributaries in that reach of stream have likely been impacted from former and current waste activities. Further study would be required to determine if refugia of aquatic macroinvertebrates exist near BCK 12.3.

BCK 9.6 continued to show improvement in 2015 and in 2016, if compared to previous years. This station compares well with the two reference stations (GHK 2.9, MBK 1.6) in a number of the metrics. With a TMI score of 34 (compared to 32 in 2015) (Figure 2.2.4.27; Table 2.2.4.8), BCK 9.6 lags only slightly behind GHK 2.9. BCK 9.6 compares favorably with the reference stations in taxa richness

(Figure 2.2.4.28), EPT richness (Figure 2.2.4.29), % OC (Figure 2.2.4.31), % clingers (Figure 2.2.4.33), and intolerant taxa (Figure 2.2.4.35). On the negative side, BCK 9.6 has a higher NCBI score than either GHK 2.9 or MBK 1.6 (Figure 2.2.4.32), and BCK 9.6 shows a considerably higher value for the percent of nutrient-tolerant organisms (% NUTOL: Figure 2.2.4.34). The EPT-Cheum metric (Figure 2.2.4.30) shows that BCK 9.6 continues to suffer some pollution stress with the majority of the EPT at the site consisting of the more tolerant caddisfly *Cheumatopsyche* sp.

A third station in Bear Creek (BCK 3.3) was used to better evaluate the downstream area of the creek. BCK 3.3 displayed a TMI score of 42 (a perfect score) clearly ranking it with the reference stations. Metrics such as taxa richness (Figure 2.2.4.28), EPT richness (Figure 2.2.4.29), % EPT-Cheum (Figure 2.2.4.30), % OC (Figure 2.2.4.31), NCBI (Figure 2.2.4.32), % clingers (Figure 2.2.4.33), % TNUTOL (Figure 2.2.4.34), and intolerant taxa (Figure 2.2.4.35) also compare well with the reference stations.

GHK 2.9 and MBK 1.6 have historically displayed high TMI scores. In 2016, GHK 2.9 had a TMI score of 40 and both MBK 1.6 and MBK 1.6 DUP (duplicate samples) possessed TMI scores of 42 (Table 2.2.4.8; Figure 2.2.4.27). Of note are the values for taxa richness (Figure 2.2.4.28), EPT richness (Figure 2.2.4.29), % EPT-Cheum (Figure 2.2.4.30), NCBI (Figure 2.2.4.32), % NUTOL (Figure 2.2.4.34) and numbers of intolerant taxa (Figure 2.2.4.35). In all, these streams appear to have high diversity and little organic loading.

<u>White Oak Creek and Melton Branch</u>

White Oak Creek is the main drainage for the majority of ORNL's disturbed areas flowing from its headwaters near the SNS through the main plant area in Bethel Valley, then passing into Melton Valley, through the SWSA, entering White Oak Lake, exiting the reservation through White Oak Embayment, and into the Clinch River. The reference station (WCK 6.8) is in the headwaters fed by several springs just below SNS. Station WCK 3.9 is located in the main plant area in Bethel Valley with both WCK 3.4 and WCK 2.3 located in the SWSAs in Melton Valley. Melton Branch drains the eastern portion of Melton Valley with the sampling station MEK 0.3 being located near the HFIR facility. Before the development of SNS, WCK 6.8 was relatively un-impacted. The construction of SNS resulted in some sediment inputs into WOC; however, the negative impacts caused by that sedimentation have since dissipated. WCK 3.9 is located on the south side of the ORNL downstream of Fifth Creek, and receives inputs from a large part of the main campus of ORNL.

At one time, this station was heavily impacted by discharges, spills, and former waste sites and, based on the data in this report, may well continue to be suffering such impacts. WCK 3.4 is located on the north side of the SWSAs soon after White Oak Creek passes over into Melton Valley. WCK 3.4 receives inputs from the main portion of White Oak Creek and inputs from First Creek and the Northwest Tributary. WCK 2.3, on the south of the SWSAs, receives added impact from the SWSAs. MEK 0.3, near HFIR, receives impacts from HFIR and other area facilities. Parts of Melton Branch have also been channelized.

Traditionally, all samples were collected in the field, preserved in ethanol, and returned to the DoR-OR laboratory for processing; however, processing samples in the DoR-OR lab left DoR-OR with radioactive sediment in need of proper disposal. In 2015, the decision was made to process White Oak Creek contaminated sites (WCK 3.9, WCK 3.4, WCK 2.3, and MEK 0.3) in the field to avoid having to return sediment to the laboratory. During 2016, all contaminated sites were processed in the field removing all organisms and returning the sediment to the site of their origin.

In order to determine the condition of the sampling stations in White Oak Creek and Melton Branch, the following series of nine graphs (Figures 2.2.4.36 through 2.2.4.44) compare total score, taxa richness, EPT richness, % EPT-Cheum, % OC, NCBI, % clingers, % TNUTOL, and intolerant taxa. Table 2.2.4.9 provides metrics data for all White Oak Creek stations and Melton Branch

- Figure 2.2.4.36: Metric Values, Scores, and Biological Condition Ratings for White Oak Creek and Melton Branch
- Figure 2.2.4.37: Taxa Richness for White Oak Creek and Melton Branch
- Figure 2.2.4.38: EPT Richness for White Oak Creek and Melton Branch
- Figure 2.2.4.39: % EPT-Cheum for White Oak Creek and Melton Branch
- Figure 2.2.4.40: % OC for White Oak Creek and Melton Branch
- Figure 2.2.4.41: NCBI Scores for White Oak Creek and Melton Branch
- Figure 2.2.4.42: % Clingers for White Oak Creek and Melton Branch
- Figure 2.2.4.43: % TNUTOL for White Oak Creek and Melton Branch
- Figure 2.2.4.44: Intolerant Taxa for White Oak Creek and Melton Branch

Table 2.2.4.9: Metric Values, Scores, and Biological Condition Ratings for White Oak Creek and Melton Branch

2016 RESULTS	White Oak Creek and Melton Branch									
Stream station	WCK 6.8		WCK 3.9		WCK 3.4		WCK 2.3		MEK 0.3	
METRIC	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
Taxa Richness	71	6	29	2	35	4	39	4	56	6
EPT Richness	25	6	4	0	7	2	11	2	18	6
% EPT-Cheum	52.04	6	4.69	0	4.87	0	9.36	0	22.34	0
% OC	26.61	6	18.02	6	8.66	6	5.26	6	1.84	6
NCBI	3.16	6	6.87	2	4.26	6	4.99	4	4.79	6
% Clingers	33.35	6	64.94	6	77.98	6	82.95	6	76.09	6
%TNUTOL	9	6	35.80	6	31.41	6	49.10	4	50.24	4
Intolerant Taxa	18		3		6		6		12	
INDEX SCORE (Tenn. Macro. Index)		42		22		30		26		34
RATING		A		B		B		B		A

TMI = Tennessee Macroinvertebrate Index
A = Supporting / Non Impaired (Tenn. Macro. Index Scores ≥32)
B = Partially Supporting / Slightly Impaired (TMI Scores 21-31)
C = Partially Supporting / Moderately Impaired (TMI Scores 10-20)
D = Non Supporting / Severely Impaired (TMI Scores <10)

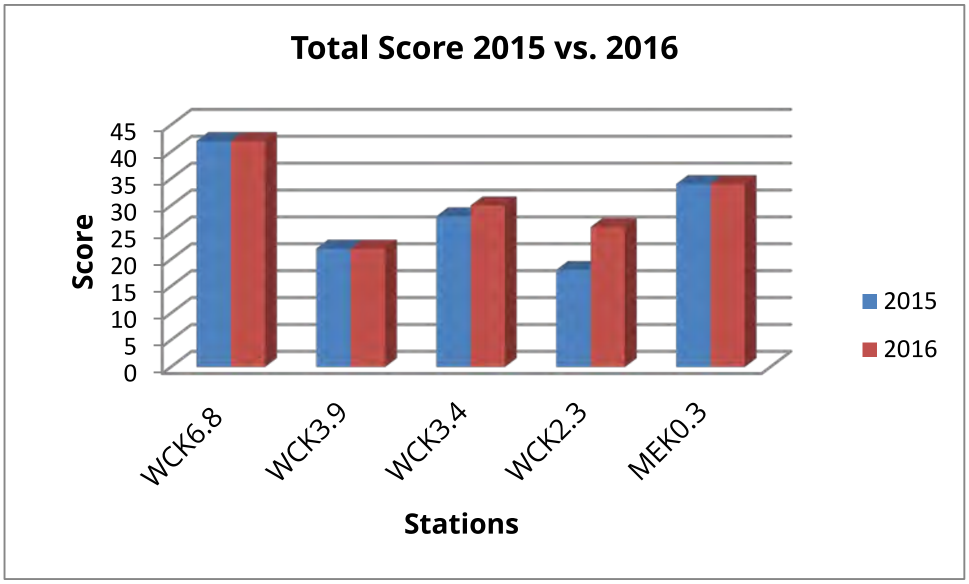


Figure 2.2.4.36: Metric Values, Scores, and Biological Condition Ratings for White Oak Creek and Melton Branch

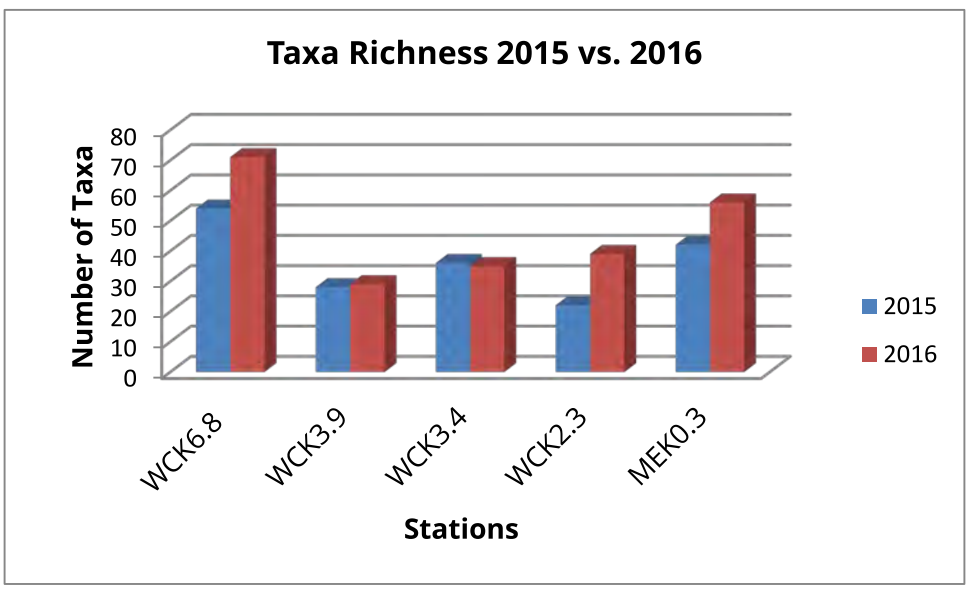


Figure 2.2.4.37: Taxa Richness for White Oak Creek and Melton Branch

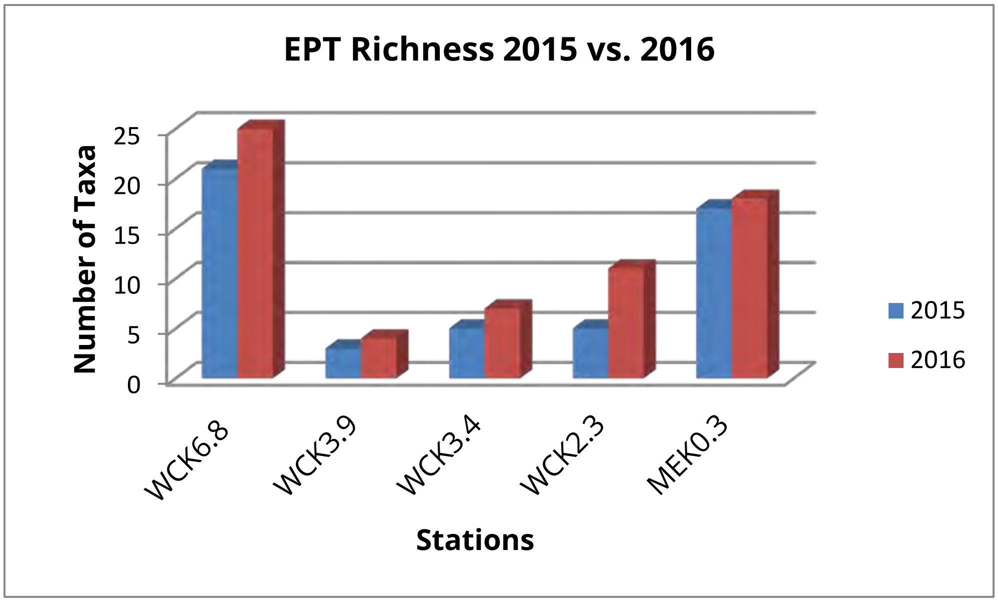


Figure 2.2.4.38: EPT Richness for White Oak Creek and Melton Branch

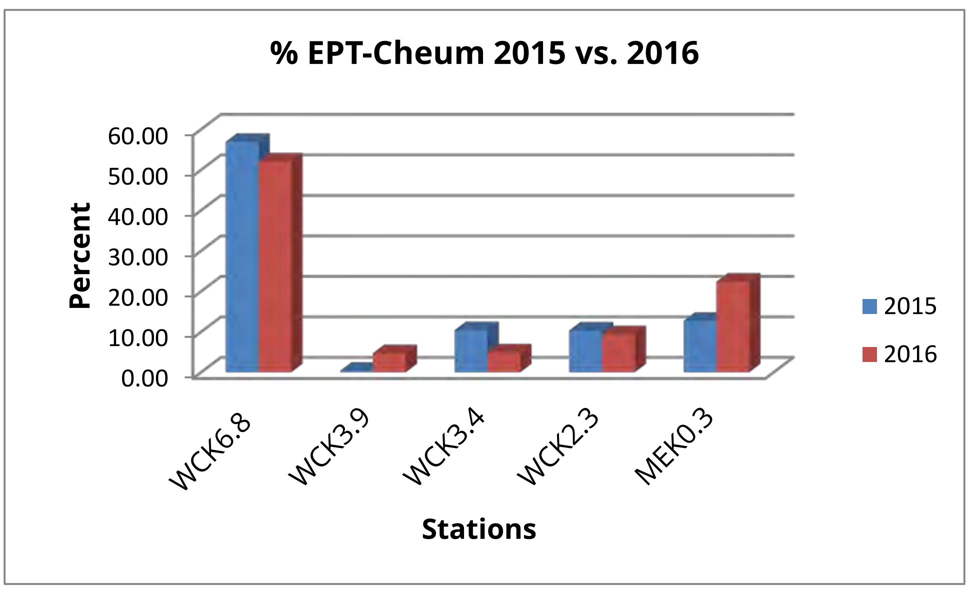


Figure 2.2.4.39: % EPT-Cheum for White Oak Creek and Melton Branch

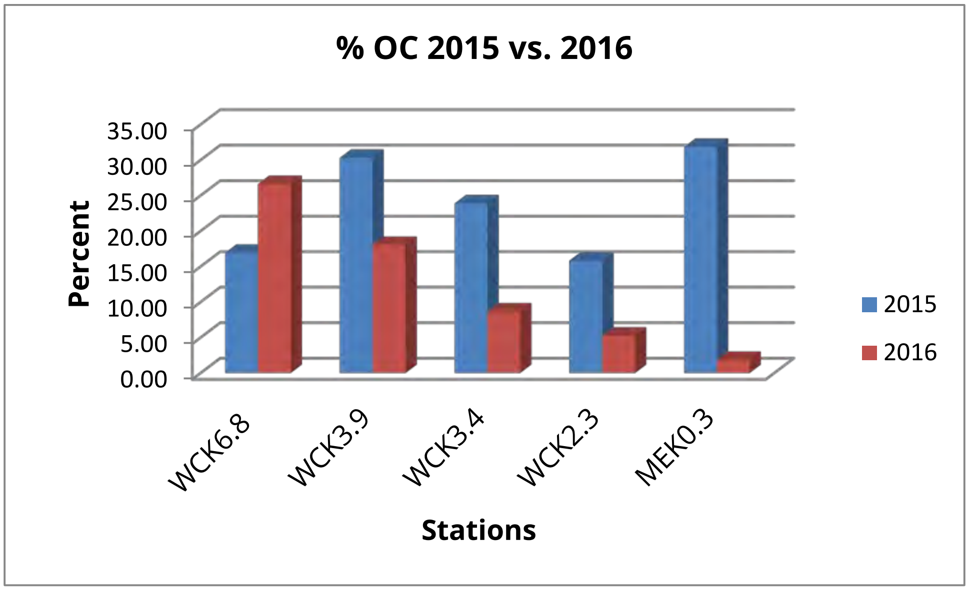


Figure 2.2.4.40: % OC White Oak Creek and Melton Branch

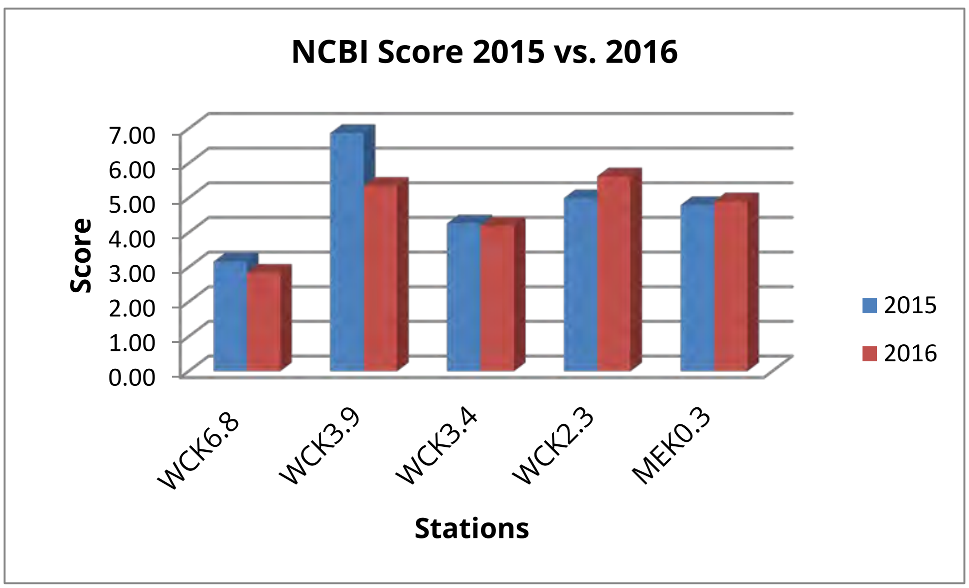


Figure 2.2.4.41: NCBI Score for White Oak Creek and Melton Branch

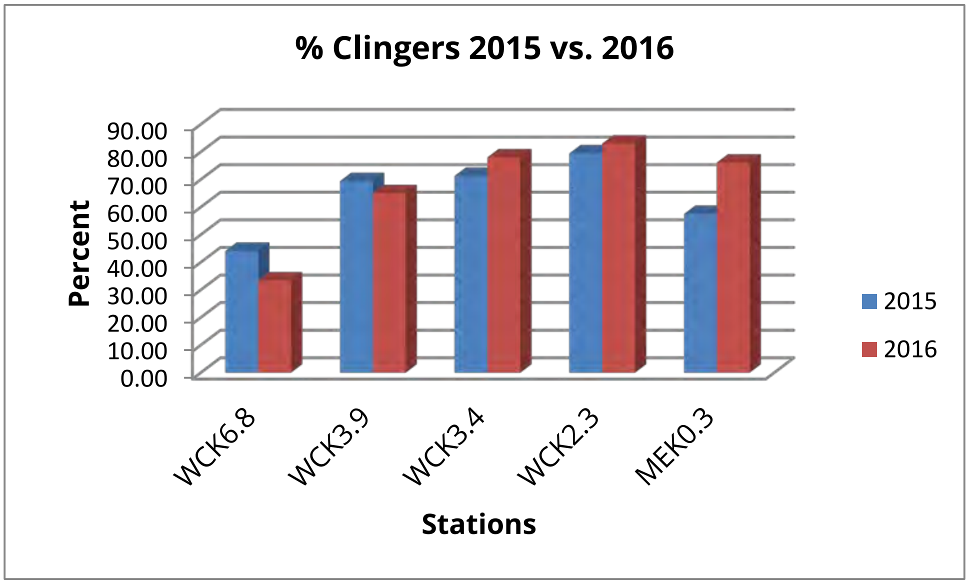


Figure 2.2.4.42: % Clingers for White Oak Creek and Melton Branch

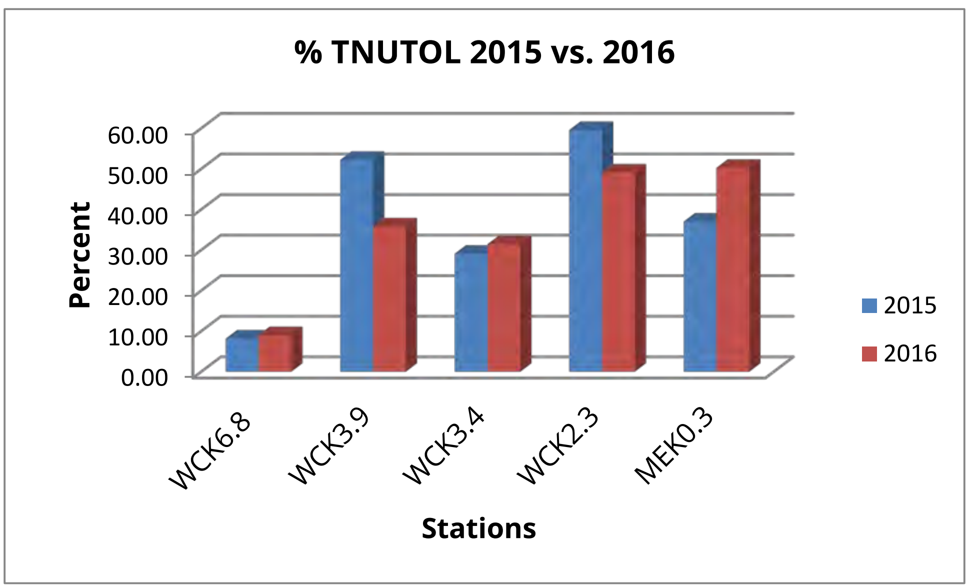


Figure 2.2.4.43: % TNUTOL for White Oak Creek and Melton Branch

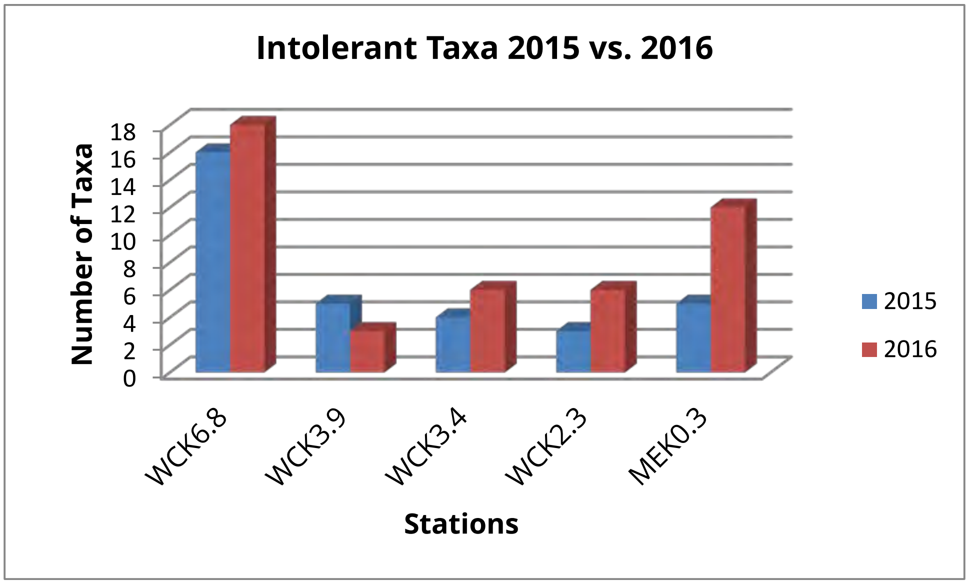


Figure 2.2.4.44: Intolerant Taxa for White Oak Creek and Melton Branch

The TMI total scores (Figure 2.2.4.36) for the White Oak Creek watershed are highest for the upstream reference site (WCK 6.8) and for the site on Melton Branch, a tributary to White Oak Creek in Melton Valley (MEK 0.3). TMI scores for stations downstream in White Oak Creek (WCK 3.9, WCK 3.4, WCK 2.3) are considerably lower, indicating some degree of impairment.

As indicated above, both the reference station WCK 6.8 and MEK 0.3 score high on the TMI (Figure 2.2.4.36). The remaining White Oak Creek stations score somewhat lower; their scores indicative of some degree of impairment. Both the 2015 and 2016 data show taxa richness (Figure 2.2.4.37) is higher for the reference station (WCK 6.8) and MEK 0.3, with the remaining White Oak Creek stations (WCK 3.9, WCK 3.4, WCK 2.3) possessing considerably fewer total taxa. WCK 6.8 and MEK 0.6 also compare well in terms of EPT richness (Figure 2.2.4.38). The metric % OC (Figure 2.2.4.40) is similar for all stations in 2015, but actually higher at the reference station than the impacted stations in 2016. Higher % OC values are often indicative of poorer water quality; however, even with a slightly higher % OC value, WCK 6.8 scored a perfect 6 for that metric. In terms of EPT-Cheum (Figure 2.2.4.39), NCBI score (Figure 2.2.4.41), % clingers (Figure 2.2.4.42), % TNUTOL (Figure 2.2.4.43), and intolerant taxa (Figure 2.2.4.44), MEK 0.3 is more similar to the other White Oak Creek stations (WCK 3.9, WCK 3.4 and WCK 2.3) than to the reference station WCK 6.8. Parameters % TNUTOL, NCBI, and % EPT-Cheum may be indicative of greater organic loading present at MEK 0.3. The major differences between the impacted White Oak Stream stations (WCK 3.9, WCK 3.4, WCK 2.3) and the reference station (WCK 6.8) are apparent in the reduced number of EPT taxa at impacted stations (Figure 2.2.4.37), and the decrease in the % EPT-Cheum (Figure 2.2.4.39) at the impacted stations. More differences include the significantly higher NCBI score at the impacted stations (Figure 2.2.4.41), and the decreased number of intolerant taxa at the impacted stations (Figure 2.2.4.44). All these differences indicate that the White Oak Creek stations (WCK 3.9, WCK 3.4, and WCK 2.3) continue to be biologically impaired.

Based strictly on metric scores, WCK 3.9, WCK 3.4, and WCK 2.3 are classified as partially supporting/slightly impaired (Grade B). Familiarity with the sites, however, shows that the condition of the White Oak Creek impacted stations is much worse than indicated by metrics. Another way of looking at the condition of a stream is by population density and seeing what makes up that population. Population is often presented in organisms/m^2.

All sites exclusive of MEK 0.3, WCK 3.9, WCK 3.4, and WCK 2.3 (all contaminated White Oak Creek watershed sites) were subsampled with approximately 1/7th of the sample picked clean of organisms. In the case of the contaminated White Oak Creek watershed sites, the entire sample was picked. The values for the subsampled sites were extrapolated and adjusted to organisms/m^2. The resulting numbers are presented in Figure 2.2.4.45, below.

As seen from the Figure, WCK 2.3, WCK 3.4, and WCK 3.9 fall far below any other sites in density of populations of benthic macroinvertebrates. Clearly, something adverse is affecting these stations. Stations with good, clean water can be expected to have diverse communities (many different species, especially tolerant EPTs) and healthy population sizes. Stations with organic loading will typically have less diverse communities with fewer and more tolerant species. The White Oak Creek stations (with lower diversity, few tolerant species, and extremely reduced population numbers) lead one to believe that these stations are being impacted by intermittent slugs of toxic pollutants. Further study is needed to clearly define what is happening at these stations in order to attempt to remediate impacts and allow for eventual recovery of the stream.

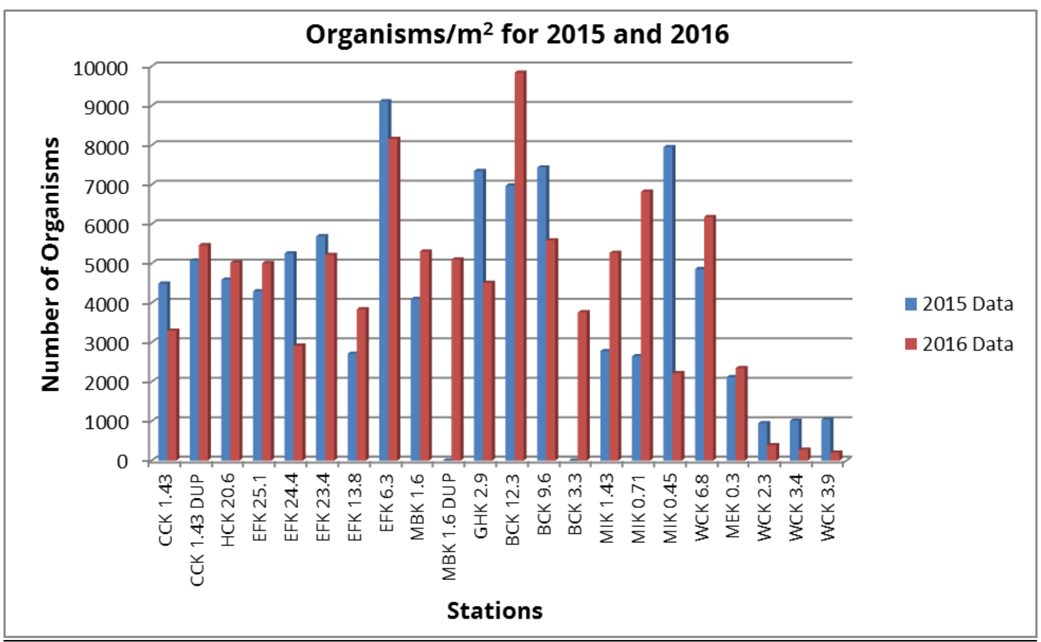


Figure 2.2.4.45: Organisms/m^2 for 2015 and 2016

Quality Control Results

Duplicate samples were collected at the Clear Creek 1.45 station and at the Mill Branch 1.6 station as a quality control check for field sampling and laboratory sample processing during 2016. As seen in Table 2.2.4.10 and Figure 2.2.4.46, both sets of duplicate samples returned similar results for their respective sites. Both duplicates attained perfect TMI scores (Alternative Reference Stream Method). These results indicate that both field sampling and lab processing were done with a high rate of consistency.

Table 2.2.4.10: Metric Values, Scores and Biological Condition Ratings for Quality Control Duplicates

2016 RESULTS	QUALITY CONTROL DUPLICATES							
Stream station	CCK 1.45		CCK 1.45 DUP		MBK 1.6		MBK 1.6 DUP	
METRIC	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
Taxa Richness	50	6	61	6	69	6	76	6
EPT Richness	26	6	26	6	26	6	27	6
% EPT-Cheum	55.11	6	34.31	6	48.15	6	54.60	6
% OC	14.10	6	13.38	6	8.71	6	18.66	6
NCBI	3.06	6	2.61	6	3.03	6	2.83	6
% Clingers	28.45	6	52.30	6	63.26	6	42.11	6
%TNUTOL	9.43	6	4.99	6	19.13	6	5.01	6
Intolerant Taxa	17	0	20	0	19	0	21	0
INDEX SCORE (Tenn. Macro. Index)		42		42		42		42
RATING		A		A		A		A

TMI = Tennessee Macroinvertebrate Index

A = Supporting / Non Impaired (Tenn. Macro. Index Scores ≥ 32

B = Partially Supporting / Slightly Impaired (TMI Scores 21-31)

C = Partially Supporting / Moderately Impaired (TMI Scores 10-20)

D = Non Supporting / Severely Impaired (TMI Scores <10)

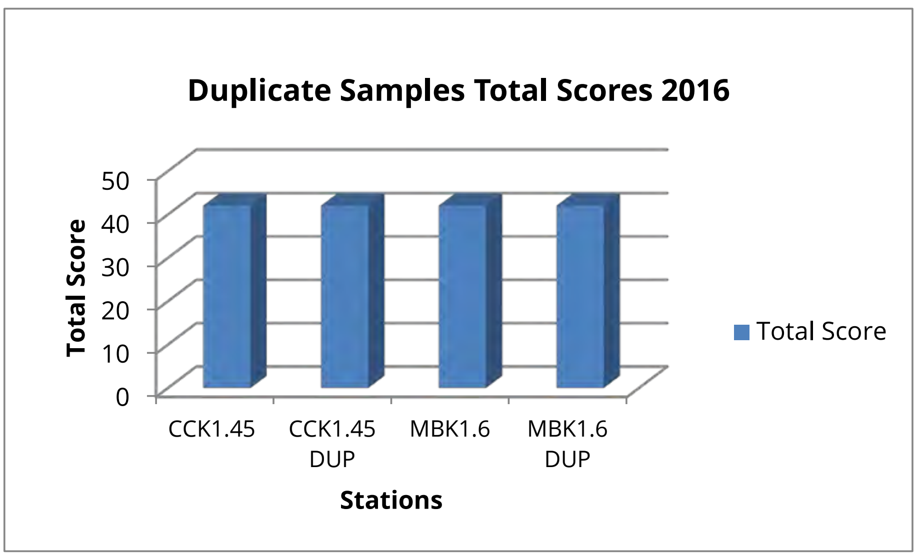


Figure 2.2.4.46: Duplicate Samples Total Scores for 2016

Conclusions

The biotic integrity of most impacted streams on the ORO is less than optimal compared to reference conditions. Of all sites sampled during 2016, three locations (EFK 25.1, EFK 24.4, and EFK 23.4) received the lowest TMI scores and ratings, partially supporting/moderately impaired (TMI equals 10-20, C rating). A number of other stations in the study including EFK 6.3, MIK 1.43, MIK 0.71, MIK 0.45, BCK 12.3, WCK 2.3, WCK 3.4, and WCK 3.9 received TMI scores and ratings considered as partially supporting/slightly impaired (TMI equals 21-31, B rating). The reasons why these stations ranked considerably below reference stations in score are varied. In part, the poor scores are likely due to continued pollution at the sites. As indicated in the Results and Discussion, the White Oak Creek impacted stations (WCK 3.9, WCK 3.4, and WCK 2.3) are an anomaly with very low benthic community densities. Further investigation of the cause(s) of these low populations in White Oak Creek is warranted. Remarkably, four of the impacted stations show scores that favorably compare to those of reference sites. These include BFK 9.6, BCK 3.3, EFK 13.8, and MEK 0.3. The high ranking of some of the impacted sites and the improvement in others is encouraging and shows the positive results of the remediation work that has been completed at both Y-12 and ORNL.

2.3 Fugitive Air Monitoring

Introduction

DoR-OR performs routine monitoring of fugitive air emissions on the ORR. The monitoring program focuses on locations where the potential for airborne releases of radioactive contaminants from diffuse (non-point) sources exists. At the time this report was compiled, results were only available through April 19, 2017. During the interval from January, 1 2016 through April 19 2017, monitored locations included the decommissioning and demolition of uranium enrichment facilities at ETTP; the Central Campus Removal Action at ORNL; footprint reduction activities at Y-12; and the disposal of radioactive waste at EMWMF in Bear Creek Valley. Data from the program are used to accomplish the following:

- identify and characterize unplanned releases
- evaluate DOE controls to prevent releases to the environment
- verify data reported by DOE and its contractors
- assess the potential impact of DOE activities on the public health and environment

Eight high-volume air samplers were used in the program. Seven of the units were mounted on trailers or elevated platforms positioned near the location and/or activities of interest. The eighth sampler is stationed at Fort Loudoun Dam in Loudon County to collect background information.

Methods and Materials

The eight high-volume air samplers used in the program run continuously, except during filter collection, maintenance, or power outages. Each sampler used an 8x10 inch glass-fiber filter to collect particulates from air as air is drawn through the unit at a rate of approximately 35 cubic feet per minute. Airflow through each sampler is calibrated quarterly and routine maintenance is performed, as described in DoR-OR Standard Operational Procedure 203, *High Volume Total Suspended Particulate System Maintenance.* Samples were collected weekly, composited every four weeks, and shipped to the state of Tennessee's environmental laboratory in Nashville, Tennessee for analyses based on the radionuclides of concern for the location being monitored (varying for different locations).

When the results were received from the laboratory, the data from the reservation samplers were compared to the background results to assess if releases had occurred. An assessment of compliance was made from limits provided in Title 40 of the Code of Federal Regulations Part 61 (40CFR61) Appendix E Table 2 (Concentration Levels for Environmental Compliance). For compliance purposes, these concentrations are based on a yearly average. The locations of the monitoring stations (January 1, 2016 through April 19, 2017 sampling period) are depicted in Figure 2.3. The analyses for the stations (ETTP K25 K11, ETTP K27, EMWMF, Y-12 Building B9723, Y-12 Building 9212, and the background station at Ft. Loudoun Dam) were isotopic uranium and technetium-99 (Tc-99). ORNL stations B4007 and Corehole 8 were analyzed for isotopic uranium.

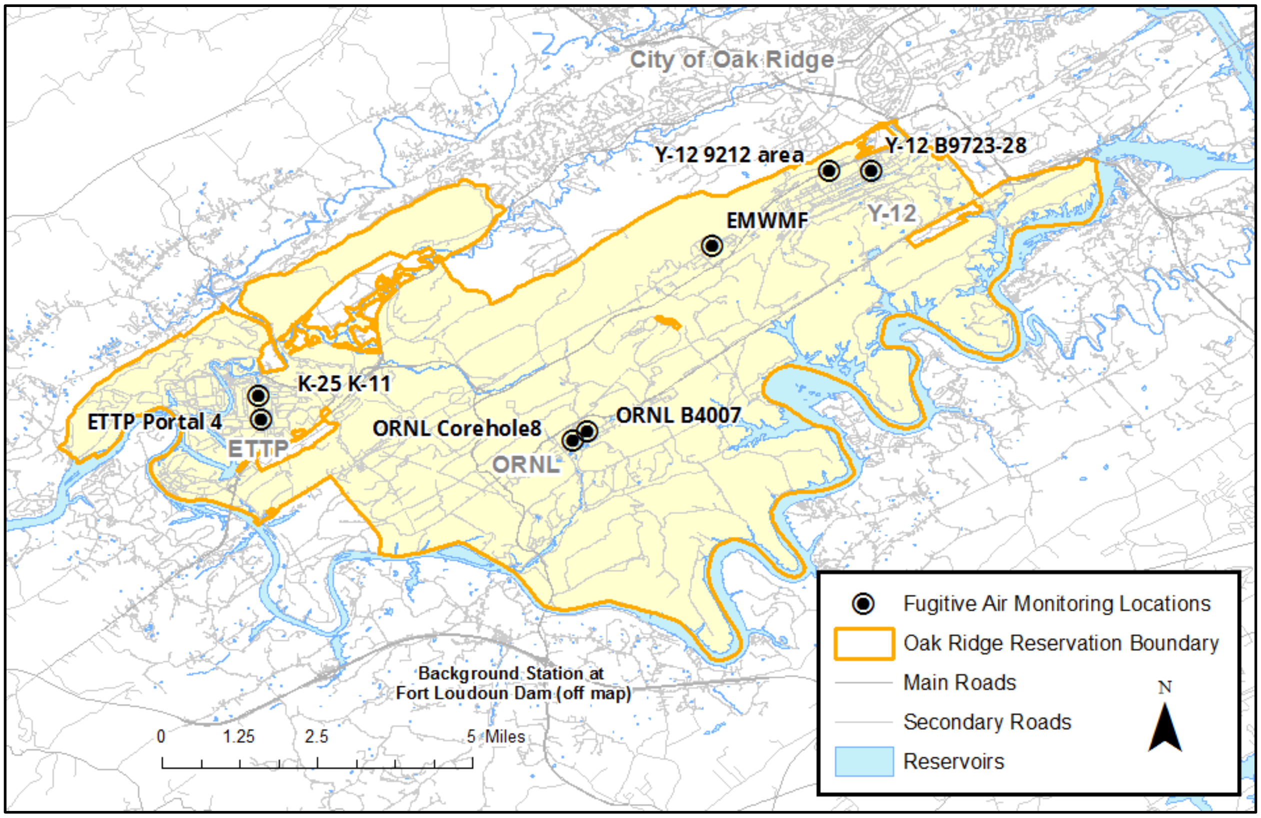


Figure 2.3.: Locations of Sites Monitored for Fugitive Air Emissions

Results from the ORR samplers were compared to the results from the background location to determine if releases occurred and to standards provided in the Clean Air Act (CAA) to assess compliance with federal regulations. Title 40 of the Code of Federal Regulations Part 61 (40CFR61), *National Emission Standards for Hazardous Air Pollutants* (NESHAPS), Subpart H (*National Emission Standards for Emissions of Radionuclides other than Radon from Department of Energy Facilities*) limits DOE radiological emissions to quantities that would not cause a member of the public to receive an effective dose equivalent greater than 10 mrem in a year.

The effective dose equivalent is the sum of the products of absorbed dose and appropriate factors to account for differences in biological effectiveness due to the quality of radiation and its distribution in the body of reference man. The unit of the effective dose equivalent is the rem. The environmental concentration for individual radionuclides that would be equivalent to the ten mrem/year dose limit if inhaled continuously over the course of a year can be found in 40CFR61.91(a) Appendix E, Table 2.

To account for the synergistic effect of multiple radionuclides in the air, the rule calls for using the sum of the fractions to determine compliance (when more than one radionuclide is present). To calculate the sum of the fractions, the annual average concentration for each radionuclide was divided by its limit and the results summed. If the sum of the fractions is equal to, or greater than, one (1), then the facility would be considered out of compliance. The compliance point is the nearest off-site residence, school, business, or office. DOE is required to meet provisions of the law that require all radioactive emissions to be as low as reasonably achievable (ALARA).

The fugitive air monitoring program was designed to identify air releases from non-point sources (remedial activities) to the environment and evaluate DOE control measures and ALARA consideration. Consequently, the monitors were located as near to the activity of interest as feasible.

Results and Discussion

East Tennessee Technology Park

The K-25 Gaseous Diffusion Plant, now known as the East Tennessee Technology Park, began operations in World War II as part of the Manhattan Project. Its original mission was to produce uranium enriched in the uranium-235 isotope (U-235) for use in the first atomic weapons and later to fuel commercial and government-owned reactors. The plant was permanently shut down in 1987. Because of operational practices and accidental releases, many of the facilities scheduled for decontamination and decommissioning (D&D) at ETTP remain contaminated to some degree. Uranium isotopes are the primary contaminants; however, Tc-99 and other fission and activation products are also present due to the processing of recycled uranium obtained from spent nuclear fuel originating from reactors.

Two samplers were used at ETTP. Both samplers operated for the period January 1, 2016 through April 19, 2017. Samples were collected weekly from the two units and composited every four weeks for radiochemical analysis. Current analyses include uranium, U-234, U-235, U-238, and Tc-99. Tables 2.3.1. and 2.3.2 provide a summary of the results for K-25/K-11 and K-27, respectively.

