TENNESSEE DEPARTMENT
OF
ENVIRONMENT AND CONSERVATION

DIVISION OF REMEDIATION
OAK RIDGE OFFICE

ENVIRONMENTAL MONITORING PLAN

July 2017 – June 2018

Tennessee Department of
Environment and Conservation,
Authorization No. 327023
July 1, 2017

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List of Acronyms

BCK	Bear Creek and Bear Creek kilometer
CBSQG	consensus-based sediment quality guidelines
CCK	Clear Creek kilometer
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminants of concern
D&D	decontamination and decommissioning
DOE	Department of Energy
DoR-OR	Division of Remediation, Oak Ridge Office
EFPC	East Fork Poplar Creek
EMP	Environmental Monitoring Plan
EMWMF	Environmental Management Waste Management Facility
EPA	Environmental Protection Agency
ETTP	East Tennessee Technology Park
FCAP	Filled Coal Ash Pond
FFA	Federal Facility Agreement
HCK	Hinds Creek kilometer
MCL	maximum contaminant level
MEK	Melton Branch kilometer
MIK	Mitchell Branch kilometer
mrem	millirem
MSRE	Molten Salt Reactor Experiment
NAREL	National Air and Radiation Environmental Laboratory
NAWQA	National Water-Quality Assessment Program
NERP	National Environmental Research Park
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NT	north tributary
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge operations

ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyls
pCi/L	picoCuries per liter
pCi/m^3	picoCuries per cubic meter
ppm	parts per million
PRG	preliminary remediation goals
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RadNet	Radiation Monitoring Network
RDA	Records Disposition Authorization
ROD	Record of Decision
RPM	radiation portal monitor
RSP	radiation sensor panels
SD	storm drain
SOP	standard operating procedure
SQKICK	semi-quantitative kicknet sampling
T&E	Threatened and Endangered Species
TDEC	Tennessee Department of Environment and Conservation
TDH	Tennessee Department of Health
TOA	Tennessee Oversight Agreement
USAEC	United States Atomic Energy Commission
WAC	waste acceptance criteria
WCK	White Oak Creek kilometer
WOC	White Oak Creek
WOL	White Oak Lake
Y-12	U.S. Department of Energy Y-12 National Security Complex

1.0 Introduction

The Tennessee Department of Environment and Conservation (TDEC), Division of Remediation, Oak Ridge Office (DoR-OR), submits its Environmental Monitoring Plan (EMP) under the terms of the Tennessee Oversight Agreement (TOA) Section A.6.1.1 (TDEC 2016) and in support of activities being conducted under the Federal Facilities Agreement (FFA). As specified by the TOA, the EMP is prepared annually and describes the monitoring and surveillance projects proposed by DoR-OR as part of DoR-OR's independent oversight of Department of Energy's (DOE's) environmental monitoring and surveillance programs on the Oak Ridge Reservation (ORR) and environs.

This EMP covers DoR-OR's monitoring and oversight of DOE's monitoring and surveillance programs for the period of July 1, 2017 through June 30, 2018, and focuses on radiological emissions and releases; biological monitoring, air monitoring, surface water and sediment monitoring, groundwater monitoring, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) landfill. Work performed under this EMP will be conducted using elements stated in DoR-OR's Quality Assurance Project Plan (QAPP) and the Life Safety Plan.

1.1 Objective

The objective of this EMP is to provide a comprehensive and integrated monitoring and surveillance program for all media (i.e., air, surface water, soil, sediment, groundwater, drinking water, food crops, fish and wildlife, and biological systems) and the emissions of any materials (hazardous, toxic, chemical, radiological) on the ORR and environs. In addition, this EMP will assist in evaluating the adequacy and effectiveness of the DOE environmental monitoring program to ensure that DOE activities do not adversely impact the public health, safety, and the environment.

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 ORR 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 of Oak Ridge. Figure 1.1 Location of the Oak Ridge Reservation in relation to surrounding counties shows the general location of the Oak Ridge Reservation in relation to nearby cities and surrounding counties.

The ORR, shown in Figure 1.2 The Oak Ridge Reservation, encompasses approximately 35,000 acres and three major DOE facilities: East Tennessee Technology Park (ETTP), Y-12 National Security Complex (Y-12), and Oak Ridge National Laboratory (ORNL). Facilities at these sites were constructed as part of the Manhattan Project. Their primary missions have evolved and continue to evolve to meet the changing research, defense, and environmental restoration needs of the United States.

The initial objectives of the Oak Ridge Operations (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.

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

The hydrogeology of the ORR is complex. A number of variables influence the direction, quantity, and velocity of groundwater flow although the complexity of the hydrogeology may not be evident from surface topography.

- Localized, shallow groundwater appears to travel primarily along short flow paths to nearby streams
- Regional groundwater flow is at depth to the southwest that allows for the potential offsite migration of ORR-related contaminants to the public

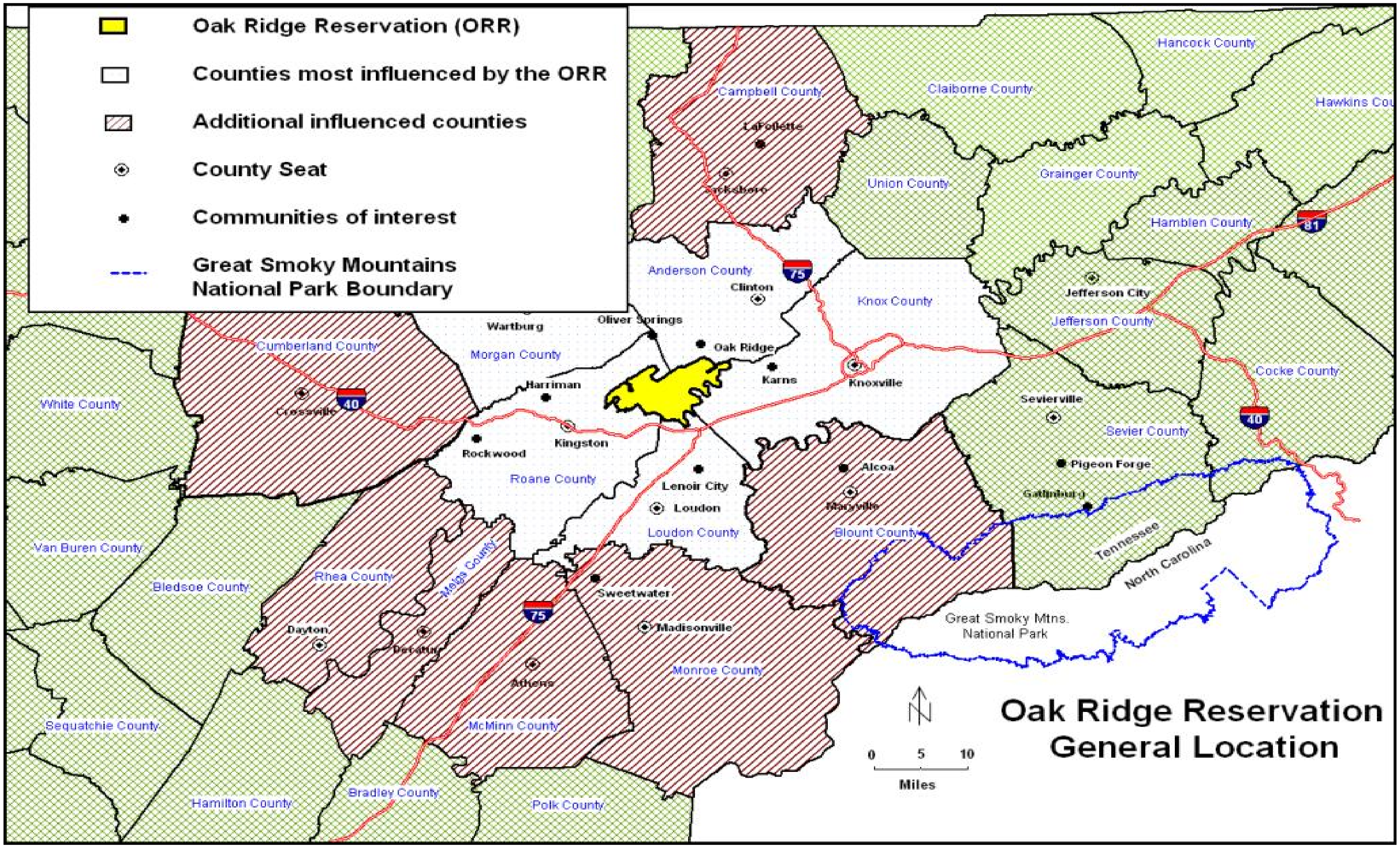

Figure 1.1: Location of the Oak Ridge Reservation in relation to surrounding counties

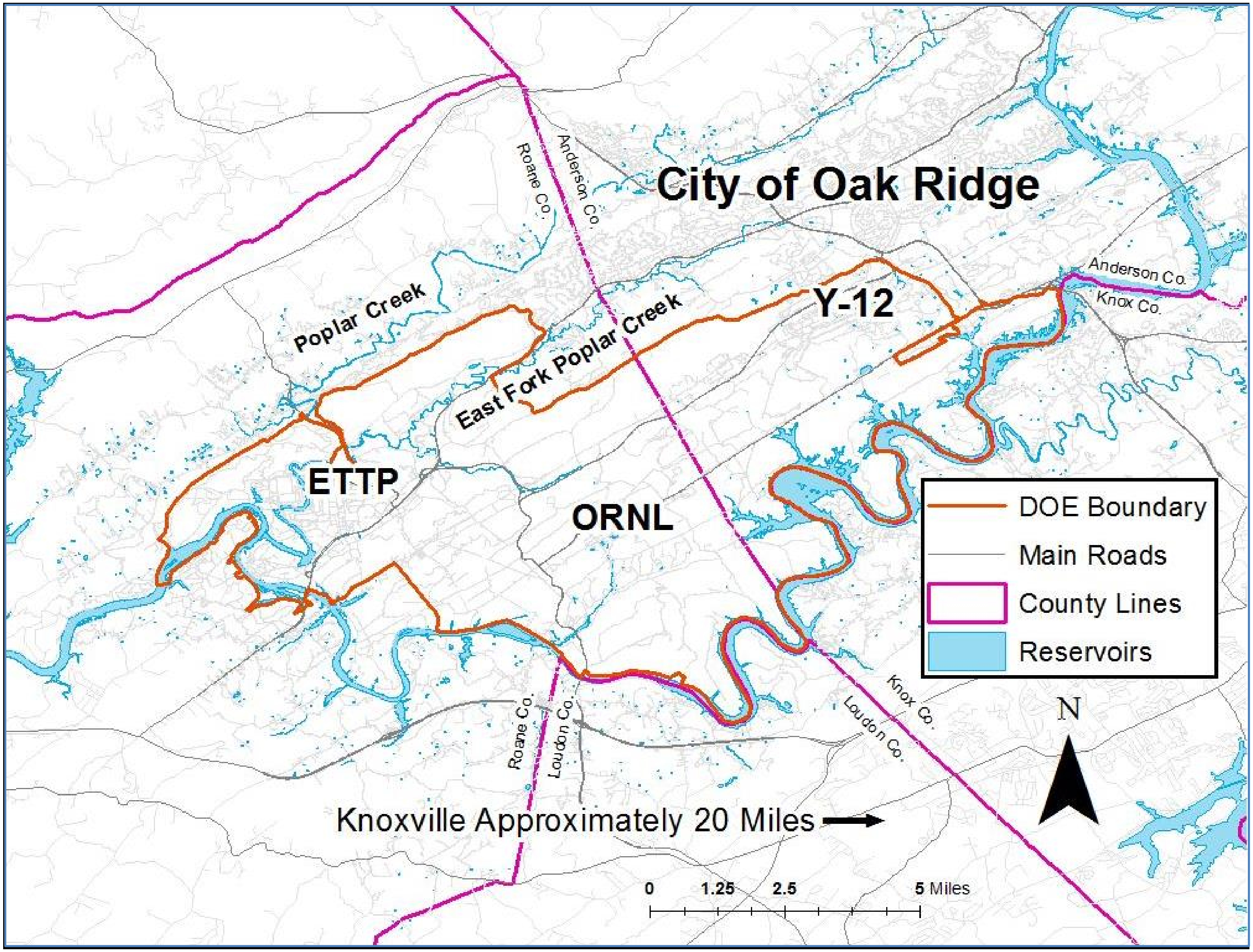

Figure 1.2: The Oak Ridge Reservation

1.3 Organization of the Environmental Monitoring Plan

This EMP is comprised of and organized by seven focus areas:

1. Radiological Monitoring
2. Biological Monitoring
3. Air Monitoring
4. Surface Water and Sediment Monitoring
5. Groundwater Monitoring
6. CERCLA Landfill Monitoring
7. RadNet

2.0 Environmental Monitoring Plan

The EMP is DoR-OR's program strategy to design and execute a project for each targeted focus area in accordance with the requirements of the TOA. This EMP discusses the purpose, methods, and locations of each project as detailed in the following sections.

2.1 Radiological Monitoring

DoR-OR plans to execute five radiological monitoring projects. Each will measure radiation dose or scan for radionuclide contamination to assess radiation exposure as well as allow for the containment of radioactive substances, and report the results.

Five radiological monitoring projects are listed below:

1. environmental dosimeters
2. gamma tracer
3. portal monitor
4. surplus material verification
5. haul road survey

2.1.1 Environmental Dosimeters

DoR-OR's environmental dosimeter project provides:

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

Environmental dosimeters are used to measure the radiation dose attributable to external radiation at 140 locations on and in the vicinity of the ORR. The areas being monitored with environmental dosimeters are identified in Table 2.1.

The dosimeters used by the environmental dosimeter project are obtained from and returned to Landauer, Inc., Glenwood, Illinois. Landauer, Inc. analyzes the data and returns the results to DoR-OR. The dosimeters are collected quarterly and returned to the vendor for sample results processing.

Each of the dosimeters uses an aluminum oxide photon detector to measure the dose from gamma radiation [minimum reporting value = 1 millirem (mrem)]. Dosimeters that contain an allyl diglycol carbonate based neutron detector (minimum reporting value = 10 mrem) are used at locations where the potential for the release of neutron radiation exists.

To account for exposures received during transit, control dosimeters are provided with each shipment of dosimeters received from Landauer, Inc. These control dosimeters are stored in a lead container (lead pig) at the DoR-OR until they are returned to Landauer, Inc. with the associated field-deployed dosimeters for processing. Any dose reported for the control dosimeters is subtracted from the results for the field-deployed dosimeters prior to the results being reported.

Table 2.1: Environmental Dosimeters

Sample Site	Number of Dosimeter Locations	Sampling Rationale
Offsite	13	Determine normal background
Y-12	3	Monitor three areas at Y-12
ETTP	24	Monitor areas at ETTP
ORNL	37	Monitor areas on ORNL and its surrounding areas
ORNL SNS	16	Monitor areas at SNS
EMWMF	47	Monitor EMWMF cells and ponds

ETTP - East Tennessee Technology Park
ORNL - Oak Ridge National Laboratory
SNS - Spallation Neutron Source
EMWMF - Environmental Management Waste Management Facility

2.1.2 Gamma Exposure Rate Monitoring

Under this EMP, the Gamma Exposure Rate Monitoring project will be executed to ensure that DOE activities do not adversely impact the public health, safety, and the environment with regard to gamma radiation exposure. DoR-OR will use monitors equipped with microprocessor-controlled data loggers as the primary means to record exposure rates at locations where the radiation levels are expected to fluctuate significantly over relatively short periods of time (e.g., remedial and waste management activities) and to supplement the integrated dose rates provided by the DoR-OR environmental dosimetry project.

DoR-OR will monitor gamma emissions exposure rates at the five locations listed below and shown in Figure 2.1 Gamma exposure rate monitoring locations.

1. Fort Loudon Dam (background location)
2. Environmental Management Waste Management Facility (EMWMF) in Bear Creek Valley southwest of Y-12
3. ORNL Central Campus Remediation (Radioisotope Development Lab Removal Action – 3000 Area)
4. ORNL Molten Salt Reactor Experiment (MSRE)
5. ORNL Spallation Neutron Source exhaust stack

While the environmental dosimeters provide the cumulative dose over the time period monitored (months), the results cannot account for the specific time, duration, and magnitude of fluctuations in the dose rates. Consequently, when using dosimeters alone, a series of small releases cannot be distinguished from a single large release.

The exposure rate monitors measure and record gamma radiation levels at predetermined intervals (e.g., minutes), providing an exposure rate profile that can be correlated with activities and/or changing conditions. The results are compared to background levels and dose limits provided in state regulations. Findings are used to identify unplanned releases of radioactivity, to assess compliance with state regulations and DOE orders, and to evaluate DOE control measures.

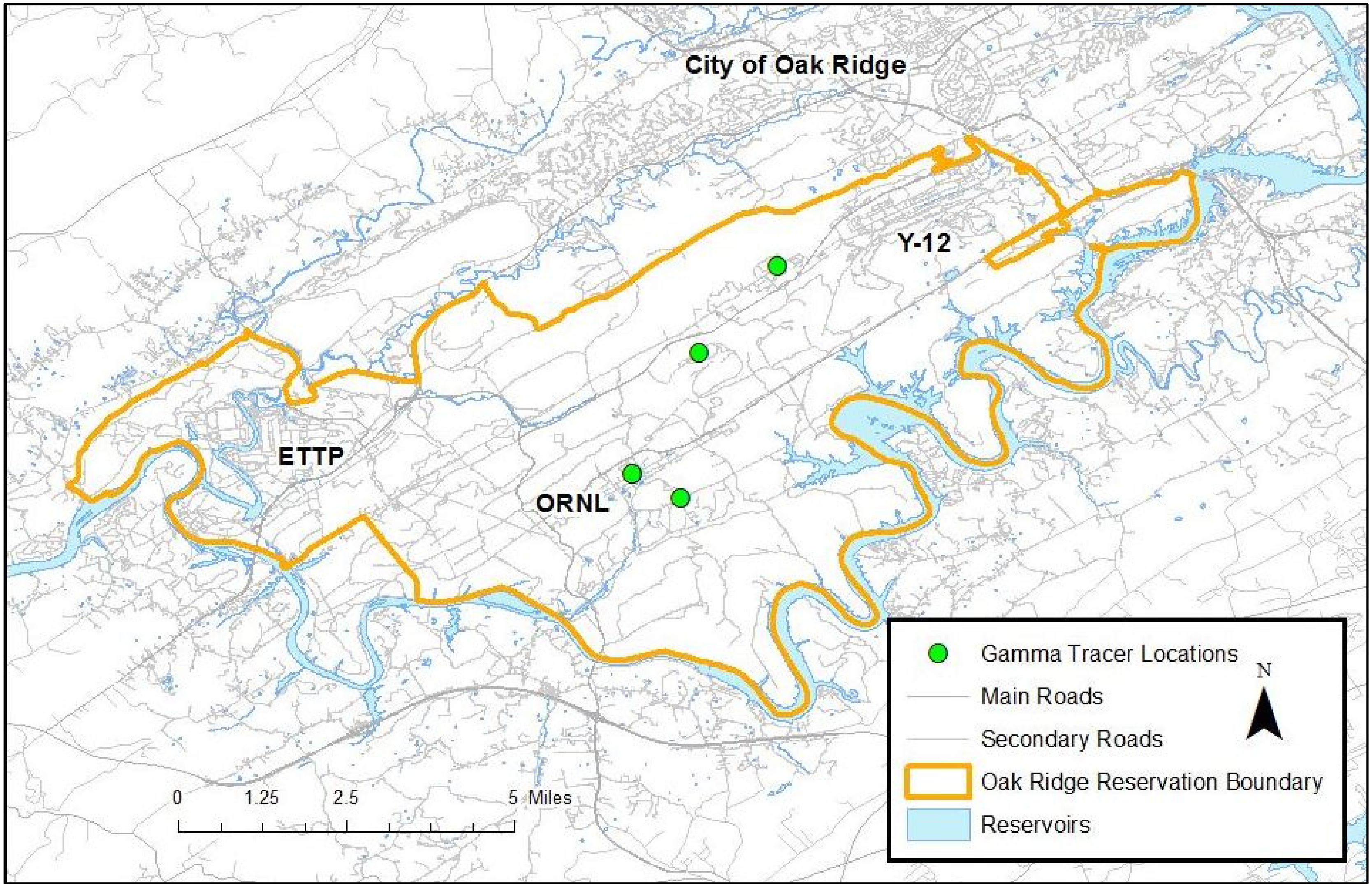

Figure 2.1: Gamma exposure rate monitoring locations

2.1.3 Portal Monitor

To help ensure compliance with the waste acceptance criteria (WAC) for the CERCLA landfill (EMWMF), DoR-OR placed a radiation portal monitor (RPM) at the check-in station to scan trucks transporting waste into EMWMF for disposal. As the trucks pass through the portal, gamma radiation levels are measured and can be viewed by DoR-OR personnel in real time. The data is recorded for remote or local retrieval. If needed, basic information (the nature and origin of the waste passing through the portal at the time of the measurements) is obtained from EMWMF personnel.

A Canberra© RadSentry Model S585 portal monitor is used in the program. The system includes two large area gamma-ray scintillators, an occupancy sensor, a control box, a computer, and associated software. The gamma-ray scintillators and instrumentation are contained in radiation sensor panels (RSPs) mounted on stands located on each side of the road at the check-in station for trucks hauling waste into the disposal area. Measurements (one per 200 milliseconds) are initiated by the occupancy sensor when a truck enters the portal. Results are transmitted from the RSPs to the control box, where the control box is stored, analyzed, and uploaded to a secure website, along with the date, time, and background measurements.

Data on the website is monitored by DoR-OR personnel and available for review by DOE and its authorized contractors. If radiation levels exceed a predetermined level, the RPM alerts DoR-OR by email. When an alert notification is received or anomalies are noted in review of the data, DOE and EMWMF personnel are contacted and the origin of the waste passing through the portal monitor at the time of the measurements is determined.

2.1.4 Surplus Material Verification

To assure compliance with the Nuclear Regulatory Commission's U.S. Atomic Energy Commission Regulatory Guide 1.86 (USAEC, June 1974), Table 2.2, Acceptable Surface Contamination Levels, DoR-OR performs radiological oversight of DOE surplus "free release" material offered to the public. In addition, DoR-OR reviews and ensures compliance to the procedures used for release of surplus material under DOE radiological regulations.

DOE currently operates its surplus material release program under *DOE O 458.1 Admin Chg 3, Radiation Protection of the Public and the Environment*. Some surplus material, such as scrap metal, may be sold to the public under annual sales contracts, whereas other surplus material is staged at various sites around the ORR awaiting public auction and/or sale. DoR-OR, as part of its larger radiological monitoring role on the reservation, conducts these surveys to help ensure no potentially contaminated material reaches the public. If items are found with elevated levels of radionuclides, the information is provided to the surplus sales manager and the items are removed from the sale and disposed of as waste.

