

Conceptual Site Model for the West Valley Site

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ACRONYMS AND ABBREVIATIONS

ABL	atmospheric boundary layer
AEA	Atomic Energy Act
ALARA	As Low As Reasonably Achievable
AMOC	Atlantic meridional overturning circulation
ASER	Annual Site Environmental Report
AUF	area use factor
BCG	biota concentration guide
BDAC	Biota Dose Assessment Committee
BoSF	Balance of Site Facilities
BP	before present
BPM	byproduct material
CDDL	Construction and Demolition Debris Landfill
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHILD	Channel-Hillslope Integrated Landscape Development
CLFS	Clarendon-Linden Fault System
CPCWSA	Chemical Process Cell Waste Storage Area
CR	concentration ratio
CSAP	Characterization Sampling and Analysis Plan
CSM	conceptual site model
DCF	dose conversion factor
DCS	derived concentration standard
DOE	(United States) Department of Energy
Eco-SSL	ecological soil screening level
ECS	Enviro Compliance Solutions, Inc.
EID	Environmental Information Document
EIS	Environmental Impact Statement
EMIC	Earth System Models of Intermediate Complexity
EPA	(United States) Environmental Protection Agency
ESM	Earth System Model
EWG	Erosion Working Group
FEIS	Final EIS
FEPS	features, events, processes, and scenarios
FGR	Federal Guidance Report
FSSP	Final Status Survey Plan
GCM	General Circulation Model
GHG	greenhouse gases
GIS	geographic information system
GLFC	Great Lakes Fishery Commission
GtC	gigaton of carbon (1 gigaton = 1 Pg, or petagram)
HLW	high-level radioactive waste
HSI	habitat suitability index
IAEA	International Atomic Energy Agency

IC	institutional control
ICRP	International Commission on Radiological Protection
IERT	Independent Expert Review Team
ILCR	incremental lifetime cancer risk
IPCC	Intergovernmental Panel on Climate Change
IRIS	Integrated Risk Information System
IT	isomeric transition
ka	one thousand years ago
KRS	Kent Recessional Sequence
KT	Kent Till
LLW	low-level radioactive waste
LLWTF	LLW Treatment Facility
LPS	Liquid Pretreatment System
LTR	License Termination Rule
LTS	Lavery Till Sand
Ma	one million years ago
MARSSIM	Multiagency Radiation Survey and Site Investigation Manual
MCL	Maximum Contaminant Level
MDC	minimum detectable concentration
MEI	maximally exposed individual
MFP	mixed fission product
MIS	marine isotope stage
MLLW	mixed (hazardous) and LLW waste
MOP	member of the public
MPPB	main plant process building
MTRU	mixed hazardous and TRU waste
MUF	material unaccounted for
NDA	NRC-Licensed Disposal Area
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFS	Nuclear Fuel Services, Inc.
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NRC	(United States) Nuclear Regulatory Commission
NWS	National Weather Service
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYSDOT	New York State Department of Transportation
NYSERDA	New York State Energy Research and Development Authority
ORS	Olean Recessional Sequence
OSL	optically stimulated luminescence
PA	performance assessment
PAUF	population area use factor
PAWG	PA working group
PCBs	polychlorinated biphenyls
PCE	tetrachloroethene

PET	potential evapotranspiration
PMF	probable maximum flood
PMP	probable maximum precipitation
PPA	probabilistic performance assessment
PSHA	probabilistic seismic hazard analysis
PTW	Permeable Treatment Wall
PUREX	plutonium-uranium extraction
PVC	Polyvinyl Chloride
PVS	Permanent Ventilation System building
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RFI	RCRA facility investigation
RH	remote-handled
ROI	region of interest
RSL	Remote Sensing Laboratory
S&G	Sand and Gravel unit
SDA	State-Licensed Disposal Area
SEIS	Supplemental EIS
SEQRA	State Environmental Quality Review Act
SF	slope factor
SM	source material
SNF	spent nuclear fuel
SNM	special nuclear material
SOC	system of controls
SOF	sum of fractions
SPDES	State Pollutant Discharge Elimination System
SSL	soil screening level
STS	Supernatant Treatment System
SWS	Slack-Water Sequence
TBU	thick-bedded unit
TCE	trichloroethene
TED	total effective dose
THOREX	thorium extraction
TLD	thermoluminescent dosimeter
TRU	transuranic waste
ULT	Unweathered Lavery Till
UNF	used nuclear fuel
USGS	United States Geological Survey
VLDPE	very low density polyethylene
WB	weathered bedrock
WIPP	Waste Isolation Pilot Plant
WIR	waste incidental to reprocessing
WLT	Weathered Lavery Till
WMA	Waste Management Area
WNYNSC	Western New York Nuclear Service Center

WTF	Waste Tank Farm
WVDP	West Valley Demonstration Project
WVES	West Valley Environmental Services LLC
WVNS	West Valley Nuclear Services, Inc.
YMP	Yucca Mountain Project

1.0 Introduction

The New York State Energy Research and Development Authority (NYSERDA) is the owner of the Western New York Nuclear Service Center (WNYNSC), a 1,351 ha (3,338 ac) site located approximately 48 km (30 mi) south of Buffalo, New York. The WNYNSC was established in 1961 as the site of a commercial spent nuclear fuel reprocessing and radioactive waste disposal facility. Nuclear Fuel Services, Inc. (NFS) built and operated the spent fuel reprocessing plant and waste disposal facilities, processing 640 Mg (metric tons, or 705 short tons) of spent nuclear fuel from 1966 to 1972 under an Atomic Energy Commission license. Nuclear fuel reprocessing operations ended in 1972 and never reopened, leaving behind radioactive and chemical wastes.

The reprocessing operations and subsequent plant remediation generated radioactive and hazardous chemical wastes, which are disposed in what is now known as the Nuclear Regulatory Commission (NRC)-Licensed Disposal Area (NDA). Additional radioactive wastes generated by West Valley Demonstration Project (WVDP) decontamination and decommissioning activities were disposed in the NDA between 1982 and 1986. Radioactive and chemical wastes were also disposed in the State-Licensed Disposal Area (SDA) from 1963 until 1975. As a regional disposal facility, the SDA received waste from off-site locations, as well as waste generated at the WNYNSC by nuclear fuel reprocessing operations. Liquid high-level radioactive waste (HLW) generated during nuclear fuel reprocessing operations was stored in underground storage tanks in the Waste Tank Farm (WTF). This liquid HLW was subsequently solidified in borosilicate glass as part of the U.S. Department of Energy (DOE) West Valley Demonstration Project (WVDP).

The scope of this conceptual site model (CSM) is larger than just these facilities, however. Some of the radioactive and hazardous chemical contamination at the West Valley Site (or simply the Site, consisting of the WVDP and WNYNSC) is the result of operations, inadvertent releases, and remaining contaminated facilities. This contamination ranges from the tanks, piping, and associated infrastructure that is the WTF, to potential light contamination along the Rail Spur, to the Construction Demolition Debris Landfill, to a plume of strontium-90 (^{90}Sr) migrating in North Plateau groundwater, to an off-site release of cesium-137 (^{137}Cs) known as the Cesium Prong. A full list of the modeled facilities is found in Table 1 and Table 10.

While some facilities and contamination at the Site have been clearly identified for removal during Phase 1 decommissioning, Phase 2 decommissioning decisions need to be made for those facilities remaining at the WNYNSC after the completion of Phase 1 decommissioning. The National Environmental Policy Act (NEPA) provides the overarching process for decision making. Key to this process is the development of a site-specific Environmental Impact Statement (EIS), in which alternatives are evaluated in the context of environmental, social, and economic objectives. A Final EIS (FEIS) was prepared for the Site in 2010 (DOE 2010a, 2010b, 2010c). A Supplemental Environmental Impact Statement (SEIS) will be prepared to support Phase 2 decision making for those facilities remaining at the Site following Phase 1 decommissioning. New York State also requires an EIS under the State Environmental Quality Review Act (SEQRA), 6 NYCRR§617 (NYSDEC 2016).

One important tool that is needed in order to inform the decision-making process is a science-based model of the Site and its potential future consequences for human health and the

environment. This document outlines the conceptualization of such a model: the Conceptual Site Model, or CSM. The CSM forms the foundation for the West Valley PPA Model (i.e., the science-based computational model).

1.1 Purpose

Neptune and Company, Inc. (Neptune) has been contracted to develop a probabilistic performance assessment (PPA) model of the West Valley Site in order to support Phase 2 decision making for those facilities remaining at the WNYNSC following the completion of Phase 1 decommissioning. The purpose of this Model is to evaluate the long-term performance of the Site, meaning the way in which contamination resulting from past operations will disperse into the surrounding environment, with potential adverse consequences for human health and the environment. Further, the Model can evaluate the effectiveness of proposed remedial actions, including contaminant removal, in terms of future consequences. The computer model must be able to accommodate uncertainty, which is inherent in nearly all aspects of the problem. Uncertainty is included by capturing the current state of knowledge surrounding the nature of the wastes, the environmental features, processes, and events that govern fate and transport of contaminants, the potential for exposure of humans to harmful substances, and the consequences of such exposures. Because it is not possible to know everything with certainty, the Model is designed to operate probabilistically, so that it evaluates many possible outcomes. The West Valley PPA Model is a tool intended to provide support for decision making in the context of uncertainty, in a manner that is transparent, defensible, and robust.

The West Valley PPA Model will provide additional information to regulators and the public, beyond that of the FEIS and associated assessments, in order to inform the SEIS, which will be used to make informed and defensible decisions at the Site. The basic decision context involves whether particular waste forms and contaminated environmental media such as soils should remain or be stored at the Site, or transported and disposed elsewhere (largely sites in the western US). An initial step carefully defines features, events, processes, and scenarios (FEPS) that can influence future radiation doses and chemical risks to humans and the environment. The FEPS process, documented in the Neptune report *FEPS Analysis for the West Valley Site* (Neptune 2016), assists in developing the site-specific CSM documented here. The CSM establishes those potentially significant mechanisms and processes by which different types of exposed individuals might experience doses and risks associated with wastes over long periods of time (e.g., thousands of years after closure). The CSM in turn is the foundation for the development of the quantitative probabilistic West Valley PPA Model, which will provide estimates of potential future doses and risks under different exposure scenarios and remediation alternatives.

1.2 Organization and Context

This CSM starts by outlining the regulatory context in Section 2.0, since it is important in identifying the types of results needed from the Model. The features of the facilities at the Site are discussed in Section 3.1. Section 3.2 follows, with a description of the Site, its environs, and its demographic context. The development of the modeling of human exposure is discussed in Section 4.0. The details of contaminant fate and transport modeling are covered in Section 5.0.

2.0 Regulatory Context

The West Valley Site has different characteristics and a different regulatory structure from that of typical radioactive waste disposal facilities. Due to its history as a commercial venture and its range of waste types, including high-level radioactive waste (HLW), a wide variety of low-level radioactive wastes (LLW) including mixed hazardous and LLW (MLLW), chemical hazardous waste, transuranic waste (TRU), mixed hazardous and TRU (MTRU), and spent nuclear fuel (SNF), a complex overlay of regulatory responsibilities and jurisdictions must be managed.

The West Valley PPA Model addresses the expectations of the various regulatory entities in a coherent manner, so that the same basic science model is used to produce a variety of results, or model endpoints. This is relevant to the CSM development, since the CSM must anticipate the needs of regulatory decision makers and provide information that will be useful to the SEIS.

In 1980, the US Congress passed the WVDP Act (United States Code 1980), directing the DOE to conduct a demonstration project for solidification of the HLW at the Site. The WVDP Act also directed DOE to:

1. solidify the high-level radioactive waste at the WNYNSC,
2. develop containers suitable for permanent disposal of the waste,
3. transport the solidified waste to a Federal repository for permanent disposal,
4. dispose of LLW and TRU waste, and
5. decontaminate and decommission the underground HLW tanks, facilities, and any material and hardware used in connection with the Project in accordance with such requirements as the NRC may prescribe.

DOE is the lead Federal agency for Phase 2 decisions made under the WVDP Act. NYSERDA is the lead state agency under SEQRA and shares in this role: It monitors and maintains the SDA and other areas of the WNYNSC not being used by DOE for its WVDP activities. NRC is charged with developing decommissioning criteria for the NRC-licensed portions of the West Valley Site, and has responsibility under the WVDP Act for review, consultation, and monitoring activities.

Since the WVDP is a significant proposed Federal action, a formal consideration of environmental values comes into play, as required by the National Environmental Policy Act (NEPA) of 1969, as amended in NEPA (1982). In order to demonstrate consideration of environmental and social consequences of the proposed action, the DOE has developed an EIS, which is an analysis of the affected environment and its relationship with humans. New York State has a similar requirement to consider environmental, social, and economic consequences in decision making, requiring an EIS under SEQRA, 6 NYCRR§617 (NYSDEC 2016).

In 1990, DOE and NYSERDA agreed to prepare a joint environmental impact statement (EIS) as part of a NEPA/SEQRA process to address both WVDP completion and closure of WNYNSC, which ultimately resulted in the 2010 *Final Environmental Impact Statement for Decommissioning and/or Long-Term Stewardship at the West Valley Demonstration Project and Western New York Nuclear Service Center* (DOE 2010a), or FEIS. The FEIS identified Phased Decision making as the preferred alternative for the WVDP and WNYNSC and identified

Phase 1 decommissioning activities. A Supplemental EIS (SEIS) will be prepared to evaluate Phase 2 decommissioning activities and will incorporate the West Valley PPA Model as a decision-making tool.

The alternatives presented in the EIS developed by DOE and NYSERDA were evaluated by the NRC, the U.S. Environmental Protection Agency (EPA), the New York State Department of Environmental Conservation (NYSDEC), and the New York State Department of Health (NYSDOH). The EPA has promulgated generally applicable radioactive air emissions monitoring and regulation under the National Emissions Standards for Hazardous Air Pollutants (NESHAPS) (40 CFR 61, Subpart H) (CFR 2014b).

In addition to radioactive wastes, there are also hazardous non-radioactive chemicals and MLLW and MTRU that are being managed in accordance with the EPA's Resource Conservation and Recovery Act (RCRA) Subtitle C Hazardous Waste Management Program (40 CFR 260–279) (CFR 2014c) and the State's equivalent 6 NYCRR§373 (NYSDEC 2006). The West Valley Site is currently under a RCRA 3008(h) Administrative Order on Consent and Corrective Action Program.

As required by the WVDP Act, NRC developed and published the *Decommissioning Criteria for the WVDP at the West Valley Site, Final Policy Statement* (NRC 2002). In this notice, NRC announced its decision to apply its *License Termination Rule* (LTR) (10 CFR 20, Subpart E) (CFR 2014a) as the decommissioning goal for the entire NRC-licensed site. In addition, the NRC *Final Policy Statement* provided specific criteria for classification of waste incidental to reprocessing (WIR) that might be present after decontamination activities. While the NRC does not have regulatory authority over the SDA, NYSERDA has agreed to apply the LTR criteria described by NRC (2002) for evaluating the SDA. As discussed below in Section 2.4, other New York State regulations apply as well.

2.1 Nuclear Regulatory Commission Regulations

NRC issues 10 CFR Part 50 licenses for “Domestic Licensing of Production and Utilization Facilities.” NRC licensing and radiation protection, environmental safety and health, security, and management policies are applicable to activities conducted by NYSERDA for facilities at the Site that are under the 10 CFR Part 50 license but outside the authority of the WVDP Act.

Therefore, most of the West Valley Site, with the exception of the SDA, is licensed by the NRC, although the technical specifications of this license are held in abeyance until DOE has completed its decommissioning obligations under the WVDP Act, at which time control of the Site reverts to NYSERDA. At that time, NRC expects to review the SEIS in considering termination of NYSERDA's license. Therefore, the West Valley PPA Model and the SEIS need to be developed with future NRC concordance in mind.

As previously mentioned, NRC applies its LTR (CFR 2014a) to the NRC-licensed site. The LTR itself provides the formally applicable decommissioning criteria for the areas under the NRC license, except for the SDA. The NRC's West Valley Final Policy Statement applied the NRC's LTR criteria as the decommissioning criteria for the WVDP (NRC 2002). The New York State Department of Environmental Conservation (NYSDEC) and New York State Department of

Health (NYSDOH), however, will provide the formally applicable criteria for the SDA. In addition, the NRC Final Policy Statement also provides specific criteria for classification of WIR that might be present after decontamination activities. The LTR does not apply a single public-dose criterion for meeting license termination requirements. Rather, it provides for a range of criteria:

- For unrestricted use, the annual total effective dose (TED) to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) and is as low as is reasonably achievable (ALARA). This is outlined in 10 CFR 20.1401 and 1402 (CFR 2014a).
- For restricted use, with institutional control (IC) in place, the annual TED to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) and ALARA. This is outlined in 10 CFR 20.1403(b) (CFR 2014a).
- If IC is assumed to fail, the annual TED from residual radioactivity to the average member of the critical group is ALARA and would not exceed 1 mSv (100 mrem) annual dose, or 5 mSv (500 mrem) annual dose provided the licensee demonstrates that further reductions in residual radioactivity necessary to comply with 1 mSv (100 mrem) are “not technically achievable,” would be prohibitively expensive, or would result in net public or environmental harm.

These criteria could be applied variously to different portions of the Site. If none of these criteria can be met, the possibility remains that the license will not be terminated. In the event that institutional controls should fail, the NRC retains authority to take action.

The LTR also specifies a 1000-yr period of performance, though it is recognized that decision makers desire to understand the magnitude of impacts whenever they may occur. The NRC concluded that, for the types of facilities and source terms considered, it was reasonable to use a 1000-yr period. The Site presents some unique challenges, however, in that quantities of mobile, long-lived radionuclides are present. Because an evaluation of reasonably foreseeable impacts is required under NEPA, the NRC concluded that an analysis of impacts beyond 1000 years should be provided.

Title 10 CFR 20.1403(a) determines eligibility (not approval) for restricted release. A site would be eligible if “further reductions in residual radioactivity necessary to comply with the provisions of Part 20.1402 would result in net public or environmental harm, or were not being made because the residual levels associated with restricted conditions are ALARA” (CFR 2014a). These cost/benefit analyses are to follow the guidance in NUREG-1757 Appendix N (NRC 2006).

There is also allowance in the LTR for alternative release criteria for restricted release, as specified in 10 CFR 20.1404 (CFR 2014a) and NUREG-1757 (NRC 2006). This alleviates the need for exemptions for exceeding the aforementioned doses.

If none of these criteria can be met, there is the possibility of not terminating the NRC license. This would involve a specific System of Controls and a long-term or perpetual license where LTR requirements are technically impractical or prohibitively expensive, as discussed in Appendix M of NRC (2006).

The System of Controls shares the goal of annual doses to be kept below 0.25 mSv (25 mrem), and would include:

- legally enforceable and durable ICs,
- engineered barriers to contaminant transport,
- site monitoring and maintenance with checking at 5-year intervals,
- appointment of an independent third-party site custodian, with financial assurance, and
- a perpetual license as needed.

2.2 Department of Energy Radiation Protection

DOE Order 458.1, *Radiation Protection of the Public and the Environment* (DOE 2013), establishes the standards and requirements for radiological protection of the public and the environment at DOE facilities. A public total effective dose (TED) limit of 1 mSv (100 mrem) in a year from all sources and exposure pathways is established in DOE O 458.1, excepting dose from radon and its decay products, dose from natural background radiation, and medical or occupational doses. If TED exceeds 0.25 mSv (25 mrem) in a year, dose calculations must be performed to include major non-DOE sources (excepting dose from radon and its decay products, dose from natural background radiation, and medical or occupational doses) as well as DOE-related sources. Additionally, an assessment to ensure that individual and collective doses to the public and releases to the environment are ALARA, using a graded approach, is required. The DOE annually evaluates the dose to the public from operations at the WVDP and publishes this information in the Annual Site Environmental Report for the WVDP. The TED to the public from WVDP operations in 2015 was <0.49 mrem (DOE 2016).

2.3 Environmental Protection Agency Regulations

As the primary Federal agency responsible for environmental protection, the EPA also has regulations that are applicable to wastes present at the Site.

2.3.1 RCRA

EPA is responsible for issuing guidelines and regulations for proper management of solid and hazardous waste including mixed waste (waste that is both radioactive and RCRA hazardous). In New York State, EPA has delegated the authority to issue permits and to enforce these regulations to the New York State Department of Environmental Conservation (NYSDEC). In 1990, the WVDP submitted a RCRA Interim Status Part A application for treatment and storage of waste to NYSDEC. The WVDP has operated under RCRA Interim status ever since. Additionally, the West Valley Site is currently under a RCRA 3008(h) Administrative Order on Consent requiring corrective action to protect human health and the environment from releases of hazardous waste or hazardous constituents.

2.3.2 NESHAPS

DOE facilities are subject to the NESHAPS: 40 CFR 61 (CFR 2014b). Subpart H states that “emissions of radionuclides to the ambient air from Department of Energy facilities shall not

exceed those amounts that would cause any member of the public to receive in any year a TED of 10 mrem/yr.” There are also specified monitoring requirements. Subpart Q states that “no source at a Department of Energy facility shall emit more than $[0.84 \text{ Bq}/(\text{m}^2 \text{ s})]$, or] 20 picocuries per square meter per second ($\text{pCi}/(\text{m}^2\text{-sec})$) ($1.9 \text{ pCi}/(\text{ft}^2\text{-sec})$) of radon-222 as an average for the entire source, into the air.” No time frame is specified. There are also standards for some specific non-radioactive substances, which will be reviewed as to applicability to the Site.

2.4 New York State Regulations

New York State authority for the Radiological Health Program (12 New York Code of Rules and Regulations [NYCRR] Part 38), was transferred from the New York State Department of Labor to the New York State Department of Health (NYSDOH) in 2006. Thus, NYSDOH now has jurisdiction over radioactive materials at the SDA and now maintains authority over the radioactive materials license (originally issued by the New York State Department of Labor) that authorizes NYSERDA to possess and manage emplaced radioactive waste at the SDA. The license requires NYSERDA to conduct its operations in accordance with a radioactive safety program to minimize radiation exposures to workers and the public resulting from SDA operations. NYSDEC serves as the lead agency for the decommissioning project. NYSDOH will participate in the project by reviewing and concurring with NYSDEC on any remedial actions.

Under the New York Agreement State Program, NYSDEC has jurisdiction over discharges of radioactive material to the environment and disposal of radioactive waste. NYSDEC’s role at the SDA is to ensure that NYSERDA properly maintains the integrity of the SDA, minimizes discharges of radioactive material to the environment, and properly closes the facility in a manner that is protective of the public health and environment and in compliance with 6 NYCRR Part 380, “Prevention and Control of Environmental Pollution by Radioactive Materials.”

NYSDEC has jurisdiction over inactive waste sites under the State Superfund Program (6 NYCRR Part 375), as well as permitting and closure of RCRA interim and final status units under the Hazardous Waste Program (6 NYCRR Parts 370–374, 376). The New York State RCRA regulations apply to DOE and its contractors. The state-licensed sites and activities such as the SDA, however, are regulated under both NYSDEC radiation protection and RCRA regulations.

The primary mechanism to control potential water pollution is the requirement that direct dischargers obtain a discharge permit, pursuant to the State implementation of the Federal Clean Water Act. The WVDP monitors discharges from surface waters from various on-site sources pursuant to a State Pollutant Discharge Elimination Permit issued by NYSDEC. NYSERDA was issued a separate permit for the SDA.

3.0 Disposal Facility Characteristics

3.1 West Valley Site Facilities

The West Valley Site is a collection of a large number of discrete facilities, including buildings, tanks, piping, lagoons, and waste disposal areas. Section 3.1.1 provides an overview of the Site layout and facilities. Details of engineered structures relevant to the CSM and Site processes are presented in Section 3.1.2. Some of these structures are contaminated with radiological and often RCRA hazardous chemical constituents and all have been remediated, are being remediated, or are being considered for remediation. Physiographical and topographical features of the Site are described in Section 3.2.1.

3.1.1 Regions within the West Valley Site

The West Valley Site is subdivided into two distinct areas, consisting of the Project Premises and the Retained Premises. The Project Premises is the WVDP portion of the WNYNSC and is under the control of the DOE. The Retained Premises include the remainder of the non-WVDP WNYNSC and is under the control of NYSERDA. The description of geographic regions at the West Valley Site is complex, and there are many overlapping areas and boundaries that are based on ownership, responsibility, and nature of contamination. The geographical layout of major facility components discussed in this CSM is presented in the sections below. The regulatory context for these facilities is presented in Section 2.0. The WNYNSC Retained Premises boundary line is shown in Figure 1. It comprises 13.5 km² (1350 ha, or 3,338 ac) and is surrounded by a barbed-wire fence (DOE 2010a). The WVDP Premises boundary is also shown in Figure 1. This 0.68 km² (167 acre) portion of the WNYNSC includes the main engineered facilities and disposal units, with the exception of the State-licensed Disposal Area (SDA), discussed in this CSM. These political boundaries are not used specifically in the West Valley PPA Model, which includes all of these as well as more receptor locations downstream and downwind.

The list of facilities to be evaluated for Phase 2 decision making is provided in Table 1 later in this section. Note that residuals from Phase 1 actions are to be included in the analysis, since they will still have minor contributions to dose and risk.

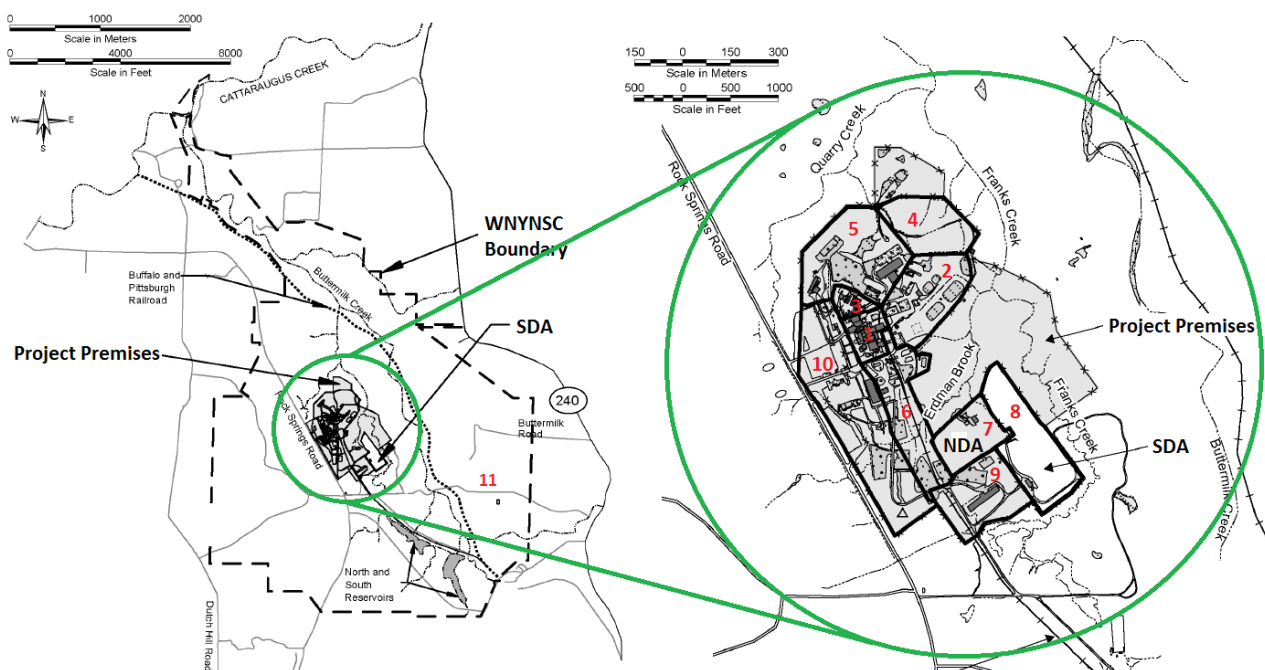


Figure 1. Map of the West Valley Site, including the WNYNSC, the SDA, and WVDP Project Premises. WMAs 1 through 10 are shown in inset (labeled in red). WMA 12 is the balance of the WNYNSC. (Adapted from Figures 2-1 and 2-3 of DOE (2010a).)

3.1.1.1 Waste Management Areas

The West Valley Site is subdivided into distinct non-overlapping geographic regions called Waste Management Areas (WMAs). Most modeled entities, such as constructed facilities, are contained within a single WMA. Others, like the North Plateau groundwater plume, cross several WMA boundaries. Contaminated surface soils, subsurface soils, and groundwater exist to some extent within many WMAs.

Locations of WMAs 1 through 10 are shown in Figure 2. These are briefly described in Table 1 (DOE 2010a), along with the remaining WMAs. Detailed descriptions of relevant engineered structures within the WMAs are provided in Section 3.1.2. A complete list of facilities to be included in the West Valley PPA Model is provided in Table 10 in Section 5.1.1.3.

The NDA (WMA 7), the SDA (WMA 8), and the WTF (WMA 3) are described separately in Sections 3.1.1.2, 3.1.1.3, and 3.1.1.4. The other WMAs and other areas of contamination are described in greater detail in the *Phase 1 Decommissioning Plan for the West Valley Demonstration Project* (DOE 2009) and in Appendix C of the FEIS (DOE 2010c). Chapter 7 of the Decommissioning Plan outlines the extent of Phase 1 activities, by WMA; these are discussed for their relevance to the Model in Section 5.1.1.1. Some WMAs will have extensive soil excavations and all of their aboveground facilities removed, and others contain facilities that are subject to Phase 2 decision making. All will have some residual contamination, and will be characterized in accordance with requirements in the Phase 1 Characterization Sampling and Analysis Plan (CSAP) (ANL 2011b) and the guidance in NRC's Multiagency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC 2000). The facilities and residual

contamination expected to be included in the West Valley PPA Model are discussed in Section 5.1.