Table 2.3.1: ETTP K-25/K-11 Air Monitoring Average Result (pCi/m^3)

ETTP K-25/K11	U-234	U-235	U-238	Tc-99	Sum of Fractions
Average for 1/1/2016 through 4/19/2017	7.59E-05	6.77E-06	4.26E-05	2.58E-04	
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05	1.71E-04	
Net Activity (Avg. Minus Background)	3.10E-05	1.50E-06	6.82E-06	8.74E-05	
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03	1.40E-01	
Fraction of Limit Net/Limit	4.03E-03	2.11E-04	8.22E-04	6.24E-04	5.69E-03

Table 2.3.2: ETTP K-27 Air Monitoring Average Result for (pCi/m^3)

ETTP K-27	U-234	U-235	U-238	Tc-99	Sum of Fractions
Average for 1/1/2016 through 4/19/2017	1.49E-04	1.34E-05	6.54E-05	6.83E-04	
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05	1.71E-04	
Net Activity (Avg. Minus Background)	1.04E-04	8.16E-06	2.96E-05	5.12E-04	
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03	1.40E-01	
Fraction of Limit Net/Limit	1.35E-02	1.15E-03	3.56E-03	3.66E-03	2.19E-02

Y-12 National Security Complex

The Y-12 Plant, now known as the Y-12 National Security Complex, was constructed during World War II to enrich uranium, in this case by the electromagnetic separation process. In ensuing years, the facility was expanded, and used to produce fuel for naval reactors, conduct lithium/mercury enrichment operations, manufacture components for nuclear weapons, dismantle nuclear weapons, and store highly enriched uranium. The Y-12 B9723 air monitor was located centrally at Y-12 near Building 9723 in July 2010 to monitor the D&D of contaminated facilities associated with the Y-12 Integrated Facilities Disposition Project.

A second air monitor was stationed east of Building 9212 in September 2012 to monitor footprint reduction activities. Building 9212 was constructed in 1945 and is currently used to process highly enriched uranium. The aging facility is expected to be replaced by the proposed Uranium Processing Facility in the future. Samples were collected weekly from the two Y-12 samplers and composited every four weeks for radiochemical analysis. Current analyses include U-234, U-235, U-238, and Tc-99. Tables 2.3.3 and 2.3.4 provide a summary of the results for Buildings 9212 and 9723-28 area fugitive air monitors, respectively.

Table 2.3.3: Y-12 Building 9212 Air Monitoring Average Result for January 1, 2016 through April 19, 2017 (pCi/m^3)

Building 9212	U-234	U-235	U-238	Tc-99	Sum of Fractions
Average for 1/1/2016 through 4/19/2017	1.82E-04	1.42E-05	4.88E-05	1.29E-04	
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05	1.71E-04	
Net Activity (Avg. Minus Background)	1.37E-04	8.89E-06	1.30E-05	-4.21E-05	
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03	1.40E-01	
Fraction of Limit Net/Limit	1.78E-02	1.25E-03	1.57E-03	-3.01E-04	2.03E-02

Table 2.3.4: Y-12 Building 9723-28 Air Monitoring Average Result (pCi/m^3)

Building 9723-28	U-234	U-235	U-238	Tc-99	Sum of Fractions
Average for 1/1/2016 through 4/19/2017	5.50E-05	6.21E-06	4.33E-05	7.07E-05	
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05	1.71E-04	
Net Activity (Avg. Minus Background)	1.02E-05	9.42E-07	7.48E-06	-1.00E-04	
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03	1.40E-01	
Fraction of Limit Net/Limit	1.33E-03	1.33E-04	9.01E-04	-7.14E-04	1.65E-03

Oak Ridge National Laboratory

Construction of the ORNL began in 1943. While the initial mission of K-25 and Y-12 was the production of enriched uranium, the ORNL site focused on reactor research, the production of plutonium, and the production of other activation and fission products, which were chemically extracted from uranium irradiated in ORNL's Graphite Reactor and later other ORNL and Hanford reactors. During early operations, leaks and spills were common in the facilities. Associated radioactive materials were released from operations as gaseous, liquid, and solid effluents, with little or no treatment (ORAU, 2003).

Consequently, many of the facilities are contaminated with a long list of fission and activation products and are considered the highest risk facilities at ORNL. This is due to their physical deterioration, the presence of loose contamination and their proximity to privately funded facilities, active ORNL facilities, and pedestrian and vehicular traffic. Over recent years, a concerted effort has been made to D&D these facilities and to remediate associate sites. Two of the fugitive air monitors are positioned to monitor the remedial efforts: one to the southwest of the W1A/Corehole 8 removal action completed in 2012, and the other at Building B4007, northeast of the D&D of the 3026 Radioisotope Development Laboratory, and near other facilities undergoing or scheduled for remediation.

Samples were collected weekly from the two ORNL samplers and composited every four weeks for radiochemical analysis. Current analyses include U-234, U-235, U-238, and gamma spectrometry. The gamma spectrometry analysis is not shown because only naturally occurring daughter products of radon were detected.

Tables 2.3.5 and 2.3.6 provide a summary of the isotopic uranium results for ORNL B4007 and ORNL Corehole 8 area fugitive air monitors, respectively.

Table 2.3.5: ORNL B4007 Air Monitoring Average Result (pCi/m^3)

ORNL B4007	U-234	U-235	U-238		Sum of Fractions
Average for 1/1/2016 through 4/19/2017	3.69E-05	3.42E-06	3.16E-05		
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05		
Net Activity (Avg. Minus Background)	-7.91E-06	-1.85E-06	-4.21E-06		
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03		
Fraction of Limit Net/Limit	-1.03E-03	-2.60E-04	-5.07E-04		-1.79E-03

Table 2.3.6: ORNL Corehole 8 Air Monitoring Average Result (pCi/m^3)

ORNL Corehole 8	U-234	U-235	U-238		Sum of Fractions
Average for 1/1/2016 through 4/19/2017	3.54E-05	3.26E-06	2.89E-05		
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05		
Net Activity (Avg. Minus Background)	-9.42E-06	-2.01E-06	-6.87E-06		
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03		
Fraction of Limit Net/Limit	-1.22E-03	-2.83E-04	-8.28E-04		-2.33E-03

The Environmental Management Waste Management Facility

The EMWMF was constructed in Bear Creek Valley near the Y-12 National Security Complex to dispose of low-level radioactive waste and hazardous waste generated by remedial activities on the reservation. During disposal, and prior to being covered, wastes disposed of in the facility are subject to dispersion by winds that typically travel northeast through the valley in the daytime and southwest at night. To monitor the air emissions at EMWMF, one of the fugitive air samplers was placed at the southeast corner of the facility in December 2004. Samples were collected weekly and composited every four weeks for radiochemical analysis. Current analyses include U-234, U-235, U-238 and Tc-99. Table 2.3.7 provides a summary of the results for the EMWMF area fugitive air monitor.

Table 2.3.7: EMWMF Air Monitoring Average Result (pCi/m^3)

EMWMF	U-234	U-235	U-238	Tc-99	Sum of Fractions
Average for 1/1/2016 through 4/19/2017	6.56E-05	5.88E-06	4.77E-05	2.60E-05	
Average Background (Ft. Loudoun Dam)	4.48E-05	5.27E-06	3.58E-05	1.71E-04	
Net Activity (Avg. Minus Background)	2.08E-05	6.15E-07	1.19E-05	-1.45E-04	
40CFR Part 61 Limit Appendix E (Table 2)	7.70E-03	7.10E-03	8.30E-03	1.40E-01	
Fraction of Limit Net/Limit	2.70E-03	8.66E-05	1.44E-03	-1.03E-03	3.19E-03

Conclusions

During January 1, 2016 through April 19, 2017, results were similar to background. The average concentrations for all sites were below the federal standards.

2.4 Surface Water Monitoring

2.4.1 Surface Water Physical Parameter Monitoring

Introduction

The surface water physical parameter project collected discrete ambient water quality monitoring data at seven stream sites located in several watersheds from January 2016 through June 2017. The main ORR watersheds include portions of East Fork Poplar Creek, Bear Creek, and Mitchell Branch. Field parameters were also measured from Mill Branch, a small reference stream located in the City of Oak Ridge. The EFK 13.8 monitoring site is located outside the ORR. Specifically, it is located approximately 10 kilometers (km) downstream of the Y-12 National Security Complex. The project objectives were to create a baseline of water quality monitoring data, physical stream parameters measured on a monthly basis to evaluate water quality. Furthermore, this monitoring project was directed toward determining long-term water quality trends, assessing the attainment of water quality standards, and providing background data for evaluating stream recovery due to toxicity stressors. Table 2.4.1.1 and Figure 2.4.1.1 show locations selected for data collection.

Table 2.4.1.1: Ambient Surface Water Parameters Monitoring Locations

Ambient Surface Water Parameters Monitoring Locations				
Site DWR Name	**Site Description**	**DoR-OR Site**	**Latitude**	**Longitude**
EFPOP014.5AN	East Fork Poplar Creek Mile 14.5/km 23.4	EFK 23.4	35.99596	-84.24004
EFPOP008.6AN	East Fork Poplar Creek Mile 8.6/km 13.8	EFK 13.8	35.99283	-84.31371
BEAR007.6AN	Bear Creek Mile 7.6/km 12.3	BCK 12.3	35.973	-84.27814
BEAR006.0AN	Bear Creek Mile 6.0/km 9.6	BCK 9.6	35.96032	-84.29741
BEAR002.8RO	Bear Creek Mile 2.8/km 4.5	BCK 4.5	35.9375	-84.33938
MITCH000.1RO	Mitchell Branch Mile 0.1/ km 0.1	MIK 0.1	35.94146	-84.3922
FECO67I12	Mill Branch Mile 1.0/km 1.6	MBK 1.6	35.98886	-84.28935

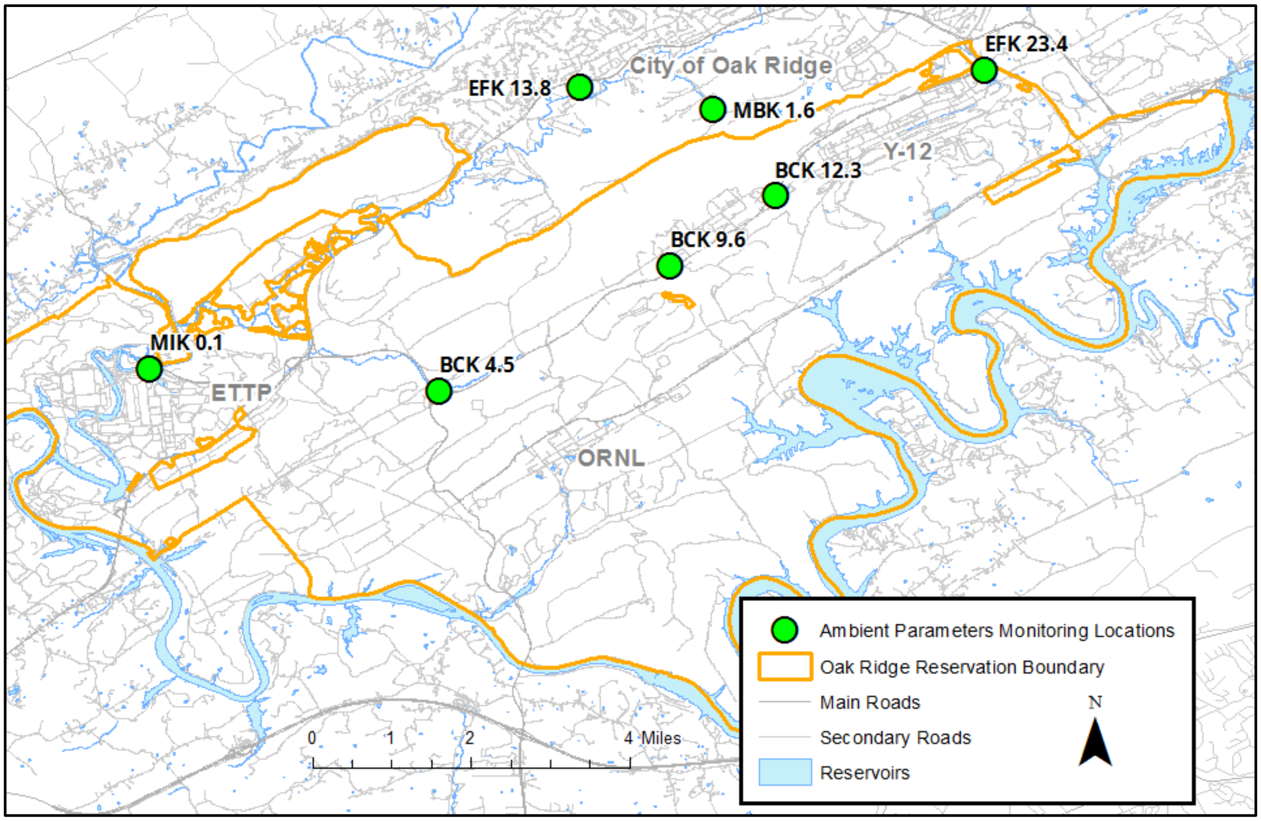


Figure 2.4.1.1: Oak Ridge Reservation Ambient Parameter Monitoring Locations

Methods and Materials

The parameters measured in the field were temperature, pH, conductivity, and dissolved oxygen (DO). YSI© Professional Plus multi-parameter water quality instruments were used to collect the data. The instruments were calibrated prior to operation in the field. During each stream examination, data were recorded in a field notebook including time, date, and weather conditions. Unusual occurrences relating to stream conditions were noted.

In cases when field readings such as pH and conductivity were beyond benchmark ranges, the following actions are taken:

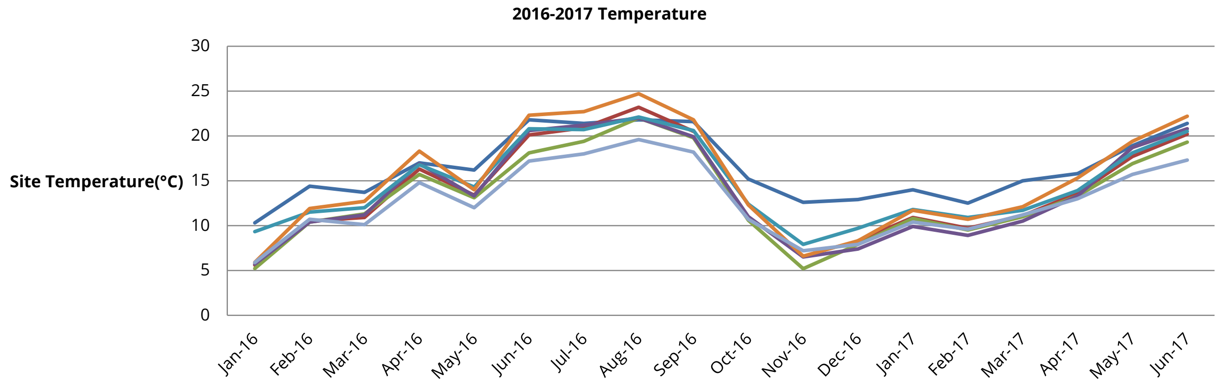
Wait 24 hours, re-calibrate the instrument, and collect new physical parameter readings.

- If readings are still deviant, investigate possible causes (e.g., defective equipment, storm surge/rain events, releases that may have affected pH, etc.).
- Following the investigation, report findings to appropriate program(s) within the office to determine if further action is needed.

Field and monitoring methods and health and safety procedures were followed according to the Tennessee Department of Health's Standard Operating Procedures (TDH 1999), and the DoR-OR Health and Safety Plan (TDEC 2017).

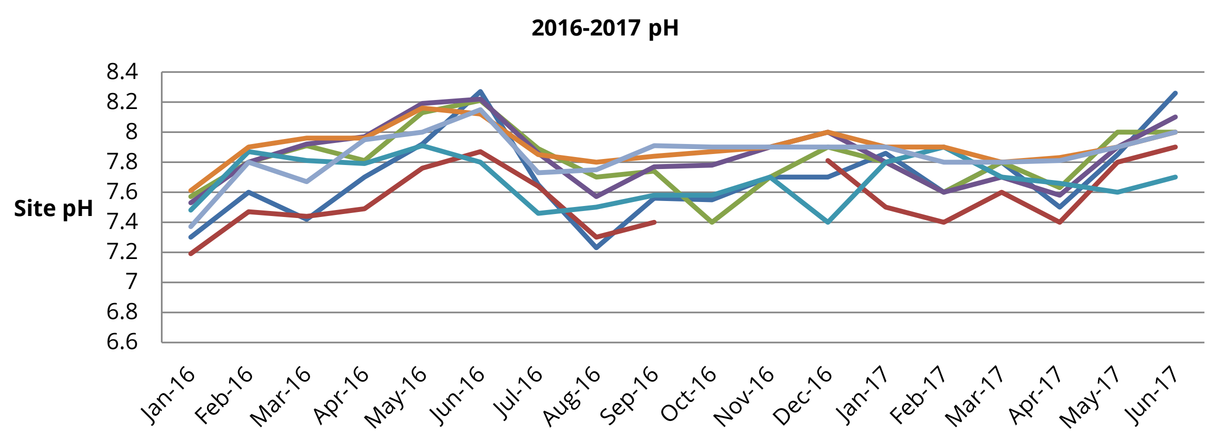
Results and Discussion

Field data was collected on a monthly basis from the seven monitoring sites. Figures 2.4.1.2, 2.4.1.3, 2.4.1.4, and 2.4.1.5 provide monthly temperatures, pH, conductivity, and dissolved oxygen results.



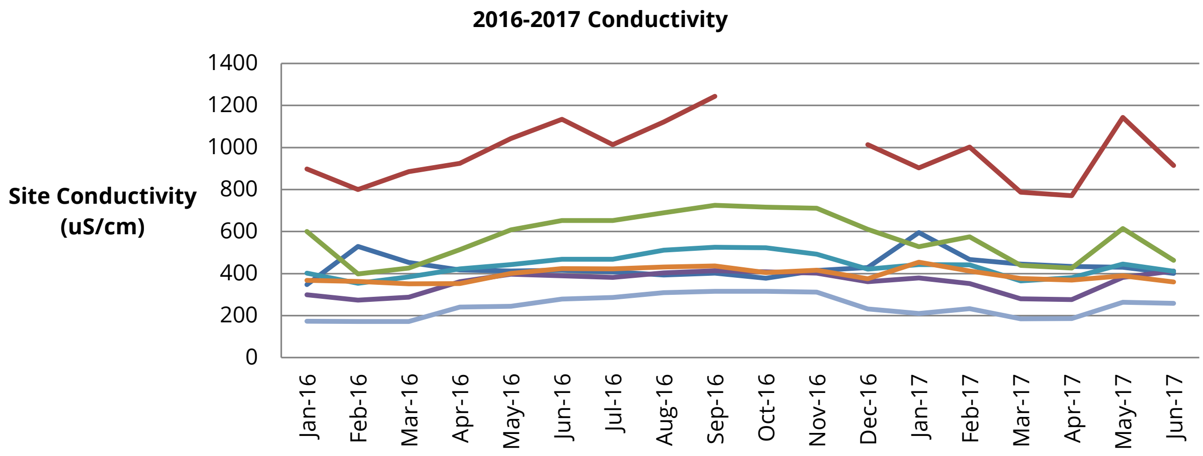
	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
EFK 23.4	10.3	14.4	13.7	17	16.2	21.8	21.4	21.8	21.6	15.2	12.6	12.9	14	12.5	15	15.8	18.9	21.4
BCK 12.3	5.6	10.5	10.9	16.3	13.4	20.1	20.9	23.2	20.5	DRY		8.3	10.9	9.7	11.1	13.6	17.7	20.2
BCK 9.6	5.21	10.4	11.3	15.7	13.1	18.1	19.4	22	19.8	10.6	5.2	7.9	10.8	9.5	11	13.3	16.9	19.3
BCK 4.5	5.7	10.4	11.2	16.9	13.3	20.6	21.2	22.0	19.9	11	6.5	7.4	9.9	8.9	10.5	13.3	18.7	20.8
MIK 0.1	9.32	11.5	12.0	16.8	14.3	20.8	20.7	22.1	20.6	12.4	7.9	9.7	11.8	10.9	11.7	13.9	18.1	20.5
EFK 13.8	5.91	11.9	12.7	18.3	14	22.3	22.7	24.7	21.8	12.3	6.6	8.3	11.7	10.7	12.1	15.3	19.4	22.2
MBK 1.6	5.88	10.7	10.1	14.8	12	17.2	18	19.6	18.2	10.7	7.2	7.9	10.4	9.6	11.2	13	15.7	17.3

Figure 2.4.1.2: 2016-2017 Monthly Temperature



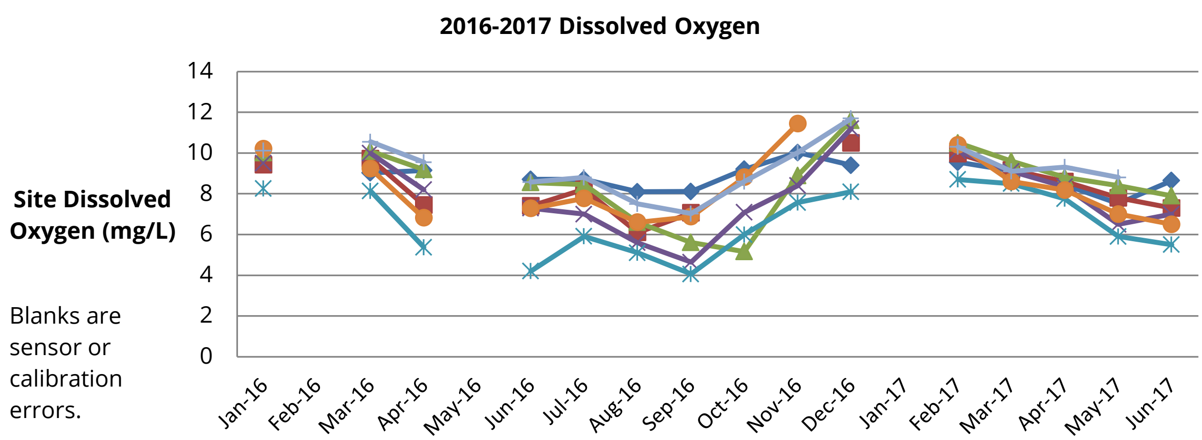
	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
EFK 23.4	7.3	7.6	7.42	7.7	7.92	8.27	7.65	7.23	7.56	7.55	7.7	7.7	7.86	7.6	7.8	7.5	7.85	8.26
BCK 12.3	7.19	7.47	7.44	7.49	7.76	7.87	7.64	7.3	7.4	DRY		7.81	7.5	7.4	7.6	7.4	7.8	7.9
BCK 9.6	7.57	7.8	7.91	7.81	8.13	8.21	7.89	7.7	7.74	7.4	7.7	7.9	7.8	7.6	7.8	7.63	8	8
BCK 4.5	7.53	7.8	7.92	7.97	8.19	8.22	7.86	7.57	7.77	7.78	7.90	8.00	7.8	7.6	7.7	7.58	7.9	8.1
MIK 0.1	7.48	7.87	7.81	7.79	7.91	7.8	7.46	7.5	7.58	7.58	7.7	7.4	7.8	7.9	7.7	7.66	7.6	7.7
EFK 13.8	7.61	7.9	7.96	7.96	8.16	8.12	7.85	7.8	7.84	7.87	7.9	8	7.9	7.9	7.8	7.83	7.9	8
MBK 1.6	7.37	7.8	7.67	7.95	8	8.15	7.73	7.75	7.91	7.9	7.9	7.9	7.9	7.8	7.8	7.81	7.9	8

Figure 2.4.1.3: 2016-2017 Monthly pH



	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
EFK 23.4	347	528.9	453.2	418	411.8	415.7	408.5	393	402.5	378.3	415.3	429.1	596	467.4	445	434.6	429.9	401.1
BCK 12.3	898	800.1	885	925	1043	1134	1013	1122	1244	DRY		1013	903	1002	787	771	1143	915
BCK 9.6	601	398.3	426.6	513.7	607.7	653	652	689	725	716	711.4	611	528	575	439	426	615	463.6
BCK 4.5	299	274.1	287.5	361.6	397.5	390	381.4	403.1	413.6	408.3	402.8	361.1	379	353	280	275.8	382	412.3
MIK 0.1	402	354.5	385	422	443.4	468.7	468.9	511.8	526	523.5	491.9	421	443	441	365	380.4	445	410.8
EFK 13.8	368	362.5	351.3	352.8	400.9	423.6	422	431.6	436	405	415.8	376.1	454	412.2	377	369.1	389	359.7
MBK 1.6	172.9	172.1	171.7	241.4	244.8	279.3	287	310	315.5	315.4	311.5	232.4	210	233	185	186.7	264	258.3

Figure 2.4.1.4: 2016-2017 Monthly Conductivity



	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
EFK 23.4	9.71		9.03	9.15		8.71	8.71	8.1	8.11	9.2	10.02	9.4		9.55	9.13	8.44	7.52	8.65
BCK 12.3	9.43		9.72	7.45		7.4	8.22	6.1	7.06			10.5		9.97	9.16	8.6	7.8	7.3
BCK 9.6	10.02		10.09	9.19		8.55	8.46	6.6	5.61	5.16	8.9	11.6		10.5	9.6	8.8	8.4	7.9
BCK 4.5	9.5		9.99	8.2		7.29	7	5.6	4.64	7.09	8.4	11.2		10.1	9.1	8.35	6.5	7
MIK 0.1	8.26		8.13	5.37		4.2	5.91	5.1	4.06	6	7.57	8.1		8.7	8.5	7.75	5.9	5.5
EFK 13.8	10.21		9.23	6.82		7.28	7.77	6.6	6.87	8.81	11.44			10.4	8.6	8.18	7	6.5
MBK 1.6	10.11		10.55	9.55		8.57	8.8	7.5	7.03	8.6	10.02	11.7		10.3	9.1	9.31	8.8	

Figure 2.4.1.5: 2016 through 2017 Monthly Dissolved Oxygen

Bear Creek km 12.3 consistently shows elevated conductivity values. There are no Tennessee Water Quality Criteria for conductivity to give perspective to the elevated values. Elevated conductivity levels indicate the presence of contaminants that suggest degraded surface water quality in Bear Creek. All three Bear Creek sites are located downstream of the legacy capped S-3 ponds and the Y-12 West End water treatment facility. It is thought that a contaminated groundwater plume has migrated into the surface water thus causing the elevated conductivity values in Bear Creek.

Conclusions

For the surface water physical parameters data, all samples met Tennessee water quality criteria for the parameters observed at the seven monitoring stations on the ORR. The elevated conductivity values observed in Bear Creek are of concern because they likely indicate the presence of contaminants such as dissolved metals. As legacy DOE ORR pollution has negatively affected East Fork Poplar Creek, Bear Creek, and Mitchell Branch, DoR-OR recommends continued physical parameter monitoring at the seven monitoring creek stations.

2.4.2 Ambient Surface Water Monitoring

Introduction

DoR-OR personnel collected surface water grab samples at two locations on the Clinch River and 19 locations on tributaries of the Clinch River to detect and assess contamination from DOE facilities in Oak Ridge, Tennessee. Due to the presence of anthropogenic point and non-point source contamination on the ORR, there exists the potential for pollution to impact surface waters on the ORR and downstream aquatic systems off-site. This project complements the Benthic Macroinvertebrate Monitoring Project; assessment of the water quality of a stream can more accurately determine the stream's total overall biological health. The evaluation of benthic macroinvertebrate communities is used to determine if a stream is supportive of fish and aquatic life. An integral element of this evaluation is the physical and chemical analysis of the stream's surface water.

Methods and Materials

DoR-OR personnel collected samples during May through June 2016 and in October of 2016. The tributaries were sampled in the spring, and the Clinch River locations were sampled in the fall. The tributaries were sampled again in the spring of 2017.

Since a major portion of the 2017 data has not yet been received from the lab, the 2017 results will be reported in the 2018 EMR. Table 2.4.2.1 lists the sampling locations. Figure 2.4.2.1 is a map of the sampling locations. Table 2.4.2.2 lists the test analyses, units, method detection limits (MDLs), method quantification limits (MQLs), and analytical methods. The data provide a baseline for evaluation of possible future changes.

Table 2.4.2.1: Ambient Surface Water Monitoring Locations

Sampling Locations					
Monitoring Location	**DWR ID**	**Alt. ID**	**Monitoring Rationale**	**Latitude**	**Longitude**
Clinch River Mile 17.9	CLINC017.9RO	CRK 28.8	Surveillance of water quality downstream of White Oak Creek outfall.	35.89809	-84.3738
Clinch River Mile 10.0	CLINC010.0RO	CRK 16.1	Surveillance of water quality downstream of all DOE ORR facilities.	35.92186	-84.42942
Raccoon Creek Mile 1.6	RACCO001.6RO	RCK 2.6	Surveillance of water quality possibly influenced by contaminated groundwater from SWSA 3.	35.91606	-84.33633
East Fork Poplar Creek Mile 15.6	EFPOP015.6AN	EFK 25.1	Surveillance of water quality at East Fork Poplar Creek (EFPC) headwaters.	35.98456	-84.2551
East Fork Poplar Creek Mile 15.2	EFPOP015.2AN	EFK 24.4	Surveillance of water quality at point downstream of the Y-12 West End Mercury Area (WEMA).	35.95922	-84.24282
East Fork Poplar Creek Mile 14.5	EFPOP014.5AN	EFK 23.4	Surveillance of water quality at point where EFPC leaves leaves DOE property and enters Oak Ridge.	35.99596	-84.24004
East Fork Poplar Creek Mile 8.6	EFPOP008.6AN	EFK 13.8	Surveillance of EFPC water quality just upstream of Oak Ridge sewage treatment outfall.	35.99283	-84.31371
East Fork Poplar Creek Mile 3.9	EFPOP003.9RO	EFK 6.3	Surveillance of EFPC water quality downstream of Oak Ridge.	35.96293	-84.35905
Bear Creek Mile 7.6	BEAR007.6AN	BCK 12.3	Surveillance of Bear Creek water quality near headwaters.	35.97300	-84.27814
Bear Creek Mile 6.0	BEAR006.0AN	BCK 9.6	Surveillance of Bear Creek water quality downstream of Environmental Management Waste Management Facility (EMWMF).	35.96032	-84.29741
Bear Creek Mile 2.0	BEAR002.0RO	BCK 3.3	Surveillance of Bear Creek water quality downstream of Y-12 footprint.	35.94354	-84.34911
Mitchell Branch Mile 0.9	MITCH000.9RO	MIK 1.43 *	Surveillance of Mitchell Branch (MIK) water quality upstream of ETTP.	35.93784	-84.37747
Mitchell Branch Mile 0.4	MITCH000.4RO	MIK 0.71	Surveillance of MIK water quality at a point influenced by ETTP activities.	35.93782	-84.38650
Mitchell Branch Mile 0.3	MITCH000.3RO	MIK 0.45	Surveillance of MIK water quality at a point influenced by ETTP activities.	35.93783	-84.38951
White Oak Creek Mile 4.2	WHITE004.2RO	WCK 6.8 *	Reference site upstream of ORNL.	35.90834	-84.31856
White Oak Creek Mile 2.4	WHITE002.4RO	WCK 3.9	Surveillance of White Oak Creek (WCK) at a point influenced by ORNL.	35.91778	-84.31612
White Oak Creek Mile 1.4	WHITE001.4RO	WCK 2.3	Surveillance of White Oak Creek (WCK) at a point downstream of Melton Valley Burial Grounds.	35.94151	-84.30161
Melton Branch Mile 0.2	MELTO000.2RO	MEK 0.3	Surveillance of Melton Branch (MEK) at a point influenced by Melton Valley Burial Grounds.	35.91123	-84.31423
Gum Hollow Branch Mile 1.8	GHOLL001.8RO	GHK 2.9 *	Reference site on Oak Ridge Reservation.	35.95469	-84.29821
Hinds Creek Mile 12.8	HINDS012.8AN	HCK 20.6 *	Reference site north of Oak Ridge.	36.15797	-83.99944
Mill Branch Mile 1.0	FECO67I12	MBK 1.6 *	Reference site in Oak Ridge.	35.98886	-84.28935

DWR ID = Division of Water Resources site designation

ID is an abbreviation of the stream name with the distance from mouth in km

* = Reference Streams

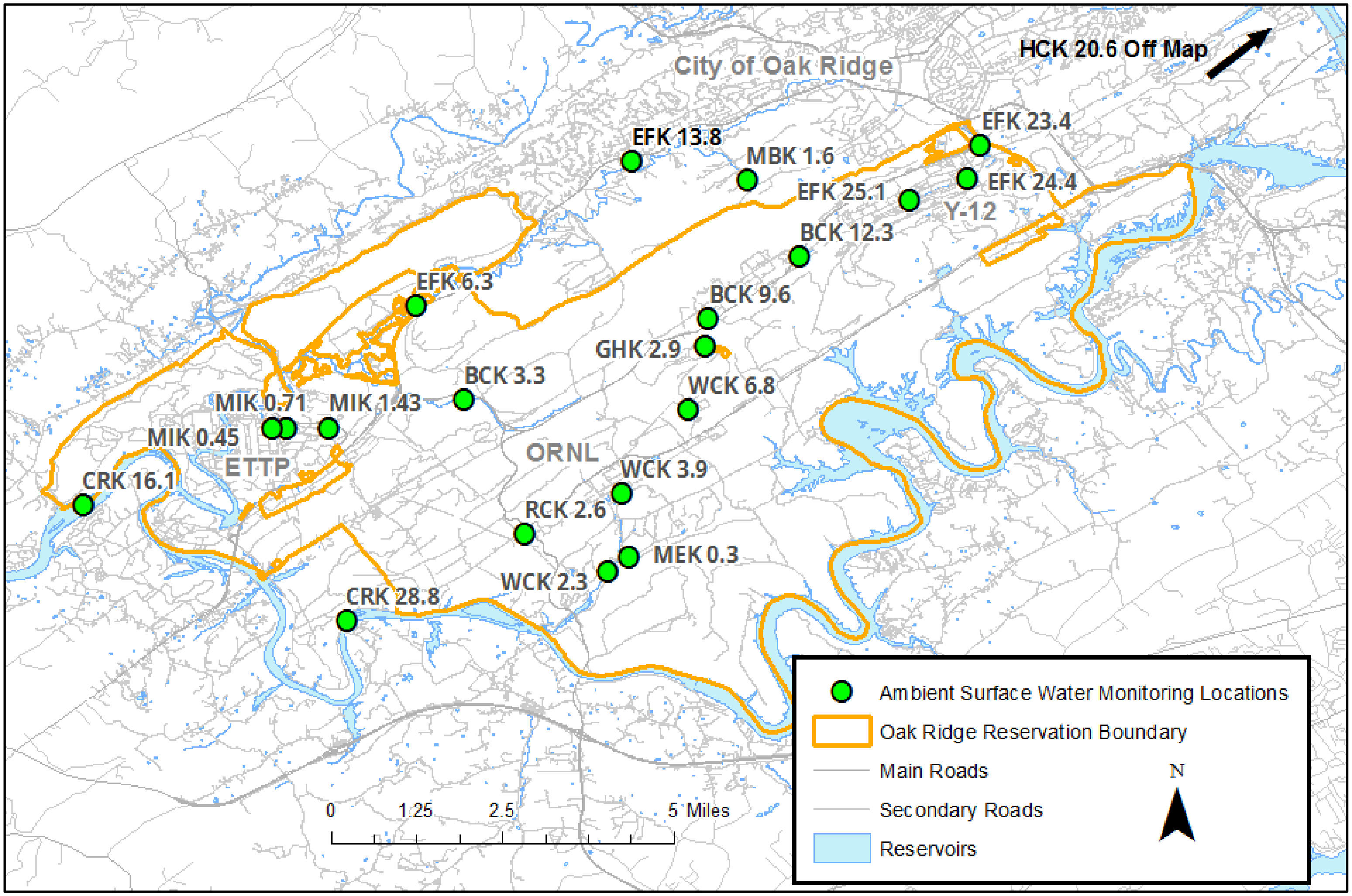


Figure 2.4.2.1: Map of Ambient Surface Water Monitoring Locations

Table 2.4.2.2: Test Analyses, Units, MDLs, MQLs, and Methods

Test Analyses, Units, MDLs, MQLs, and Methods					
Parameter	**Unit**	**MDL**	**MQL**	**Analytical Method Context**	**Analytical Method ID**
Ammonia-nitrogen	mg/l	0.025	0.10	APHA	4500-NH3(G)
Arsenic	µg/l	0.54	5	USEPA	200.8
Cadmium	µg/l	0.26	1	USEPA	200.8
Chromium	µg/l	0.90	5	USEPA	200.8
Copper	µg/l	0.40	1	USEPA	200.8
Dissolved oxygen (DO)	mg/l	0.01	0.01	USEPA	360.1
Hardness, Ca, Mg	mg/l	0.23	0.66	APHA_SM20ED	2340C
Inorganic nitrogen (nitrate and nitrite)	mg/l	0.036	0.10	APHA	4500-NO3(F)
Iron	µg/l	6.2	10	USEPA	200.8
Kjeldahl nitrogen	mg/l	0.16	0.50	USEPA	351.2
Lead	µg/l	0.28	1	USEPA	200.8
Manganese	µg/l	0.35	1	USEPA	200.8
Mercury	µg/l	0.046	0.2	USEPA	245.1
Nickel	µg/l	0.39	1	USEPA	200.8
pH	None	0.01	0.01	USEPA	150.1
Phosphorus	mg/l	0.015	0.050	APHA	4500-P-H
Specific conductance	µS/cm	0.1	0.1	USEPA	120.1
Temperature, water	deg C	0.01	0.01	USEPA	170.1
Total dissolved solids	mg/l	10	10	APHA	2540-C
Total suspended solids	mg/l	10	10	APHA	2540-D
Zinc	µg/l	1.1	5	USEPA	200.8
Parameter	**Unit**	**Rad Error**	**MDL**	**Analytical Method Context**	**Analytical Method ID**
Gross alpha radioactivity, (Thorium-230 ref std)	pC/L	0.43 - 2.9	1.8 - 2.4	USEPA	900
Gross beta radioactivity, (Cesium-137 ref std)	pC/L	1.9 - 4.4	3.5 - 4.0	USEPA	900
Strontium-89	pC/L	1.4	0.44	USEPA	901.1
Technetium-99	pC/L	0.24	0.69	USEPA	901.1
Strontium-90	pC/L	2.9	0.22	USEPA	901.1

USEPA: United States Environmental Protection Agency
APHA: American Public Health Association - Standard Methods for the Examination of Water and Wastewater.
APHA_SM20ED APHA Standard Method SM20ED

Results and Discussion

Bear Creek

Tables 2.4.2.3 and 2.4.2.4 present a summary of the 2016 surface water sample results for Bear Creek. BCK 12.3 is just to the west and downstream of the Y-12 legacy S-3 ponds, which are now capped. In the past, the S-3 ponds were used as holding basins for nitric acid and other wastes. It is believed that these ponds have created a plume of contaminated groundwater that has traveled to the west and migrated to the headwaters of Bear Creek. At BCK 12.3, the elevated specific conductance values are likely due to contaminated groundwater. Another concern in the Bear Creek watershed is the presence of uranium contamination. In the 1980s, within the Bear Creek Burial Grounds, it is estimated that approximately 20,500 tons of depleted uranium are buried.

Table 2.4.2.3: Bear Creek Ambient Surface Water Monitoring Results

Bear Creek Results							
Parameter	**BCK 12.3**	**BCK 9.6**	**BCK 3.3**	**Units**	**TWQC**	**GHK 2.9 (ref.)**	**MBK 1.6 (ref.)**
pH	7.56	7.56	7.79	None	5.5-9[a]	7.29	8.04
Specific conductance	1213.0	647	381	µS/cm	NA	267.4	249.1
Temperature, water	21.1	19.3	21.4	°C	<=30.5	14.4	15.2
Dissolved oxygen (DO)	**	**	7.54	mg/L	5.0[a]	**	9.56
Total dissolved solids	850	350	260	mg/L	NA	110	130
Total suspended solids	U	U	U	mg/L	NA	U	U
Arsenic	U	U	U	µg/L	10[c]	U	U
Cadmium	0.56J	U	U	µg/L	2.0[d]	U	U
Chromium	U	U	U	µg/L	16[e]	1.3J	1.5J
Copper	0.82J	0.51J	0.46J	µg/L	13[d]	U	U
Lead	U	U	0.32J	µg/L	5[f]/65[a]	U	U
Nickel	8.8	5.9	2.4	µg/L	470	0.93J	1.4
Zinc	1.6J	2J	1.9J	µg/L	120[d]	U	U
Mercury	U	U	U	mg/L	0.051[c]	U	U
Hardness, Ca, Mg	490	280	180	mg/L	NA	86	120

Tennessee Water Quality Criteria:

[a] Fish and Aquatic Life (FAL), applies to all sites

[c] Recreation (organisms only), applies to all sites

[d] Fish and Aquatic Life (FAL), applies to all sites. This value is for total hardness of 100mg/L

[e] FAL (Chromium VI)

** Equipment Error - failure of DO sensor or calibration error

J - signifies a figure that is between the Method Detection Limit and the Method Quantification Limit; it is an estimate.

U - Undetected

NA - not applicable

°C - degrees centigrade

mg/L - milligrams per Liter

µg/L - micrograms per Liter

pCi/L - pico Curies per Liter

µS/cm - micro Siemens per centimeter

Table 2.4.2.4: Bear Creek Radiological Results

Bear Creek Radiological Results in pCi/L				
Parameter	**BCK 12.3**	**BCK 9.6**	**BCK 3.3**	**HCK 20.6 (ref.)**
Gross alpha radioactivity, (Thorium-230 ref std)	54.8	18.1	4.8	0.28
Gross alpha combined standard uncertainty at 1-sigma	2.9	1.4	0.9	0.49
Gross beta radioactivity, (Cesium-137 ref std)	485	66.8	9.4	6.5
Gross beta combined standard uncertainty at 1-sigma	12	2.8	1.9	1.8

pCi/L - picoCuries per Liter

ref std - reference standard

Specific conductance was elevated at BCK 12.3 [1213 microSiemens per centimeter (µS/cm)] as compared to the Hinds Creek reference location (267.4 µS/cm), then decreased downstream to BCK 3.3 (381 µS/cm). Monthly specific conductance data from BCK 12.3 show no discernible trend over an 18-month period in 2016 to 2017 (Figure 2.4.2.2).

Figure 2.4.2.3 shows that gross alpha activities were the highest at BCK 12.3 (54.8 pCi/L), and decreased as the stream flowed downstream to BCK 3.3 (4.8 pCi/L). The reference location, Hinds Creek km 20.6, had an alpha value of 0.28 pCi/L. Gross beta activities were the highest at BCK 12.3 (485 pCi/L) and decreased as the stream flowed downstream to BCK 3.3 (9.4 pCi/L). The reference location, HCK 20.6, had a beta value of 6.5 pCi/L (Figure 2.4.2.4). TMI scores for Bear Creek show that BCK 12.3 is partially supporting/slightly impaired while BCK 9.6 and BCK 3.3 are supporting/non-impaired, as designated in TDEC (2006).