Table 2.2: Acceptable Surface Contamination Levels			
Nuclide [a]	**Average [b,c]**	**Maximum [b,d]**	**Removable [b,e]**
U-natural, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-natural, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emissions or spontaneous fission) except Sr-90 and other noted above	5,000 dpm β-γ/100 cm^2	15,000 dpm β-γ/100 cm^2	1,000 dpm β-γ/100 cm^2

(USAEC, 1974)

[a] Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should be applied independently.

[b] As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector by background, efficiency, and geometric factors associated with the instrumentation.

[c] Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such objects.

[d] The maximum contamination level applies to an area of not more than 100 cm^2.

[e] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping the area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination of objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

2.1.5 Haul Road Surveys

The haul road was constructed exclusively for trucks transporting CERCLA radioactive and hazardous waste from remedial activities on the ORR for disposal to EMWMF in Bear Creek Valley. To account for wastes that may have fallen or been blown from the trucks in transit, DoR-OR performs walk over inspections of the road and associated access roads quarterly or more often. Anomalous items noted are surveyed for radiological contamination, logged, and their descriptions and locations submitted to DOE for disposition. The nine-mile long haul road is typically surveyed in segments consisting of one to two miles.

2.2 Biological Monitoring

The four biological monitoring projects include the following:

1. bat monitoring
2. mercury uptake in biota
3. radiochemical uptake in aquatic vegetation
4. benthic macroinvertebrates

2.2.1 Bat Monitoring

DoR-OR assesses seasonal use of DOE federal lands by bat species to determine if there is an increase in mercury uptake by bats inhabiting areas along stretches of EFPC. To accomplish this, DoR-OR identifies and inventories the bat community present on the ORR, particularly bats federally listed as threatened or endangered. This is done using ultrasonic acoustic bat call recording equipment. DoR-OR deploys bat boxes to collect guano (bat droppings). To assess mercury uptake, guano is analyzed for potential body burdens of mercury. Locations to be acoustically surveyed and sampled for guano are identified in Table 2.3 Bat Acoustic Survey and Sampling Locations and shown in Figures 2.2 Bat box and guano sample locations, 2.3 Bat acoustic survey and sample locations (caves)(a), 2.4 Bat acoustic survey and sample locations (caves)(b) and 2.5. Bat box and guano sample locations.

Table 2.3: Bat Acoustic Survey and Sampling Locations			
Sample Location	**No. of Sites**	**Sampling Rationale**	**Survey/Sampling**
Bull Bluff Caves (Gallaher Bend)	15 Sites	Monitor caves for the presence or absence of WNS-infected bats	Acoustic bat surveys Roost tree monitoring
Hickory Bend Caves			
Park City/Price Road Caves (ORNL)			
Rainy Knob Caves (Freels Bend)			
Tower Sheilding Area Caves			
EFPC and BCK bat houses	10 EFPC sites 4 BCK sites	Determine if bats are uptaking mercury from EFPC & BCK emergent insects	Bat box deployment (guano sampling for mercury assays)
		Determine species occupying bat houses	Acoustic bat surveys
		Determine if bat roost trees are present in the EFPC & BCK riparian zones	Field surveys with video borescope inspection camera (with flexible scope)
Bear Creek Valley: siting of the proposed EMDF waste cell	20 Sites	Determine if T&E bat species are present on the proposed site(s)	Acoustic bat surveys Roost tree monitoring

BCK - Bear Creek
EFPC - East Fork Poplar Creek
EMDF - Environmental Management Facility
ORNL - Oak Ridge National Laboratory
T&E species - Threatened and endangered Species
WNS - White Nose Syndrome

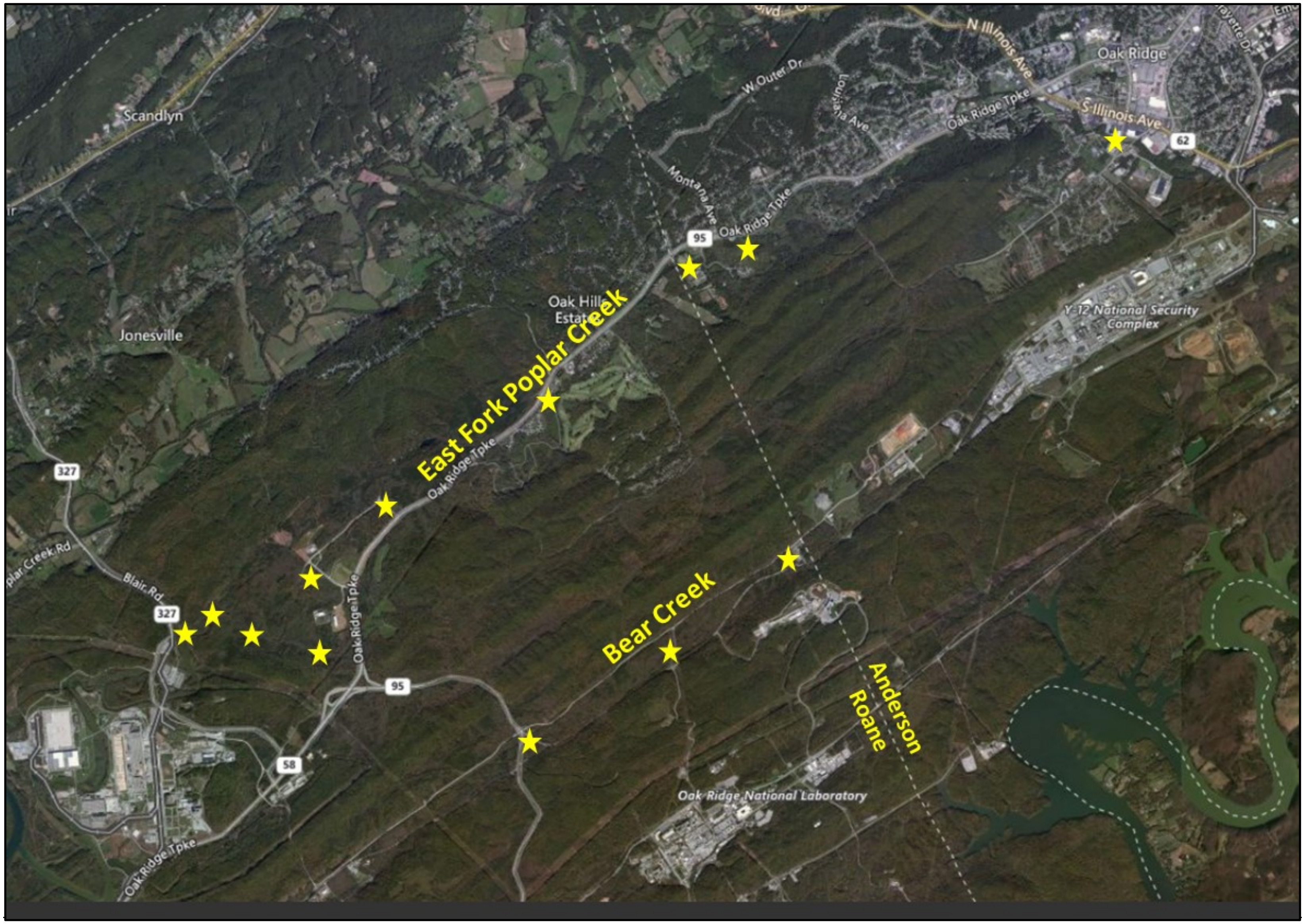

Figure 2.2: Bat box and guano sample locations

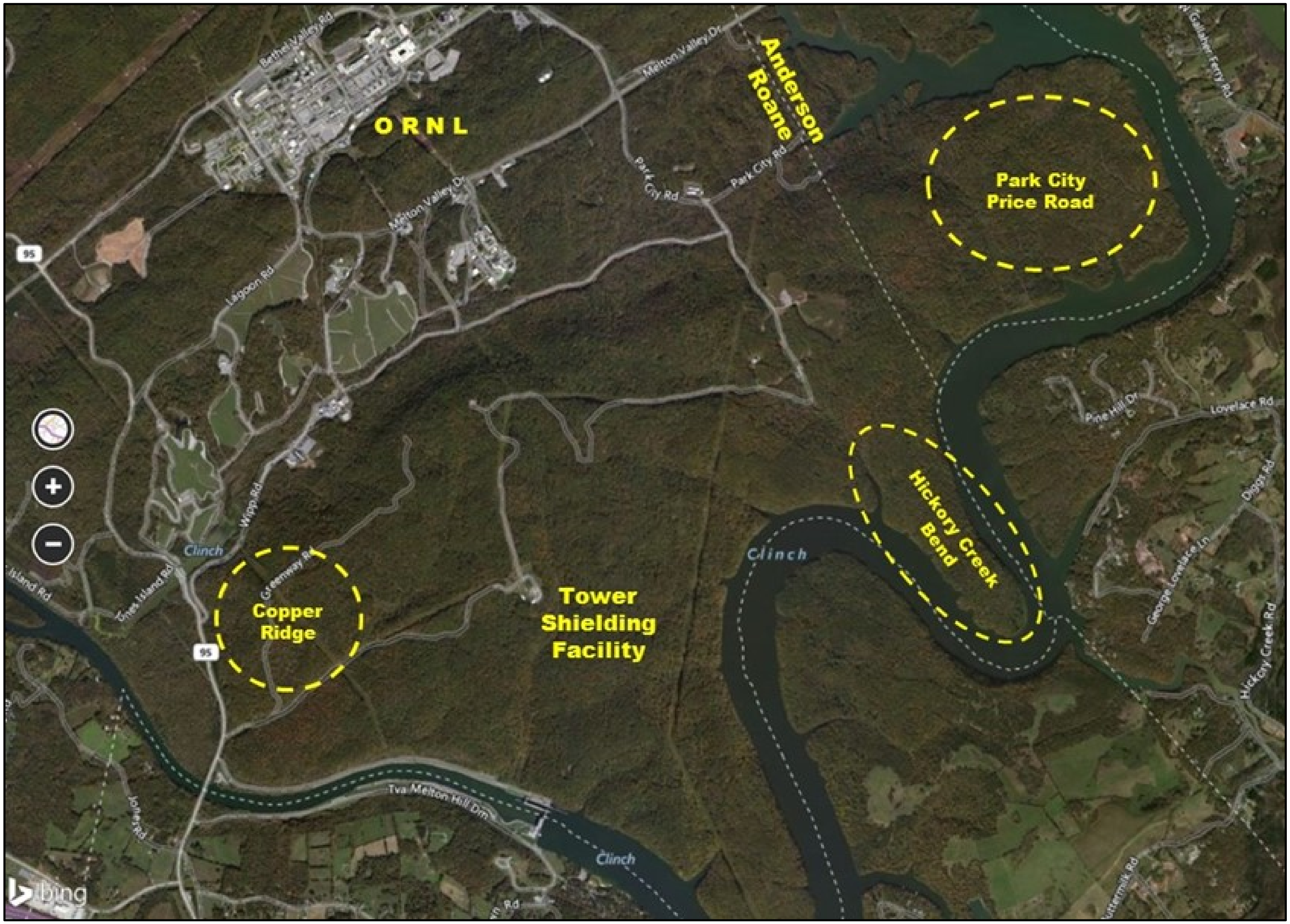

Figure 2.3: Bat acoustic survey and sample locations (caves) (a)

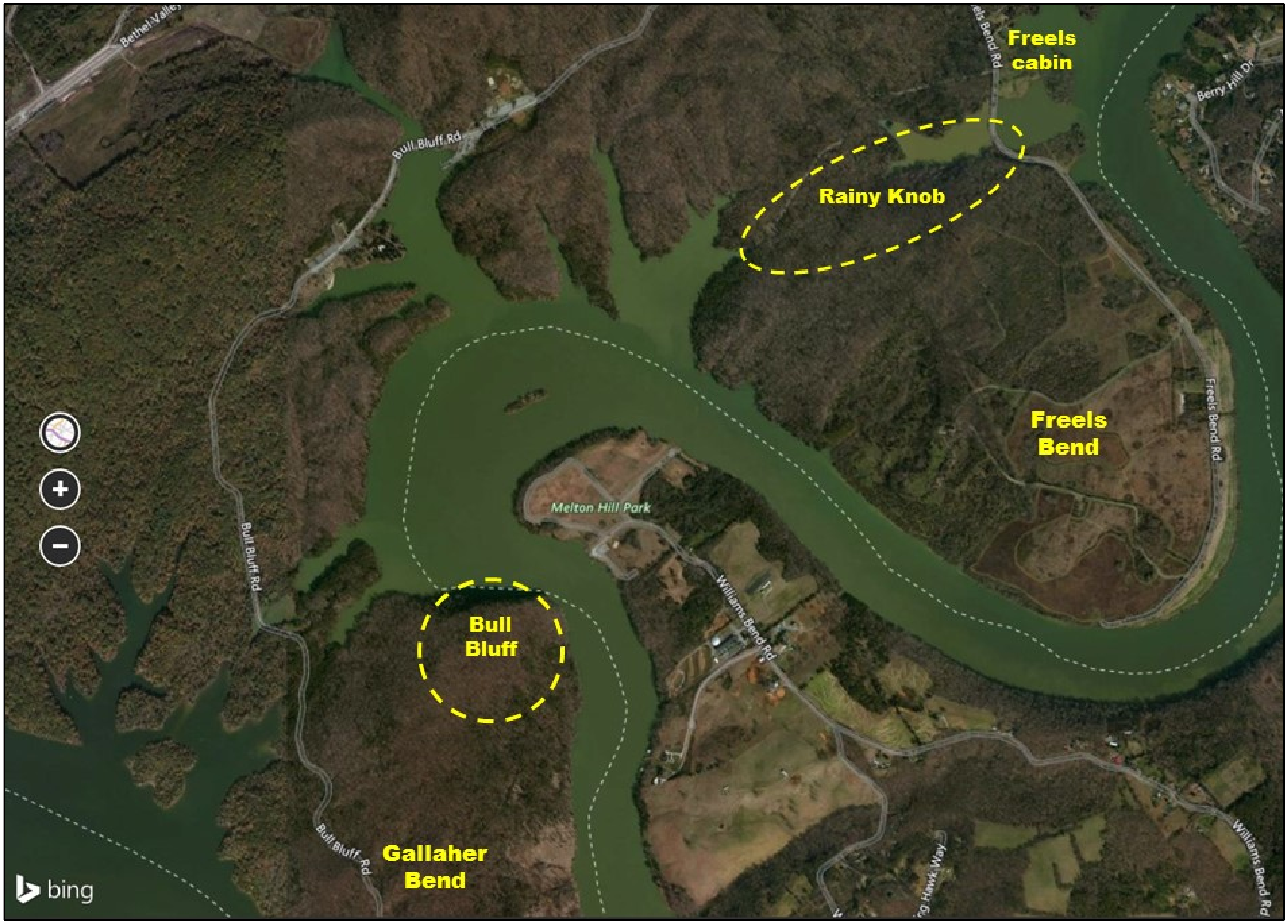

Figure 2.4: Bat acoustic survey and sample locations (caves) (b)

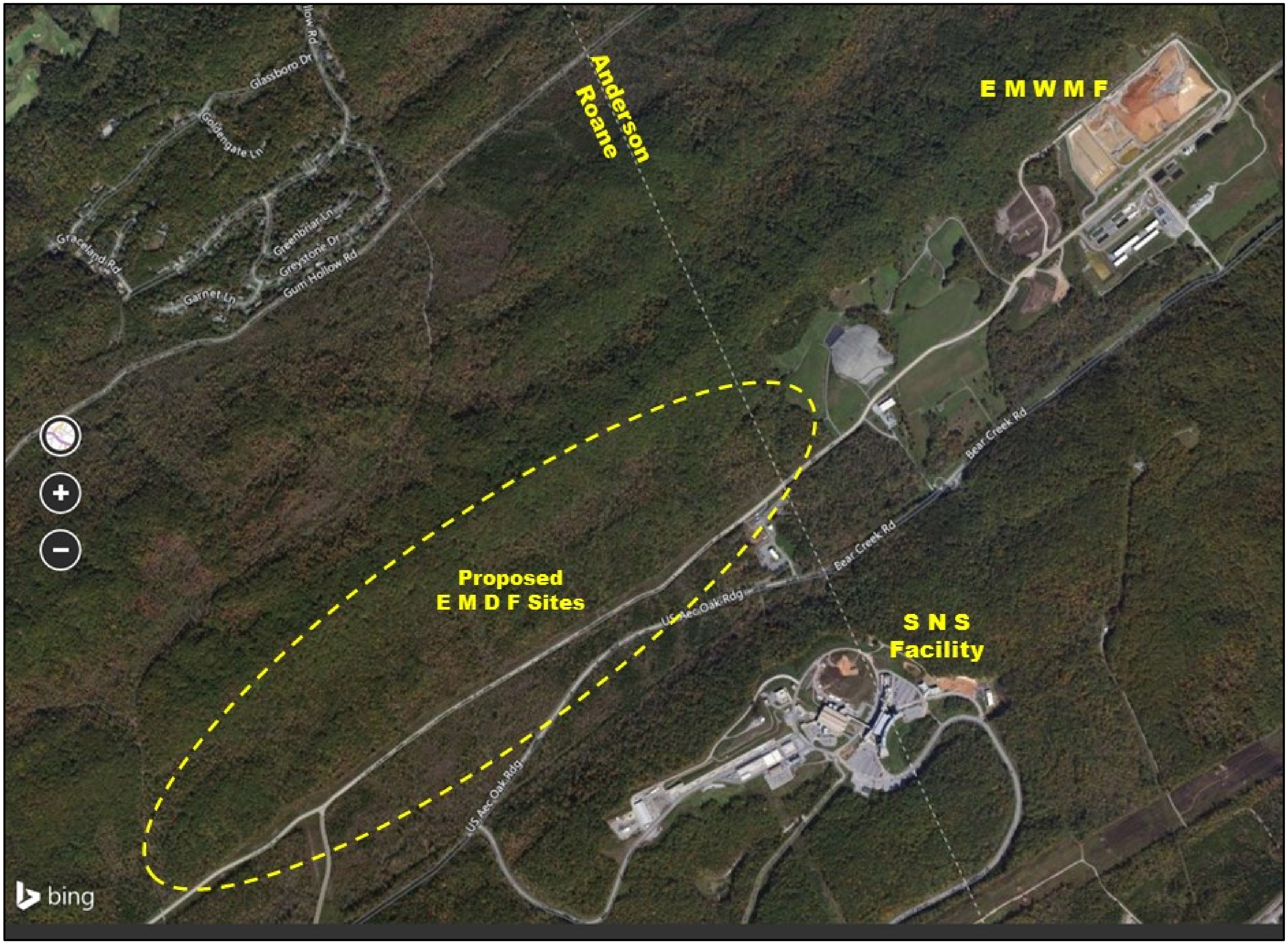

Figure 2.5: Bat acoustic survey and sample locations

The acoustic surveys aid in determining the status of federally endangered bats (Indiana bat and Gray bat) in Tennessee. Acoustic information should be helpful in identifying areas where netting surveys could further build upon bat distribution data, especially where calls of the genus Myotis are recorded most frequently. The Northern Long-eared bat is currently listed as a federally threatened species by the U.S. Fish and Wildlife Service.

Many bat investigations on federal land have been limited to short-term 2-4 night surveys of mist-netting and acoustic surveys to meet the Indiana bat monitoring requirements of Section 7 of the Endangered Species Act. As a result, few bat acoustic surveys have been conducted over the years, and historical bat data are inconsistent or is often non-existent in critical habitat areas such as the forested National Environmental Research Park (NERP) area of the ORR.

DoR-OR's monitoring supports the protection and conservation of endangered bat species, a major component of the TDEC mission, and supports efforts to combat white-nose syndrome, and determine if there is an effect from the historic and ongoing releases of mercury to the bat community. This project, along with a concurrent ORNL Environmental Science Division bat project, represents the first long-term, large-scale acoustic bat community investigation on the ORR.

2.2.2 Mercury Uptake in Biota

Mercury (Hg) and methylmercury (MeHg) are environmental concerns due to their abilities to cause neurological, reproductive, and other physical damage to wildlife and humans (Standish 2016). Mercury can bio-accumulate to high levels in biota as it moves up in the food chain, especially in areas where mercury exists as a point-source contaminant (Bell and Scudder 2007, Bergeron et al. 2011, Hothem et al. 2010).

Microorganisms (anaerobic bacteria), found in sediment, naturally convert anthropogenic mercury deposited in wetlands and sediment into the more bioavailable and toxic form of methylmercury (Southworth et al. 2010). Mercury deposited within the EFPC floodplain soils and sediment is known to be methylated by periphyton (primary production) that has colonized benthic substrates (Olsen and Brooks 2015). Accordingly, methylmercury is likely to move from aquatic systems via emigrating salamanders and invertebrates entering terrestrial food webs and bioaccumulating in higher trophic levels through predation (Wolfe et al. 2007).

Biota sampling efforts include collecting adult flying insects, benthic larvae, crayfish, earthworms, isopods, periphyton, riparian spiders, salamanders, and small mammals. The primary objective is to quantify and document how mercury transfers from aquatic animals to the terrestrial segment of the stream floodplain. To determine if mercury contamination has moved from EFPC into the adjacent terrestrial food web, we will analyze total mercury and methylmercury concentrations in tissues collected and from biota species within 15 miles of the creek (Figures 2.6, 2.7).