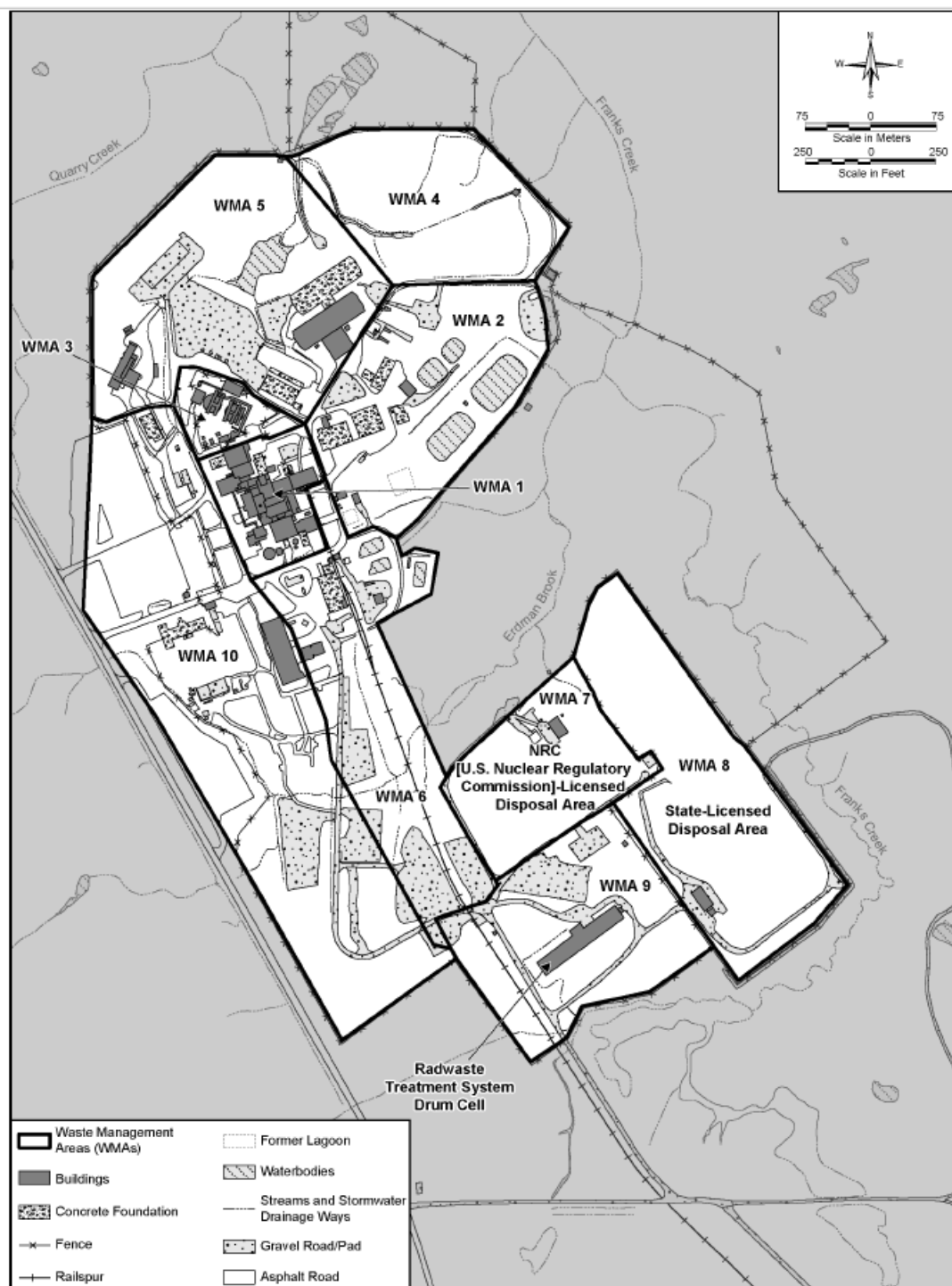


Figure 2. Detailed map of WMAs 1–10 and key facilities. (Adapted from Figure 2-2 of DOE (2010a).)

Table 1. Summary of facilities within the Waste Management Areas.

WMA	Description/Primary Components
WMA 1	Main Plant Process Building (MPPB), Vitrification Facility, Fuel Receiving and Storage Building, Load-In/Load-Out Facility, Utility Room and Expansion, Fire Pumphouse and Water Storage Tank, Plant Office Building, Electrical Substations, underground lines and tanks, Source Area of the North Plateau Plume, and Vitrification Off-Gas Line and Trench, plus surface soils, subsurface soil, and groundwater
WMA 2	LLW Treatment Facility (LLWTF), Lagoons 1 through 5, Neutralization Pit, Old and New Interceptors, Solvent Dike, Maintenance Shop leach field, wastewater lines, foundations and slabs, and the Permeable Treatment Wall
WMA 3	Waste Tank Farm (WTF) and HLW Transfer Trench and Piping, Equipment Shelter and condensers, Permanent Ventilation System (PVS) Building, and Supernatant Treatment System Support Building
WMA 4	Construction and Demolition Debris Landfill
WMA 5	Remote-Handled Waste Facility, Lag Storage Additions 3 and 4, Chemical Process Cell Waste Storage Area, and foundations and pads
WMA 6	Sewage Treatment Plant, Demineralizer Sludge Ponds, Equalization Basin and Tank, Rail Spur, and foundations and pads
WMA 7	NRC-Licensed Disposal Area (NDA) and associated facilities
WMA 8	State-Licensed Disposal Area (SDA) and associated facilities
WMA 9	Radioactive Waste Treatment System Drum Cell and the Trench Soil Container Area
WMA 10	New Warehouse, Security Buildings, and parking lots
WMA 11	Bulk Storage Warehouse, Scrap Material Landfill, and Hydrofracture Test Well Area
WMA 12	Balance of Site Facilities (BoSF), including soils and stream sediments ¹ , the North Plateau Groundwater Plume, and parts of the Cesium Prong

¹The stream sediments include those in Quarry Ck, Frank's Ck, Erdman Bk, and Buttermilk Ck downstream of the Site. Additional downstream contamination would extend into Cattaraugus Ck, Lake Erie, and beyond. Off-site areas affected by potential future atmospheric dispersion would extend off-site and outside the WNYNSC boundary.

3.1.1.2 NDA

The NDA (Figure 1) measures about 120 m by 180 m (400 by 600 ft) overall, and contains solid and liquid wastes from reprocessing and Site decontamination operations in disposal holes and trenches. The locations of NDA facilities are shown in Figure 3. The NDA was operated for disposal of radioactive and chemical wastes generated from fuel reprocessing and Site decontamination operations from 1966 to 1986.

The NDA includes the Special Holes and deep burial holes known as the NFS disposal area, the WVDP disposal trenches and caissons, the NDA Interceptor Trench and the associated Liquid Pretreatment System structures, a leachate transfer line, a former lagoon, and the NDA Hardstand Staging Area (DOE 2010a).

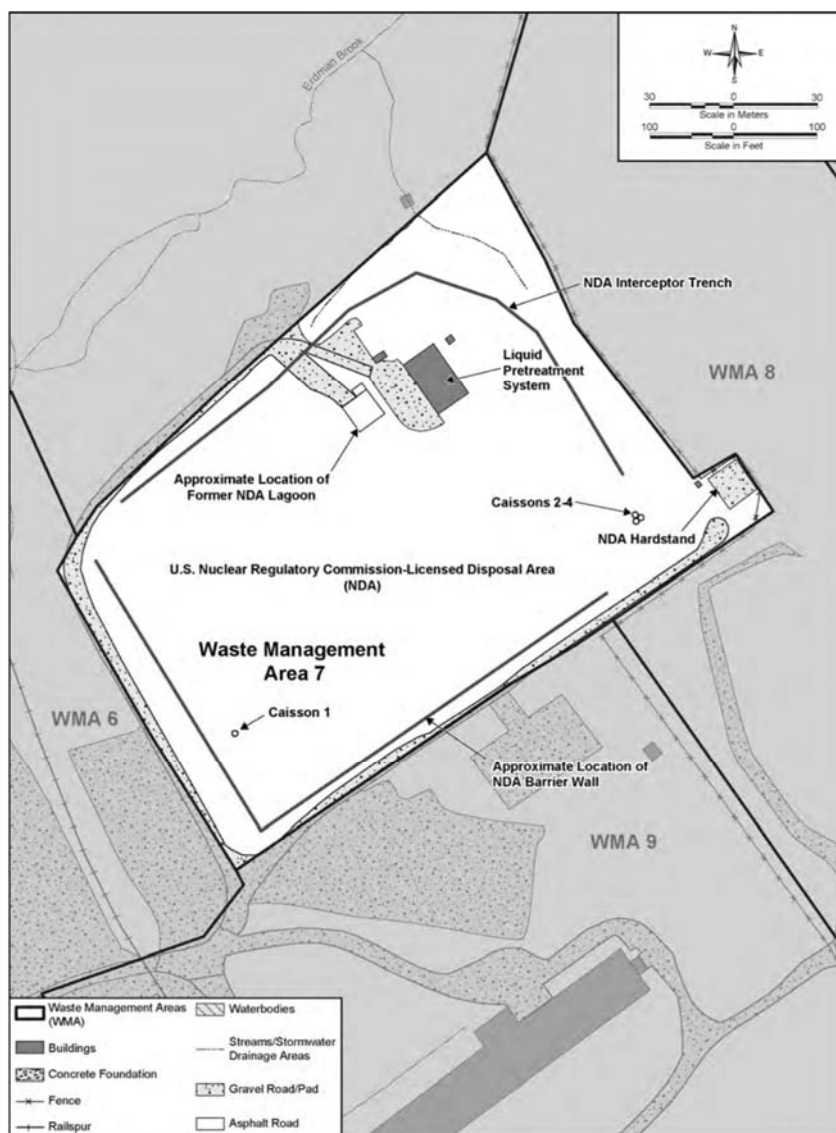


Figure 3. NDA (WMA 7) and associated facilities. (From Figure C-8 of DOE (2010c).)

In late 2008, an upgradient subsurface soil bentonite barrier wall (Section 3.1.2.2) and a geomembrane cover (Section 3.1.2.3) were installed at the NDA as an interim measure.

The NFS disposal area includes approximately 100 deep disposal holes (Deep Holes) and 130 Special Holes. The Deep Holes are generally 0.8 by 2 m (2.7 by 6.5 ft) in area and 15 to 21 m (50 to 70 ft) deep (DOE 2010c). The Special Holes are about 6 m (20 ft) deep and are mostly about 3.6 m (12 ft) wide and 6 to 9 m (20 to 30 ft) long. The Deep Holes and Special Holes were used by NFS to dispose of radioactive waste generated during its operations from 1966 to 1980.

The WVDP trenches are about 9 m (30 ft) deep by 4.6 m (15 ft) wide and lengths range from 9 to 76 m (30 to 250 ft). The WVDP trenches were used by the WVDP from 1982–1986 to dispose of waste generated during WVDP site decontamination activities. One steel-lined cylindrical concrete vault (caisson 1) near the eastern and southern corners of the NDA received approximately 23.3 m³ (823 ft³) of waste in drums. The caisson is plugged with concrete and covered with a plastic barrier to prevent infiltration (DOE 2010c). Caissons 2 through 4 did not receive waste and are empty.

The Leachate Transfer Line is a contaminated 5.1-cm (2-in) diameter, 1,220-m (4,000-ft) long, black PVC and galvanized steel pipeline that runs along the northeast and northwest sides of the NDA, continues into WMA 6, and ends at Lagoon 2 in WMA 2.

3.1.1.3 SDA

The SDA operated as a commercial low-level waste disposal facility from 1963 to 1975, with solid and liquid wastes disposed primarily in trenches. Figure 4 shows the facilities within the SDA.

The SDA includes the North Disposal Area, the South Disposal Area, the Mixed Waste Storage Facility, and three filled lagoons. The trenches are presently covered with an impermeable geomembrane (Section 3.1.2.3).

The North Disposal Area is composed of Trenches 1 through 7. Trenches 1 through 5 are 10.7 m (35 ft) wide by 6.1 m (20 ft) deep. The cumulative length of Trenches 1 and 2 is about 214 m (700 ft), with a berm separating the two. The lengths of Trenches 3 through 7 are about 213, 206, 183, 53, and 23 m (968, 675, 600, 174, and 75 ft), respectively (WVNS 1995b). Trench 6 contains 19 special purpose holes, 0.6 to 1.8 m (2 to 6 ft) wide, 1.2 to 3.6 m (4 to 12 ft) long, and 2.4 to 3.6 m (8 to 12 ft) deep. Trench 7, with a depth of about 3.3 m (11 ft), had a concrete slab below the wastes with concrete poured over the 33 packages of high specific activity wastes (WVNS 1995b). The South Disposal Area has Trenches 8 through 14, which are about 10.7 m (35 ft) wide and 6.1 m (20 ft) deep. The lengths of Trenches 8 through 14 are about 172, 171, 169, 169, 169, 186, and 201 m (564, 561, 554, 554, 554, 610, and 659 ft), respectively (WVNS 1995b). The Mixed Waste Storage Facility has two aboveground buildings, one of which contains two unused storage tanks (DOE 2010c).

Three filled lagoons are in the SDA. The unlined Northern and Southern Lagoons (Figure 4) were closed by removing liquids and placing adsorbent material and compacted native soil over the contaminated soil (DOE 2010c). The Inactive Lagoon had a vinyl liner installed with compacted native till soils and clay above. As seen in Figure 4, a hydraulic barrier wall, also

known as a slurry wall, has been installed upgradient of Trench 14 in order to divert the lateral inflow of groundwater into the South Disposal Area.

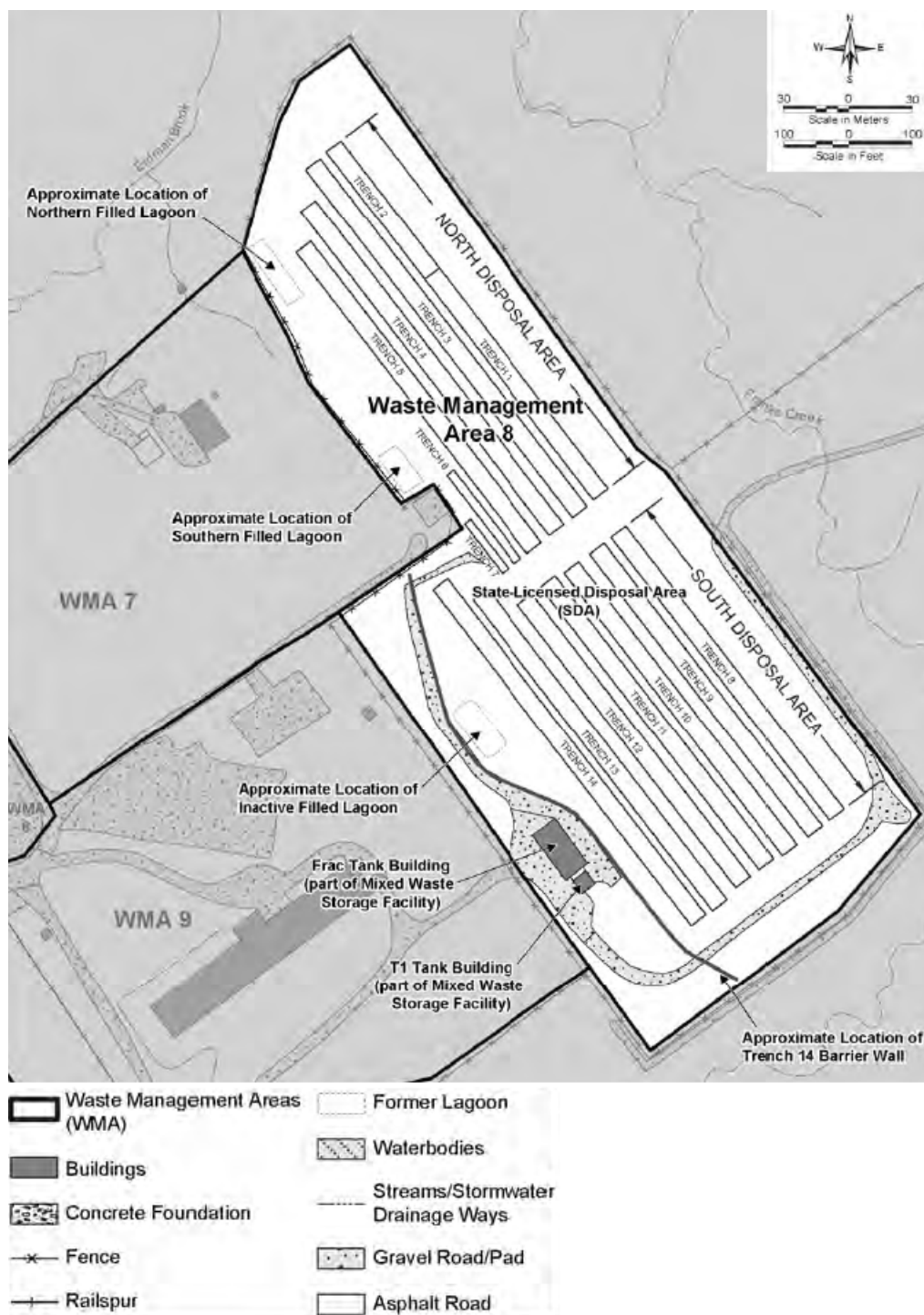


Figure 4. SDA (WMA 8) facilities, including trenches, buildings, and the location of the Trench 14 slurry barrier wall. (Figure C-9 from DOE (2010c).)

3.1.1.4 WTF

WMA 3 includes Waste Storage Tanks 8D-1, 8D-2, 8D-3, and 8D-4, their associated vaults, High-Level Waste Transfer Trench, Permanent Ventilation System Building, Supernatant Treatment System (STS) and STS Support Building, Equipment Shelter and Condensers, and Con-Ed Building. Also included in WMA 3 is the North Plateau Groundwater Plume, which extends through WMAs 1 through 6, and underground pipelines, which transferred waste from WMA 1 (DOE 2010a).

Waste Storage Tanks 8D-1, 8D-2, 8D-3, and 8D-4 were built to store liquid high-level radioactive waste generated during spent nuclear fuel reprocessing operations. Tanks 8D-2 and 8D-4 were used to store plutonium-uranium extraction (PUREX) and thorium extraction (THOREX) wastes respectively from reprocessing operations. Tanks 8D-1 and 8D-3 were used to store condensate from the THOREX waste. These tanks were subsequently modified to support treatment of high-level radioactive waste during implementation of WVDP. The tanks will contain residual radiological as well as hazardous chemical constituents, but all the tank contents will be dry (DOE 2010a).

3.1.1.5 Off-Site Areas

There are also contaminated regions beyond the boundaries of the WNYNSC, such as the Cesium Prong and the waters and sediments of the surface water system beyond the mouth of Buttermilk Creek. The West Valley PPA Model will evaluate concentrations and risks in these off-site areas, though decisions regarding Site cleanup are driven by higher risk, which will occur closer to the Site.

3.1.2 Engineered Structures

Contaminated engineered structures that remain at the Site following Phase 1 decommissioning are considered to be sources of contamination themselves. These may include tanks, lagoons, pits, holes, trenches, and foundations and pads from removed buildings. Decommissioning activities before the start time of the Model (Section 5.2.2) will include the removal of many of the currently existing facilities, as well as construction of additional remediation-related structures. Possible remaining structures and residual contaminated areas are presented in Section 5.1. The following sections describe several engineered structures that affect the CSM and are expected to remain a part of modeled processes. Lagoons and other surface water-related structures are discussed in Section 3.2.8.1.1.

3.1.2.1 Reactive Barriers

Two chemically reactive engineered barriers have been installed at the West Valley Site, though others may be proposed as part of remediation alternatives. The pilot-scale and full-scale Permeable Treatment Walls (PTWs) are designed to capture strontium within the North Plateau groundwater plume, which is principally ⁹⁰Sr. The pilot-scale PTW, 9 m (30 ft) in length, was installed in WMA 2 in 1999 to test the efficacy of the approach, and the final full-scale PTW was completed in 2010 (Figure 5). The full-scale PTW is approximately 1 m (3 ft) wide, 5.8 to 9.1 m (19 to 30 ft) deep, and 259 m (860 ft) long (Chamberlain et al. 2011). The geochemical operation of these PTWs is described in Section 3.2.8.3.3.

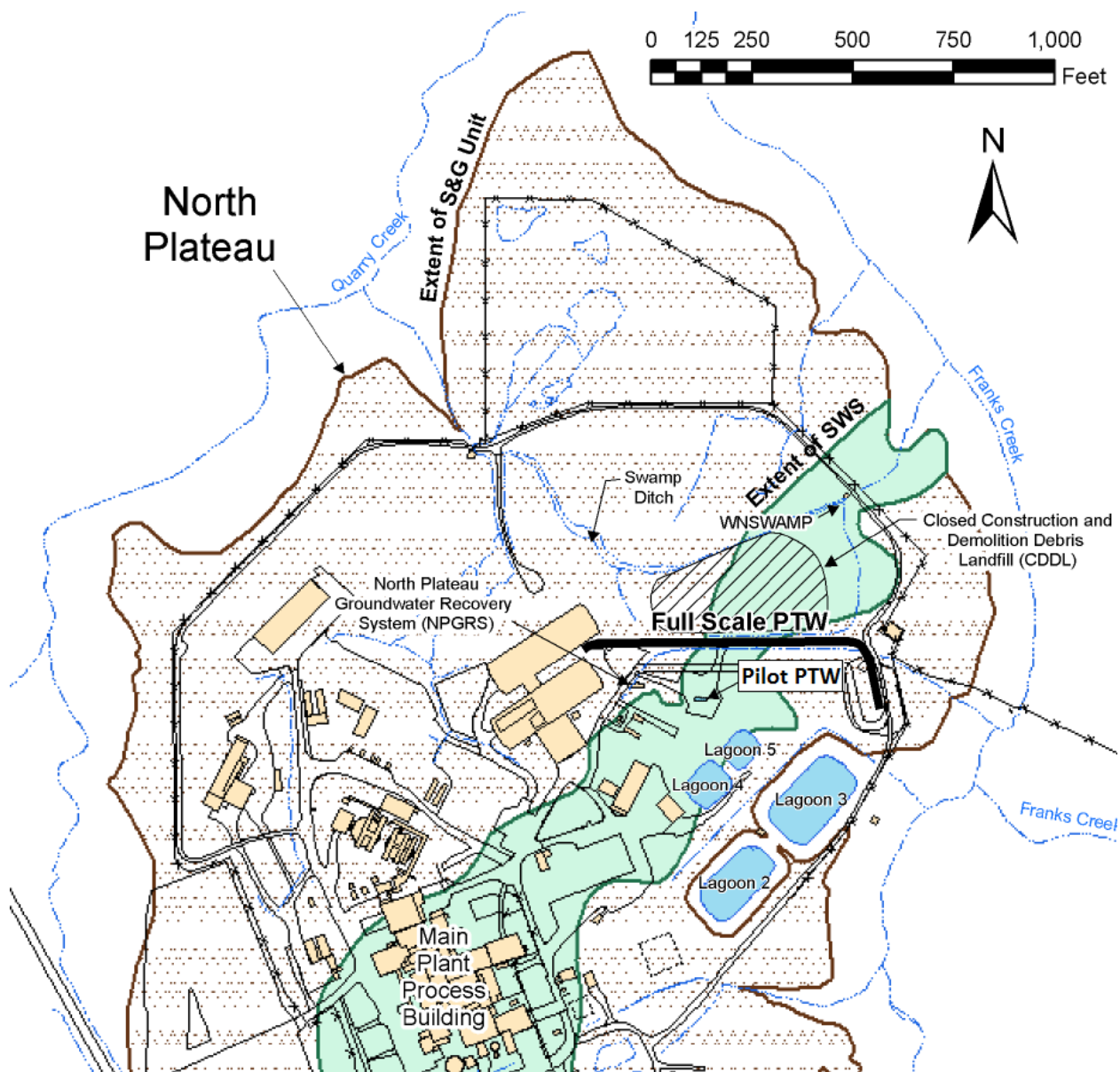


Figure 5. Locations of the pilot and full-scale PTWs. (Figure 2 from CHBWV (2012).)

3.1.2.2 Below-Grade Walls and Interceptor Trenches

An interceptor trench was installed downgradient of the NDA (Figure 3) after the detection of groundwater contaminated with radionuclides and a solvent mixture of n-dodecane and tributyl phosphate (Section 3.2.8.3.1). The trench is 3.3 to 4.3 m (11 to 14 ft) deep and drains to a central sump where the intercepted groundwater is routinely characterized for radiological indicator parameters and the presence of solvent. If solvent is not present, the accumulated groundwater is transferred from the sump to Lagoon 2 in WMA 2 for treatment in the WVDL LLWTF before being transferred to Lagoon 3 for discharge to Erdman Brook through a State Pollutant Discharge Elimination System (SPDES)-permitted outfall (DOE 2010c). If solvent were to be

detected, the accumulated groundwater would be transferred to the Liquid Pretreatment System (LPS) in WMA 7 for treatment. However, the LPS has not been required to treat groundwater from the NDA interceptor trench.

Slurry walls, which are not meant to be permeable or reactive, are included in the modeling as modifiers to local groundwater flow. While their geochemical characteristics may be different from native soils due to the addition of bentonite or other materials, they are primarily intended to affect the flow field.

In the SDA, a 259 m (850 ft) long soil-bentonite slurry wall was installed in 1992 along the west side of Trench 14 to limit groundwater infiltration into Trench 14 (Figure 4). (DOE 2010c). Prior to that installation, a subsurface concrete wall was emplaced in 1987 immediately west of Trench 14. The concrete wall is a minimum of 1.2 m (4 ft) thick, 39.6 m (130 ft) long, and contains approximately 320 m³ (11,300 ft³) of concrete (DOE 2010c). The effect of these installations on groundwater levels in the trenches is presented in Section 3.2.8.2.4.

A slurry wall composed of bentonite and soil was constructed upgradient of the NDA in 2008 (Figure 3). The two perpendicular sections of the wall, in total, sum to 290 m (950 ft) in length, are 1 m (3 ft) in width, and 4.6 to 6.1 m (15 to 20 ft) in depth (Mann et al. 2009). Its effect on groundwater flow is discussed in Section 3.2.8.2.5.

Additional barrier walls may be considered as part of the Phase 2 decommissioning alternatives to be evaluated in the SEIS. These features will be modeled as appropriate to the alternatives under consideration.

3.1.2.3 Covers

Covers have been installed in some areas to limit accumulation of rainwater in trenches and disposal units, and to direct the flow of stormwater. A geomembrane cover was installed over the NDA in 2008. In the SDA, the northern trenches were originally capped with 1.2 m (4 ft) of silty till soil, and later covered with 1.2 m (4 ft) of compacted silty clay soil. The southern trenches were originally covered with 2.4 m (8 ft) of compacted silty clay soil. In 1980, the covers on Trenches 11 through 14 were amended. In June 1993, a very low density polyethylene (VLDPE) geomembrane cover was installed over part of Trench 12 through Trench 14 (Figure 6). Other geomembrane covers were added to the remaining SDA trenches from 1995 to 1999.

Other types of covers may be considered as part of the Phase 2 decommissioning alternatives to be evaluated in the SEIS. These features will be modeled as appropriate to the alternatives under consideration.

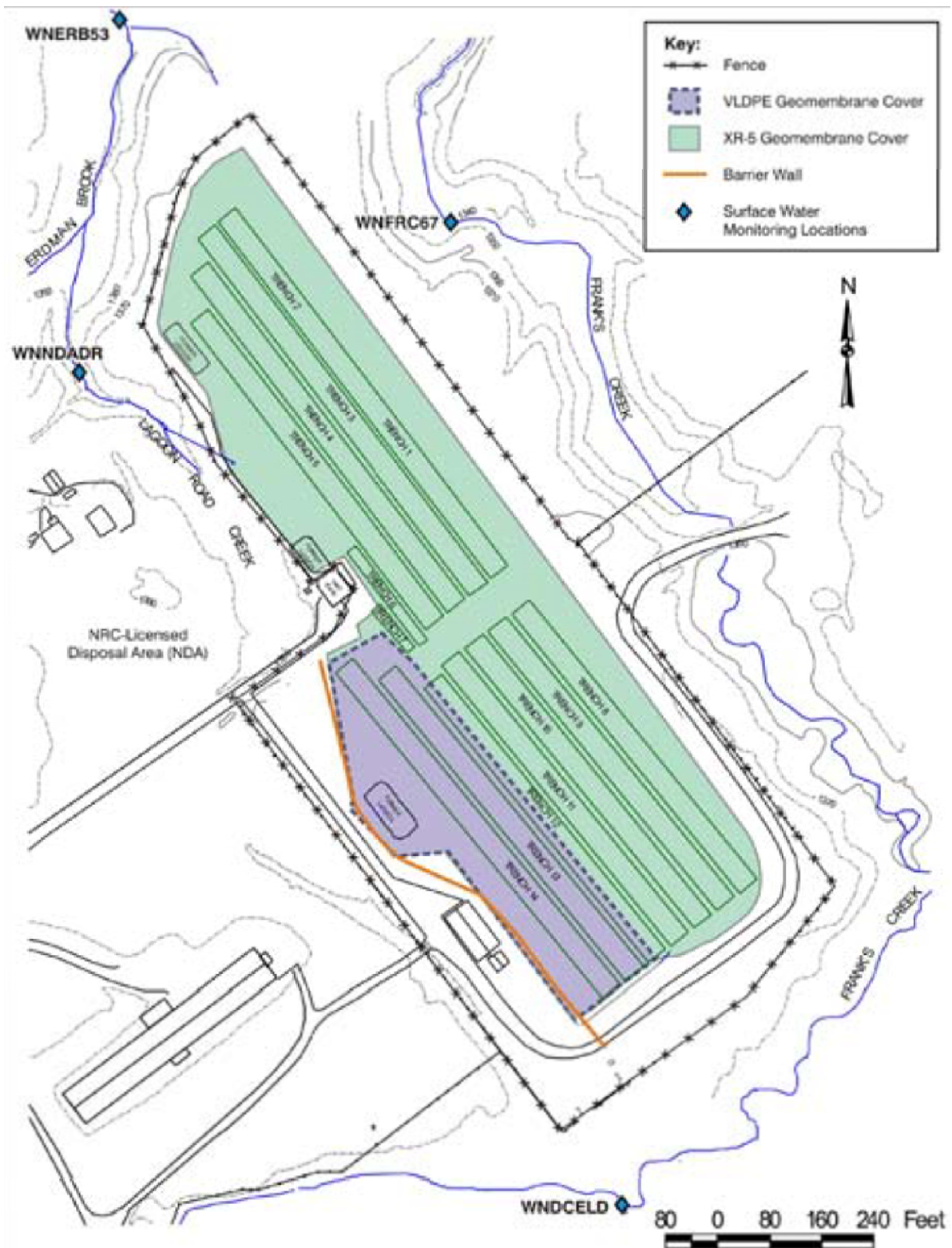


Figure 6. SDA trenches showing impermeable cover (from Ecology and Environment (2010), Figure 2-1). All of the SDA is currently under the XR-5 geomembrane cover.