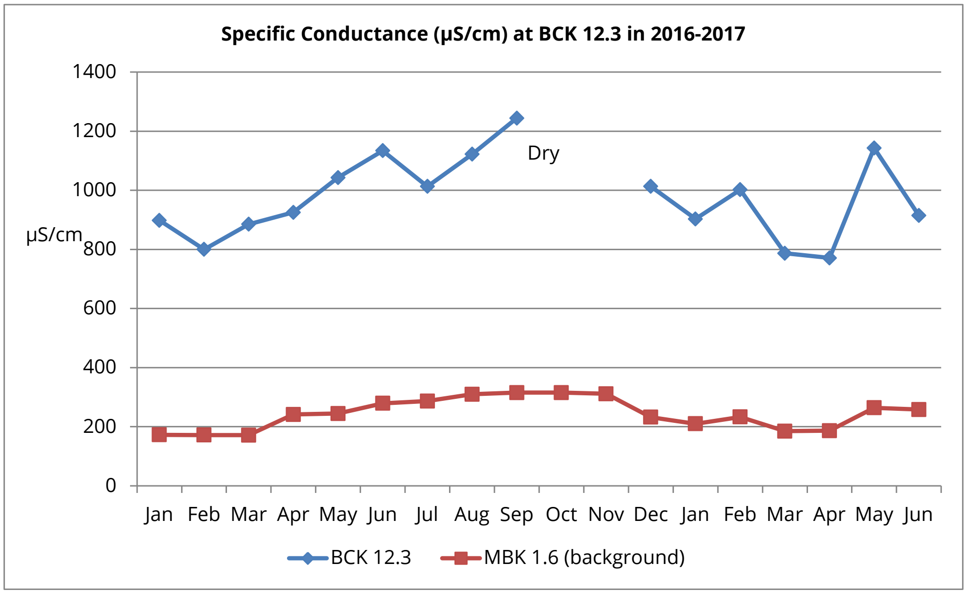


Figure 2.4.2.2: Specific Conductance at Bear Creek Km 12.3 (2016 through 2017)

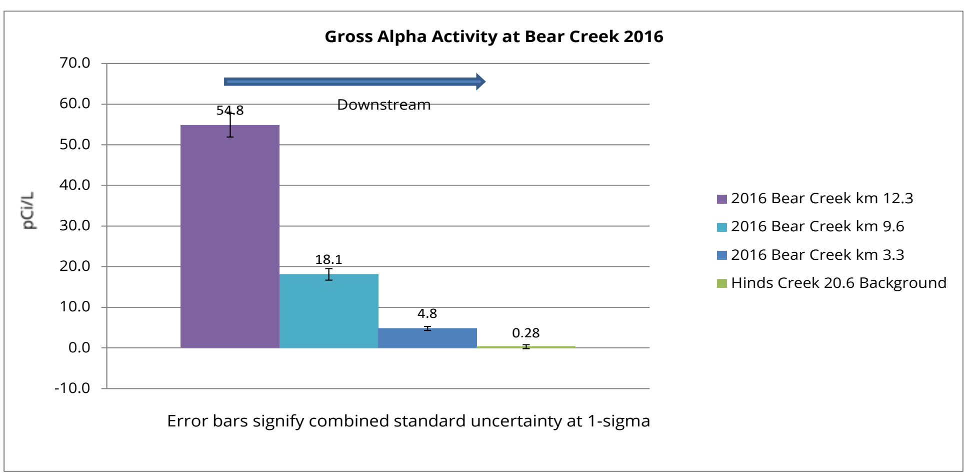


Figure 2.4.2.3: Gross Alpha Activity at Bear Creek

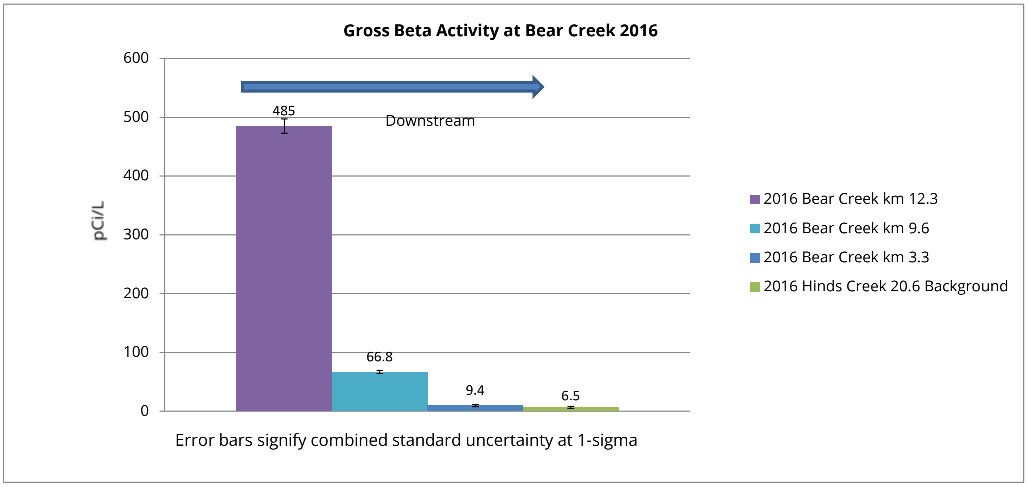


Figure 2.4.2.4: Gross Beta Activity at Bear Creek

East Fork Poplar Creek

Tables 2.4.2.5 and 2.4.2.6 present a summary of the 2016 through 2017 surface water sample results for East Fork Poplar Creek. Laboratory data indicate that the only detections of mercury were at the two uppermost sampling locations at EFK 25.1 and EFK 24.4. Both locations had values of 0.19J µg/L. A J value is an estimate between the minimum detection limit (MDL) and the method quantitation limit (MQL). These estimated values are higher than the Tennessee Water Quality Criteria for recreational uses.

Table 2.4.2.5: East Fork Poplar Creek Results

East Fork Poplar Creek Results								
Parameter	**EFK 25.1**	**EFK 24.4**	**EFK 23.4**	**EFK 13.8**	**EFK 6.3**	**Units**	**TWQC**	**HCK 20.6 (ref.)**
pH	7.93	7.96	8.05	8.07	8.08	None	5.5-9[a]	8.30
Specific conductance	489.5	510	460	403.1	397	µS/cm	NA	383
Temperature, water	19.90	18.6	17.2	15.2	15.80	°C	<=30.5	16.4
Dissolved oxygen (DO)	6.58	7.68	9.57	9.96	9.26	mg/L	5.0[a]	**
Ammonia-nitrogen	0.320	0.18	0.066J	0.058J	0.04J	mg/L	NA	0.025J
Inorganic nitrogen (nitrate and nitrite)	3.8	3.7	2.9	1.3	2.4	mg/L	NA	0.52
Total dissolved solids	290	280	280	240	240	mg/L	500[b]	220
Total suspended solids	U	U	U	U	U	mg/L	NA	U
Kjeldahl nitrogen	1.50	1.0	0.72	U	0.19J	mg/L	NA	U
Phosphorus	0.81	0.67	0.50	0.062	0.210	µg/L	NA	0.042J
Arsenic	U	U	U	U	U	µg/L	10[c]	U
Cadmium	0.97J	0.69J	0.45J	U	U	µg/L	2.0[d]	U
Chromium	1.5J	1.5J	1.5J	1.2J	1.2J	µg/L	16[e]	1.3J
Copper	20	15	10	1	1.4	µg/L	13[d]	0.44J
Lead	U	U	U	U	U	µg/L	5[f]/65[a]	U
Nickel	2.8	2.7	2.4	2.2	2.4	µg/L	470[d]	2.4
Zinc	58	44	29	1.6J	8.9	µg/L	120[d]	U
Mercury	0.19J	0.19J	U	U	U	mg/L	0.051[c]	U
Hardness, Ca, Mg	200	210	190	190	180	mg/L	NA	200

Tennessee Water Quality Criteria
[a] Fish and Aquatic Life (FAL), applies to all sites
[b] Industrial Water Supply, applies only to Clinch River Sites
[c] Recreation (organisms only), applies to all sites
[d] Fish and Aquatic Life (FAL), applies to all sites. This value is for total hardness of 100mg/L
[e] FAL (Chromium VI)
** Equipment Error - DO sensor failure or calibration error
J signifies a figure that is between the Method Detection Limit and the Method Quantification Limit; it is an estimate.
U - non detect
NA - not applicable
°C - degrees centigrade
mg/L - milligrams per Liter
µg/L - micrograms per Liter
pCi/L - pico Curies per Liter
µS/cm - microSiemens per centimeter

Table 2.4.2.6: East Fork Poplar Creek Radiological Results

East Fork Poplar Creek Radiological Results in pCi/L						
Parameter	**EFK 25.1**	**EFK 24.4**	**EFK 23.4**	**EFK 13.8**	**EFK 6.3**	**HCK 20.6 (ref.)**
Gross alpha radioactivity, (Thorium-230 ref std)	7.7	7.93	7.14	5.27	2.95	0.28
Gross alpha combined standard uncertainty at 1-sigma	0.96	0.97	0.94	0.88	0.82	0.49
Gross beta radioactivity, (Cesium-137 ref std)	9.4	9.7	9.1	6	5.4	6.5
Gross beta combined standard uncertainty at 1-sigma	1.9	1.9	1.9	1.8	1.8	1.8

pCi/L - picoCuries per Liter
ref std - reference standard

Figure 2.4.2.5 presents select nutrient data from the upstream location at km 25.1 to the farthest downstream location at km 6.3. There is a general decrease in values downstream. The increase between EFK 13.8 and EFK 6.3 may be due to the influence of the Oak Ridge wastewater treatment facility, which is just downstream of the EFK 13.8 sampling location.

Cadmium, copper, and zinc show a decreasing trend downstream of EFK 25.1; however, concentrations increase downstream of EFK 13.8, perhaps a result of discharges from the Oak Ridge wastewater treatment facility (Figure 2.4.2.6). Gross alpha values generally decrease from EFK 25.1 to EFK 6.3. All of these alpha values are higher than the reference location (Figure 2.4.2.7).Gross beta values also show a downward trend going downstream; they dip below the reference location's value (6.5 pCi/L) by EFK 13.8 (Figure 2.4.2.8). TMI scores for EFPC indicate that the stream is moderately impaired at the three uppermost sampling locations (EFK 25.1, 24.4, and 23.4). At EFK 13.8, the stream is supporting/non-impaired. At the most downstream sampling location, EFK 6.3, the TMI score drops again to partially supporting/slightly impaired.

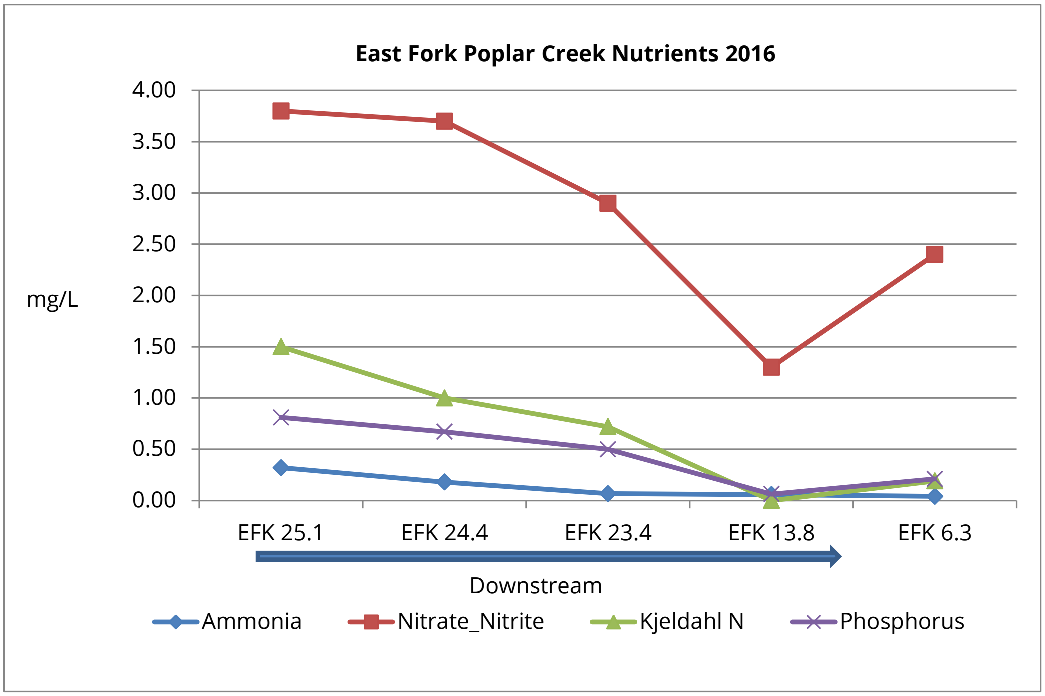


Figure 2.4.2.5: Nutrients in East Fork Poplar Creek 2016

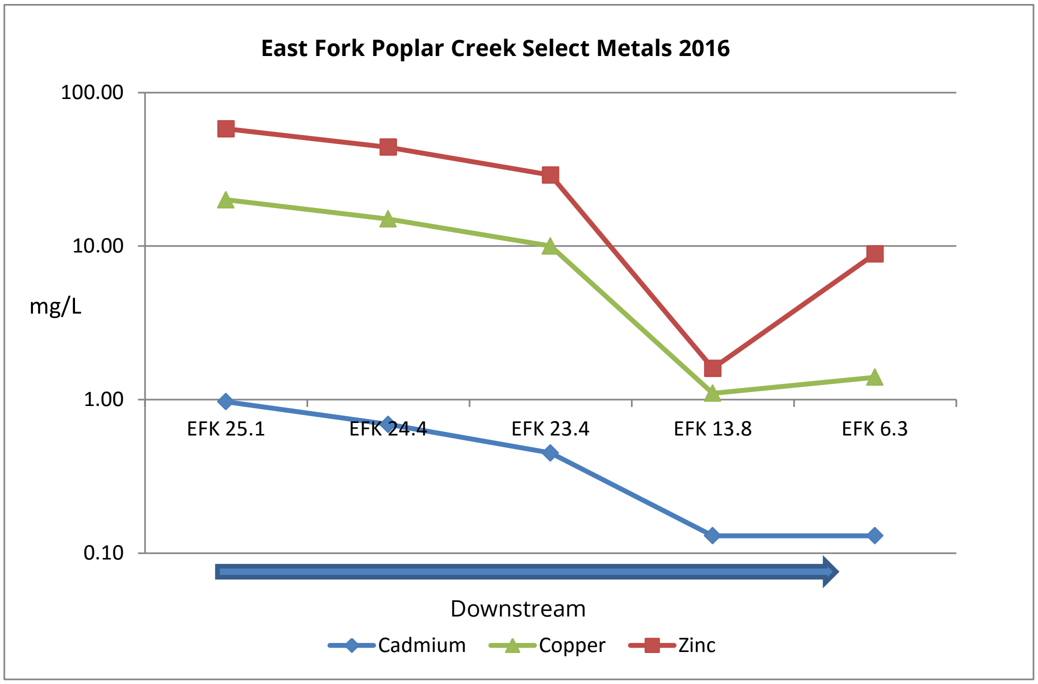


Figure 2.4.2.6: Cadmium, Copper, and Zinc in East Fork Poplar Creek 2016

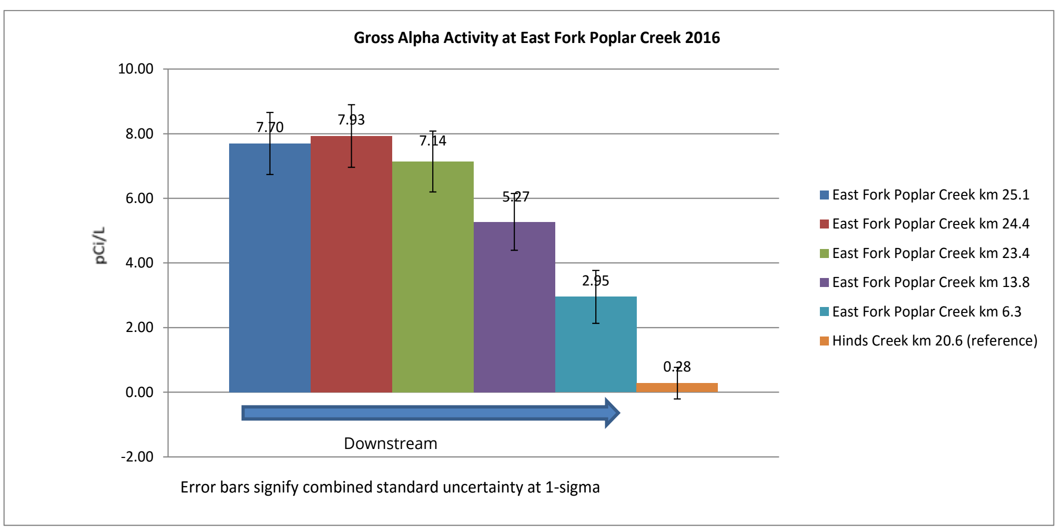


Figure 2.4.2.7: Gross Alpha Activity at East Fork Poplar Creek

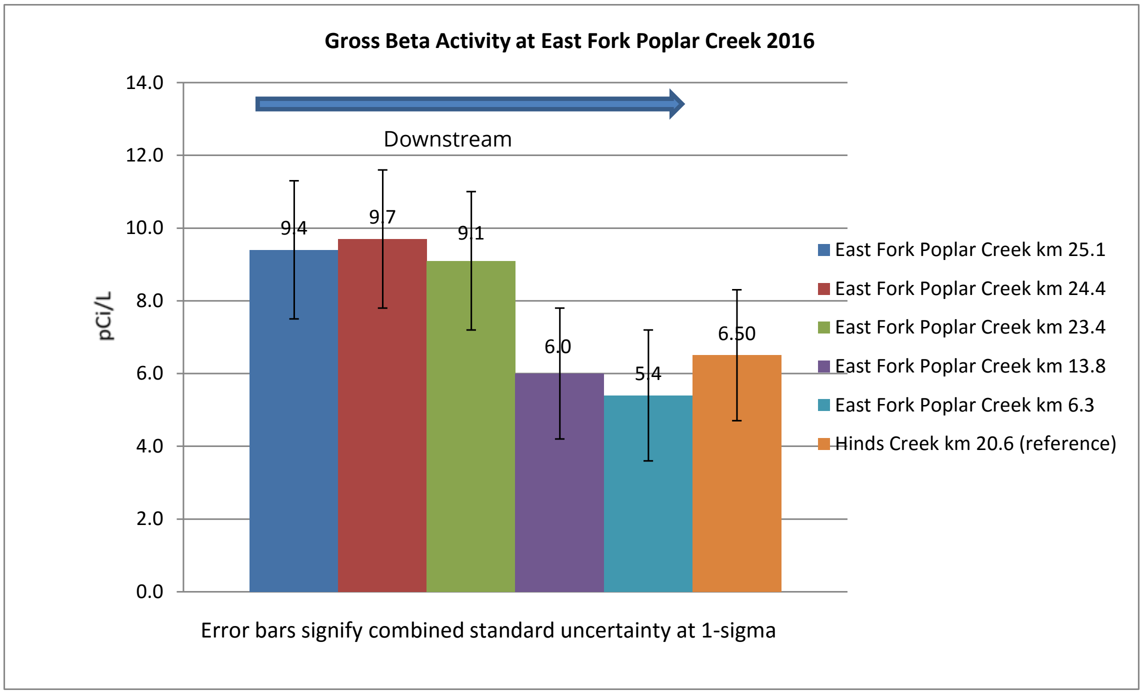


Figure 2.4.2.8: Gross Beta Activity at East Fork Poplar Creek

<u>Mitchell Branch</u>

Tables 2.4.2.7 and 2.4.2.8 present a summary data of the 2016 surface water sampling results for Mitchell Branch. Although some metals and nutrient values are higher than background locations, they are well below the Tennessee Water Quality Criteria (TWQC). The gross alpha activities at MIK 0.71 (4.24 pCi/L) and MIK 0.45 (5.20 pCi/L) were higher than those of the reference locations; reference locations MIK 1.43 and HCK 20.6 had alpha values of 0.25 and 0.28 pCi/L respectively (Figure 2.4.2.9).

The gross beta activities at MIK 0.71 (21.4 pCi/L) and MIK 0.45 (27.4 pCi/L) were higher than those of the reference locations; reference locations MIK 1.43 and HCK 2.06 had beta values of 11.7 and 6.5 respectively (Figure 2.4.2.10). All of the Mitchell Branch sampling locations were partially supporting/slightly impaired in terms of TMI scores.

Table 2.4.2.7: Mitchell Branch Surface Water Monitoring Results

Mitchell Branch Results						
Parameter	**MIK 0.71**	**MIK 0.45**	**MIK 1.43 (ref.)**	**HCK 20.6 (ref.)**	**TWQC**	**Units**
pH	7.97	7.66	8.25	8.30	5.5-9[a]	None
Specific conductance	378.9	436.0	188.5	383.0	NA	µS/cm
Temperature, water	17.0	16.3	15.6	16.4	<=30.5	°C
Dissolved oxygen (DO)	9.48	8.93	**	**	5.0[a]	mg/L
Ammonia-nitrogen	0.058J	0.051J	0.035J	0.025	NA	mg/L
Inorganic nitrogen (nitrate and nitrite)	0.14	0.21	0.075	0.52	NA	mg/L
Total dissolved solids	220	260	99	220	500[b]	mg/L
Total suspended solids	U	U	U	U	NA	mg/L
Kjeldahl nitrogen	U	U	U	U	NA	mg/L
Phosphorus	U	0.019J	U	0.042	NA	µg/L
Arsenic	U	U	U	U	10[c]	µg/L
Cadmium	U	U	U	U	2.0[d]	µg/L
Chromium	1.6J	2.7J	1.4J	1.2J	16[e]	µg/L
Copper	0.71	0.82	U	0.44	13[d]	µg/L
Lead	U	U	U	U	5[f]/65[a]	µg/L
Nickel	4.6	5.2	1.3	2.40	470[d]	µg/L
Zinc	3.1J	2.6J	U	U	120[d]	µg/L
Mercury	U	U	U	U	0.051[c]	mg/L
Hardness, Ca, Mg	190	210	99	200	NA	mg/l

Tennessee Water Quality Criteria:

[a] Fish and Aquatic Life (FAL), applies to all sites

[b] Industrial Water Supply, applies only to Clinch River Sites

[c] Recreation (organisms only), applies to all sites

[d] Fish and Aquatic Life (FAL), applies to all sites. This value is for total hardness of 100mg/L

[e] FAL (Chromium VI)

** Equipment Error

J signifies an estimate between the Method Detection Limit and the Method Quantification Limit.

U - non detect

NA - not applicable

°C - degrees centigrade

mg/L - milligrams per Liter

µg/L - micrograms per Liter

pCi/L - pico Curies per Liter

µS/cm - microSiemens per centimeter

Table 2.4.2.8: Mitchell Branch Radiological Results

Mitchell Branch Radiological Results in pCi/L				
Parameter	**MIK 1.43**	**MIK 0.71**	**MIK 0.45**	**HCK 20.6 (ref.)**
Gross alpha radioactivity, (Thorium-230 ref std)	0.25	4.24	5.20	0.28
Gross alpha combined standard uncertainty at 1-sigma	0.50	0.80	0.90	0.49
Gross beta radioactivity, (Cesium-137 ref std)	11.7	21.4	27.4	6.5
Gross alpha combined standard uncertainty at 1-sigma	1.9	2.0	2.1	1.8

pCi/L - picoCuries per Liter

ref std - reference standard

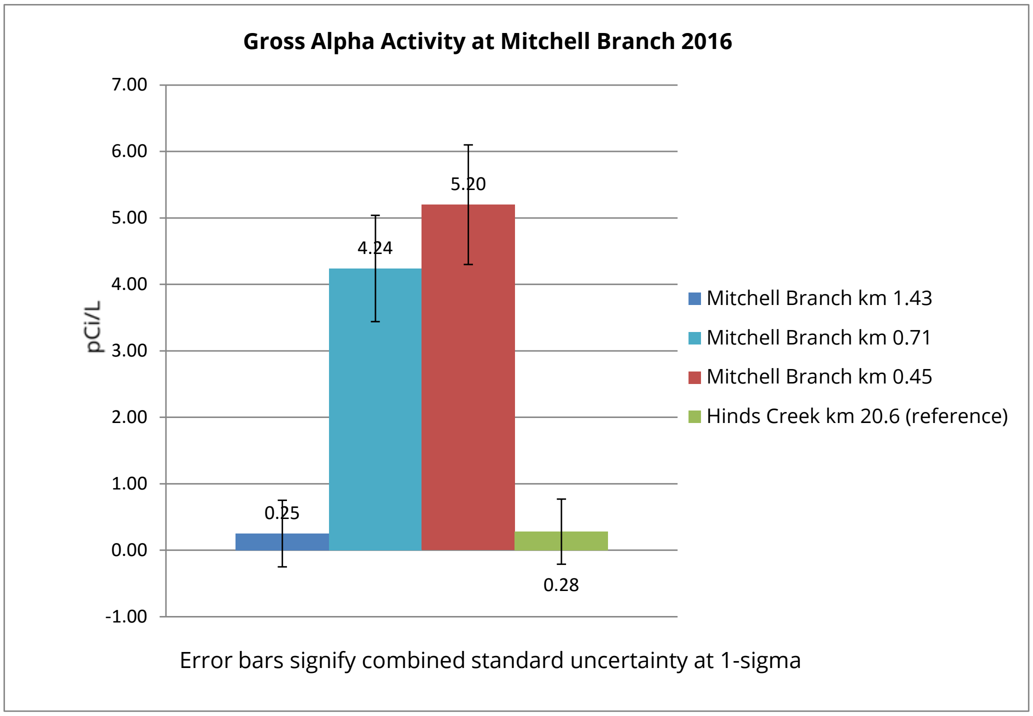


Figure 2.4.2.9: Gross Alpha Activity at Mitchell Branch 2016

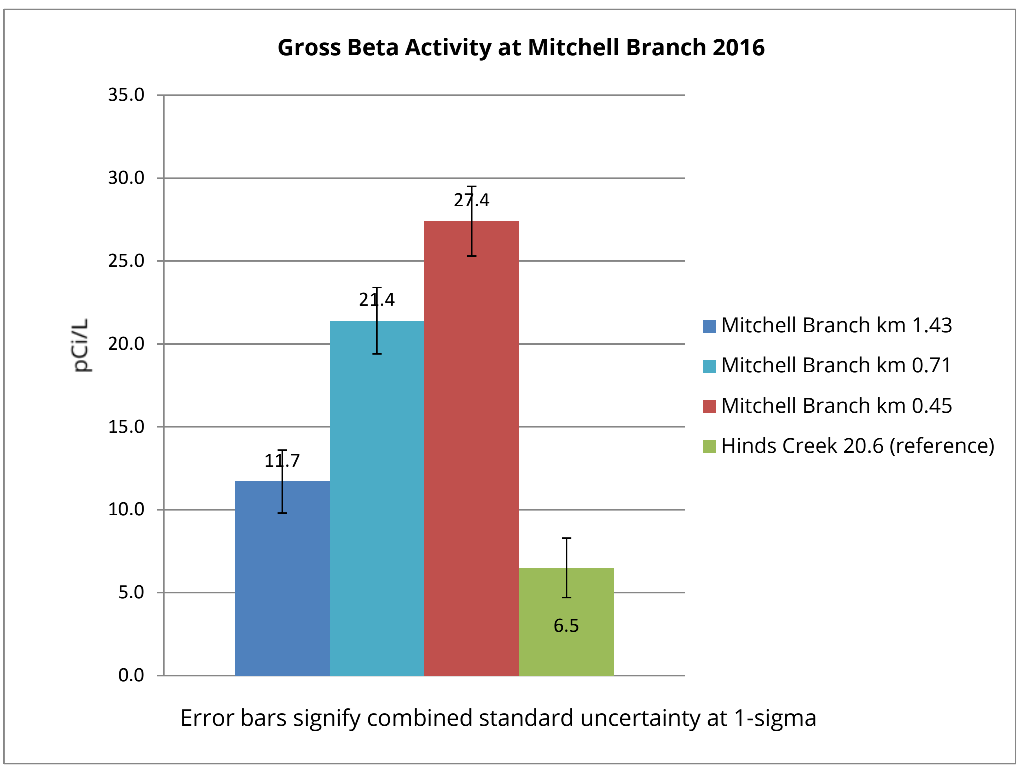


Figure 2.4.2.10: Gross Beta Activity at Mitchell Branch 2016

White Oak Creek and Melton Branch

Tables 2.4.2.9 and 2.4.2.10 present a summary of the 2016 surface water sampling results for White Oak Creek and Melton Branch.

- Although some metals values are higher than background locations, they are well below the TWQC.
- The gross alpha activities at WCK 3.9 (6.1 pCi/L), WCK 2.3 (11.7 pCi/L), and MEK 0.3 (25.6 pCi/L) were higher than that of the reference locations; reference locations WCK 6.8 and HCK 20.6 had alpha values of 0.02 and 0.28 pCi/L respectively (Figure 2.4.2.11).
- The gross beta activities at WCK 3.9 (110.7 pCi/L), WCK 2.3 (154.8 pCi/L) and MEK 0.3 (62.8 pCi/L) were higher than that of the reference locations; reference locations WCK 6.8 and HCK 20.6 had alpha values of 1.8 and 6.5 pCi/L respectively (Figure 2.4.2.12).
- WCK 6.8 (a reference location) was supporting/non-impaired with regard to the benthic macroinvertebrate community. The other White Oak Creek sampling locations (WCK 2.3, WCK 3.9) were partially supporting/slightly impaired. Melton Branch (MEK 0.3) was supporting/non-impaired.

Table 2.4.2.9: White Oak Creek Surface Water Monitoring Results

White Oak Creek Results						
Parameter	**WCK 2.3**	**WCK 3.9**	**WCK 6.8 (ref.)**	**MBK 1.6 (ref.)**	**TWQC**	**Units**
pH	7.82	8.14	8.40	8.04	5.5-9[a]	None
Specific conductance	450.4	438.2	293.6	249.1	NA	µS/cm
Temperature, water	21.7	20.6	16.5	15.2	<=30.5	°C
Dissolved oxygen (DO)	8.18	**	**	9.56	>5.0[a]	mg/L
Total dissolved solids	260	240	170	130	NA	mg/L
Total suspended solids	U	U	U	U	NA	mg/L
Arsenic	U	U	U	U	10.0[b]	µg/L
Cadmium	U	U	U	U	2.0[c]	µg/L
Chromium	U	U	U	1.5	16[d]	µg/L
Copper	5.30	12	U	U	13[c]	µg/L
Lead	0.39J	0.40J	U	U	65[c]	µg/L
Nickel	2.7	2.6	1.8	1.4	470[c]	µg/L
Zinc	6.2	19	1.3J	U	120	µg/L
Mercury	U	U	U	U	0.051[e]	µg/L
Hardness, Ca, Mg	180	180	150	120	NA	mg/L

TWQC - Tennessee Water Quality Criteria

[a] Fish and Aquatic Life (FAL), applies to all sites

[b] Recreation (organisms only), applies to all sites

[c] Fish and Aquatic Life (FAL), applies to all sites. This value is for total hardness of 100mg/L

[d] FAL (Chromium VI)

** Equipment error

J signifies a figure between the Method Detection Limit and the Method Quantification Limit; it is an estimate.

U - non detect

NA - not applicable

°C - degrees centigrade

mg/L - milligrams per Liter

µg/L - micrograms per Liter

pCi/L - pico Curies per Liter

µS/cm - microSiemens per centimeter

Table 2.4.2.10: White Oak Creek Radiological Results

White Oak Creek Radiological Results in pCi/L					
Parameter	**WCK 6.8**	**WCK 3.9**	**WCK 2.3**	**MEK 0.3**	**HCK 20.6 (ref.)**
Gross alpha radioactivity, (Thorium-230 ref std)	0.02	6.1	11.7	25.6	0.28
Gross alpha combined standard uncertainty at 1-sigma	0.47	1.00	1.60	3.30	0.49
Gross beta radioactivity, (Cesium-137 ref std)	1.8	110.7	154.8	62.8	6.5
Gross beta combined standard uncertainty at 1-sigma	1.8	3.5	4.4	2.6	1.8

pCi/L - picoCuries per Liter

ref std - reference standard

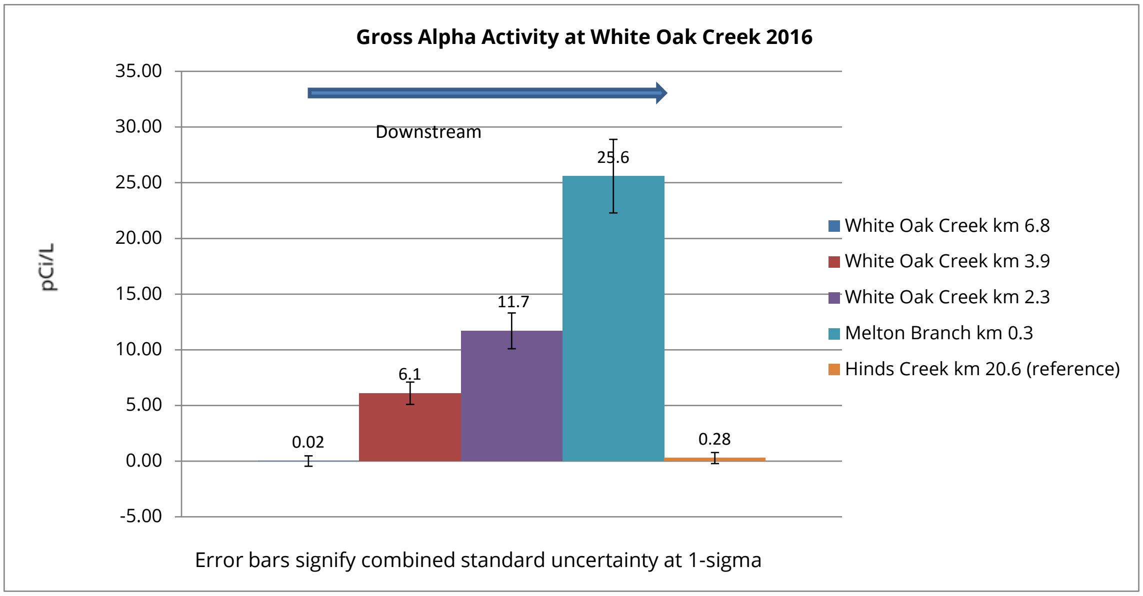


Figure 2.4.2.11: Gross Alpha Activity at White Oak Creek and Melton Branch 2016

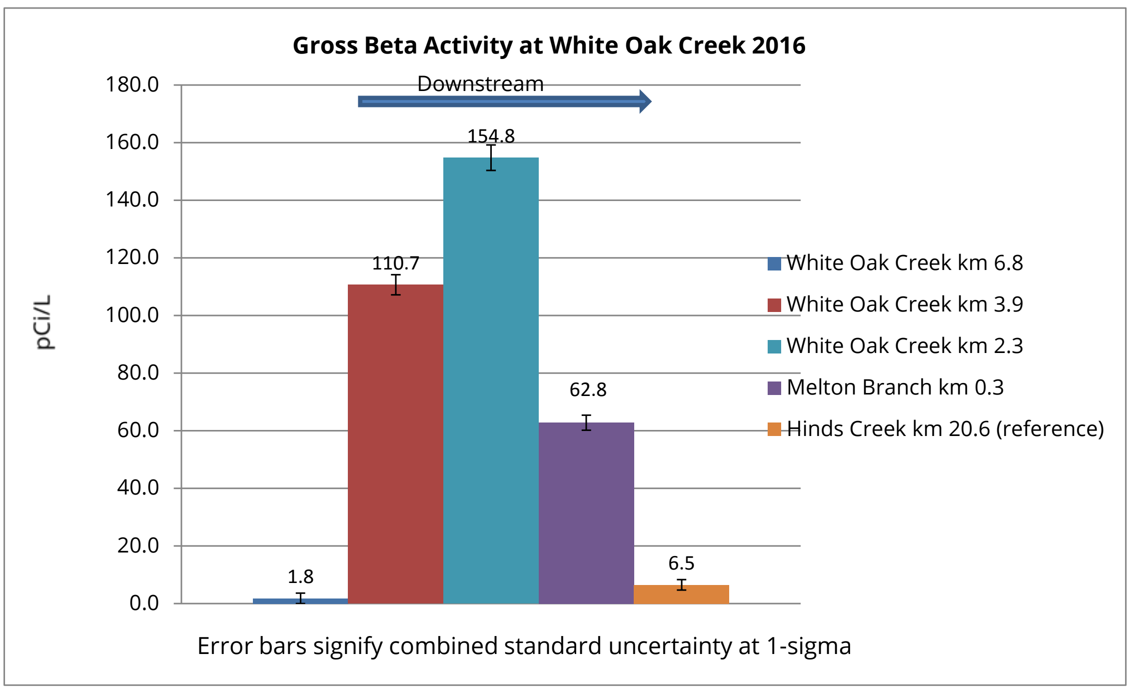


Figure 2.4.2.12: Gross Beta Activity at White Oak Creek and Melton Branch 2016

Raccoon Creek

Raccoon Creek is impacted by contaminated groundwater from SWSA 3; the primary radiological contaminant is strontium-90. Strontium-90 analysis of the sample collected at Raccoon Creek showed a value of 10.1 pCi/L. This value is above the EPA strontium-90 Maximum Contaminant Level (MCL) for drinking water of (8 pCi/L). The MCLs are used for comparison because there are no TWQC that address radionuclides. Radiological data are shown in Table 2.4.2.11. The metals data were all non-detects with the exception of nickel (8 µg/L). This value is greater than the MBK 1.6 reference location (1.4 µg/L), but less than the TWQC (470 µg/L). This stream was not sampled for nutrient characteristics.

Table 2.4.2.11: Raccoon Creek Radiological Results

Raccoon Creek Radiological Results in pCi/L		
Parameter	**RCK 2.6**	**HCK 20.6 (ref.)**
Gross alpha radioactivity, (Thorium-230 ref std)	5.75	0.28
Gross alpha combined standard uncertainty at 1-sigma	0.93	0.49
Gross beta radioactivity, (Cesium-137 ref std)	25.7	6.5
Gross beta combined standard uncertainty at 1-sigma	2.1	1.8
Strontium-89	0.50	NA
Strontium-89 combined standard uncertainty at 1-sigma	1.40	NA
Strontium-90	10.10	NA
Strontium-90 combined standard uncertainty at 1-sigma	2.90	NA
Technetium-99	-0.23	NA
Technetium-99 combined standard uncertainty at 1-sigma	0.24	NA

NA - no detected activity

pCi/L - picoCuries per Liter

ref std - reference standard

<u>Clinch River</u>

Sampling was conducted at two locations on the Clinch River: CRK 28.8 (mile 17.9) and CRK 16 (Mile 10). CRK 28.8 is just below Grubb Islands; this location is affected by ORNL's White Oak Creek outfall at CRK 33.5. The CRK 16 sampling location is near Brashear Island, and this location integrates with water discharged from all outfalls from DOE facilities in Oak Ridge. The data obtained from samples was collected at these locations in fall of 2016 (Tables 2.4.2.12 and 2.4.2.13) indicate that, based on the analyzed characteristics, TWQC were met.

Table 2.4.2.12: Clinch River Radiological Results

Clinch River Radiological Results in pCi/L		
Parameter	**CRK 28.8**	**CRK 16.1**
Gross alpha radioactivity, (Thorium-230 ref std)	0.13	-0.20
Gross alpha combined standard uncertainty	0.44	0.43
Gross beta radioactivity, (Cesium-137 ref std)	2.5	4.9
Gross beta combined standard uncertainty	1.9	1.9

ref std - reference standard

pCi/L - picoCuries per Liter

Table 2.4.2.13: Clinch River Surface Water Monitoring Results

Clinch River Results				
Parameter	**CRK 28.8**	**CRK 16**	**TWQC**	**Units**
pH	7.66	7.76	5.5-9[a]	None
Specific conductance	294.3	276.6	NA	µS/cm
Temperature, water	18.2	18.1	<=30.5	°C
Dissolved oxygen (DO)	5.5	**	5.0[a]	mg/l
Arsenic	0.86J	U	10[c]	µg/L
Cadmium	U	U	2.0[d]	µg/L
Chromium	U	U	16[e]	µg/L
Copper	0.94J	0.48J	13[d]	µg/L
Lead	U	U	5[f]/65[a]	µg/L
Nickel	1.9	1.4	470[c]	µg/L
Zinc	U	2J	120[d]	µg/L
Mercury	U	U	0.051[e]	µg/L
Hardness, Ca, Mg	130	120	NA	mg/l

*Tennessee Water Quality Criteria

[a] Fish and Aquatic Life (FAL), applies to all sites

[b] Industrial Water Supply, applies only to Clinch River Sites

[c] Recreation (organisms only), applies to all sites

[d] Fish and Aquatic Life (FAL), applies to all sites. This value is for total hardness of 100mg/L

[e] FAL (Chromium VI)

** Equipment Error

J- an estimate between the Method Detection Limit and the Method Quantification Limit.

µS/cm - microSiemens per centimeter

mg/L - milligrams per Liter

µg/L - micrograms per Liter

°C - degrees Celsius

NA - not applicable

U - non detect

Conclusions

Bear Creek

- Specific conductivity was elevated at BCK 12.3 (1213 µS/cm), as compared to the Hinds Creek reference location (267.4, µS/cm), then decreased downstream to BCK 3.3 (381 µS/cm Figure 2.4.2.3). Monthly specific conductance data from BCK 12.3 show no discernible trend over an 18-month period in 2016 through 2017 (Figure 2.4.2.2).
- Figure 2.4.2.3 shows that gross alpha activities were the highest at BCK 12.3 54.8 pCi/L), 3 (4.8 pCi/L). The reference location decreased as the stream flowed downstream to BCK 3. Hinds Creek km 20.6 (alpha value 0.28 pCi/L).

- Gross beta activities were the highest at BCK 12.3 (485 pCi/L), and decreased as the stream flowed downstream to BCK 3.3 (9.4 pCi/L). [The reference location, HCK 20.6, had a beta value of 6.5 pCi/L (Figure 2.4.2.4)].
- TMI scores for Bear Creek show that BCK 12.3 is partially supporting/slightly impaired while BCK 9.6 and BCK 3.3 are supporting/non-impaired.

<u>East Fork Poplar Creek</u>

- Figure 2.4.2.5 presents select nutrient data from the upstream location at km 25.1 to the farthest downstream location at km 6.3. There is a general decrease in values downstream. The increase between EFK 13.8 and EFK 6.3 may be due to the influence of the Oak Ridge wastewater treatment facility, which is just downstream of the EFK 13.8 sampling location.
- Cadmium, copper, and zinc show a decreasing trend downstream of EFK 25.1; however, concentrations increase downstream of EFK 13.8, perhaps a result of discharges from the Oak Ridge wastewater treatment facility (Figure 2.4.2.6).
- Gross alpha values generally decrease from EFK 25.1 to EFK 6.3. All of these alpha values are higher than the reference location (Figure 2.4.2.7).
- Gross beta values also show a downward trend going downstream; they dip below the reference location's value (6.5 pCi/L) by EFK 13.8.
- TMI scores for East Fork Poplar Creek indicate that the stream is moderately impaired at the three uppermost sampling locations (EFK 25.1, 24.4, and 23.4). At EFK 13.8, the stream is supporting/non-impaired. At the most downstream sampling location, EFK 6.3, the TMI score drops again to partially supporting/slightly impaired.

<u>Mitchell Branch</u>

- Although some metals and nutrient values are higher than background locations, they are well below the TWQC.
- The gross alpha activities at MIK 0.71 (4.24 pCi/L) and MIK 0.45 (5.20 pCi/L) were higher than those of the reference locations; reference locations MIK 1.43 and HCK 20.6 had alpha values of 0.25 and 0.28 pCi/L respectively (Figure 2.4.2.9).
- The gross beta activities at MIK 0.71 (21.4 pCi/L) and MIK 0.45 (27.4 pCi/L) were higher than those of the reference locations; reference locations MIK 1.43 and HCK 2.06 had beta values of 11.7 and 6.5 respectively (Figure 2.4.2.10).
- All of the Mitchell Branch sampling locations were partially supporting/slightly impaired in terms of TMI scores.