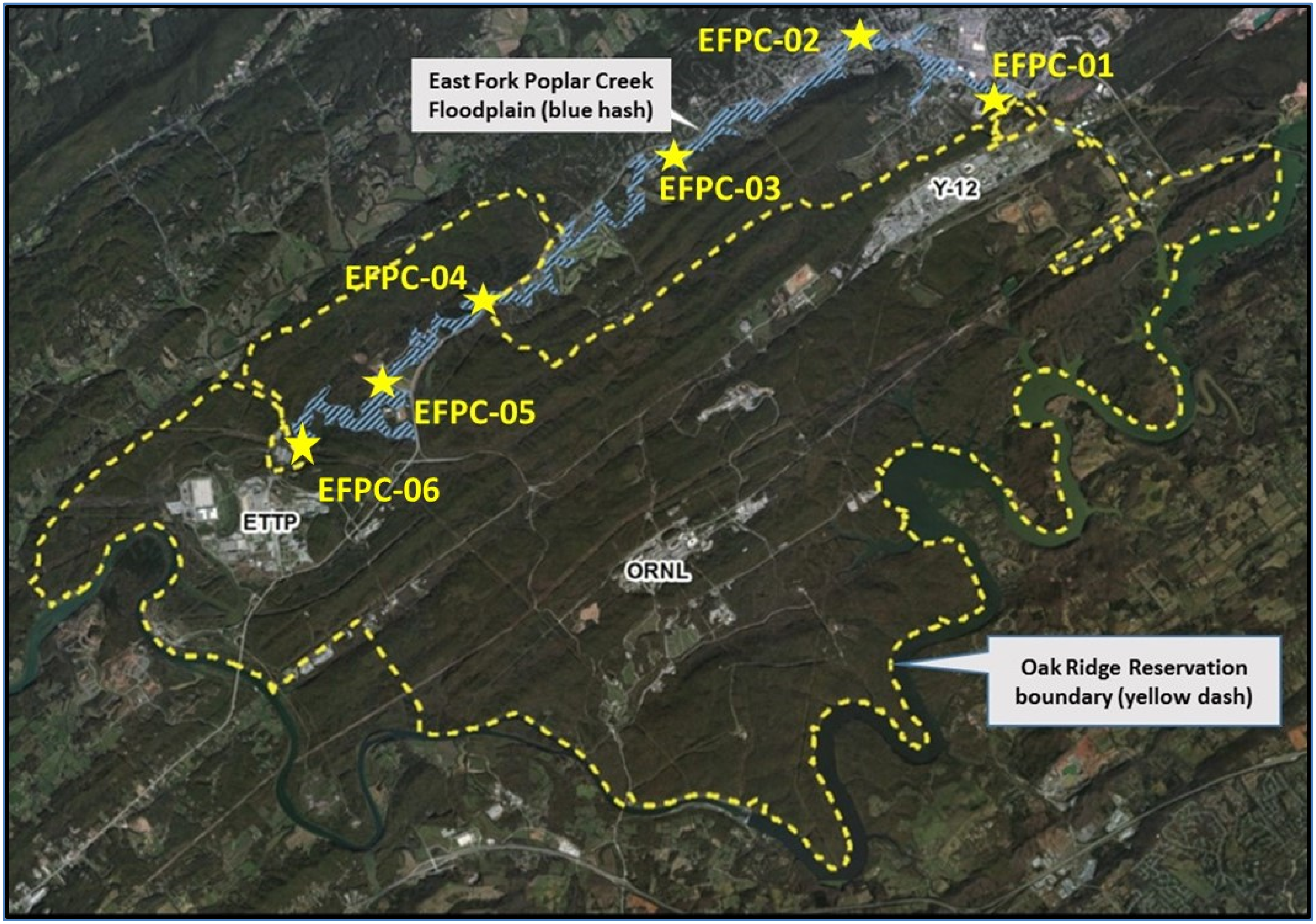

Figure 2.6: Biota sampling locations East Fork Poplar Creek

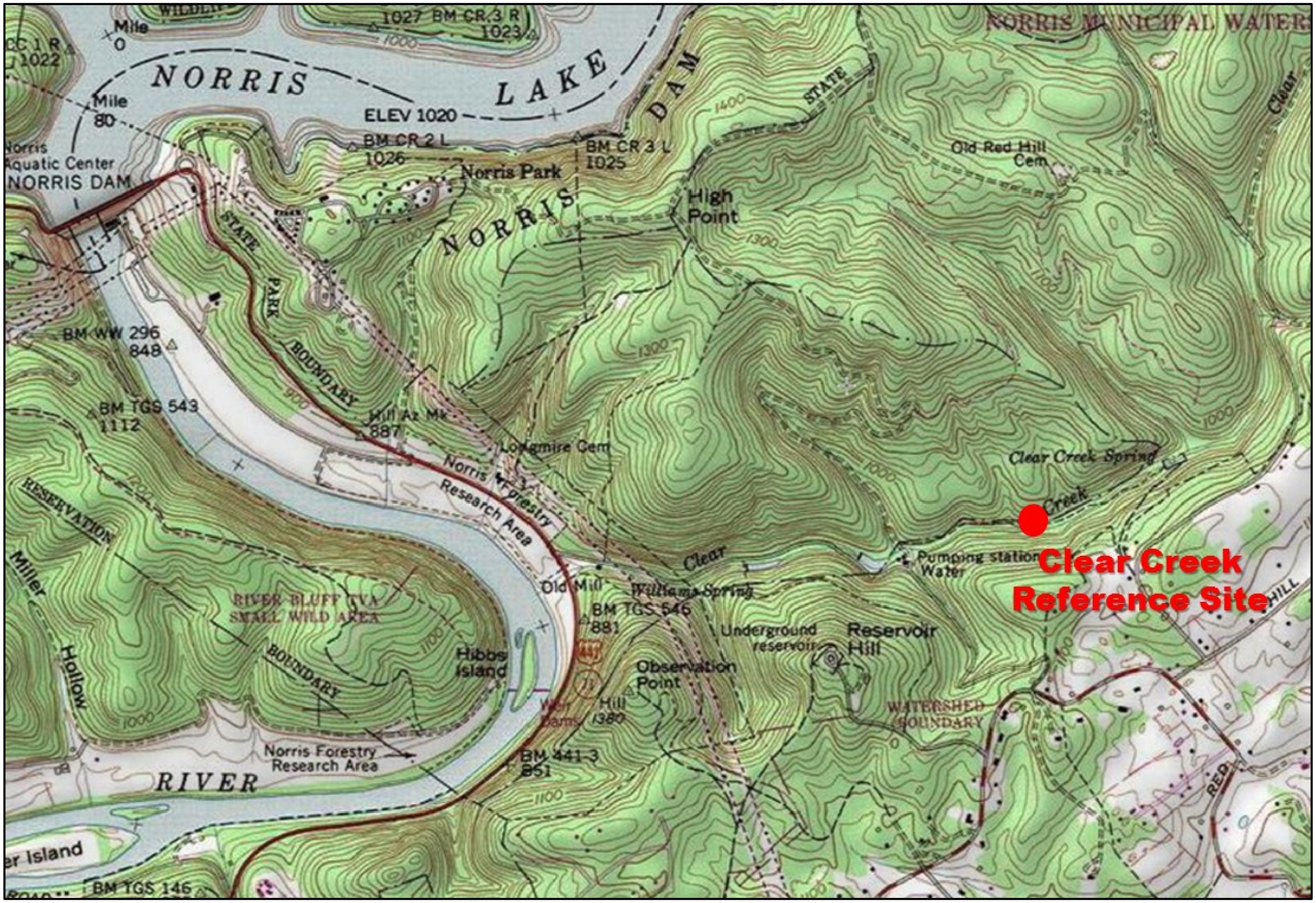

Figure 2.7: Biota sampling reference site (Clear Creek)

Biota samples will be collected from up to six EFPC locations and one reference site. Biota sampling locations along EFPC are shown in Figure 2.6 Biota sampling locations East Fork Poplar Creek. The biota sampling reference location (Clear Creek) is shown in Figure 2.7 Biota sampling reference site (Clear Creek). Samples are collected to provide laboratory assays for both total mercury (THg) and methylmercury.

Adult Flying Insects

Many fauna inhabit the contaminated floodplain of EFPC. Murphy et al. (2005) reported that redbreast sunfish and smallmouth bass in the South River in Virginia consume appreciable quantities of the terrestrial green June beetle (*Cotinis nitida*) during the summer months. These beetles have been shown by Murphy (2004) to accumulate mercury from the contaminated floodplain of the river. Terrestrial insects in the EFPC floodplain may be a potential vector for the spread of mercury contamination to the aquatic and terrestrial food chain.

Benthic Larvae

Invertebrates from mercury contaminated aquatic systems sometimes have very high mercury concentrations that may exceed those of the top predators within the system (Parkman and Meli 1993, Tremblay et al. 1995). Several studies have found that the percent of the total mercury body burden in the methylated form increases within the trophic position of invertebrate groups (Tremblay et al. 1995, Tremblay and Lucotte 1997, Tremblay 1999). Benthic macroinvertebrates and emergent insects often comprise a large proportion of the diets of many juvenile (Christensen & Moore 2007) and adult (Duffield and Nelson 1998) fish as well as a variety of terrestrial invertebrates that live adjacent to bodies of water. As such, they may be vectors of contaminants through the food chain by transfer of mercury from aquatic environments to terrestrial consumers (Nagle et al. 2001, Henderson et al. 2012).

Algal uptake may be a methylmercury entry point for stream food webs and primary consumption by scrapers, such as Heptageniidae (Mayflies) and may be a pathway of mercury transfer from aquatic to terrestrial habitats to higher trophic levels (Mason et al. 2000, Castro et al. 2007, Cremona et al. 2009, Ward et al. 2010). For this project, Trichoptera larvae are the preferred group; however, Plecoptera and Ephemeroptera may be sampled in order to meet biomass requirements for the laboratory analysis.

Dragonfly larvae (Odonata—Anisoptera) have been collected in multiple studies over the years and recently were used as biosentinels of methylmercury in a study encompassing multiple lakes in national parks located in the Great Lakes region (Haro et al. 2013). Collection of dragonfly larvae and subsequent analysis of methylmercury could be used as a screening and monitoring tool to assess spatial and temporal methylmercury levels in aquatic systems. For this project, Anisoptera (dragonfly) larvae is the preferred group; however, Zygoptera (damselfly) larvae may be sampled in order to meet biomass requirements for the laboratory analysis.

Crayfish

Crayfish (Decapoda) are frequently used as bioindicators of heavy metal contamination (Eisemann et al. 1997). Crayfish typically have higher mercury levels than other detritivores and most of their predators, likely due to their size and longer life span (Martin 1997). Crayfish are among the largest, longest-lived benthic invertebrates [2–3 years in northern climates (Martin 1997)]. They are intimately associated with the substrate, have a ubiquitous distribution, and are a food source for many organisms (Pennuto et al. 2005). Therefore, they represent a trophic link between benthic and water-column food webs in lakes and streams and have been suggested as excellent indicator species for mercury bioavailability studies (Verneer 1972, Armstrong and Hamilton 1973, Allard and Stokes 1989, Parks 1988, Parks et al. 1991). Methylmercury concentrations may represent ≥ 90% of total mercury in fish and crayfish (Lafrancois and Carlisle 2004).

Earthworms

Earthworms (Oligochaeta) are a source of food for many smaller mammals and birds (Standish 2016). Earthworms make up the most biomass of all the invertebrates that inhabit the soil and are a source of food and protein to birds and small mammals like the Carolina wren and shorttail shrew (*Blarina brevicauda*) (Zhang et al. 2009). Earthworms may play a role in the movement of contaminants, such as mercury, in the terrestrial environment (Han et al. 2012). Earthworms provide suitable conditions for the methylation of inorganic mercury by gut-inhabiting bacterial communities in their digestive tract (Rieder et al. 2013). Earthworms will be analyzed without depuration (voiding the gut) to evaluate their full potential mercury contribution to higher trophic level predators (Talmage and Walton 1993).

Isopods

Isopods ("roly-poly bugs") feed on the detritus in their habitat, including leaf litter, fungi, and dead or decaying plants and animals. Recent studies have shown that detrital isopods had a higher bioconcentration of methylmercury fractions compared to those of earthworms (Standish 2016). This may be because isopods feed on organic matter consisting of higher concentrations of methylmercury. High concentrations of methylmercury in isopods may pose a greater danger to upper-level predators that feed on them (Standish 2016).

Periphyton

Periphyton (benthic algae and diatoms) is a primary producer and basal food web assemblage of algae and other microorganisms that colonize benthic substrates (Stoermer and Smol 1999, Stevenson et al. 2001) and are excellent indicators of pollution in aquatic systems (Dixit et al. 1992, Kelly et al. 1995, Stevenson & Pan 1999). Because periphyton assemblages are attached to natural substrates, the benthic algae community responds to biological and physiochemical disturbances that occur longitudinally in a stream reach during algal colonization (Medley & Clements 1998). Periphyton communities contain many diatom taxa with individual tolerances to anthropogenic stressors such as elevated concentrations of heavy metals and high nutrient loads (Deniseger et al. 1986, Takamura et al. 1989, Medley & Clements 1998). Benthic periphyton provides a continuous record of environmental quality and reveals various environmental changes of natural and anthropogenic origin (Genter 1996, Pérès 1996, Ivorra et al 1999). Periphyton is a food source for invertebrates and some fish, and can be an accumulator of high methylmercury concentrations (Miles et al. 2001, Desrosiers et al. 2006, Hamelin et al. 2015). These accumulated metals may be transferred from periphyton to the consuming organisms (Tang et al. 2014) creating a major entry point of methylmercury into the food web (Chasar et al. 2009, Molina et al. 2010). Bell and Scudder (2007) reported high concentrations of methylmercury in periphyton samples with high abundance of diatoms, suggesting a greater transfer of methylmercury to herbivores when diatoms dominate in the periphyton.

Riparian Spiders

Invertebrates are a source of protein for many organisms (Zhang et al. 2009). A few recent studies have determined terrestrial food chains may be contaminated by the cross-habitat transfer of mercury by insects and spiders (Brasso and Cristol 2008, Cristol et al. 2008, Henderson et al. 2012). Evidence shows that substantial methylmercury movement into the floodplain trophic web via aquatic insect consumption by riparian spiders and floodplain songbird predation on emergent aquatic insects (Cristol et al. 2008) exists. For example, spiders [fishing spiders & wolf spiders (Arachnida)] that live in the flood plain (riparian zones) and prey on aquatic insects may serve as a link for contaminant transfer between aquatic and terrestrial ecosystems (Burdon and Harding 2008, Cristol et al. 2008).

These spiders primarily inhabit large tree trunks, large accumulations of woody debris along the edge of the water, soils on the stream banks, and large rocks along the shoreline of riparian zones. Much of their diet consists of emerging aquatic insects and small fish (young-of-the-year) found in their riparian habitat (Carico 1973). Cristol et al. (2008) found that much of the mercury in the spiders was in the form of highly bioavailable methylmercury, whereas invertebrates lower in the food web had less methylmercury. A 2011 ecological assessment of EFPC revealed data indicating high concentrations of mercury in spiders in the EFPC floodplain, which included a high concentration of the bioavailable methylmercury in spiders (Mathews et al. 2011).

Salamanders

Recent studies have shown that mercury is both geographically widespread and can elicit deleterious effects on amphibian behavior (Burke et al. 2010), fitness, and survival (Unrine et al. 2004, Bergeron et al. 2007, Day et al. 2007, Grillitsch and Schiesari 2010, Bergeron et al. 2011, Turnquist et al. 2011, Hopkins et al. 2013). Due to their abundance and life history, amphibians with complex lifecycles often link trophic levels and facilitate the transfer of nutrients, contaminants and energy between aquatic and terrestrial habitats (Beard et al. 2002, Regester et al. 2006, Wyman 1998).

In headwater streams, several Plethodontid salamander species replace fish as an endpoint species and become the dominant vertebrate predator; however, they also serve as prey for higher trophic level birds and mammals. In these environments, salamanders become the preferred, if not the only, vertebrate bioindicator for assessing stream health as sentinel species (Carroll et al. 1999, Hamed 2014). One factor that contributes to salamander's environmental sensitivity is their permeable skin, which provides toxins with an easy pathway of entry into the body (Boone and Bridges 2003). Most amphibians are dependent on aquatic environments early in their life and their complex life cycle allows them to metamorphose onto land (Wells 2007). Therefore, EFPC floodplain salamanders are potentially exposed to toxins in both aquatic and terrestrial environments (Standish 2016).

Due to the sensitive status of salamander species, there is a need to employ non-lethal tissue sampling techniques to quantify mercury exposure in amphibians (Pfleeger 2015). Mercury concentrations found in tail and toe clips from salamanders and frogs have been shown to correlate with whole-body or blood concentrations (Townsend and Driscoll 2013, Bergeron et al. 2010, Todd et al. 2012).

Small Mammals

It has been documented that small mammals residing in contaminated areas can bioaccumulate contaminants in various body tissues (Beyer et al. 1985, Neithammer et al. 1985, Dodds-Smith et al. 1992, Peles and Barrett 1997, Appleton et al. 2000). The significance of small mammals as an intermediate step in the transfer of toxic contaminants to higher tropic levels and implications regarding the potential bioaccumulation of contaminants can be drawn from small mammal studies (Taylor et al. 1981, Hunter et al. 1987, Brueske and Barrett 1991, Brewer and Barrett 1995, Kaplan et al. 1996).

Mercury concentrations as high as 6.0, 33.2, 3.5 and 7.9 parts per million (ppm) have been documented in EFPC crayfish, earthworms, wrens, and shrews, respectively (Facemire et al. 1995). Methylmercury is known to be toxic to small mammals. For example, in a laboratory study, the feeding of diets containing 1.8 ppm of mercury (as methylmercury) produced clinical intoxication and death of mink within as little as 59 days (Wobeser and Swift 1976).

Shorttail shrews are primarily insectivorous whereas white-footed mice are primarily omnivorous and opportunistic feeders (Talmage and Walton 1993). According to Whitaker (1980), a favorite food item of white-footed mice is the seeds of jewelweed; whereas, the diet of shorttail shrews is rich in earthworms, slugs, and snails (Whitaker and French 1984). A 1990s study of small mammals in EFPC found the mean concentration of mercury in kidney tissue of shorttail shrews from EFPC was significantly greater than that of shorttail shrews from the reference site (Talmage and Walton 1993). Therefore, the shorttail shrew's trophic position makes it an ideal sentinel for a variety of contaminants. In another study, mercury concentrations in shorttail shrew kidney tissue were more than an order of magnitude greater than those of other mammal species examined and were related to the soil-associated habitat and feeding habits of this species (insects, slugs, snails, centipedes, & spiders; Talmage 1990).

All these major biota groups will be sampled at each of the six EFPC sites and from one reference site. DoR-OR anticipates collecting 10 sample groups per site with 70 total maximum samples expected for analysis of total mercury and methylmercury.

2.2.3 Radiological Contaminant Uptake in Vegetation

If surface water bodies have been impacted by radiological contamination, certain aquatic organisms in the immediate vicinity may uptake radionuclides. The Radiological Contamination project will focus on the detection and characterization of radiological constituents that may be bioaccumulated by vegetation on and in the vicinity of the ORR.

Target vegetation for sampling includes, but will not be limited to, common cattail (Typha latifolia) and watercress (*Nasturtium officinale*). Locations considered as potential monitoring sites include springs, seeps, streams, creeks, wetlands, ponds, floodplains, and adjacent areas. Watersheds such as Bear Creek and its tributaries, White Oak Creek/Lake and its tributaries, Mitchell Branch, and EFPC are all probable target locations for sampling. Actual sampling locations depend on vegetation availability and other variables.

As many as twenty locations will be sampled and analyzed for gross alpha, gross beta, and gamma radionuclides. Samples will consist of at least one gallon of vegetation, generally cut to not include roots. The monitoring will focus on areas likely to have radiological contamination, either from past or current DOE activities. Current activities may include areas downstream of the demolition of buildings with radiological contamination from past activities to determine if radiological constituents are migrating into the environment. This project will continue to focus on the detection and characterization of radiological constituents that may be bioaccumulated by aquatic vegetation in and near water on the ORR.

2.2.4 Benthic Macroinvertebrates

Benthic macroinvertebrates include insects, crustaceans, annelids, mollusks, and other organisms with long aquatic life cycles (multiple stages of larval instars) 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).

Semi-quantitative kicknet 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 are used to calculate the Tennessee Macroinvertebrate Index. 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) and 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 (EFPC, Bear Creek, Mitchell Branch, and the WOC/Melton Branch watershed) have been impacted by DOE-related activities. EFPC and Bear Creek have received input from Y-12, Mitchell Branch from ETTP, and the White Oak Creek/Melton Branch watershed from ORNL. Contaminant releases to surface water and groundwater vary among these industrial sites, but generally include organic pollutants, heavy metals, and radionuclides.

On the ORR, fourteen stream stations will be sampled from the four main watersheds (EFK, BCK, MIK, and WOC). From Melton Branch ((MEK) a tributary to WOC), six reference streams will be sampled and two duplicate samples will be taken. These monitoring locations are identified in Table 2.4 Benthic Macroinvertebrates Monitoring Locations and shown in Figure 2.8 Benthic macroinvertebrate monitoring locations.