3.2 Environmental Setting

3.2.1 Physiography and Topography

The West Valley Site is located in the glaciated Allegheny Plateau region of the Appalachian Plateau physiographic province in western New York State (Figure 7). This province is bounded by the Catskill Mountains and the Hudson-Mohawk lowlands to the east (Isachsen et al. 2000; NYSDOT 2013). To the north and west this province is bounded by the Central Lowland province along the shores of Lake Erie and Lake Ontario. The boundary between the plateau and the lowlands is marked by a series of escarpments (NYSDOT 2013).

The glaciated Allegheny Plateau is lower, more level, more fertile, and less forested than the unglaciated North Central Appalachians (Bryce et al. 2010). This area is characterized by rolling hills, wide valleys, and low mountains (Bryce et al. 2010). The physiography of the Allegheny Plateau in the vicinity of the West Valley Site is composed of two regions: the glaciated low Allegheny Plateau and the Cattaraugus Hills.

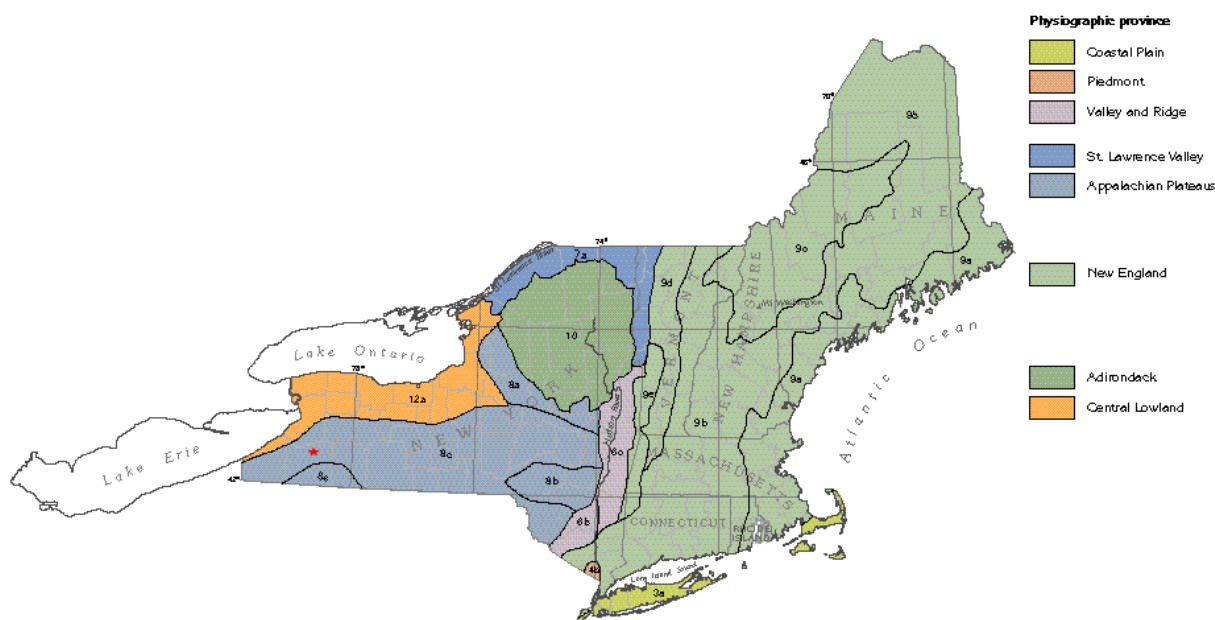


Figure 7. Physiographic provinces of New York and the New England States. The approximate location of the West Valley Site is indicated by the red star. (Adapted from Figure 2 of Ground Water Atlas of the United States, http://pubs.usgs.gov/ha/ha730/ch_m/M-text.html.)

The terrain of the glaciated Allegheny Plateau region has been smoothed by glaciers, resulting in rounded hilltops and broad stream valleys. Soils are shallow and drainage generally poor. The plateau is dissected by streams; the hilltops have been cleared for agriculture and the slopes are forested (Bryce et al. 2010).

The Cattaraugus Hills region lies between the West Valley Site and the lowlands, with Cattaraugus Creek forming the southern boundary of the Cattaraugus Hills section (Bryce et al.

2010). This section forms the lower slopes of the Allegheny Plateau (Bryce et al. 2010), with hills broader and lower and with more cleared land than further south on the Allegheny Plateau. Streams have cut deeply into the bedrock in this region but morainal blocking of streamflow to the north did not occur here, so lakes did not form in the valleys (Bryce et al. 2010).

Cattaraugus Creek flows westward from the vicinity of the West Valley Site across the Central Lowland physiographic province to Lake Erie (Figure 8). The Erie lake plain of the Central Lowland province is a narrow region several miles wide along the lake shore, sloping from 244 to 274 m (800 to 900 ft) to the level of Lake Erie and bordering the lake along the western edge of New York (NYSDOT 2013).

The West Valley Site is in a region of the Appalachian plateau that is dissected by drainages and altered by glaciation (LaFleur 1979). The Site is located on a glacial till complex that forms the floor of the valley of Buttermilk Creek (DOE 2010a; LaFleur 1979). Buttermilk Creek and its tributaries have shaped the landscape in the vicinity of the West Valley Site with streams that have downcut into bedrock and surrounding topography, creating ravines and uplands (DOE 2010a). Buttermilk Creek flows for 5 km (3 miles) to the north-northwest from the Site, where it joins Cattaraugus Creek.

The Buttermilk Creek drainage basin is shown in Figure 8. The Project Premises and SDA are separated into North and South Plateau areas by Erdman Brook (not shown in Figure 8) (DOE 2010a). Erdman Brook, Frank's Creek, and Quarry Creek drain the North and South Plateau areas. These stream channels are actively eroding the plateau areas by stream channel downcutting and valley rim widening (DOE 2010a). The maximum elevation on the West Valley Site of 435 m (1,426 ft) is located at the southwest corner of the property, and the minimum elevation of 338 m (1,109 ft) is at the confluence of Buttermilk Creek and Cattaraugus Creek at the northern extent of the Site (DOE 2010a).

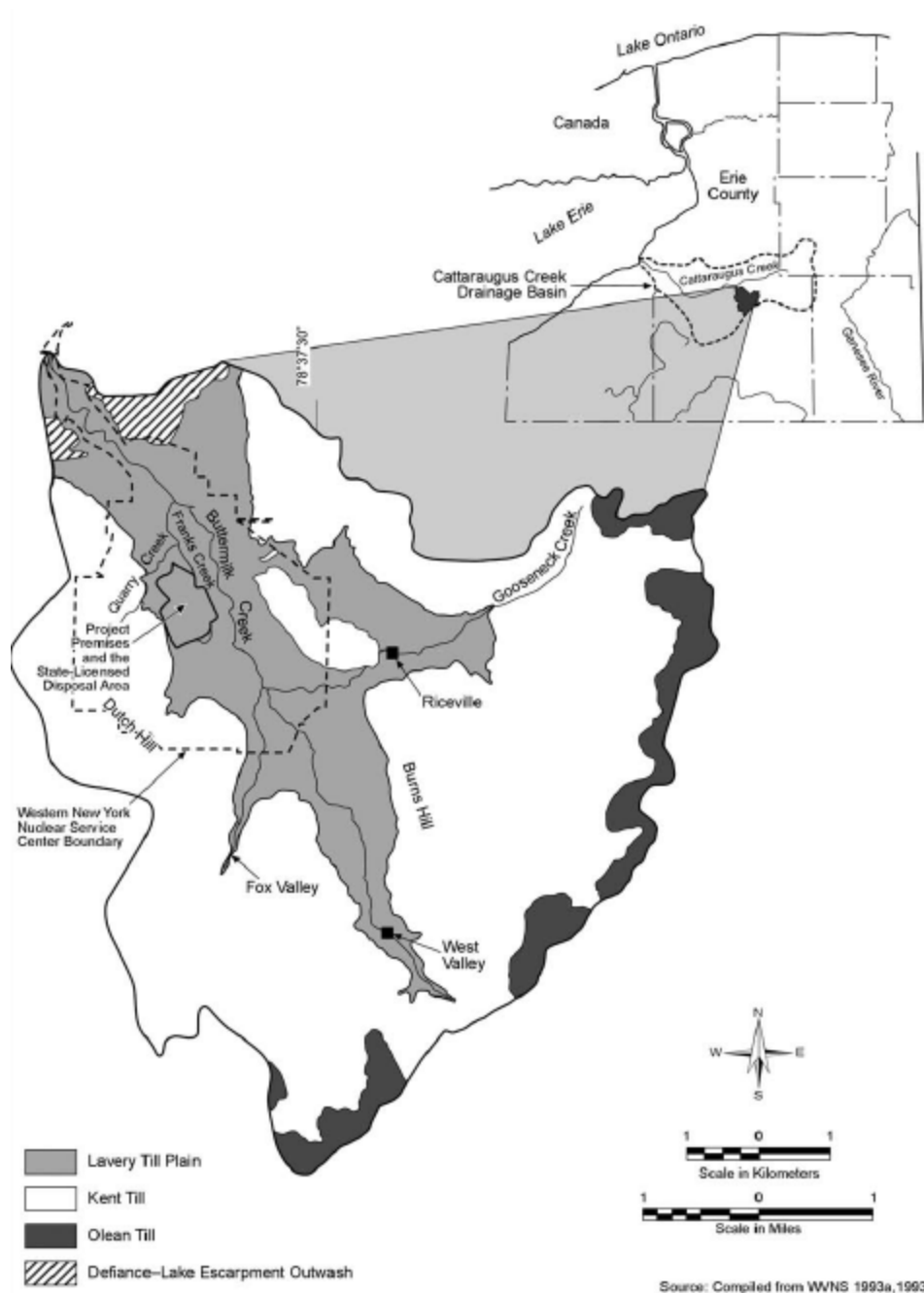


Figure 8. Cattaraugus Creek and Buttermilk Creek Drainage Basins. (Figure 3-19 from DOE (2010a).)

3.2.2 Demography

The FEIS (DOE 2010a), Section 3.10.2, discusses the socioeconomics of the Site area, including an assessment of demographics. This information has been updated, where necessary, using United States Census Bureau data and other sources as noted.

The West Valley Site is in north-central Cattaraugus County, New York. The nearest county, to the north, is Erie County. The nearest settlement is the hamlet of West Valley, in the Town of Ashford (note that “towns” in New York are municipal corporations that are major divisions within counties, similar to townships in other states). The nearest substantial settlements are Springville (14 km, or 9 mi from the WVDP, although the northern boundary of the WNYNSC is essentially adjacent to Springville), Machias/Lime Lake (11 km, or 7 mi), and Ashford (10 km, or 6 mi). The nearest urban/suburban area is the southern border of the Buffalo metropolitan area, approximately 40 km (25 mi) to the northwest. The Seneca Nation of Indians is located within Cattaraugus and Erie Counties and comprises the Allegany, Cattaraugus, and Oil Springs Territories. A relatively large Amish community is also located in the western part of the county.

The FEIS evaluated a Region of Influence (ROI) that included Cattaraugus and Erie Counties, as the West Valley Site is located near the border. The same geographic area is evaluated here.

The population of Cattaraugus County has grown from several thousand in the early 1800s to a peak of almost 86,000 in 1980. Since then, the population has been slowly shrinking. The US Census 2015 population estimate is 77,922 (US Census 2015). The population density of the county is approximately 24 persons per km² (61 persons per mi²). The total number of housing units is 41,048. According to Cornell University’s Program on Applied Demographics (Cornell University 2016), which makes projections based on demographic trends, the following near-future projections have been made for the county:

- 2020: 76,004
- 2030: 70,321
- 2040: 63,500

According to the 2010 census, the dominant race was White (94%), followed by Native American (3%), Hispanic (1%), Black (1%), Asian (<1%), and Pacific Islander (<1%) races.

The age distribution for the area indicates a bimodal distribution, with teens to early 20s and middle-aged residents 50–65 comprising the greatest percentage of the population. Projected distributions do not appear to change substantially in the future. Males and females appear to be represented in approximately equal numbers. The average household size is 2.5 and the average family size is 3.0 (Cornell University 2016). The median income for a household in the county is \$33,404, and the median income for a family is \$39,318. About 14% of the population lives below the poverty line.

The history of Erie County is similar to that of Cattaraugus County. There are two Seneca territories in Erie County. The Cattaraugus Territory overlaps with Cattaraugus County, and the Tonawanda Territory overlaps with Genesee County.

The population of Erie County is much larger than that of Cattaraugus County, largely due to the presence of the Buffalo metropolitan area. The population has grown from about 36,000 in 1830 to a peak of 1,015,000 in 1980. Since then, the population has been slowly declining. The US Census 2015 population estimate is 919,040 (US Census 2015). The population density of the county is approximately 340 persons per km² (880 persons per mi²). The total number of housing units is 383,164. According to Cornell University (2016), the following near-future projections have been made for the county:

- 2020: 878,075
- 2030: 829,685
- 2040: 769,396

According to the 2010 census, the dominant race was White (82%), followed by Black (13%), Hispanic (3%), Asian (1%), Native American (<1%), and Pacific Islander (<1%) races.

The age distribution for the area indicates a bimodal distribution, with teens to early 20s and middle-aged residents 50–65 comprising the greatest percentage of the population. Projected distributions appear to represent a more “even” distribution. Males and females appear to be represented in approximately equal numbers. The average household size is 2.4 and the average family size is 3.0 (Cornell University 2016). The median income for a household in the county is \$38,567, and the median income for a family is \$49,490. About 12% of the population lives below the poverty line.

The total current population in Cattaraugus and Erie Counties together is approximately 997,000. Over 80% of this population is white. Approximately 7,000 Native Americans live in the two counties (note that New York in general has the highest percentage of Native Americans among Eastern US States).

3.2.3 Land Use

The FEIS (DOE 2010a), Section 3.1.1, consists of an evaluation of the land use of the Site area. This information has been updated, where necessary, using other sources as noted.

The discussion below largely focuses on Cattaraugus County. If the ROI is expanded to Erie County, the degree of urban/suburban development and associated land uses increases dramatically. Lake Erie provides a wide variety of lake-related uses (recreation, commercial fishing, etc.). Therefore, most types of land uses that are conceivable in an Eastern US mixed rural/urban area are potentially applicable for defining future land use and receptor scenarios at the Site and in surrounding areas. It is entirely possible, for example, that a future land use of the Site itself would be as a town, a gravel pit, or a farm, or all of the above depending on the time frame.

Figure 9 indicates an approximately 6 km (4 mi) radius around the Site. Figure 10 indicates an approximately 80 km radius around the Site (the 50 mi radius of interest used in the FEIS).

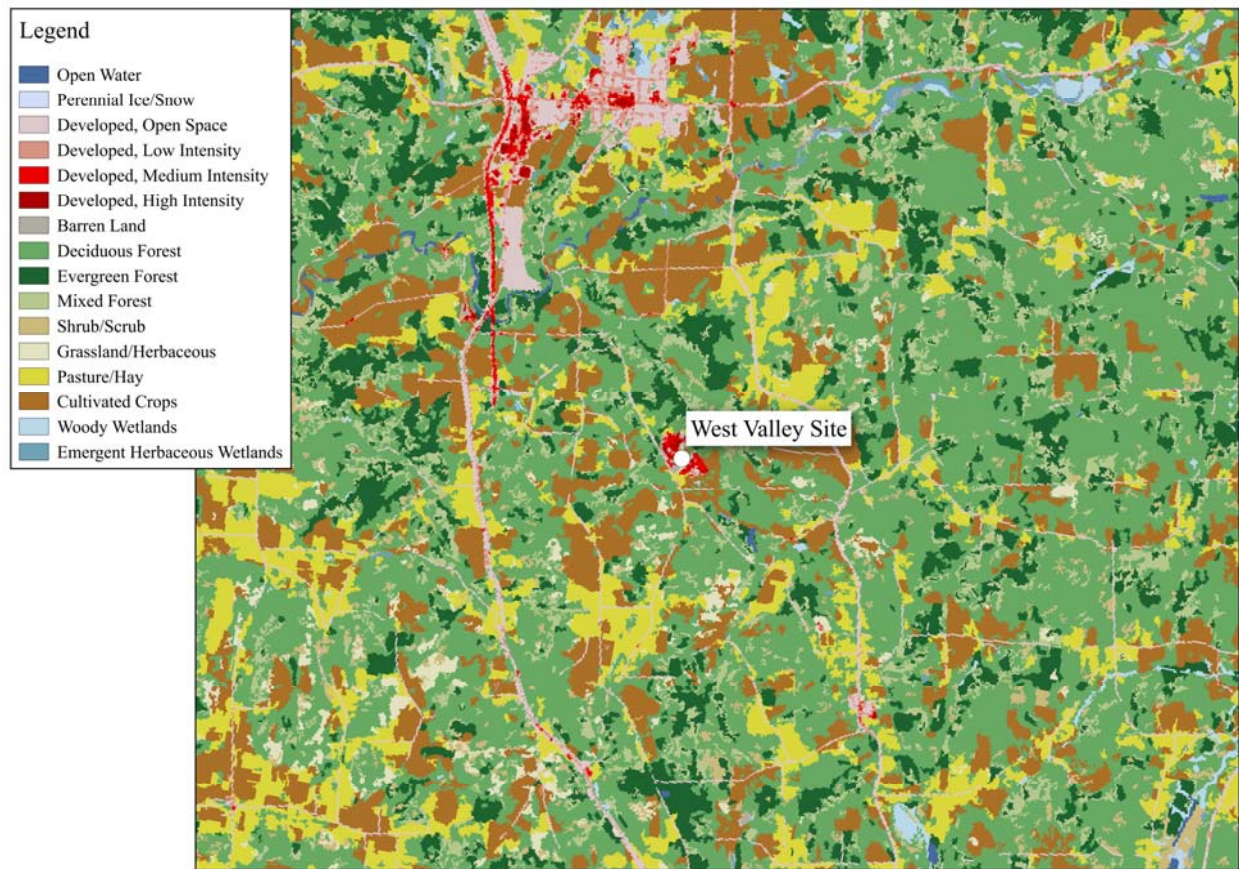


Figure 9. Land use within an approximately 6 km (4 mi) radius of the Site (Homer et al. 2015).

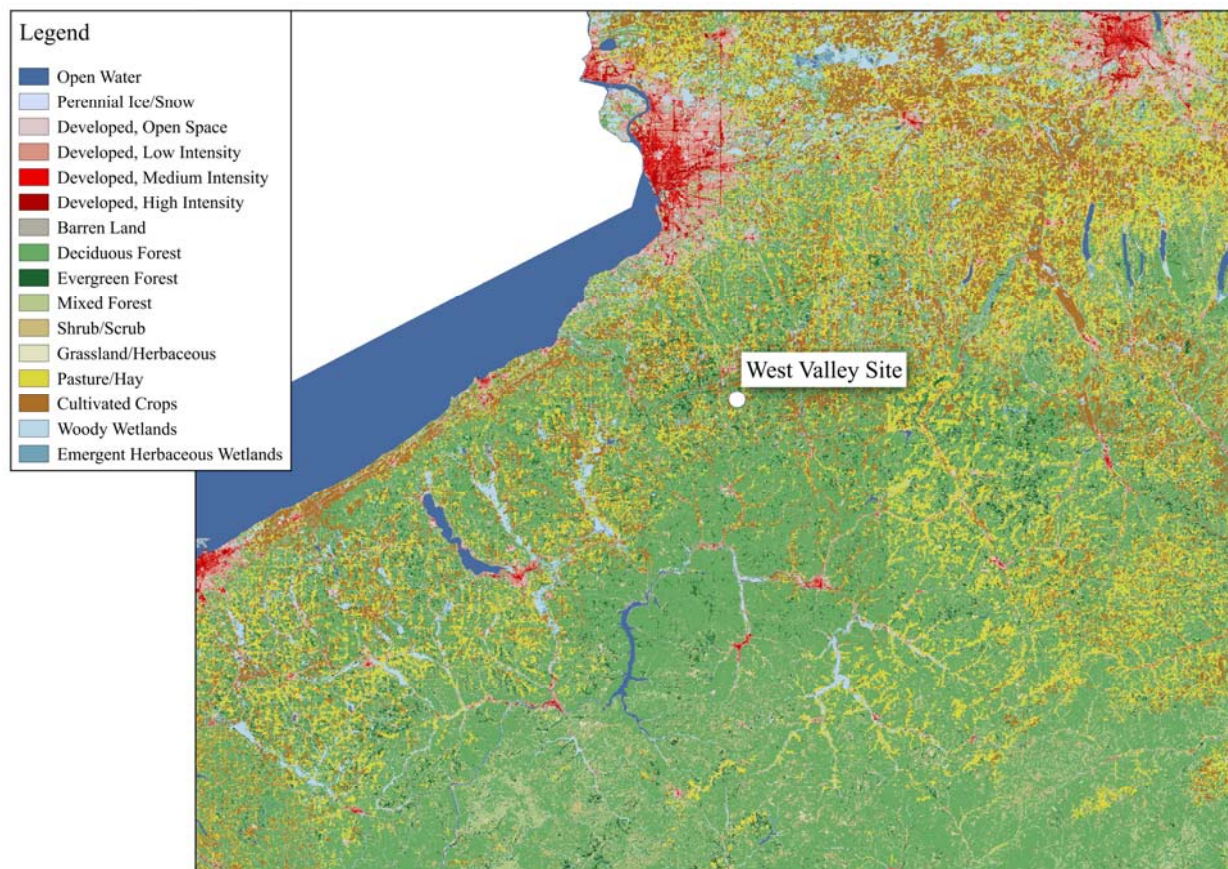


Figure 10. Land use within an approximately 80 km (50 mi) radius of the Site (Homer et al. 2015).

The overall setting in Cattaraugus County includes cropland, pasture, woodlands, and residential properties. Major land uses include the following (DOE 2010a):

- Residential (29.3 percent)
- Wild, forested, or conservation lands, plus public parks (22.8 percent)
- Vacant land (unspecified former use, 22.4 percent)
- Agriculture (19.2 percent)
- Community services, recreation and entertainment, public services, industrial, commercial, or unknown (6.3 percent)

Land use in the immediate vicinity of the Site (Figure 9) is predominantly agricultural. The number of Cattaraugus County farms in 2012 was over 1000, with a total area of almost 80,000 ha (197,000 ac). Major crops in terms of land usage include forage (hay, grass, etc.), corn for silage and grain, soybeans, and “woody crops” (e.g., Christmas trees). Major cash products include milk from cows, beef, and grains/beans. There are over 30,000 cattle, 33,000 bee colonies, 3000 chickens, and 1500 sheep in the county (USDA 2012). Other commercial agricultural products or activities include bison, bee colonies, hops, shitake mushrooms, maple syrup, and horses (Cattaraugus County 2016).

The hamlet of West Valley (in the Town of Ashford) is characterized by residential and commercial land uses. The larger Village of Springville includes residential, commercial, and industrial land uses. Urban land use increases north of the Site toward Buffalo and northwest along the Lake Erie shoreline (Figure 10). Recreational land use increases to the south toward Allegany State Park and west toward Lake Erie (DOE 2010a).

Many types of government, industrial, and commercial (retail and service-oriented) land uses exist in Cattaraugus County. The largest employers are the County of Cattaraugus, the Seneca Nation of Indians, the Seneca Allegany Casino and Hotel, Olean General Hospital, Dresser-Rand's Turbo Products Division, Cuttco Corporation, and several educational institutions (Cattaraugus County 2016). The FEIS mentions that "a small military research installation is located approximately 5 kilometers (3 miles) northeast of the Project Premises. The facility, operated by Calspan Corporation, is used to conduct research operations for the U.S. Department of Defense." However, no additional information was located regarding this facility, based on an Internet search. Representative industrial facilities in Springville include Winsmith-Peerless-Winsmith, Inc., a gear and conveyor drive manufacturer; Wayne Concrete Co., Inc., a readi-mix concrete supplier and concrete equipment manufacturing facility; and Springville Manufacturing, a fabricating facility for air cylinders.

There are 195 permitted, non-permitted, and reclaimed sand/gravel mines in the county, up to 40 ha (100 ac) in extent and 20 m (70 ft) deep. There are also clay and peat mines (New York State 2016a, 2016b). There are over 2300 currently producing oil and/or gas wells in the county (Drilling Edge 2016).

State parks near the Site include Allegany State Park to the south, and two parks on Lake Erie to the northwest. There are 18 State Forests, and two State Wildlife Management Areas in Cattaraugus County. In addition, there are numerous Cattaraugus County Parks, as well as municipal parks. There are hiking and snowmobile trails that pass near the Site. Cattaraugus Creek north of the Site is a popular fishing destination. The Zoar Valley State Multiple Use Area is a popular area on Cattaraugus Creek that is used for hunting, hiking, white-water rafting, and wildlife/scenic viewing.

Observed changes over time in Cattaraugus County include a decrease in active agricultural land acreage, an increase in maturing forest acreage, and an increase in the number of recreational, commercial, and residential lots. Residential growth is expected to continue in the Towns of Yorkshire, Machias, and Ashford (which includes the Site). Other towns in the county are expected to remain largely rural. Commercial land use is expected to continue in the commercial areas of the county's main population centers. Industrial land use is expected to increase in the Town of Yorkshire. Various business and industrial parks are currently planned or being built throughout the area (DOE 2010a).

3.2.4 Natural Resources

"Natural resources" is a broad term that can encompass all of Earth's resources that exist in the absence of humans. These can include air, water, land, geology, and biota. Here, the term is used in the context of human use. Natural resources in this context for most Western US radioactive waste disposal facilities are limited, as they are located in isolated arid areas. However, western

New York contains a larger human population and a wider variety of natural resources that are used or exploited by humans as compared to these sites.

Water is a major resource in the Site area. For example, the Cattaraugus Creek drainage, north of the Site, is designated as a “sole source aquifer” under the Safe Drinking Water Act, as described in Sections 3.6.2.2 and 5.2 of the FEIS (DOE 2010a; EPA 2003a). Sole-source aquifers have no alternative source or sources that could physically, legally, and economically supply all those who obtain their drinking, agricultural, or other-use water from the aquifer. Sole-source aquifers are protected from Federal financially assisted activities determined to be potentially unhealthy for the aquifer. However, aquifer systems in the Site area are generally discrete, isolated, and not connected, as discussed in Section 3.2.8.2.1.

Fishing is a major use of surface water resources in the area. For example, Cattaraugus Creek is a major destination for recreational trout fishing (DEC 2009). Lake Erie is the 13th largest lake in the world, and one of the world’s largest freshwater commercial and sport fisheries. Fish populations declined due to industrial and other-source pollution in the 1960s, but these have largely rebounded. Although precise numbers do not appear to be available, a 2005 Great Lakes Fishery Commission report (GLFC 2005) lists “a potential annual sustainable harvest of 13.6–27.3 million kg (30–60 million lb)” for Lake Erie in general. The Eastern Basin, adjacent to western New York, provides habitat for walleye, smallmouth bass, yellow perch, whitefish, rainbow smelt, lake trout, rainbow trout, and other salmonids, as well as other species of valued fish.

As agriculture (both plants and animals) is a dominant land use in Cattaraugus County (see Section 3.2.3, Land Use), soils are an important natural resource. Soil quality also contributes to forest resources. Wild or forested lands (including parks) comprise 22.8 percent of the county (DOE 2010a). Data on annual yields of hardwood trees in the county were not located, but the latest “Stumpage Price Report” for western New York (DEC 2016) lists prices up to over \$1660 for a single black cherry tree.

Aside from the economic value of trees, Cattaraugus County contains a number of parks and wild areas that contribute to the economy in terms of tourism (hiking, hunting, fishing, sightseeing, rafting, skiing, etc.) and other uses. State parks (Section 3.2.3) such as Allegany State Park to the south, two parks on Lake Erie to the northwest, and the Zoar Valley State Multiple Use Area on Cattaraugus Creek provide nearby recreation opportunities.

As previously indicated, there are sand, gravel, clay, and peat mines in the county, as well as oil and gas wells.

3.2.5 Meteorology and Climate

Local and regional meteorological processes, climatic forcings, and feedback effects influence which human activities, processes, and pathways are likely to determine the release and transport of wastes. Climate affects the characteristics of home construction, agriculture, and industry. Climate also affects the ecology of a region, erosion potential, and drainage to the aquifer. An understanding of relevant meteorology and climate is a requirement for the development of a CSM.

3.2.5.1 Climate Classification

The West Valley Site is located in a region classified as having a warm summer continental climate with significant precipitation in all seasons according to the Köppen climate classification of “Dfb” (Peel et al. 2007). Criteria for this climate classification are that the temperature of the hottest month exceeds 10°C (50°F), the temperature of the coldest month is less than or equal to 0°C (32°F), the temperature of the hottest month is less than 22°C (72°F), and the number of months with temperature above 10°C (50°F) is greater than or equal to four.