<u>White Oak Creek</u>

- Although some metals values are higher than background locations, they are well below the Tennessee Water Quality Criteria (TWQC).

- The gross alpha activities at WCK 3.9 (6.1 pCi/L), WCK 2.3 (11.7 pCi/L), and MEK 0.3 (25.6 pCi/L) were higher than that of the reference locations; reference locations WCK 6.8 and HCK 20.6 had alpha values of 0.02 and 0.28 pCi/L respectively (Figure 2.4.2.11).
- The gross beta activities at WCK 3.9 (110.7 pCi/L), WCK 2.3 (154.8 pCi/L), and MEK 0.3 (62.8 pCi/L) were higher than that of the reference locations; reference locations WCK 6.8 and HCK 20.6 had alpha values of 1.8 and 6.5 pCi/L respectively (Figure 2.4.2.12)
- WCK 6.8 (a reference location) was supporting/non-impaired with regard to the benthic macroinvertebrate community. The other White Oak Creek sampling locations (WCK 2.3, WCK 3.9) were partially supporting/slightly impaired. Melton Branch (MEK 0.3) was supporting/non-impaired.

Raccoon Creek

- Strontium-90 analysis from the sample collected at Raccoon Creek showed a value of 10.1 pCi/L. This value is above the EPA strontium-90 Maximum Contaminant Level (MCL) for drinking water of eight pCi/L. The MCLs are used for comparison because there are no TWQC that address radionuclides. Radiological data are shown in Table 2.4.2.11.
- The metals data were all non-detects with the exception of nickel (8 μg/L). This value is greater than the MBK 1.6 reference location (1.4 μg/L), but less than the TWQC (470 μg/L).

Clinch River

The data obtained from Clinch River samples collected in the fall of 2016 (Tables 2.4.2.12 and 2.4.2.13) indicate that, based on the analyzed characteristics, TWQC were met.

2.4.3 Rain Event Surface Water Monitoring

Introduction

Heavy rains may lead to point and non-point source contaminant releases to streams on the ORR. These rain events, defined as one inch or more of rain in a 24-hour period or two inches or more in a 72-hour period, have the potential to displace contamination at greater levels than a rain event of lesser magnitude. Additionally, a heavy rain event may cause the release of an unidentified contaminant or one that has previously been of little concern.

This sampling program has been established to assess the degree of impact, if any, caused by heavy rain events. Beginning in January 2016, seven locations originating on the ORR were sampled quarterly. Mill Branch serves as a reference location and is located off of the ORR. Table 2.4.3.1 and Figure 2.4.3.1 show locations that were selected for sampling. Figure 2.4.3.2 shows DoR-OR personnel collecting water samples and field parameters following a storm event.

Table 2.4.3.1: Rain Event Surface Water Monitoring Locations in Kilometers (mile equivalents)

Sample locations in Kilometers (mile Equivalents)	
Site	**Location**
EFK 23.4 (14.5)	East Fork Poplar Creek (Station 17)
WCK 0.0 (0.0)	White Oak Creek (Weir at Clinch River)
BCK 4.5 (2.8)	Bear Creek (Weir at Hwy. 95)
MIK 0.1 (0.06)	Mitchell Branch (Weir at ETTP)
SD 430	Storm Drain located at ETTP
SD 490	Storm Drain located at ETTP
P1 Pond Weir	Weir located at ETTP
MBK 1.6 (1.0)	Mill Branch (Reference)

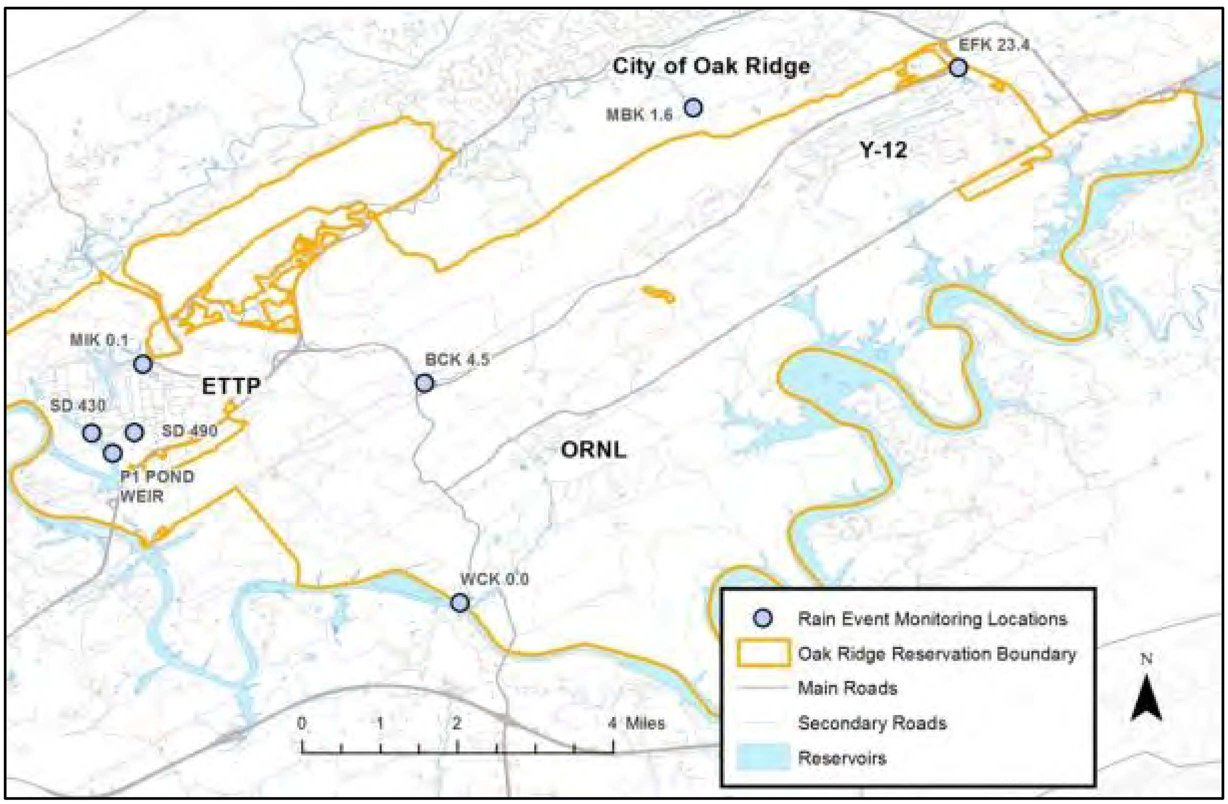


Figure 2.4.3.1: Map of Rain Event Surface Water Monitoring Locations

Figure 2.4.3.2: DoR-OR Personnel Collecting Samples Following a Rain Event

Methods and Materials

Qualifying rain event samples were collected following rain events during each calendar quarter starting in January 2016 through June 2017. Samples were scheduled on the following days: February 3, 2016, June 6, 2016, August 22, 2016, December 1, 2016, January 23, 2017 and April 4, 2017. However, due to a change in entrance policy, samples at WCK 0.0 were unable to be collected on June 6, 2016.

Figure 2.4.3.3 illustrates data for the six sampling events that exceeded the one-inch within a 24-hour period or two inches in a 72-hour period as recorded at the Oak Ridge Office of the National Oceanic and Atmospheric Administration data site. The following field parameters were taken at each site using an YSI© meter: pH, temperature, dissolved oxygen, and conductivity. Figures 2.4.3.3 through 2.4.3.7 show the recorded field parameters. Surface water samples collected during this period were analyzed for the following parameters:

Metals: Arsenic, chromium, copper, lead, manganese, zinc, mercury and iron were analyzed for all locations. Cadmium was analyzed in January 2016 for all sample locations. After a review of sampling history, a decision was made to begin sampling cadmium in June 2016 at EFK 23.4, BCK 4.5, MBK 1.6, and SD 430.

Samples were collected for hexavalent chromium analysis at MIK 0.1, SD 490, SD 430, and the P1 Pond Weir during each sampling event. Water samples were tested for uranium at the P1 Pond Weir, SD 490, SD 430, and MBK 1.6.

Radionuclides: analysis for gross alpha and gross beta was conducted at all sites during each event.

Samples were collected for strontium-90 and gamma radionuclides analysis at WCK 0.0 during all events, except during the June 6, 2016 rain event. Samples for gamma radionuclides analysis were collected during the first quarter at BCK 4.5, P1 Pond Weir, SD 430, and MBK 1.6. A review of past data led to the decision to discontinue sampling for gamma radionuclides except at WCK 0.0. Rain event samples were collected for tritium and technetium-99 analysis (Tc-99) at SD 490 and P1 Pond Weir during all events. Samples were collected for Tc-99 analysis at SD 430 during all events.

PCBs: Polychlorinated biphenyls were sampled at SD 430 during all sample events.

Solids: Beginning in June 2016, residue solids were sampled at EFK 23.14, BCK 4.5, and MIK 0.1. In August 2016, MBK 1.6 and WCK 0.0 sample sites were added. These sample sites were selected to compare rain event samples to samples collected under the ambient surface water program.

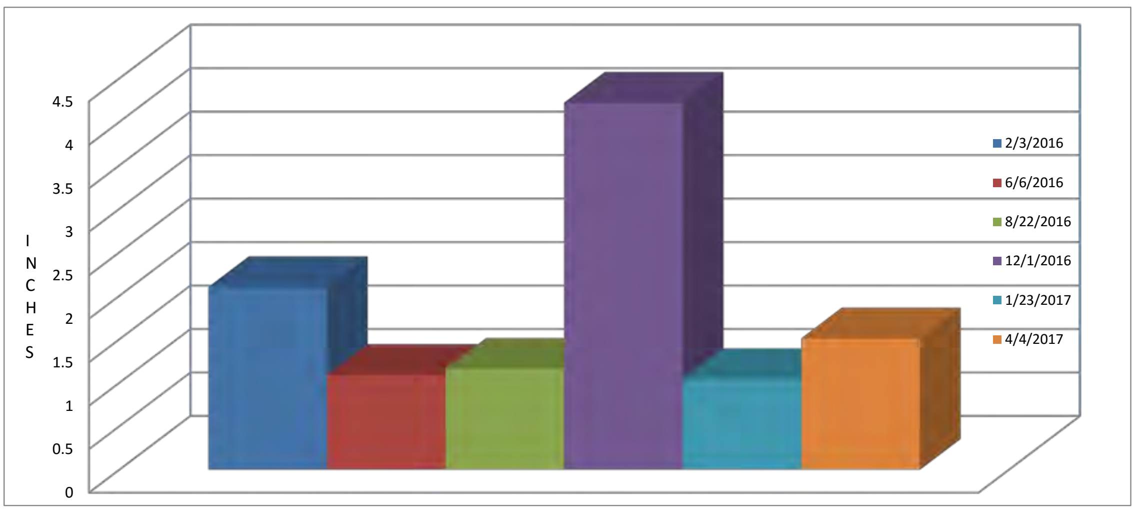


Figure 2.4.3.3: Qualifying Rain Events for Each Sampling Event

Results and Discussion

Relative to the six rain events, summarized field parameters are presented in Figures 2.4.3.4 through 2.4.3.7. The results of metal analysis are shown in Table 2.4.3.2. The results of the gross alpha, gross beta and gamma radionuclide scans are shown in Table 2.4.3.3 and Table 2.4.3.4.

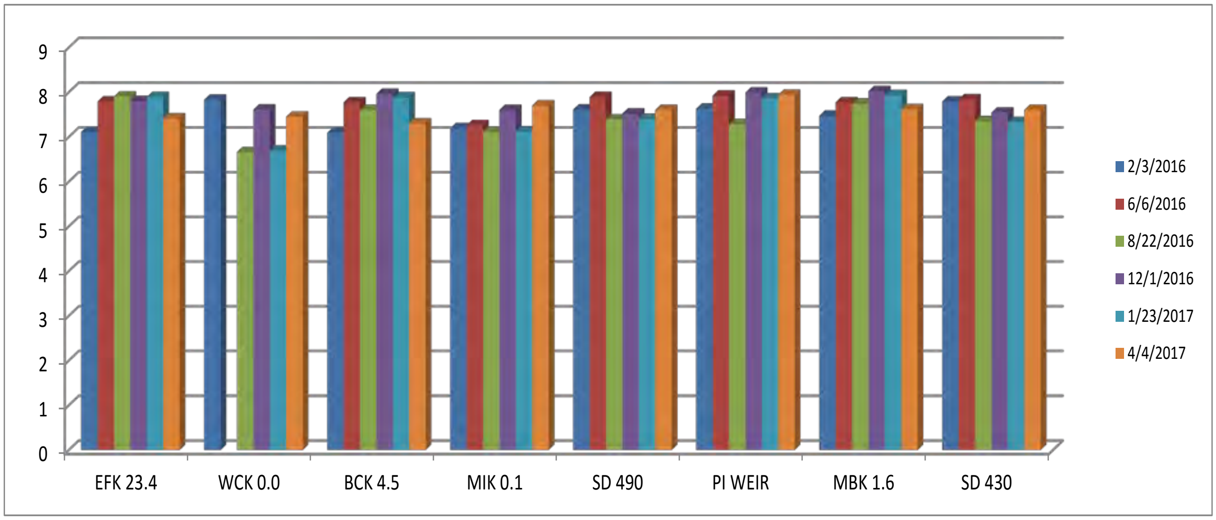


Figure 2.4.3.4: Field pH Measurements

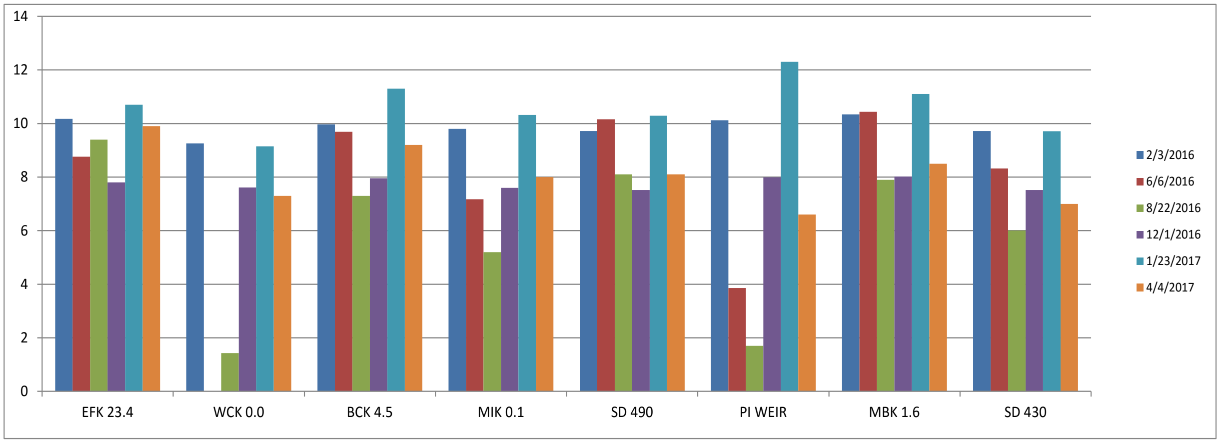


Figure 2.4.3.5: Dissolved Oxygen in mg/L

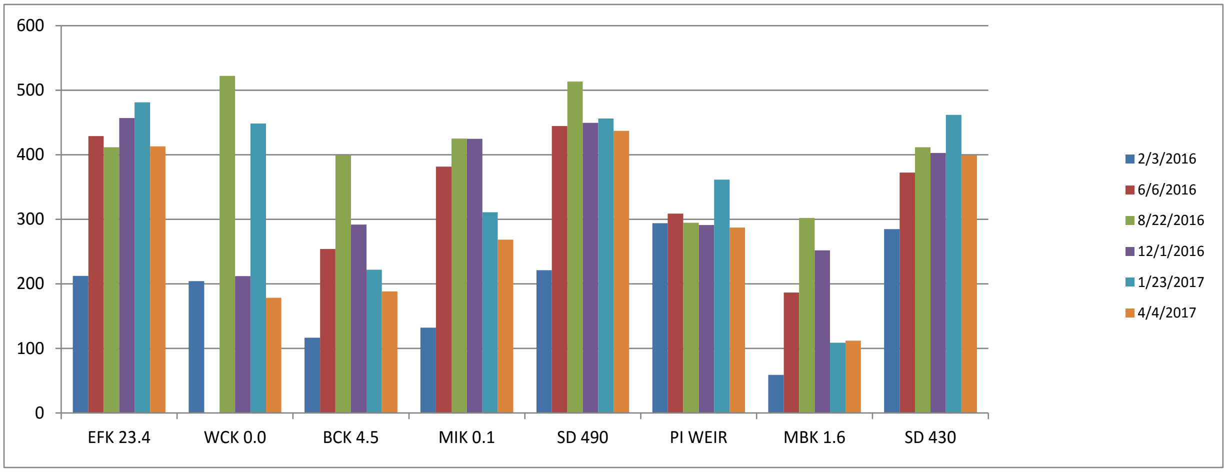


Figure 2.4.3.6: Conductivity in µS/cm (MicroSiemens per Centimeter)

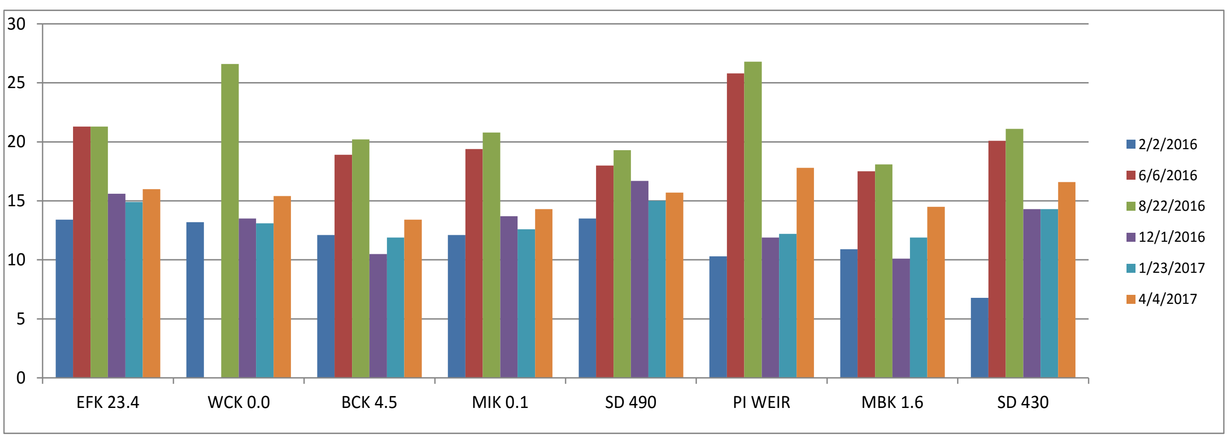


Figure 2.4.3.7: Temperature in Degrees Celsius

Table 2.4.3.2: Metals Analysis

Metals Analysis											
SITE	As µg/L	Cd µg/L	Cr µg/L	Cr(hex) µg/L	Cu µg/L	Fe µg/L	Pb µg/L	Mn µg/L	Hg µg/L	Zn µg/L	U µg/L
			2/2/2016								
EFK 23.4	1.0J	U	3.1J		4.9	2400	4	150	0.53	40	
WCK 0.0	0.72J	U	4.5J		4.6	2400	3.6	180	U	24	
BCK 4.5	1.2J	0.7	8		6.3	6700	11	800	0.078J*	32	
MIK 0.1	1.8J	U	4.2J	U	11	2700	6.2	260	U	31	
SD 490	U	U	1.8J	U	3	660	2.8	42	U	28	1.3
P1 WEIR	U	U	1.2J	U	1.4	610	1.2	84	U	8.9	0.51J
MBK 1.6	U	U	1.6J		1.8	1600	2	110	U	6	U
SD 430	2.9J	1.1	28	U	15	14000	65	260	U	210	1.7
			6/6/2016								
EFK 23.4	U	U	0.94J		3.4	150	U	34	0.15J*	14	
WCK 0.0**											
BCK 4.5	U	U	1.1J		1.3	800	0.71J	74	U	4.8J	
MIK 0.1	U		2.5J	U	3.8	510	0.98J	150	U	9.4	
SD 490	U		1.9J	U	1.1	80	U	110	U	7.8	1.5
P1 WEIR	U		U	U	U	250	U	490	U	2.6J	0.30J
MBK 1.6	U	U	U		0.56J	520	U	47	U	3.1J	U
SD 430	U	U	3.8J	U	1.9	440	3	98	U	31	0.73J
			8/22/2016								
EFK 23.4	U	U	2.5J		3.5	93	U	65	U	20	
WCK 0.0	1.2J		1.1J		1.3	310	0.45J	460	U	4.3J	
BCK 4.5	U	U	U		U	220	U	91	U	1.4J	
MIK 0.1	U		1.9J	U	2.1	190	0.30J	120	U	4.0J	
SD 490	U		2.6J	U	0.89J	62	U	170	U	6.8	1.2
P1 WEIR	U		U	U	U	430	U	1100	U	1.5J	U
MBK 1.6	U	U	U		U	220	U	86	U	1.5J	U
SD 430	U	U	9.9	U	0.87J	150	1.3	12	U	13	1.9
			12/1/2016								
EFK 23.4	U	U	1.6J		6.5	160	U	32	0.22	16	
WCK 0.0	0.61J		4.1J		4	860	1.3	150	U	9.9	
BCK 4.5	U	U	1.5J		1.7	570	0.63J	54	U	2.9J	
MIK 0.1	U		3.2J		2.3	98	U	53	U	4.0J	
SD 490	U		2.5J		1.2	60	U	60	U	7.3	4.4
P1 WEIR	U		1.0J		0.90J	910	0.36J	110	U	4.9J	0.51J
MBK 1.6	U	U	1.6J		0.69J	360	U	32	U	1.3J	
SD 430	U	U	7.4		2.4	330	1.6	19	U	19	1.1
			1/23/2017								
EFK 23.4	U	U	U		2.2	130	0.28J	26	U	15	
WCK 0.0	U		3.1J		3.9	830	1.1	190	U	9.8	
BCK 4.5	U	U	1.7J		1.5	1200	1.1	67	U	6.1	
MIK 0.1	U		1.7J	U	4.1	530	0.80J	45	U	12	
SD 490	U		2.0J	U	1.1	72	U	72	U	17	4.7
P1 WEIR	U		U	U	0.47J	420	U	320	U	1.9J	1
MBK 1.6	U	U	0.92J		.082J	690	0.50J	38	U	2.8J	U
SD 430	U	U	5		2.1	160	1.1	8.1	U	11	1.3
			4/4/2017								
EFK 23.4	U	U	1.5		3	170	U	29	0.073	15	
WCK 0.0	U		4.0J		3.1	1400	1.6	100	U	12	
BCK 4.5	U	U	1.9J		0.74J	710	0.66J	52	U	3.8J	
MIK 0.1	U		2.1J	U	1.7	400	0.45J	39	U	5.5	
SD 490	U		3.0J	U	0.70J	75	U	84	U	10	5
P1 WEIR	U		1.8J	U	0.47J	310	U	180	U	3.4J	0.66J
MBK 1.6	U	U	1.7J		0.53J	510	0.35J	34	U	3.5J	U
SD 430	U	U	5.7	U	1.8	740	1.9	16	U	17	1.1

µg/L= micrograms per Liter
U= Undetected
J= Estimated Value between MDL and MQL
* Result verified to be accurate
** Not sampled due to scheduling error

The levels of chromium at site MIK 0.1 continue to be elevated, likely due to the history of CERCLA clean-up activities in the vicinity of the stream. Figure 2.4.3.8 illustrates MIK 0.1 chromium concentrations sampled during storm events which encompass years 2014 through 2017.

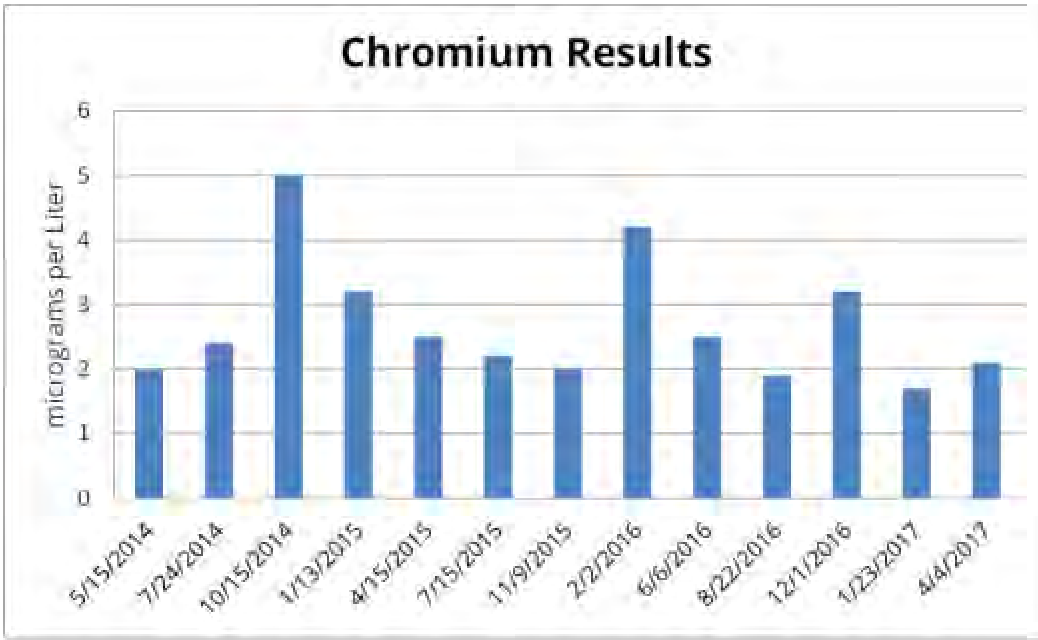


Figure 2.4.3.8: Chromium Results in µg/L at MIK 0.1

Site EFK 23.4 exhibited mercury concentrations which were higher than the TWQC for recreation (organisms only) Criterion Maximum Concentration of 0.051 µg/L. The EFK 23.4 elevated values were 0.53 µg/L (2/2/2016), 0.15 µg/L (6/6/2016), 0.23 µg/L (12/2/2016), and 0.073 µg/L (4/4/2017). The elevated mercury levels at EFK 23.4 were expected, given the levels of mercury contamination present in East Fork Poplar Creek. EFK 23.4 mercury rain events in µg/L results (from years 2014 to 2017) are shown in Figure 2.4.3.9.

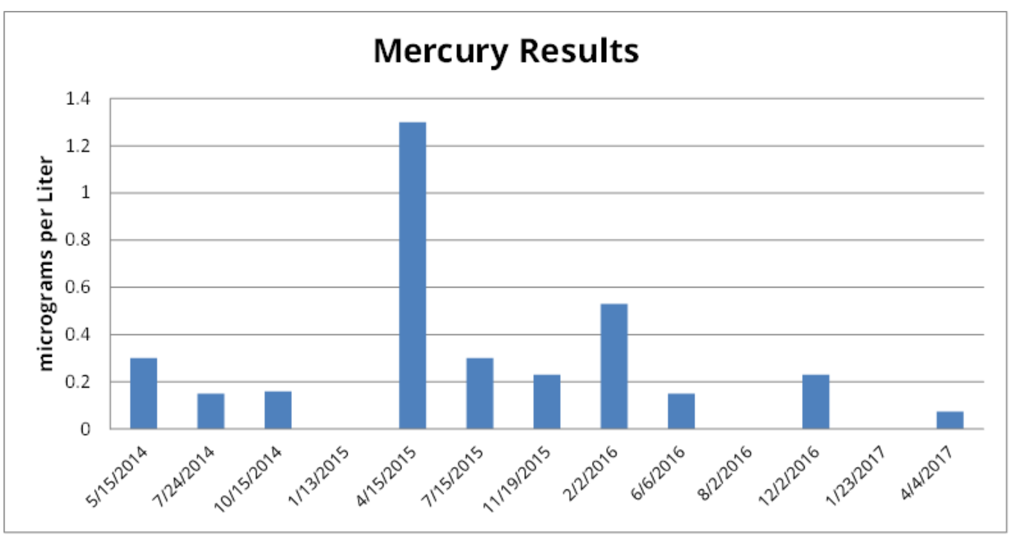


Figure 2.4.3.9: Mercury Results in µg/L

Table 2.4.3.3: Results of Gross Alpha/Beta Radionuclide Analysis

Results of Gross Alpha/Beta Radionuclide Analysis									
Site	**Gross Alpha pCi/L**	**CSU**	**Gross Beta**	**CSU ± pCi/L**	**Site**	**Gross Alpha pCi/L**	**CSU**	**Gross Beta**	**CSU ± pCi/L**
		2/3/2016					**12/1/2016**		
EFK 23.4	14.9	1.2	15.4	2	EFK 23.4	15.2	1.8	17.2	2.1
WCK 0.0	6.54	0.98	73.4	3	WCK 0.0	2.77	0.65	91.1	3.2
BCK 4.5	6.79	0.92	8.1	1.9	BCK 4.5	4.1	0.58	15.8	1.9
MIK 0.1	5.14	0.88	6.1	1.8	MIK 0.1	16.9	1.9	54.9	2.6
SD 490	-3.95	0.88	247.8	7	SD 490	-23.7	2.6	659	13
P1 WEIR	-0.62	0.52	42.9	2.3	P1 WEIR	1.43	0.54	25.8	2.2
SD 430	2.58	0.85	49.1	2.5	SD 430	-0.88	0.53	66.2	2.7
MBK 1.6	0.18	0.48	1.9	1.8	MBK 1.6	0.25	0.47	3.6	1.9
		6/6/2016					**1/23/2017**		
EFK 23.4	17.3	2.3	16.4	1.9	EFK 23.4	25.6	2.8	18	2.1
WCK 0.0	NS	NS	NS	NS	WCK 0.0	15.1	1.2	176.2	4.8
BCK 4.5	5.26	0.84	17.5	1.9	BCK 4.5	6.56	0.86	12.8	2
MIK 0.1	9.7	1.3	24.6	2	MIK 0.1	11.8	1.3	18.6	2.1
SD 490	-9.8	1.4	295.7	7.2	SD 490	-106	11	2563	48
P1 WEIR	0.02	0.48	16.4	1.9	P1 WEIR	-4.55	0.69	145.1	4
SD430	1.07	0.56	28.5	2.1	SD 430	-1.18	0.52	68.5	2.8
MBK 1.6	0.37	0.48	1.9	1.8	MBK 1.6	-0.02	0.46	2.8	1.9
		8/22/2016					**4/4/2017**		
EFK 23.4	5.9	1.3	10.7	1.8	EFK 23.4	21.5	2.4	17.4	2.1
WCK 0.0	24	2.9	145.5	4.4	WCK 0.0	2.82	0.59	49.9	2.5
BCK 4.5	6.4	1.2	8.8	1.7	BCK 4.5	3.69	0.7	5.5	1.9
MIK 0.1	5.5	1.2	22.2	1.9	MIK 0.1	6.89	0.97	12.7	2
SD 490	-6.1	1.4	312.3	7.5	SD 490	-42.5	4.7	976	19
P1 WEIR	-1.35	0.86	15.1	1.8	P1 WEIR	-1.85	0.51	36.6	2.3
SD 430	0.1	0.9	56.5	2.4	SD 430	-4.1	0.69	120.4	3.5
MBK 1.6	0.14	0.87	3.2	1.7	MBK 1.6	0.43	0.48	0.6	1.9

CSU - combined standard uncertainity at 1 - sigma

NS - Not Sampled

pCi/L - picoCuries per Liter

Table 2.4.3.4: Gamma Radionuclide Analysis

Gamma Radionuclide Analysis								
Site	**Gamma Pb-212 pCi/L**	**Gamma CSU ± pCi/L**	**Gamma Pb-214 pCi/L**	**Gamma CSU ± pCi/L**	**Gamma Bi-214 pCi/L**	**Gamma CSU ± pCi/L**	**Gamma Cs-137 pCi/L**	**Gamma CSU ± pCi/L**
2/3/2016								
WCK 0.0	NDA	NDA	NDA	NDA	**12.9**	**7.2**	NDA	NDA
BCK 4.5	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA
P1 WEIR	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA
SD 510	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA
MBK 1.6	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA
6/6/2016								
WCK 0.0 Unable to access gate, no sample taken								
8/22/2016								
WCK 0.0	NDA	NDA	NDA	NDA	NDA	NDA	**6.8**	**3.7**
12/1/2016								
WCK 0.0	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA
1/23/2017								
WCK 0.0	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA
4/4/2017								
WCK	NDA	NDA	**19.5**	**7.6**	**53.8**	**9.7**	NDA	NDA

NDA - Indicates that the analyte was analyzed but not detected.

CSU - Represents combined standard uncertainty at 1-sigma

pCi/L - picoCuries per Liter

Beginning with the 6/6/2016 only WCK 0.0 is to be sampled for gamma

Strontium-90 was analyzed for WCK 0.0 due to historical evidence of contamination at this site. Tritium and Tc-99 were sampled at SD 490, P1 Pond Weir, and SD 430. Analysis was conducted to monitor for contamination from CERCLA work in these areas. Results from these analyses are shown in Tables 2.4.3.5 and 2.4.3.6.

Table 2.4.3.5: Strontium Radionuclide Analysis

Strontium Radionuclide Analysis		
Site	Strontium-90 pCi/L	Strontium-90 CSU ± pCi/L
2/3/2016		
WCK 0.0	32	17
6/6/2016		
WCK 0.0	Unable to access area	
8/22/2016		
WCK 0.0	69	1.7
12/1/2016		
WCK 0.0	23.4	9.1
1/23/2017		
WCK 0.0	7.2	25
4/4/2017		
WCK 0.0	23	12

CSU - combined standard of uncertainty at 1 sigma

pCi/L - picoCuries per Liter

Table 2.4.3.6: Tritium and Technetium-99 Radionuclide Analysis

Tritium and Technetium-99 Radionuclide Analysis				
Site	Tritium pCi/L	Tritium CSU	Tc-99 pCi/L	Tc- 99 CSU
2/3/2016				
SD 490	115	35	183.2	7
P1 Weir	277	51	35.2	1.2
SD 430			41.3	1.4
6/6/2016				
SD 490	101	42	379	22
P1 Weir	285	92	11.2	0.46
SD 430			19.64	0.72
8/22/2016				
SD 490	109	35	248.2	6.8
P1 Weir	104	34	10.74	0.46
SD 430			42.5	1.4
12/1/2016				
SD 490	4	30	555	30
P1 Weir	-9	31	21.89	0.77
SD 430			52.3	1.7
1/23/2017				
SD 490	80	32	2322*	237
P1 Weir	469	74	147.3	5.9
SD 430			46.1	1.5
4/4/2017				
SD 490	116	44	768	48
P1 Weir	85	37	31	1
SD 430			105.4	3.8

Tc-99 - Technetium-99

pCi/L - picoCuries per Liter

CSU - Represents combined standard uncertainty at 1-sigma

* -Estimated value due to high activity

In mid-2013, a Tc-99 release occurred while building K-25 was undergoing demolition at ETTP, therefore Tc-99 and gross beta were recorded at SD 490. The slower than expected reduction of Tc-99 in sample point SD 490 has led to the sanitary sewer lines and the electrical conduits in the area being investigated as potential points of pooling, allowing heavy rains to provide a mode of transport to SD 490. The conductivity readings on the storm flow though SD 490 have raised the possibility that Tc-99 has entered the ground and is being flushed out under heavy rain conditions. This is a possibility that is being investigated. Beginning with the February 3, 2016 sample, isotopic uranium was analyzed at SD 430. Results are presented in Table 2.4.3.7.

Table 2.4.3.7: Isotopic Uranium

Isotopic Uranium						
Site	**Uranium-233/234**	**Uranium-233/234**	**Uranium-235**	**Uranium-235**	**Uranium -238**	**Uranium -238**
	pCi/L	***CSU**	**pCi/L**	***CSU**	**pCi/L**	***CSU**
2/3/2016						
SD 430	1.34E+00	1.87E-01	1.33E-01	4.30E-02	5.81E-01	9.70E-02
6/6/2016						
SD 430	6.19E-01	9.97E-02	4.98E-02	2.39E-02	3.29E-01	6.24E-02
8/22/2016						
SD 430	1.21E+00	1.78E-01	1.10E-01	4.07E-02	7.74E-01	1.24E-01
12/1/2016						
SD 430	6.96E-01	1.25E-01	6.28E-02	3.16E-02	3.41E-01	7.48E-02
1/23/2017						
SD 430	7.89E-01	1.26E-01	4.03E-02	2.44E-02	4.95E-01	9.06E-02
4/4/2017						
SD 430	5.92E-01	9.87E-02	5.29E-01	2.45E-02	2.84E-01	5.87E-02

CSU - combined standard uncertainty at 1-sigma
pCi/L - picoCuries per Liter

Hexavalent chromium is being monitored at the P1 Pond Weir, SD 490, SD 430, and MIK 0.1. The basis for monitoring these sites is the CERCLA D&D work being conducted at ETTP. Sample results were non-detect until the April 4, 2017 sampling event. Results for the April 4, 2017 sampling event are shown in Table 2.4.3.8. PCBs were analyzed at SD 430 to monitor for possible contamination from CERCLA work being conducted in the area. PCBs were non-detect in all samples submitted for analysis.

Table 2.4.3.8: Hexavalent Chromium

Hexavalent Chromium	
4/4/2017	
P1 Pond Weir	ND
SD 490	1.3 μg/L
SD 430	4.4 μg/L
MIK 0.1	0.73 μg/L

μg/L - micro grams per Liter
ND= Non Detect

Conclusions

The results may indicate long-term radiological contaminants continue to impact White Oak Creek. Metals are present in Mitchell Branch, hexavalent chromium is sporadically present in SD 490, SD 430, and MIK 0.1; and mercury continues to be a concern at East Fork Poplar Creek. A radiological contaminant (Tc-99) from the 2013 incident continues to impact SD 490. DoR-OR recommends continued monitoring of impacted sites in areas undergoing CERCLA D&D.

2.5 Sediment Monitoring

2.5.1 Ambient Sediment Monitoring

Introduction

Sediment is an important part of aquatic ecosystems. Many aquatic organisms depend on sediment for habitat, sustenance, and reproduction. Anthropogenic chemicals and waste materials (such as metals, radionuclides, PCBs, polycyclic aromatic hydrocarbons (PAHs), and agricultural chemicals) that are introduced into aquatic systems often accumulate in sediment. Contaminants may accumulate in sediment such that their concentrations are higher than in the water column. Some sediment contaminants may be directly toxic to benthic organisms or may bioaccumulate in the food chain, creating health risks for wildlife and humans. Sediment analysis is an important aspect of environmental quality and impact assessment for rivers, streams, and lakes.

Contaminants from past DOE activities on the ORR have made their way into several streams that drain into Poplar Creek and the Clinch River. Based on data collected by DOE and DoR-OR over the years, the major pathways of concern are White Oak Creek and East Fork Poplar Creek. The major contaminants of concern from White Oak Creek are strontium-90 and cesium-137. East Fork Poplar Creek is contaminated with mercury from past Y-12 activities. To characterize and monitor the impact from these streams, DoR-OR sampled sediment in the Clinch River, Poplar Creek, East Fork Poplar Creek, Bear Creek, and Mitchell Branch. Sediment samples were analyzed for metals and radiological parameters. DoR-OR sampled sediment at seven locations in October 2016 (Table 2.5.1.1 and Figure 2.5.1.1). Since there are no federal or state sediment cleanup levels, the metals data were compared to Consensus-based Sediment Quality Guidelines (CBSQGs) (MacDonald et al. 2000). Radiological data were compared to background streams unaffected by site influences.

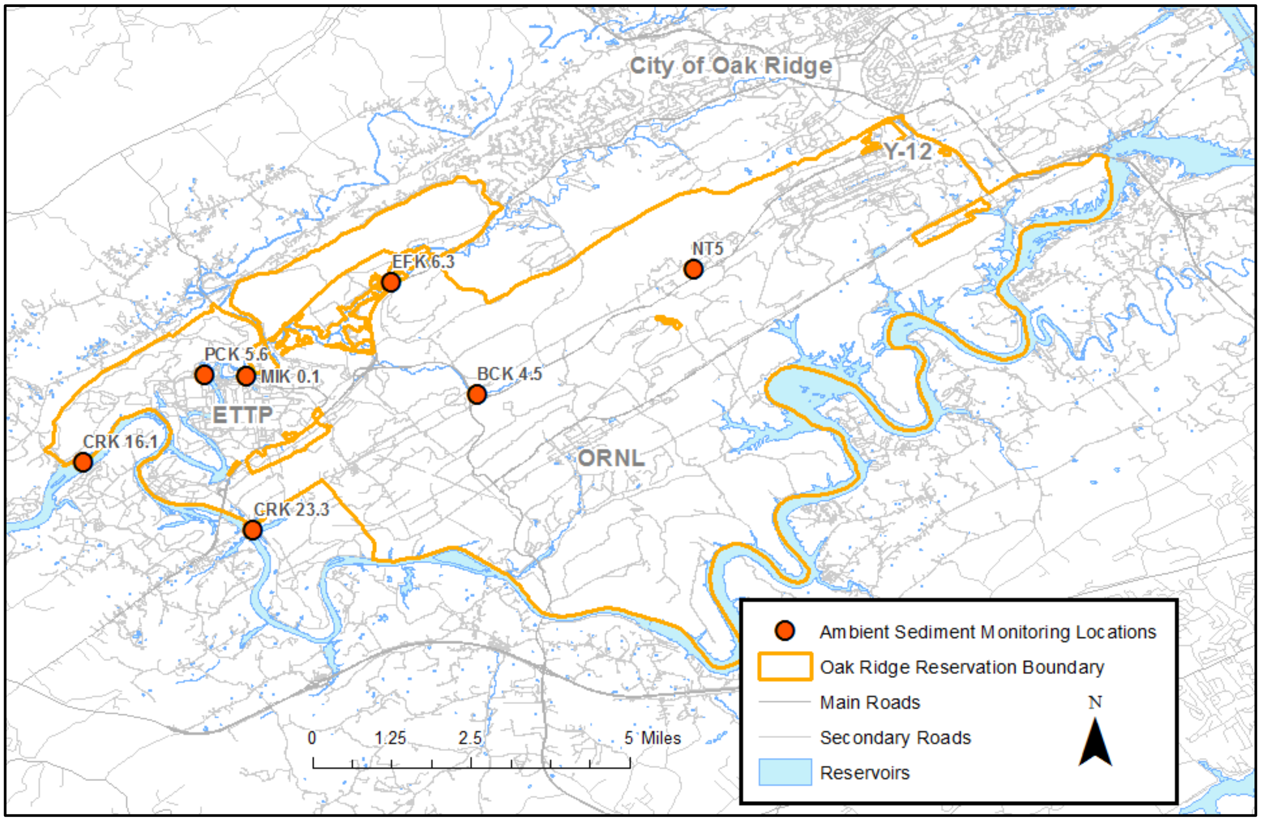


Figure 2.5.1.1: Ambient Sediment Sampling locations

Methods and Materials

Sediment samples were collected during October 2016 using the methods described in the DoR-OR Sediment Monitoring Standard Operating Procedure. Grab samples were collected from streams by wading and by hand collecting with a stainless steel spoon; river samples were collected with the use of petite Ponar sampling devices. At least three grab samples were collected at each location; the grab samples were combined and containerized for transport to the analytical laboratory. The Tennessee State laboratories processed the samples according to EPA approved methods. Samples were analyzed for arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, and uranium. In addition, samples were analyzed for gross alpha, gross beta, and gamma radionuclides.