Table 2.4: Benthic Macroinvertebrates Monitoring Locations				
Station	**Description**	**Reference**	**TDEC DWR Designation**	**Sampling Rationale**
EFK 25.1	East Fork Poplar Creek km 25.1	thin canopy	EFPOP015.6AN	Impacted Site
EFK 24.4	East Fork Poplar Creek km 24.4	canopy	EFPOP015.2AN	Impacted Site
EFK 23.4	East Fork Poplar Creek km 23.4	open	EFPOP014.5AN	Impacted Site
EFK 13.8	East Fork Poplar Creek km 13.8	open	EFPOP008.6AN	Impacted Site
EFK 6.3	East Fork Poplar Creek km 6.3	canopy	EFPOP003.9RO	Impacted Site
HCK 20.6	Hinds Creek km 20.6 reference	canopy	HINDS012.8AN	Reference Site
CCK 1.45	Clear Creek km 1.45 reference	thin canopy	ECO67F06	Reference Site
GHK 2.9	Gum Hollow Branch km 2.9 reference	canopy	GHOLL001.8RO	Reference Site
MIK 1.43	Mitchell Branch km 1.43 reference	canopy	MITCH000.9RO	Reference Site
MIK 0.71	Mitchell Branch km 0.71	open	MITCH000.4RO	Impacted Site
MIK 0.45	Mitchell Branch km 0.45	thin canopy	MITCH000.3RO	Impacted Site
BCK 12.3	Bear Creek km 12.3	canopy	BEAR007.6AN	Impacted Site
BCK 9.6	Bear Creek km 9.6	canopy	BEAR006.0AN	Impacted Site
BCK3.3	Bear Creek km 3.3	canopy	BEAR002.0RO	Impacted site
MBK 1.6	Mill Branch km 1.6 reference	canopy	FECO67I12	Reference Site
WCK 6.8	White Oak Creek km 6.8 reference	thin canopy	WHITE004.2RO	Reference Site
WCK 3.9	White Oak Creek km 3.9	thin canopy	WHITE002.4RO	Impacted Site
WCK 3.4	White Oak Creek km 3.4	canopy	WHITE002.1RO	Impacted Site
WCK 2.3	White Oak Creek km 2.3	canopy	WHITE001.4RO	Impacted Site
MEK 0.3	Melton Branch km 0.3	thin canopy	MELTO000.2RO	Impacted Site

km - kilometer

TDEC DWR - Tennessee Department of Environment and Conservation Division of Water Resources

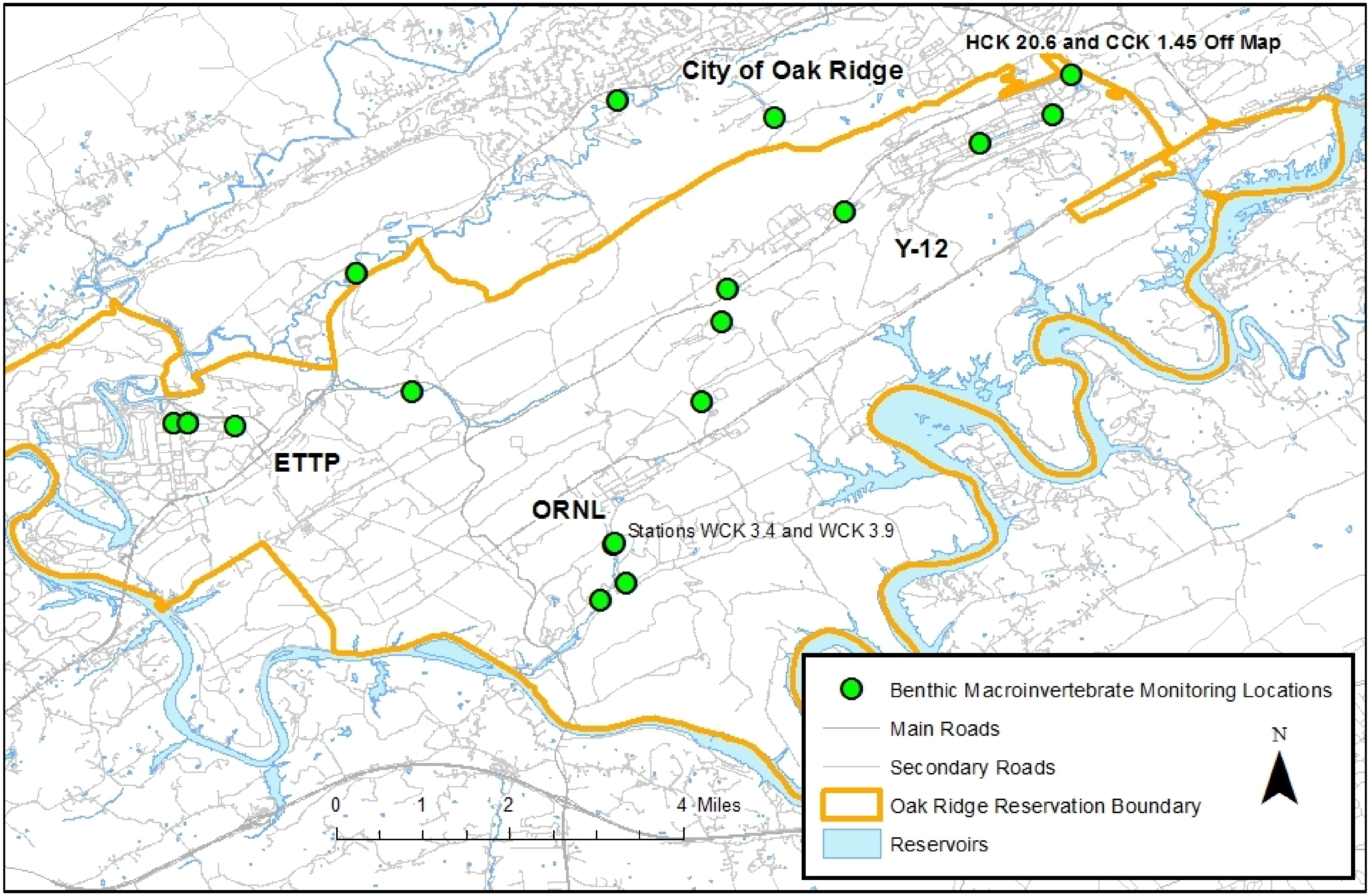

Figure 2.8: Benthic macroinvertebrate monitoring locations

2.3 Air Monitoring

Currently, only the fugitive air monitoring program for the ORR is planned; however, DoR-OR will supplement this project with an EPA program discussed in Section 2.8.

The fugitive air monitoring program uses eight mobile high-volume air samplers. The fugitive air monitoring project focuses on locations with the potential for airborne releases of radioactive pollutants from non-point sources of contaminants (fugitive emissions). The sampling frequency and analyses for each location are identified in Table 2.5 Fugitive Air Monitoring and shown in Figure 2.9 Fugitive air monitoring locations. The results from ORR monitors are compared to background measurements to determine if releases are occurring and compared to limits provided in the Clean Air Act to assess compliance with associated emission standards. Findings are used to identify and characterize unplanned releases, assess any dose to the public as defined in 10 Code of Federal Regulations 835, and to evaluate DOE monitoring and control measures for preventing airborne releases to the environment as required by the TOA (C.2 Radiological Oversight).

Efforts will be made to determine what is required to analyze air emissions for mercury at Y-12. With the threats of mercury in the environment and the amount of mercury that may be in some of the buildings scheduled for demolition in subsequent years, DoR-OR will explore mercury monitoring technologies to enhance monitoring prior to any airborne releases.

Table 2.5: Fugitive Air Monitoring

Station	Sampling Frequency	Analyses
Y12 B9723-28	Collected weekly, composited every four weeks	Isotopic Uranium, Technetium-99
Y12 B9212		Isotopic Uranium, Technetium-99
ETTP K25 K11		Isotopic Uranium, Technetium-99
ETTP Portal 4		Isotopic Uranium, Technetium-99
ORNL Corehole 8		Isotopic Uranium, Gamma Radionuclides
ORNL B4007		Isotopic Uranium, Gamma Radionuclides
EMWMF		Isotopic Uranium, Gamma Radionuclides, Technetium-99
Background		Isotopic Uranium, Gamma Radionuclides, Technetium-99

ETTP - East Tennessee Technology Park
ORNL - Oak Ridge National Laboratory
EMWMF - Environmental Management Waste Management Facility
B - building number

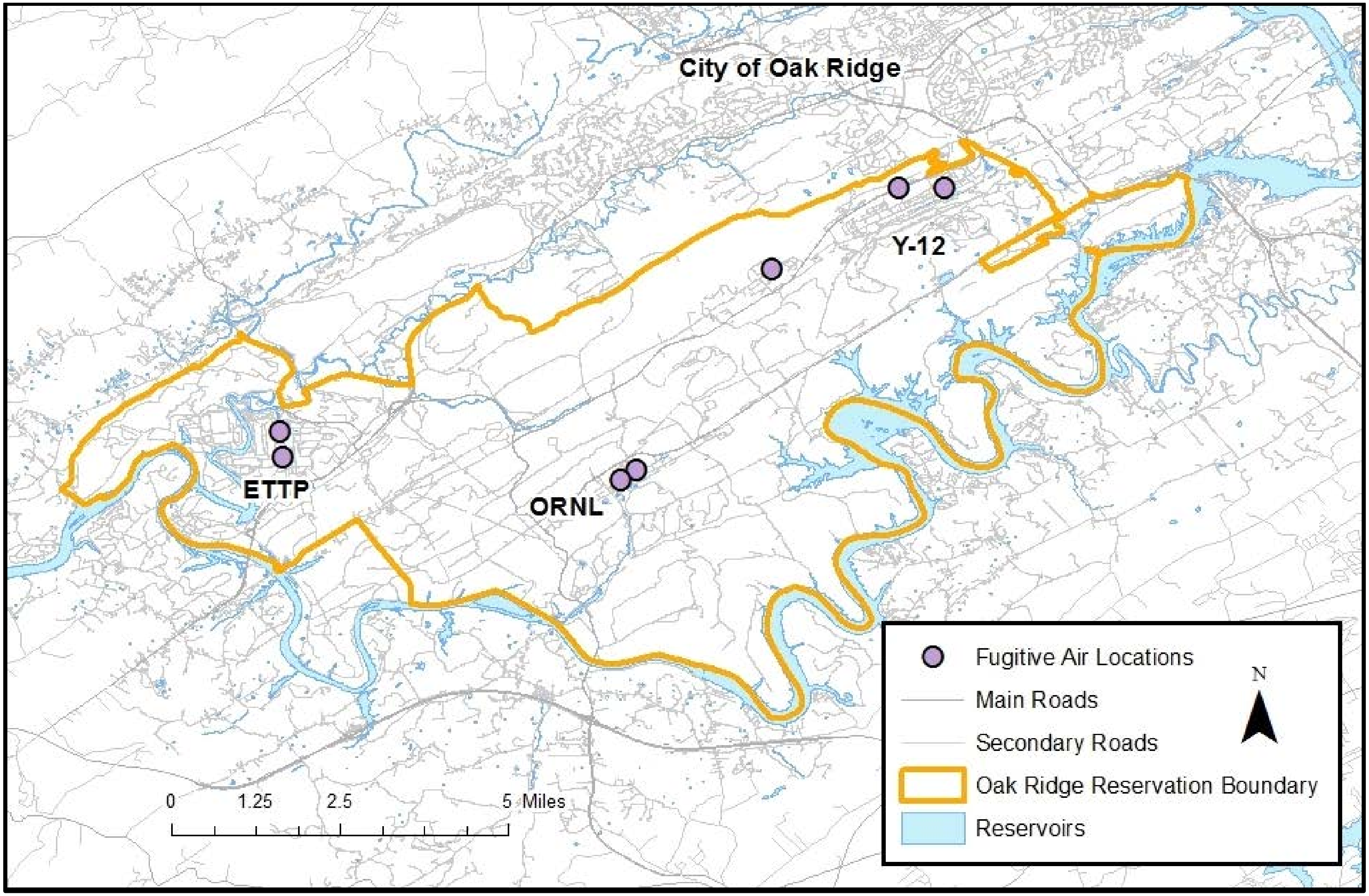

Figure 2.9: Fugitive air monitoring locations

2.4 Surface Water Monitoring

There are four surface water monitoring projects:

1. surface water physical parameters
2. ambient surface water
3. rain event surface water
4. FCAP surface water sampling

2.4.1 Surface Water Physical Parameter Monitoring

Due to the presence in some areas of anthropogenic point- and non-point source contamination on the ORR, the potential for contamination to impact surface water exists on the ORR. To assess the degree of surface water impact relative to this potential contamination displacement, stream monitoring data will be collected monthly to establish a database of physical stream parameters (specific conductivity, pH, temperature, and dissolved oxygen). The purpose of this monitoring is to establish a database/baseline of conditions on and around the ORR and to record ambient conditions that can be compared in the event of an accident that may impact surface water bodies. DoR-OR will conduct surface water physical parameter monitoring at the locations identified in Table 2.6 Surface Water Physical Parameter Monitoring Locations and shown in Figure 2.10 Surface water physical parameter monthly monitoring locations.

Table 2.6: Surface Water Physical Parameter Monitoring Locations

Stream	TDEC DWR ID	Alternate ID	Location
East Fork Poplar Creek	EFPOP015.6AN	EFK 23.4	East Fork Poplar Creek (near Y-12 east gate)
	EFPOP014.5AN	EFK 13.8	East Fork Poplar Creek (near Big Turtle Park)
Bear Creek	BEAR007.6AN	BCK 12.3	Bear Creek (near Y-12 west gate)
	BEAR006.0AN	BCK 9.6	Bear Creek (near Walk-in Pits)
	BEAR002.8AN	BCK 4.5	Bear Creek (Weir at Hwy 95)
Mitchell Branch	MITCH00.06RO	MIK 0.1	Mitchell Branch (Weir at ETTP)
Mill Branch	FEC067112	MBK 1.6	Mill Branch (Reference)

ETTP - East Tennessee Technology Park
DWR ID - Division of Water Resources's Identification
Alternate ID is an abbreviation of the stream name with the distance from the mouth in kilometers
TDEC DWR - Tennessee Department of Environment and Conservation Division of Water Resources

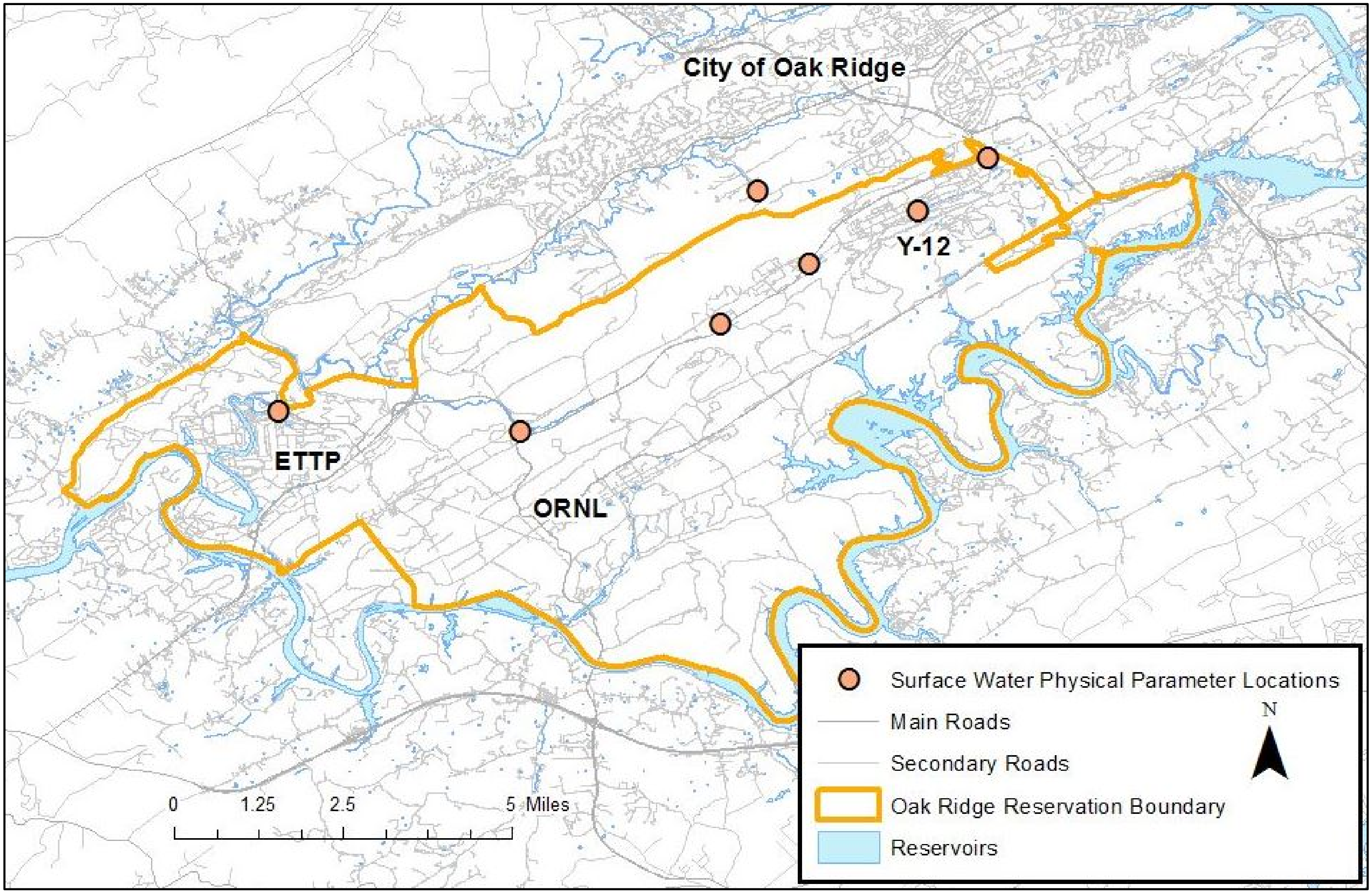

Figure 2.10: Surface water physical parameter monthly monitoring locations

2.4.2 Ambient Surface Water Monitoring

The ORR Clinch River tributaries of Bear Creek, East Fork Poplar Creek, Grassy Creek, Ish Creek, Mitchell Branch, Raccoon Creek, and White Oak Creek drain into the Clinch River. The ORR nuclear processing facilities in this area of the Clinch River are ETTP, Y-12, and ORNL. To obtain public drinking water and industrial plant processing water, all of these areas utilize the surface water of the Clinch River. To detect possible contamination from ORR DOE facilities, DoR-OR will conduct surface water sampling and analysis for select metals, nutrients, and radiochemistry characteristics at the 22 locations identified in Table 2.7 - Ambient Surface Water Monitoring Locations. Figure 2.11 (Ambient surface water monitoring locations) displays 20 of the sampling locations; the other two are located off the map to the northeast.

Table 2.7: Ambient Surface Water Monitoring Locations				
Monitoring Location	**TDEC DWR ID**	**Alt. ID**	**Frequency**	**Monitoring Rationale**
Raccoon Creek headwaters	RACCO001.6RO	RCK 2.6	quarterly	Surveillance of water quality possibly influenced by contaminated groundwater.
Ish Creek headwaters	TBD*	TBD*	quarterly	Surveillance of water quality possibly influenced by contaminated groundwater.
Grassy Creek headwaters	TBD*	TBD*	quarterly	Surveillance of water quality possibly influenced by contaminated groundwater.
Clinch River km 32	CLINC019.9RO	CRK 32	monthly	Surveillance of water quality possibly influenced by radiological contaminants from the Oak Ridge National Laboratory and/or the Melton Valley burial grounds.
Clinch River km 33.5	CLINC020.8RO	CRK 33.5	monthly	Surveillance of water quality possibly influenced by radiological contaminants from the Oak Ridge National Laboratory and/or the Melton Valley burial grounds.
Clinch River km 34.9	CLINC021.7RO	CRK 34.9	monthly	Surveillance of water quality possibly influenced by radiological contaminants from the Oak Ridge National Laboratory and/or the Melton Valley burial grounds.
White Oak Creek headwaters	WHITE004.2RO	WCK 6.8	monthly	Background sampling station
East Fork Poplar Creek Mile 15.6	EFPOP015.6AN	EFK 25.1	Annually	Surveillance of water quality at East Fork Poplar Creek (EFPC) headwaters.
East Fork Poplar Creek Mile 15.2	EFPOP015.2AN	EFK 24.4	Annually	Surveillance of water quality at EFPC intermediate to EFK 25.1 and EFK 23.4.
East Fork Poplar Creek Mile 14.5	EFPOP014.5AN	EFK 23.4	Annually	Surveillance of water quality at point where EFPC leaves leaves DOE property and enters Oak Ridge.
East Fork Poplar Creek Mile 8.6	EFPOP008.6AN	EFK 13.8	Annually	Surveillance of EFPC water quality just upstream of Oak Ridge sewage treatment outfall.
East Fork Poplar Creek Mile 3.9	EFPOP003.9RO	EFK 6.3	Annually	Surveillance of EFPC water quality downstream of Oak Ridge.
Bear Creek Mile 7.6	BEAR007.6AN	BCK 12.3	Annually	Surveillance of Bear Creek water quality near headwaters.
Bear Creek Mile 6.0	BEAR006.0AN	BCK 9.6	Annually	Surveillance of Bear Creek water quality downstream of Environmental Management Waste Management Facility (EMWMF).
Bear Creek Mile 2.0	BEAR002.0AN	BCK 3.3	Annually	Surveillance of Bear Creek water quality downstream of Y-12.
Mitchell Branch Mile 0.1	MITCH000.1RO	MIK 0.1	Annually	Surveillance of Mitchell Branch (MIK) water quality downstream of ETTP.
White Oak Creek Mile 2.4	WHITE002.4RO	WCK 3.9	Annually	Surveillance of White Oak Creek (WCK) at a point influenced by ORNL.
White Oak Creek Mile 2.1	WHITE002.1RO	WCK 3.4	Annually	Surveillance of White Oak Creek (WCK) at a point downstream of ORNL.
White Oak Creek Mile 1.4	WHITE001.4RO	WCK 2.3	Annually	Surveillance of White Oak Creek (WCK) at a point downstream of Melton Valley Burial Grounds.
Clear Creek Mile 1.0	ECO67F06	CCK 1.6	Annually	Reference site upstream of DOE facilities.
Hinds Creek Mile 12.8	HINDS012.8AN	HCK 20.6	Annually	Reference site north of Oak Ridge.
Mill Branch Mile 1.0	FECO67I12	MBK 1.6	Annually	Reference site in Oak Ridge.

TBD - To be determined

Alt ID - an abbreviation of the stream name with the distance from the mouth in kilometers

TDEC DWR - Tennessee Department of Environment and Conservation, Division of Water Resources

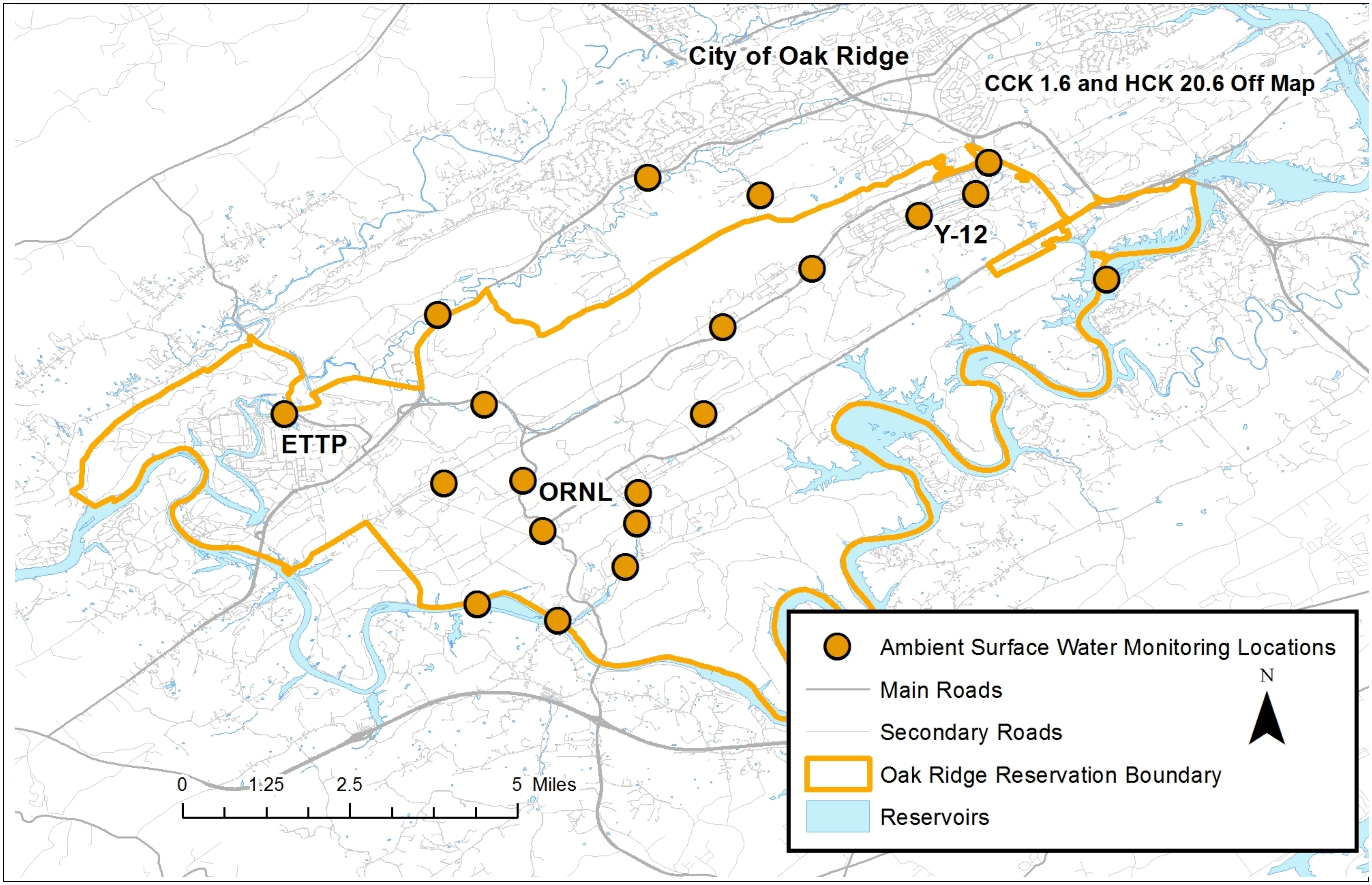

Figure 2.11: Ambient surface water monitoring locations

2.4.3 Rain Event Surface Water Monitoring

The rain event surface water monitoring project was established to assess the degree of impact, if any, caused by heavy rain events. Eight locations will be monitored routinely and sampled after a qualifying rain event each quarter. DoR-OR will conduct rain event surface water monitoring at the locations identified in Table 2.8 Rain Event Surface Water Monitoring Locations and shown in Figure 2.12 Rain event surface water monitoring locations.