3.2.5.2 Influence of Atmospheric Circulation

The prevailing upper level winds in eastern North America are westerly (Barry and Chorley 2003; WVNS 1993d). This is a result of unobstructed air mass movement across the interior of the continent due to the low topography. Air masses from the Arctic or the Gulf of Mexico are able to move eastward across the interior and move through or near the State of New York (Barry and Chorley 2003; SRI 2012). This planetary scale atmospheric circulation brings cold, dry air from the northern interior of the continent as well as warm, humid air from the Gulf of Mexico, providing a wide range of temperature and moisture conditions to the northeast (SRI 2012).

The polar jet stream is a band of strong upper level westerly winds located between latitudes 40 and 50°, with the strongest winds occurring over eastern North America in winter (Barry and Chorley 2003). Variations in the track of the jet stream during winter can result in abnormal weather conditions in the northeast as the jet stream blocks or enhances the movement of pressure systems (Barry and Chorley 2003; SRI 2012).

Weather and climate are influenced by the movement of atmospheric pressure systems across the continent. Cyclonic systems are low pressure systems of circulating air characterized by horizontal convergence of air resulting in the rise of air in the center of the system. The air cools as it rises and moisture condenses to form clouds and precipitation (Barry and Chorley 2003; WVNS 1993d). These low pressure systems crossing the West Valley Site regularly result in significant precipitation over all seasons (WVNS 1993d). An anticyclonic system is a high pressure system with sinking air that diverges at the surface, usually associated with fair weather (WVNS 1993d). Unusually cold or warm weather in the vicinity of the Site can result from anticyclonic systems (WVNS 1993d). Anticyclonic systems of arctic air masses flowing south from central Canada or Hudson Bay produce abnormally cold temperatures in New York, while stalled systems off of the Atlantic coast produce airflow from the southwest or south, keeping temperatures unusually warm and humid during the summer or more moderate during other seasons (SRI 2012).

3.2.5.3 Influence of Physiography

Characteristics of the Earth surface also exert influences on climate. These include topography and the influence of nearby large water bodies.

Topography

Climate and atmospheric processes are affected by the regional and local topography. These influences include total precipitation, snowfall, wind speed, and wind direction (DOE 2010a). The region has been altered by glaciation and dissected by drainages. Elevations in the region vary from 175 m (574 ft) at the mouth of Cattaraugus Creek on Lake Erie to 640 m (2,100 ft) on hill tops near the Site (WVNS 1993d). The topography of the Site and surrounding region is described in Section 3.2.1.

Lake Erie

Heavy snowfall in the vicinity of the Site occurs due to the increase in elevation between Lake Erie and the Site combined with the moist air produced by the lake. During winter, westerly winds crossing Lake Erie are forced to rise by the topography, resulting in cooling of the air and condensation that produces precipitation (WVNS 1993d). These “lake-effect” storms occur most often in November and December before the lake surface freezes (Prudic 1986).

Inland water bodies like Lake Erie have a moderating influence on temperature, acting to lower temperatures in summer and raise temperatures in early winter (Barry and Chorley 2003). This moderating effect is of importance for the production of frost-sensitive crops (SRI 2012). Lake Erie warms slowly during the spring. This slow warming reduces the temperatures of the land areas and slows plant growth early in the year, minimizing frost damage during early stage growth. In the fall, the lake cools more slowly than the land surface, keeping air temperatures higher and lengthening the growing season (SRI 2012).

3.2.5.4 Meteorological Records

The following sections discuss meteorological records that characterize climate at the Site. Data are presented from the West Valley Site meteorological station, the National Oceanic and Atmospheric Administration (NOAA) station in Arcade, NY, and the NOAA Buffalo Niagara International station in Buffalo, NY. The location of the WVDP (West Valley Site) station is in the southwest portion of the Site. The NOAA Arcade station is located approximately 20 km (12 mi) northeast of the Site at a similar elevation to the Site. The NOAA Buffalo Niagara International station is located approximately 54 km (34 mi) north of the Site.

Temperature

Thirty-year averages of monthly maximum and minimum temperatures from the nearby Arcade station compiled by the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>) are shown in Figure 11. Minimum temperatures in January, the coldest month, average -9.6°C (14.8°F). Maximum temperatures in July, the hottest month, average 13.6°C (56.5°F). The average annual temperature is 7.9°C (46.2°F). Average monthly minimum temperatures are below freezing for five months of the year.

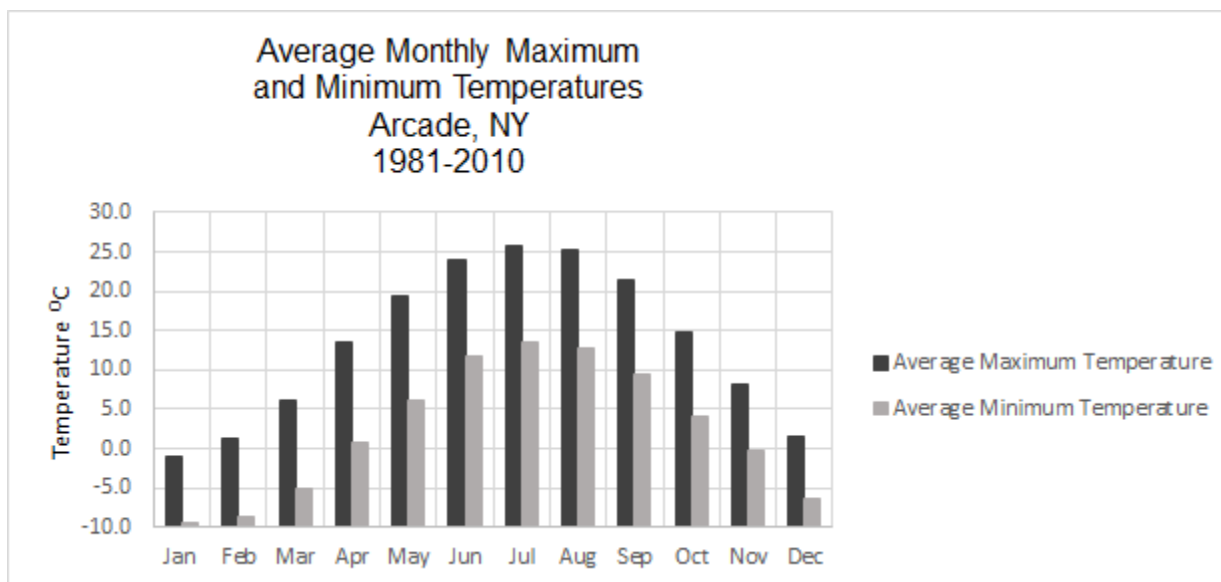


Figure 11. Average monthly maximum and minimum temperatures measured at the Arcade, NY NOAA station for the years 1981 through 2010 (Source: Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>).)

Precipitation

The type and amount of precipitation in western New York is strongly influenced by topography and proximity to large water bodies (SRI 2012). Total annual precipitation at the Site averages 1080 mm (42.4 in) (DOE 2015), with most of the precipitation in winter coming as snowfall (WVNS 1993d). Average monthly total precipitation measured at the Site is shown in Figure 12. Total average precipitation is spread throughout the year with no seasonal pattern. Monthly averages range from 59 to 126 mm (2.3 to 5 inches). Precipitation in summer occurs as the result of the passage of low pressure systems through the region, with either warm or cold fronts, or from thunderstorms developing as air heated by the ground surface rises (WVNS 1993d).

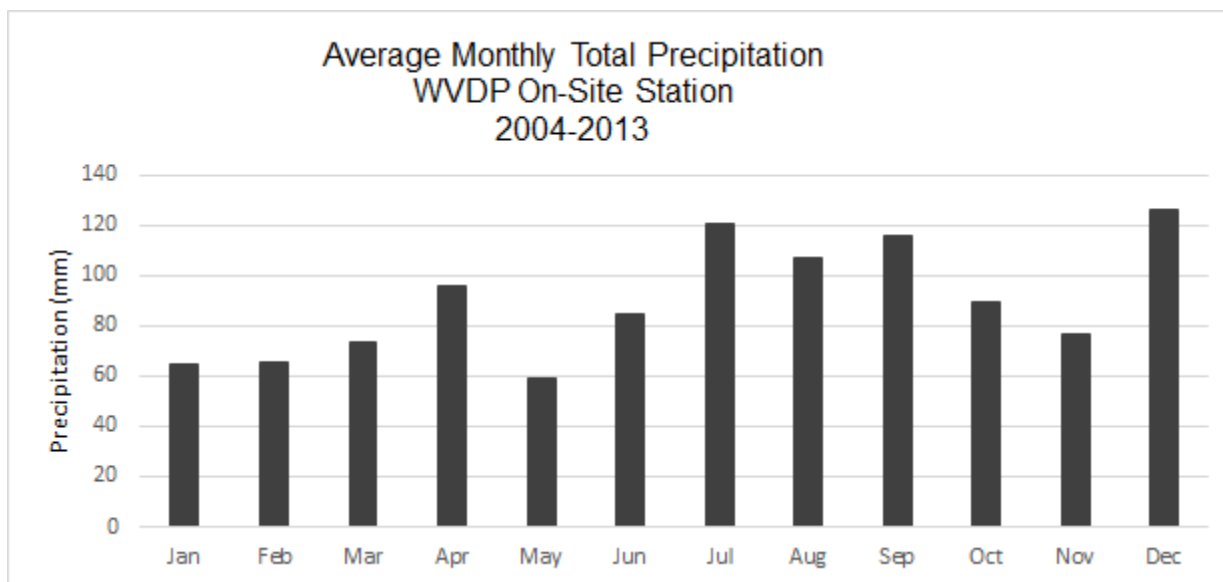


Figure 12. Average monthly total precipitation recorded at the on-site meteorological station for the years 2004 through 2013 (DOE 2015).

Snow

Average annual snow totals for the years 1981 through 2010 compiled by the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>) are shown in Figure 13. The approximate location of the Site is shown on the map as a star. The Site is located between the 80 in/yr and 100 in/yr (2.0 and 2.5 m/yr) snow total contours. The effects of Lake Erie and Lake Ontario on snowfall totals can be seen from the map contours.

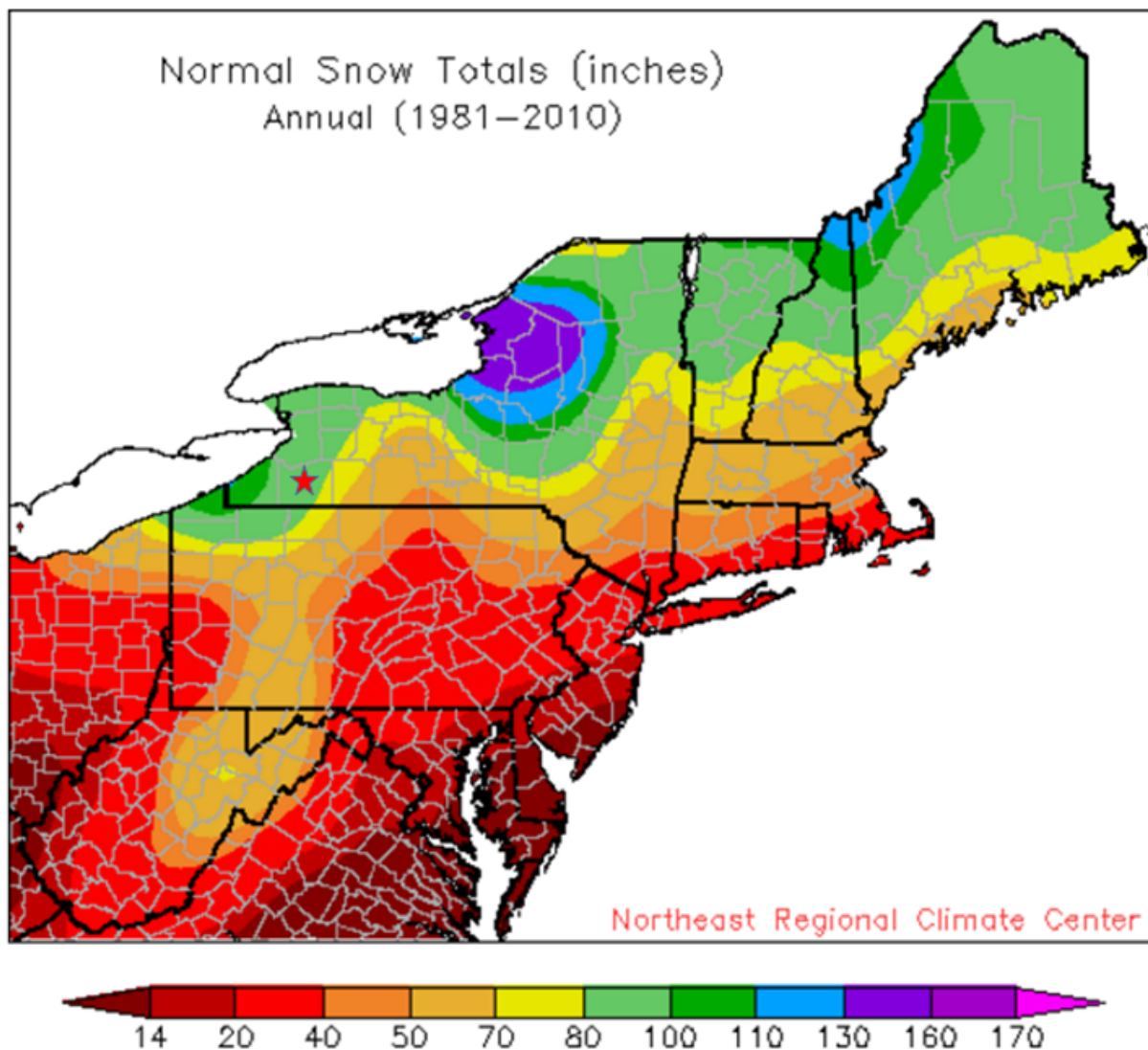


Figure 13. Average annual snow totals in inches. The approximate location of the Site is indicated by the star. (Source: Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>).)

Monthly average snow totals for the Arcade, NY station compiled by the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>) for the same years are shown in Figure 14. The highest average monthly snowfall of 0.67 m (26 in) occurs in December.

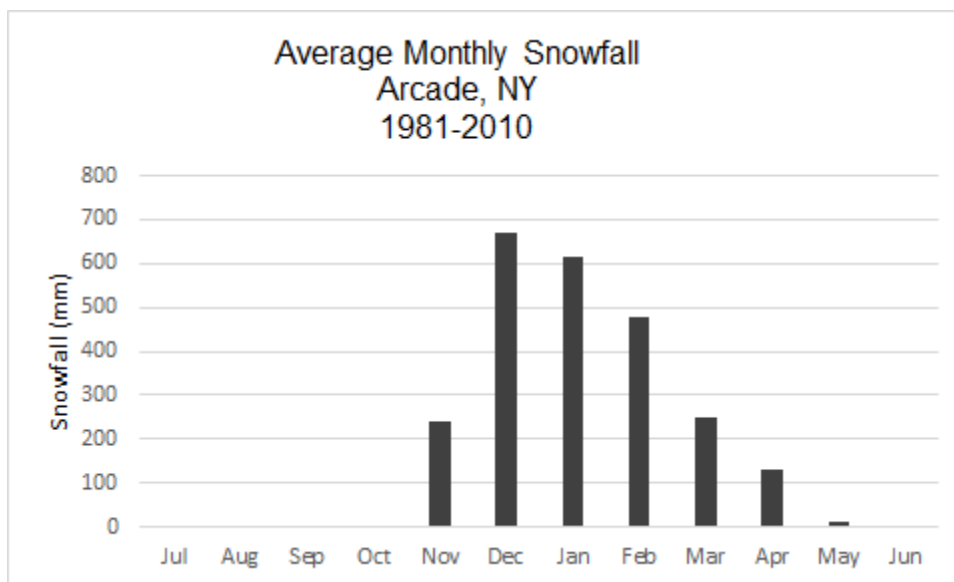


Figure 14. Monthly average snowfall recorded at the Arcade, NY station. (Source: Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>).)

Evapotranspiration

Potential evapotranspiration (PET) can be calculated from hourly measurements that are made at first-order weather stations. The closest station to the Site with these data acquisition capabilities is located in Buffalo. Monthly PET estimates calculated using a modified Penman-Monteith method (DeGaetano et al. 1994) for Buffalo data are shown in Figure 15. These values represent the average PET for a grass-covered surface.

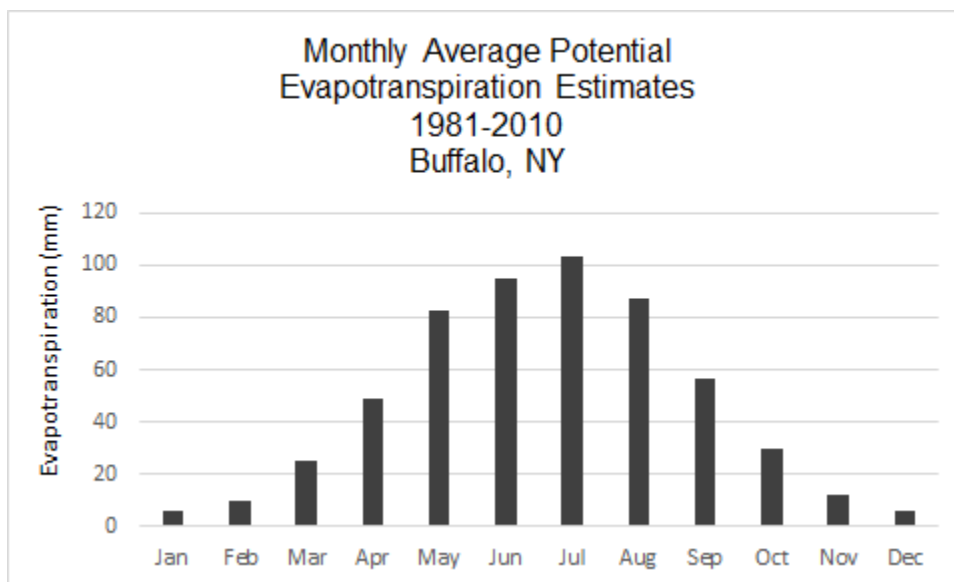


Figure 15. Calculated monthly average potential evaporation estimates for Buffalo, NY for the 30-year period 1981–2010. (Source: Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/wxstation/pet/pet.html>).)

For the 30-year record the total average annual estimated PET is 563 mm (22.2 in), approximately one half of the 10-year average annual precipitation measured at the Site. PET reaches its highest average monthly value of 103 mm (4.1 in) in July and its lowest value in December and January of 6.1 mm (0.24 in).

Evaporation from a Class A pan located at the on-site meteorological station is reported by WVNS (1993d) to be approximately 910 mm (36 in) per year. Pan evaporation measurements are generally larger than PET calculated for a reference surface such as grass. The magnitude of adjustment coefficients used to convert pan evaporation measurements to equivalent PET depend on the extent of vegetation around the pan, wind speed, and relative humidity with coefficients ranging from 0.5 to 0.85 (FAO 2016). Using this range of coefficients, annual PET at the Site could range from 455 to 773 mm (18 to 31 in). The estimates calculated from the Buffalo station data are within this range.

Relative Humidity

Monthly average morning and afternoon relative humidity observations over a 52-year time period for Buffalo compiled by the Northeast Regional Climate Center (Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/>)) are shown in Figure 16. Relative humidity observations are shown as the ratio of the vapor density of an air sample to the saturation vapor density at the same temperature expressed as a percentage (Campbell 1977). Relative humidity changes throughout the day, with morning observations showing values higher than afternoon observations for all months. The annual average for morning observations is 79 percent and for afternoon observations 62 percent.

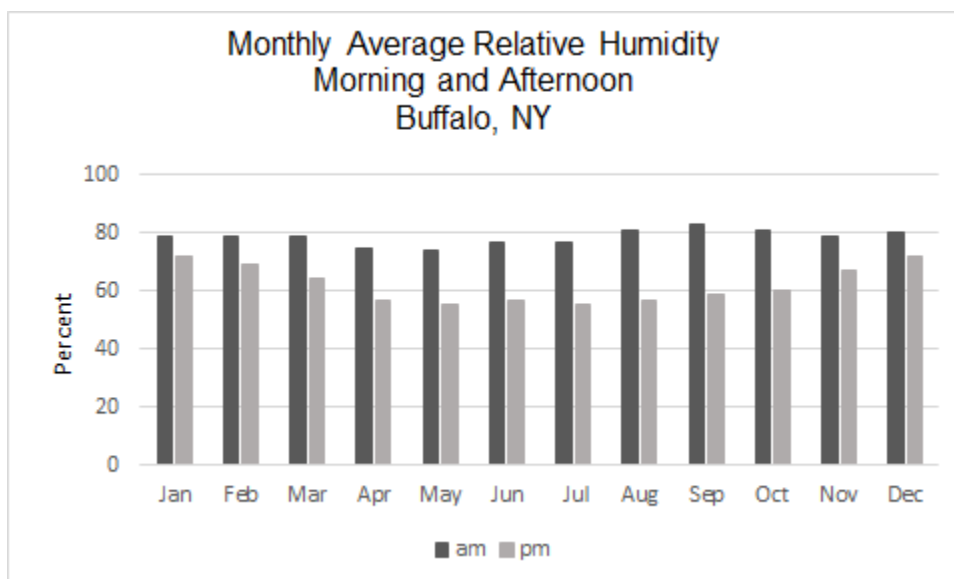


Figure 16. Monthly average morning and afternoon relative humidity observations for Buffalo. (Source: Northeast Regional Climate Center (<http://www.nrcc.cornell.edu/wxstation/comparative/comparative.html#>).)

Wind

Regionally the prevailing wind is southwesterly ranging from northwest to southeast. However, locally, terrain and vegetation influence both wind speed and direction (SRI 2012; WVNS 1993d). This is illustrated by the distribution of wind speed and direction at the 10-m and 60-m towers located at the on-site meteorological station for the year 2014 (DOE 2015), shown in the wind roses in Figure 17.

The observations from the 10-m tower show the influence of topography and vegetation. At this height wind speeds rarely exceed 6 m/s (13 miles per hour [mph]) and winds are channeled in the Buttermilk Creek Valley, resulting in a dominant pattern of northwest and south-southeast flows (WVNS 1993d).

The observations from the 60-m tower are taken above the influence of local topography and represent regional conditions. Wind directions are more variable, with an average flow from the southwest and higher wind speeds.

Average monthly wind speeds compiled from observations from the 10-m tower for the years 1984–1989 are shown in Figure 18 (WVNS 1993d).

A characteristic of wind flow at the Site resulting from topography is the occurrence of upslope and downslope winds. Local control of surface winds by terrain features is described generally by Barry and Chorley (2003). Under warm, clear sky conditions, upslope winds develop due to differential heating of the valley sides and floor. At night the process reverses, with the dense cold air draining downslope. The West Valley Site is positioned on the upper slopes of a ridge where local air flow is influenced by these winds.

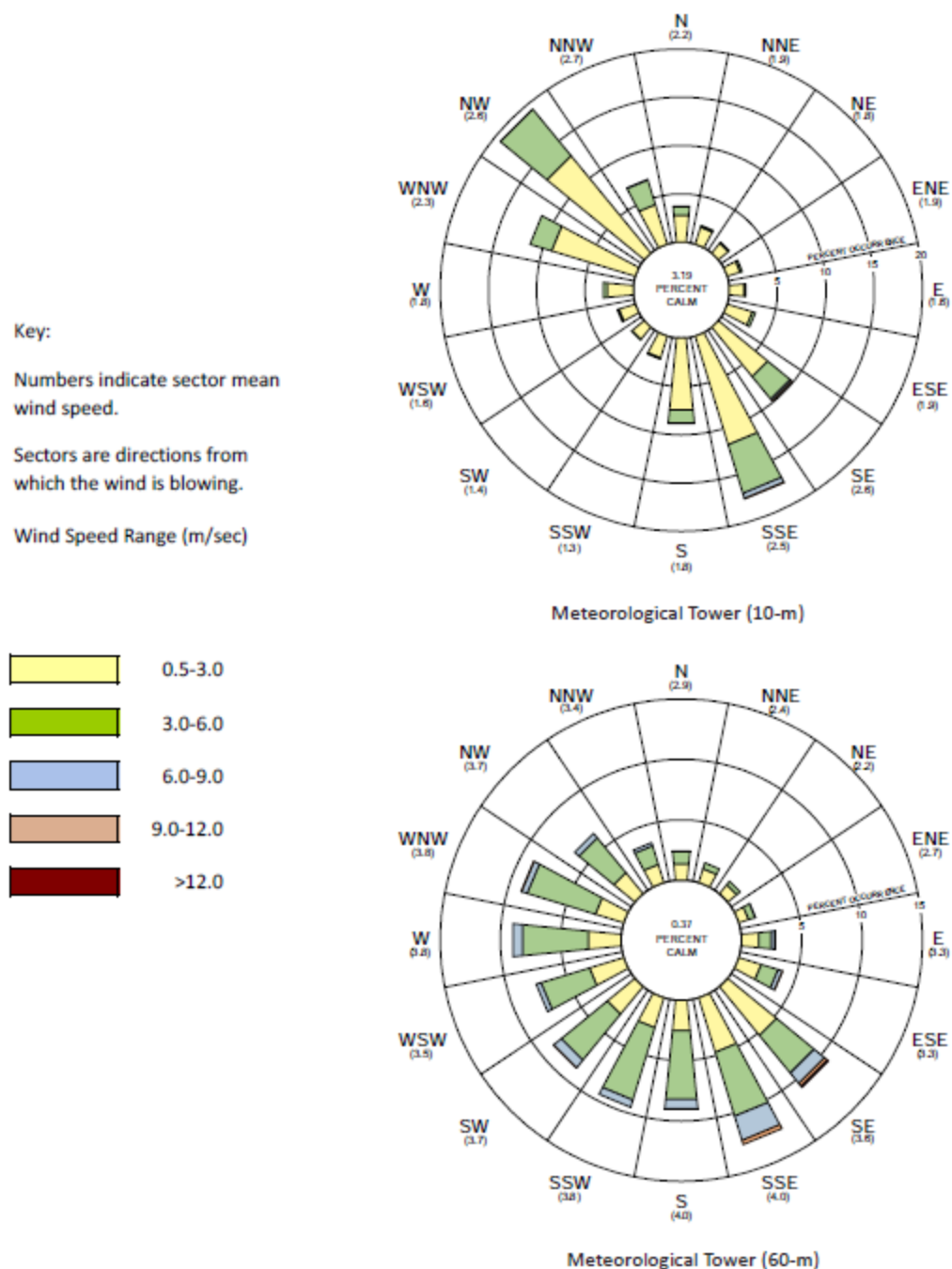


Figure 17. Wind roses compiled from observations at the 10-m and 60-m tower at the on-site meteorological station showing the distribution of wind speed and direction for 2014 (DOE 2015).

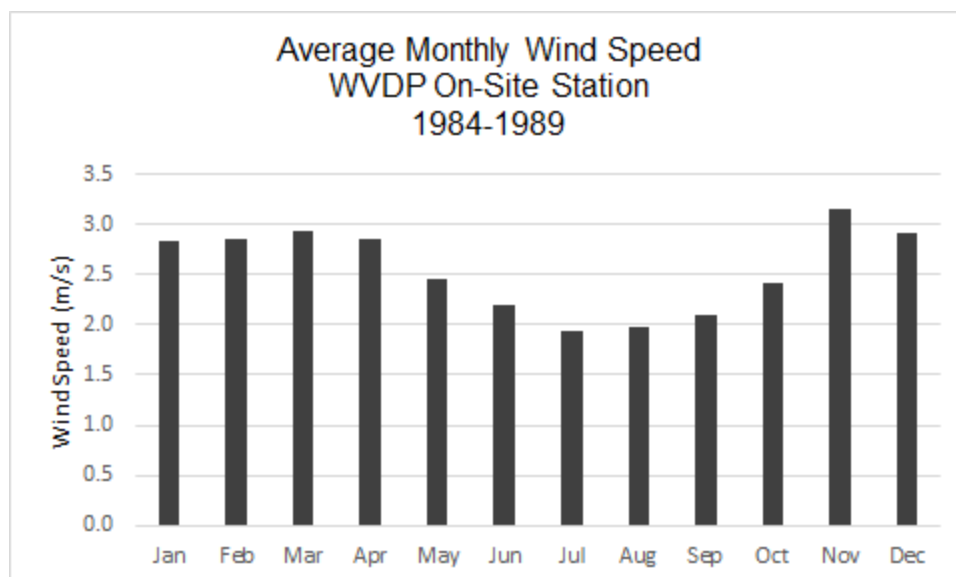


Figure 18. Average monthly wind speeds from the 10-m tower at the on-site meteorological station for the years 1984–1989 (WVNS 1993d).

3.2.5.5 Severe Weather

Thunderstorms and freezing rain incidents do occur in the region of the Site. The NOAA Storm Events Database indicates that, since 1955, 278 thunderstorm wind events have been recorded for Cattaraugus County. Two of the events occurred in the vicinity of the hamlet of West Valley. The first occurred in January of 2012 with winds of 27 m/s (60.4 mph) recorded and associated property damage estimated at \$10,000. The second event occurred in July of 2014 with winds of 26 m/s (58.2 mph) recorded and associated property damage estimated at \$15,000 (NOAA 2016).

Flash floods occur in Cattaraugus County (NOAA 2016) but impact to facilities is not considered likely due to the location of the Site on the upper slopes of a ridge (WVNS 1993d). Flooding at the Site is discussed in more detail in Section 3.2.8.1.3.

Snowfall averages in the vicinity of the Site were discussed above. A heavy snow storm event is defined by NOAA as 10 cm (4 in) or greater accumulation in 12 hours or less or snowfall accumulation of 15 cm (6 in) or more in 24 hours or less. The NOAA Storm Events Database (NOAA 2016) reports 85 events in the Cattaraugus zone since March of 1996, resulting in a reported \$12.7 million in property damage.