Table 2.5.1.1: Ambient Sediment Sampling Locations 2016 through 2017

Ambient Sediment Sampling Locations 2016-2017			
Monitoring Location	**ID**	**Alternate ID**	**Monitoring Rationale**
Clinch River Mile 14.5	CLINC014.5RO	CRK 23.3	Evaluate the effect of contaminant sources in the White Oak Creek watershed on sediment quality in the Clinch River
Clinch River Mile 10.0	CLINC010.0RO	CRK 16.1	Evaluate the effect of contaminant sources in the White Oak Creek and Poplar Creek watersheds on sediment quality in the Clinch River
Poplar Creek Mile 3.5	POPLA003.5RO	PCK 5.6	Evaluate the effect of contaminant sources in the Mitchell Branch and East Fork Poplar Creek watersheds on sediment quality in Poplar Creek
East Fork Poplar Creek Mile 3.9	EFPOP003.9RO	EFK 6.3	Evaluate the effect of Y-12 contaminant sources on sediment quality in East Fork Poplar Creek
Bear Creek Mile 2.8	BEAR002.8RO	BCK 4.5	Evaluate the effect of Y-12 contaminant sources on sediment quality in Bear Creek
Mitchell Branch Mile 0.1	MITCH000.1RO	MIK 0.1	Evaluate the effect of ETTP contaminant sources on sediment quality in Mitchell Branch
NT5	BEAR006.5T0.1AN	NT5	Evaluate the effect of EMWMF contaminant sources on sediment quality in Bear Creek

Results and Discussion

Metals Analyses

Table 2.5.1.2 shows the metals and particle size data. The only metals found at concentrations above the Consensus Based Sediment Quality Guidelines (CBSQGs) Probable Effects Concentration (PEC) were mercury (EFK 6.3, MIK 0.1, PCK 5.6) and nickel (MIK 0.1). The PECs are CBSQGs that were established as concentrations of individual chemicals above which adverse effects in sediment are expected to occur frequently (MacDonald et al. 2000). Adverse effects in this case refer to effects to benthic macroinvertebrate species (WDNR 2003). The CBSQGs are considered protective of human health and wildlife except where bioaccumulative or carcinogenic organic chemicals, such as PCBs or methylmercury, are involved. In these cases, other tools such as human health and ecological risk assessments, bioaccumulation-based guidelines, bioaccumulation studies, and tissue residue guidelines should be used (in addition to the CBSQGs) to assess direct toxicity and food chain effects (WDNR 2003). The Threshold Effects Concentrations (TECs) are concentrations below which adverse effects are not expected to occur (MacDonald et al. 2000). The TECs were exceeded for several metals (arsenic, chromium, copper, lead, nickel, and mercury) at MIK 0.1. In addition, CRK 16 and CRK 23.3 had mercury levels above the TEC.

The mercury concentration in sediment at East Fork Poplar Creek Mile 3.9 (6.3 mg/kg) exceeds the PEC of 1.1 mg/kg (MacDonald et al. 2000). The mercury in East Fork Poplar Creek and Poplar Creek sediment results from historical activities at Y-12 and to a lesser extent ETTP. Figure 2.5.1.2 shows the effect of the East Fork Poplar Creek mercury contamination on the Clinch River sediment downstream. East Fork Poplar Creek empties into Poplar Creek at Poplar Creek Mile 5.5; the mouth of Poplar Creek lies near Clinch River Mile (CRM) 12. For this data set, mercury levels are highest at EFK 6.3, and generally decrease downstream. Both EFK 6.3 and PCK 5.6 had mercury concentrations above the PEC.

Table 2.5.1.2: Ambient Sediment Metals Data and Particle Size Analysis Results

Ambient Sediment Metals and Particle Size Analysis Results 2016										
Parameter	**Units**	**BCK 4.5**	**NT5**	**EFK 6.3**	**MIK 0.1**	**PCK 5.6**	**CRK 23.3**	**CRK 16**	**TEC***	**PEC****
Boron	mg/kg	2.7	4.3	2.9	5.9	8.6	13.0	9.5	NA	NA
Arsenic	mg/kg	2.2	6.3	2.2	16.0	1.6	4.8	3.2	9.8	33
Barium	mg/kg	130	170	83	160	55	90	63	NA	NA
Beryllium	mg/kg	0.75	0.55	0.44	0.83	0.37	0.63	0.46	n.a	n.a
Cadmium	mg/kg	0.55	U	0.29	0.90	0.40	U	U	0.99	5
Chromium	mg/kg	19.0	20.0	14.0	89.0	11.0	17.0	8.4	43	110
Copper	mg/kg	9.1	8.5	13.0	130.0	11.0	14.0	6.3	32	150
Lead	mg/kg	15.0	11.0	18.0	80.0	10.0	22.0	9.7	36	130
Nickel	mg/kg	16.0	17.0	11.0	300.0	14.0	20.0	8.7	23	49
Uranium	mg/kg	8.00	2.40	2.20	51.00	1	0.82	U	n.a	n.a
Mercury	mg/kg	0.150	0.083	6.300	2.700	2.10	0.50	0.20	0.18	1.1
Particle size, 0.5 inch (12.5mm) (Gravel)	%	2	10	2	7	0	0	1	NA	NA
Particle size, Sieve No. 100, 100 mesh, (0.150mm)(Sand)	%	30	36	43	35	49	35	43	NA	NA
Particle size, Hydrometer (0.007mm) (Silt)	%	57	42	43	44	41	51	45	NA	NA
Particle size, 0.002.mm (Clay)	%	11	12	12	14	10	14	9	NA	NA

*Consensus Based Sediment Quality Criteria, Threshold Effects Concentration (McDonald *et al.* 2000)

**Consensus Based Sediment Quality Criteria, Probable Effects Concentration (McDonald *et al.* 2000)

Values above the TEC are shaded orange; values above the PEC are shaded red.

U - undetected

NA - criteria not established for that characteristic

mg/kg - milligrams per kilograms

Figure 2.5.1.3 shows total mercury in sediment at Mitchell Branch km 0.1 (1992 through 2016) and gives a chronological view of changes in sediment mercury content from 1992 through 2016. The graph incorporates data obtained from the Oak Ridge Environmental Information System (OREIS), DOE Environmental Surveillance Soil & Sediment Data, DOE Remedial Effectiveness Reports, and DOE Environmental Monitoring Plans. Sometime between 2004 and 2008, sediment mercury levels increased, as shown in Figure 2.5.1.3. Similarly, nickel, and chromium concentrations increased during the same period at this location (Figures 2.5.1.4 and 2.5.1.5).

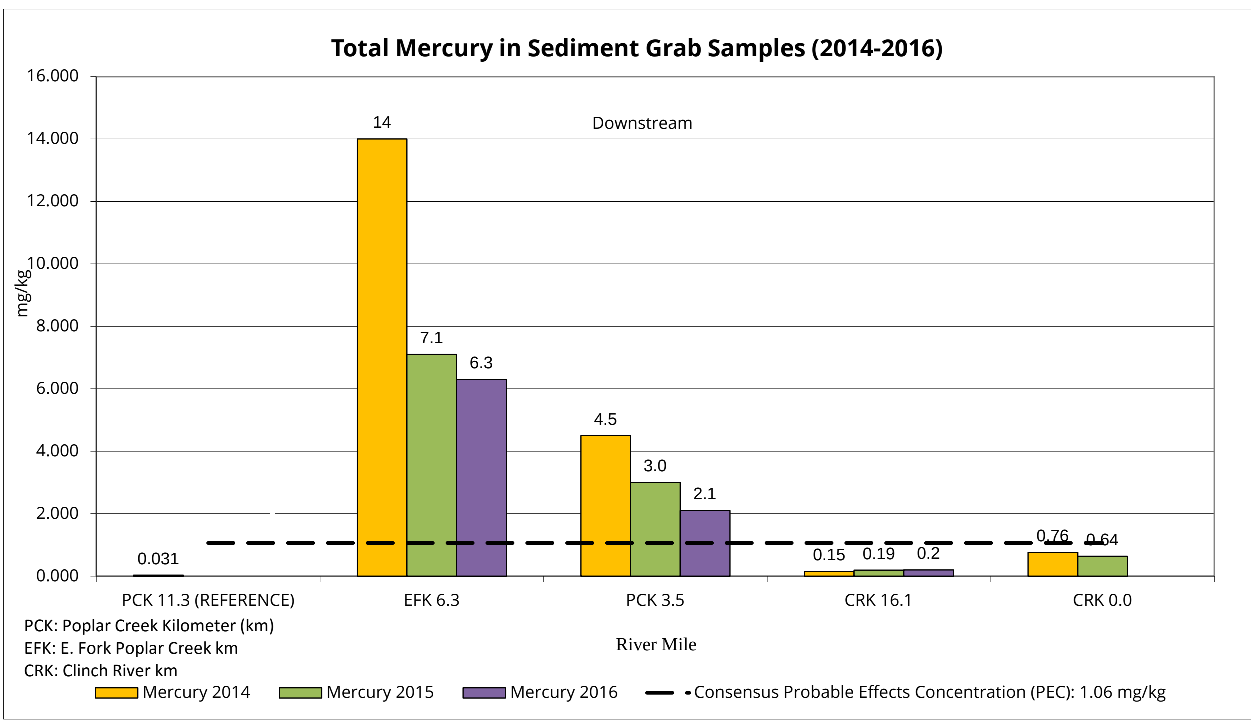


Figure 2.5.1.2: Total Mercury in Clinch River and Poplar Creek Sediment 2014 through 2016

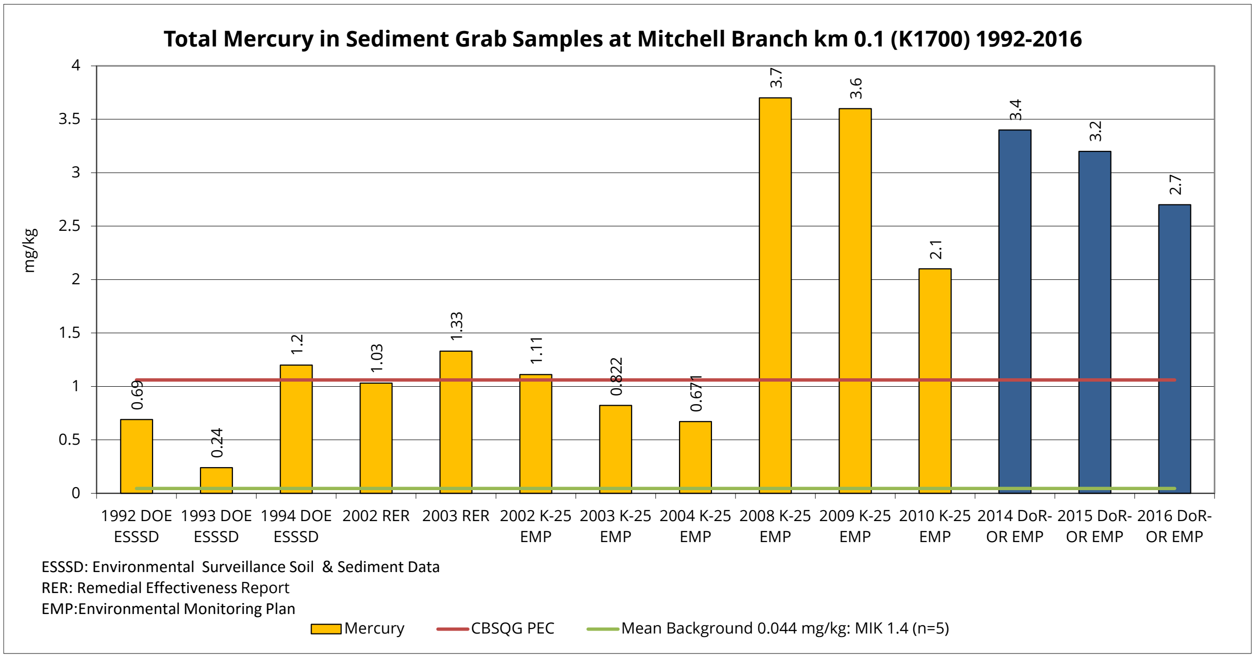


Figure 2.5.1.3: Total Mercury in Sediment at Mitchell Branch km 0.1 (1992 through 2016)

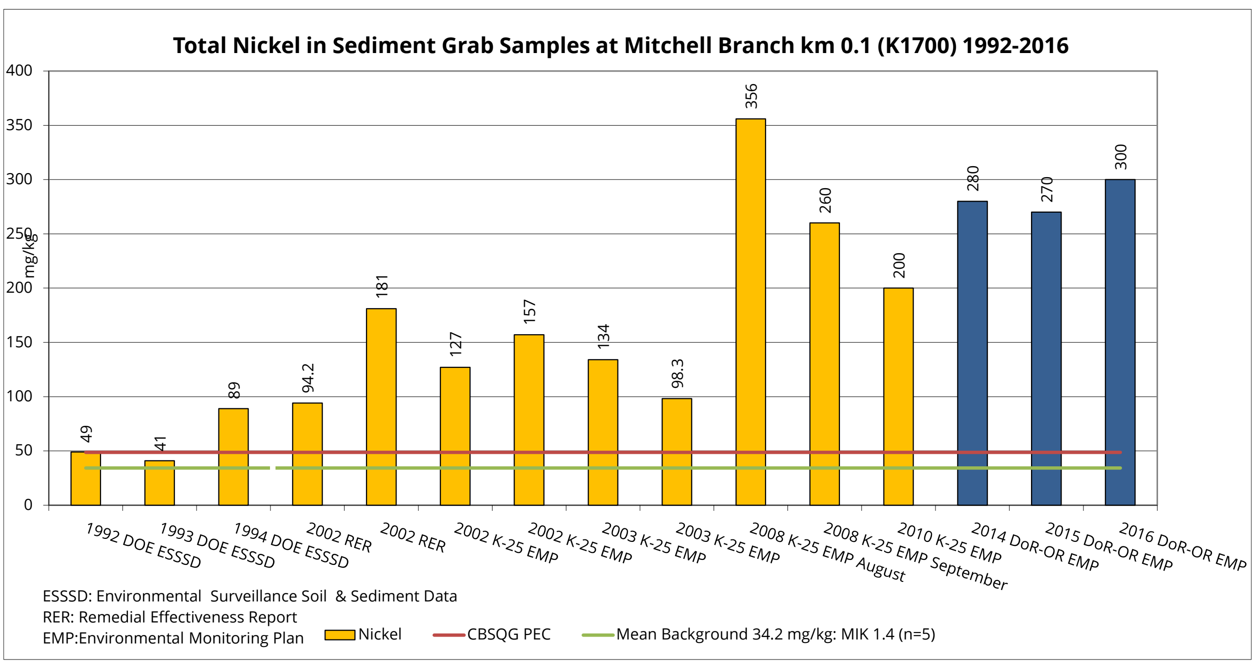


Figure 2.5.1.4: Total Nickel in Sediment at Mitchell Branch km 0.1 (1992 - 2016)

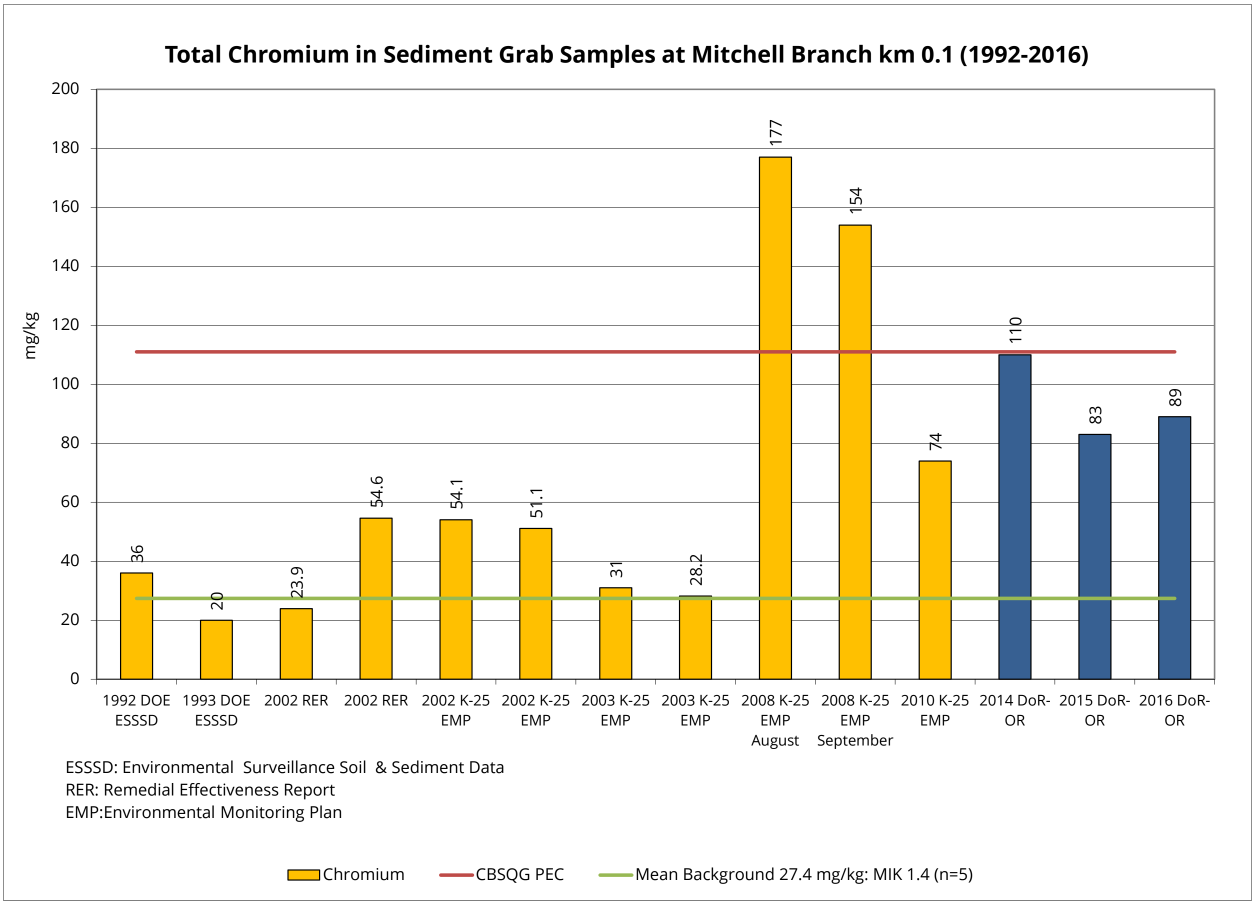


Figure 2.5.1.5: Total Chromium in Sediment at Mitchell Branch Km 0.1 1992 - 2016

Radiological Analyses

In 2016, Cs-137 was detected (24.4 pCi/g) in the Clinch River sample at river kilometer 23.3. Figure 2.5.1.6 displays a comparison of gross beta activities at some ORR exit pathway streams sampled in 2014 and through 2016. Gross beta activity was highest at the Mitchell Branch location (189.6 pCi/g). A chronological view (1992 through 2016) of the gross beta activity at MIK 0.1 is shown in Figure 2.5.1.7. These graphs incorporate data obtained from OREIS, include DOE Environmental Surveillance Soil and Sediment data and DOE Remedial Effectiveness Reports and use the 2014, 2015, and 2016 DoR-OR data. Table 2.5.1.3 is a summary of the radiological data from this project.

Table 2.5.1.3: Ambient Sediment Monitoring Radiological Data

Radiological Results								
Parameter	**Units**	**NT5**	**BCK 4.5**	**EFK 6.3**	**MIK 0.1**	**PCK 5.6**	**CRK 23.3**	**CRK 16**
Radioactivity, alpha	pCi/g	8.99	4.22	2.28	1.46	1.93	3.09	0.98
combined standard uncertainty	pCi/g	0.34	0.27	0.22	0.29	0.22	0.26	0.2
Radioactivity, beta	pCi/g	40.5	8.1	4.42	189.6	3.69	22.03	1.05
combined standard uncertainty	pCi/g	1.0	0.88	0.81	1.6	0.76	0.89	0.71
Cesium-137	pCi/g	ND	ND	ND	ND	ND	24.4	ND
combined standard uncertainty	pCi/g	NA	NA	NA	NA	NA	0.88	NA

ND - non-detect

NA - not applicable

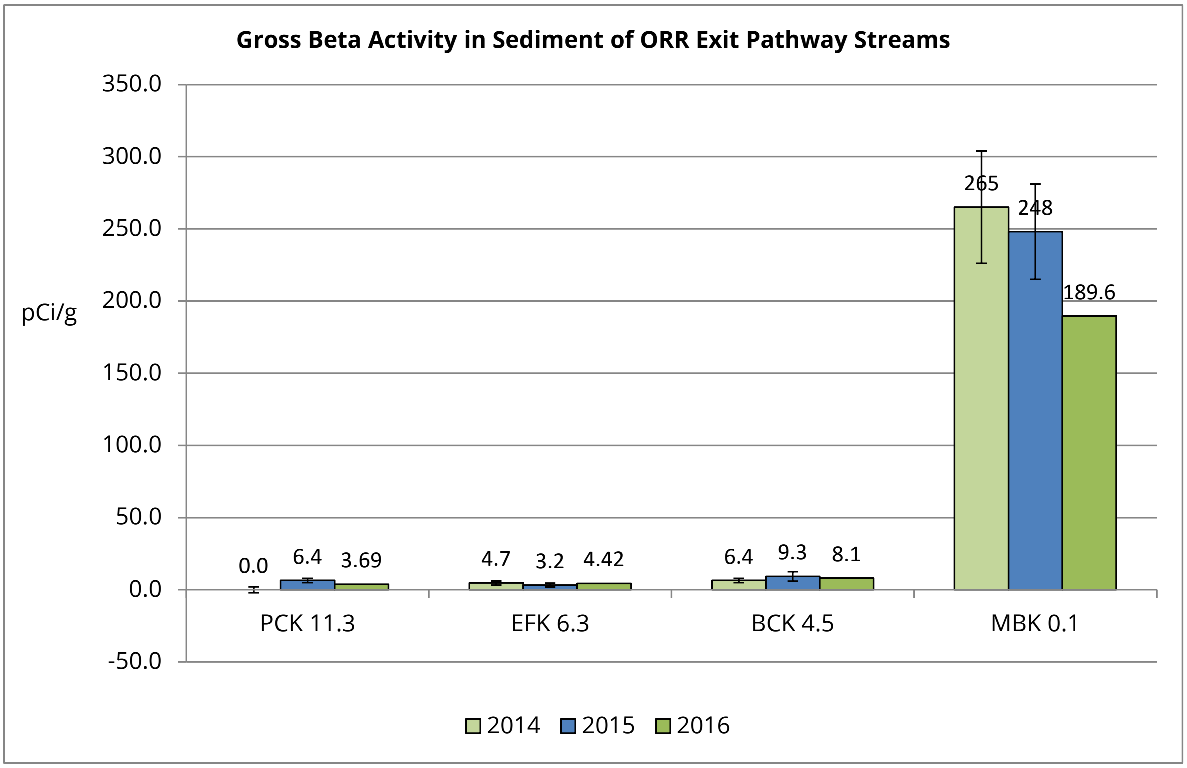


Figure 2.5.1.6: Gross Beta Activity in Sediment (2014-2016) in ORR Exit Pathway Streams

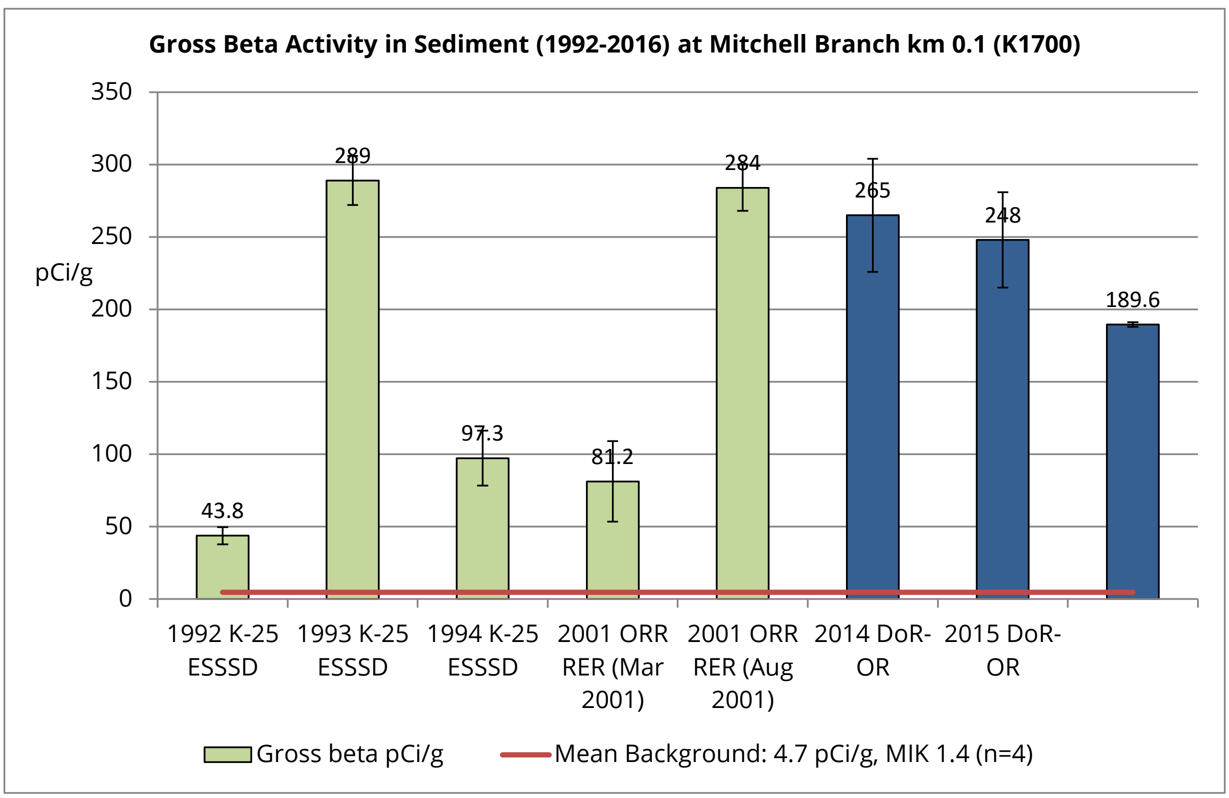


Figure 2.5.1.7: Gross Beta Activity in Sediment (1992 through 2016) at Mitchell Branch Km 0.1 (K1700)

Conclusions

The East Fork Poplar Creek Mile 3.9 sediment mercury concentration (6.3 mg/kg) exceeds the PEC of 1.1 mg/kg (MacDonald et al. 2000). The mercury in East Fork Poplar Creek and Poplar Creek sediment results from historical activities at Y-12 and to a lesser extent ETTP. Figure 2.5.1.2 shows the effect of the East Fork Poplar Creek mercury contamination on the Clinch River sediment. East Fork Poplar Creek empties into Poplar Creek at Poplar Creek Mile 5.5; the mouth of Poplar Creek is located at approximately Clinch River Mile (CRM) 12. Mercury levels are highest at East Fork Poplar Creek km 6.3 and generally decrease downstream. Mercury concentrations exceeded the PEC at the locations sampled on East Fork Poplar Creek and Poplar Creek.

Historical data from OREIS combined with DoR-OR data indicate that mercury levels increased significantly at Mitchell Branch km 0.1 (K1700) between 2004 and 2008. Similarly, nickel, chromium, boron, and barium concentrations increased during the same time period for this location. In 2016, Cs-137 was detected (24.4 pCi/g) in the Clinch River sample at river kilometer 23.3. Figure 2.5.16 compares gross beta activities at some ORR exit pathway streams sampled during 2014 through 2016. Gross beta activity was highest at the Mitchell Branch location (189.6 pCi/g). A chronological view (1992 through 2016) of the gross beta activity at MIK 0.1 is shown in Figure 2.5.1.7. These graphs incorporate data obtained from ORIES, DOE Environmental Surveillance Soil and Sediment Data, DOE Remedial Effectiveness Reports, and use 2014, 2015, and 2016 DoR-OR data.

2.5.2 Trapped Sediment Monitoring

Introduction

Many aquatic organisms depend on sediment for habitat, sustenance, and reproduction. Anthropogenic chemicals and waste materials, such as metals, radionuclides, PCBs, polycyclic aromatic hydrocarbons (PAHs), and agricultural chemicals that are introduced into aquatic systems often accumulate in sediment. Contaminants may accumulate in sediment such that their concentrations are higher than in the water column. Some sediment contaminants may be directly toxic to benthic organisms or may bioaccumulate in the food chain, creating health risks for wildlife and humans. Sediment analysis is an important aspect of environmental quality and for the impact assessment of rivers, streams, and lakes.

This project evaluates the concentrations of potential contaminants in suspended sediment currently transported in East Fork Poplar Creek, Bear Creek, and North Tributary 5 (NT5) by using passive sediment collectors. NT5 is the main outfall for EMWMF (a mixed-waste landfill that has received waste primarily from ETTP D&D activities since 2002). The sediment samplers were deployed from May 4, 2016 through December 19, 2016. Data from sediment traps deployed in the first half of 2017 have not yet been received from the laboratory. Sediment samples were analyzed for radiological activity and metals. Past sediment sampling activities by DoR-OR have shown that Poplar Creek and East Fork Poplar Creek have elevated levels of mercury in sediment. This mercury can be attributed to historical discharges from Y-12 and, to a lesser extent, ETTP.

Methods and Materials

Sediment sampling was performed in accordance with the following documents:

- Standard Operating Procedures. Tennessee Department of Environment and Conservation. DOE Oversight. Oak Ridge, Tennessee 1996.

- Phillips, J. M., Russell, M.A., and Walling, D.E. *Time-integrated Sampling of Fluvial Suspended Sediment: a Simple Methodology for Small Catchments.* Hydrological Processes, v. 14, no. 14, p. 2,589-2,602. 2000.
- Field Branches Quality System and Technical Procedures: Field Sampling Procedures – Sediment Sampling. United States Environmental Protection Agency. Region IV, Athens, GA. 2010.

Sediment traps were deployed at the following stream locations: East Fork Poplar Creek kms (EFK) 6.3, 13.8, 23.4; Bear Creek kms (BCK) 4.5, 7.6; and at NT5 (Figure 2.5.2.1). The sediment traps were modeled after a design described by Phillips et al. (2000) (Figure 2.5.2.2). Figure 2.5.2.3 shows one of the sediment traps; the body is constructed of 4-inch diameter polyvinyl chloride (PVC) pipe with 4-inch fittings. The other components of the trap are common items available in most hardware stores. The sediment traps are fastened to the streambed with metal stakes and are oriented horizontally parallel to the flow of the current (Figure 2.5.2.4). Safety caps constructed of PVC pipe are attached to tops of the metal stakes. Once deployed, the sediment traps are visited weekly for maintenance: debris is removed from the sediment trap and the inlet and outlet tubes are cleared of algae and biofilm with a brush.

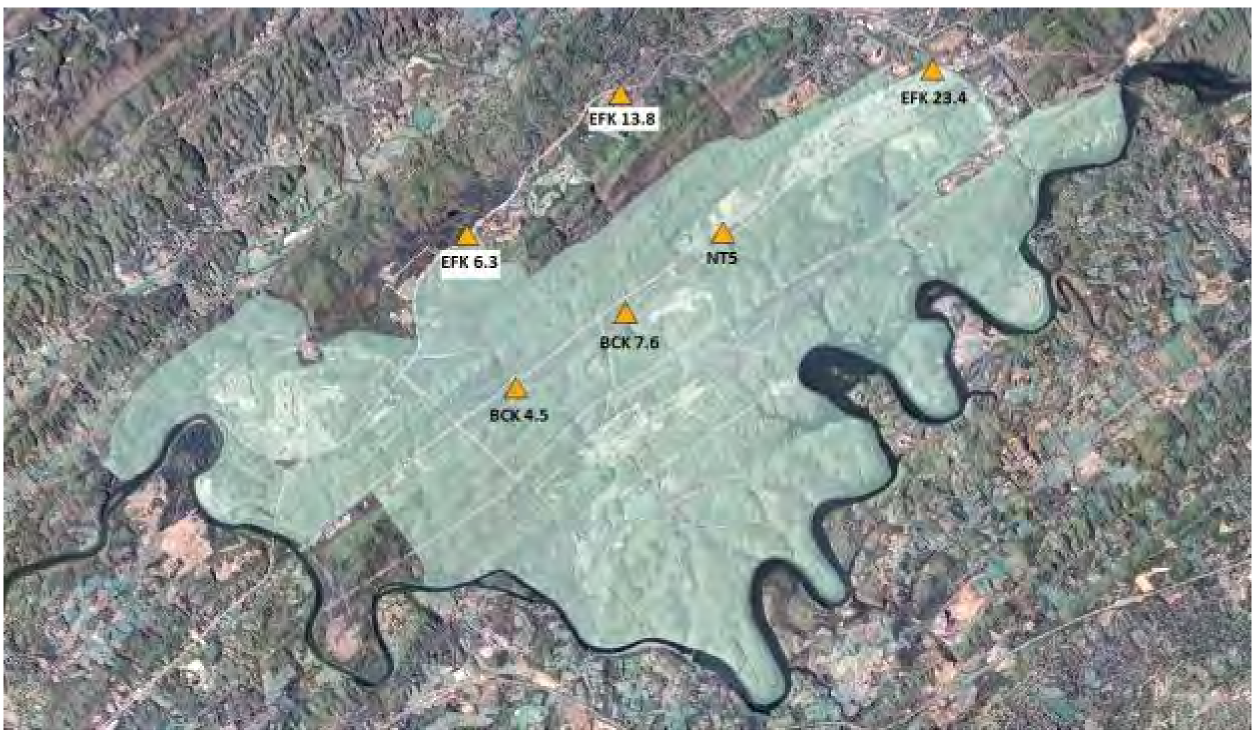
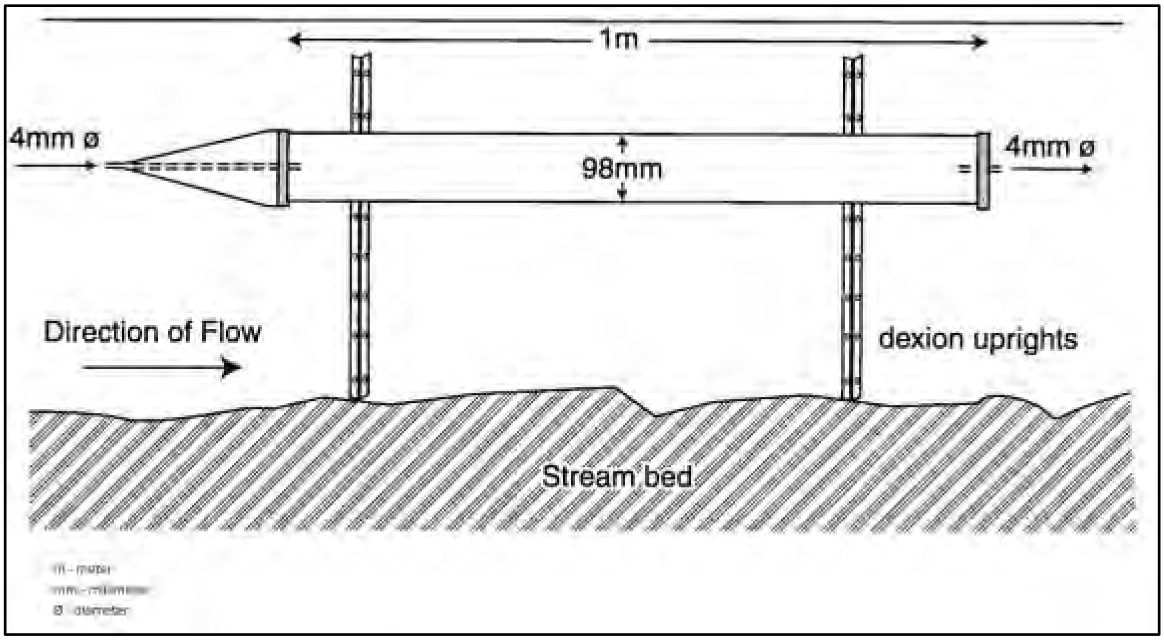


Figure 2.5.2.1: Sampling Locations



Phillips et al. (2000)

Figure 2.5.2.2: Sediment Trap Design

Figure 2.5.2.3: Photo of Sediment Trap

Figure 2.5.2.4: Sediment Trap Deployed

Results and Discussion

Trapped sediment results were compared with the CBSQGs probable effects concentrations (PECs) for each metal. The PECs are CBSQGs that were established as concentrations of individual chemicals above which adverse effects in sediment are expected to frequently occur (Ingersoll et al. 2000). Adverse effects, in this case, refer to effects to benthic macroinvertebrate species only (WDNR 2003). The CBSQGs are considered protective of human health and wildlife except where bioaccumulative or carcinogenic organic chemicals, such as PCBs or methylmercury, are involved. In these cases, other tools such as human health and ecological risk assessments, bioaccumulation-based guidelines, bioaccumulation studies, and tissue residue guidelines should be used in addition to the CBSQGs to assess direct toxicity and food chain effects (WDNR 2003). The threshold effects concentrations (TECs) are concentrations below which adverse effects are not expected to occur (MacDonald et al. 2000).

Figure 2.5.2.5 shows the total mercury results for East Fork Poplar Creek for 2014 through 2016; concentrations decrease downstream. All East Fork Poplar Creek samples exceed the PEC for total mercury (1.06 mg/kg). Figure 2.5.2.6 shows total mercury at NT5 and Bear Creek; concentrations decrease downstream on Bear Creek. In 2016, metals analysis at NT5 was not possible due to insufficient yield. All of the Bear Creek mercury data were below the PEC.

All of the locations had chromium values that were well above the Hinds Creek km 20.6 background location (Figure 2.5.2.7). Although the chromium values are many times higher than the background location, they are well below the PEC for chromium (110 mg/kg).

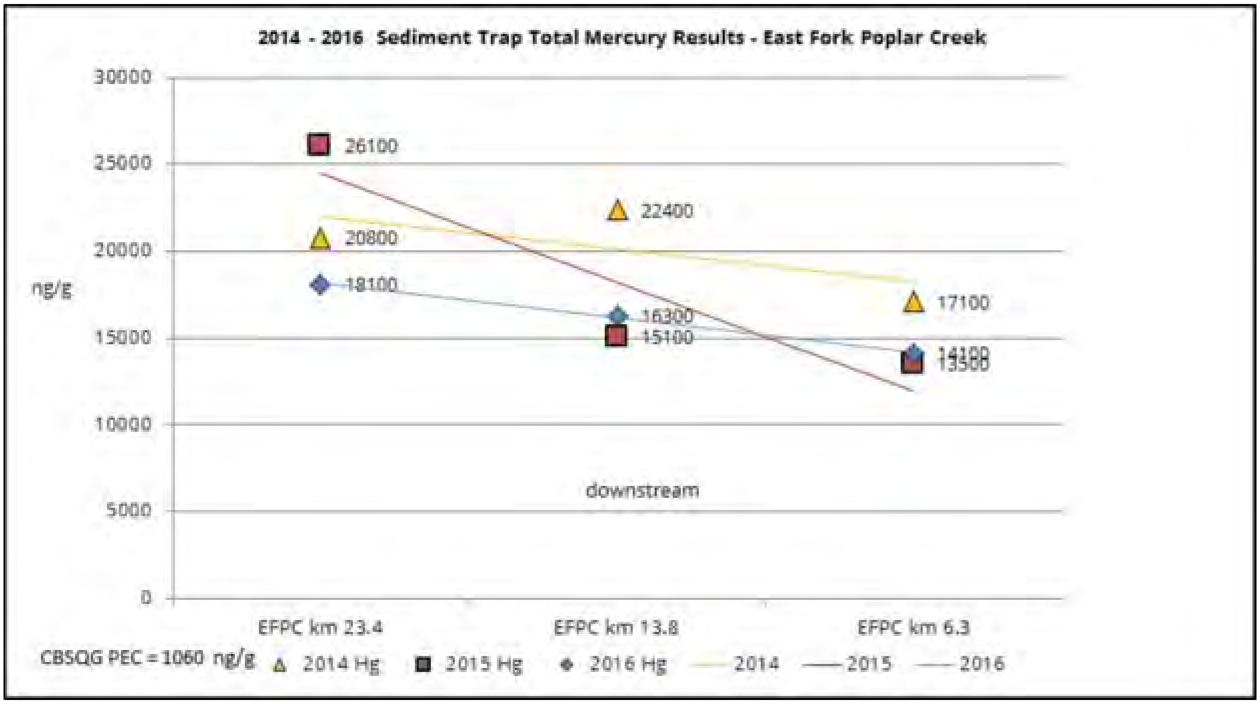


Figure 2.5.2.5: 2014 through 2016 Sediment Trap Total Mercury Results East Fork Poplar Creek

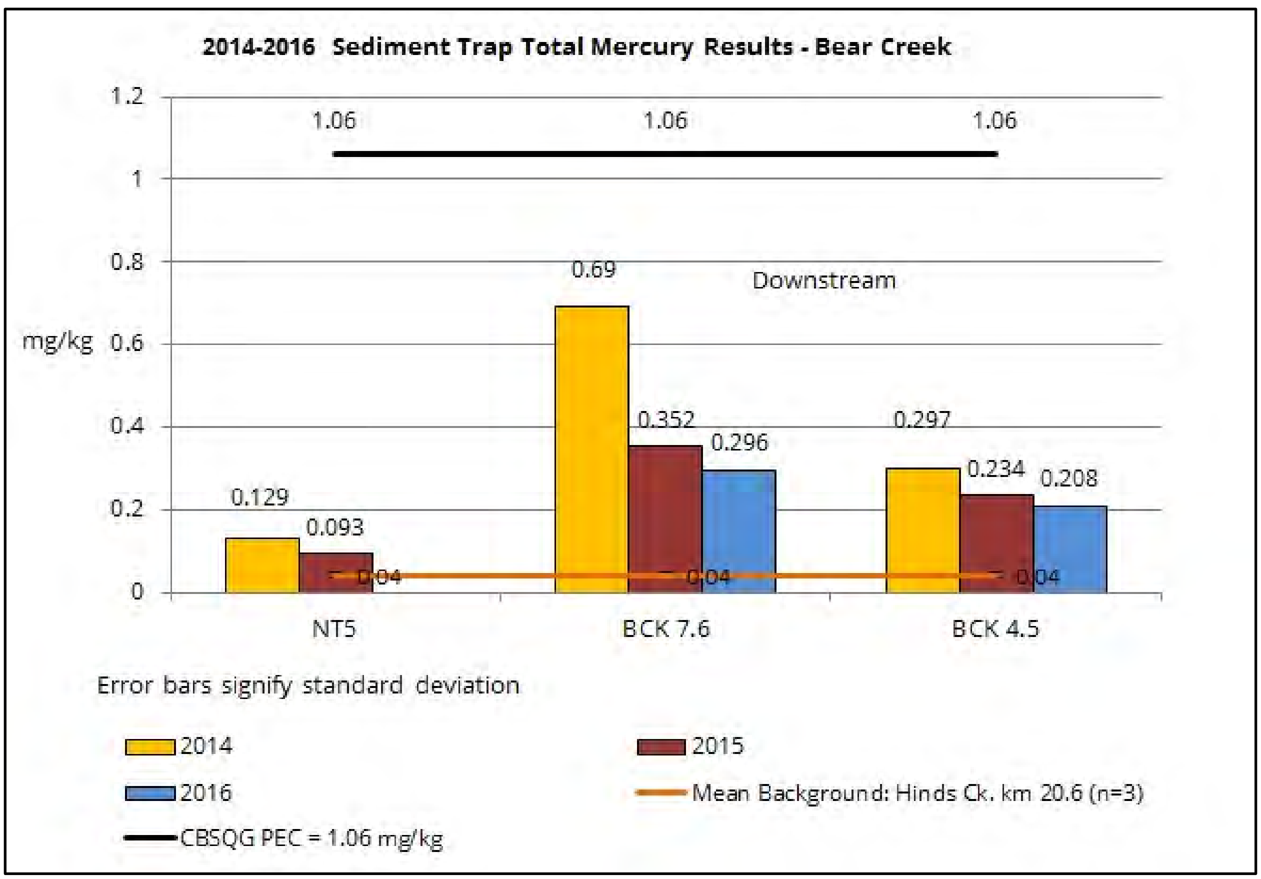


Figure 2.5.2.6: 2014 through 2016 Sediment Trap Total Mercury Bear Creek

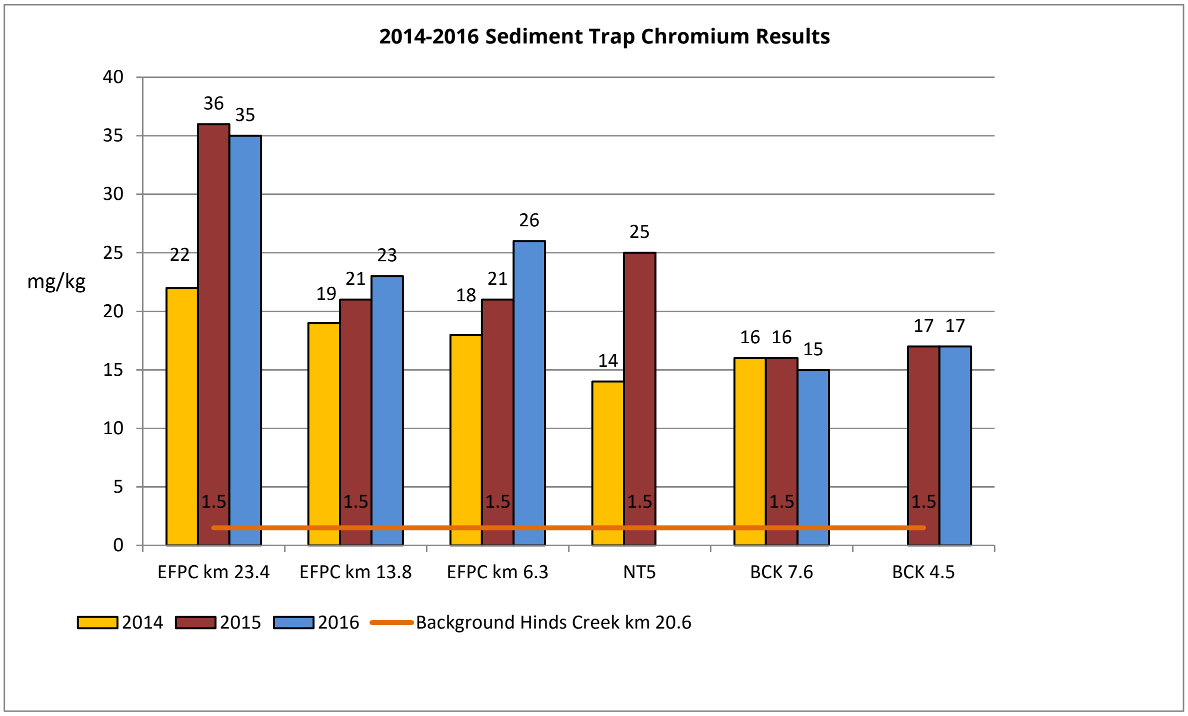


Figure 2.5.2.7: 2014 through 2016 Sediment Trap Chromium Results

Radiological Results

Radiological analyses included gross alpha and gross beta activities. Gross alpha activity (Figure 2.5.2.8) was relatively uniform among the sampling locations. All of the values were well above the alpha activity of the Clear Creek background locations. Gross beta values showed a generally decreasing trend downstream, with the highest amounts at NT5 on the Bear Creek watershed and EFK 23.4 on East Fork Poplar Creek (Figure 2.5.2.9).