- Mill Branch serves as a reference location and is located off the ORR.
- The sampling EFK 23.4 location will help determine if contamination exits the eastern side of Y-12.
- The WCK 0.0 sample location was selected to capture surface water exiting ORNL Melton Valley and the Central Campus area. The BCK 4.5 sample location is intended to capture water exiting the western side of Y-12, along with EMWMF and the burial grounds.
- The Mitchell Branch (kilometer (MIK) 0.01) location was selected to sample runoff along the north side of ETTP.
- The P1 pond weir was selected to sample the runoff along the south side of ETTP. Storm drain (SD) 490 is sampled to study and quantify the observed technetium-99 (Tc-99) release that may have occurred during the demolition activities from the K-25 building.
- SD 430 is sampled to understand possible contamination transportation off-site from the demolition activities from the surrounding area.

Samples will be analyzed for gross alpha and gross beta radionuclides, tritium and Tc99; metals, including arsenic, cadmium, chromium (total and hexavalent), copper, iron, lead, manganese, mercury, zinc and uranium.

Table 2.8: Rain Event Surface Water Monitoring Locations			
Monitoring Location	**TDEC DWR ID**	**Alternate ID**	**Monitoring Rationale**
East Fork Poplar Creek Mile 14.5	EFPOP014.5AN	EFK 23.4	Surveillance from Y-12, along EFPC
White Oak Creek Mile 0.0	WHITE000.0RO	WCK 0.0	Surveillance of White Oak Creek (WCK) and ORNL prior to discharging in the Clinch River
Bear Creek mile 2.8	BEAR002.8RO	BCK 4.5	Surveillance from Y-12, EMWMF, and the burial grounds along Bear Creek
Mitchell Branch	MITCH000.1RO	MIK 0.1	Surveillance from ETTP and hexavalent chromium
Storm Drain 490	NA	SD 490	Surveillance from ETTP, Technetium-99 release tracking
P1 Pond Weir	NA	P1 POND WEIR	Surveillance from ETTP
Mill Branch Mile 1.0	FECO67I12	MBK 1.6	Background location
Storm Drain 510	NA	SD 510	Surveillance from ETTP, monitoring remedial action activities in the area

TDEC DWR - Tennessee Department of Environment and Conservation Division of Water Resources
Alternate ID is an abbreviation of the stream name with the distance from the mouth in kilometers
NA - not applicable
EFPC - East Fork Poplar Creek
EMWMF - Environmental Management Waste Management Facility
ETTP - East Tennesee Technology Park
ORNL - Oak Ridge National Laboratory

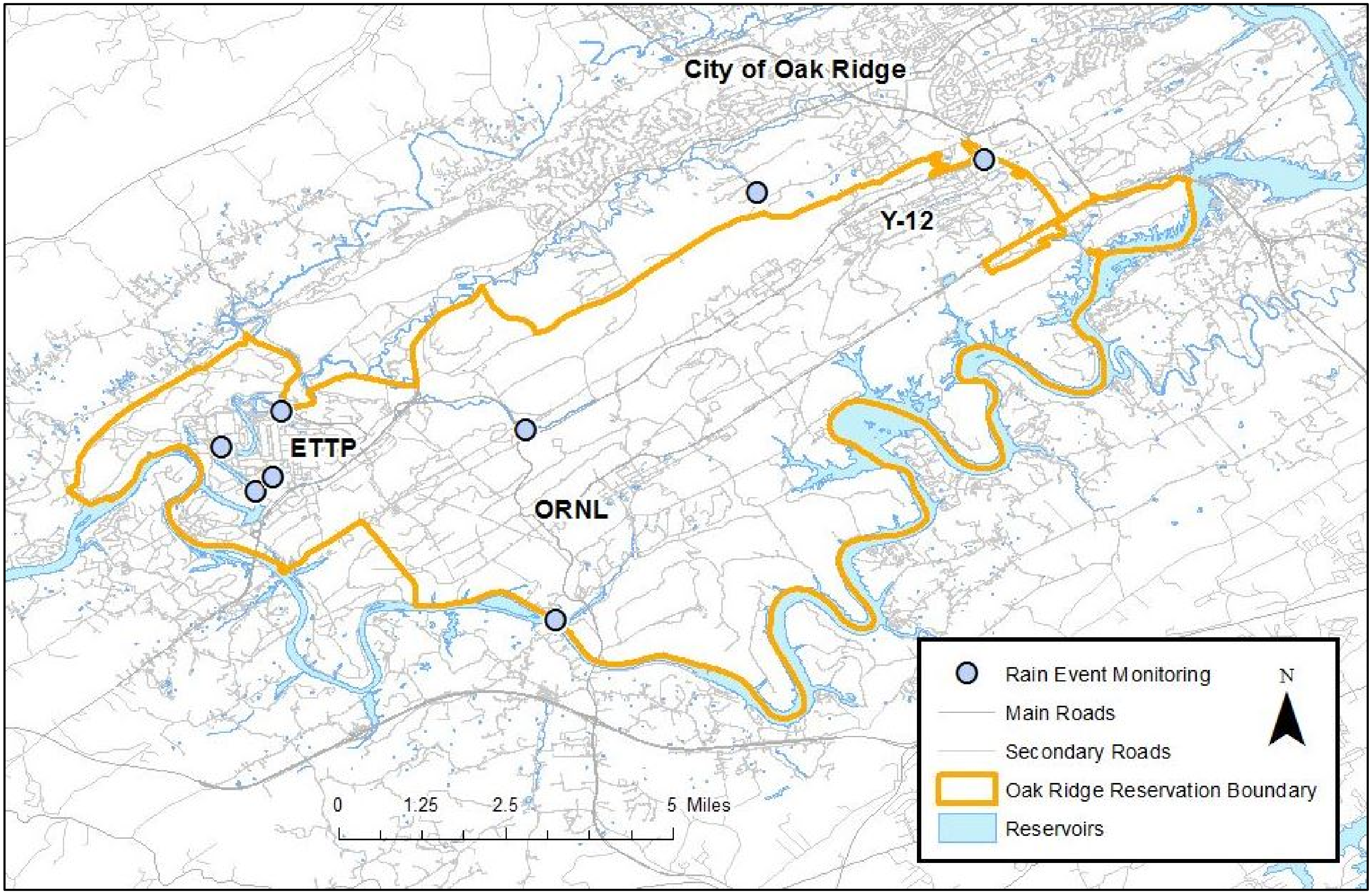

Figure 2.12: Rain event surface water monitoring locations

2.4.4 Y-12 Chestnut Ridge Filled Coal Ash Pond Surface Water Monitoring

The Y-12 Chestnut Ridge Operable Unit (OU) 2 Filled Coal Ash Pond (FCAP) surface water sampling project is being established to evaluate the impact of metals to the surface waters of McCoy Branch. The 1995 FCAP Record of Decision (ROD) identified the primary contaminants of concern (COCs) to be aluminum, arsenic, iron, manganese, mercury, selenium and zinc.

The FCAP is located near the crest of Chestnut Ridge, approximately one-half mile south of the Y-12 Plant. In 1955, a 62-foot high earthen dam facing southwest was constructed across Upper McCoy Branch to create a retention pond, which was used as a settling basin for coal ash generated from the Y-12 steam plant. A slurry comprised of steam plant coal ash and untreated Clinch River water was pumped to the crest of Chestnut Ridge (north side of ridge) and over into the sluice channel area (south side of ridge). Gravity flow carried the slurry from the sluice channel area down the south slope of the ridge into the pond. By 1967, the pond was filled with coal ash slurry and until 1989; it was allowed to overtop the dam and flow down its spillway into Upper McCoy Branch and into Rogers Quarry.

In the early 1990s, remedial investigative studies were conducted and the results indicated FCAP surface water, sediment, and soils were contaminated from the deposited coal ash and its leachate. During1997, the remedial action began and was completed.

The headwaters of Upper McCoy Branch are comprised of two Chestnut Ridge tributaries. The tributaries converge at the ash pond and their surface water flows over and through the ash in the pond and then down the dam's spillway. The discharge point for the pond subsurface flow/leachate is located at the base of the dam. This leachate flows into the wetland system for treatment; however, the dam spillway surface water flow is not treated as it is diverted around the wetland. The wetland treated leachate effluent and the bypassed untreated dam spillway surface water flow converge just south of the wetland to form Upper McCoy Branch. The Upper McCoy Branch then flows into Rogers Quarry. Utilizing the S19 National Pollutant Discharge Elimination System (NPDES) outfall site, surface water flows out of the quarry and underneath Bethel Valley Road and becomes Lower McCoy Branch. Approximately one mile downstream of Bethel Valley Road, Lower McCoy Branch drains into the Clinch River/Melton Valley Lake

All sampling locations (Table 2.9, Figure 2.13) will be analyzed for aluminum, arsenic, iron, manganese, mercury, selenium, and zinc. The field physical parameters (temperature, pH, conductivity, and dissolved oxygen) will be measured at all monitoring and sampling locations, as well.

- On a bi-monthly basis, to determine if the dam spillway surface water flow is intermittent or constant, DoR-OR will monitor the volume and flow rate of the leachate water entering and exiting the wetlands and the surface water flowing down the dam spillway.
- On a quarterly basis, to determine any impact of metals to McCoy Branch surface water, DoR-OR will conduct sampling.

Table 2.9: FCAP Monitoring Locations			
Monitoring Location	**Sample ID**	**Frequency**	**Sampling Rationale**
Exit drainage pipes at the bottom of the dam spillway	M-1	Bi-Monthly	Surveillance of the dam spillway surface water flow rate/volume
Influent/Effluent points of the wetland	M-2	Bi-Monthly	Surveillance of the wetland leachate flow rate/volume
Exit drainage pipes at the bottom of the dam spillway	SW-1	Quarterly	Surveillance of water quality downstream of the Upper McCoy Branch two tributaries
Influent point of the wetland	SW-2	Quarterly	Surveillance of water quality at the wetland influent point
Effluent point of the wetland	SW-3	Quarterly	Surveillance of water quality at the wetland effluent point
Confluence of the dam spillway flow and wetland effluent	SW-4	Quarterly	Surveillance of water quality at the confluence point of the dam spillway surface water flow and the wetland effluent
South exit of the McCoy Branch Bethel Valley Road culvert	SW-5	Quarterly	Surveillance of water quality downstream of Rogers Quarry

FCAP - Filled Coal Ash Pond

If the dam spillway surface flow is intermittent, then during the dry season SW-1 may not be sampled due to low or no spillway flow. The surface water samples will be collected utilizing grab methodology.

The locations of the two monitoring and five sampling sites are identified in Table 2.9 FCAP Monitoring Locations and shown in Figure 2.13 Y-12 Chestnut Ridge FCAP monitoring locations.

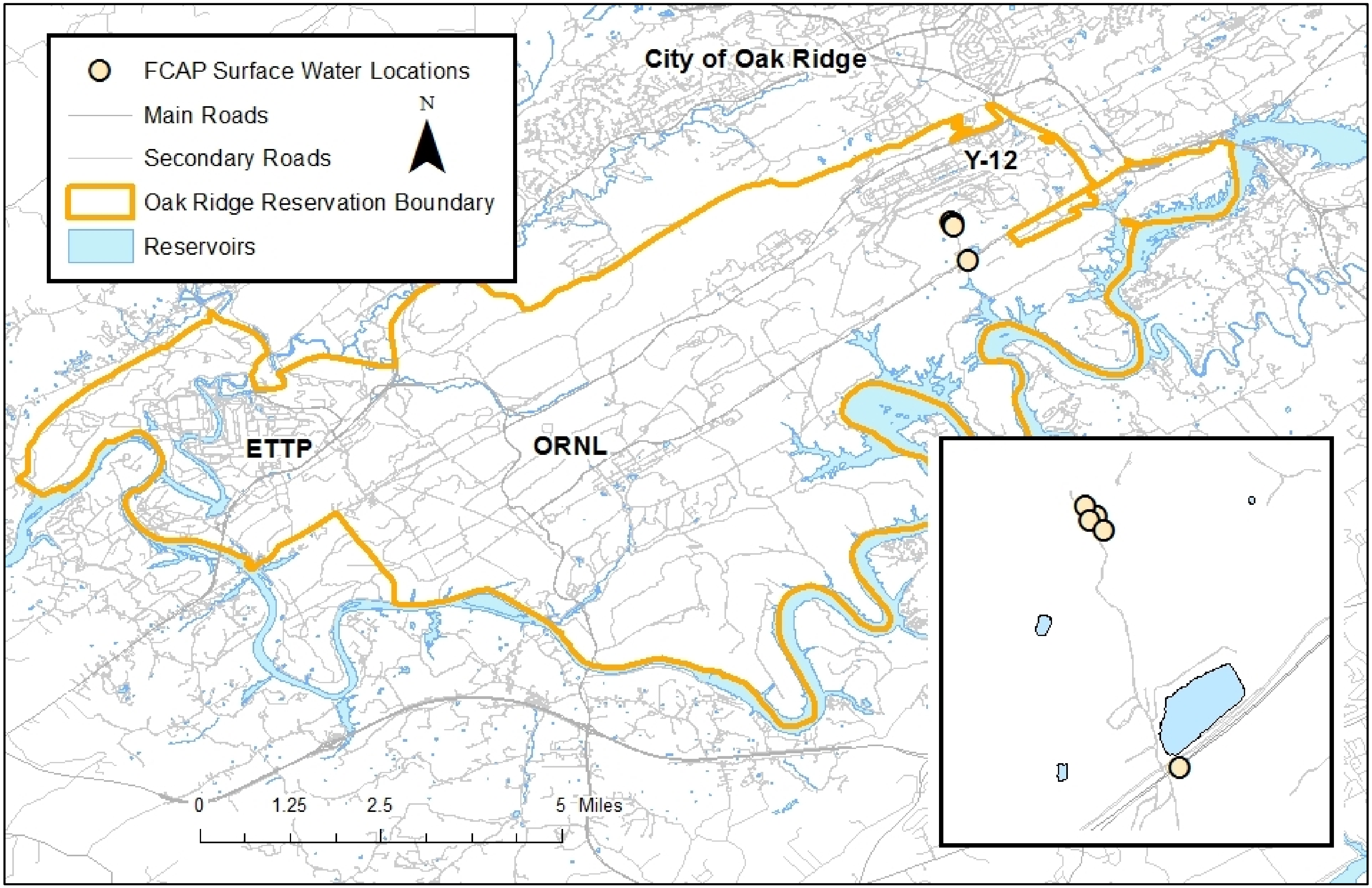

Figure 2.13: Y-12 Chestnut Ridge FCAP sampling locations

2.5 Sediment Monitoring

Sediment is a part of the aquatic ecosystems. Many aquatic organisms depend on sediment for habitat, sustenance, and reproduction. Sediment is a depository for anthropogenic chemicals and waste materials such as metals, radionuclides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and agricultural chemicals. Concentrations of contaminants can be higher in sediment 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 aspect of environmental quality and impact assessment for rivers, streams, and lakes. Past sediment sampling activities by DoR-OR have shown that Poplar Creek has elevated levels of mercury in sediment. This mercury can be attributed to historical discharges from Y-12, and, to a lesser extent, ETTP.

Contaminants from past DOE activities on the ORR have made their way into several streams that feed into Poplar Creek and the Clinch River. The major pathways of concern are WOC and EFPC. The major contaminants of concern from WOC are strontium-90 and cesium-137. EFPC is contaminated with mercury from past activities at Y-12.

This EMP will execute two sediment monitoring projects:

1. Ambient sediment
2. Trapped sediment

2.5.1 Ambient Sediment Monitoring

In order to characterize and monitor the impact from sediment in these streams, DoR-OR will sample sediment in the Clinch River, EFPC, Bear Creek, Mitchell Branch, NT-5, and Mill Branch (background location) as identified in Table 2.10 Ambient Sediment Monitoring Locations. These are shown in Figure 2.14 Ambient sediment monitoring locations. DoR-OR will collect one sample from each background location, annually.

Sediment samples are analyzed for metals (arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, uranium, and zinc) and radiological parameters (Sr-90 and Cs-137). Isotopic uranium is included in the analyses of sediment at North Tributary 5 (NT-5). The metals data are compared to Consensus-based Sediment Quality Guidelines (CBSQGs) (MacDonald et al. 2000). Radiological data are compared to the DOE Preliminary Remediation Goals (PRGs) (DOE 2013). PRGs are upper concentration limits for specific chemicals in environmental media that are intended to protect human health. PRGs are often used at CERCLA sites for risk assessment (Efroymson et al. 1997).

Table 2.10: Ambient Sediment Monitoring Locations			
Monitoring Location	**TDEC DWR ID**	**Alternate ID**	**Monitoring Rationale**
East Fork Poplar Creek Mile 3.9	EFPOP003.9RO	EFK 6.3	Sediment depositional area downstream of Y-12 influence
Bear Creek Mile 2.0	BEAR002.0RO	BCK 3.3	Sediment depositional area downstream of Y-12 influence
Mitchell Branch Mile 0.1	MITCH000.1RO	MIK 0.1	Sediment depositional area downstream of some ETTP influences
NT5	BEAR006.5T0.1AN	NT5	Sediment depositional area downstream of EMWF
Clinch River Mile 20.3	CLINC020.3RO	CRK 32.7	Sediment depositional area downstream of White Oak Creek
Mill Branch Mile 1.0	FECO67I12	MBK 1.6	Sediment depositional area in a background stream

TDEC DWR - Tennessee Department of Environment and Conservation Division of Water Resources
Alternate ID is an abbreviation of the stream name with the distance from the mouth in kilometers
BCK - Bear Creek kilometer
EFK - East Fork Poplar Creek kilometer
ETTP - East Tennessee Technology Park
MIK - Mitchell Branch kilometer
EMWMF - Environmental Waste Management Facility
CRK - Clinch River kilometer
MBK - Mill Branch kilometer

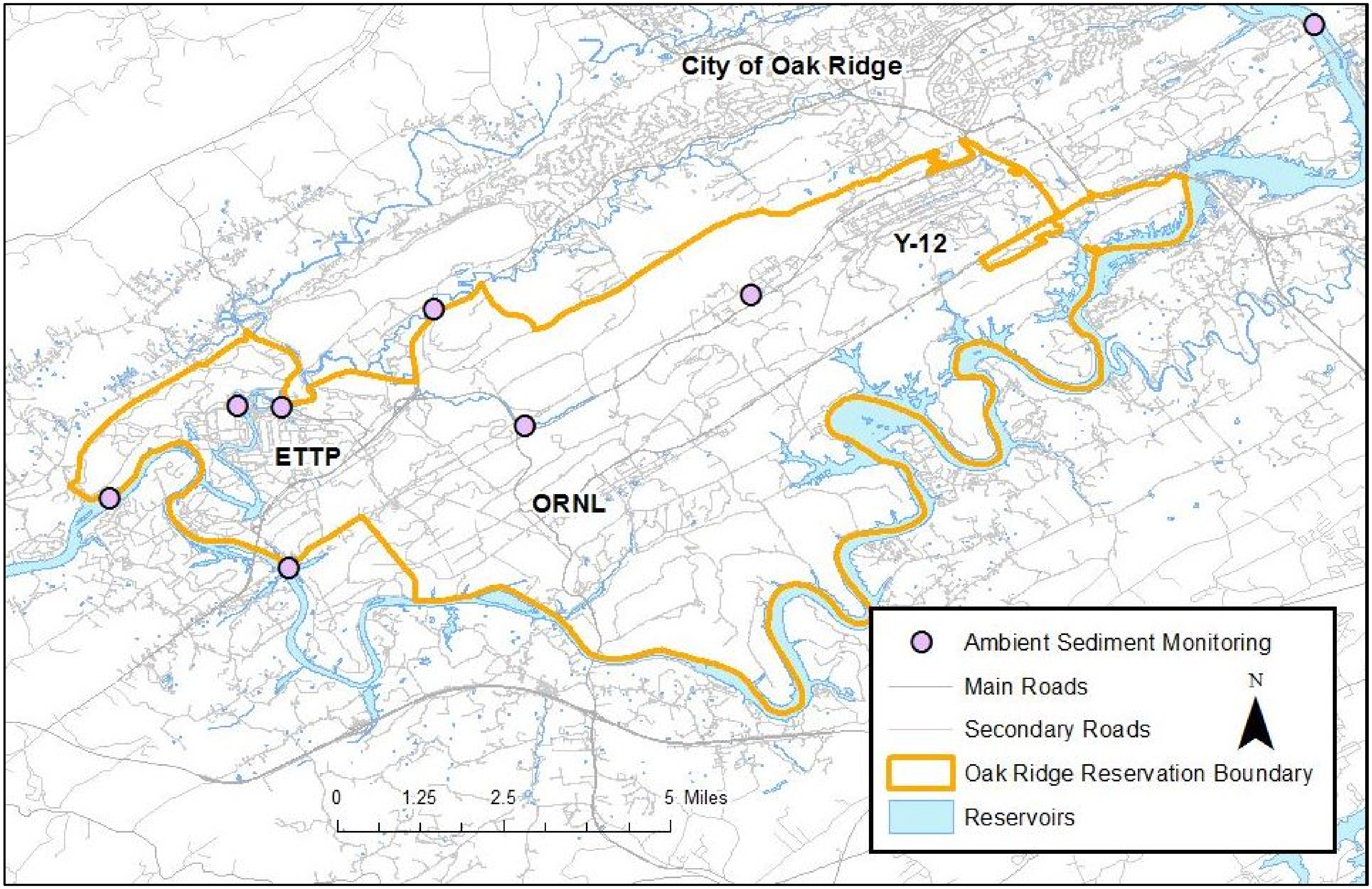

Figure 2.14: Ambient sediment monitoring locations

2.5.2 Trapped Sediment Monitoring

Suspended sediments that are currently being transported in EFPC and the Clinch River will be monitored by using passive sediment collection at determined locations identified in Table 2.11 Trapped Sediment Monitoring Locations and shown in Figure 2.15 Trapped sediment monitoring locations. In order to monitor for changes in contaminant flow through sediment transport, passive sediment samplers (traps) are deployed. Sediment samples are analyzed for metals (arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, uranium, and zinc) and radiological parameters (Sr-90 and Cs-137). The metals data are compared to CBSQGs (MacDonald et al. 2000). Radiological data are compared to the DOE PRGs (DOE 2013).