Twenty-nine high wind (straight-line wind) events have been recorded in the Cattaraugus zone since 1996, resulting in an estimated \$2.6 million in property damage. The prevailing directions of high winds are 66 percent from the southwest and 25 percent from the west due to the orientation of Lake Erie (Fujita et al. 1979). Maximum straight-line wind speeds at the Site expected over a range of time periods were estimated by Fujita et al. (1979). These speeds were 30 m/s (67 mph) over a ten-year period, 36.7 m/s (82 mph) over 100 yr, and 43.4 m/s (97 mph) over 1,000 yr.

Fujita et al. (1979) describe straight-line winds as being the dominant process that determines risk for probabilities of 10^{-5} or higher. These authors explain that at lower probabilities the primary phenomena for developing higher wind speeds are tornadoes. Results of their analysis for the Site provide an estimate of the probability of a tornado generating a maximum wind speed of 22.4 m/s (50 mph) of 10^{-4} . The authors reframe this estimate, stating that a tornado of maximum speed of 50 mph should occur in any given square-mile of the Site only once in 10,000 yr.

The NOAA Storm Events Database (NOAA 2016) reports 16 tornadoes in Cattaraugus County since May of 1961. These events include three F0 and one EF0 tornado, four F1 and three EF1 tornadoes, one EF2, and two F3 tornadoes, resulting in a reported \$13.9 million in property damages.

3.2.5.6 Air Dispersion

The temporal and spatial distribution of airborne contaminants on-site depends on the release rate of gases and the resuspension of soil particles from the ground surface, which is influenced by surface winds, surface roughness, vegetation, and soil characteristics. The temporal and spatial distribution of airborne contaminants off-site occurs by dispersion by wind, which depends on topography, vegetation, season, and time of day.

Processes and characteristics occurring at the Site that increase dispersion and lead to mixing and dilution of contaminants released to the atmosphere include the large aerodynamic roughness due to terrain and forests. Larger values of the roughness length produce greater horizontal and vertical mixing. In addition, higher wind speeds and unstable atmospheric conditions are associated with increased mixing heights that will reduce atmospheric concentrations. Seasonal mixing heights observed at Buffalo are shown in Figure 19. Assuming that the upper atmospheric conditions at Buffalo are similar to the Site, dispersion will on average increase through the daylight hours during the spring, summer, and autumn as the mixing height grows.

Processes that suppress mixing and turbulence, leading to higher airborne contaminant concentrations, include light winds and clear nighttime skies that lead to strong shallow temperature inversions. The generation of turbulence due to air moving over rough surfaces is reduced with lower wind speeds, and temperature inversions act to suppress vertical mixing. Both of these processes lead to increased contaminant concentrations in air. Vertical mixing can also be reduced on cold clear nights as the flow of cold downslope drainage winds into low areas intensifies temperature inversions. The deep, narrow geometry of the creek valleys is another feature of the Site that can reduce dispersion through channeling of air movement.

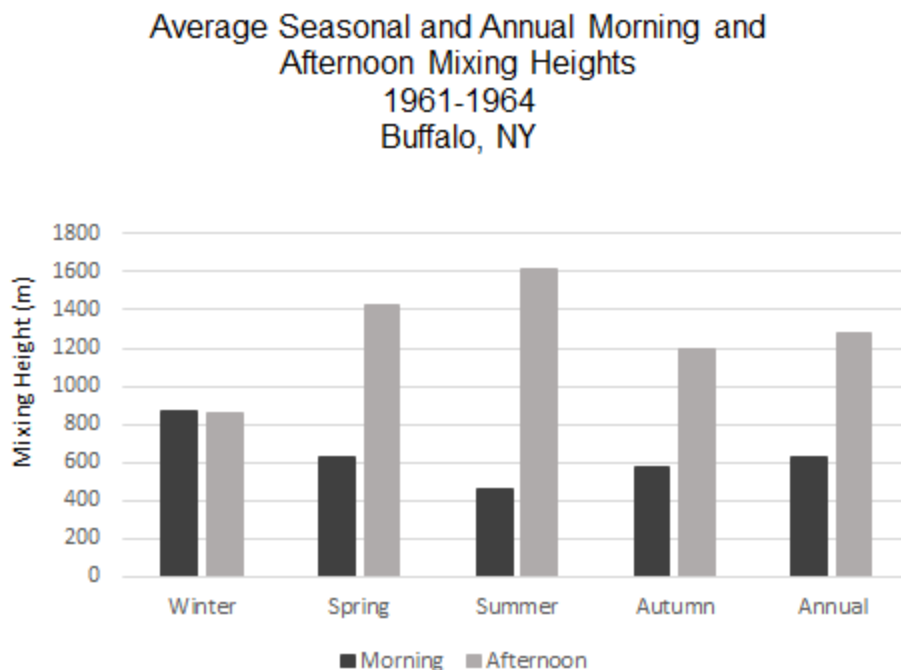


Figure 19. Average morning and afternoon mixing heights by season observed at Buffalo, NY for the years 1961–1964 (Holzworth 1972).

3.2.6 Ecology

The West Valley Site lies within the northern deciduous forest biome, and the diversity of its vegetation is typical of the region. Equally divided between forest and open land, the Site provides a habitat especially attractive to white-tailed deer and various indigenous and migratory birds, reptiles, and small mammals. No species on the federal endangered species list are known to reside on the Site.

3.2.6.1 Plants

The ecoregions of the United States provide some information on the plant communities expected in various geographic areas. The West Valley Site is in the Level III Northern Appalachian Plateau and Uplands ecoregion (Omernik 1987). The State of New York designates this as the High Allegheny Plateau Ecoregion (<http://www.dec.ny.gov/animals/9402.html>), which is defined by a broad series of high elevation hills that form a plateau rising to 1,700–2,100 ft, extending in the north from the Great Lakes Plains of Lake Ontario to the ridge and valley region of the Central Appalachians to the south, and from the Lake Erie Plain in the west to the Hudson River Valley.

Plant surveys have been conducted in the larger West Valley Site (that includes the WVDP area) to document the ecological resources as part of NEPA evaluations. These studies have been

documented in the WVDP-EIS-010 (WVNS 1994a). A summary of the findings related to terrestrial vegetation is presented below:

- The Site is within the Eastern Deciduous Forest Floristic Province, and its climax community forests are characterized by the dominance of sugar maple, beech, and eastern hemlock.
- The Site is about equally divided between forestland and abandoned farm fields.
- Plants found on-site have been categorized into thirteen plant communities. The plant communities found on-site are characteristic of western New York.
- The relatively undisturbed nature of large portions of the Site allowed natural succession of previous agricultural areas within its boundaries. Because neither the setting nor the former agricultural land use are unique, the forest communities that will eventually develop in the abandoned fields will be common to the region.

3.2.6.2 Mammals

Wildlife surveys have been conducted in the larger West Valley Site (that includes the WVDP area) to document the ecological resources as part of NEPA evaluations. These studies have been documented in the WVDP-EIS-010 (WVNS 1994a). A summary of the findings related to mammals is presented below:

- Terrestrial wildlife is abundant within the Site and surrounding areas because of the mixture of open areas and forested lands as well as the Site's protected nature.
- Common game species found on the Site and in the region include whitetail deer, Eastern cottontail, and red fox.
- Characteristic of the region, beavers use the Site extensively. Many beaver dams and mine lodges were found during seasonal wildlife studies.
- Mammals, or their signs, observed by Site biologists include opossum, voles, shrews, mice, raccoon, striped skunk, red fox, gray fox, woodchuck, porcupine, Eastern chipmunk, Eastern gray squirrel, red squirrel, muskrat, beaver, Eastern cottontail, and whitetail deer. The most frequently sighted animal was whitetail deer.
- Within the Site, the Department of Environmental Conservation recognizes a deer concentration area. This area is not unique in western New York as other such areas are delineated within Cattaraugus and Allegany Counties.
- A potential ecological imbalance may occur on-site as a result of whitetail deer overpopulation within the fenced-in protected area because there are no deer predators or hunters to restrict their population growth. At various times during the WVDP and NFS operations, deer overpopulation has occurred. Deer populations on Project Premises have been removed by culling or herding deer off-site, in cooperation with the NYSDEC.

3.2.6.3 Birds

A summary of the wildlife survey findings related to birds in the WVDP-EIS-010 (WVNS 1994a) is presented below:

- Common game species found on the Site and in the region include wild turkey and ruffed grouse.
- The Site is not on a normal migratory flyway nor is it extensively used as a normal resting area for migratory waterfowl.
- Birds observed at the Site have been categorized into four groups: permanent residents, summer residents, migrants, and visitants.
- Permanent residents frequently encountered include red-tailed hawk, ruffed grouse, wild turkey, great horned owl, downy woodpecker, blue jay, American crow, black-capped chickadee, white-breasted nuthatch, northern cardinal, and dark-eyed junco.
- Summer residents frequently encountered that breed in the vicinity of the Site include great blue heron, Canada goose, American kestrel, ruby-throated hummingbird, eastern kingbird, great-crowned flycatcher, barn swallow, house wren, gray catbird, eastern bluebird, red-eyed vireo, American redstart, red-winged blackbird, northern oriole, and song sparrow.
- Special avian nesting programs have been instituted to increase bluebirds and duck nesting on the Site.

3.2.6.4 Other Animal Life

A summary of the wildlife survey findings related to amphibians and reptiles in the WVDP-EIS-010 (WVNS 1994a) is presented below:

- Amphibians noted during one or more of the Site surveys include red-spotted newt, northern dusky salamander, northern two-lined salamander, American toad, Fowler's toad, spring peeper, bullfrog, green frog, wood frog, northern leopard frog, and the pickerel frog.
- No snakes have been observed during the field studies nor are any site-specific records available from past studies. Several snapping turtles have been observed in the on-site reservoirs and also occasionally in the liquid waste treatment lagoons.

Earthworms are among the more important animals for biological transport of buried wastes (Rodriguez 2006). There are three ecological categories of earthworms: anecic, endogeic, and epigeic. Anecic worms (like the common nightcrawler *Lumbricus terrestris*) build permanent, vertical burrows that extend from the soil surface down through the mineral soil layer. These worm species coat their burrows with mucous which stabilizes the burrow so it does not collapse, and build little mounds (called middens) of stone and castings outside the burrow opening. Endogeic worms build complex lateral burrow systems through all layers of the upper mineral soil. These worms rarely come to the surface, instead spending their lives in these burrow systems where they feed on decayed organic matter and bits of mineral soil. The worms used in vermicomposting systems, like *Eisenia fetida*, are in the epigeic category. In nature epigeic worms live in the topsoil and duff layer on the soil surface. These small worms have a poor

burrowing ability, preferring instead an environment of loose organic litter or loose topsoil rich in organic matter deeper soils. Consistent with general observations, Rodriguez (2006) compiled the definite burrowing depths of these ecological groups: anecic at 20 cm, endogeic at 8 cm, and epigeic at 2 cm. However, maximum burrow depths of 1 m or more have been reported for earthworms (Rodriguez 2006).

Although surveys of earthworm populations at the West Valley Site have not been conducted, a review of the earthworm species in the Northern Appalachian Plateau and Uplands Ecoregion has been published (Reynolds 2016). A total of 22 species are reported in the ecoregion and six species are noted as present in Cattaraugus County, New York. Lack of a report from the county where the Site is located is likely not indicative of a species absolute absence. Existing earthworm surveys are not exhaustive in defining this part of the fauna and the distribution of the earthworms is changing fairly rapidly. In fact, 18 of the 22 species reported in the ecoregion were introduced from Europe or Asia. The presence of the introduced species, many of which have anecic life habits, is thought to have implications on soil nutrient profiles with the potential to modify future plant communities. The six species identified from Cattaraugus County are *Aporrectodea trapezoids*, *Aporrectodea tuberculata*, *Aporrectodea turgida*, *Bimastos tumidus*, *Dendrodrilus rubidus*, and *Lumbricus rubellus*. Only *Bimastos tumidus* is a native North American species; the rest are introduced from Europe.

3.2.6.5 Aquatic Environments

The West Valley Site has wetlands (swamplands, bogs, fens) and several streams, the largest of which are the Cattaraugus and Buttermilk Creeks (Section 3.2.8.1). Numerous open water systems have been created by humans and by beavers. Two larger reservoirs are found near the southeast corner of the Site. Small relict farm ponds dot the higher elevations. Beavers have created shallow ponds in the headwaters of the larger tributaries and in Buttermilk Creek back channels.

Aquatic biota surveys have been conducted in the larger West Valley Site (that includes the WVDP area) to document the ecological resources as part of NEPA evaluations. These studies have been documented in the WVDP-EIS-010 (WVNS 1994a). A summary of the findings related to aquatic biota is presented below:

- Aquatic flora include free-floating algae (phytoplankton), algae attached to rocks and other substrates within the stream (periphyton), and larger, rooted macrophytes. For example, at Buttermilk Creek plankton samples were dominated by green algae (Chlorophyceae) and diatoms (Bacillariophyceae), the Chlorophyceae being represented largely by the planktonic *Cosmarium* spp., *Closterium* spp., and *Pediastrum* spp. Also found in plankton tows were the filamentous green algae *Spirogyra* spp., *Cladophora* spp., and *Ulothrix* spp., which were also significant components of the periphyton communities at both upstream sites.
- Aquatic fauna include fish, zooplankton (free-floating animals), benthic invertebrates (animals living on or in the stream or pond bottoms), microscopic animals associated with the periphyton, and vertebrates using the stream habitat for part of their life cycle (e.g. amphibians). For example, at Buttermilk Creek, benthic invertebrates found in all sites were mayflies (Ephemeroptera), crane flies (Tipulidae), and midges (Chironomidae).

The fish species along Buttermilk Creek were composed primarily of common shiners (*Notropis cornutus*), blacknose dace (*Rhinichthys atratulus*), and common white suckers (*Catostomus commersoni*).

3.2.6.6 Protected Species

The Endangered Species Act (16 USC §460, et. seq.) provides protection for Federally threatened or endangered plant and animal species and their critical habitats; it authorizes the Secretary of the Interior to develop and implement recovery plans for each listed species. See also 6 NYCRR Part 182, *Endangered and Threatened Species of Fish and Wildlife; Species of Special Concern*. Endangered species are those that are in danger of extinction throughout all or a significant portion of their range. Threatened species are those likely to become endangered in the foreseeable future. Species that the U.S. Fish and Wildlife Service is considering for listing as Federally threatened or endangered, but for which a proposed rule has not yet been developed, are called Federal species of concern or candidate species.

The Environmental Conservation Online System was queried to determine which special status species occur in Cattaraugus County, New York. Only one terrestrial species was listed: the Northern Long-Eared Bat (*Myotis septentrionalis*). Two aquatic species, both clams, are listed: Clams Rayed Bean (*Villosa fabalis*) and clubshell (*Pleurobema clava*). Several ecological surveys of the West Valley Site have been conducted. Except for occasional transient individuals, no plant or animal species protected under the Federal Endangered Species Act are known to reside at the Site (DOE 2003, 2015).

The Migratory Bird Treaty Act of 1918 implemented various treaties and conventions between the U.S. and foreign countries for the protection of migratory birds. Under the Act, taking, killing, or possessing migratory birds is unlawful. DOE maintains a U.S. Fish and Wildlife Bird Depredation Permit for the Site (Bird Depredation Permit, MB747595□0) for the limited taking of migratory birds and active bird nests. The permit is renewed annually in August.

3.2.7 Geology

The purpose of this section is to describe the regional geologic and tectonic setting of the West Valley Site, the geology and stratigraphy specific to the Site, patterns of faulting and seismicity in support of probabilistic seismic hazard assessment, and the Cenozoic record of volcanic activity (the latter is not an issue for the Site).

3.2.7.1 Regional Geology and Tectonic Setting

The West Valley Site is located in the northern section of the Appalachian Plateau province, one of eleven physiographic provinces of New York State (Figure 7) (Cooper and Mylroie 2015; DOE 2010a; NYSDOT 2013). As described in Section 3.2.1, the Appalachian Plateau province is generally divided into northern glaciated and southern unglaciated sections; the West Valley Site is located in the glaciated Allegheny Plateau section just north of the boundary of the southernmost extent of Wisconsin glaciation (DOE 2010a).

The geology of the West Valley Site region and the state of New York involves a long history of Late Precambrian, Paleozoic, and Mesozoic plate tectonic interactions. Multiple cycles of

continental rifting, followed by the development of ocean basins east of the margin of the North American continent, occurred during the Paleozoic and Mesozoic. Cycles of marine sedimentation transitioned from passive margin settings to oceanic arc settings to collisional settings (Isachsen et al. 2000; Thomas 2006). These tectonic events are preserved primarily in rocks of New England, eastern New York State, and the central Appalachian Mountain region. Paleozoic sedimentary rocks beneath the West Valley Site region were deposited in foreland basins during multiple Paleozoic tectonic and mountain building events. Mesozoic and Cenozoic erosion in the region removed high-standing topography associated with the older orogenic events (orogenic events or orogeny refers to mountain building tectonic/deformation events associated with plate tectonic interactions). Multiple cycles of Quaternary glaciation subsequently modified the eroded terrain, with most of the modern deposits formed during or following the last glacial maximum (Wisconsin glaciations and deglaciations).

The West Valley Site is underlain by glacial and fluvial-glacial sedimentary deposits that are the country rock for groundwater flow (Section 3.2.8.2) and contaminant migration at the Site. Additionally, the underlying Paleozoic sedimentary rocks exhibit multiple fracture sets and lineaments that affect the structural setting and may control sites of historical seismicity in the Site vicinity. The following sections present the regional tectonic history and geology of the area.

3.2.7.1.1 Precambrian Rocks and the Grenville Orogeny

Juvenile crust and accreted arc terrane of 1.45 to 1.35 Ga age (billion years) of the eastern North American continent (Laurentia) underlie the western part of New York State (Whitmeyer and Karlstrom (2007); see their Figure 13). Additionally, the rocks of the Grenville-age province (1.3 to 1.0 Ga) extend from Vermont to Georgia and are interpreted as accreted collisional terrane of oceanic island arc systems or alternatively as rifted fragments of Laurentia that became reattached during subsequent Appalachian orogenic events (Thomas 2006; Whitmeyer and Karlstrom 2007). Rocks of Grenville age consist mostly of highly deformed metasedimentary and metaigneous rocks. The Grenville orogeny was one of the final events during the assembly of the supercontinent of Rodinia. The rocks of the Grenville Orogeny comprise the basement rocks for most of New York State and are exposed locally in the Adirondack Mountains and the Hudson Highlands (Isachsen et al. 2000). Complex tectonic contacts between Precambrian basement rocks beneath the West Valley Site partly control fault zones and lineaments in Paleozoic rocks beneath the Site vicinity (DOE 2010a; Jacobi 2002; URS 2002b; Wong et al. 2004).

3.2.7.1.2 Paleozoic Rocks of New York State and the Eastern Coast of the North American Continent

The Late Precambrian basement and Paleozoic sedimentary rocks of New York and adjoining regions record a succession of plate tectonic events associated with the Taconic, Acadian, and Alleghanian Orogenies.

Taconic Orogeny

The transition from the Precambrian Era to the Paleozoic Era was marked by rifting and breakup of the Rodinia supercontinent along complex rift segments that paralleled the continental edge

formed during the previous Grenville Orogeny (Thomas (2006); see his Figure 3). This rifting led to the opening of the Iapetus Ocean and the formation of a passive continental margin setting along the continent edge (Isachsen et al. 2000). Cambrian and Ordovician sediments were deposited along this margin and probably covered most of the geographic area of New York State—these sediments unconformably overlie metamorphic rocks and record an approximate 500 million-year time gap in the geologic record (Bennington and Merguerian 2007). During the Late Cambrian, a subduction zone formed an oceanic island arc east of the North American continent and west of the divergent plate boundary within the Iapetus Ocean (Isachsen et al. 2000). As subduction continued, the volcanic arc collided with and accreted to the continent during the Taconic Orogeny (Middle Ordovician time approximately 550 Ma to 450 Ma [million years ago]). Associated with this event, the carbonate platform of the Iapetus Ocean was replaced by silty carbonate, shale, and coarser clastic sediments. Inland of the folded and uplifted continent edge, a foreland basin developed that marks the initiation of the Appalachian Basin (Ettensohn 2004). Time-transgressive clastic wedges propagated westward across the basin toward the continental interior—the upper part of one of these wedges, the Queenston wedge, is associated with Ordovician and Silurian sediments beneath the West Valley Site. The upper part of the wedge is truncated by an unconformity that marks the end of Taconian clastic sedimentation in western New York (Ettensohn 2004).

Acadian Orogeny

The original mountainous terrain formed during the Taconic Orogeny was progressively eroded and covered by a transgressive sea marking a return to the passive continental margin conditions of the early Paleozoic Era. Coastal sediments were primarily clastic conglomerate and sandstone derived from erosion of the Taconian highlands (Isachsen et al. 2000). As the sediment supply decreased, deposition transitioned to a carbonate assemblage of mid-Silurian and Devonian sedimentary rocks (eastern New York). In the Middle Devonian, carbonate sedimentation transitioned to deep-water shales associated with the Acadian Orogeny (Middle Devonian, approximately 375 Ma). Closure of the northern Iapetus Ocean in the Devonian juxtaposed the northern Europe, Greenland, and North American continents (Bennington and Merguerian 2007). In the New England region, including part of eastern New York, the Avalonia continental landmass was accreted to the North American continent during the Acadian Orogeny. These events formed the uplifted Acadian mountain belt and an associated large plateau highland. A second phase of clastic deposition within a re-developed foreland basin formed a west-thinning clastic wedge (Catskill Delta complex) during the middle Devonian (Ettensohn (2004); see Figure 20 this CSM). These deposits underlie the West Valley Site. Devonian rocks of the West Valley Site that were deposited in the ancient foreland basin are now preserved in local bedrock of western New York State.

The left image in Figure 20 shows Precambrian basement features of the North American continent (Laurentia), with complex terranes consisting of juvenile volcanic arcs and oceanic crust accreted to the Archean core (> 2.5 Ga; gray-shaded areas), modified from Figure 15 of Whitmeyer and Karlstrom (2007). The right image shows a paleogeographic map of the Late Devonian centered on the North American continent. Noteworthy features are the Iapetus Ocean (lower right part of the figure), areas of oceanic arcs near the east edge of the North American continent, and foreland basins developed behind the arc and continental edge (adapted from Ron Blakey and the Colorado Plateau Geosystems Inc., <http://cpgeosystems.com/paleomaps.html>).

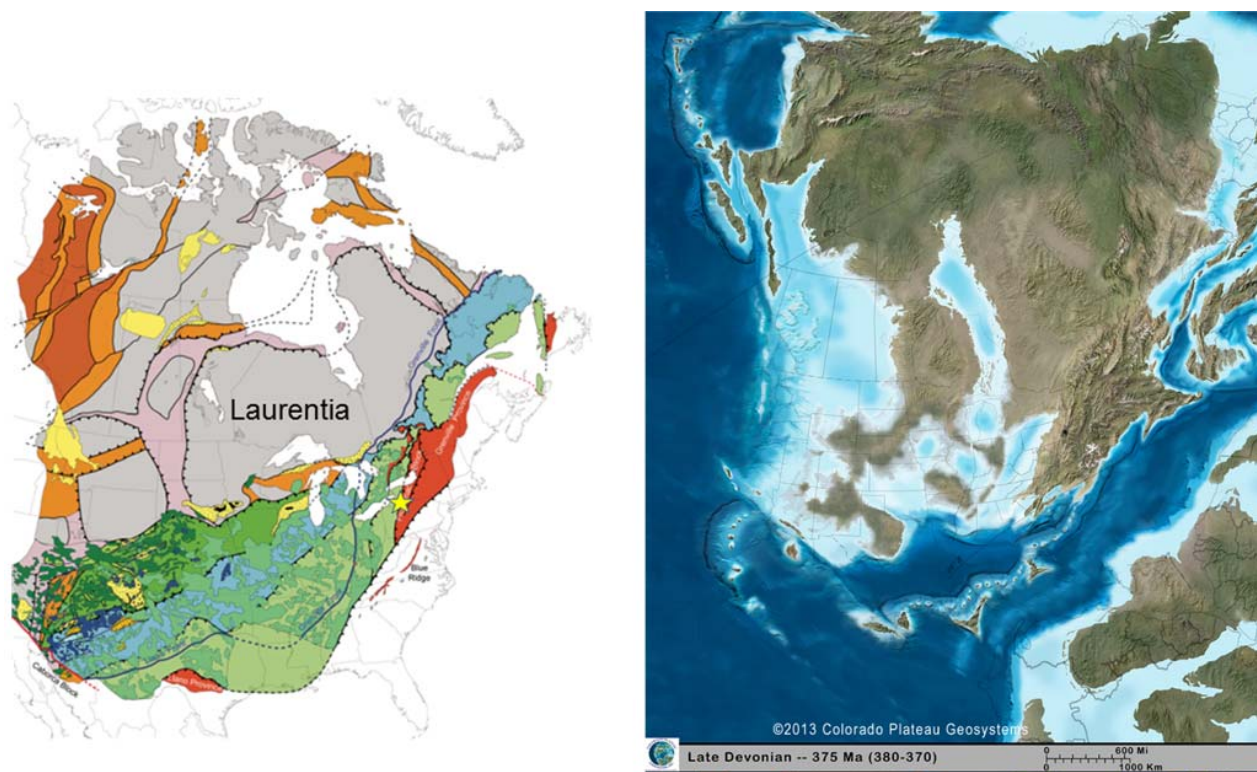


Figure 20. Left: Precambrian basement features of the North American continent. The approximate location of the West Valley Site is marked by the yellow star. Right: Paleogeographic map of the Late Devonian centered on the North American continent.

Alleghanian Orogeny

The final phase of closure of the Iapetus Ocean occurred during the Pennsylvanian and Permian Periods associated with continent-continent collision of western Africa and eastern North America during the Alleghanian Orogeny (325 to 260 Ma; Bennington and Merguerian (2007)). North America at that time was part of the Euramerica supercontinent and Africa was part of Gondwana. The collision formed the supercontinent of Pangaea and elevated the colliding continental edges leading to a prolonged phase of continental erosion. Sedimentary rocks of Mississippian through Permian age are not present in the West Valley Site region.

3.2.7.1.3 Mesozoic and Cenozoic Geologic History of New York State

Rifting of the Pangaea supercontinent initiated in the late Triassic and culminated with the opening and expansion of the Atlantic Ocean in the Cretaceous (Isachsen et al. 2000). Rifting events occurred east of the West Valley Site region; these events are not recorded in the geologic and sedimentary record of western New York. Poag and Sevon (1989) argue that the Appalachian Highlands were uplifted, deeply weathered, and eroded in three intervals since the Triassic: early to middle Jurassic, early Cretaceous, and middle Miocene. They suggest that intervals of tectonic stability followed the erosion, forming a regional erosional surface

(peneplanation). The following sequence of Mesozoic and Cenozoic events is identified for the West Valley Site region (WVNS 1993e):

1. South-flowing drainage system developed on Paleozoic rocks in the Mesozoic.
2. Interruption of the drainage system by an east-west trending lowland along the axis of the modern Erie-Ontario basin.
3. Uplift in the mid-Cenozoic to form the highland and valley drainage system of the Allegheny Plateau.
4. Recurrent glacial advances and retreats during the Illinoisan and Wisconsinan glacial cycles.

Cenozoic sedimentary deposits (non-glacial) are conspicuously absent throughout New York State, with the only record of geologic events marked by marine sediments deposited offshore in the passive continental margin. The lack of Cenozoic deposits is generally attributed to a combination of regional domal uplift and erosion and, additionally, scouring and removal of any sediments during Quaternary glacial cycles.

Quaternary Glaciation

Global cycles of glacial and interglacial intervals in the Quaternary Period followed a long interval of progressive global cooling during mid-to-late Cenozoic time (cooling initiated approximately 50 Ma ago). The end of the Paleocene-Eocene Thermal Maximum (Figure 21) was marked by a progressive decrease in atmospheric CO₂ with subsequent development of Antarctic Ice Sheets in the late Eocene and Oligocene, ice sheets in the Northern Hemisphere in the late Miocene and Pliocene, and cyclical glacial and interglacial intervals in the Quaternary (National Academy of Sciences 2011). Figure 21 illustrates the systematic decline in temperature from the Paleocene-Eocene Thermal Maximum approximately 50 Ma until the cyclic glacial and interglacial intervals of the Quaternary (Pliocene and Pleistocene).

The detailed history of Quaternary glaciation in New York is not well established because of combined erosional removal and cover of older glacial deposits by successively younger glacial activity (Larson and Kincare 2009; Ridge 2004). Preserved glacial deposits in the region are primarily from the Last Glacial Maximum, the Wisconsinan glaciation that extended from about 110 ka to 12 ka; the maximum extent of Late Wisconsinan glacial advance probably occurred around 18 to 24 ka Before Present (BP) (Ridge 2004). The history of middle and late Wisconsin glaciation in the Genesee Valley northeast of the West Valley Site extends back at least to approximately 50 ka age (Young and Burr 2006). Pockets of glacial sediments of Illinoisan age are locally preserved in the West Valley Site region (160 to 180 ka) (Larson and Kincare 2009; Ridge 2004).