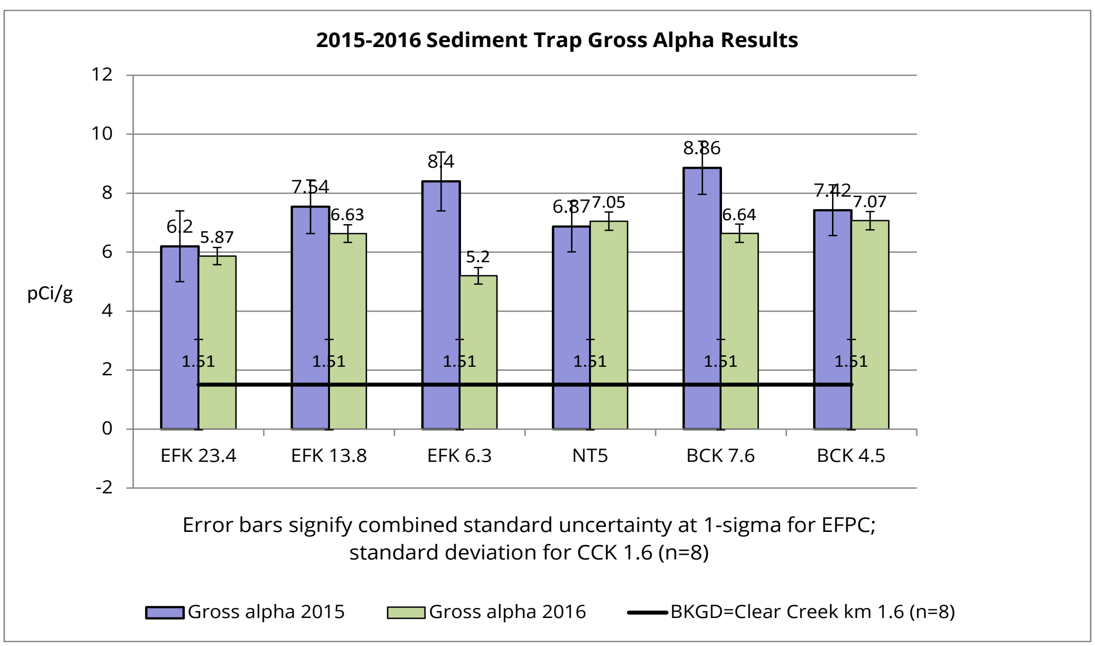


Figure 2.5.2.8: Sediment Trap Gross Alpha Results

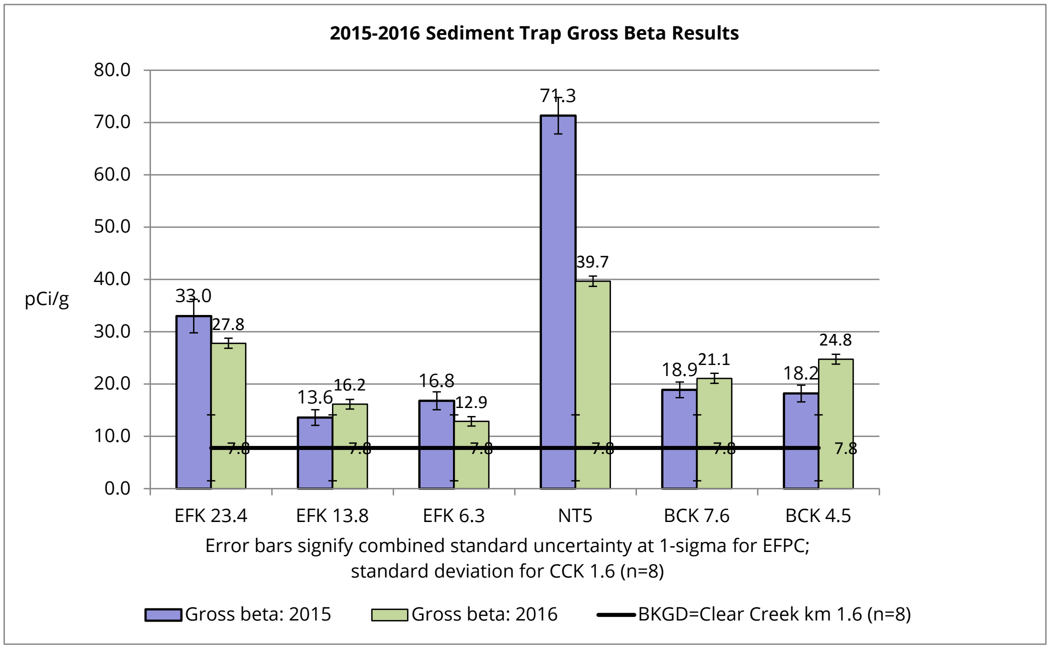


Figure 2.5.2.9: 2015 through 2016 Gross Beta Results

Conclusions

The following conclusions can be drawn from the sediment sampling results.

East Fork Poplar Creek

- Total mercury concentrations exceeded the CBSQGs PEC (1.06 mg/kg) at all sample locations.
- Total mercury results decreased with distance downstream from the Y-12 outfalls in each of the three years monitored: 2014, 2015 and 2016.
- Chromium concentrations were well above the level (1.5 mg/kg) measured at the Hinds Creek km 20.6 background location but well below the PEC (110 mg/kg).
- Gross alpha activities were relatively uniform among the sampling locations; all values were well above the level at the Clear Creek background location.
- Gross beta activities generally decreased downstream; the highest activities were at EFK 23.4.

Bear Creek

- Total mercury concentrations were below the CBSQGs PEC (1.06 mg/kg) in sediment at all sample locations.
- Gross beta activities generally decreased downstream; the highest activities were at NT5.

2.6 EMWMF – CERCLA Landfill

Introduction

The Tennessee Oversight Agreement requires the State of Tennessee to provide monitoring to verify DOE data and to assess the effectiveness of DOE contaminant control systems on the Oak Ridge Reservation (ORR). During the timeframe between January 1, 2016 and June 30, 2017, DoR-OR monitored effluents, surface water runoff, and sediment at DOE's EMWMF. This facility was constructed to dispose of waste generated by remedial activities on the ORR and is operated under the authority of CERCLA. While the facility holds no permit from any state or federal agency, it is required to comply with applicable or relevant and appropriate requirements (ARARs) in the CERCLA ROD (DOE, 1999) and with requirements associated with responsibilities delegated to DOE by the Atomic Energy Act.

Methods and Materials

To verify that EMWMF is meeting its design, a program was initiated to monitor several parameters, discharges, and groundwater locations. Tasks for this program included monitoring parameters at two exit pathways: the sediment basin outfall (EMWMF-3), and the underdrain (EMWMF-2), collecting water samples from various locations on EMWMF to ensure compliance, and collecting sediment samples from the sediment basin to observe radiological deposition rates over time. In addition, to ensure best practices are utilized to limit contaminant migration, DoR-OR visits EMWMF bi-weekly to perform general monitoring of the site. DoR-OR monitors the water levels in the contact water ponds and tanks, notes discharges and water condition, observes the condition of the sediment basin and notes daily activity of the facility. Any concerns are brought to the attention of EMWMF personnel. Field notes are recorded in a bound field book and events reported in the monthly report. Samples are collected for radiological analysis at EMWMF-1 (GW-918), EMWMF-2, EMWMF-3, EMWMF-4B, EMWMF-6 (NT-4), EWMNT-3A, EWMNT-5, at the contact water ponds (CWPs) and at the contact water tanks (CWTs). In addition, sediment samples from the sediment basin are collected when dry conditions allow. The radiological sample locations are shown in Figure 2.6.

Figure 2.6: Radiological Sample Locations
(Basemap reproduced using Google Maps DigitalGlobe©, et al., 2011)

Results and Discussion

<u>Evaluation of Water Parameters</u>

DoR-OR personnel performed basic monitoring of the underdrain (EMWMF-2) and the sediment basin outfall (EMWMF-3) for temperature, pH, conductivity, DO, and ORP usually twice per week utilizing a YSI® Professional Plus water quality meter. Calibration or a confidence check of this instrument is performed prior to field use. Locations and rationale are listed in Table 2.6.1.

Table 2.6.1: YSI® Professional Plus Monitoring Locations

DoR-OR Designation	EMWMF Site Designation	Rationale
EMWMF-2	EMW-VWUNDERDRAIN	Monitor to determine the integrity of the landfill and establish a baseline of water quality parameters for comparison
EMWMF-3	EMWW-VWEIR	Monitor water being discharged to North Tributary 5 from the sediment basin receives both uncontaminated stormwater runoff and water that has been in contact with the waste stream.

EMWMF - Environmental Management Waste Management Facility
DoR-OR - Tennessee Division of Remediation Oak Ridge Office

Tables 2.6.2 and 2.6.3 provide a summary of the data recorded at the two sites with the YSI®. Professional Plus multi-parameter water quality instrument. Results are summarized in the text below.

Table 2.6.2: Water Quality Parameters Measured – EMWMF-2 UNDERDRAIN

Water Quality Parameters Measured - EMWMF-2 UNDERDRAIN		Jan 2016	Feb 2016	Mar 2016	Apr 2016	May 2016	Jun 2016	Jul 2016	Aug 2016	Sep 2016	Oct 2016	Nov 2016	Dec 2016	Jan 2017	Feb 2017	Mar 2017	Apr 2017	May 2017	Jun 2017
pH	H	6.64	6.64	6.57	6.83	6.83	6.89	6.9	6.61	6.61	6.82	7.51	6.6	7.535	7.78	7.61	7.41	7.56	7.36
	L	6.51	6.38	6.29	6.4	6.26	6.41	6.39	6.38	6.44	6.42	5.97	6.29	6.52	6.94	6.67	6.61	7.11	6.5
	A	6.57	6.55	6.42	6.55	6.58	6.59	6.6	6.51	6.53	6.56	6.6	6.41	7.14	7.22	7.03	6.92	7.35	7.02
DO	H	6.92	5.76	5.56	5.49	4.16	2.72	2.03	1.98	1.94	3.85	5.46	5.21	6.46	7.66	6.06	4.86	5.09	4.63
	L	4.83	3.64	3.12	2.13	1.66	1.57	1.33	1.23	1.15	1.41	2.25	5.2	4.59	3.88	3.29	2.55	2.69	2.91
	A	5.6	4.9	4.36	3.78	2.76	1.97	1.62	1.69	1.64	2.61	3.81	5.21	5.27	5.64	4.64	3.71	3.89	3.85
Cond	H	583.6	597	573	537.2	537.6	531	511.7	499	498	486	746	630	596	550	599	603	573	596
	L	517.4	552	507	506	505	507	482.1	487	479	461	463	547	402	522	543	538	547	543
	A	548.5	573	543	526	523	519	499	493	488	474	509	579	544	537	556	565	557	561
Temp	H	15.4	15.9	16.1	16.6	17.4	17.9	18.7	18.7	19	18.6	18.1	17.4	16.3	16.2	16.6	16.8	17.4	17.9
	L	13.9	13.9	14.9	15.7	16.2	17.4	17.7	18.1	18.5	17.7	16.5	15.4	15.2	15	15.5	16.1	16.6	17.2
	A	14.7	15	15.6	16.2	16.9	17.6	18.2	18.4	18.7	18.1	17.3	16.1	15.8	15.7	15.9	16.6	17.1	17.6
ORP	H	382.7	349	315.9	320	285	285	255.7	264.6	265	357	291	224	257	327	476	397	402	267
	L	291.8	259	246	227	180	143	160	197	158	128	151	121	212	247	303	285	202	201
	A	337.6	291	268	275	237	220	216	243	197	223	224	190	239	277	359	336	291	242
visits		7	7	6	6	9	7	8	9	9	7	8	8	6	9	8	8	9	9

H - High Measurement　L - Low Measurement　A - Average Measurement　pH - Alkalinity

DO-Dissolved Oxygen　Cond - Specific Conductivity　TEMP- Temperature　ORP - Oxidation Reduction Potential

Alkalinity (pH) is an important limiting chemical factor for aquatic life. If the water in a stream is too acidic or basic, the H+ or OH- ion activity may disrupt the aquatic organism's biochemical reactions by either harming or killing the stream organisms. Streams generally have a pH value ranging from 6.0 to 9.0, depending upon the presence of dissolved substances that come from bedrock, soils and other materials in the watershed. The discharge criteria for the EMWMF is between 6.5 – 9.0.

Dissolved oxygen is expressed as a concentration in water. Concentration is the amount of a particular substance per a given volume of liquid. The DO concentration in a stream is the mass of the oxygen gas present in milligrams/liter of water or ppm. This number can be affected by temperature, flow, aquatic life, altitude, dissolved or suspended solids or human activity. The DO should be above 5.0 for EMWMF-3. Since there is no interface with the atmosphere until it surfaces at EMWMF-2, the DO is logically lower.

Specific conductivity is a measure of how well water can pass an electrical current. It is an indirect measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron and aluminum. The presence of these substances increases the

Table 2.6.3: Water Quality Parameters Measured – EMWMF-3 OUTFALL

Water Quality Parameters Measured - EMWMF-3 OUTFALL		Jan 2016	Feb 2016	Mar 2016	Apr 2016	May 2016	Jun 2016	Jul 2016	Aug 2016	Sep 2016	Oct 2016	Nov 2016	Dec 2016	Jan 2017	Feb 2017	Mar 2017	Apr 2017	May 2017	Jun 2017
pH	H	8.37	7.99	8.66	8.61	8.89	8.56	9.22	8.09	7.65	7.91		8.07	8.12	8.68	8.74	8.94	9.15	8.86
	L	7.62	7.64	7.88	8.14	8.32	7.27	6.89	7.17	7.32	7.3		7.44	7.88	7.64	7.48	7.51	8.22	7.26
	A	8.09	7.78	8.13	8.37	8.61	7.99	8	7.63	7.48	7.54		7.76	8	7.94	7.93	8.14	8.53	8.14
DO	H	15.25	14.55	11.47	10.69	8.01	7.11	7.33	6.18	6.5	7.42		11.94	19.19	16.01	13.14	10.66	11.41	8.93
	L	12.78	11.54	8.91	5.61	5.69	5.68	4.65	4.43	4.78	5.35		10.78	11.14	10.98	9.43	8.43	7.99	5.71
	A	14.3	12.5	9.4	8.48	6.83	6.27	5.89	5.43	5.41	6.06		11.36	13.88	13.62	11.37	9.42	9.21	7.53
Cond	H	661.4	607	636	214.6	147	515	555	221.1	515	408		423	616	639	474	527	745	352
	L	292	170	282	151	129.8	136.9	311	166.3	221	355		174	378	421	208	174	149	172
	A	552	373	435	180	136	347	380	191	348	378		274	457	505	306	298	486	266
Temp	H	15	12.8	15.7	23.3	26.4	31.1	30.5	30.6	26.6	20.1		10.5	11.7	13.6	19.2	22.2	26.4	26.7
	L	13.9	2.1	10.4	13.9	19.5	27	27.6	24.8	21.5	15.9		4	3.9	8.2	9.1	16.2	19.1	23.4
	A	14.7	6.7	13.8	17.2	22.9	28.5	29.5	27.9	24.3	18.6		7	9.2	9.6	13.1	18.5	22.5	24.9
ORP	H	382.7	287.6	265	265.7	216	260.6	245.6	270.4	299	228.4		206	240	284	427	314	285	250.8
	L	292	211.5	187	175.3	154	147	163	195.3	166	211		107	216	223	248	238	184	164.2
	A	338	256	223	216	194	212.7	215	232.2	226	220		158	224	246	303	267	211	187
visits		7	7	6	6	9	7	8	9	9	3*	0*	8	6	9	8	8	9	9

H - High Measurement L - Low Measurement A - Average Measurement pH - Alkalinity
*During part of October and November there was no water flow from the Outfall
DO-Dissolved Oxygen Cond-Specific Conductivity TEMP-Temperature ORP-Oxidation Reduction Potential

specific conductivity in water. Conversely, substances like oil or alcohol will lower the specific conductivity. The specific conductivity should be greater than 150 microSiemens/centimeters. It should remain fairly constant for EMWMF-2 and vary slightly for EMWMF-3 based on conditions.

Temperature of water is a controlling factor for aquatic life. It controls the rate of metabolism, reproduction activities and, therefore, life cycles. Temperature can be influenced by seasonal fluctuations and flow rate.

Oxidation Reduction Potential (ORP) or Redox potential is a measurement of water's ability to oxidize contaminants. The higher the ORP, the greater the number of oxidizing agents present. ORP is compared with specific conductivity.

EMWMF-2

The temperature fluctuated slightly during the seasons. The pH was relatively constant (and consistent with previous years) as expected with groundwater, until January of 2017. At this point, an upward trend of approximately 0.5 pH has been observed. DoR-OR is in the process of taking additional samples and evaluating the area for changes. The DO dropped minimally during the summer months and fall as expected with slightly higher temperatures. The conductivity maintained a consistent average, also expected with groundwater. The 2016 data was consistent with the 2015 data. The 2017 data displays a slight increase in pH as previously mentioned. These results are subject to meeting the storm water monitoring criteria shown in Table 2.6.4.

EMWMF-3

Temperatures rise and fall with the seasons. The pH was relatively constant throughout the year. The pH was found to be above the release criteria (>9) during two monitoring events (July 16 and May 17). Both occurrences are most likely the result of algae blooms. Site personnel were notified of the occurrences. No other instances of a high pH occurred to raise concerns. The DO dropped as the temperatures rose during the weather cycle. Conductivity displayed small spikes throughout the year. No correlation to conditions was determined. These results are subject to meeting the storm water monitoring criteria listed in Table 2.6.4.

Sampling

To ensure contaminants from the cell are not adversely affecting the surrounding environment, sediment samples from the sediment basin and water samples from monitoring locations connected with EMWMF were collected to determine if levels leaving the facility exceed previously established limits or if nearby tributaries have potentially been affected by processes associated with the EMWMF.

Table 2.6.4: Storm Water Monitoring Criteria

Stormwater Monitoring Criteria	
Parameter	**Release Criteria Level**
5-day Biological Oxygen Demand	40 mg/L
Total Suspended Solids (TSS)	110 mg/L
Ammonia as Nitrogen	0.2 mg/L
Oil and Grease	30 mg/L
pH	6.0-9.0 (standard units)
Gross Alpha	15 pCi/L
Gross Beta	50 pCi/L
Radiological COCs	25% of Nuclide specific DCG from DOE Order 5400.5

(Safe Drinking Water Act, TDEC 0400-40-03-.03[3(g)] and 0400-20-11-.16)
mg/L – milligram per liter
pCi/L – picoCuries per liter
COC – contaminants of concern
DCG – derived concentration guides
DOE – Department of Energy

Radiological Sediment Samples

Two sediment samples were collected from the sediment basin at different localities on the same day in 2016. Three samples from 2015 are shown for comparison. Due to the heavy amount of precipitation received in 2014, there was not an opportunity to collect sediment samples from the sediment basin that year. Samples are collected to determine if any deposition of radiological contaminants has occurred in the sediment basin. The results of this data are shown in Table 2.6.5. Samples were analyzed for gross alpha, gross beta, strontium-90, total uranium and technetium-99. Data points depict an upward trend of technetium-99 since last year. Other data is inconclusive at this time. DoR-OR will continue to monitor the sediment basin in 2017 – 2018.

Table 2.6.5: EMWMF Sediment Basin Sampling Results

EMWMF Sediment Basin Sampling Results						
Station ID	Date	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Technetium-99 (pCi/g)	Strontium-90 (pCi/g)	Total Uranium (pCi/g)
SB-1	10/19/2016	7.06	81.9	57.8	0.606	9.32
SB-2	10/19/2016	7.16	313.5	206	0.367	26.64
SB-1	6/7/2015	9.4	117.4	34.6	-0.06	14.82
SB-2	6/7/2015	14.4	311	49.2	0.56	27.17
SB-3	6/7/2015	19.3	171	20.5	0.4	12.78

pCi/g – picoCuries per gram

Radiological Water Samples

Five location groupings were routinely sampled at EMWMF and analyzed for radionuclides. The analyses varied and included gross alpha, gross beta, gamma, strontium-90, technetium-99, tritium, and isotopic uranium.

EMWMF-1 (GW-918)

Four samples were collected at the background location, EMWMF-1, during the 18-month time period for this report. This location was co-sampled during the quarterly groundwater sampling events for EMWMF-1 at GW-918. The samples were analyzed for gross alpha, gross beta, gamma radionuclides, strontium-90, technetium-99, isotopic uranium, and tritium. Results are listed in Table 2.6.6. The data for May 24, 2017 were not available at the time of this report. The 2015 data are shown for comparison purposes.

Table 2.6.6: EMWMF-1 (GW-918) Sample Results

EMWMF-1 (GW-918) Sample Results						
Date	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Strontium-90 (pCi/L)	Technetium-99 (pCi/L)	Total Uranium (pCi/L)	Tritium (pCi/L)
2/25/2015	-0.02	6.8	0.58	0.17	0.71	-13
8/11/2015	0.61	1.5	-0.34	0.02	0.045	58
2/10/2016	0.95	2.9	0.16	-0.23	0.461	144
8/10/2016	0.18	2.6	0.08	-0.18	0.407	12
2/13/2017	0.47	3	0.02	-0.06	0.071	16
5/24/2017	pending	pending	pending	pending	pending	pending

pCi/L - picoCuries per liter
GW - groundwater well

EMWMF-2 (Underdrain Discharge)

Eight samples were collected at EMWMF-2. The samples were analyzed for gross alpha, gross beta, technetium-99, tritium, strontium-90, and isotopic uranium. The sample results are listed in Table 2.6.7. The sample results from June 6, 2017 had not been received prior to the writing of this report. While the levels do not raise a health concern/risk, the presence of Tc-99 activity as well as uranium will be observed closely for upward trends and potential seeps in the liner. Based on the data, there are no concerns at this time.

Table 2.6.7: EMWMF-2 (Underdrain Discharge) Sample Results

EMWMF-2 (Underdrain Discharge) Sample Results						
Date	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Technetium-99 (pCi/L)	Tritium (pCi/L)	Strontium-90 (pCi/L)	Uranium (pCi/L)
3/24/2016	0.81	1.9	-0.02	96	0.74	0.511
5/12/2016	0.98	3.8	-0.34	-33	-0.38	1.99
8/2/2016	-0.4	3.5	0.09	38	0.1	0.551
10/28/2016	0.4	-0.9	-0.06	386	-0.04	0.214
1/26/2017	0.87	1.4	0.52	27	-0.15	0.572
2/28/2017	-0.66	4.9	0.26	106	0.018	0.639
4/4/2017	-0.12	1.6	-0.37	17	0	0.615
6/6/2017	pending	pending	pending	pending	pending	pending

pCi/L - picoCuries per liter

<u>EMWMF-3 (Sediment Basin Discharge)</u>

Seven samples were collected at EMWMF-3 during the period from January 1, 2016 through June 30, 2017. At the time of this report, results for one sample (June 6, 2017) had not been received from the lab. The samples were analyzed for gross alpha, gross beta, strontium-90, technetium-99, isotopic uranium, and tritium. The sample results are listed in Table 2.6.8. The results at EMWMF-3 were elevated in all the analyses except Sr-90, indicating some radionuclides are being discharged at EMWMF-3. Sr-90 results have steadily decreased since 2014.

Table 2.6.8: EMWMF-3 Sediment Basin Outfall Results

EMWMF Sediment Basin Outfall Results						
Date	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Strontium-90 (pCi/L)	Technetium-99 (pCi/L)	Total Uranium (pCi/L)	Tritium (pCi/L)
3/15/2016	51.3	11.8	0.77	185.2	49.16	1605
5/12/2016	4.79	26.6	0.04	21.05	6.85	445
8/9/2016	5.1	18.5	0.23	12.33	5.16	152
12/2/2016	1.33	13.5	0.16	8.91	2.23	36
1/26/2017	36.1	135.8	0.22	115.7	43.01	747
4/6/2017	5.2	12.6	-0.19	6.21	5.36	115
6/6/2017	pending	pending	pending	pending	pending	pending

pCi/L - picoCuries per liter

This location is subject to the release criteria shown in Table 2.6.4. There are exceedances to the gross alpha and gross beta release criteria; however, DOE Order 5400.5 establishes Derived Concentration Guides (DCGs) for radionuclides in process effluents, listed in Table 2.6.9, which are used as reference concentrations for conducting environmental protection programs. According to the DOE agreement with DoR-OR, annual average sum of fractions (SOF) calculations for storm water discharge into Bear Creek are based on 25% of the 100 millirem per year DCG specified under DOE Order 5400.5, which corresponds to a SOF of 1.042. In addition to the TDEC limit for SOF, a modified annual average SOF of 0.625 serves as the environmental ALARA goal for EMWMF. The storm water SOF is calculated each calendar year using radiological contaminants of concern results reported for monthly surface water, monthly storm water, other storm-water, quarterly surface water, and miscellaneous surface water samples collected at the discharge point of the EMWMF storm water retention and sedimentation pond. For 2016, the annual storm water SOF result is 0.4, which is within compliance with the TDEC limit of 25 mrem/yr specified under TDEC Rule 0400-20-11-16.

Table 2.6.9: Derived Concentration Guides for Selected Isotopes

Derived Concentration Guides (DCGs) for Selected Isotopes		
Isotope	**DCG (100 mrem/year)**	**¼ of DCG (25 mrem/year)**
Tritium	2,000,000 pCi/L	500,000 pCi/L
Strontium-90	1,000 pCi/L	250 pCi/L
Technetium-99	100,000 pCi/L	25,000 pCi/L
Uranium-234	500 pCi/L	125 pCi/L
Uranium-235	600 pCi/L	150 pCi/L
Uranium-238	600 pCi/L	150 pCi/L

pCi/L - picoCuries per liter
mrem/year – millirem per year

EMWMF-4B (Uncontaminated Storm-water Discharge)

Six samples were collected at EMWMF-4B. The samples were analyzed for gross alpha, gross beta, strontium-90, total uranium, technetium-99 and tritium. The sample results are listed in Table 2.6.10.

Table 2.6.10: EMWMF-4B Sample Results

EMWMF-4/4B Sample Results						
Date	**Gross Alpha (pCi/L)**	**Gross Beta (pCi/L)**	**Strontium-90 (pCi/L)**	**Technetium-99 (pCi/L)**	**Total Uranium (pCi/L)**	**Tritium (pCi/L)**
1/26/2016	1.73	5.2	0.13	0.99	0.616	304
4/4/2016	1.48	5.5	-0.12	-0.22	0.476	1034
7/12/2016	0.22	1.6	0.48	0.04	0.271	-6
1/24/2017	1.33	5.4	0.07	-0.12	0.949	324
2/14/2017	0.55	2.3	-0.01	0.08	0.413	202
4/11/2017	0.12	1.8	0.05	0.37	0.46	53

pCi/L - picoCuries per liter

This location is also subject to the release criteria listed in Table 2.6.4 as it is discharged to EMWMF-3. The samples at EMWMF-4B did not exceed their release criteria.

Surface Water Runoff

One sample was collected at NT-3A and one at NT-5. NT-4 was not sampled during this period. The samples were analyzed for gross alpha, gross beta, strontium-90, technetium-99, isotopic uranium, and tritium. The sample results are listed in Table 2.6.11. The results from the tributaries do not indicate a concern at this time. DoR-OR will continue to monitor the tributaries for changing conditions.

Table 2.6.11: Surface Water Results

Surface Water Results							
Station ID	Date	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Strontium-90 (pCi/L)	Technetium-99 (pCi/L)	Total Uranium (pCi/L)	Tritium (pCi/L)
NT-3A	7/8/2016	0.66	3.5	-0.16	0.4	0.447	48
NT-4	NS	NS	NS	NS	NS	NS	NS
NT-5	5/27/2016	-0.52	11.3	0.08	-0.04	2.066	63

pCi/L - picoCuries per liter
NS - not sampled

This location is subject to the release criteria shown in Table 2.6.4. The surface water runoff enters Bear Creek. No concerns are reported for these sites.

Conclusions

- There are still concerns with occasional elevated pH at EMWMF-3. This is most likely caused by algae blooms. Site personnel are aware of the concern. Continuous water quality parameters document discharges, changing conditions and monitor releases at EMWMF-2 and EMWMF-3.

- The results from the radiological water samples suggest that radionuclides are being discharged from EMWMF-3. However, those discharges are within compliance under TDEC Rule 0400-20-11-.16. DoR-OR will continue to monitor sediment samples downstream EMWMF-3 to determine potential impacts to Bear Creek.

- DoR-OR will continue to monitor sediment in the sediment basin to determine if levels of contaminants are increasing to numbers that could cause ecological risks. DOE will be notified of any potential concerns.

- DoR-OR and DOE contractors will continue to monitor the sampling and analysis methods used for strontium-90. Quality assurance/quality control merits additional scrutiny of elevated samples.

2.7 RadNet

2.7.1 RadNet Air Monitoring

Introduction

The RadNet Air Monitoring program on the Oak Ridge Reservation (ORR) began in August 1996 and provides radiochemical analysis of air samples taken from five air monitoring stations located near potential sources of radiological air emissions on the ORR. DoR-OR personnel collect RadNet samples and analysis is performed at the EPA National Air and Radiation Environmental Laboratory in Montgomery, Alabama. From 2016 through the first part of June 2017, as in past years, the data for each of the five RadNet air monitors largely exhibited similar trends and concentrations. The results for 2016 through the first part of June 2017 do not indicate a significant impact on the environment or public health from ORR emissions.

Air emissions from DOE activities on the ORR in the past, were believed to have been a potential cause of illnesses affecting area residents. While these emissions have substantially decreased over the years, concerns have remained that air pollutants from current activities (e.g., production of radioisotopes and demolition of radioactively contaminated facilities) could pose a threat to public health, the surrounding environment, or both. Consequently, DoR-OR has implemented a number of air monitoring programs to assess the impact of ORR air emissions on the surrounding environment and the effectiveness of DOE controls and monitoring systems.

Methods and Materials

The locations of the five RadNet air samplers are shown in Figure 2.7.1.1 and the EPA analytical parameters and frequencies for analysis are listed in Table 2.7.1.1. The RadNet air samplers run continuously, collecting suspended particulates on synthetic fiber filters (10 centimeters in diameter) as air is drawn into and through the units by a pump at approximately 35 cubic feet per minute. DoR-OR personnel collect the filters from each sampler twice weekly. Following EPA protocol (U.S. EPA 1988, U.S. EPA 2006), the filters are then shipped to EPA's laboratory (NAREL) for analysis following EPA protocol (U.S. EPA 1988, U.S. EPA 2006).

NAREL performs gross beta analysis on each sample collected. If the gross beta result for a sample exceeds one picocurie per cubic meter (pCi/m^3), then gamma spectrometry analysis is performed on that sample. Every four years, a composite of the air filters collected from each monitoring station during the year is analyzed for uranium and plutonium isotopes.

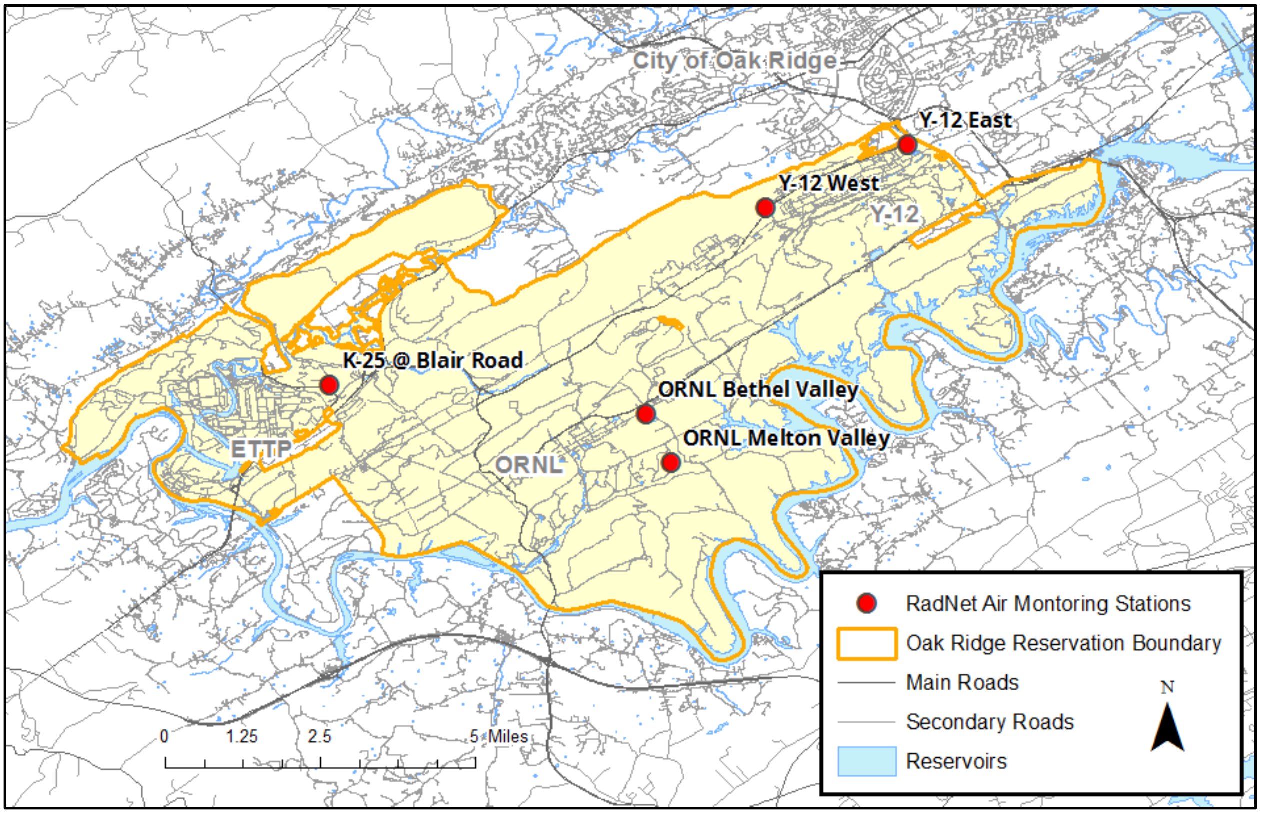


Figure 2.7.1.1: Locations of RadNet Air Monitoring Stations on the Oak Ridge Reservation

Table 2.7.1.1: RadNet Air Monitoring Analyses and Frequencies

RadNet Air Monitoring Analyses and Frequency	
ANALYSIS	**FREQUENCY**
Gross Beta	Each sample, twice weekly
Gamma Scan	As needed on samples showing greater than 1 pCi/m^3 of gross beta
Plutonium-238, Plutonium-239, Plutonium-240, Uranium-234, Uranium-235, Uranium-238	Every four years on an annual composite from each station (started in 2014, previously annually)

pCi/m^3 - picoCuries per cubic meter

Results and Discussion

The results of the NAREL analysis of the nationwide RadNet air data are available at NAREL's website in the Envirofacts RadNet searchable database, via either a simple or a customized search. The results shared in the report cover all of 2016 and the data available at the time the report was written (through June 8, 2017, for the RadNet air stations on the ORR and through May 3, 2017, for the station used for comparison in Knoxville, Tennessee).

Gross beta from the RadNet air monitoring program is compared to background data from the RadNet air monitor in Knoxville, Tennessee, and to the Clean Air Act (CAA) environmental limit for strontium-90 as it is a pure beta emitter with a conservative limit.

As shown in Figure 2.7.1.2, the results for the gross beta analysis in 2016 through the first part of June 2017 were generally similar for each of the five ORR RadNet monitoring stations and most were similar to the results reported for the Knoxville RadNet air station used as background for comparison. There were some exceptions during this time. The general fluctuations seen in the results are largely attributable to natural phenomena (wind and rain) that influence the amount of particulates suspended in the air and deposited on the filters. Some of the differences between the RadNet stations on the ORR and the background station in Knoxville may be attributable to differences in the collection schedule. The increased levels seen at the end of 2016 may be due to the drought, which was the worst during that same period, as evidenced in Figure 2.7.1.3. The 2016 through the first part of June 2017 ORR gross beta results for the RadNet air program are all below 1.0 pCi/m^3, which is the screening level requiring further analysis.

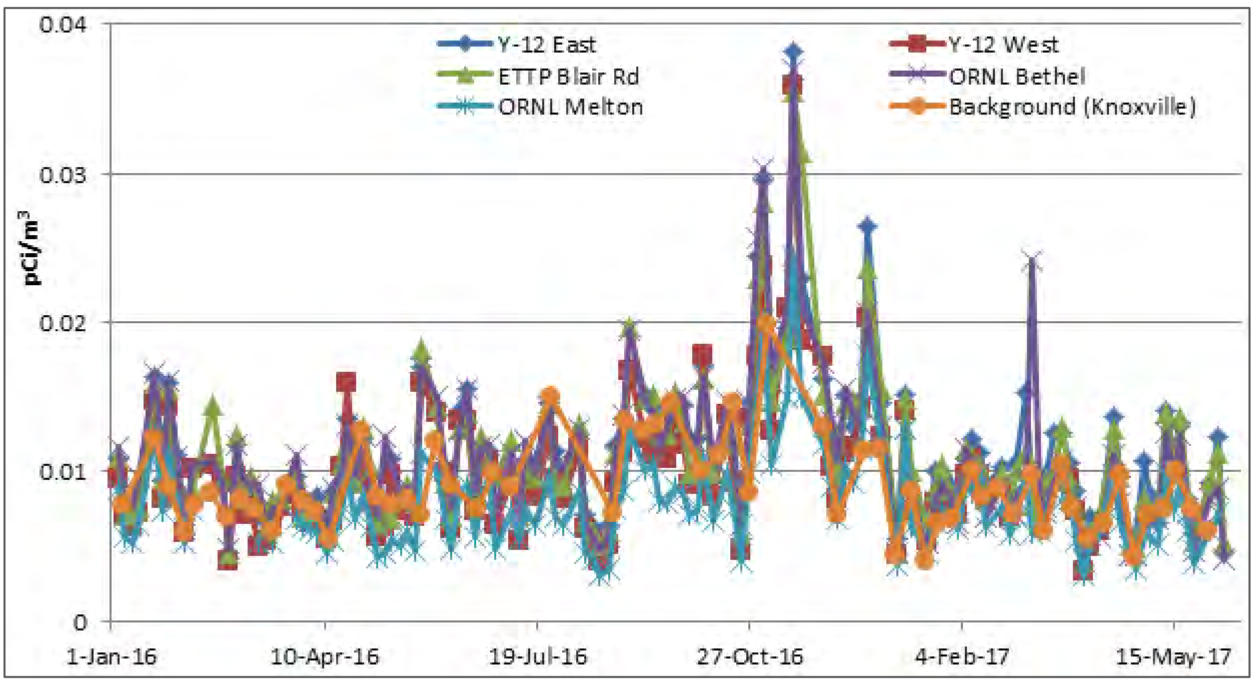


Figure 2.7.1.2: RadNet Air Monitoring Program 2016 Through the First Part of June 2017: Gross Beta Results and Background Measurements from the RadNet Air Station in Knoxville

Note: This Figure is intended to convey the correlation of the results for the various monitoring stations, not to depict individual results. Individual measurements are available at the DoR-OR office and online from EPA.