Table 2.11: Trapped Sediment Monitoring Locations

Monitoring Location	DWR ID	Alternate ID	Monitoring Rationale
East Fork Poplar Creek Mile 14.5	EFPOP014.5AN	EFK 23.4	Surveillance of suspended sediment at point where EFPC leaves DOE property
Clinch River Mile 20.3	CLINC0020.3RO	CRK 32.7	Surveillance of suspended sediment downstream of the mouth of White Oak Creek
Mill Branch Mile 1.0	FECO67I12	MBK 1.6	Surveillance of suspended sediment at a background site

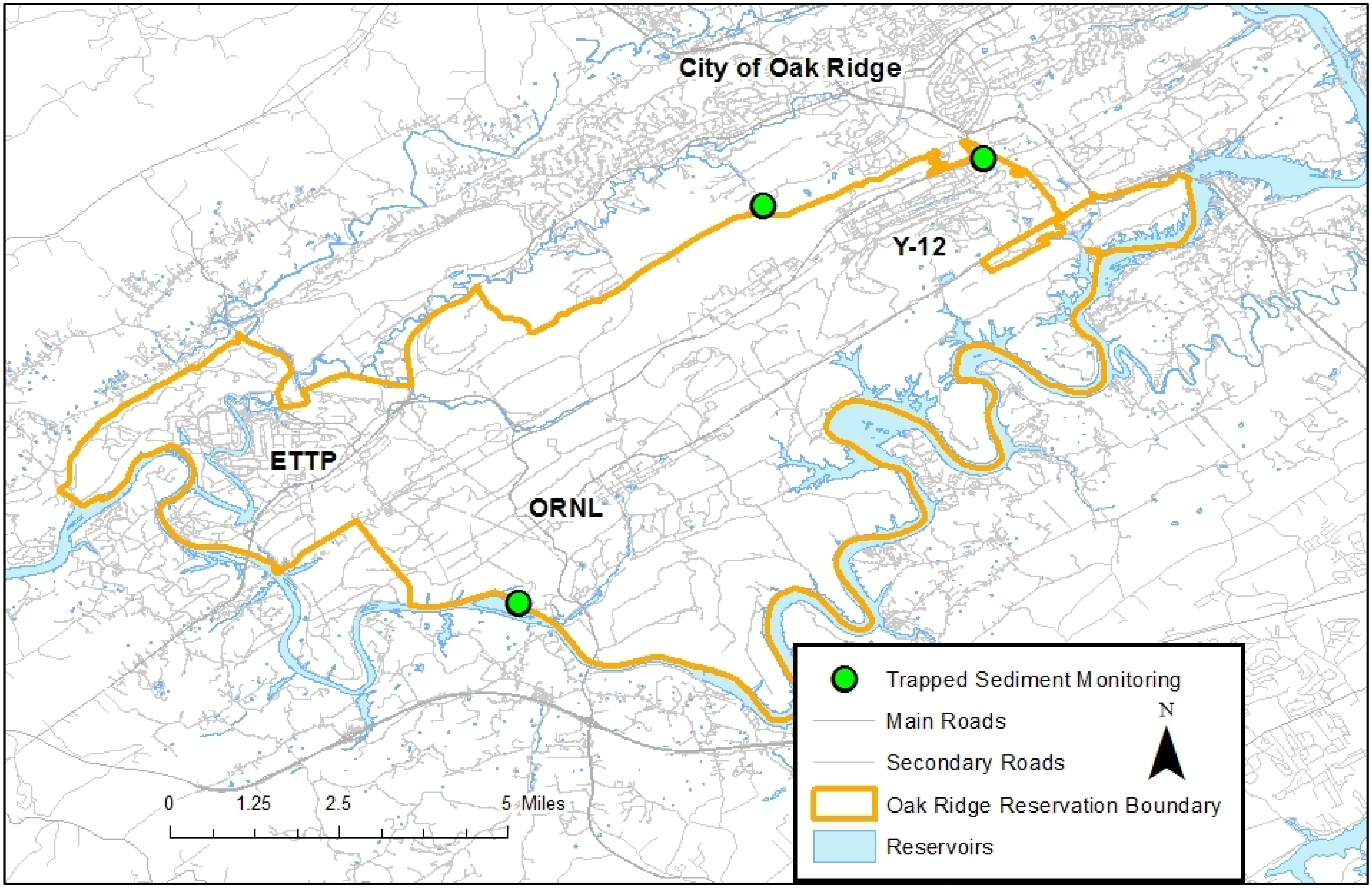

Figure 2.15: Trapped sediment monitoring locations

2.6 Groundwater Monitoring

DoR-OR plans to conduct groundwater monitoring to the southwest of the ORR (downgradient), to the northeast of the ORR (upgradient), and on the ORR. This monitoring is intended to assess groundwater quality to assist in the FFA cleanup decision-making process.

DoR-OR monitoring to the southwest of the ORR is a continuation of previous FFA tri-party efforts (DOE, EPA and TDEC) to assess groundwater quality in areas adjoining ORR and any potential impacts of DOE legacy waste disposals. Sampling and analysis in this area is a response to the recognition that contaminated groundwater is capable of moving beneath the Clinch River and potentially impacting downgradient residential wells and springs.

Three separate groundwater monitoring tasks include:

1. background residential well monitoring
2. offsite residential well monitoring
3. spring monitoring

A total of 65 samples will be collected including applicable quality assurance/quality control (QA/QC). Samples from offsite residential wells and background wells will be collected from an outside tap located as close to the well and before filtration when possible. Wells that are not in use may be sampled by peristaltic or bladder pump depending on local conditions.

Spring samples will be collected as close to the spring orifice as possible and will be grab samples, but drop tubes and the peristaltic pump may be used if conditions warrant. DoR-OR will coordinate with DOE and its contractors to facilitate co-sampling. Field parameters including conductivity, pH, temperature, dissolved oxygen (DO), and oxidation reduction potential (ORP) will be measured for all groundwater samples collected. All field measurements and sample collection will be conducted in accordance with the Division Standard Operating Procedure (SOP) 300 *Groundwater Sampling for Residential Wells*.

Analytic results for offsite wells and springs will be compared to the results from the background locations, the NAWQA 90^{th} percentile results for the major aquifers of the United States (Desimone, 2008), EPA primary and secondary MCLs, and any other relevant criteria. Results indicating any potential of health risk will be referred to the Tennessee Department of Health for consultation with the property owner, if appropriate. Table 2.12 Groundwater Monitoring Sampling Analytes identifies the constituents for which all samples will be analyzed. Figure 2.16, Background and offsite residential groundwater survey and sample areas, shows the area where groundwater monitoring will be conducted.

Table 2.12: Groundwater Monitoring Sampling Analytes			
Analytes			
VOCs	Volatile Organic	**Inorganics**	Alkalinity
Metals	Aluminum		Chloride
	Antimony		Fluoride
	Arsenic		Hardness
	Barium		Nitrate/Nitrite
	Boron		Ammonia
	Beryllium		TDS
	Cadmium		Sulfate
	Calcium		Stable Isotopes (N_{15}, O_{18}, H_2)
	Chromium	**Radionuclides**	Alpha/Beta
	Copper		Gamma Radionuclides
	Iron		Technetium-99
	Lead		Tritium
	Lithium		Radium-226
	Magnesium		Radium-228
	Manganese		Strontium-89/90
	Nickel		Transuranics
	Potassium		Uranium Isotopic
	Selenium		
	Silver		
	Sodium		
	Strontium		
	Thallium		
	Uranium	N - Nitrogen	
	Vanadium	O - Oxygen	
	Zinc	TDS - Total Dissolved Solids	
	Mercury	VOC - Volatile Organic Compounds	

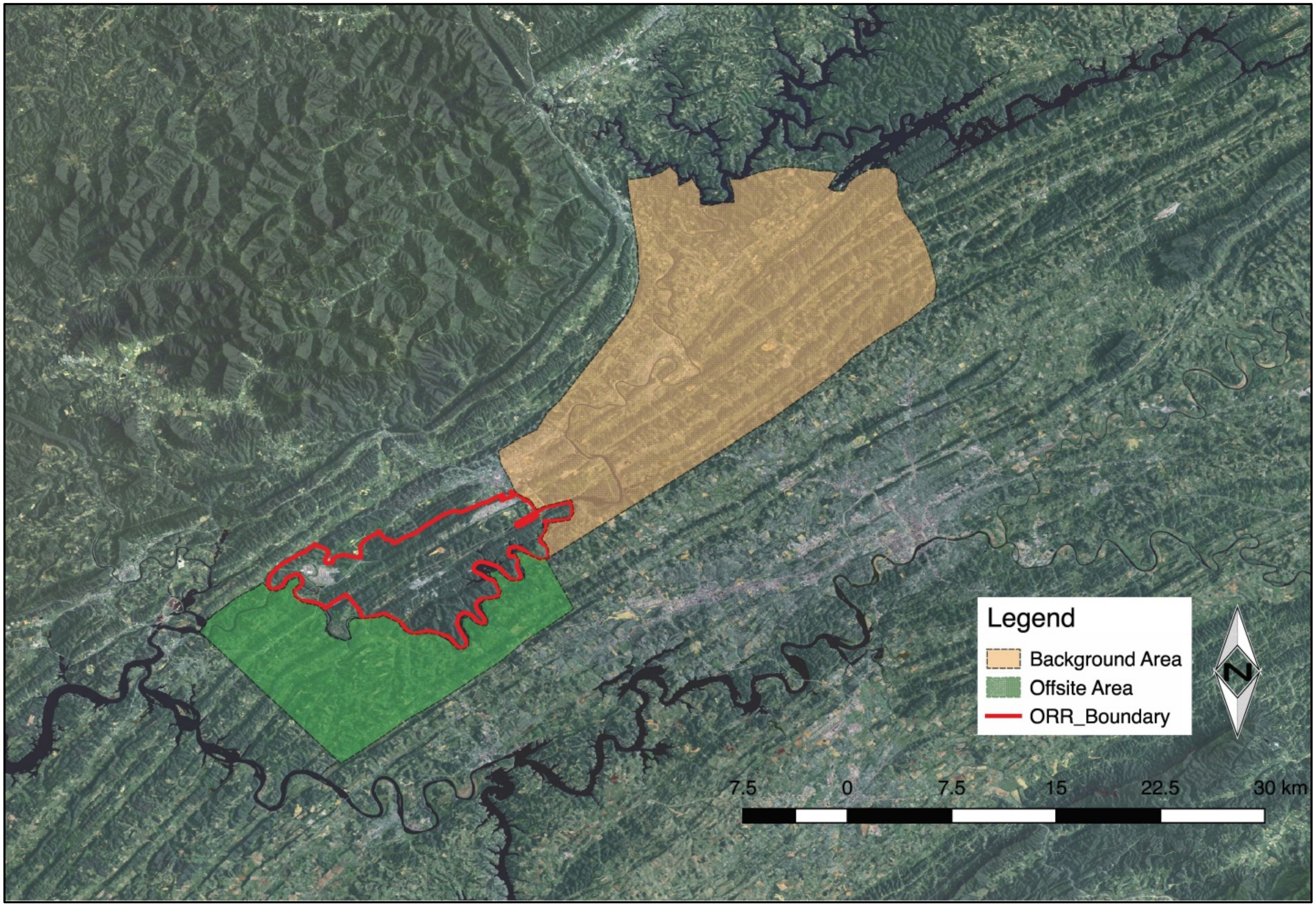

Figure 2.16: Background and offsite residential groundwater survey and sample areas

2.6.1 Background Residential Well Monitoring

Sixteen samples upgradient and northeast of the ORR will be collected and analyzed. Approximately 10% of samples will be for QA/QC purposes. Each residential well will be sampled once during the twelve-month sampling period. The background residential well monitoring evaluates background radiological, chemical, hydrogeologic, and geochemical characteristics of groundwater by comparing areas that potentially have not been impacted by anthropogenic activities or anomalous geologic conditions to past and future groundwater data collected downgradient of the ORR in similar lithologies.

Criteria for specific locations for background samples include the review of satellite imagery, topographic and geologic maps, and a review of area National Priorities List (NPL) sites. All efforts will be made to ensure that chosen background sites represent unaltered groundwater typical of the geologic conditions occurring on the ORR. Upgradient sampling will include those locations previously sampled and may incorporate new locations if warranted.

2.6.2 Offsite Residential Well Monitoring

Thirty-four samples will be collected and analyzed from downgradient and southwest of the ORR. Approximately 10% of all samples will be used for QA/QC purposes. Each residential well will be sampled once during the twelve-month sampling period. This effort is a continuation of past investigations of privately owned water wells southwest of the ORR to better understand the distribution of contaminants and potential contaminant pathways.

The offsite residential well monitoring continues a comprehensive assessment of hazardous substances present in residential groundwater wells and will determine if these hazardous substances may have migrated from the ORR and evaluate any potential risk. Downgradient sampling will include those locations previously sampled and may incorporate new locations if warranted.

2.6.3 Spring Monitoring

Fifteen groundwater samples from springs on and off the ORR will be collected and analyzed. Approximately 10% of samples will be used for QA/QC purposes. The spring monitoring will compare current results with historical analyses of groundwater contamination in order to determine long-term trends.

2.7 CERCLA Landfill

There is one CERCLA landfill monitoring project (EMWMF); however, additional information on radiological, biological, air, surface water, and sediment projects (Sections 2.1 through 2.5) also support evaluation of EMWMF performance.

DoR-OR will monitor surface water, storm water, groundwater, effluents, and sediment at EMWMF, located in eastern Bear Creek Valley. This facility was constructed to dispose of low-level radioactive waste and hazardous 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 agency, it is required to comply with substantive portions of relevant and appropriate legislation contained in the CERCLA ROD (DOE, 1999) and DOE directives developed to address responsibilities delegated to the agency by the Atomic Energy Act of 1946.

Currently, the only authorized discharges from EMWMF are contaminated storm water (contact water), which tends to pond in the disposal cells above the leachate collection system. The contact water is routinely pumped from the disposal cells to holding ponds and tanks, sampled, and, based on the results, either sent offsite for treatment or released to a storm water sedimentation basin. The sedimentation basin discharges to the NT-5 tributary of Bear Creek.

To ensure EMWMF is meeting its operational requirements, discharge data collected by EMWMF will be reviewed quarterly. In addition, DoR-OR will collect confirmation samples identified in Table 2.13 EMWMF Sampling Locations and shown in Figure 2.17 EMWMF sampling locations. To ensure best practices are utilized to limit contaminant migration, site visits will be performed to monitor ongoing activities at EMWMF.

Table 2.13: EMWMF Sampling Locations

Sample Location	Sample ID	Frequency	Sampling Rationale
GW-918	EMWMF-1	Semiannually	Upgradient well linked to a spring. The spring is the headwaters for both NT4 and NT5. This sample is co-sampled with EMWMF personnel for quality control.
EMWMF-Underdrain	EMWMF-2	Monthly	NT4 discharge below the landfill. The underdrain was installed below Cell 3 and it is theorized that if cells 1, 2 and 3 were to leak contaminants, they would first be observed at the underdrain.
Sediment Basin Outfall	EMWMF-3	Quarterly	Provides confirmation of contaminants levels being discharged from the sediment basin
Cell 6 Drainage	EMWMF-4B	Spot checked semiannually	This location is used as a verification that water collected in Cell 6 (prior to waste placement) is, in fact, storm water.
Sediment Basin Sediment	EMWSB-1 and EMWSB-2	Annually	This location is only sampled when the sediment basin is dry. The results are used to observe the loading of radionuclides in the sediment of the basin.

GW - groundwater
EMWMF - Environmental Management Waste Management Facility
NT - North Tributary

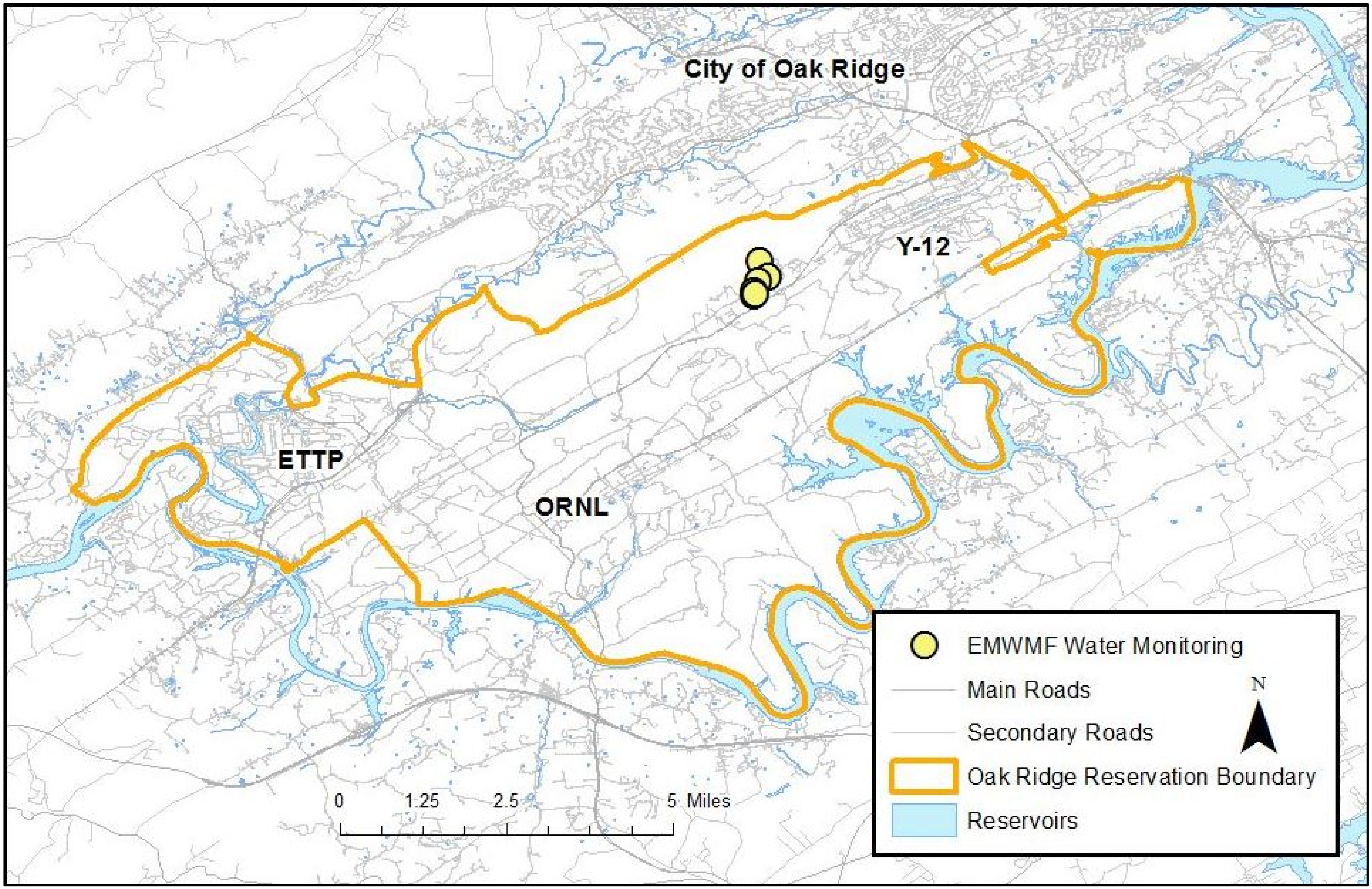

Figure 2.17: EMWMF sampling locations

2.8 RadNet

TDEC's participation in the EPA RadNet Air, Precipitation, and Drinking Water Monitoring programs supplements data from DoR-OR monitoring programs while providing independent third-party analysis. The EPA RadNet system monitors the nation's air, precipitation, and drinking water for radiation. Results from the RadNet programs are provided to DoR-OR and are available on the EPA RadNet searchable Envirofacts database.

2.8.1 RadNet Air Monitoring

The RadNet Air Monitoring program on the ORR began in August of 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. RadNet samples are collected by DoR-OR and analysis is performed at the EPA National Air and Radiation Environmental Laboratory (NAREL) in Montgomery, Alabama.

The EPA analytical parameters and sampling frequencies are identified in Table 2.14 EPA Analyses of Air Samples and the locations of the five RadNet air samplers are shown in Figure 2.18 Locations of air stations monitored by DoR-OR on the ORR. The RadNet air samplers run continuously, collecting suspended particulates on synthetic fiber filters (10 centimeters in diameter) as air is drawn through the units by a pump at approximately 35 cubic feet per minute. DoR-OR collects the filters from each sampler twice weekly and ships them to EPA NAREL for analysis.

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

The results of the NAREL analyses of the nationwide RadNet air data are available at the NAREL website in the Envirofacts RadNet Searchable Database.