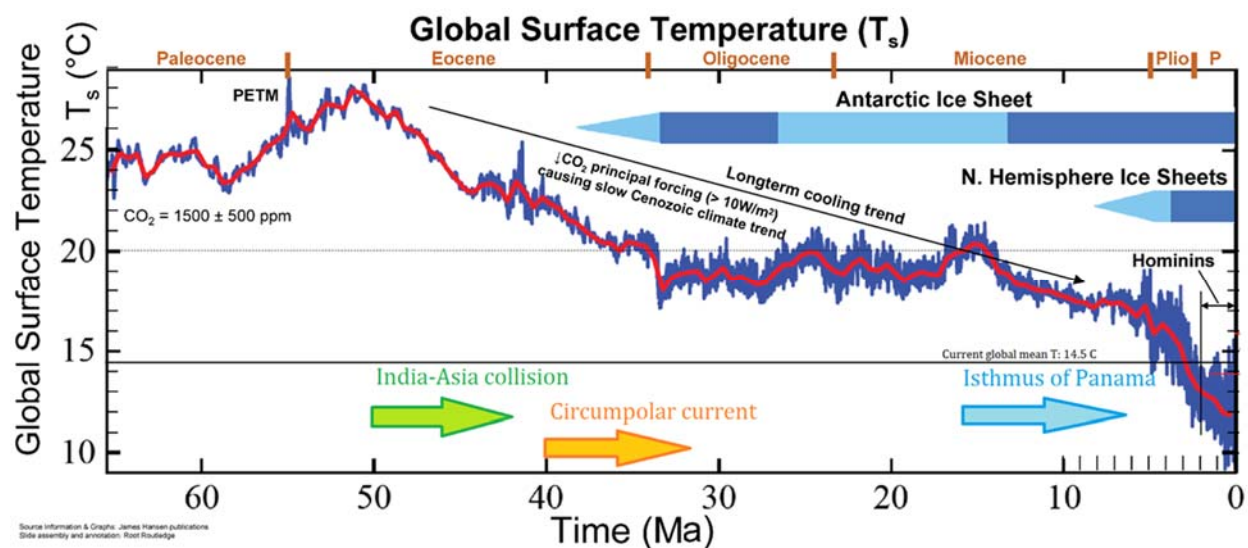


Figure 21. Global surface temperature for the Cenozoic era (from Steven Earle, <https://opentextbc.ca/geology/chapter/16-1-glacial-periods-in-earths-history/>).

Isachsen et al. (2000) describe the Wisconsinan glacial features of the major physiographic provinces of New York. Glacial deposits in the Allegheny Plateau occur primarily in U-shaped valleys formed by cyclical intervals of southward advance and retreat of ice lobes of the Laurentide ice sheet. Deposits include till preserved in moraine landforms, kame deltas formed at the front of ice lobes, glaciofluvial deposits, and lacustrine deposits of proglacial lakes. Margold et al. (2015) describe 117 ice streams in the Laurentide Ice sheet based on combined comparisons with modern ice sheets, geomorphology and topography, glacial till properties, glacial bedforms, and ice-rafted deposits in ocean sediment cores. A major feature of the West Valley Site region is the Huron-Erie Lobe (ice stream) that followed the direction of elongation of Lake Superior and Lake Erie lowlands (Dreimanis and Goldthwait (1973); see also Margold et al. (2015), their Figure 11). The southern limit of late Wisconsinan glaciation in the West Valley Site region is shown on Figure 22 (Figure 1 of from Mickelson and Colgan (2003)). The paleographic map in Figure 22 shows the maximum extent of ice sheets in North America during the Last Glacial Maximum (from Ron Blakey and the Colorado Plateau Geosystems Inc. (<http://cpgeosystems.com/paleomaps.html>)).

Establishing the regional history of Wisconsinan glacial events in the northeastern U.S. remains problematic for glacial geologists. Larson and Kincare (2009) summarize issues with the timing of local and regional glacial events. Ice margin fluctuations of individual lobes of the Laurentide ice sheet may be temporally asynchronous across glaciated regions. Glacial deposits are complex lithostratigraphic units that vary both laterally and vertically. Contact boundaries of till, stream outwash, and glacial-lake deposits are typically both erosional and time transgressive. Chronology constraints on individual glacial deposits are difficult to establish and highly uncertain. The West Valley Erosion Working Group (EWG) ((ECS 2013); see their Figure 7) summarizes chronology constraints on recessional moraines in the West Valley Site area and possible correlations with glacial surges (Heinrich Events) established in paleoclimate studies.

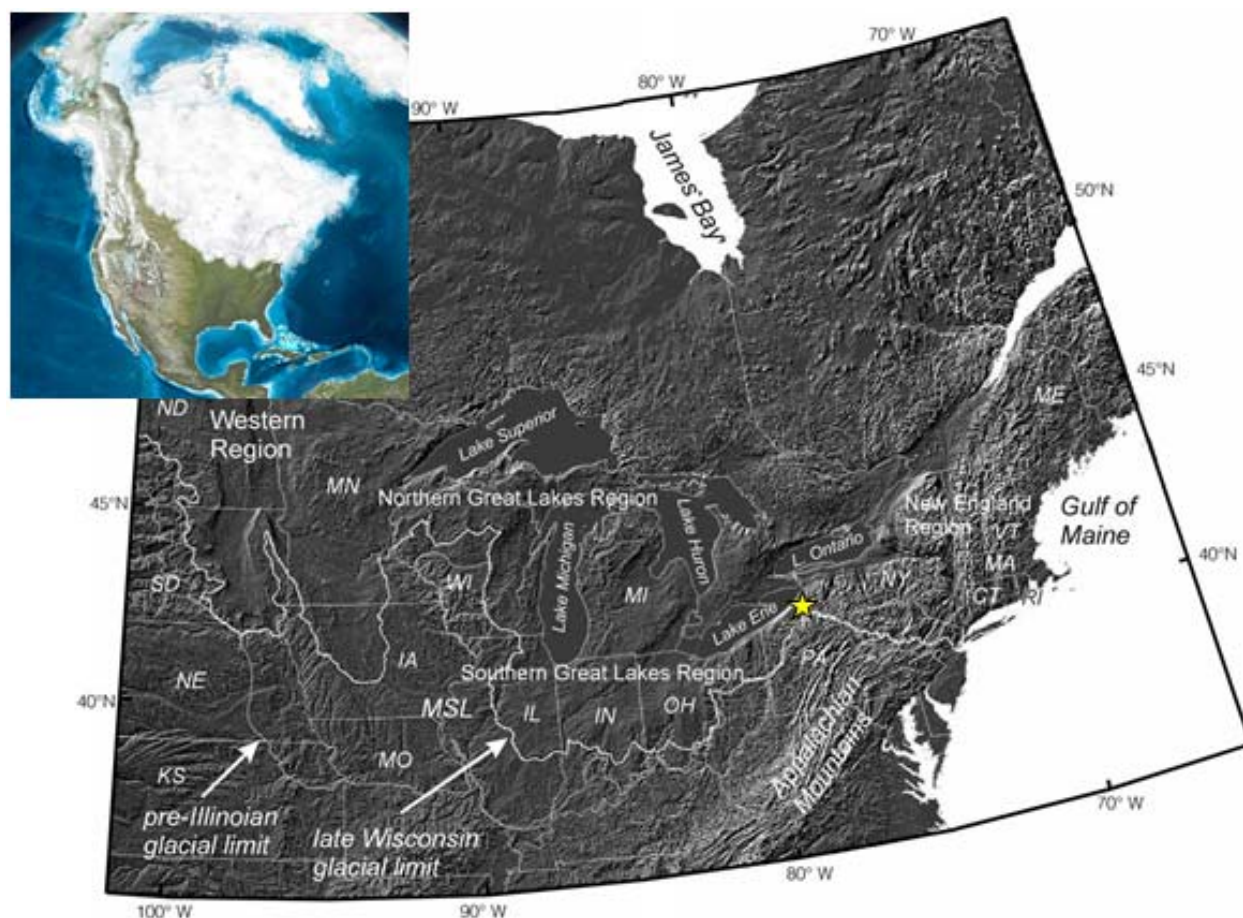


Figure 22. Southern limits of selected ice advances in the Great Lakes region. The yellow star marks the location of the West Valley Site.

3.2.7.2 Geomorphology

3.2.7.2.1 Overview

The West Valley Site is located on a stream-dissected till plateau in the glaciated Allegheny section of the Appalachian Plateau (Section 3.2.1). The region south of the West Valley Site is drained by the Allegheny River with southward directed drainage; the Site and surrounding northern regions drain northwest into streams that merge into Cattaraugus Creek, which flows west into Lake Erie (WVNS 1993d) (Section 3.2.8.1). Topography within the Site is highest to the west-southwest and decreases to the east-northeast into the U-shaped valley of Buttermilk Creek (Section 3.2.1). Local to the Site, Frank's Creek drains into Buttermilk Creek, and Erdman Brook separates the Project Premises into North and South Plateau areas that form the west flank of the Buttermilk Creek Valley.

The topography and geomorphology of the Site region is in a continuing process of responding and adjusting to the retreat of continental ice sheets that ended approximately 13 ka (Wilson and Young 2017 [in preparation]) at the transition from the Last Glacial Maximum to the current interglacial cycle. The modern topography is still adjusting to isostatic rebound that is estimated to be as much as 30 m (98 ft) since the retreat of the ice sheets. The drainage catchment in the

West Valley Site exhibits three stages of development as described in Appendix F of DOE (2010c):

1. Rounded bedrock hills incised into Paleozoic sedimentary rocks. This topography, with peak altitudes of approximately 550 m (1,800 ft), has a complex history from inherited drainage topography developed during periods of erosion and landform stability in the Mesozoic and Cenozoic (Poag and Sevon 1989; WVNS 1993e), and topographic readjustments associated with Quaternary cycles of glaciation and deglaciation.
2. Inset glacial terraces, including multiple cycles of till plateaus formed primarily during Wisconsin glacial advances and retreats, that form intermediate topographic levels within the Buttermilk Creek drainage (approximately 400 m [1,310 ft]; DOE (2010c), Appendix F).
3. Local hillslope accumulations of alluvial sediments and soil that are incised by the modern tributary systems and creek drainages. These drainages have locally incised several tens of meters below the intermediate-level glacial terraces and feed into Buttermilk Creek.

The maximum extent of glacial ice is marked by the Kent moraine south of the West Valley Site, which is dated at less than 24 ka (DOE (2010c), Appendix F). The timing of glacial recessions is complicated and may be constrained by studies at the Finger Lakes and Seneca Lake, with rapid recessions recorded at about 16 ka to 17 ka (DOE (2010c), Appendix F). Glacial retreat was almost certainly complete by the Holocene (approximately 12 ka). Ridge (2004) estimates that the Late Wisconsin ice reached maximum limits in the New England region at 24 to 28 ka, with the late phases of glaciation ending at about 13 to 19 ka. The EWG (ECS (2013), see their Figure 1) provides a summary of the most recent age estimates of glacial features and events in the West Valley Site area (Kent recessional moraines approximately 29 to 30 ka, Lavery recessional moraines approximately 17 ka). Continuing work on erosional studies, discussed further in Section 3.2.7.2.2, will refine the chronology of glacial events and geomorphic features in the Site region.

The geomorphic framework for the modern drainage network of Buttermilk Creek was established during the Late Pleistocene transition from the Last Glacial Maximum to the current interglacial climate. Post-glacial incision of the creek was controlled by local base level at the confluence of Buttermilk and Cattaraugus Creeks. The incision history of Buttermilk Creek was affected by the dynamics of ice-sheet retreat, local residual areas of glacial ice and glacial lakes, as well as the evolutionary history of the drainage system of Cattaraugus Creek (Wilson and Young 2016 [in preparation]). The incision history was also likely affected by the dynamics of isostatic rebound in the Lake Superior–Lake Erie area and water level fluctuations in Lake Erie (DOE (2010c), Appendix F). A DEM model of the topography of the pre-incision valley of Buttermilk Creek was used to calibrate the CHILD Landscape Evolution and to serve as a starting point for erosion prediction studies at the West Valley Site (DOE (2010c), Appendix F). Continuing geomorphic studies of the Buttermilk Creek Valley support a slightly younger age of glacial retreat in the valley (13 to 14 ka) and possible slowing of stream incision over the last 2,000 years from the presence of sedimentary bedrock near the intersection of Buttermilk and Cattaraugus Creeks (Wilson and Young 2016 [in preparation]).

The erosional geomorphic regime of the Buttermilk Creek drainage is expected to persist for tens of thousands of years. The future climate in the West Valley region is projected to remain in the

current interglacial state with progressive but variable warming. The probability of a return of continental ice sheets is remote. Anticipated future changes in erosion rates for the Buttermilk Creek drainage would occur only with significant climate change and/or modifications of base level controls at the intersection of Buttermilk and Cattaraugus Creeks or Lake Erie.

3.2.7.2.2 Erosion

Numerous studies of geomorphology and erosion since the early 1970s have documented active erosional processes within the Buttermilk Creek Valley that are specific to the West Valley Site. These are described and summarized in WVNS (1993a), WVNS (1993f), and DOE (2010c). Additional erosion studies are being conducted by the Phase 1 Studies Erosion Working Group (EWG), and preliminary results have been reported in ECS (2013), Bennett (2016 [in preparation]), Wilson and Young (2016 [in preparation]), and in Wilson and Young (2017 [in preparation]).

The entire Site is vulnerable to gully migration and stream bank failure from nearby stream valleys (see Figure 23 and Figure 24). Wind erosion was not addressed in past studies at a landscape scale. Dense vegetation limits eolian erosion; however, there is the potential for contaminants exposed in bare soil or dry stream channel sediments to be entrained and transported off site.

Buttermilk Creek and particularly the Frank's Creek system are still responding to incision following glacial retreat more than 13 ka. Erosion is primarily driven by fluvial action, with widespread mass wasting and landsliding occurring on steep stream channel banks. As the local streams incise their valleys, side slopes destabilize and fail, which widens valleys. Gullies can form off the failure sites and migrate toward Site facilities. Increased runoff volume and peak flow rates from impervious cover and storm water routing may accelerate the incision.

The same processes operate along the west bank of Buttermilk Creek, with lateral channel migration an additional factor in destabilizing slopes. Active landsliding is sustained or enhanced by rapid erosion of the landslide toe. Boothroyd et al. (1979) and Boothroyd et al. (1982) noted fluvial transport of valley wall material from steep incised channels across alluvial fans into the channel. Gullies migrating westward from Buttermilk Creek potentially impact the Site by stream capture of Frank's Creek. While future rates of downcutting in Buttermilk Creek are controlled by sedimentary bedrock at the intersection with Cattaraugus Creek, Boothroyd et al. (1982) predicted continuing tributary incision and valley widening independent of the base level of Buttermilk Creek.

Stream capture could initiate rapid channel incision in Frank's Creek and new active gully networks in the uplands in response to the sudden decrease in base level. Other existing gullies, or new gullies spawned by slope failures on the Buttermilk Creek valley wall, represent additional initiation of stream capture.

The EWG is continuing a range of erosion studies to assess uncertainty reduction in future erosion predictions ECS (2013). Current studies are focused on three topics:

- terrain analysis and age-dating of geomorphic features,
- studies of Site-specific erosion and deposition processes, and
- improved modeling of the processes of erosion and deposition.

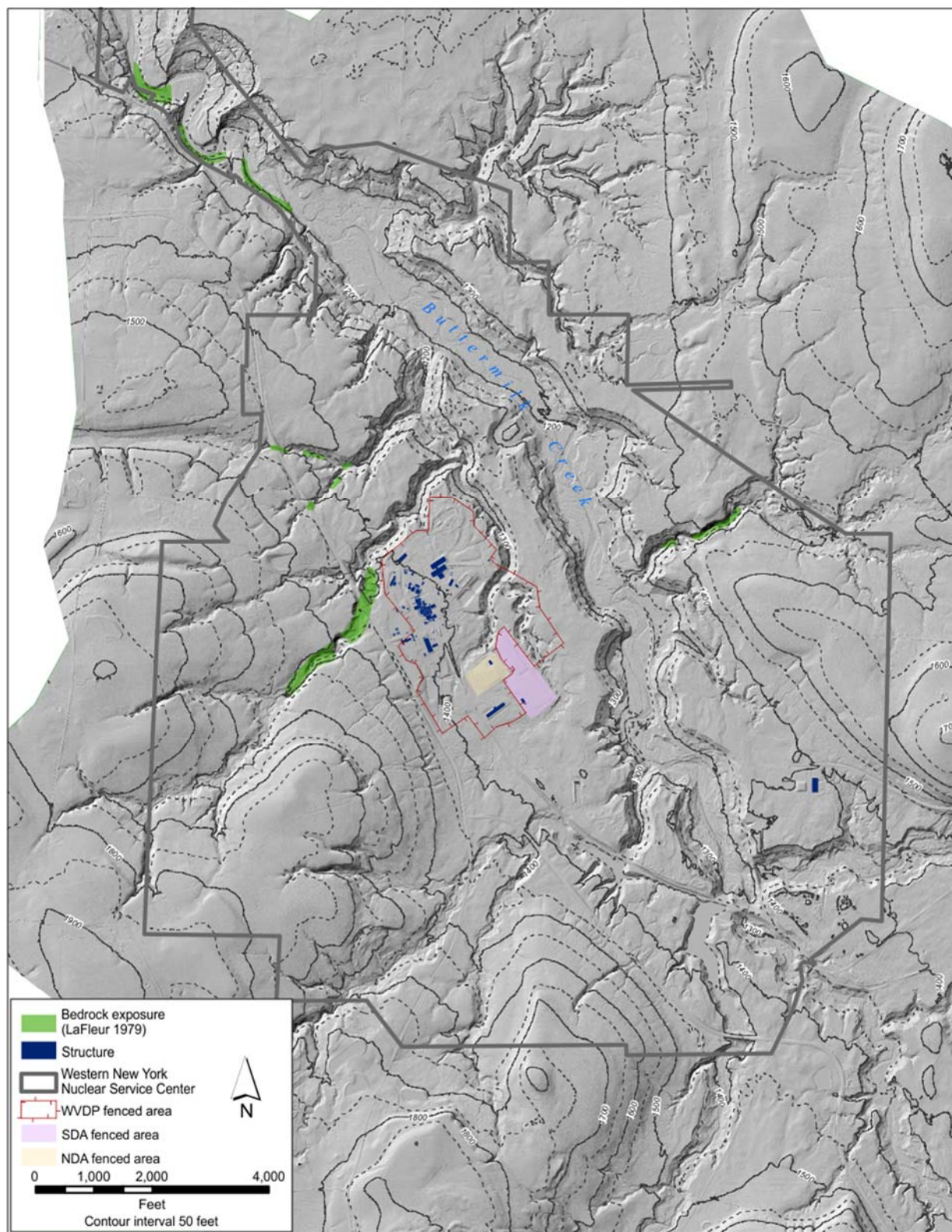


Figure 23. Wide-view shaded-relief imagery (Sanborn 2016) of the West Valley Site depicting Site facilities situated among deeply incised stream valleys. (Spatial data courtesy NYSERDA.)

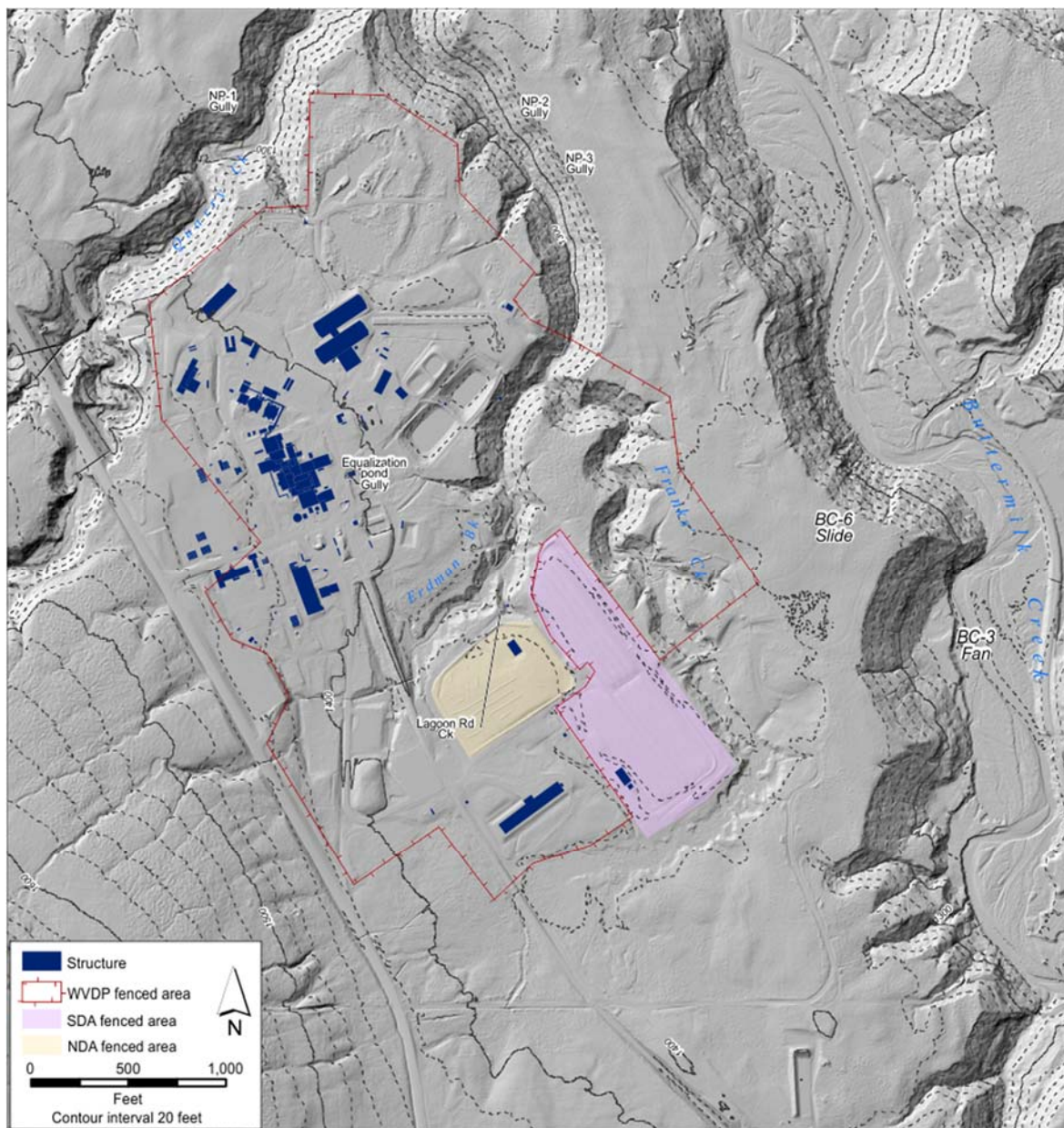


Figure 24. Detail view of shaded-relief imagery of the North and South Plateaus (Sanborn 2016) with disposal areas. (Spatial data courtesy NYSERDA.)

Wilson and Young (2017 [in preparation]) present new data, information, and analyses that support the following conclusions:

- “Future erosion within the Buttermilk Creek watershed will be dominated by headward erosion up tributary streams and gullies such as Frank’s Creek, and valley-widening processes, rather than by significant base-level lowering of the main stem Buttermilk Creek.
- Westward migration of the Buttermilk Creek channel opposite the Heinz Creek confluence is likely to continue and will likely lead to incorporation of Frank’s Creek

adjacent to the SDA within a time frame of roughly 4,000 to 6,000 years from now, or sooner depending upon the rate of widening of Frank's Creek which could hasten the process....

- *Unlike the westward migration of the Buttermilk Creek channel at Heinz Creek, the map position (x-y) of the Buttermilk Creek/Frank's Creek confluence appears to have changed very little in middle to late Holocene time. The stability of the channel at this location makes it a good candidate location for setting base level boundary conditions for models of the Frank's Creek watershed.*
- *When evaluating the variability of historical vertical incision rates of Buttermilk Creek for use in modeling future erosion, appropriate weight should be given to the most-recent approximately 2,000-year period during which the incision rate appears to have slowed dramatically. The reasons for the slowing include emergence of resistant bedrock sections in downstream reaches of both Buttermilk and Cattaraugus Creeks, and the overall flattening of the gradient with increasing age. These conditions will continue into the future, as opposed to many of the transient conditions that accompanied variable incision rates during earlier periods.*
- *Climate change is expected to produce more precipitation and storms of greater intensity in the relatively near future; although, little reliable information is available to forecast climate change more than roughly 100 years in the future. The erosive energy of runoff from increased future storms will likely produce more landsliding and valley widening in erodible sediments than base-level lowering because base-level lowering is constrained and slowed by emergent resistant bedrock.*
- *Patterns of storm water runoff have changed over the last approximately 200 years owing to deforestation, agriculture, and paving of ground surfaces resulting from changes in land use. Concentration of runoff will likely increase if these trends continue in the future.*
- *The results of this study have provided a much-improved and well-documented late glacial chronology, as well as a reasonable estimate for when the modern Buttermilk Creek gradient became established at close to its present configuration in the vicinity of the Site. The new glacial chronology requires a significant revision in our understanding of the late glacial events throughout western New York. Historical Buttermilk Creek incision is now reasonably documented as having started approximately 13,000 calendar years before present, which is considerably younger than previously assumed.*
- *The data and information from Study 1 should enable prediction of future erosion with greater confidence than has heretofore been possible."*

The West Valley PPA Model models erosion as a set of processes driven by surface water flow that act to remove protective cover while reducing the length of a hillslope profile that lies between a source of contamination and a stream channel. An example is illustrated in Figure 25A, which depicts a stream channel incising into the local till, a stream valley wall with slope angle θ , the hillslope profile linked to the stream valley edge, and a buried contaminant source area. Cover material and the hillslope profile are subject to sheet flow and rill erosion. Figure 25B depicts a gully eroding along a path with concentrated flow in addition to the other erosion processes.

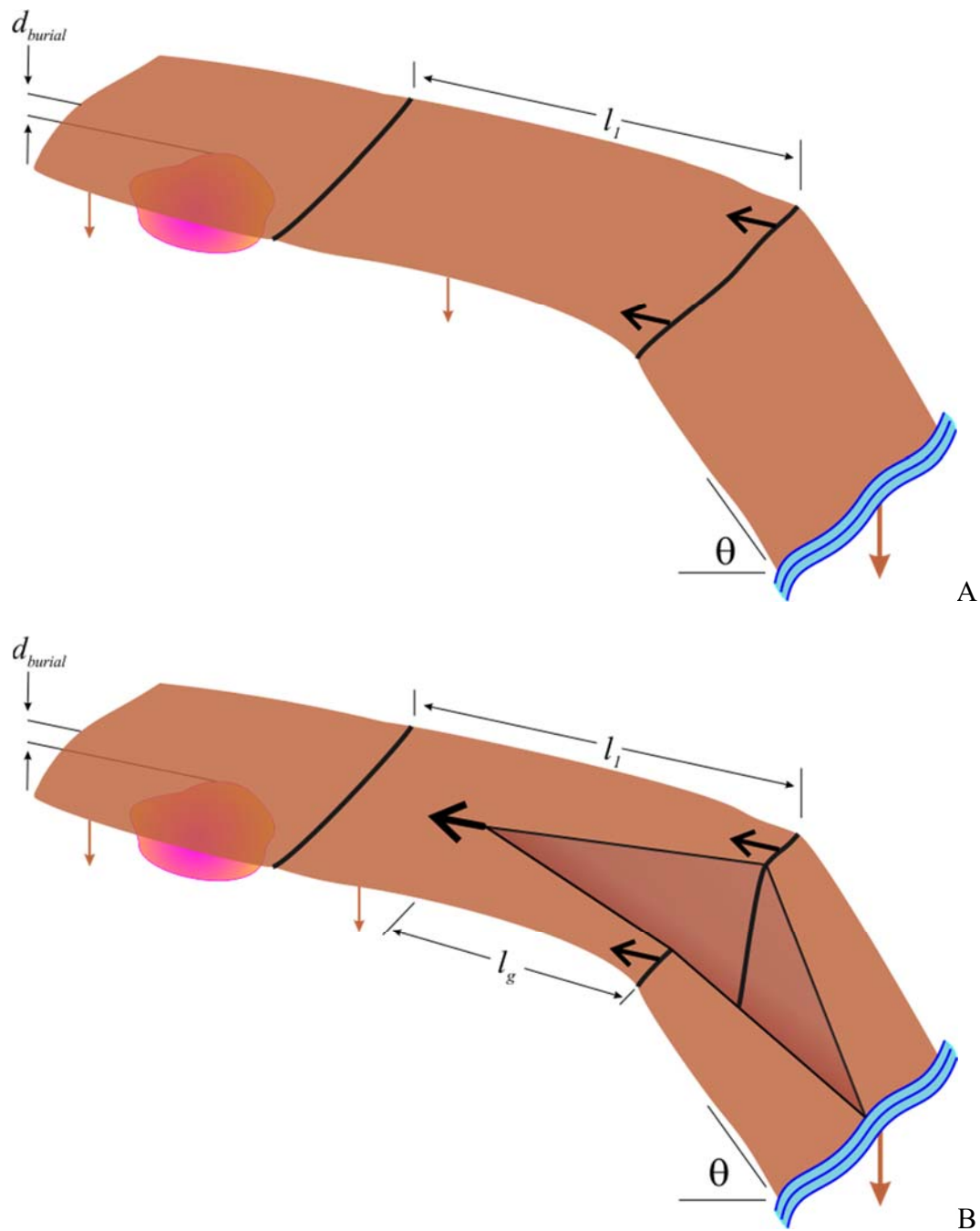


Figure 25. A. Conceptual hillslope profile of length l_1 linking a source of contamination (left color-shaded area) with a local stream. L_1 decreases through time by stream valley widening caused by progressive failure of the stream valley wall as the stream channel incises. Elevations along the profile decrease through sheet flow and rill erosion. B. Concentrated flow across the hillslope profile allows a gully to erode toward the contamination.

Lengths, slopes, and elevations for the conceptual hillslope sequence are developed from calculations performed on topographic data in a geographical information system (GIS). The conceptual configuration is amenable to direct modeling in GoldSim, in which stochastic inputs would drive each applicable erosion process (e.g. stream incision rate, gully headcut migration rate, stream valley wall angle of repose). Sudden slope failures may be implemented as disruptive events in probabilistic modeling. Statistical distributions applied to each erosion process rate are developed from sources which may include previous Site-specific studies (e.g., as summarized in (DOE 2010d)), analysis of changes measured between topographical datasets, review of applicable geomorphological and erosion literature, expert elicitation, and results from the EWG field and modeling teams.