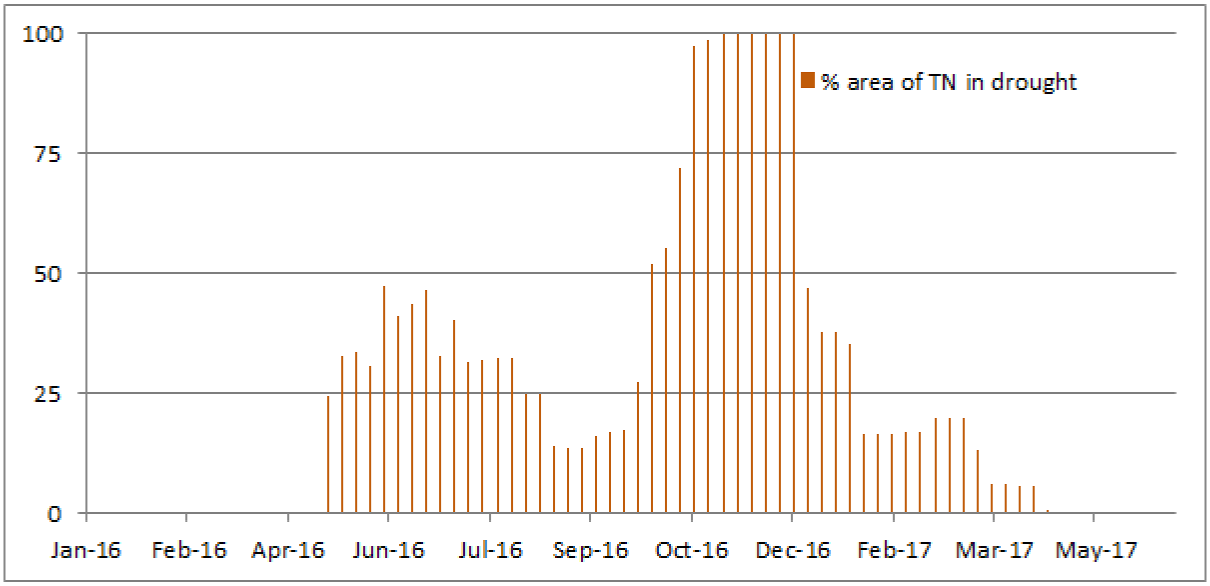


Figure 2.7.1.3: Percent Area of Tennessee in Drought 2016 through June 2017 **(drought.gov data)**

Figure 2.7.1.4 shows the 2016 average gross beta results for each of the five stations in the ORR RadNet air program, the average background concentration measured at the Knoxville RadNet location and the CAA environmental limit for strontium-90.

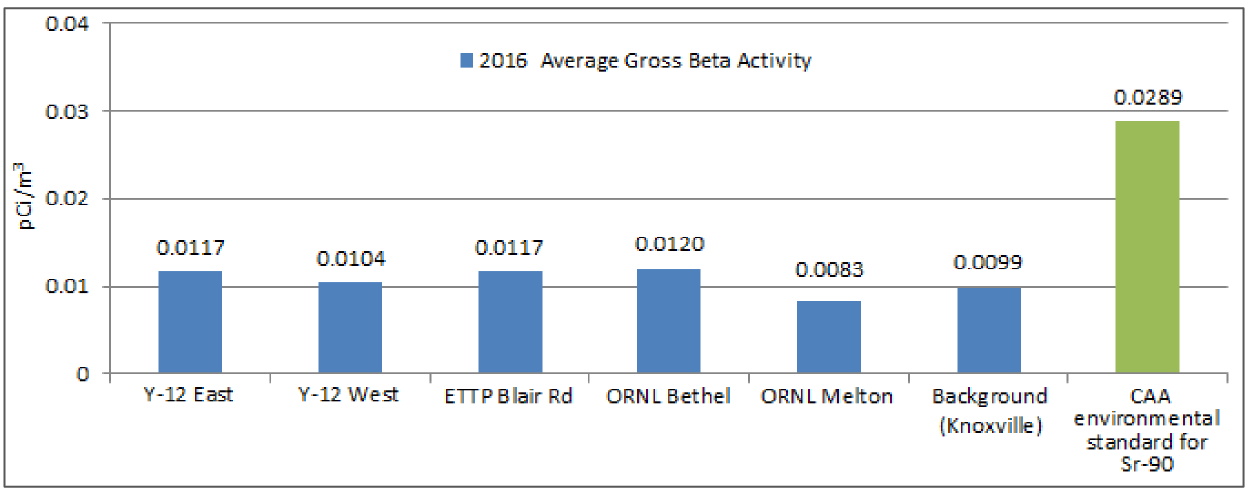


Figure 2.7.1.4: 2016 RadNet Air Monitoring Program Average Gross Beta Results

Note: Typical background values for gross beta range from 0.005- 0.1 pCi/m^3 (ORISE, 1993). The standards provided by the Clean Air Act apply to the dose above background; therefore, the standard provided for reference in this figure has been adjusted to include the average of the background measurements taken from the RadNet station in Knoxville for 2016 [CAA value for Sr-90 (0.019 pCi/ m^3) plus annual average gross beta at a background location equals CAA environmental standard for Sr-90].The CAA's environmental limit for strontium-90 is used as a screening mechanism and is provided here for comparison. It is unlikely that this isotope contributes a major portion of the gross beta activity reported for the samples.

The CAA specifies that exposures to the public from radioactive materials released to the air from DOE facilities shall not cause members of the public to receive an effective dose equivalent greater than 10 mrem above background measurements in one year. For point-source emissions, compliance with this standard is generally determined with air dispersion models that predict the dose at offsite locations. The CAA also provides environmental concentrations for radionuclides equivalent to a dose of 10 mrem in a year to determine compliance (EPA 2010).

To evaluate the RadNet data, DoR-OR compares the average gross beta results reported for the program to the CAA limit for strontium-90, which has one of the most stringent standards of the beta-emitting radionuclides. The standards apply to the dose above background, so the limit shown in Figure 2.7.1.4 has been adjusted to include the average gross beta measurement taken at the RadNet station in Knoxville, as background. It is important to note that strontium-90 is unlikely to be a large contributor to the total beta measurements reported here and is used only as a reference point to determine if further analysis is warranted.

While the 2016 results at all the RadNet air stations are largely comparable (results showed that all sites responded in a similar pattern during each sampling period), the average gross beta results for the RadNet program in 2016 were lower, overall, at the ORNL Melton Valley and Y-12 West locations. The station with the highest gross beta average for 2016 on the ORR, the ORNL Bethel Valley location, was just slightly over that seen at the Y-12 East and ETTP Blair Road locations. The average results from each of the ORR RadNet monitoring stations fall below the strontium-90 limit as shown in Figure 2.7.1.4.

From January 2016 through the first part of June 2017, none of the gross beta results reported for the program exceeded the screening level (1.0 pCi/m^3) requiring further analysis by gamma spectrometry.

The most recent results for uranium and plutonium analysis, since the switch to this analysis being run every four years rather than annually, are from 2013. The 2013 results for the uranium and plutonium analysis performed on annual composites of the air filters are shown in Table 2.7.1.2, using the RadNet station in Knoxville as the background.

The analysis for uranium and plutonium on annual composites has been changed and is performed every four years instead of annually. Since the change, the most recent composite results available are from 2013. The 2013 annual composites are shown in Table 2.7.1.2, using the RadNet station in Knoxville as the background.

Table 2.7.1.2: 2013 Composite Results for Uranium and Plutonium in RadNet Air (pCi/m^3)

	Y-12 East	Y-12 West	ETTP Blair Rd	ORNL Bethel	ORNL Melton	Background (Knoxville RadNet)	CAA standard (amount over background)	CAA standard (amount including background)
Pu238	-7.00E-08	-2.60E-07	-3.00E-08	-2.10E-07	2.60E-07	4.00E-07	2.10E-03	2.10E-03
Pu239	3.70E-07	2.60E-07	-8.00E-08	2.10E-07	0.00E+00	3.30E-07	2.00E-03	2.00E-03
U234	2.03E-05	4.63E-05	4.32E-05	1.34E-05	5.10E-06	6.10E-06	7.70E-03	7.71E-03
U235	1.86E-06	2.00E-06	2.90E-06	1.35E-06	8.10E-07	3.80E-07	7.10E-03	7.10E-03
U238	8.20E-06	2.36E-05	1.04E-05	6.50E-06	4.00E-06	6.30E-06	8.30E-03	8.31E-03

Note: The colored bars can be used as a quick comparison of results of the same isotope (same color). Negative values are not compared.

The annual composite uranium and plutonium values for the five ORR RadNet air stations were compared to the values from the RadNet air station in Knoxville as the background location. The background levels of each isotope seen at the Knoxville location generally reflected the composite results seen at the five stations on the ORR. The CAA standard is an amount over background. All values listed in Table 2.7.1.2 are below the Clean Air Act standards for each isotope.

Conclusions

The 2016 through the first part of June 2017 gross beta results for each of the five RadNet air monitoring stations generally exhibited similar trends and concentrations. The available RadNet data for 2016 through the first part of June 2017 do not indicate a significant impact on the environment or public health from ORR emissions.

2.7.2 RadNet Precipitation Monitoring

Introduction

The RadNet precipitation monitoring program on the Oak Ridge Reservation (ORR) provides radiochemical analysis of precipitation samples taken from monitoring stations at three locations on the ORR. Samples are collected by DoR-OR and analysis is performed at the EPA National Air and Radiation Environmental Laboratory (NAREL). Analysis for gamma radionuclides is performed on each monthly composite sample. Since there is not a regulatory limit for radioisotopes in precipitation, the results from ORR sampling locations are compared to the EPA drinking water limits and can also be compared to data from other sites nationwide. While the stations located on the ORR are in areas near nuclear sources, most of the other stations in the RadNet precipitation program are located near major population centers with no major sources of radiological contaminants nearby. Regardless, the radiological results seen in the precipitation samples collected at the RadNet sites on the ORR were all below the EPA drinking water limits. The EPA drinking water limits pertain to drinking water, not precipitation, and are only used here as conservative reference values.

The RadNet Precipitation monitoring program measures radioactive contaminants washed out of the atmosphere and carried to the earth's surface by precipitation. While there are no standards that apply directly to contaminants in precipitation, the data provide an indication of the presence of radioactive materials that may not be evident in the particulate samples collected by the DoR-OR air monitors. EPA has provided three precipitation monitors to date, which have been co-located at RadNet air stations at each of the ORR sites. One is located at ORNL in Melton Valley near the High Flux Isotope Reactor and burial grounds. Another is located east of ETTP, off Blair Road and monitors contaminants from demolition activities at ETTP. The third is co-located with the RadNet air station east of Y-12 and could potentially provide an indication of any other gamma radioisotopes traveling from ORNL toward the City of Oak Ridge. Analysis for gamma radionuclides is performed on the monthly composite samples for each of the three precipitation monitoring locations. Figure 2.7.2.1 shows the locations of the RadNet Precipitation samplers.

Since there are no regulatory limits for radiological contaminants in precipitation, the results of the gamma analyses are compared to drinking water limits used by EPA as conservative reference values. The EPA radionuclides rule for drinking water allows gross alpha levels of up to 15 pCi/L, while beta and photon emitters are limited to four mrem per year and are radionuclide specific. The monthly composite samples are analyzed for gamma radionuclides. Not all gamma isotopes have EPA drinking water limits, so only those that do are compared and only those that have been seen in RadNet precipitation samples. A large portion of the results is less than the minimum detectable concentration for each analysis. Barring nuclear accidents, the results for gamma radionuclides with drinking water limits would be expected to be below these regulatory limits. Table 2.7.2. shows the Maximum Contaminant Levels (MCLs) of beta and photon emitters that EPA uses as drinking water limits for select isotopes.

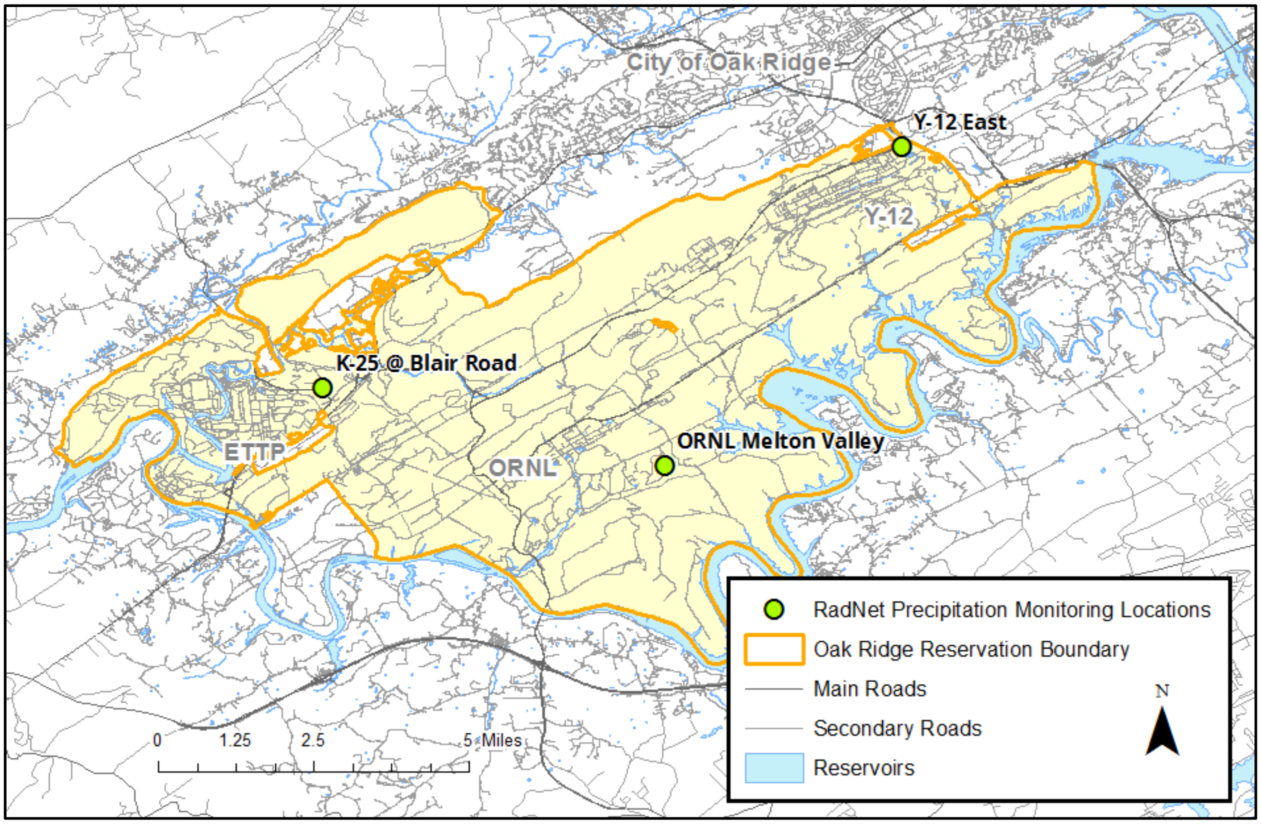


Figure 2.7.2.: Locations of the RadNet Precipitation Samplers on the ORR

Table 2.7.2.: EPA Drinking Water Limits (MCLs) for Select Isotopes

EPA Drinking Water Limits for Selected Isotopes	
Isotope	**EPA NPDWR (pCi/L)**
Barium-140 (Ba-140)	90
Beryllium-7 (Be-7)	6,000
Cobalt-60 (Co-60)	100
Cesium-134 (Cs-134)	80
Cesium-137 (Cs-137)	200
Tritium (H-3)	20,000
Iodine-131 (I-131)	3

NPDWR - National Primary Drinking Water Regulations

pCi/L - picoCuries per Liter

Methods and Materials

The precipitation samplers provided by the EPA RadNet program are used to collect samples for the RadNet precipitation program. Each sampler drains precipitation that falls on a 0.5 square meter fiberglass collector into a five-gallon plastic collection bucket. A sample is measured, then collected from the bucket (in a four-liter Cubitainer®), and sent to EPA when a minimum of two liters of precipitation has accumulated in the Cubitainer®, or potentially less than that if it is the final sample of the month. The sample is processed as specified by EPA (US EPA 1988, US EPA 2013) and is shipped to NAREL in Montgomery, Alabama for analysis. The NAREL laboratory composites the samples collected during the month for each station, and analyzes each composite by gamma spectrometry.

The results of the NAREL analyses are available at the NAREL website in the Envirofacts RadNet searchable database, via either a simple or a customized search. The data are used to identify anomalies in radiological contaminant levels to assess the significance of precipitation in contaminant pathways, to evaluate associated control measures, to appraise conditions on the ORR compared to other locations in the RadNet program and to determine levels of local contamination in the case of a nuclear disaster anywhere in the world.

Results and Discussions

The gamma spectrometry analysis results are for January 2016 through March 2017. The gamma isotopes for which there were data for this time period were beryllium-7, cesium-137, cobalt-60, potassium-40, radium-226, and radium-228. For all isotopes except beryllium-7, the reported results were less than the Minimum Detectable Concentration (MDC). As stated in the RadNet user guide, the MDC reflects the ability of the analytical process to detect the analytes for a given sample. The MDC is the activity concentration for which the analytical process detects the radioactive material in a given sample that provides a 95% chance that the radioactive material will be detected.

The average result for beryllium-7 from the three ORR samplers from January 2016 through March 2017 was 56.7 pCi/L, compared to an average MDC of 26 pCi/L. The national average for the same time period was 46.5 pCi/L. The highest beryllium-7 result from the ORR stations during this time period was 90 pCi/L. Beryllium-7 however, is a cosmogenic isotope, formed by the action of cosmic rays on the atmosphere. When compared to the relatively conservative EPA drinking water limit for beryllium-7 of 6,000 pCi/L, the values seen in the monthly composite precipitation samples on the ORR are relatively small.

Conclusions

Overall, the highest values observed for January 2016 and the first three months of 2017 in the composited monthly precipitation samples for each of the three ORR stations were below the MCLs set by the EPA for drinking water. All results for cesium-137, cobalt-60, potassium-40, radium-226, and radium-228 for this time period were less than the MDCs. While there are not regulatory limits for radionuclides in precipitation, the comparison to the EPA drinking water limits can be used as a conservative reference value.

2.7.3 RadNet Drinking Water Sampling

Introduction

The RadNet Program was developed by EPA to ensure public health and environmental quality as well as to monitor potential pathways for significant population exposures from routine and accidental releases of radioactivity (U.S. EPA, 1988). The RadNet program focuses on nuclear sources and population centers. The RadNet Drinking Water Program in the Oak Ridge area provides for radiochemical analysis of finished water from four public water supplies located near and on the ORR. Quarterly samples are collected by DoR-OR and an analysis for radiological contaminants is performed at the EPA National Air and Radiation Environmental Laboratory (NAREL). Analyses include tritium, iodine-131, gross alpha, gross beta, strontium-90, and gamma spectrometry with further analysis performed when warranted. All results generated by the program have remained below regulatory criteria since its inception in 1996.

Radioactive contaminants released on the ORR can potentially enter local streams and be transported to the Clinch River. While monitoring of the river and local water treatment facilities has indicated that concentrations of radioactive pollutants are below regulatory standards, a concern remains that area water supplies could be impacted by ORR pollutants. The RadNet Drinking Water Program provides quarterly radiological sampling of finished water at public water supplies near major population centers throughout the United States. The RadNet program also provides a mechanism to evaluate the impact of DOE activities on area water systems and to supplement DOE monitoring, providing independent third-party analysis.

Methods and Materials

For the Oak Ridge RadNet drinking water program, EPA provides radiochemical analysis of finished drinking water samples taken quarterly by DoR-OR at four public water supplies located on and in the vicinity of the ORR. The samples are collected using procedures and supplies prescribed by EPA protocol (U.S. EPA, 1988; U.S. EPA, 2013). The samples are analyzed at NAREL. The analytical frequencies and parameters are provided in Table 2.7.3.1.

The four locations sampled in the Oak Ridge area (listed from upstream to downstream) on the Clinch and then Tennessee River are the Anderson County Water Authority Water Treatment Plant, the Y-12 Water Treatment Plant (run by the city of Oak Ridge), the West Knox Utility District Water Treatment Facility, and the Kingston Water Treatment Plant. Figure 2.7.3 depicts the locations of the raw water intakes associated with these facilities.

The results of NAREL's analyses are available, along with nationwide data, at NAREL's website in the Envirofacts RadNet searchable database, via either a simple or a customized search (websites listed in references).

Table 2.7.3.1: RadNet Drinking Water Analyses and Frequencies

ANALYSIS	FREQUENCY
Tritium	Quarterly
Iodine-131	Annually on one individual sample/sampling site
Gross Alpha, Gross Beta, Strontium-90, Gamma Scan	Annually on composite samples
Radium-226, Uranium-234, Uranium-235, Uranium-238, Plutonium-238, Plutonium-239, Plutonium-240	Annually on samples with gross alpha >2 pCi/L
Radium-228	Annually on samples with Radium-226 between 3-5 pCi/L

pCi/L - picoCuries per Liter

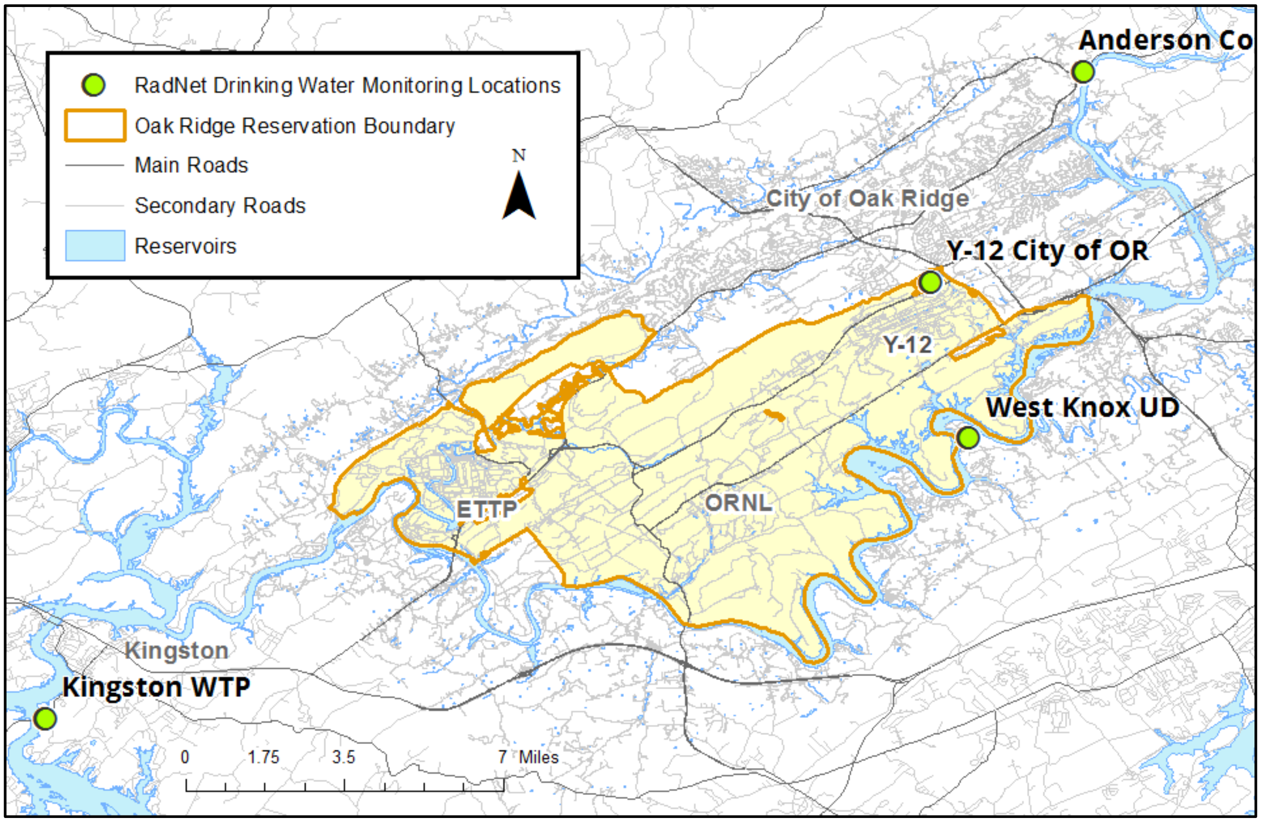


Figure 2.7.3.: RadNet Drinking Water Facility Intakes

Results and Discussions

Many radioactive contaminants are transported off the ORR in surface water and enter the Clinch River by way of White Oak Creek, which drains the ORNL complex and associated waste disposal areas in Bethel and Melton Valleys. When contaminants carried by White Oak Creek and other ORR streams enter the Clinch River, their concentrations have been significantly lowered by the dilution provided by the river. With exceptions, contaminant levels are further reduced in finished drinking water by conventional water treatment practices used by area water treatment plants. Consequently, the levels of radioactive contaminants measured in the Clinch River and at area water supplies are far below the concentrations measured in White Oak Creek and many of the other streams on the ORR.

Since the Kingston Water Treatment Plant is now the closest water supply downstream from the White Oak Creek, this facility would be expected to exhibit the highest concentrations of radioactive contaminants of the four utilities monitored by the ORR RadNet drinking water program. Previously, the ETTP Water Treatment Plant, run by the city of Oak Ridge, was the closest water supply downstream of White Oak Creek, but that plant was permanently closed at the end of September 2014. Conversely, the Anderson County facility (located upstream from the Oak Ridge Reservation) would be expected to be the least vulnerable of the facilities to ORR pollutants. The data collected since the Oak Ridge RadNet program began in July of 1996, indicates that this is the case; however, all results for these water treatment facilities have remained below applicable MCL drinking water standards set by EPA (Table 2.7.3.2).

Table 2.7.3.2: EPA Drinking Water Standards (pCi/L)

Isotope	EPA MCL (pCi/L)
Iodine-131 (I-131)	3
Strontium-90	8
Tritium (H-3)	20,000
Cobalt -60	100
Cesium-137 (Cs-137)	200

EPA - Environmental Protection Agency
MCL - Maximum Contaminant Levels (national primary drinking water regulation limits)
pCi/L - picoCuries per Liter

Tritium results for the four quarters of 2016 and the first quarter of 2017 were available from the Envirofacts website. These data are similar to the results received in past years. NAREL typically performs tritium analysis on each of the quarterly samples taken at the facilities in the program. Tritium is not readily removed by conventional treatment processes and is one of the most prevalent contaminants discharged by White Oak Creek into the Clinch River. Of the quarterly samples taken during this time period from each of the four area water treatment plants, all were well below the MDC.

The results below the MDC are colored gray in Table 2.7.3.3. The average MDC for the 2016 quarterly tritium samples and the first quarter of 2017 was 19 pCi/L and ranged from -73 to 116 pCi/L. Historically, the results of the tritium analyses are significantly below the MDC. The results for tritium at the drinking water plants monitored since the program's inception range from undetected to 1,000 pCi/L. The drinking water standard for tritium is 20,000 pCi/L, so even the highest levels of tritium that have been detected by this program in the Oak Ridge area are below this limit.

Since the net tritium results are obtained by subtracting the value of a tritium-free sample from that of the actual sample, negative numbers can be present. For a group of samples with no tritium, the results (positive and negative) should be distributed symmetrically around 0 pCi/L. Negative values are especially useful for unbiased statistical data, but can also be used to get a better picture of the range of results. The same is true for the analysis of other isotopes.

Table 2.7.3.3: Quarterly Tritium Results from the Four Water Treatment Facilities in pCi/L

RadNet Drinking Water - Tritium					
Utilities	2016				2017
	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1
Anderson	31	-11	33	-25	64
Y-12 (Oak Ridge)	-7	-18	-73	-13	63
West Knox	17	96	13	-12	97
Kingston	22	-37	2	15	116

MDC - Minimum Detectable Concentration
Values below the MDC are in gray
pCi/L - picoCuries per Liter

One quarterly sample per location per year is analyzed for I-131. The I-131 analysis for 2016 was performed for the first quarter sample at each of the four stations. The results for I-131analysis for 2017 were from the first and second quarters. All results were below the MDC for the analytical method used, as seen in Table 2.7.3.4.

Table 2.7.3.4: 2016 and 2017 Iodine-131 Four Water Treatment Facilities Results (pCi/L)

2016 and 2017 Iodine-131 Results				
Utilities	Quarter-Year	Result	MDC	Units
Anderson	QTR 1-2016	-0.029	0.3	pCi/L
Y-12 (Oak Ridge)	QTR 1-2016	-0.03	0.34	pCi/L
West Knox	QTR 1-2016	-0.007	0.31	pCi/L
Kingston	QTR 1-2016	-0.08	0.28	pCi/L
Anderson	QTR 1-2017	0.015	0.33	pCi/L
Y-12 (Oak Ridge)	QTR 1-2017	0.25	0.35	pCi/L
West Knox	QTR 2-2017	0.1	0.75	pCi/L
Kingston	QTR 1-2017	0.05	0.29	pCi/L

MDC - Minimum Detectable Concentration
Values below the MDC are in gray
pCi/L - picoCuries per Liter

Gross alpha, gross beta, gamma, and strontium-90 analyses are performed annually on a composite of the quarterly samples taken from each of the monitored facilities. Results of the 2016 composite analyses are not yet available, as it can be well into the following year before they are able to be composited. The available 2015 annual composite results are noted below.

In 2015, there was only one gross alpha result above the sample-specific MDC as seen in Table 2.7.3.5. EPA's drinking water standard for gross alpha in drinking water is 15 pCi/L (MCL). The four composite samples from 2015 were all below this amount.

Table 2.7.3.5: 2015 Annual Gross Alpha Composite Results in pCi/L

Annual Gross Alpha Composite Results				
Utilities	**Station Number**	**Result**	**MDC**	**Units**
Anderson	768	1.5	3.1	pCi/L
Y-12 (Oak Ridge)	772	1.5	3.1	pCi/L
West Knox	371	3.4	2.9	pCi/L
Kingston	360	-0.1	3	pCi/L

pCi/L - picoCuries per Liter
MDC - Minimum Detectable Concentration
Values below the MDC are in gray
pCi/L - picoCuries per Liter

The 2015 gross beta results are listed in Table 2.7.3.6. The drinking water standard for beta emitters depends on the specific radionuclides present, but radionuclide specific analysis is generally not required at gross beta measurements below 50 pCi/L. While there are no drinking water limits for gross beta, one can use strontium-90 limits as a conservative comparison, although strontium-90 is unlikely to make up a large percentage of the total gross beta result, if any. The gross beta results for the 2015 annual composites from drinking water sampling location near and on the ORR are below EPA's drinking water standard for strontium-90 (limit 8.0 pCi/L).

Table 2.7.3.6: 2015 Annual Gross Beta Composite Results in pCi/L

Annual Gross Beta Composite Results				
Utilities	Station Number	Result	MDC	Units
Anderson	768	2.1	4.1	pCi/L
Y-12 (Oak Ridge)	772	1.7	4.1	pCi/L
West Knox	371	1.8	3.7	pCi/L
Kingston	360	2.2	3.8	pCi/L

pCi/L - picoCuries per Liter

MDC - Minimum Detectable Concentration

Values below the MDC are in gray

The gamma spectrometry on the annual composites for 2015 showed no values above MDCs for cobalt-60 (Co-60), cesium-137 (Cs-137), and radium-228 (Ra-228). Potassium-40 (K-40) had two results higher than the sample specific MDCs. However, Potassium-40 is a naturally occurring radioactive isotope of potassium, which is widely distributed in nature. The 2015 results were below these EPA drinking water standards and below the sample specific MDCs.

The annual composite analysis of drinking water samples for strontium-90 in 2015 was not yet available at the time this report was written. The data from 2014 are below the minimum detectable concentrations. The highest strontium-90 in 2014 was 0.35 pCi/L (from West Knox). This was below the 8.0 pCi/L EPA drinking water limit for strontium-90. All samples analyzed from this program for the Oak Ridge area since its inception have been below the associated drinking water standards and often below the minimum detectable concentrations.

Conclusions

Radioactive contaminants migrate from the ORR to the Clinch River, which serves as a raw water source for area public drinking water supplies. The impact of these contaminants is diminished by the dilution provided by the waters of the Clinch River. Contaminant concentrations are further reduced in finished drinking water by conventional water treatment practices employed by area water treatment plants. Results of samples collected from public water supplies on and in the vicinity of the ORR in association with EPA's RadNet program have all been well below drinking water standards, since the inception of the project in 1996.

3.0 Findings and Recommendations by Focus Areas

3.1 Findings

Below is a list of the more significant findings from the DoR-OR projects beginning in January 2016 through June 30, 2017. These findings are loosely grouped by focus areas, as described in the 2016 Environmental Monitoring Plan and in this report.

- Seventeen dosimeter locations exceeded the 100 mrem screening level over the year: sixteen at ORNL and one at SNS.
- Three dosimeter stations at ORNL (D-36, D-37, and D-42) showed substantial decreases in exposure for radiation during 2016.
- Overall, the radiation doses measured in the environmental dosimetry program in 2015 decreased or remained statistically unchanged from 2014.
- EMWMF gamma levels were consistent with gamma exposure rate background measurements.
- ORNL Central Campus D&D (3000 Area) gamma exposure rate levels were consistent with background measurements.
- Gamma exposure rate measurements taken at the MSRE did not indicate any releases during the period.
- Gamma exposure rate levels at SNS varied substantially depending on the power level at which the accelerator was operating. During periods when the accelerator was shut down, gamma rates approximated background levels. This would tend to indicate that radioactive materials are not adhering to the interior of the stack. The gamma rates (during operation) are attributed to the expelling of noble gases. Members of the public do not have access to the area.
- During the Haul Road surveys between January 1, 2016 and June 30, 2017, no items with elevated levels of alpha and beta radiological contamination exceeded the DOE release criteria. However, occasional items requiring further evaluation were found.
- The fugitive air monitoring results were similar to background between January 1, 2016 and April 19, 2017 monitoring period. The average concentrations for all sites were below the federal standards.
- Multiple Anabat™ detectors spanning 578 survey nights surveyed 62 ORR field sites.
- Fourteen (14) different bat species were detected on the ORR.
- Threatened and endangered bats were detected at 46 of 62 combined ORR survey sites. Bats detected were the endangered gray bat and Indiana bat and the threatened northern long-eared bat.
- Tree bat calls were considerably more numerous than cave bat calls (except at East Fork Poplar Creek sites).

- Most dominant bats recordings (greatest number of calls) were for the big brown bat, hoary bat, eastern red bat, silver-haired bat, and tri-colored bat.

- Townsend's big-eared bat range does not include the ORR; however, that bat was recorded (acoustical hits) at 32 of 62 of the total 2016 survey sites.

- Southeastern bats (not been previously trapped or acoustically recorded on the ORR) were detected at 37 of 62 of the total 2016 survey sites.

- No daytime bat flight activity was recorded at the three caves surveyed (pertinent to the fight against white nose syndrome disease).

- The data from the samples collected in 2016 for the radiological contaminant uptake in vegetation project suggests limited areas of elevated radionuclide concentrations in the vegetation associated with surface water on the ORR.

- Of all benthic sites sampled during 2016, three locations (EFK 25.1, EFK 24.4 and EFK 23.4) received the lowest TMI scores and ratings, partially supporting/moderately impaired (TMI equals 10-20, C rating).

- The White Oak Creek impacted stations (WCK 3.9, WCK 3.4, and WCK 2.3) are an anomaly with very low benthic community densities.

- Four of the impacted benthic macroinvertebrate stations show scores that favorably compare to those of reference sites. These include BFK 9.6, BCK 3.3, EFK 13.8, and MEK 0.3. The high ranking of some of the impacted sites and the improvement in others is encouraging and the positive results are attributed to the remediation work completed at Y-12 and ORNL.

- For the surface water physical parameters data, all samples met Tennessee water quality criteria for the parameters observed at the seven monitoring stations on the ORR.

- In Bear Creek surface water physical parameters data, specific conductance was elevated, as compared to the Hinds Creek reference location (267.4 μS/cm), at BCK 12.3 (1213 microSiemens per centimeter [μS/cm]), then decreased downstream to BCK 3.3 (381 μS/cm). Monthly specific conductance data from BCK 12.3 show no discernible trend over an 18-month period in 2016 through 2017.

- Gross alpha activities were the highest at BCK 12.3 (54.8 picocuries per liter [pCi/L]), and decreased as the stream flowed downstream to BCK 3.3 (4.8 pCi/L). The reference location, Hinds Creek km 20.6, had an alpha value of 0.28 pCi/L.

- Gross beta activities were the highest at BCK 12.3 (485 pCi/L), and decreased as the stream flowed downstream to BCK 3.3 (9.4 pCi/L). The reference location, HCK 20.6 had a beta value of 6.5 pCi/L.

- TMI scores for Bear Creek show that BCK 12.3 is partially supporting/slightly impaired while BCK 9.6 and BCK 3.3 are supporting/non-impaired, as designated in TDEC (2006). Benthic,

- In Bear Creek, total mercury concentrations were below the CBSQGs PEC (1.06 mg/kg) in sediment at all sample locations.

- In Bear Creek, gross beta activities generally decreased downstream; the highest activities were at NT5.
- In East Fork Poplar Creek, Figure 2.4.2.5 presents select nutrient data from the upstream location at EFK 25.1 to the farthest downstream location at EFK 6.3. There is a general decrease in values downstream. The increase between EFK 13.8 and EFK 6.3 may be due to the influence of the Oak Ridge wastewater treatment facility just downstream of the EFK 13.8 sampling location.
- Cadmium, copper, and zinc show a decreasing trend downstream of EFK 25.1, but concentrations increase downstream of EFK 13.8, perhaps a result of discharges from the Oak Ridge wastewater treatment facility (Figure 2.4.2.6).
- Gross alpha values generally decrease from EFK 25.1 to EFK 6.3. All of these alpha values are higher than the reference location (Figure 2.4.2.7).
- Gross beta values also show a downward trend going downstream; they dip below the reference location's value (6.5 pCi/L) by EFK 13.8.
- TMI scores for East Fork Poplar Creek indicate that the stream is moderately impaired at the three uppermost sampling locations (EFK 25.1, 24.4, and 23.4). At EFK 13.8, the stream is supporting/non-impaired. At the most downstream sampling location, EFK 6.3, the TMI score drops again to partially supporting/slightly impaired. Benthic,
- In East Fork Poplar Creek, total mercury concentrations exceeded the CBSQGs PEC (1.06 mg/kg) at all sample locations.
- Total mercury results decreased with distance downstream from the Y-12 outfalls in each of the three years monitored: 2014, 2015, and 2016.
- Chromium concentrations were well above the level (1.5 mg/kg) measured at the Hinds Creek km 20.6 background location but well below the PEC (110 mg/kg).
- In East Fork Poplar Creek, gross alpha activities were relatively uniform among the sampling locations; all values were well above the level at the Clear Creek background location.
- In East Fork Poplar Creek, gross beta activities generally decreased downstream; the highest activities were at EFK 23.4.
- The East Fork Poplar Creek Mile 3.9 sediment mercury concentration (6.3 mg/kg) exceeds the PEC of 1.1 mg/kg (MacDonald et al. 2000). The mercury in East Fork Poplar Creek and Poplar Creek sediment results from historical activities at Y-12 and to a lesser extent ETTP.
- Although some metals and nutrient values in Mitchell Branch are higher than background locations, they are well below the Tennessee Water Quality Criteria (TWQC).
- The gross alpha activities at MIK 0.71 (4.24 pCi/L) and MIK 0.45 (5.20 pCi/L) were higher

than those of the reference locations. Reference locations MIK 1.43 and HCK 20.6 had alpha values of 0.25 and 0.28 pCi/L, respectively (Figure 2.4.2.9).

- The gross beta activities at MIK 0.71 (21.4 pCi/L) and MIK 0.45 (27.4 pCi/L) were higher than those of the reference locations. Reference locations MIK 1.43 and HCK 2.06 had beta values of 11.7 and 6.5, respectively (Figure 2.4.2.10).

- All of the Mitchell Branch sampling locations were partially supporting/slightly impaired in terms of TMI scores.

- In White Oak Creek, some metals values are higher than they are at background locations. However, they are well below the Tennessee Water Quality Criteria (TWQC).

- The gross alpha activities at WCK 3.9 (6.1 pCi/L), WCK 2.3 (11.7 pCi/L), and MEK 0.3 (25.6 pCi/L) were higher than that of the reference locations. Reference locations WCK 6.8 and HCK 20.6 had alpha values of 0.02 and 0.28 pCi/L, respectively (Figure 2.4.2.11).

- The gross beta activities at WCK 3.9 (110.7 pCi/L), WCK 2.3 (154.8 pCi/L), and MEK 0.3 (62.8 pCi/L) were higher than those at the reference locations. Reference locations WCK 6.8 and HCK 20.6 had alpha values of 1.8 and 6.5 pCi/L, respectively (Figure 2.4.2.12).

- White Oak Creek 6.8 (a reference location) was supporting/non-impaired with regard to the benthic macroinvertebrate community. The other White Oak Creek sampling locations (WCK 2.3, WCK 3.9) were partially supporting/slightly impaired. Melton Branch (MEK 0.3) was supporting/non-impaired.

- Strontium-90 analysis from the sample collected at Raccoon Creek showed a value of 10.1 pCi/L. This value is above the EPA strontium-90 MCL for drinking water of 8 pCi/L. The MCLs are used for comparison because there are no TWQC that address radionuclides.

- The metals data from the ambient surface water project were all non-detects with the exception of nickel (8 μg/L). This value is greater than the MBK 1.6 reference location (1.4 μg/L), but less than the TWQC (470 μg/L).

- The rain event sampling results seem to indicate that long-term radiological contaminates continue to impact White Oak Creek. Metals are present in Mitchell Branch, hexavalent chromium is sporadically present in SD 490, SD 430, and MIK 0.1 while mercury continues to be of concern at East Fork Poplar Creek. A radiological contaminant (Tc-99) from a 2013 release continues to impact SD 490.

- At EMWMF-3, occasional elevated pH is still a concern. Algae blooms most likely cause the elevated pH.

- The results from the EMWMF radiological water samples suggest that radionuclides are being discharged from EMWMF-3. However, those discharges are within compliance under TDEC Rule 1200-2-11-.16. Staff will continue to monitor sediment samples down-stream of EMWMF-3 to determine potential impacts to Bear Creek.

- DoR-OR will continue to monitor EMWMF sediment in the sediment basin to determine if levels of contaminants are increasing to numbers that could cause ecological risks.