Table 2.14: EPA Analyses for Air Samples	
Analysis	**Frequency**
Gross Beta	Each sample, twice weekly
Gamma Scan	As needed on samples showing greater than one pCi/m^3 of gross beta
Plutonium-238, Plutonium-239, Plutonium-240, Uranium-234, Uranium-235, Uranium-238	Annually on a composite of the filters from each station

EPA - Environmental Protection Agency
pCi/m^3 - picoCuries per cubic meter

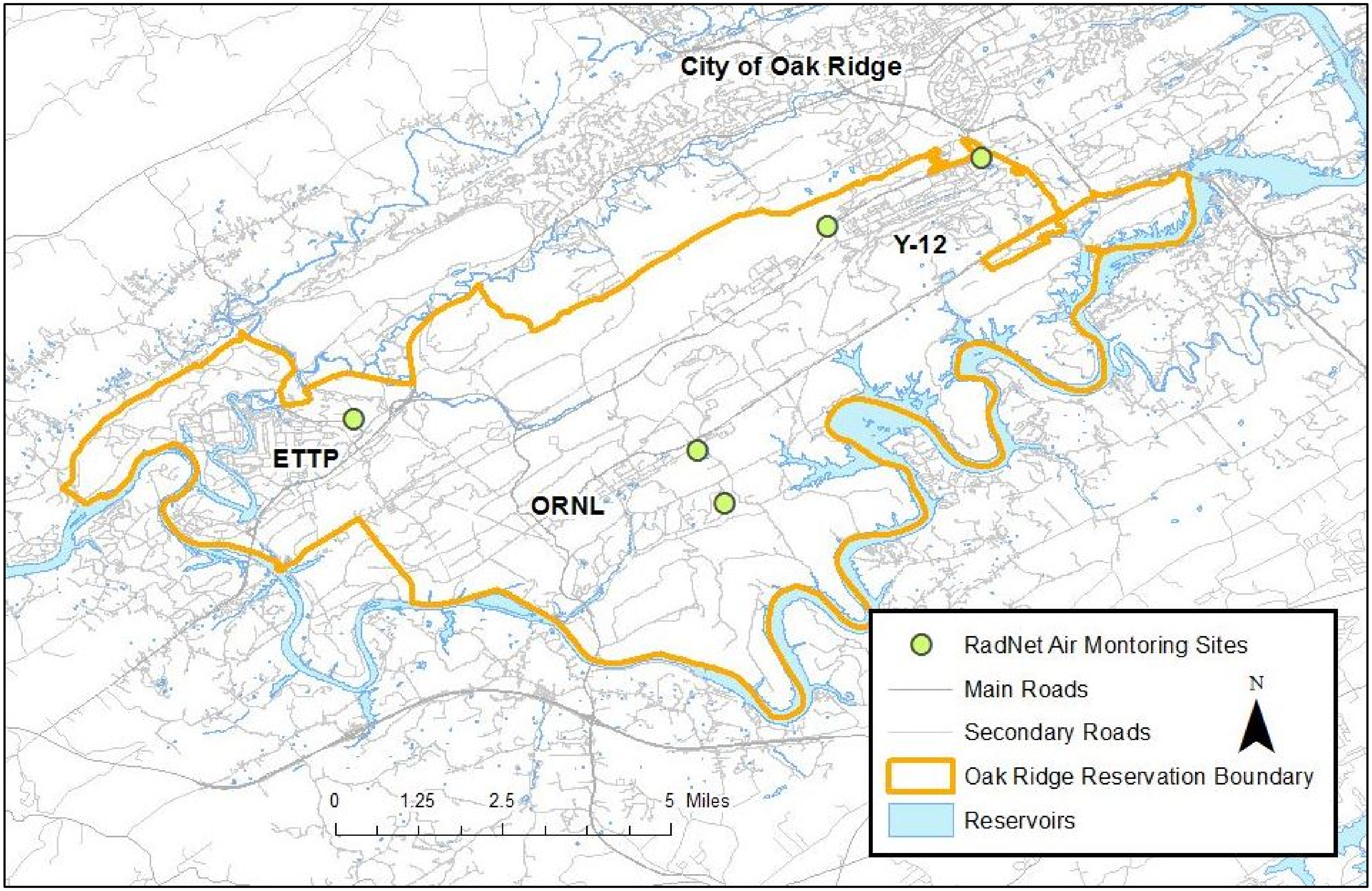

Figure 2.18: Locations of air stations monitored by DoR-OR on the ORR

2.8.2 RadNet Precipitation Monitoring

The RadNet Precipitation Monitoring program on the 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 NAREL. EPA provided DoR-OR with three precipitation collectors, which have been co-located at RadNet air stations at each of the ORR sites.

1. One is located in Melton Valley, in the vicinity of ORNL
2. The second is located east of ETTP, off Blair Road
3. The third is co-located with the RadNet air station east of Y-12

Analysis for gamma radionuclides is performed by EPA 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 be compared to data from other sites nationwide. The locations of the precipitation samplers are shown in Figure 2.19 RadNet precipitation monitoring locations.

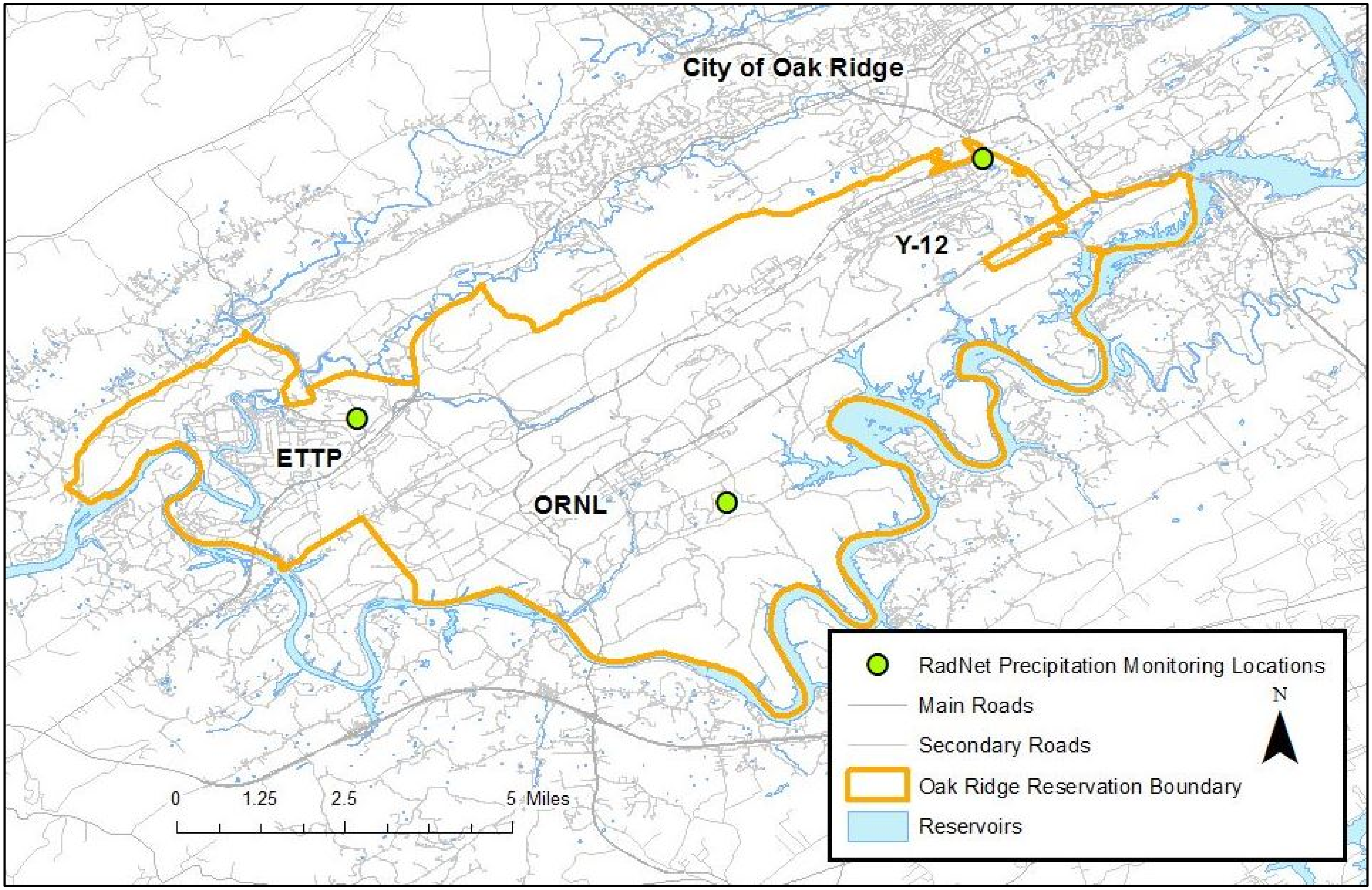

Figure 2.19: RadNet precipitation monitoring locations

2.8.3 RadNet Drinking Water Monitoring

The RadNet Drinking Water Monitoring program for the ORR monitors drinking water quarterly at four area water treatment plants. This program conducts radiological analysis of public drinking water processed from waters near the ORR. Since any radiological contaminants released on the ORR can enter local streams and be transported to the Clinch River, the possibility that ORR pollutants could impact area water supplies remains. The program provides a mechanism to evaluate the impact of DOE activities on water systems located near the ORR.

EPA provides radiochemical analysis of finished drinking water samples collected quarterly by DoR-OR at four public water supplies located on and in the vicinity of the ORR. This analysis is performed by EPA NAREL. When received, the results are compared (to identify anomalies) and to drinking water standards (to assess DOE compliance, adequacy of contaminant controls, and any associated hazards). Analytical parameters and the frequencies of RadNet analyses are identified in Table 2.15 EPA Analyses for RadNet Drinking Water Monitoring and the sample locations are shown in Figure 2.20 RadNet drinking water monitoring locations. The furthest upstream location is used for a reference site to allow for comparison to determine if there has been an impact from DOE activities.

Table 2.15: EPA Analyses for RadNet Drinking Water Monitoring

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

EPA - Environmental Protection Agency
pCi/L - picoCuries per liter

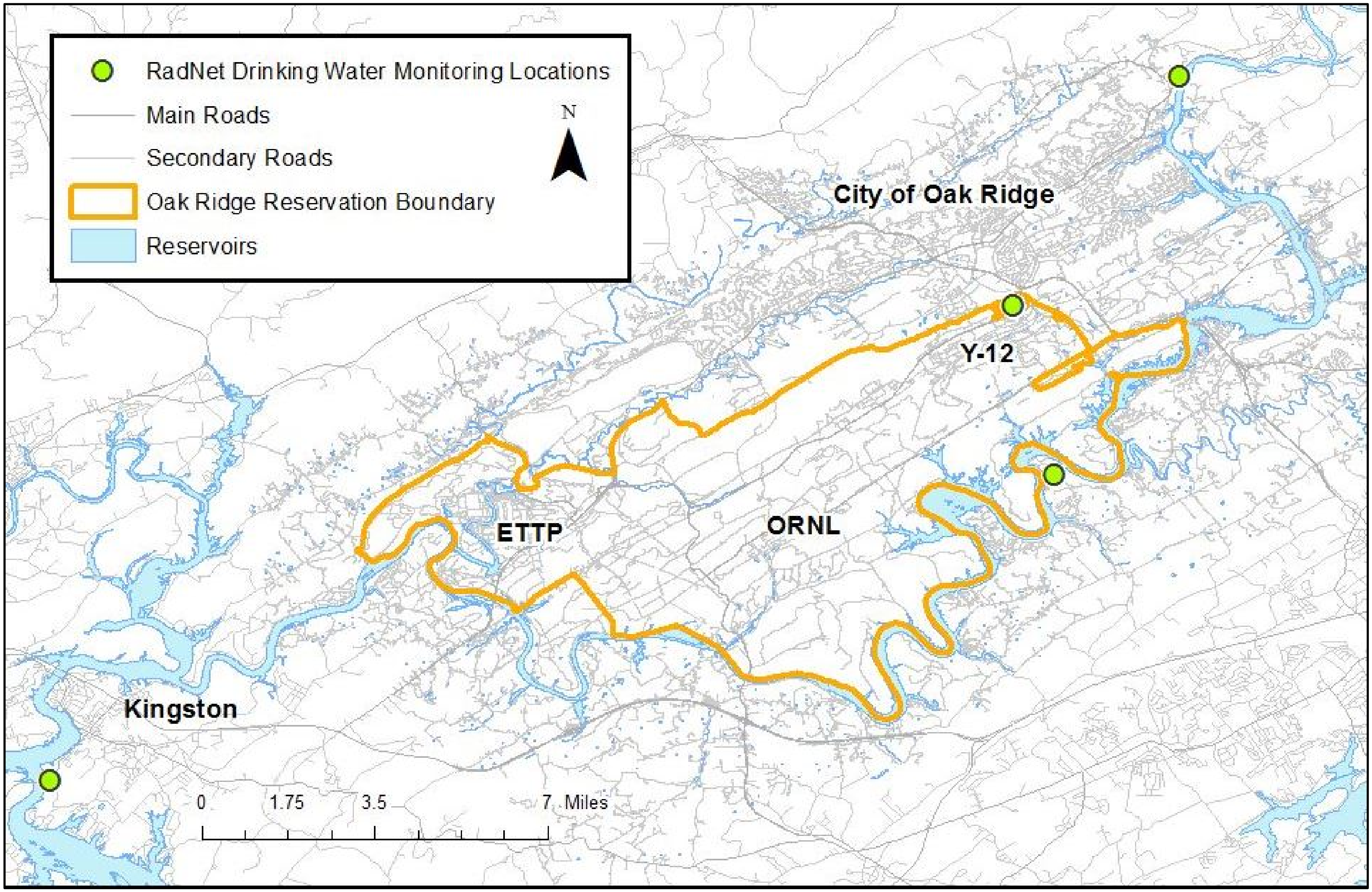

Figure 2.20: RadNet drinking water monitoring locations

3.0 Quality Assurance Program

3.1 Introduction

The application of QA/QC programs for environmental monitoring activities is essential for generating data of known and defensible quality. Each aspect of an environmental monitoring program from sample collection to data management and record keeping should address and meet applicable quality standards.

3.2 Project Planning and Control

All environmental sampling tasks are performed following the four steps required in the work control subject areas:

1. Define scope of work
2. Work planning: analyzing hazards and defining controls
3. Project execution
4. Provide feedback

A major component of the project execution phase of the Quality Assurance Program for the EMP is the use of SOPs. SOPs are used by DoR-OR personnel for execution of routine operations to improve efficiency, quality output and uniformity of performance. The SOPs define the equipment, methodology and process by which environmental samples are collected, handled, analyzed and recorded. Environmental sampling and monitoring SOPs developed for ORR environmental surveillance programs provide detailed instructions on maintaining chain-of-custody; sample identification; sample collection and handling; sample preservation; equipment decontamination; and collection of quality control (QC) samples such as field and trip blanks, duplicates, and equipment rinses.

Procedures used by DoR-OR in execution of the EMP are discussed in the following sections.

3.2.1 Radiological Monitoring

The following reference documents are used for radiological monitoring:

U.S. Department of Energy (DOE) Application of DOE Order 5400.5 requirements for release and control of property containing residual radioactive material. Air, Water and Radiation Division, EH-412; November 17, 1995.

U.S. Nuclear Regulatory Commission's (NRC) U.S. Atomic Energy Commission Regulatory Guide 1.86. Termination of Operating Licenses for Nuclear Reactors, Washington, D.C., June 1974, retyped August 1997.

American Society for Testing and Materials (ASTM). Selection and Use of Portable Radiological Survey Instruments for Performing In Situ Radiological Assessments in Support of Decommissioning. E 1893-97; March 1998.

NUREG-1575 (MARSSIM) ["Multiagency Radiation Survey and Site Investigation Manual (MARSSIM)."] December 1997.

U.S. Department of Energy. Environmental Implementation Guide for Radiological Survey Procedures. Washington, D.C.: U.S. Department of Energy; February 1997.

U.S. Nuclear Regulatory Commission (NRC). Monitoring for compliance with decommissioning termination survey criteria. NUREG/CR-2082; Washington, DC: 1981.

U.S. Nuclear Regulatory Commission. Manual for Conducting Radiological Surveys in Support of License Termination (Draft). NUREG/CR-5849; Washington, DC: May 1992.

3.2.2 Biological Monitoring

The following reference documents are used for biological monitoring:

Kentucky Division of Water (KDOW). Laboratory Procedures for Macroinvertebrate Processing, Taxonomic Identification and Reporting. (DOWSOP03005, Revision 2). Kentucky Department for Environmental Protection, Division of Water, Frankfort, Kentucky. 2009.

Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. *Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of SurfaceWaters*. EPA-600-4-90-030. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. 1990.

Moulton, S.R., II, 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. U.S. Geological Survey Open-File Report 00–212. Reston, Virginia. 49 pp. 2000.

Tennessee Department of Environment and Conservation (TDEC), Quality System Standard Operating System for Macroinvertebrate Stream Surveys, Revision 5, TDEC, Division of Water Pollution Control, Nashville, Tennessee. July 2011.

Guidance Levels for Radionuclides in Domestic and Imported Foods (CPG-7119.14), Sec.560.750, U.S. Food and Drug Administration, November 2005.

3.2.3 Air Monitoring

DoR-OR has three SOPs in preparation for air monitoring: *Fugitive Air Equipment Sample Collection*, *Fugitive Air Equipment Calibration*, and *Fugitive Air Equipment Maintenance*.

3.2.4 Surface Water and Springs Monitoring

For surface water and springs, DOR-OR currently uses the *Division of Water Pollution Control August 2011, Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water*; however, specifics to DOR-OR will be incorporated into a site specific SOP for surface water and spring sampling, currently being prepared.

3.2.5 Sediment Monitoring

DOR-OR has approved SOP 301 *Sediment Sampling* for sediment sampling.

3.2.6 Groundwater Monitoring

DOR-OR has approved SOP 300 *Groundwater Sampling for Residential Wells* for groundwater monitoring for residential wells; however, additional references include:

- U. S. Environmental Protection Agency Science and Ecosystem Support Division Athens, Georgia Groundwater Sampling SESDPROC-301-R3, March 6, 2013
- Division of Water Pollution Control August 2011, Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water

3.2.7 Sample Shipments

DOR-OR has approved SOP 101 *Shipping Samples to the State Lab in Nashville* for procedures for shipping samples to the state laboratory in Nashville.

3.2.8 Data Recording

Each SOP has a data recording requirement. However, a general requirement for data collection follows the U. S. Environmental Protection Agency Science and Ecosystem Support Division Athens, Georgia, Logbooks SESDPROC-010-R5, May 30, 2013.

3.3 Personnel Training and Qualifications

Training status is routinely monitored by the DOR-OR training officer and notices of training needs or deficiencies are sent to individual employees.

3.4 Equipment and Instrumentation

3.4.1 Calibration

DOR-OR directs all personnel to use equipment of known accuracy based on appropriate calibration requirements that are traceable to an authority standard. Procedures are in place to ensure equipment is functioning properly and within defined tolerance ranges. The determination of calibration schedules and frequencies is based on a graded approach at the activity planning level. The environmental monitoring programs follow rigorous calibration schedules to eliminate gross drift and the need for data adjustments. Instrument tolerances, functions, ranges, and calibration frequencies are established based on manufacturer specifications, program requirements, actual operating environment and conditions. At a minimum, equipment manufacturer recommendations are followed. Project plans and work control evaluations incorporate all calibration requirements.

All field equipment is inspected, calibrated weekly, and tested each day the equipment is used. In the event of malfunction, equipment is immediately sent for repair or replacement if spare equipment is not available. It is the responsibility of the project lead and/or in-house QC officer to verify procedures are followed. Calibration records are documented in the appropriate bound calibration logbook. If instruments do not maintain calibration, the source of the problem is determined and resolved with maintenance. If the problem cannot be solved in-house, a repair authorization is requested. Any maintenance or repairs are documented in the appropriate instrument logbook.

3.4.2 Standardization

Sampling and monitoring procedures include requirements and instructions for the proper standardization and use of monitoring equipment. These requirements include use of traceable standards and measurements; performance of routine, before-use equipment standardizations; and actions to follow when standardization steps do not produce required values. Sampling and monitoring SOPs include instructions for designating nonconforming instruments as “out-of-service” and initiating requests for maintenance.

3.4.3 Visual Inspection, Housekeeping and Grounds Maintenance

The DoR-OR environmental sampling personnel conduct routine visual inspections of all sampling and monitoring instrumentation and sampling locations. These inspections identify and address any safety, grounds keeping, general maintenance, and housekeeping issues or needs.

3.5 Assessment

In accordance with Attachment A of the MONITORING AND OVERSIGHT SCOPE of the TOA, *“The joint assessment of the ongoing environmental monitoring and surveillance programs shall continue to determine adequacy in providing information on the releases and impacts on public health and the environment from past and present Oak Ridge Reservation (ORR) actions. The program objective is to provide a comprehensive and integrated monitoring and surveillance program for all media (i.e., air, surface water, soil, sediments, groundwater drinking water, food crops, fish and wildlife, and biological systems) and the emissions of any materials (hazardous. toxic, chemical. radiological) on the ORR and environs.”*

Independent audits, surveillance, and internal management assessments are performed by the quality officer to verify that requirements have been accurately specified and activities conform to expectations and requirements.

3.6 Analytical Quality Assurance

The TDH Regional Environmental Laboratory performs analyses of environmental samples from DoR-OR environmental monitoring programs and has documented QA/QC programs, trained and qualified personnel, appropriately maintained equipment and facilities, and applicable certifications. If the TDH Regional Environmental Laboratory cannot perform the testing, they contract the work to a certified/approved laboratory and enforce these same quality requirements on the contractor.

A statement of work for each project specifies any additional QA/QC requirements and includes detailed information on data deliverables, turnaround times, and required methods and detection limits. Blank and duplicate samples are routinely submitted with DoR-OR environmental samples to provide an additional check on analytical laboratory performance.

Laboratory Quality Control

The TDH Regional Environmental Laboratory chemist(s) is responsible for quality control.

Laboratory Equipment and Instrument Testing, Inspection, Maintenance and Repair

All TDH Regional Environmental Laboratory instruments undergo regularly scheduled preventive maintenance either by the instrument manufacturer via service agreement or by laboratory personnel, as stipulated in the Laboratory Quality Assurance Plan. The Environmental Chemistry Laboratory SOPs (Inorganic Routines, Inorganic Metals, Radiochemistry, Aquatic Biology, Environmental Microbiology and Sample Coordination) stipulate laboratory equipment and instrument acceptance criteria, testing criteria, inspection, maintenance and repair protocols, and documentation procedures. The SOPs are updated annually and are current for 2017.

Analytical Methods

Analytical methods are used as shown on the TDH Regional Environmental Laboratory website to analyze for contaminants of potential concern as identified and delineated in the individual projects.

3.7 Data Management

The individual projects have requirements for documentation that are listed in the SOPs. Currently, the standard control of records and logbooks is similar to EPA Region 4 Science and Ecology Support Division:

- SESD Operating Procedure for Control of Records, SESDPROC-002-R6
- SESD Operating Procedures for Logbooks, SESDPROC-010-R5

ORR environmental surveillance data are summarized and reported annually in the DOR-OR Environmental Monitoring Report and the DOR-OR Status Report to the Public and are provided to the Oak Ridge Environmental Information System (OREIS), as well as the web.

3.8 Records Management

Requirements include creating and identifying record material, and scheduling, protecting, and storing records in both DOR-OR office areas and on DOR-OR servers. Records management will follow Tennessee Secretary of State Records Management Division Records Disposition Authorization (RDA) Management System procedures for the destruction of records. RDAs are the Public Records Commission's approved retention schedule that lists records grouped by a common function, the length of time they must be kept, and the required method of destruction. RDAs reflect the length of time that records have historical, administrative, legal, and/or fiscal value.

4.0 Reporting

The results of the sampling and monitoring will be reported in the DoR-OR 2017-2018 Environmental Monitoring Report and the DoR-OR Status Report to the Public as described in the TOA.

5.0 References

Allard M, Stokes PM. Mercury in crayfish species from thirteen Ontario lakes, Canada in relation to water chemistry and smallmouth bass (*Micropteru dolomieui*) mercury. Canadian Journal of Fisheries and Aquatic Science 46:1040-1046. 1989.