Contamination is exposed by erosion when the length of the hillslope segment (l_1 in Figure 25A, l_2 for a second flow path, etc.) is reduced to zero or below, when a gully encroaches upon the source area (l_g exceeds l_1 in Figure 25B), or when sheet flow and rill erosion remove cover from above. Modeling of contamination release will depend on the nature of the source. Residual contamination in fill may contribute contaminants to overland sediment transport across the hillslope profile. A gully breaching an SDA trench may result in a mass of leachate immediately flowing to the local stream, followed by fluvial transport of contaminated soil.

Stream Channels

Estimates of the rate of postglacial incision of Buttermilk Creek have been developed based on radiocarbon and optically stimulated luminescence (OSL) dating. A sample of wood excavated from a trench near the surface of the plateau (LaFleur 1979) was dated as between 10 ka (uncorrected radio carbon date, Boothroyd et al. (1979)) and 12 ka (calibrated radiocarbon date, DOE (2010c)).

Using the uncalibrated date, Boothroyd et al. (1979) calculated a rate of 5.5 mm/y incision based on 55 m of downcutting at the Bond Road Bridge over 10,000 yr. A 1980 estimate of 6 mm/y in till and 3 mm/y in bedrock for Buttermilk and Cattaraugus Creeks by LaFleur was cited by Prudic (1986). Later samples obtained for radiocarbon and OSL dating suggested that Buttermilk Creek began to incise between 16 and 18 ka (DOE 2010c), but Wilson and Young (2016 [in preparation]), reporting radiocarbon dates from samples collected by the EWG, propose that final glacial recession occurred between 13.2 and 14 ka.

The EWG collected numerous samples for radiocarbon and OSL dating from surfaces at varying elevations at sites shown in Figure 26. Wilson and Young (2016 [in preparation]) reported results from radiocarbon dating. Using dates from the upper Heinz Creek and the abandoned meander loop, they suggested deposition was occurring at elevation 1,400 ft between 5 and 10 ka, which is approximately the elevation of the South Plateau near Heinz Creek. They tentatively estimated the meander loop itself, approximately 1,300 ft elevation, as being active between 5.6 and 9.5 ka.

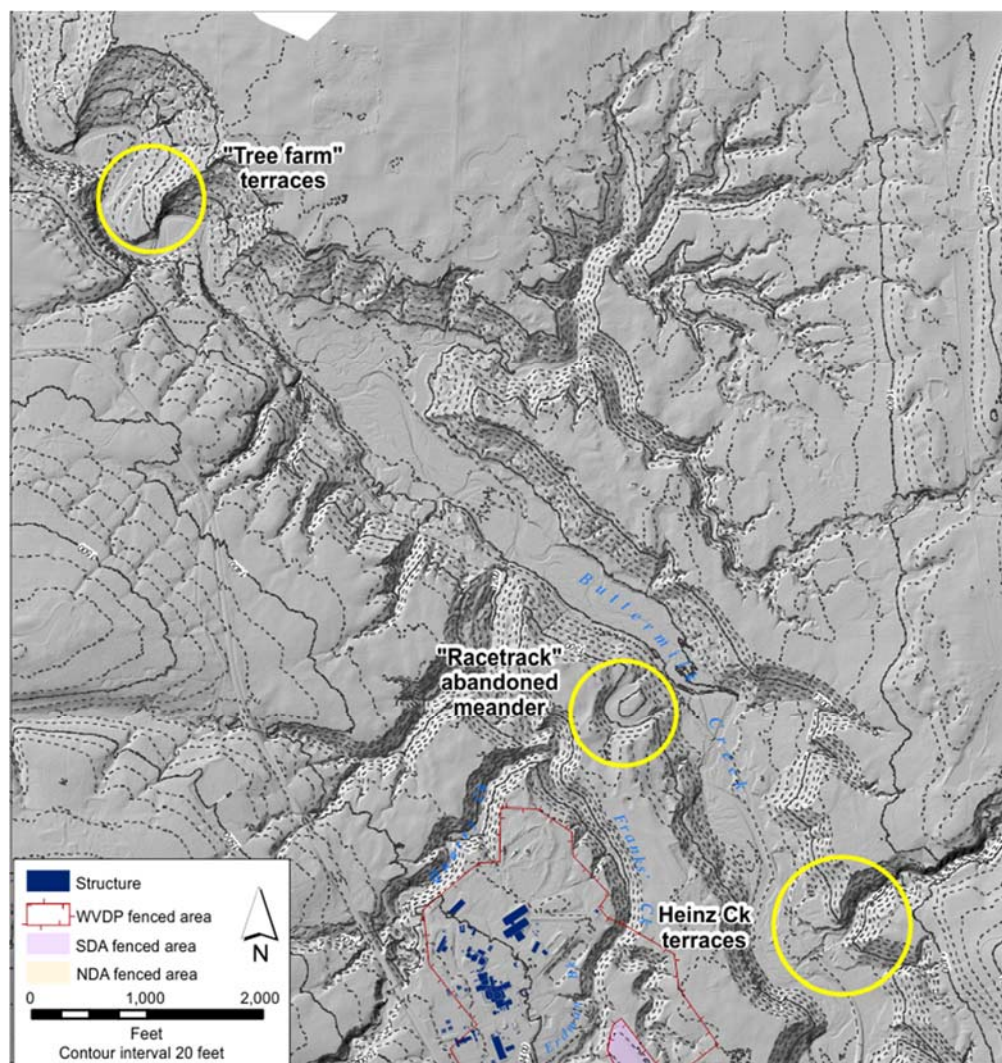


Figure 26. Sampling locations for radiocarbon and OSL dating under EWG field program (Wilson and Young (2016 [in preparation])); shaded relief imagery derived from 2015 LiDAR data, Sanborn (2016)).

Wilson and Young (2016 [in preparation]) reported landsliding activity at approximately 1,200 ft elevation in the “tree farm” site as occurring 3.6 ka, while a sample from a Heinz Creek terrace near 1,240 ft was dated to 3.785 ka. The modern channel crosses the 1,135- and 1,225-ft contours near these locations, respectively (Sanborn 2016). Based on these dates, along with dates obtained from low terraces, Wilson and Young (2016 [in preparation]) suggested that the current channel elevation of Buttermilk Creek may have been attained 2 ka. A decreasing rate of downcutting would be expected as fine sediments are removed downstream and the stream channel becomes armored with gravels and cobbles. Forthcoming OSL dates are anticipated to further constrain the history of incision along Buttermilk Creek. Confirmation of a decreasing trend will have implications on the forward modeling of erosion along the western valley wall even if the Frank’s Creek system continues rapid, independent incision per Boothroyd et al. (1982).

Frank's Creek and Erdman Brook are noted for their steep, convex-up longitudinal profiles, indicating unstable channels subject to rapid incision (Boothroyd et al. 1982). Both streams exhibit V-shaped profiles in the lower reaches and U-shaped profiles in the upper reaches. Knickpoints with scour points characterize the transition between valley forms. These knickpoints may advance in a manner similar to gully heads during higher runoff events. The EWG (2012) reported knickpoint migration rates of 3 m/y for Erdman Brook between 1977 and 2015, and 7 to 8 m/y for Frank's Creek between 1992 and 2012. Ten meters of migration in Frank's Creek was reported during 2011 (ECS 2012b).

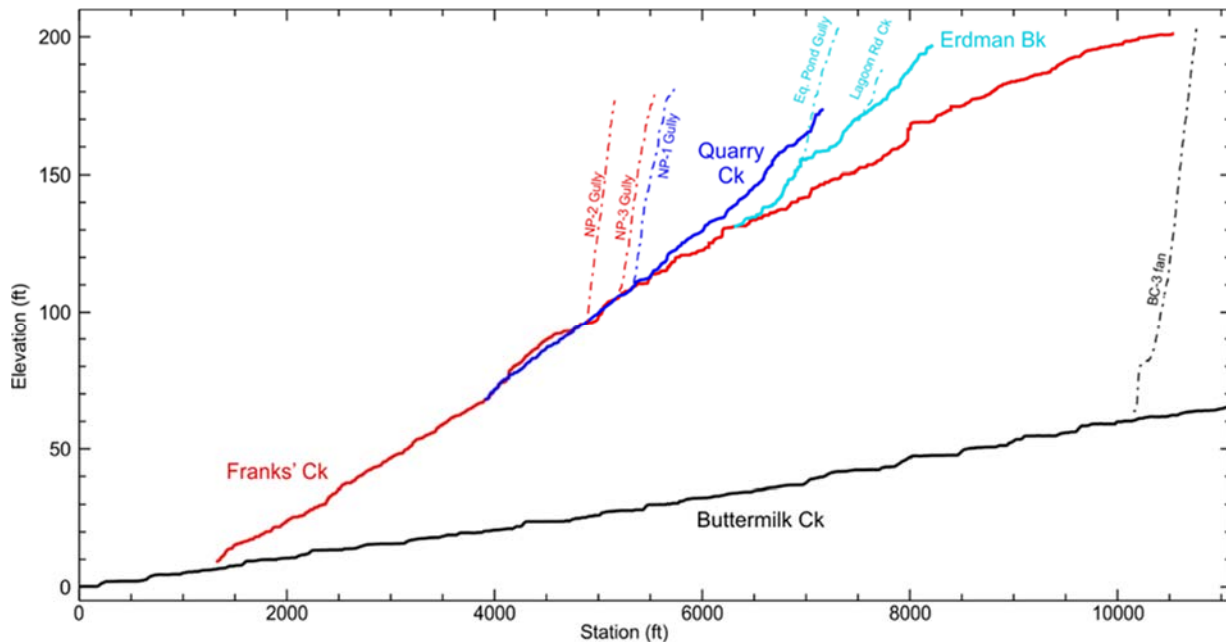


Figure 27. Profiles of major streams affecting the WVDP Site and SDA and selected gullies mapped by WVNS (1993e). Profiles were extracted from 2015 LiDAR data. Station 0 in Buttermilk Creek is approximately 13,000 river ft above the Cattaraugus Creek confluence (Sanborn 2016).

Between 1980 and 1990, 60 cm (24 in.) of downcutting was reported through the V-shaped valley reaches of Frank's Creek, based on surveys of the longitudinal profile (WVNS 1993a). Fifteen cm (5.9 in.) of downcutting was reported in the U-shaped valley upstream of the transition knickpoint. As of DOE (2010c), no estimate of incision rate was available for Erdman Brook, but WVNS (1993a) expected downcutting at the same or higher rates because of urbanization. At this rate, approximately 30 cm (12 in.) of downcutting might be expected to be observed by comparing the 2010 and 2015 topographic LiDAR datasets. Detecting and quantifying channel incision first requires conditioning the LiDAR data by correcting a variable shift in horizontal coordinates between the two datasets (Sanborn 2016) and by analyzing LiDAR points in the "water" class to remove points which represent misclassified vegetation or exhibit high elevation errors.

WVNS (1993a) described Quarry Creek as the most developed of the streams affecting the Site, exhibiting a meandering pattern and numerous terraces. The channel has incised to bedrock in many locations upstream of the wreckage of the former Rock Springs Road Bridge. That wreckage, as well as culverts under the new Rock Springs Road, were described as impeding transport of larger clasts from the uplands. Armoring of the downstream channel from rounded cobbles and gravels derived from local till, along with lower rates of urbanization in the catchment, led WVNS (1993f) to suggest a lower rate of downcutting for Quarry Creek compared to the other streams affecting the Site.

WVNS (1993f) suggested that higher sediment loads would be expected in stream channels in late summer and early autumn (due to drier soil and decreased vegetation) and in early April (after the ground has thawed and before vegetation has recovered). Suspended sediments tend to be dominated by silt, with reported proportions greater than 65 to 70 percent corresponding to two to three times the clay fraction (WVNS 1993f). Channel sediments vary, with coarse gravels and cobbles in Buttermilk Creek and highly varied characteristics in the Frank's Creek system.

Suspended and channel sediments were sampled in Frank's Creek, Buttermilk Creek, and Cattaraugus Creek by Pacific Northwest National Laboratory beginning in 1977 (Ecker and Onishi 1979; Ecker et al. 1982; Walters et al. 1982a, 1982b) to support development of a radiological contaminant transport model. Only sand, silt, and clay fractions of the bed sediment samples were reported. Boothroyd et al. (1982) sampled suspended sediments from Buttermilk Creek at Thomas Corners Road Bridge in 1980. Boothroyd et al. (1979) and Boothroyd et al. (1982) performed detailed geomorphic mapping of the Buttermilk Creek channel. WVNS (1993f) sampled suspended sediments at numerous locations along the Frank's Creek system, including major gullies.

Suspended sediment sampling associated with Erdman Brook and Frank's Creek indicate increasing sediment load with increasing discharge and an increasing downstream trend, which WVNS (1993f) tied to gully and stream bank erosion. Quarry Creek sampling displayed a decreasing trend in sediment load downstream of NP-1 gully, ascribed to dilution and low rates of bank or channel erosion above the confluence with Frank's Creek. Suspended sediment loads increased across knickpoints in Erdman Brook and Frank's Creek as active erosion and upstream migration occurred during sampled flow events.

Buttermilk Creek bed sediments are predominantly gravel- and cobble-sized, with sand and very minor silt fractions (Boothroyd et al. 1979; Boothroyd et al. 1982). Medium-sized clasts were observed to move during floods of less than one-year recurrence, while large clasts were mobilized in one-year-equivalent flows. Based on tracer cobbles, transport rates for large clasts were estimated to be between 3 and 6 meters per year. Boothroyd et al. (1982) proposed a gravel exchange process between the active channel of Buttermilk Creek and low terraces. Higher-frequency, lower-magnitude events eroded terraces, while gravels were deposited on terraces as longitudinal bars during a ten-year equivalent flood.

Channel sediments sampled in lower Frank's Creek contained sand and silt with minor clay amounts (WVNS 1993f). Silt dominated a sample obtained during snow melt runoff at over twice the proportion of sand, while the proportions were reversed in samples gathered during "low" and "medium" flow. WVNS (1993f) did not characterize bed sediments in the Frank's Creek system, citing very high variability in bed cover and form along the stream channels.

Tucker and Doty (2016 [in preparation]) identified the following stream channel processes that must be accounted for in models of long-term erosion at the West Valley Site:

- Generation and routing of storm runoff and stream flow.
- Occurrence of quasi-equilibrium stream hydraulic geometry properties such as bankfull width, depth, roughness, and their variations downstream.
- Detachment erosion of cohesive sediment (clay-rich till) by flowing water.
- Detachment erosion of sedimentary bedrock by flowing water.
- Transport of coarse bed-load.
- Space-time variation in sediment grain size and cover fraction due to effects of coarse-sediment enrichment as downcutting proceeds.

Hillslopes

Dense vegetation common to undisturbed or recovered areas of the Site is an important control for sheet flow erosion and development of rilling. Tucker and Doty (2016 [in preparation]) suggest that overland flow is infrequent across the Site, apart from areas with convergent topography or high soil moisture content, and impermeable areas such as roads and parking lots.

Rills were observed over the North Slope of the SDA in aerial photography from 1955 and 1961 (WVNS 1993f), at which time vegetation was sparse. The lack of exposed tree roots observed and reported in WVDP (WVNS 1993f) suggested that sheet flow and rill erosion were lower order erosional processes overall on vegetated slopes. If the impermeable covers are removed from trenches in the disposal areas, there would be a high risk for sheet flow and rill erosion until vegetation could be established (e.g. Garrick et al. (2009b)).

Sheet flow and rill erosion monitoring was implemented by periodic monitoring of 23 erosion frames at locations distributed around the Site in 1990. Two were placed near the edges of stream valley walls to monitor potential slumping (DOE 2010a), but these have not been monitored since 2001. Subsequent to WVNS (1993f), three frames were removed due to construction activities around the SDA, and one was lost to a slump failure in gully NP-1. Erosion by sheet flow and rilling was reported at seven locations while aggradation was observed at eight frames. Magnitudes were generally less than 30 cm (1 ft).

Prudic (1986) reported colluvium covering stream valley slopes at thicknesses of 30 to 90 cm. However, freeze-thaw effects and soil creep were discounted by WVNS (1993f) as significant processes compared to slump failure of slopes. Evidence of soil slumping was observed at up to six of the erosion frames, but the largest changes in elevation were ascribed to survey error in thick forest. Temperature logging along soil profiles at selected sites showed freezing temperatures at only the shallowest depths. Snow cover conditions were not disclosed. Tree trunks observed to be affected by mass movement exhibited abrupt bends rather than gentle curvature (WVNS 1993f), as well as split trunks where the upslope portion of a tree's root mass was anchored above the scar and the rest in the slump block. Gentler curvature in tree trunks indicating slower creep is observable in field photography taken by NYSERDA following a major flood in 2009 (Figure 28).



Figure 28. Abrupt slope failure as trees and root-bound soil slide down stream bank destabilized by erosion during 2009 flood. (Photograph courtesy of NYSERDA.)

The most common mass wasting process proposed by WVNS (1993f) was described as a series of surficial slump blocks forming along valley walls. A single block of limited extent forms, after which others appear in response to redistributed stresses. LaFleur (1979) reported “common” shallow rotational slumps in Lavery till on gully walls with relief exceeding 2 m (6 ft), with larger slumps occurring on high bluffs along Buttermilk Creek. Fleming (1976) interpreted slope failure as the major factor in stream valley widening. It is possible that the colluvial mantling described by Prudic (1986) is the result of long-term slump failure combined with minor earthflow.

WVNS (1993f) listed oversteepening due to channel incision and loading by tree growth and transmission of wind drag forces through tree trunks as primary factors forming the initial slump block. Modulating these at the local scale are factors such as vegetation, groundwater conditions, and manmade loads (DOE 2010a). Sudden variation in local groundwater conditions could arise from altered subsurface flowpaths. Prudic (1986) described significant subsurface flow in mole runs during precipitation events. Similarly, fractures in the weathered Lavery till (WLT) could be connected into a flow path by animal burrowing.

Particular landslides have been highlighted by investigators on the basis of size, persistence, or both. The “BC-6” landslide on the west side of Buttermilk Creek has been documented in aerial photographs since the 1930s. Pinned against the west valley wall by a tributary draining a large highlands catchment to the east, a major slope failure occurred in 2009 (personal communication: Lee Gordon [NYSERDA], 23 June 2016). The North Slope of the SDA consists of fill atop unstable native material (WVNS 1993f). Early reported rates of movement were ascribed to settling of the fill and potential sliding along the contact with the original surface.

Recent monitoring has detected annual rates of elevation change on the order of 30 cm (1 ft) (NYSERDA 2015, 2016).

The apparent threshold slope for stability in Lavery till in the Site vicinity is 38 percent or 21 degrees. This estimate is based on cross sections developed from topographic mapping by WVNS (1993f) along the Frank's Creek system and is consistent with results of a contemporaneous geotechnical analysis. DOE (2010c) combined this slope as an average stable slope with downcutting rates reported above to derive rim retreat rates of 0.6 to 1.4 cm/y on Buttermilk Creek and 18 cm/y on Frank's Creek.

Rates of valley widening were also derived using slope movement measurements made on the BC-6 and North Slope of the SDA landslides. Measurements on the BC-6 slide led to estimated rates of edge retreat of 4.9 to 5.8 m/y (Boothroyd et al. (1982), cited by DOE (2010c)). Measurements of movement along the North Slope of the SDA led to estimated retreat rates of 2 to 3 cm/y (DOE 2010c). The higher rate is based on a short monitoring period, which included the influence of flooding due to Hurricane Frederic. The lower rate is based on 22 yr of monitoring of the North Slope of the SDA.

McKinney (1986) developed estimates of valley edge retreat by assuming continued average rates of downcutting and a profile based on the uncalibrated date of the terrace wood sample. By advancing channel profiles and cross section form in time, rates of approximately 5 cm/y for Buttermilk Creek and 3 to 5 cm/y for Frank's Creek and Erdman Brook were developed.

Tucker and Doty (2016 [in preparation]) emphasize the importance of regolith production for hillslope processes at the West Valley Site, where regolith refers to unconsolidated granular material that can be transported by hillslope processes as grain-by-grain or consolidated or semi-consolidated clasts. They distinguish regolith from bedrock and till where regolith (including soil) does not require breakage or detachment of material by erosion. They also note that most of the terrain at the West Valley Site is covered by regolith. Tucker and Doty (2016 [in preparation]) argue that erosion rates by landsliding and gully erosion are higher than soil creep, but the process of soil creep affects surface materials over a wide geographic extent. They identify the following suite of hillslope processes that must be represented in modeling of hillslope erosion:

- production of mobile regolith from bedrock and Quaternary sediments,
- downslope motion of soil by creep-related processes,
- occurrence of rotational/translation landsliding in Quaternary sediments, and
- generation and routing of storm runoff.

Gully Erosion

Gullies have been identified as the principal surface erosion threat to the stability of the Site (Garrick et al. 2009a), with the waste disposal areas at risk on the decadal scale (ECS 2013). DOE (2010c) identified the North Plateau as more susceptible than the South Plateau due to its larger area and greater development. At the Site, gullies are “characterized by steep bank slopes, active slumping, bank erosion, and a ‘V’ cross sectional shape” by WVNS (1993f). Particular gullies classified as major, moderate, and minor are described and mapped in WVNS (1993f).

Some gullies were incorporated into the drainage control system, extended, or otherwise modified for operational needs.

Bennett (2016 [in preparation]) summarized morphological measurements of a set of gullies on and near the Site, including many mapped by WVNS. A gridded digital elevation model (DEM) derived from the 2010 LiDAR dataset was analyzed to measure characteristics such as contributing area, channel slope, depth, etc. In addition, Bennett (2016 [in preparation]) noted linear channel profiles of an average slope of 70 percent.

The gullies were segmented into an inner section that is incised into the plateau, and an outer section that erodes into a stream valley wall. Off-site gullies were selected to serve as analogues to on-site gullies for further analyses based on similar inner section morphometric characteristics. Such analyses might include change detection using the 2015 LiDAR dataset and potential field data collection.

Gullies may be initiated where concentrated flow is intense enough to exceed a local erodibility threshold and establish a step and plunge pool. This dyadic feature may then migrate rapidly upstream as a self-sustaining configuration while eroding a channel (Alonso et al. 2002; Bennett 1999; Bennett and Casali 2001). Once established, a gully headcut can migrate rapidly during a single storm, and intense single-day events were deemed to be the primary cause of extensive gully headcut migration (Garrick et al. 2009b). Garrick et al. (2009a) noted limited data on gully head advance at the Site, but estimated average rates ranging from 0.4 to 0.7 m/yr. These rates are similar to the average rate of incision calculated assuming the inner section of on-site gullies reported by Bennett (2016 [in preparation]) incised into the plateau over approximately 100 to 200 yr of European style agricultural practice. Poesen et al. (2011) reviewed potential threshold mechanisms related to hydraulics, rainfall, topography, pedogenics and lithology, and land use. Stream valley edges appear to be conducive to gully initiation as apparent in the moderate and major gullies mapped by WVNS (1993f), all of which extend off the local stream network. A fresh edge exposed by a slope failure in an area of convergent flow would disturb established surface and shallow subsurface flow conditions, which might in turn spawn a gully headcut during a subsequent runoff event.

The steep west wall of Buttermilk Creek exhibits another manifestation of gullying. Boothroyd et al. (1979) and Boothroyd et al. (1982) mapped numerous alluvial fans on low terraces with incised channels running up the wall, describing them as a manifestation of fluvial transport of valley wall material into Buttermilk Creek's channel. In some cases the incision continues into the top of the plateau. LaFleur (1979) mapped the paired gully heads corresponding to the BC-3 alluvial fan.

Wind Erosion

Dense vegetation cover suppresses wind erosion. Intensified fluvial transport tends to dominate eolian transport following disturbance in humid or sub-humid settings (Field et al. 2009). Contaminated soil and sediment could be entrained and exported from areas denuded by agricultural practices, drought, or wildfire, or from dry stream channel bedforms. Rapid recovery of vegetation should limit the duration of enhanced eolian erosion compared to semi-arid or arid regions.

DOE (2010a) noted the potential for wind erosion from disturbed surfaces during construction activities and mobilization of dust by heavy equipment operation, which could be mitigated by applicable best practices during such work. The quantitative risk assessment considered a scenario of high winds damaging impermeable covers over the disposal areas, which actually occurred in 2009 (Garrick et al. 2009b). However, eolian erosion does not appear to be considered as an erosional threat on the order of fluvial erosion and mass wasting.

Conceptual Site Model for Geomorphology and Erosion

Following is an overview of the conceptual site model to be applied in the West Valley PPA Model:

- The West Valley Site overlies multiple glacial till plateaus and local sediments deposited within a glacial valley incised into Paleozoic sedimentary rocks. These glacial sediments formed during advances and retreats of the Late Pleistocene Laurentide ice sheet.
- North-northwest retreat of the last ice sheet approximately 13 to 14 ka established an erosional setting for the Buttermilk Creek drainage that is characterized by incision of the Buttermilk Creek Valley and progressive incision/development of tributary stream drainages that feed into the Valley. Base level for the drainage system is controlled by the confluence of the Buttermilk and Cattaraugus Creeks and secondarily by the Lake Erie lowland. The presence of sedimentary bedrock at the intersection of the creeks and continuing isostatic rebound and fluctuations in water level at Lake Erie will control future base levels and associated adjustments in the Cattaraugus and Buttermilk Creek drainages.
- The Buttermilk Creek drainage system is expected to remain erosional with local transitory areas of deposition. The future climate at the West Valley Site is expected to be a continuation of the current interglacial climate accompanied by increasing but variable global warming. Hence, the probability of a return to glacial climate with formation of continental ice sheets is low for the next tens to hundreds of thousands of years (see Section 3.2.10). The challenge presented by the climate, geomorphic, and erosional setting of the West Valley Site is to evaluate the impact of future erosional events on areas of residual contamination.
- The disposal areas and sites of contaminant release at the West Valley Site are potentially vulnerable to gully migration and stream-bank collapse in adjacent drainages (Quarry and Frank's Creeks and Erdman Brook). Surface-water flow, primarily in areas of topographic convergence but locally limited by surface vegetation, is the primary driver of erosion. Local processes of hillslope erosion such as soil creep, sites of slope failure/landsliding, processes of channel erosion, formation and migration of gully downcutting, and head-scarp migration contribute to local erosion. Rapid stream channel incision is indicated by transitions from U-shaped to V-shaped profiles and migrating knickpoints in the drainages. Transport of bed-load sediment by flowing water will occur in channels and creeks with significant space-time variations in sediment grain size and water flow. Transitory wind transport of sediment will occur in disturbed surfaces and in dry stream channels.

- The expected sequence of erosional processes associated with potential contaminant release includes:
 - Breaching of contaminant sites by combined gully migration, channel undercutting, and hillslope processes of erosion.
 - Downslope migration of surface contaminants to stream channels.
 - Transport of contaminated sediments in stream channels with subsequent convergence into Buttermilk Creek.
- There is considerable uncertainty in understanding and quantifying hillslope and gully erosion and stream channel transport. These uncertainties require probabilistic representation of the processes in the conceptual site model. Significant topics of uncertainty include:
 - Prediction of sites of future gully formation and channel undercutting.
 - Estimation of rates and directions of gully migration.
 - Identification of sites of erosional breaching of contaminants given the spatially complex and variable distribution of contamination.
 - Estimation of rates of contaminant transport by hillslope and stream channel processes.
 - Dynamic coupling between climate change, surface and subsurface hydrology, and erosion.
 - Assessment of the effects of vegetation changes, future man-driven disturbances of natural surfaces, and erosional barriers.
- Quantification of uncertainties is aided by chronology studies of past erosional and depositional features in the Site vicinity (terraces, abandoned meanders) and Site-specific measurements of erosion processes (for example, sheet and rill erosion rates, rates of knickpoint advance, estimates of stream channel incision rates, estimates of valley and channel rim widening, and measurement of gully advance rates). Predictions of patterns of erosion and sedimentation from landscape evolution models can be compared with Site measurement data. The landscape modeling patterns may be particularly useful for identification of areas of “hotspot” erosion.
- Studies of past and potential future erosional processes are ongoing and will likely require iterative reassessment and refinement of the conceptual site model.

3.2.7.3 Stratigraphy of the Site

Rock units in the West Valley Site are comprised of two groups: shales and siltstones of the Devonian Canadaway Group and Late Wisconsin age glacial sediments of Buttermilk Creek Valley (DOE 2010a; LaFleur 1979; Prudic 1986).

3.2.7.3.1 Paleozoic Bedrock

The stratigraphy of the Paleozoic bedrock beneath the West Valley Site is summarized in Figure 3-11 in DOE (2010a). Descriptions of the upper part of the Paleozoic section are provided from exploration drill hole 69 USGS 1-5 located in the southeast part of the West Valley Site area (Bergeron et al. 1987). The upper approximately 300 m (984 ft) of the stratigraphic section

consists of the shale, siltstone, and sandstone of the Canadaway Group. While this unit dips gently (< 1 degree), the rocks were affected by the Late-Paleozoic Alleghanian Orogeny. Lash and Engelder (2011) note that basin deposition of Devonian sediments in western New York were affected by reactivation of Precambrian basement structures and structural discontinuities caused by Acadian plate convergence. Smith and Jacobi (2001) suggest that depositional sequences of sediments of the Canadaway Group are localized along the syndepositionally active Clarendon-Lindon fault system. Ettensohn (2004) describes the tectonic setting of the Catskill Delta complex, a foreland basin that deposited delta-alluvial sediment wedges of Devonian age during the Acadian orogeny. Lash (2006) describes cyclical marine shale deposits of the Canadaway Group in stratigraphic sections near Lake Erie northwest of the West Valley Site. He suggests that the basal Dunkirk shale of the Canadaway Group served as a hydraulic seal that restricted upward migration of fluids and gases, an important constraint on resource assessments for the West Valley Site region.