- Mercury levels in sediment are highest at East Fork Poplar Creek km 6.3 and generally decrease downstream. Mercury concentrations exceeded the PEC at the locations sampled on East Fork Poplar Creek and Poplar Creek.
- Mercury levels in sediment increased significantly at Mitchell Branch km 0.1 (K1700) between 2004 and 2008, as did nickel, chromium, boron, and barium.
- In 2016, Cs-137 was detected (24.4 pCi/g) in the Clinch River sediment sample at river kilometer 23.3.
- The DOE never collected background groundwater data before beginning operations at the ORR.
- The groundwater data collected thus far is representative of the aquifers that exist on and downgradient of the ORR and can be used to compare with offsite residential well monitoring program data.
- Results for the springs located off the ORR did not indicate constituents above the NPDWR. There were a total of five exceedances in three springs of the NSDWRs for aluminum, iron, and manganese. SPG-055 had exceedances of manganese and iron. SPG-081 had exceedances of aluminum and iron and SPG-063 exceeded the NSDWR for aluminum.
- The available RadNet air monitoring data for 2016 through the first part of June 2017 do not indicate a significant impact on the environment or public health from ORR emissions.
- Results of samples collected from public water supplies on and near the ORR in association with EPA's RadNet program have all been well below drinking water standards, since the inception of the project in 1996.
- The average result for beryllium-7 for the three ORR RadNet precipitation samplers from 2016 through March 2017 was 56.7 pCi/L, compared to an average minimum detectable concentration of 26 pCi/L. The national average for the same time period was 46.5 pCi/L. The highest beryllium-7 result for the ORR stations during this time period was 90 pCi/L. Beryllium-7 however, is a cosmogenic isotope, formed by the action of cosmic rays on the atmosphere. When compared to the relatively conservative EPA drinking water limit for beryllium-7 of 6,000 pCi/L, the values seen in the monthly composite precipitation samples on the ORR are relatively small.
- The highest values seen for 2016 and the first three months of 2017, in the composited monthly RadNet precipitation samples for each of the three ORR stations, were all below the NPDWRs set by the EPA for drinking water

3.2 Recommendations

The following recommendations are brought forward by the project authors:

- Future bat acoustic surveys are recommended to fill data gaps where there is little, no, or un-organized bat species data on additional ORR areas.
- Further benthic macroinvertebrate investigation of the cause(s) of low benthic populations in White Oak Creek is warranted.
- Continued physical parameter monitoring at the seven monitoring creek stations is warranted.
- Continued rain event monitoring of impacted sites along with areas undergoing CERCLA D&D is warranted.
- More isotopic data from groundwater offsite, including stable nitrogen, oxygen, and carbon isotopes, is necessary to understand sources of contamination and the origin of groundwater (meteoric or connate); which has large implications for the ORR Hydrologic Conceptual Site Model.
- Continue long-term sampling to gain spatial and temporal trends for the behavior of the wells. With more data collected, we will be better able to make those trend predictions, over time.
- Borehole logging with the USGS to geophysically, visually, and geochemically profile wells in strategic background locations is warranted.
- Analyze surface water and groundwater samples for the stable carbon isotope, 13C. In doing so, the source of organics dissolved in the water can be identified.

4.0 References

2012 Edition of the Drinking Water Standards and Health Advisories, EPA 822-S-12-001. U.S. Environmental Protection Agency, Office of Water April 2012, Washington, D.C. Available at https://www.epa.gov/sites/production/files/2015-09/documents/dwstandards2012.pdf. August 30th, 2017.

Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies. Center for Devices and Radiological Health. U.S. Food and Drug Administration. Rockville, Maryland. August 1998. http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf

Adam, M. D., and J. P. Hayes. *Use of Bridges as Night Roosts by Bats in the Oregon Coast Range*. Journal of Mammalogy 81: 402–407. 2000.

Agranat, I. Bat Species Identification from Zero Crossing and Full Spectrum Echolocation Calls Using HMMs, Fisher Scores, Unsupervised Clustering and Balanced Winnow Pairwise Classifiers. Wildlife Acoustics, Inc., Maynard, Mass. 2012.

Allah, A.T.A., M.Q.A. Wanas and S. N. Thompson. *Dissolved Heavy Metals: Lead, Cadmium and Mercury, Accumulates in the Body of the Schistosome Vector, Biomphalaria glabrata (Gastropoda: Pulmonata).* Journal of Molluscan Studies 69:35-41. 2003.

Allard, M. and P. M. Stokes. Mercury in Crayfish Species from Thirteen Ontario Lakes in Relation to Water Chemistry and Smallmouth Bass (*Micropterus dolomieui*) Mercury. Canadian Journal of Fisheries and Aquatic Sciences 46: 1040–1046. 1989.

Allen, C. R., S. E. Romeling and L. Robbins. *Acoustic Monitoring and Sampling Technology*. Acoustic Monitoring Technology, 1-19. http://batcallid.com/SamplingTechnology.html. 2015.

Ammerman, L. K., C. L. Hice, and D. J. Schmidly. Bats of Texas. Texas A&M University Press, College Station, Texas. 305 pp. 2012.

Andersen™ Flow Manager High Volume (FMHV) Air Particulate Sampler Operation Procedure. RadNet/SOP-3. Monitoring and Analytical Services Branch, National Air and Radiation Environmental Laboratory. U.S. Environmental Protection Agency. Montgomery, Alabama. June 2006.

Anthony, E. L. P, M. H. Stack, and T. H. Kunz. *Night Roosting and the Nocturnal Time Budget of the Little Brown Bat, Myotis lucifugus: Effects of Reproductive Status, Prey Density, and Environmental Conditions*. Oecologia (Berlin) 51:151–156. 1981.

Argonne National Laboratory. *Radiological and Chemical Fact Sheets to Support Health Risk Analyses for Contaminated Areas.* Human Health Fact Sheet: Potassium-40. March 2007. https://www.remm.nlm.gov/ANL_ContaminantFactSheets_All_070418.pdf

Armstrong, F.A.J. and A. L. Hamilton. Trace Metals and Metal-organic Interaction in Natural Waters. pp. 131–156. Ann Arbor Science Publishers, Inc. Ann Arbor, MI 1973.

Arunee, S. *Acute Toxicity of Mercury and Copper to the Freshwater Snail*. Kasetsart Newsletter 31:39–51. 1986.

Avila-Flores, R. and M. B. Fenton. *Use of Spatial Features by Foraging Insectivorous Bats in a Large Urban Landscape*. Journal of Mammalogy 86:1193–1204. 2005.

Bailey, Z. C. and R. W. Lee. Hydrogeology and Geochemistry in Bear Creek and Union Valleys, Near Oak Ridge, Tennessee. Water Resources Investigations Report, 90-4008. U.S. Geological Survey. Nashville, Tennessee. 1991.

Barataud, M. *Inventaire au de´tecteur d'ultrasons des chiropte`res fre´quentant les zones d'altitude du nord du Parc National du Mercantour (Alpes, France).* Le Rhinolophe 13:43–52. 1998.

Barbour, M.T., J. Gerritsen , B.D. Snyder and J.B. Stribling. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. EPA 841-B-99-002. 11 chapters, 4 appendices. U.S. Environmental Protection Agency. 1999.

Barbour, M. T., J. L. Plafkin, B. P. Bradley, C. G. Graves, and R. W. Wisseman. *Evaluation of EPA's Rapid Bioassessment Benthic Metrics: Metric Redundancy and Variability Among Reference Stream Sites*. Environmental Toxicology and Chemistry 11:437-449. 1992.

Barclay, R. M. R. *Bats Are Not Birds—A Cautionary Note on Using Echolocation Calls to Identify Bats: A Comment*. Journal of Mammalogy 80:290-296. 1999.

Barclay, R. M. R. *Interindividual Use of Echolocation Calls: Eavesdropping by Bats*. Behavioral Ecology and Sociobiology 10:271-275. 1982.

Bell, A. H. and B. C. Scudder. *Mercury Accumulation in Periphyton of Eight River Ecosystems*. Journal of American Water Resources Association 43:957-968. 2007.

Bergeron, C.M., W.A. Hopkins, B.D. Todd, M.J. Hepner and J.M. Unrine. *Interactive Effects of Maternal and Dietary Mercury Exposure Have Latent and Lethal Consequences for Amphibian Larvae*. Environmental Science and Technology 45:3781–3787. 2011.

Brigham, A. R., W.U. Brigham, and A. Gnika, eds. Aquatic Insects and Oligochaetes of North and South Carolina. Midwest Aquatic Enterprises, Mahomet, Illinois. 837 pp. 1982.

Britzke, E. R. Use of Ultrasonic Detectors for Acoustic Identification and Study of Bat Ecology in the Eastern United States. Dissertation. Tennessee Technological University, Cookeville, Tennessee. 2003.

Britzke, E. R., J. E. Duchamp, K. L. Murray, R. K. Swihart and L. W. Robbins. *Acoustic Identification of Bats in the Eastern United States: A Comparison of Parametric and Nonparametric Methods*. Journal of Wildlife Management 75:660-667. 2011.

Bulk Survey for Release. Available at http://www.tennessee.gov/environment/article/rh-bulk-survey-for-release. Tennessee Department of Environment and Conservation. Division of Radiological Health, August 30, 2017.

Carlisle, D. M. and W. H. Clements. *Sensitivity and Variability of Metrics Used in Biological Assessments of Running Waters*. Environmental Toxicology and Chemistry 18:285-291. 1999.

Carmichael, J. K. An Investigation of Shallow Groundwater Quality Near East Fork Poplar Creek, Oak Ridge, Tennessee. USGS Water Resources Investigation Report 88-4219. U.S. Department of the Interior, Nashville, TN. 1989.

Clements, W. H. *Benthic Invertebrate Community Responses to Heavy Metals in the Upper Arkansas River Basin, Colorado*. Journal of the North American Benthological Society 13:30-44. 1994.

Clements, W. H. *Community Responses of Stream Organisms to Heavy Metals: A Review of Observational and Experimental Approaches*. In Metal Ecotoxicology: Concepts & Applications. M.C. Newman and A.W. McIntosh (eds.). Lewis Publishers. Chelsea, MI 1991.

Clements, W. H., D. S. Cherry, and J. H. van Hassel. *Assessment of the Impact of Heavy Metals on Benthic Communities at the Clinch River (Virginia): Evaluation of an Index of Community Sensitivity*. Canadian Journal of Fisheries and Aquatic Sciences 49:1686-1694. 1992.

Clements, W. H. and P. M. Kiffney. *The Influence of Elevation on Benthic Community Responses to Heavy Metals in Rocky Mountain Streams*. Canadian Journal of Fisheries and Aquatic Sciences 52:1966-1977. 1995.

Concentration Levels For Environmental Compliance. Code of Federal Regulations*.* Title 40: Protection of Environment. Part 61: National Emission Standards for Hazardous Air Pollutants. Appendix E, Table 2, Clean Air Act. U.S. Environmental Protection Agency. July 1, 2010.

Consensus-based Sediment Quality Guidelines: Recommendations for Use & Application, Interim Guidance*.* PUBL-WT-732 2003. Wisconsin Department of Natural Resources. 2003.

Cristol, D. A., R. L. Brasso, A. M. Condon, R. E. Fovargue, S. L. Friedman, K. H. Hallinger, A. P. Monroe and A. E. White*. The Movement of Aquatic Mercury Through Terrestrial Food Webs*. Science 320:335. 2008.

Cummins, K. W. *Structure and Function of Stream Ecosystems*. BioScience 24:631-641. 1974.

Daniel, S., C. Korine, and B. Pinshow. *Central-place Foraging in Nursing, Arthropod-gleaning Bats*. Canadian Journal of Zoology 86:623–626. 2008.

Davis, W. S. and T. P. Simons, eds. Biological Assessment and Criteria: Tools for Resource Planning and Decision Making. Lewis Publishers. Boca Raton, Florida. 1995.

Denton, G. M. Mercury Levels in Tennessee Fish. Division of Water Pollution Control, Tennessee Department of Environment and Conservation. Nashville, TN. 2007.

Derived Concentrations of Beta and Photon Emitters in Drinking Water. U.S. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-09/documents/guide_radionuclides_Table-betaphotonemitters.pdf

Doherty, F. G. *The Asiatic Clam, Corbicula spp., as a Biological Monitor in Freshwater Environments*. Environmental Monitoring and Assessment 15:143-181. 1990.

Driscoll, C. T. and A. K. Sauer. Methylmercury Bioaccumulation Within Terrestrial Food Webs in the Adirondack Park of New York State. NYSERDA Report 16-06. Syracuse University, Syracuse, NY. 2015.

Edmunds, G., S. L. Jensen and L. Berner. Mayflies of North and Central America. University of Minnesota Press. Minneapolis, Minnesota. 330 pp. 1976.

Eisenmann, J.D., W.N. Beyer, R.E. Bennetts and Morton, A. *Mercury Residues in South Florida Apple Snails (Pomacea paludosa)*. Bulletin of Environmental Contamination and Toxicology 58:739-743.1997.

Envirofacts RadNet Searchable Database: NAREL RadNet Data links. U.S. Environmental Protection Agency. Search http://iaspub.epa.gov/enviro/erams_query_v2.simple_query
customized search https://www.epa.gov/enviro/radnet-customized-search

Environmental Air Sampling. Oak Ridge Institute for Science and Education (ORISE). Handout from Applied Health Physics Course. 1993.

Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM). U. S. Environmental Protection Agency, Enforcement and Investigations Branch. Region 4. Athens Georgia. 1997.

Environmental Management Waste Management Facility (EMWMF) Environmental Monitoring Plan for Bechtel Jacobs Company LLC. BJC/OR-2712/RI. Bechtel Jacobs Company LLC (BJC). Oak Ridge, TN. January 2010.

Environmental Radiation Ambient Monitoring System (ERAMS) Manual. EPA 520/5-84-007, 008, 009. U.S. Environmental Protection Agency. May 1988.

Environmental Radiation Measurements. NCRP report No. 50. National Council on Radiation Protection and Measurements. August 1, 1985.

Epler, J. H. Identification Manual for the Aquatic and Semi-aquatic Heteroptera of Florida: *Belostomatidae, Corixidae, Gelastocoridae, Gerridae, Hebridae, Hydrometridae, Mesoveliidae, Naucoridae,* *Nepodae, Notonectidae, Ochiteridae, Pleidae, Saldidae, Veliidae*. Division of Environmental Assessment and Restoration, State of Florida Department of Environmental Protection, Tallahassee, Florida. 2006.

Epler, J. H. Identification Manual for the Larval Chironomidae (Diptera) of North and South Carolina: A Guide to the Taxonomy of the Midges of the Southeastern United States, Including Florida. Special Publication SJ2001-SP13. North Carolina Department of Environment and Natural Resources, Raleigh, NC, and St. Johns River Water Management District, Palatka, Florida. 526 pp. 2001.

Epler, J. H. The Water Beetles of Florida: An Identification Manual for the Families: *Chrysomelidae, Curiculionidae, Dryopidae, Dytiscidae, Elmidae, Gyrinidae, Halipidae, Helophoridae, Hydraenidae, Hydrochidae, Hydrophildae, Noteridae, Psephenidae, Ptilodactylidae and Sciritidae*. Division of Environmental Assessment and Restoration, Florida Department of Environmental Protection. Tallahassee, Florida. 2010.

Evers, D. C., N. M. Burgess, L. Champoux, B. Hoskins, A. Major, W. M. Goodale, R. J. Taylor, R. Poppenga and T. Daigle. *Patterns and Interpretation of Mercury Exposure in Freshwater Avian Communities in Northeastern North America*. Ecotoxicology 14:193-221. 2005.

Farm Service Agency (2010) Google Maps [online]. U.S. Geological Survey, US Department of Agriculture. [Accessed 10 February 2011]. Available at http://maps.google.com/.

Federal Facility Agreement. Tennessee Department of Environment and Conservation, DOE Oversight Division, U.S. EPA and U.S. DOE. January 1992 (with revisions).

Fenton, M. B. Bats. Revised edition. Facts on File, New York, NY, USA. 207 pp. 1992.

Fenton, M. B. and G. P. Bell. *Recognition of Species of Insectivorous Bats by Their Echolocation Calls.* Journal of Mammalogy 62:233-243. 1981.

Field Branches Quality System and Technical Procedures: Field Sampling Procedures – Sediment Sampling U.S. Environmental Protection Agency. Region IV, Athens, GA. 2010

Focused Feasibility Study for Waste Management for the Disposal of CERCLA Waste on the Oak Ridge Reservation, Oak Ridge, Tennessee. DOE/OR/01-2664&D1. U.S. Department of Energy. URS/CH2M Oak Ridge, LLC. 2015.

Ford, W. M., M. A. Menzel, J. L. Rodrique, J. M. Menzel and J. B. Johnson. *Relating Bat Species Presence to Habitat Measures in a Central Appalachian Forest*. Biological Conservation 126:528-539. 2005.

Fore, L. S., J. R. Karr and R. W. Wisseman. *Assessing Invertebrate Responses to Human Activities: Evaluating Alternative Approaches*. Journal of the North American Benthological Society 15:212-231. 1996.

FRMAC Monitoring and Sampling Manual, Vols. 1 & 2. DOE/NV/11718-181-Vol. 1 & Vol. 2. Federal Radiological Monitoring and Assessment Center, National Nuclear Security Administration. Nevada Test Site. 2012.

Gelhaus, J. K. Manual for the Identification of Aquatic Crane Fly Larvae for Southeastern United States. Academy of Natural Sciences, Philadelphia, Pennsylvania. 2002.

General Water Quality Criteria, State of Tennessee Water Quality Standards, Rules of the Department of Environment And Conservation Chapter 1200-4-3.Tennessee Department of Environment and Conservation, Bureau of Environment, Division of Water Pollution Control Nashville, TN. 1997

Gimbert, F., F. Perrier, A-L. Caire and A. de Vaufleury. *Mercury Toxicity to Terrestrial Snails in a Partial Life Cycle Experiment.* Environmental Pollution and Pollution Research 4:3165-3175. 2016.

Global Mercury Assessment. International Organizational Programme (IOMC) for the Sound Management of Chemicals. United Nations Environment Programme. Geneva, Switzerland. 258 pp. December 2002.

Guidance Levels for Radionuclides in Domestic and Imported Foods (CPG-7119.14), Sec.560.750. U.S. Food and Drug Administration. November 2005.
https://www.fda.gov/ICECI/ComplianceManuals/CompliancePolicyGuidanceManual/ucm074576.htm

Halverson, N. V., J. A. Bowers, M. H. Paller, D. G. Jackson, J. K. King and D. L. Dunn. Final Report on the Aquatic Mercury Assessment Study. SRNS-STI-2008-100106. Savannah River National Laboratory, Aiken, South Carolina. 2008.

Han, F. X., Y. Su, Y. Xia, W. Tian, V. Philips, Z. Shi, D. L. Monts, M. Gu and Y. Liang. *Mercury Distribution and Speciation in Floodplain Soils and Uptake into Native Earthworms (Diplocardia spp.).* Geoderma 170:261-268. 2012.

Hannappel, M. Spiders in Mud Dauber Nests as Biosentinels of Mercury Contamination. Department of Biology Honors Thesis, Texas Christian University, Fort Worth, TX. 2017.

Hauer, F. R. and V. H. Resh. *Benthic Macroinvertebrates*. In Methods in Stream Ecology. F. R. Hauer and G. A. Lamberti (eds.). Academic Press, San Diego, CA. pp. 336-369. 1996.

Hilsenhoff, W. L. *An Improved Biotic Index of Organic Stream Pollution*. Great Lakes Entomologist 20:31-39. 1987.

Hilsenhoff, W. L. *Rapid Field Assessment of Organic Pollution with a Family Level Biotic Index*. Journal of the North American Benthological Society 7:65–68. 1988.

Hilsenhoff, W. L. Using a Biotic Index to Evaluate Water Quality in Streams. Technical Bulletin No. 132. Wisconsin Department of Natural Resources. Madison, Wisconsin. 1982.

Hothem, R.L., M.R. Jennings, and J.J. Crayon. *Mercury Contamination in Three Species of Anuran Amphibians from Cache Creek Watershed, California, USA*. Environmental Monitoring and Assessment 163:433-448. 2010.

Hynes H.B.N. *Biological Effects of Organic Matter*. In The Biology of Polluted Waters, Liverpool University Press: Cambridge, Great Britain; 92–121. 1978.

Indiana Bat Survey Guidance for Kentucky. U. S. Fish and Wildlife Service, Kentucky Field Office, Frankfurt, Kentucky, and the Kentucky Department for Fish and Wildlife Resources, Frankfurt, Kentucky. 2011.

Johnson, J. B. Spatial and Predictive Foraging Models for Gray Bats in Northwest Georgia and a Comparison of Two Acoustical Bat Survey Methods. Master's thesis. West Virginia University, Morgantown, WV. 2002.

Karr, J. R. *Defining and Measuring River Health*. Freshwater Biology 41:221-234. 1999.

Karr, J. R. and E. W. Chu. Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Covelo, CA. 200 pp. 1998.

Keller, R. H., L. Xie, D. B. Buchwalter, K. E. Franzieb and T. R. Simons Mercury *Bioaccumulation in Southern Appalachian Birds, Assessed Through Feather Concentrations.* Ecotoxicology 23:302-316. 2014.

Kiffney, P. M. *Main and Interactive Effects of Invertebrate Density, Predation, and Metals on a Stream Macroinvertebrate Community*. Canadian Journal of Fisheries and Aquatic Sciences 53:1595-1601. 1996.

Kiffney, P. M. and W. H. Clements. *Effects of Heavy Metals on a Macroinvertebrate Assemblage from a Rocky Mountain Stream in Experimental Microcosms*. Journal of the North American Benthic Society 13(4):511-523. 1994.

Kunz, T. H. *Resource Utilization: Temporal and Spatial Components of Bat Activity in Central Iowa*. Journal of Mammalogy 54: 14–32. 1973.

Laboratory Procedures for Macroinvertebrate Processing, Taxonomic Identification and Reporting. DOWSOP03005, Revision 2. Kentucky Division of Water. Kentucky Department for Environmental Protection, Frankfort, Kentucky. 2009

Lafrancois, B. and D.M. Carlisle, D.M. *Mercury Burdens and Trophic Position of Orconectes virilis in Voyageurs National Park*. Bulletin of the North American Benthological Society 21:381–382. 2004.

Landrum, C. L., T. L. Ashwood and D. K. Cox. Belted Kingfishers as Ecological Monitors of Contaminants: A Review. ORNL/M-2533. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 1993.

Lausen, C. Wildlife Acoustics: Bat Acoustics Training. Training class handout notes from course held in Phoenix, Arizona, April 13-16, 2015. Wildlife Acoustics, Inc. 2015.

Lenat D. R. *Chironomid Taxa Richness: Natural Variation and Use in Pollution Assessment*. Freshwater Invertebrate Biology 2: 192–198. 1983.

Life Safety Plan. Tennessee Department of Environment and Conservation, Division of Remediation, Oak Ridge Office. Oak Ridge, Tennessee. 2017.

Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for inhalation, Submersion, and Ingestion, Federal Guidance Report No. 11, EPA-520/1-88-020. U.S. Environmental Protection Agency. Oak Ridge National Laboratory, Oak Ridge, TN. 1998.

Loar, J. M., A. J. Stewart and J. G. Smith. *Twenty-five Years of Ecological Recovery of East Fork Poplar Creek: Review of Environmental Problems and Remedial Actions*. Environmental Management 47:1010-1020. 2011.

Lowe, D.J., and Waters, C.N., 2014. *Geological Influences on Cave Origin and Development in the Yorkshire Dales, UK*. Cave and Karst Science, vol 41, num. 1, p. 13-35.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. *Development and Evaluation of Consensus-based Sediment Quality Guidelines for Freshwater Ecosystems*. Archives of Environmental Contamination and Toxicology. 39:20-31. 2000.

Manley, P.N., B. Van Horne, J. K. Roth, W. J. Zielinski, M. M. McKenzie, T. J. Weller, F. W. Weckerly, and C. Vojta. Multiple Species Inventory and Monitoring Technical Guide. General Technical Report WO-73. Forest Service, Washington Office. U.S. Department of Agriculture. Washington, DC 204 pp. 2006.

Martin, C. O. and E. R. Britzke. Mammalian Survey Techniques for Level II Natural Resource Inventory on Corps of Engineers Projects (Part II—Bats). ERDC TN-EMRRP-S1-35. Ecosystem Management and Restoration RESEARCH Program. U.S. Army Corps of Engineers. 2010.

Martin, S. M. *Crayfishes (Crustacea: Decapoda) of Maine*. Northeastern Naturalist 4:165-188. 1997.

Mathews, T.J., J.G. Smith, M.J. Peterson and W.K. Roy. Assessment of Contaminant Bioaccumulation in Invertebrates and Fish in Waters in and Adjacent to the Oak Ridge Reservation—2010. ORNL/TM-2011/108. Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN. 2011.

May, K., M. Stoeppler and K. Reisinger. *Studies in the Ratio of Mercury/methylmercury in the Aquatic Food Chain.* Toxicological and Environmental Chemistry 13:1-10. 1987.

McAlpine, J. F., Peterson, B. V., Shewell, G. E., Teskey, H. J., Vockeroth, J. R., and Wood, D. M. (Coordinators) *Manual of Nearctic Diptera*. Vol. 1. , Agriculture Canada Monograph Research Branch, 27: 674 pp. 1981.

McCracken, M. K., N. R. Giffen, A. M. Haines, B. J. Guge and J. W. Evans. Bat Species Distribution on the Oak Ridge Reservation. Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN. 2015.

McMaster, W.M. Geologic Map of the Oak Ridge Reservation, Tennessee: Oak Ridge, Tennessee, ORNL/TM-713. U.S. Atomic Energy Commission, Oak Ridge National Laboratory. 23 pages. 1963.

Medley, C. N. and W. H. Clements. *Responses of Diatom Communities to Heavy Metals in Streams: The Influence of Longitudinal Variation.* Ecological Applications 8:631-644. 1998.

Menzel. J. M., W. M. Ford, M. A. Menzel, T. C. Carter, J. E. Gardner, J. D. Garner and J. E. Hofmann. *Summer Habitat Use and Home-range Analysis of the Endangered Indiana Bat*. Journal of Wildlife Management 69:430-436. 2005.

Merritt, R. W., M. B. Berg, and K. W. Cummins. An Introduction to the Aquatic Insects of North America (4th ed.). Kendall/Hunt Publishing Co., Dubuque, Iowa. 1158 pp. 2008.

Meyer, J. L. *Stream Health: Incorporating the Human Dimension to Advance Stream Ecology*. Journal of the North American Benthological Society 16:439-447. 1997.

Mitchell, W. A. and C. O. Martin. Cave- and Crevice-dwelling Bats on USACE Projects: Gray Bat (Myotis grisescens). ERDC TN-EMRRP-SI-25. EMRRP Technical Notes Collection. U. S. Army Engineer Research and Development Center, Vicksburg, Mississippi. 2002.

Moulton II, S.R., Carter, J. L., Grotheer, S. A., Cuffney, T. F., and Short, T. M. Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory-Processing, Taxonomy, and Quality Control of Benthic Macroinvertebrate Samples. 00–212. U.S. Geological Survey. Reston, Virginia. 49 pp. 2000.

Moulton II, S.R., J.G. Kennen, R.M. Goldstein and J.A. Hambrook. Revised Protocol for Sampling Algal, Invertebrate and Fish Communities as Part of the National Water Quality Assessment Program. 02-150. U.S. Geological Survey. U.S. Department of the Interior, Reston, VA. 2002.

National Integrated Drought Information System (NIDIS). Drought.gov U.S. Drought Portal https://www.drought.gov/drought/states/tennessee

National Emissions Standards for Emissions of Radionuclides other than Radon from Department of Energy Facilities. Code of Federal Regulations. Title 40: Protection of Environment. Part 61: National Emission Standards for Hazardous Air Pollutants. Subpart H: Clean Air Act. U.S. Environmental Protection Agency. July 1, 2010.

National Primary Drinking Water Regulations. U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, Available at https://www.epa.gov/sites/production/files/2016-06/documents/npwdr_complete_Table.pdf. August 30th, 2017.

National Secondary Drinking Water Regulations. U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water. Available at https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals. August 30th, 2017.

Needham, J. G., M. J. Westfall, Jr. and M. L. May. Dragonflies of North America (Revised Edition). Scientific Publishers. Gainesville, Florida, 939 pp. 2000.

Neufeld, D.S.G. *Mercury Accumulation in Caged Corbicula: Rate of Uptake and Seasonal Variation.* Environmental Monitoring and Assessment 168:385-396. 2010.

Nydick, K. and K. Williams. FINAL REPORT: Pilot Study of the Ecological Effects of Mercury Deposition in Mesa Verde National Park, Colorado. Report 2010-01. Mountain Studies Institute. 2010.

O'Farrell, M. J. and W. L. Gannon. *A Comparison of Acoustic Versus Capture Techniques for the Inventory of Bats*. Journal of Mammalogy 80:24-30. 1999.

O'Farrell, M. J., B. W. Miller, and W. L. Gannon. *Qualitative Identification of Free-flying Bats Using the Anabat Detector*. Journal of Mammalogy 80:11–23. 1999.

Occupational Radiation Protection. Surface Contamination Values. CFR-2016-title10-vol4-part835-appD, Appendix D to Part 835 - Code of Federal Regulations, US Department of Energy. 2016.

Oliver, D. R. and M. E. Roussel. *The Insects and Arachnids of Canada, Part II: The Genera of Larval Midges of Canada; Diptera: Chironomidae*. Agriculture Canada Publication 1746, 263 pp. 1983.

Operator Aid FRMAC Early Phase Vegetation Sample 2012-03. Federal Radiological Monitoring and Assessment Center. National Nuclear Security Administration. March 2012.
http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html
http://nnss.gov/docs/docs_FRMAC/Operator%20Aid%20FRMAC%20Early%20Phase%20Vegitation%20Sample%202012-03.doc

Owen, S. F., M. A. Menzel, J. W. Edwards, W. M. Ford, J. M. Menzel, B. R. Chapman, P. B. Wood and K. V. Miller. *Bat Activity in Harvested and Intact Forest Stands in the Allegheny Mountains.* Northern Journal of Applied Forestry 21:154-159. 2004.

Paller, M.H., C.H. Jagoe, H. Bennett, H.A. Brant, J.A. Bowers. *Influence of Methylmercury from Tributary Streams on Mercury Levels in Savannah River Asiatic Clams*. Science of the Total Environment 325: 209-219. 2004.

Pant, P., M. Allen and B. Tansel. *Mercury Uptake and Translocation in Impatiens walleriana Plants Grown in the Contaminated Soil from Oak Ridge*. International Journal of Phytoremediation 13:168-176. 2010.

Parks, J.W. *Selected Ecosystem Relationships in the Mercury Contaminated Wabigoon-English River System, Canada, and Their Underlying Causes*. Water Air and Soil Pollution 42: 267–279. 1988.

Parks, J.W., C. Curry, D. Romani and D.D. Russell. *Young Northern Pike, Yellow Perch and Crayfish as Bioindicators in a Mercury-Contaminated Watercourse*. Environmental Monitoring and Assessment 16:39–73. 1991.

Paul, M. J. and J. L. Meyer. *Streams in the Urban Landscape*. Annual Reviews of Ecology and Systematics 32: 333–365. 2001.

Pauza, D. H. and N. Pauziene. *Bats of Lithuania: Distribution, Status and Protection*. Mammal Review 28:53–67. 1998.

Pennak, R. W. Fresh-Water Invertebrates of the United States-Protozoa to Mollusca. 3rd Ed. John Wiley & Sons, Inc. New York. 628 pp. 1989.

Pennuto, C.M., O.P. Lane, D.C. Evers, R.J. Taylor and J. Loukmas. *Mercury in the Northern Crayfish, Orconectes virilis (Hagen), in New England, USA*. Ecotoxicology 14:149-162. 2005.

Pfeiffer, J., E. Kosnicki, M. Bilger, B. Marshall and W. Davis. Taxonomic Aids for Mid-Atlantic Benthic Macroinvertebrates. EPA-260-R-08-014. Office of Environmental Information, Environmental Analysis Division, U.S. Environmental Protection Agency, Washington, DC. 2008.

Phillips, J. M., Russell, M.A., and Walling, D.E. *Time-integrated Sampling of Fluvial Suspended Sediment: A Simple Methodology for Small Catchments*. Hydrological Processes, v. 14, no. 14, p. 2,589-2,602. 2000.

Proposed Changes to Process Waste Treatment Complex, USDOE – ORNL. Letter from V Janjic, Manager, Water-Based Systems, Tennessee Department of Environment and Conservation to Fran B. Williams, UCOR, SUBJECT: NPDES Permit No. TN0002941, Oak Ridge, Roane County, Tennessee, dated July 23, 2014. 2014b.

Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water. Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, Tennessee. 2011.

Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys. Revision 4. Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control, Nashville, Tennessee. October 2006.

Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys. Revision 5. Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control, Nashville, Tennessee. July 2011

Radiation Protection of the Public and the Environment. DOE Order 458.1 Chg. 3, Approved: 02-11-2011, Chg. 3: 01-15-2013. US Department of Energy. 2013.

Radionuclides in Drinking Water. Radionuclide Rule. U.S. Environmental Protection Agency. http://water.epa.gov/lawsregs/rulesregs/sdwa/radionuclides/

Ramusino, M. C., G. Pacchetti, and A. Lucchese. *Influence of Chromium (VI) Upon Stream Ephemeroptera in the Pre-Alps*. Bulletin of Environmental Contaminants Toxicology 26:228-232. 1981.

Range-wide Indiana Bat Summer Survey Guidelines. U. S. Fish & Wildlife Service. 2014. http://www.fws.gov/midwest/endangered/mammals/inba/surveys/pdf/2014IBatSummerSurveyGuidelines13Jan2014.pdf. [Accessed 8-28-2017].

Record of Decision for the Disposal of Oak Ridge Reservation Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Waste. DOE/OR/01-1791&D3. U.S. Department of Energy. Oak Ridge, Tennessee. November 1999.

Regional Screening Levels – Generic Tables. U.S. Environmental Protection Agency, Superfund Program, Available at https://www.epa.gov/risk/regional-screening-levels-rsls-generic-Tables-june-2017. August 30th, 2017.

Remedial Investigation Work Plan for Bear Creek Valley Operable Unit 1 (S-3 Ponds, Boneyard/Burnyard, Oil Landfarm, Sanitary Landfill I, and the Burial Grounds, Including Oil Retention Ponds 1 and 2) at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee. DOE/OR/01-1161/V2&D2. U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Oak Ridge, Tennessee. 1994.

Report on the Remedial Investigation of Bear Creek Valley at the Oak Ridge Y-12 Plant, Oak Ridge, Tennessee, Volume 1 DOE/OR/O1-1455/Vl&D2, Prepared for Lockheed Martin Energy Systems, Inc., by SAIC, Oak Ridge Y-12 Plant Oak Ridge, Tennessee. September 1996.

Resh, V. H., A. V. Brown, A. P. Couch, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace and R. C. Wissmar. *The Role of Disturbance in Stream Ecology*. Journal of the North American Benthological Society 7:433-455. 1988.

Resh, V. H., M. J. Myers and M. J. Hannaford. *Macroinvertebrates as Biotic Indicators of Environmental Quality*. In F. R. Hauer and G. A. Lamberti (eds.). Methods in Stream Ecology. Page 665, Academic Press, New York. 1996.

Risk Assessment Information System. Office of Environmental Management, Oak Ridge Operations (ORO) Office, U.S. Department of Energy, Oak Ridge, Tennessee. 2013 (http://rais.ornl.gov/).

Rosenberg, D. N. and V. H. Resh. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall. New York, NY. 488 pp. 1993.

Sampling and Analysis Plan for the Lower East Fork Poplar Creek Mercury Biouptake Study. U.S. Department of Energy, Oak Ridge, Tennessee. 2014

Scheuhammer, A. M. and J. E. Graham. *The Bioaccumulation of Mercury in Aquatic organisms from Two Similar Lakes with Differing pH.* Ecotoxicology 8:49–56. 1999.

Scheuhammer, A. M., J. A. Perrault and D. E. Bond. *Mercury, Methylmercury, and Selenium Concentrations in Eggs of Common Loons (Gavia immer) from Canada*. Environmental Monitoring and Assessment, 72:79-94. 2001.

Scheuhammer, A. M., Meyer, M. W., Sandheinrich, M. B., & Murray, M. W. *Effects of Environmental Methylmercury on the Health of Wild Birds, Mammals, and Fish*. AMBIO: A Journal of the Human Environment, 36:12-19. 2007.

Schirmacher MR, Castleberry SB, Ford WM, Miller KV. Habitat Association of Bats in South-central West Virginia. Proceedings of the Annual Conference of the Southeastern Fish and Wildlife Association 61:46–52. 2007.

Simmons, N. B. and T. M. Conway. *Evolution of Ecological Diversity in Bats.* In Kunz TH, Fenton MB, eds. Bat Ecology. Pages 493–535. University of Chicago Press. Chicago, IL. 2003.

Simon, O. and A. Boudou. *Simultaneous Experimental Study of Direct and Direct Plus Trophic Contamination of the Crayfish Astacus astacus by Inorganic Mercury and Methylmercury*. Environ Toxicol Chem 20:1206–1215. 2001.

Simpson, K. W. and R. W. Bode. Common Larvae of *Chironomidae (Diptera*) from New York State Streams and Rivers, with Particular Reference to the Fauna of Artificial Substrates. Bull. No. 439. 105 pages. N.Y.S. Museum. 1980.

Solomon, D. K., G. K. Moore, L. E. Toran, R. B. Dreier, and W. M. McMaster. Status Report: A Hydrogeologic Framework for the Oak Ridge Reservation ORNL/TM-12026. Oak Ridge National Laboratory. 1992.

Song, M. Y. Ecological Quality Assessment of Stream Ecosystems Using Benthic Macroinvertebrates. MS thesis. Pusan National University, Pusan, Korea. 2007.

Specht, W. L., D. S. Cherry, R. A. Lechleitner, and J. Cairns. *Structural, Functional, and Recovery Responses of Stream Invertebrates to Fly Ash Effluent*. Canadian Journal of Fisheries and Aquatic Sciences 41:884-896. 1984.

Standard Operating Procedure for Collecting RadNet Drinking Water Samples. SC/SOP-3. National Analytical Radiation Environmental Laboratory, Office of Radiation and Indoor Air. U.S. Environmental Protection Agency. Montgomery, Alabama. May 2013.

Standard Operating Procedures. Tennessee Department of Environment and Conservation, DOE Oversight. Oak Ridge, TN. 1996

Standard Operating Procedures. Tennessee Department of Health Laboratory Services. Nashville, Tennessee. 1999.

Standish, C. L. Evaluation of Total Mercury and Methylmercury Concentrations of Terrestrial Invertebrates Along Lower East Fork Poplar Creek in Oak Ridge, Tennessee. Master's Thesis, University of Tennessee. http://trace.tennessee.edu/utk_gradthes/4078 2016.

Stewart, K. W., and B. P. Stark. *Nymphs of North American Stonefly Genera (Plecoptera).* Thomas Say Foundation, Entomological Society of America 12. 460 pp. 1988.

Summary of Well Survey Data, Table 2.5-18, CRBR Environmental Report, Volume 1, Project Management Corporation, Tennessee Valley Authority. October, 1981, page 2.5-55.

Suren A. M. *Effects of Urbanization*. In New Zealand Stream Invertebrates: Ecology and Implications for Management, Collier K. J., Winterbourn M. J. (eds). New Zealand Limnological Society, Christchurch, New Zealand; pp 260–288. 2000.

Tennessee Department of Environment and Conservation, DOE Oversight Division Environmental Monitoring Plan January through December 2010. Tennessee Department of Environment and Conservation, DOE Oversight Division. Oak Ridge, Tennessee. 2009

Tennessee Oversight Agreement, Agreement between the Department of Energy and the State of Tennessee. Tennessee Department of Environment and Conservation, DOE Oversight Division. Oak Ridge, Tennessee. 2006.

Tennessee Oversight Agreement. Agreement between the U.S. Department of Energy and the State of Tennessee. Tennessee Department of Environment and Conservation, DOE Oversight Division. Oak Ridge, Tennessee 2011.

Termination of Operating Licenses for Nuclear Reactors. Regulatory Guide 1.86, U. S. Atomic Energy Commission (now: Nuclear Regulatory Commission). 1974.

The Status of Water Quality in Tennessee: Technical Report. Tennessee Department of Environment and Conservation, Division of Water Pollution Control. Nashville, TN.

Timpone, J. C., J. G. Boyles, K. L. Murray, D. P. Aubrey and L. W. Robbins. *Overlap in Roosting Habits of Indiana Bats (Myotis sodalis) and Northern Bats (Myotis septentrionalis).* American Midland Naturalist 163:115-123. 2010.

Tucker, Craig S. and D'Abramo, Louis R., *Managing High pH in Freshwater Ponds,* Publication No. 4604. Southern Regional Aquaculture Center. July 2008.

Use Classifications for Surface Waters. General Water Quality Criteria, Chapter 1200-4-4. Tennessee Department of Environment and Conservation. Division of Water Pollution Control. Nashville, Tennessee. 2008.

Use Classifications for Surface Waters. State of Tennessee Water Quality Standards, Rules of the Department of Environment And Conservation Chapter 1200-4-4. Tennessee Department of

Environment and Conservation, Bureau of Environment, Division of Water Pollution Control Nashville, TN. 1997

Van Hassel, J. H. and A. E. Gaulke. *Water Quality-based Criteria for Toxics: Scientific, Regulatory, and Political Considerations*. Environmental Toxicology and Chemistry 5:417-426. 1986.

Vannote R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell and C. E. Cushing. *The River Continuum Concept*. Canadian Journal of Fisheries and Aquatic Sciences 37:30-137. 1980.

Vaughn, N., G. Jones and S. Harris. *Habitat Use by Bats (Chiroptera) Assessed by Means of a Broadband Acoustic Method*. Journal of Applied Ecology 34:716–730. 1997.

Verneer, K. *The Crayfish Orconectes virilis, as an Indicator of Mercury Contamination*. Canadian Field Naturalist 86:123–25. 1972.

Warnick, S. L. and H. L. Bell. *The Acute Toxicity of Some Heavy Metals to Different Species of Aquatic Insects*. Journal of the Water Pollution Control Federation 41(2): 280-284. 1969.

Weigel, B. M., L. J. Henne and L. M. Martínez-Rivera. *Macroinvertebrate-based Index of Biotic Integrity for Protection of Streams in West-Central Mexico*. Journal of the North American Benthological Society 21:686-700. 2002.

Weller, T. J. and C. J. Zabel. *Variation in Bat Detections Due to Detector Orientation in a Forest*. Wildlife Society Bulletin 30:922-930. 2002.

Westfall, M. J. and M. L. May. Damselflies of North America, Revised Edition. Scientific Publishers, Gainesville, Florida. 503 pp. 2006.

White nose syndrome. FARM survey. U.S. Geological Survey. US Department of the Interior. nwhc.usgs.gov/disease_information/white-nose_syndrome [accessed 8-28-2017] 2017.

Whitney, M. and D. Cristol. *Rapid Depuration of Mercury in Songbirds Accelerated by Feather Molt.* Environmental Toxicology and Chemistry. doi:10.1002/etc.3888. 2017.

Wiederholm, T. *Responses of Aquatic Insects to Environmental Pollution*. In The Ecology of Aquatic Insects, Resh V. H., Rosenberg D. M. (eds). Praeger: New York; 508–557. 1984.

Wiener, J.G. and C.C. Gilmour. Mercury Strategy for the Bay-Delta ecosystem: A Unifying Framework for Science, Adaptive Management and Ecological Restoration. Final report to the California Bay Delta Authority. LaCrosse, WI. 2003.

Wiggins, G. B. Larvae of the North American Caddisfly *Genera (Trichoptera)*. Second Edition. University of Toronto Press, Toronto and Buffalo. 457 pp. 1996.

Wolfe, M.F., T. Atkeson, W. Bowerman, J. Burger, D.C. Evers, M.W. Murray and E. Zillioux. *Wildlife Indicators.* In Ecosystem Responses to Mercury Contamination—Indicators of Change. Harris, R., D.P.

Krabbenhoft , R. Mason, M.W. Murray, R. Reasch and T. Saltman (eds). CRC Press, New York, pp 123–189. 2007.

Yard, C.R., Health and Safety. Tennessee Department of Environment and Conservation, Division of Remediation, Oak Ridge Office. Oak Ridge, Tennessee. 2015.

Yard, C.R., Health and Safety Plan. Tennessee Department of Environment and Conservation, Division of Remediation, Oak Ridge Office. Oak Ridge, Tennessee. 2014.

Year 2012 303(d) List Tennessee Department of Environment and Conservation, Nashville, TN. January 2014a