Appleton, J. D. A study of the extent of mercury and related chemical pollution along the Naboc River, Monkayo, Davao del Norte; Hijo River, Apokon ore processing site; and their neighboring areas (rice fields and banana plantations) A report for UNIDO Project DP/PHI/98/00511-02, British Geological Survey, 108 pp. 2000.

Armstrong, F. A. J. & Hamilton, A. L. Pathways of mercury in a polluted northwestern Ontario Lake. In'. Trace metals and metal-organic interactions in natural waters. Ed. by P. C. Singer. Ann Arbor Sci. Publ., Ann Arbor, 131-156. 1973.

Barbour, M. T., Gerritsen, J., Snyder, B. D., and Stribling, J. B. Rapid Bioassessment Protocols for use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. Second edition. EPA 841-B-99-002. Office of Water, U.S. Environmental Protection Agency, Washington, D.C. 1999.

Beard, K.H., Vogt, K.A., Kulmatiski, A. Top-down effects of a terrestrial frog on forest nutrient dynamics. Oecologia 133:583-593. 2002.

Bell, A.H. and S.C. Scudder. Mercury accumulation in periphyton of eight river ecosystems. Journal of American Water Resources Association 43:1-12. 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. Environ Science and Technology 45:3781–3787. 2011.

Bergeron, C.M., Bodinof, C.M., Unrine, J.M., Hopkins, W.A. Mercury accumulation along a contamination gradient and nondestructive indices of exposure in amphibians. Environmental Toxicology and Chemistry 29:980-988. 2010.

Bergeron, C.M., Husak, J.F., Unrine, J.M., Romanek, C.S., Hopkins, W.A. Influence of feeding ecology on blood mercury concentrations in four turtle species. Environmental Toxicology and Chemistry 26:1733-1741. 2007.

Beyer, W. N., E. Cromartie, E. and G.B. Moment. Accumulation of methylmercury in the earthworm, *Eisenia foetida*, and its Effect on Regeneration. Bulletin of Environmental Contamination and Toxicology 35**:**157–162. 1985.

Boone, M.D. and C.M. Bridges. Impacts of chemical contaminants on amphibian populations. pp. 152-167 In: Amphibian Conservation”, edited by R.D. Semlitsch, Smithsonian Press, Washington, DC. 2003.

Brasso, R.L. and R.A. Cristol. Effects of mercury exposure on the reproductive success of tree swallows (*Tachycineta bicolor*). Ecotoxicology 17:133-141. 2008.

Brewer, S., Barrett, G., Heavy metal concentrations in earthworms following long-term nutrient enrichment. Bulletin of Environmental Contamination and Toxicology, v. 54, p. 120-127. 1995.

Brueske, C.C. and G.W. Barrett. Dietary heavy metal uptake by the Least Shrew, *Cryptotis parva*. Bulletin of Environmental Contamination and Toxicology 47:845–849. 1991.

Burdon, F.J. and J.S. Harding. The linkage between riparian predators and aquatic insects across a stream resource spectrum. Freshwater Biology 53:330-346. 2008.

Burke, J.N., C.M. Bergeron, B.D. Todd and W.A. Hopkins. Effects of mercury on behavior and performance of northern two-lined salamanders (*Eurycea bislineata*). Environmental Pollution 158:3546-3551. 2010.

Carico, J.E. Revision of the genus *Trechalea thorell* (Araneae, Trechaleidae) with a review of the taxonomy of the Trechalidae and Pisauridae of the western hemisphere. The Journal of Arachnology 21:226-257. 1993.

Carroll, R. L., A. Kuntz, and K. Albright. Vertebral development and amphibian evolution. Evol Dev. 1:36–48. 1999.

Castro MS, Hilderbrand RH, Thompson H, Heft A, Rivers SE. Relationship between wetlands and mercury in brook trout. Arch Environ Contam Toxicol 52:97–103. 2007.

Chasar, L.C., B.C. Scudder, A.R. Stewart, A.H. Bell, G.R. Aiken. Mercury cycling in stream ecosystems. 3. Trophic dynamics and methylmercury bioaccumulation. Environ. Sci. Technol.:2733-2739. 2009.

Christensen, D.R. and B.C. Moore. Differential prey selectivity of largemouth bass functional feeding groups in Twin Lakes, Washington. Lake and Reservoir Management. 23:39-48. 2007.

Cremona F, Hamelin S, Planas D, Lucotte M. Sources of organic matter and methylmercury in littoral macroinvertebrates: a stable isotope approach. Biogeochemistry 94:81–94. 2009.

Cristol, D.A., Brasso, R.L., Condon, A.M., Fovargue, R.E., Friedman, S.L., Hallinger, K.H., Monroe, A.P., White, A.E. 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.

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.

Day RD, Segars AL, & Arendt MD. Relationship of blood mercury levels to health parameters in the loggerhead sea turtle (*Caretta caretta*). Environ Health Perspect 115:1421. 2007.

Deniseger, J.; Austin, A.; Lucey, L. P. Periphyton communities in a pristine mountain stream above and below heavy metal mining operations. Freshwater biology 16: 209-218. 1986.

Desimone, 2008, *Quality of Water from Domestic Wells in the Principle Aquifers of the United States 1991-2004,* USGS Scientific Investigations Report 2008-5227, NAWQA – National Water Quality Assessment Program, 127 p.

Desrosiers, M., Planas, D., and Mucci, A. Short-term responses to watershed logging on biomass mercury and methylmercury accumulation by periphyton in boreal lakes. Can. J. Fish. Aquat. Sci. Vol. 63:1734-1745. 2006.

Desrosiers, M., Planas, D., and Mucci, A. Short-term responses to watershed logging on biomass mercury and methylmercury accumulation by periphyton in boreal lakes. Can. J. Fish. Aquat. Sci. Vol. 63:1734-1745. 2006.

Dixit, S. S., J. P. Smol, J. P., Kingston, J. C., and D. F. Charles. Diatoms: Powerful Indicators of Environmental Change. Environmental Science Tech 26:23-33. 1992.

Duffield, R. M. & Nelson, C. H. Note on stoneflies (Plecoptera), particularly *Prostoia besametsa* (Ricker) (Nemouridae), in the diet of salmonids from the headwaters of the Middle Fork of the South Platte River, Colorado. Proc. Ent. Soc. Wash. 99: 402–403. 1997.

Efroymson, R.A., G.W. Suter II, B.E. Sample, and D.S. Jones. Preliminary Remediation Goals for Ecological Endpoints. ES/ER/TM-162/R2. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 1997.

Eisenmann, J.D., Beyer, W.N., Bennetts, R.E., and Morton, A. Mercury residues in south Florida apple snails (Pomacea paludosa). Bulletin of Environmental Contamination and Toxicology, 58, 739-743. 1997.

Facemire, C. T., Augspurger, D. Bateman, M. Brim, P. Conzelmann, S. Delchamps, E. Douglas, L. Inmon.

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.

Genter RB. Ecotoxicology of inorganic chemical stress to algae. In: Stevenson RJ, Bothwell M, Lowe RL (eds). Algal Ecology: Freshwater Benthic Ecosystems. San Diego: Academic Press, pp. 403-468. 1996.

Grillitsch, B. and L. Schiesari. The ecotoxicology of metals in reptiles. In Ecotoxicology of amphibians and reptiles, 2nd edition. Edited by D.W. Sparling, G. Linder, C.A. Bishop and S.K. Krest. CRC Press, Boca Raton, FL. 916 pp. 2010.

Hamed, M.K. Impacts of climate change, human land use, and mercury contamination on Southern Appalachian salamanders. Doctoral dissertation. University of Tennessee, Knoxville, Tennessee. 2014.

Hamelin, S., Planas, D., Amyot, M. Mercury methylation and demethylation by periphyton biofilms and their host in a fluvial wetland of the St. Lawrence River (QC, Canada). Science of the Total Environment, 512–513: 464-471. 2015.

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.

Haro, R. J., S. W. Bailey, R. M. Northwick, K. R. Rolfhus, M. B. Sandheinrich and J. G. Wiener. Burrowing dragonfly larvae as biosentinels of methylmercury in freshwater food webs. Environmental Science and Technology 47:8148-8156. 2013.

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.

Henderson, B. L., M. M. Chumchal, R. W. Drenner, Y. Deng, P. Diaz, and W. H. Nowlin. Effects of fish on mercury contamination of macroinvertebrate communities of grassland ponds. Environmental Toxicology and Chemistry 31:870-876. 2012.

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.

Hopkins, B.C., J.D. Willson and W.A. Hopkins. Mercury exposure is associated with negative effects on turtle reproduction. Environmental Science and Technology 47:2416–2422. 2013.

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.

Hunter, B.A., M.S. Johnson and D.J. Thompson. Ecotoxicology of copper and cadmium in a contaminated grassland ecosystem. Journal of Applied Ecology 24:601–614. 1987.

Ivorra, N., J. Hettelaar, G. M. J. Tubbing, M. H. S. Kraak, S. Sabater, and A. Admiral. Translocation of Microbenthic Algal Communities Used for in Situ Analysis of Metal Pollution in Rivers. Archives of Environmental Contamination and Toxicology 37:1928. 1999.

K. Looney, F. Lopez, G. Masson, D. Morrison, N. Morse, and A. Robison. Impacts of mercury contamination in the southeastern United States. Water, Air, and Soil Pollution 80:923-926. 1995.

Kaplan, I., S. Lu, R. Lee and G. Warrick. Polycyclic hydrocarbon biomarkers confirm selective incorporation of petroleum in soil & Kangaroo Rat liver samples near a well blowout site in the western San Joaquin Valley, California. Environmental Toxicology and Chemistry 15:696–707. 1996.

Karr, J. R. and E. W. Chu. Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Covelo, CA. 200 pp. 1998.

Karr, J. R. Defining and Measuring River Health. Freshwater Biology 41:221-234. 1999.

Kelly, M. G., C. J. Penney, and B. A. Whitton. Comparative Performance of Benthic Diatom Indices to Assess River Water Quality. Hydrobiologia 302: 179-188. 1995.

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.

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.

Martin, S. M. Crayfishes (Crustacea: Decapoda) of Maine. Northeastern Naturalist 4:165-188. 1997.

Mason, R.P., J.M. Laporte and S. Andres. 2000. Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium, and cadmium by freshwater invertebrates and fish. Archives of Environmental Contamination and Toxicology 38:283–297. 2000.

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, Tennessee. 2011.

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.

Meyer, J. L. Stream Health: Incorporating the Human Dimension to Advance Stream Ecology. Journal of the North American Benthological Society 16:439-447. 1997.

Miles, C. J., H. A. Moye, E. J. Phillips, and B. Sargent. *Partitioning of monomethylmercury between freshwater algae and water*. Environmental Science and Technology 35:4277–4282. 2001.

Molina, C.I., F-M Gibon, J-L Duprey, E. Dominguez, J.R.D. Guimaraes and M. Roulet. Transfer of Hg and methylHg along macroinvertebrate food chains in a floodplain lake of the Beni River, Bolivian Amazonia. Science of the Total Environment 408:3382–3391. 2010.

Murphy, George W., et. al., Food Habits of Selected Fish Species in the Shenandoah River Basin, Virginia, 2005 Proc. Annu. Conf. SEAFWA, Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, 100 Cheatham Hall, Blacksburg, VA 24061. 2005.

Murphy, George W., Uptake of Mercury and Relationship to Food Habits of Selected Fish Species in the Shenandoah River Basin, Virginia, Master's Thesis, Virginia Polytechnic Institute and State University, 2004.

Nagle, R. D., C. L. Rowe, and J. D. Congdon. Accumulation and selective maternal transfer of contaminants in the turtle *Trachemys scripta* associated with coal ash deposition. Archives of Environmental Contamination and Toxicology 40:531-536. 2001.

National Security Complex: Inventories and Export Rates. ORNL/TM-2009/231, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 2010.

Niethammer, K.R., R.D. Atkinson, T.S. Baskett and F.B. Samson. Metals in riparian wildlife of the lead mining district of southeastern Missouri. Archives of Environmental Contamination and Toxicology 14:213–223. 1985.

Olsen, T. A., and S. C. Brooks. Periphyton communities methylate mercury in an industrially contaminated creek. Society of Environmental Toxicology and Chemistry North America 36th Annual Meeting, Salt Lake City, Ut., November 1–5, 2015. 2015.

Parkman, H. and M. Meili. Mercury in macroinvertebrates from Swedish forest lakes: influence of lake type, habitat, life cycle, and food quality. Canadian Journal of Fisheries and Aquatic Science 50:521–34. 1993.

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.

Peles, J. D. and G. W. Barrett. *Assessment of Metal Uptake and Genetic Damage in Small Mammals Inhabiting a Fly Ash Basin*. Bulletin of Environmental Contamination and Toxicology 59:279-284. 1997.

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.

Pérès, F. Étude des Effets de Quatre Contaminants – Herbicide (isoproturon), Dérivés du Mercure (mercure inorganique, méthyl-mercure), Cadmium – sur les Communautés de Diatomées Ppériphytiques au Sein de Mmicrocosmes d'eau Ddouce. Ph. D. Thesis, Univ. Toulouse, Toulouse (Fr), 176 p. 1996.

Pfleeger, A. Mercury bioaccumulation in remote subalpine lakes: assessing the influence of invasive trout on salamanders. Master's Thesis. Oregon State University, Corvallis, Oregon. 2015.

Regester, K.J., K.R. Lips, and M.R. Whiles. Energy flow and subsidies associated with the complex life cycle of ambystomatid salamanders in ponds and adjacent forest in southern Illinois. Oecologia 147:303-314. 2006.

Rieder, S. R., I. Brunner, O. Daniel, B. Liu and B. Frey. Methylation of mercury in earthworms and the effects of mercury on the associated bacterial communities. PLOS One 8:1-9. 2013.

Rosenberg, D.N. and V.H. Resh. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall. New York, NY. 488 pp. 1993.

Song, M. Y. Ecological Quality Assessment of Stream Ecosystems using Benthic Macroinvertebrates. MS thesis. Pusan National University, Pusan, Korea. 2007.

Southworth, G. R., et al. *Sources of Mercury to East Fork Poplar Creek Downstream from the Y-12.*

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, Knoxville, Tennessee. 2016.

Stevenson, R. J., and Y. Pan. Assessing ecological conditions in rivers and streams with diatoms. Pages 11-40 *in* E. F. Stoemer and J. P. Smol, editors. The diatoms: applications to the environmental and earth sciences. Cambridge University Press, Cambridge, United Kingdom. 1999.

Stevenson, R. J., P. V. McCormick, & R. Frydenborg. Using Algae to Assess Environmental Conditions in Wetlands. Dept. of Zoology, Michigan State University. 2001.

Stoermer, E.F., and Smol, J.P. The Diatoms: Applications for the Environmental and Earth Sciences. Cambridge University Press, Cambridge, U.K. 1999.

Takamura, N., F. Kasai, and M. M. Watanabe. Effects of Cu, Cd, and Zn on photosynthesis of freshwater benthic algae. Journal of Applied Phycology 1:39-52. 1989.

Talmage, S.S. and B.T. Walton. Food chain transfer and potential renal toxicity of mercury to small mammals at a contaminated terrestrial field site. Ecotoxicology 2:243-256. 1993.

Talmage, S.S. Comparative evaluation of several small mammal species as monitors of heavy metals, radionuclides, and selected organic compounds in the environment. PhD dissertation, University of Tennessee. Environmental Sciences Division Publication 3534, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 1990.

Tang, W., J. Cui, B. Shan, C. Wang and W. Zhang. Heavy metal accumulation by periphyton is related to eutrophication in the Hai River Basin, Northern China. PLoS One 9:1-6. 2014.

Taylor, G.N., C.W. Jones, P.A. Gardner, R.D. Lloyd, C.W. Mays and K.E. Charrier. Two new rodent models for actinide toxicity studies. Radiation Research 86:115–122. 1981.

Tennessee Department of Environment and Conservation, DOE Oversight Division. Tennessee Oversight Agreement, Agreement between the United States Department of Energy and the State of Tennessee. Oak Ridge, Tennessee. 2011.

Todd, B. D., C.M. Bergeron and W.A. Hopkins. Use of toe clips as a nonlethal index of mercury accumulation and maternal transfer in amphibians. Ecotoxicology 21:882-887. 2012.

Torre, I., D. Guixé and F. Sort. Comparing three live trapping methods for small mammal sampling in cultivated areas of northeast Spain. Hystrix It. Journal of Mammalogy 21:147-155. 2010.

Townsend, J. M. and C.T. Driscoll. Red-backed salamander (*Plethodon cinereus*) as a bioindicator of mercury in terrestrial forests of the northeastern United States. Ecological Indicators 34:168-171. 2013.

Tremblay, A. Bioaccumulation of mercury and methylmercury in invertebrates from natural boreal lakes. Pages 89-113 *in* M. Lucotte, R. Schetagne, N. Therien, C. Langlois, and A. Tremblay (eds.) Mercury in the Biogeochemical Cycle: Natural Environments and Hydroelectric Reservoirs of Northern Quebec (Canada). Springer- Verlag. Berlin, Germany. 1999.

Tremblay, A., and M. Lucotte. Accumulation of total and methylmercury in insect larvae of hydroelectric reservoirs. Canadian Journal of Fisheries and Aquatic Sciences. 54:832-841. 1997.

Tremblay, A., M. Lucotte and I. Rheault. Methylmercury in a benthic food web of two hydroelectric reservoirs and a natural lake of northern Quebec (Canada). Wat. Air Soil Pollut., in press. 1996.

Tremblay, A., M. Lucotte, and D. Rowan. Different factors related to mercury concentration in sediments and zooplankton of 73 Canadian lakes. Water, Air, and Soil Pollution. 80:961-970. 1995.

Turnquist, M.A., C.T. Driscoll, K.L. Schulz and M.A. Schlaepfer. Mercury concentrations in snapping turtles (*Chelydra serpentina*) correlate with environmental and landscape characteristics. Ecotoxicology 20:1599–1608. 2011.

U.S. Atomic Energy Commission (USAEC). Termination of Operating Licenses for Nuclear Reactors. Regulatory Guide 1.86, Washington, D.C., June 1974, retyped August 1997.

U.S. Atomic Energy Commission (USAEC). Termination of Operating Licenses for Nuclear Reactors. Regulatory Guide 1.86, Washington, D.C., June 1974, retyped August 1997.

U.S. Department of Energy (DOE) 2013. *Risk Assessment Information System*. Office of Environmental Management, Oak Ridge Operations (ORO) Office, U.S. Department of Energy, Oak Ridge, Tennessee.

U.S. Department of Energy (DOE), 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.

U.S. Department of Energy DOE/OR/01-1596&D1. *Remedial Action Report on Chestnut Ridge Operable Unit 2 (Filled Coal Ash Pond and Vicinity) at the Oak Ridge Y-12 Plant*, 1997, Oak Ridge Tennessee, U.S. Department of Energy, Office of Environmental Management, Oak Ridge, Tennessee.

U.S. Department of Energy DOE/OR/01-2707&D2. *2016 Remediation Effectiveness Report for the U.S. Department of Energy Oak Ridge Reservation, Oak Ridge, Tennessee*, 2016, U.S. Department of Energy, Office of Environmental Management, Oak Ridge, Tennessee.

U.S. Department of Energy DOE/OR/01-2718&D1. *2016 Fourth CERCLA Five-Year Review of the U.S. Department of Energy Oak Ridge Site, Oak Ridge, Tennessee*, 2016, U.S. Department of Energy, Office of Environmental Management, Oak Ridge, Tennessee.

U.S. Department of Energy DOE/OR/02-1410&D3. *Record of Decision for Chestnut Ridge Operable Unit 2 (Filled Coal Ash Pond and Vicinity) Oak Ridge, Tennessee*, 1996, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Oak Ridge, Tennessee.

U.S. Environmental Protection Agency. 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. Montgomery, Alabama. June 2006.

U.S. Environmental Protection Agency. Environmental Radiation Ambient Monitoring System (ERAMS) Manual. EPA 520/5-84-007, 008, 009. May 1988.

U.S. Environmental Protection Agency. Environmental Radiation Ambient Monitoring System (ERAMS) Manual. EPA 520/5-84-007, 008, 009. May 1988.

Unrine, J.M., C.H. Jagoe, W.A. Hopkins and H.A. Brant. Adverse effects of ecologically relevant dietary mercury exposure in southern leopard frog (*Rana sphenocephala*) larvae. Environmental Toxicology and Chemistry 23:2964–2970. 2004.

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.

Verneer, K. The crayfish *Orconectes virilis*, as an indicator of mercury contamination. Canadian Field Naturalist 86:123–25. 1972.

Ward, D.M., K.H. Nislow and C.L. Folt. Bioaccumulation syndrome: identifying factors that make some stream food webs prone to elevated mercury bioaccumulation. Annual New York Academy of Science 1195:62–83. 2010.

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.

Wells, K.D. The Ecology and Behavior of Amphibians. Chicago, The University of Chicago Press. 1148 pp. 2007.

Whitaker, J.O. and T.W. French. Foods of six species of sympatric shrews from New Brunswick. Canadian Journal of Zoology 62:622-626. 1984.

Whitaker, J.O. *Peromyscus leucopus*. *In* The Audubon Society field guide to North American mammals. New York: Alfred A. Knopf. 1980.

Williams, J. Patterson, J., George, R. D. Oak Ridge Environmental Management Waste Management Facility, DOEEM's First On-line Privatized Disposal Facility, WM-4537. WM'04 Conference, Bechtel Jacobs Company LLC, and Japp, J. M., Oak Ridge Operations, U.S. Department of Energy. February 29 – March 4, 2004, Tucson AZ. 2004.

Wobeser, G. and M. Swift. Mercury poisoning in a wild mink. Journal of Wildlife Diseases 12:335-340. 1976.

Wolfe, M.F., T. Atkeson, W. Bowerman, J. Burger, D.C. Evers, M.W. Murray and E. Zillioux. Wildlife indicators. *In*: Harris, R., D.P. Krabbenhoft, R. Mason, M.W. Murray, R. Reasch and T. Saltman (eds). Ecosystem responses to mercury contamination—indicators of change. CRC Press, New York, pp 123–189. 2007.

Wyman, R.L. Experimental assessment of salamanders as predators of detrital food webs: effects on invertebrates, decomposition and the carbon cycle. Biodiversity and Conservation 7:641-650. 1998.

Zhang, Z. S., D. M. Zheng Q. C., Wang, and X. G. Lu. Bioaccumulation of total and methyl mercury in three earthworm species (*Drawida* sp., *Allolobophora* sp., and *Limnodrilus* sp.). Bulletin of Environmental Contamination and Toxicology 83:937-942. 2009.

6.0 Supporting Documents

The following documents are used in the execution of work included in this EMP and are incorporated by reference.

- Life Safety Plan, TDEC Division of Remediation, Oak Ridge Office
- TDEC Division of Remediation, Oak Ridge Office, Quality Assurance Project Plan (QAPP)