3.2.7.3.2 Pleistocene Glacial Stratigraphy

The geology of the West Valley Site has been studied since the early 1960s; a summary of the progression of studies at the Site is provided in WVNS (1993e). Multiple ice advances culminating in the Late Pleistocene widened and steepened an existing north-trending drainage valley, forming a glacially carved U-shaped valley. The West Valley Site is located on the west flank of the glacial valley, and there is approximately 100 m (330 ft) of bedrock relief between the topographically high points of the southwestern valley ridges and the modern Buttermilk Creek Valley (WVNS 1993d). Repeated glacial advances and retreats infilled the valley, creating a plateau surface surmounting Quaternary glacial deposits of till, lacustrine sediment, moraine deposits, and glacial outwash (LaFleur 1979). The upper surface of the plateau, notably higher topography on the western and southwestern part of the Site, is partly covered by locally derived alluvial fan deposits and colluvium. These deposits were formed during surface runoff and erosion after retreat of glacial ice lobes northward out of the Buttermilk Creek drainage.

The stratigraphic relationships of the glacial deposits of the West Valley Site are described by LaFleur (1979); they are based on detailed surface mapping of regional and local glacial deposits (maximum thickness approximately 150 m (492 ft)) and 24 boreholes at the Site. Subsequent studies, including additional boreholes and horizontal trenches, refined the stratigraphy and are summarized current to the FEIS (DOE (2010a); see their Table 3-3). Modern drainages subdivide the till plateau into North and South Plateaus. The following description of stratigraphic units is presented for the two plateaus (from, primarily, DOE (2010a); WVNS (1993e); Prudic (1986); and Bergeron et al. (1987)).

A recent draft report (Wilson and Young 2017 [in preparation]) presents new data, information, and analyses that support the following conclusions:

- 1) *“The age of the last glacial recession can now be confidently dated at circa 13,000 years before present (YBP). This date establishes the starting point for late Pleistocene/Holocene Buttermilk Creek incision.*
- 2) *Historical Buttermilk Creek incision rates have been nonlinear through time. Vertical incision rates immediately following glacial retreat and for the first approximately 7,000 years vary somewhat, averaging around 0.015 feet per year (between approximately*

13,000 and 6,000 YBP), depending on the assumption of the initial surface elevation. The incision rate appears to have varied between undetermined limits during the middle to late Holocene, between approximately 6,000 and 2000 YBP, averaging around 0.018 feet per year, and then appears to have slowed dramatically during the last approximately 2,000 years as bedrock thresholds were encountered in the channel.

- 3) The actual variability of the incision rate cannot be determined with confidence; however, additional OSL dating of archived samples from intermediate terraces could help resolve this.
- 4) The reasons for the dramatic slowing of Buttermilk Creek incision rates during the past 2,000 years likely include emergence of resistant bedrock sections in downstream reaches of Buttermilk and Cattaraugus Creeks, and the overall flattening of the gradient of the creek. Both are factors that will continue to be applicable into the future.
- 5) The Buttermilk Creek channel has been pushed westward by fan growth by the westward-flowing Heinz Creek tributary at the confluence of the two streams. The west bank of Buttermilk Creek has been over-steepened leading to active landsliding at this location. The westward lateral migration of Buttermilk Creek during Holocene time is estimated to have ranged between approximately 0.09 and 0.16 feet per year. If the current westerly migration of Buttermilk continues into the future at these rates, Buttermilk Creek may remove the Frank's Creek-Buttermilk divide in the vicinity of the State-licensed Disposal Area (SDA) in an estimated 4,000 to 6,000 years, or sooner depending upon the concomitant rate of widening of Frank's Creek.
- 6) Several hundred field shear stress values for a wide variety of in situ materials were measured using a Torvane device. These data may correlate with erodibility measurements from Study 2. If so, the larger number of Torvane data points may be able to supplement the Study 2 erodibility data by serving as proxies for erodibility in modeling.
- 7) Landslides have, and will continue to have, great significance to terrain development in the Buttermilk Creek watershed. For example, two of the primary processes key to understanding past landscape development, namely Buttermilk Creek base level control, and westerly channel migration, are at least in part influenced by landslides. The large landslide in the east bank of Buttermilk Creek just downstream from the tree farm terraces may have been periodically influential in base level control, while the active landslide in the west bank opposite the Heinz Creek fan is intimately involved in westward lateral migration of the channel.
- 8) There have been substantial warmer and colder periods during the Holocene that deviate from current average temperatures. The historical effects of oscillating temperatures are likely to have been reflected as subtle variations within the overall Buttermilk Creek erosion history.
- 9) The current study has produced a significant improvement in our knowledge of the historical processes controlling landscape development and their timing in the Buttermilk Creek watershed. This has enabled a reduction in uncertainty concerning the nature and timing of these processes; although, quantifying the reduction is difficult. The vast quantity of data gathered, and the significant improvements in dating and other measurement technologies, are just two of the factors that enable the dramatic improvement in confidence when compared with the quantity and quality of data available to previous studies."

North Plateau

Figure 29 is a generalized cross section illustrating the stratigraphy of the North Plateau (DOE 2010a). Figure 30 is a geologic map of the West Valley Site and vicinity.

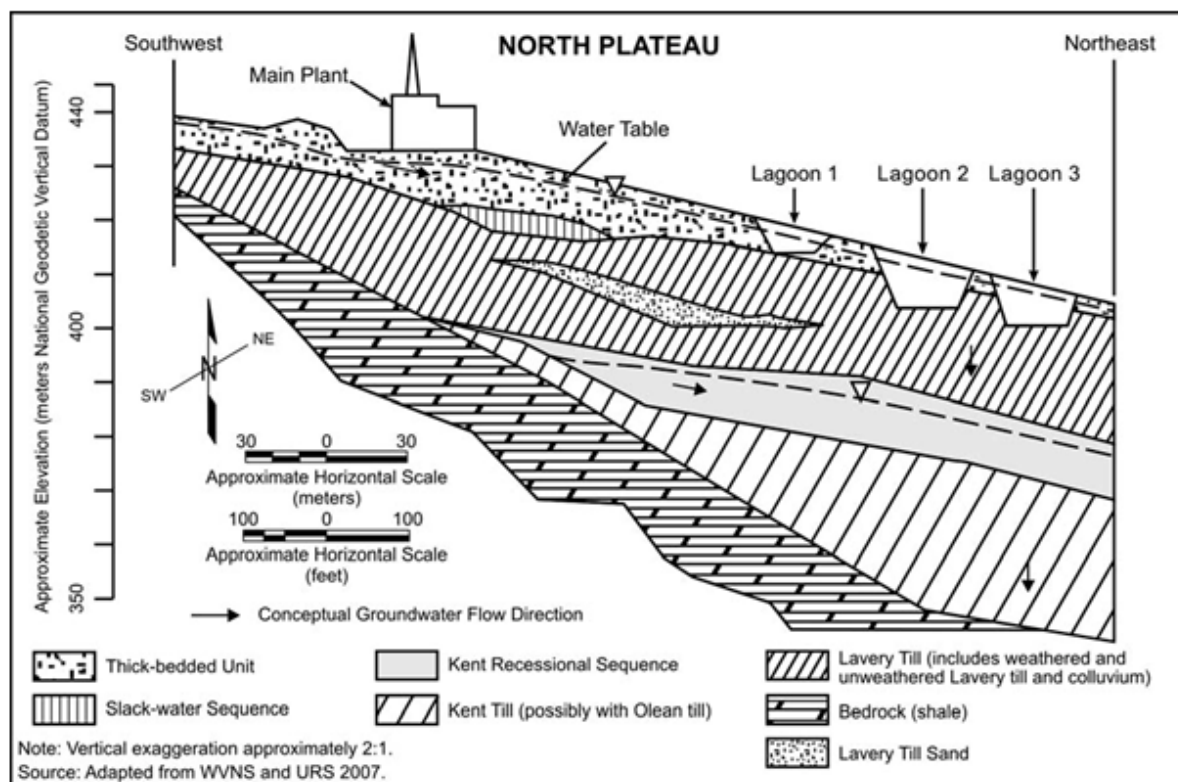


Figure 29. Generalized geologic cross section through the North Plateau area of the Project Premises showing the stratigraphic relationships of glacial sediments and Devonian bedrock (Figure 3-6 in DOE (2010a)).

Colluvium and the thick-bedded unit (TBU): Modern slopes are covered with colluvium/regolith (0.3 to 0.9 m [1 to 3 ft] thick) with multiple slumps and shallow-seated slides (Prudic 1986). The thick-bedded unit is a more extensive unit deposited from Holocene and modern streams that drained into Buttermilk Creek and reworked underlying glacial units. The deposits thin from west to east into the creek drainage and are the country rock for the shallow unconfined aquifer of the North Plateau. The thick-bedded unit ranges from 0 to 12.5 m (0 to 41 ft) in thickness; these variations occur where the unit infills channels cut into the upper surface of the underlying till (Lavery till). Sediments of the thick-bedded unit are moderately silty sand and gravel with pebble-to-cobble size clasts. The depositional environment for the deposits are inferred to be stream channel sand and gravel bar deposits that interfinger with silty overbank/flood plain deposits (Bergeron et al. 1991). The sediments are locally intermixed with mudslide deposits.

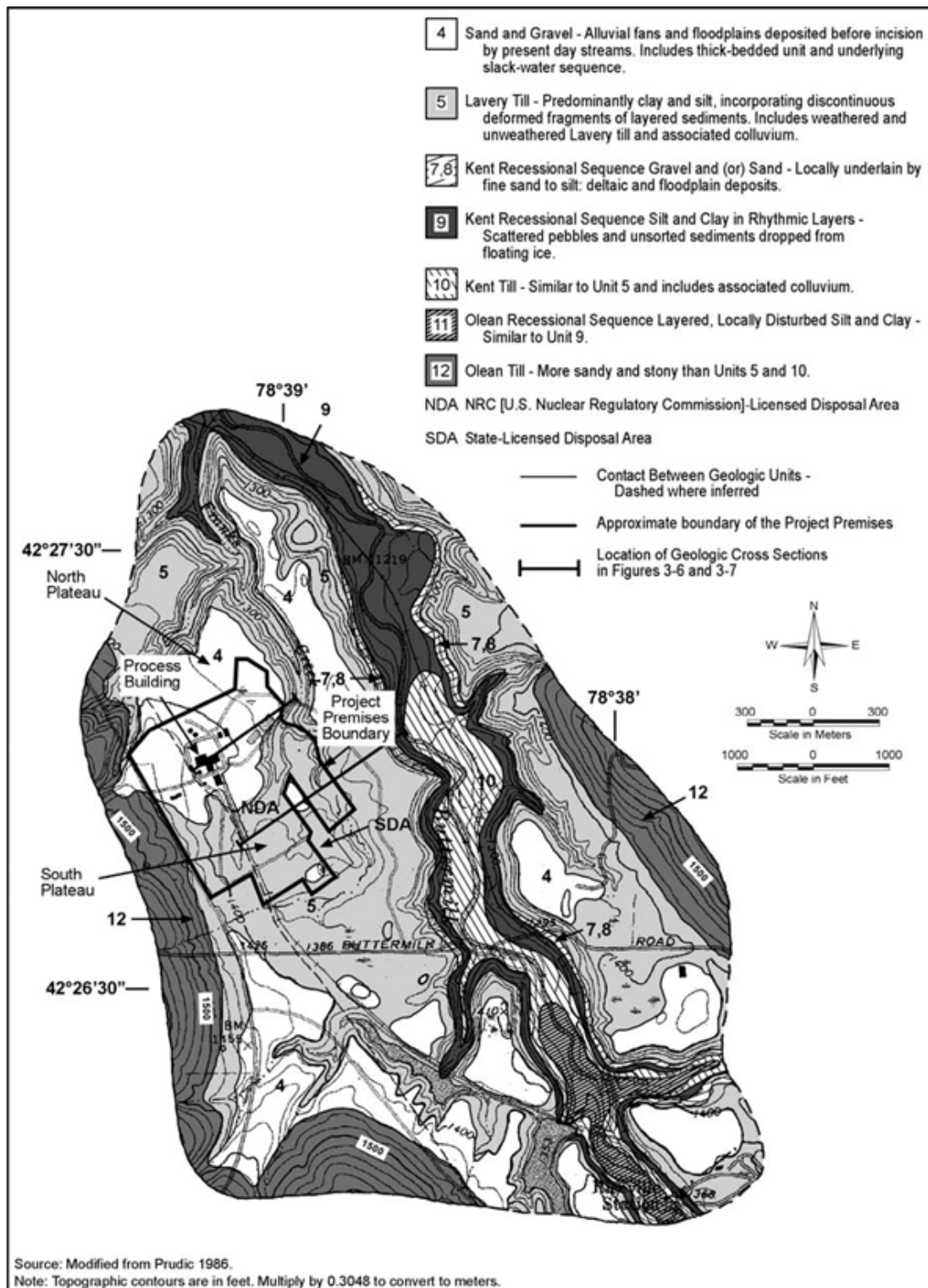


Figure 30. Surface geologic map with topography of the West Valley Site and vicinity (Figure 3-8 in DOE (2010a)).

Slack-water sequence (SWS): The slack-water sequence consists of thin-bedded lacustrine clay, silt, and sand with fine-grained gravel and sand at the base (glaciofluvial). The deposits vary from 0 to 4.6 m (0 to 15 ft) in thickness and occur in a northeast trending trough beneath the North Plateau, overlying areas of unweathered Lavery till (ULT) (Figure 29 and Figure 30; this is included with the colluvium/thick bedded unit [Unit 4] and is not differentiated in Figure 30). The slack-water sequence is inferred to represent deposits of a local lake developed on a surface depression in the underlying Lavery till.

Lavery till: The Lavery till consists of silt and clay with local pebble-sized clasts and discontinuous lenses of stratified sand, gravel, and laminated silt. The fine-grained character of the till is attributed to the underlying Devonian shale/siltstone bedrock, which disaggregates to clay- and silt-size particles during glacial and/or fluvial erosion (Prudic 1986). The till forms most of the western plateau of the Buttermilk Creek Valley and underlies the entire area of the Project Premises (Figure 30); a similar but somewhat smaller plateau area is upheld by Lavery till on the eastern flank of Buttermilk Creek (Figure 30). The Lavery till varies from 1 to 34 m (3.3 to 112 ft) in thickness and is 23 to 32 m (75 to 105 ft) thick beneath the Project Premises; it is thickest along the glacial valley floor and thins westward and buttresses against the steep west slope cut into Devonian shale. The upper part of the Lavery till is locally weathered. Exposures of the intact Lavery till are limited and the composite section through the till is reconstructed from cliff walls of drainages, from boreholes, and in excavated walls of the lagoons at the waste-burial site. The Lavery till is inferred to be deposited from advancing and retreating ice lobes within the U-shaped glacial valley of Buttermilk Creek.

LaFleur (1979) divided the Lavery till into three interfingering subfacies:

1. Pebble and cobble till with a clay-silt matrix. Clasts constitute about 10 to 20 percent of the subfacies (70% of the formation thickness).
2. A compositional similar unit to the first subfacies, with less than 5% clasts and interbeds of quartz-rich silt.
3. Stratified sand and gravel with disrupted blocks of till (subfacies 1) and thin-bedded clay. This subfacies is exposed only in excavations on the Site. LaFleur (1979) interprets subfacies 3 as local ice-frontal deposits overridden by glacial ice (the unit corresponds to the Lavery till sand shown on Figure 29).

Kent Recessional sequence (KRS). The Lavery till is underlain by interbedded deposits of gravel, sand, and clay of the KRS. These sediments formed within a lacustrine and fluvio-delta setting (kame delta) when the Kent ice lobe receded northward, impounding drainages to form local lakes. These lakes drained, allowing glacio-fluvial processes to erode and transport deposits of recessional moraines and underlying glacial sediments. Exposures of the KRS occur primarily in drainage cliffs east of the Project Premises (Figure 30). The composite section of the unit consists of basal lacustrine sediments of clay and silt overlain by coarse-grained sand and gravel. The KRS varies in thickness from 0 to 21 m (0 to 69 ft) and is thickest beneath the northeast part of the Project Premises.

Kent till, Olean Recessional sequence (ORS), and Olean till. The Kent till and ORS are exposed within the valley walls of Buttermilk Creek southeast and east of the Site (Figure 30). The Kent till is lithologically similar to the Lavery till (clay/silt matrix with clasts). LaFleur (1979) distinguishes the Kent till from the Lavery till by the higher calcareous content and the increased content of exotic clasts in the Kent till (20 to 40% exotics including sandstone, carbonate clasts, and crystalline clasts from bedrock exposures in the Canadian Shield). Additionally, the Lavery till contains inclusions of Kent till and clay. The Olean till tends to have an increased content of sand- and gravel-interbeds. The ORS is similar to the KRS (lacustrine clay and glacio-fluvial deposits). The composite sequence of the two till units and the recessional sequence reach a maximum thickness of 91 m (300 ft) beneath the North Plateau. The two till units are inferred to be direct deposits of advancing and retreating ice lobes. The recessional sequence between the tills was deposited in local lakes and transitional glacio-fluvial drainages during intervals of retreat of the ice lobes to the lowlands north of the glaciated drainages.

South Plateau

There are two major differences between the Site stratigraphy of the North and South Plateau areas. First, the sand and gravel deposits of the thick-bedded unit (TBU) and the slack-water sequence (SWS) are not present on the South Plateau (Figure 31). Because of this difference, the waste disposal trenches of the NDA and the SDA are entirely within the Lavery till. Second, the absence of the alluvial fan sediments has allowed the upper part of the Lavery till to be deeply weathered with extensive oxidation, abundant root tubes, and development of dessication structures and intersecting horizontal and vertical fractures. The thickness of the weathered Lavery till ranges from 0.9 to 4.9 m (3 to 16 ft) across the South Plateau. In contrast, the maximum thickness of the weathered upper part of the Lavery till on the North Plateau is 0.9 m (3 ft). The origin of extensive till fractures in the Lavery till is discussed below.

The remainder of the stratigraphic section of the South Plateau is largely similar to the described stratigraphic section for the North Plateau, with minor differences in thicknesses of individual units that are summarized in Table 3-3 of DOE (2010a). Two notable differences in the stratigraphic section are the absence of the Lavery till sand, and an increased thickness of gravel and sand and kame delta deposits in the KRS (compare Figure 30 and Figure 31). Note that the Site facilities are located in weathered and unweathered Lavery till because of the absence of the thick-bedded unit on the South Plateau (see also Figure 30).

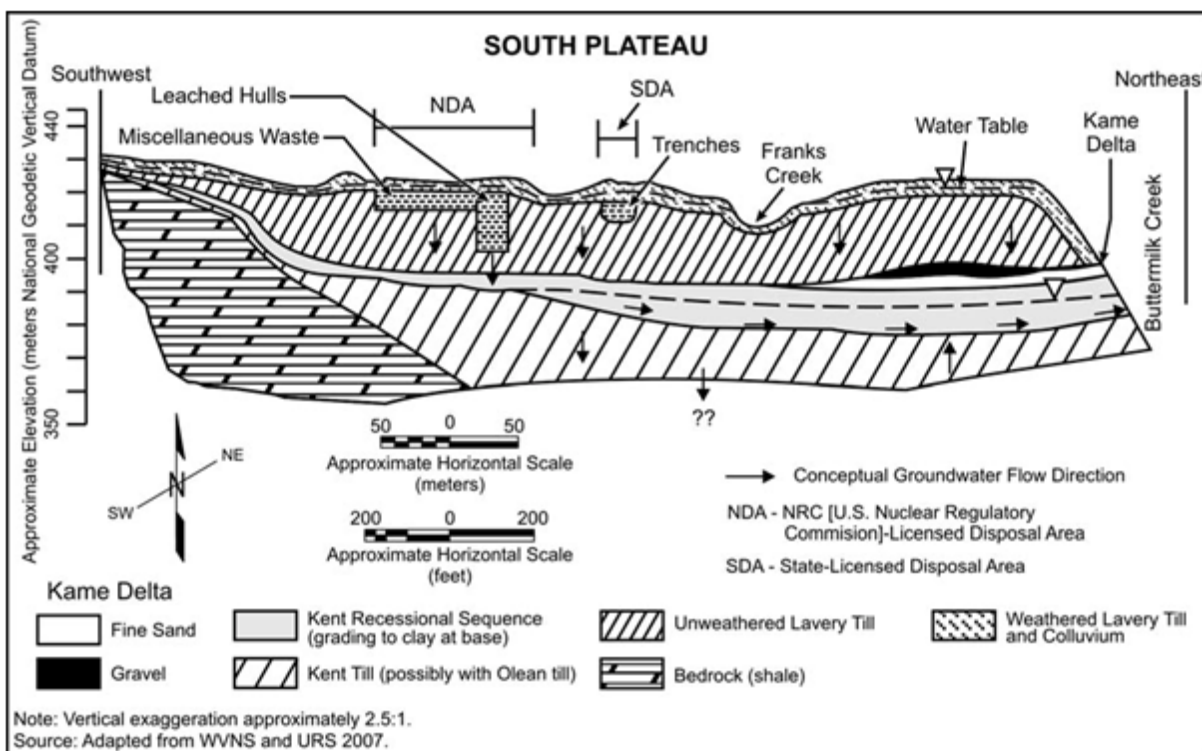


Figure 31. Generalized geologic cross section through the South Plateau area of the Project Premises showing the stratigraphic relationships of glacial sediments and Devonian bedrock (Figure 3-7 in DOE (2010a)).

Till Fracturing

Fracturing in the Lavery till, particularly the upper weathered part of the Lavery till on the South Plateau (WLT), strongly affects the lithologic and hydraulic properties of the till (DOE (2010a); see Section 3.2.8.2.2). Field studies conducted in multiple trenches within the Project Premises are used to characterize the weathered and unweathered properties of the Lavery till and to document the geometry of multiple fracture sets (Dana et al. 1979; WVNS 1993e). Fracture systems are classified as:

1. Prismatic and columnar jointing developed primarily in the weathered (soil altered) upper part of the till.
2. Longer, near vertical parallel joints within the upper weathered till, extending downward into unweathered till.
3. Small displacements/fractures associated with sand and gravel lenses.
4. Horizontal partings/fracture sets.

Multiple origins are proposed for the fracture sets. These include stresses associated with glacial rebound, stress release associated with activity along the Clarendon-Linden fault system, volumetric changes associated with freeze-thaw cycles, ion-exchange and osmotic processes and jointing “developed” from jointing patterns in underlying bedrock (WVNS 1993e).

The Ohio Fracture Flow Working Group (Christy and Weatherington-Rice (2000) and Brockman and Szabo (2000)) provide increased clarity on the origin and properties of fractures in tills of Ohio. Brockman and Szabo (2000) reviewed the literature on fracture mechanics and mechanisms of till fracturing. They suggest that the most important formative processes are desiccation, freeze-thaw, glaciotectionics, and lodgement till deposition (lodgement till is till plastered or “lodged” by ice on glacial substrates). They describe the development of horizontal partings and vertical dessication cracks that developed in compacted clay from ice freezing fronts in experiments with buried cylinders and polygonal fractures observed in a newly exposed till sheet in front of a retreating glacier, where mean annual temperatures were near freezing. Evans et al. (2006) suggest that processes of deformation, flow, sliding, lodgement, and ploughing in the subglacial traction zone can form glaciotectionically folded and faulted stratified till.

3.2.7.4 Faulting and Seismicity

3.2.7.4.1 Fault Systems—Western New York

Multiple Paleozoic bedrock structures and lineaments have been identified in western New York (Figure 32). More prominent systems include the Clarendon-Linden Fault System (CLFS) and the Attica Splay, the Elzevir-Frontenac Boundary Zone, the Bass Island Trend, and the Georgian Bay Linear Zone. Jacobi (2002) has identified multiple “fracture intensification domains” based on a combination of the strike of closely spaced fracture systems, gravity and magnetic data, soil gas anomalies, and lineaments observed in remote sensing data. These fracture intensification domains or structural systems occur throughout central and western New York (see Jacobi (2002); his Figures 2 and 3). He relates these systems to two major regional sets of lineaments with diverse regional trends:

1. North-south striking structures that are related to major structural features in Precambrian basement rocks (primarily continental accretion structures; see Whitmeyer and Karlstrom (2007)).
2. Cross-strike discontinuities that are related to structural elements of Paleozoic rifting and compressional tectonic events.

Bedrock structure is important with respect to its spatial relationship to historical seismicity. The following sections briefly discuss the important characteristics of major structural features of western New York and the West Valley Site region prior to discussing seismic hazard studies.

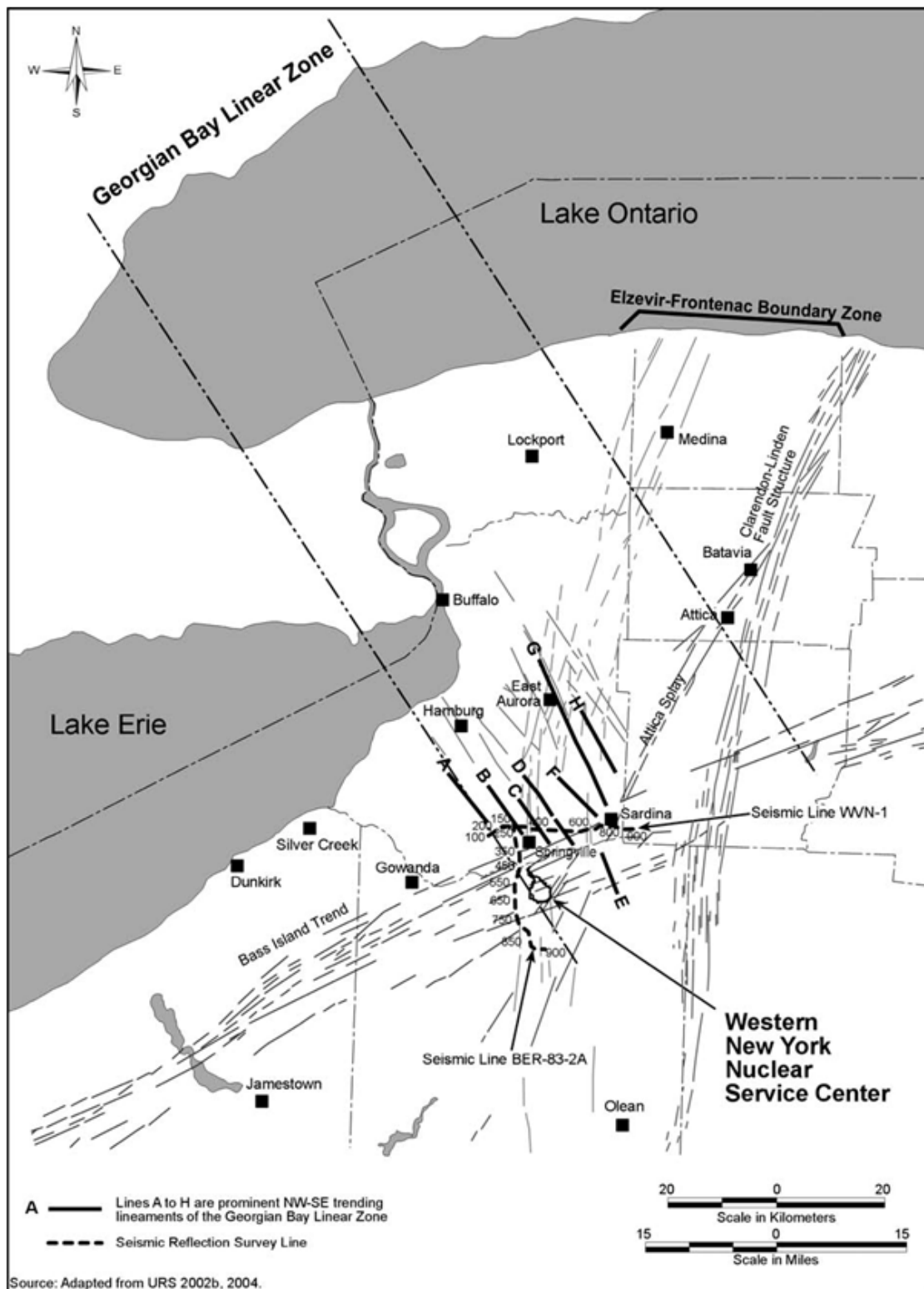


Figure 32. Major structural features and selected lineament systems in western New York (from Wong et al. (2004); DOE (2010a)).

Clarendon-Lindon Fault System

The north-south striking CLFS is located about 30 km (19 mi) east of the West Valley Site and consists of multiple discontinuous en echelon high-angle faults (URS 2002b). Jacobi and Fountain (2002) note that faults of the CLFS are locally truncated by northeast striking lineaments/discontinuities and the fault intersections form blocks with variable subsidence and uplift histories. They argue that the CLFS is the southward continuation of tectonic belts in the Elzevir-Frontenac Boundary zone (Figure 32). These fault zones were episodically active during the Taconian, Acadian, and possibly the Alleghanian Orogenies. Fakundiny and Pomeroy (2002) suggest (based on seismic-reflection profile data) that the CLFS results from tectonic adjustments within the Paleozoic bedrock located above Precambrian basement megablocks with differing earthquake characteristics. URS (2002) describe the history of investigative studies of the CLFS, including seismic reflection profiling across the Lake Ontario area and seismic reflection profiles near the West Valley Site. They note that the eastern band of faults and lineaments in the CLFS near Lake Ontario coincide with the eastern boundary of the Elzevir-Frontenac Boundary Zone. They describe high-angle faults originating in Grenville-age basement beneath the West Valley Site region that extend upward in sections into Middle Devonian sedimentary rocks. The Attica Splay extends southwestward off the CLFS near the town of Batavia and extends parallel to the Tonawanda Creek Valley. The Attica Splay was the site of the 1929 magnitude 5.2 earthquake near the town of Attica, New York (Wong et al. 2004).

Bass Island Trend

The northeast trending Bass Island Trend is an oil and gas producing structure marked by lineaments associated with a regional fold formed by a thrust fault that extends into the Lower Devonian sedimentary strata (URS 2002b). The Bass Island Trend extends through the West Valley Site area. Local structural features in bedrock in a tributary drainage to Cattaraugus Creek 12 km (7.5 mi) west of the West Valley Site are attributed to this Trend. Jacobi (2002) notes that the Bass Island Trend was first recognized by anomalous formation elevations and repeated stratigraphic sections and more recently by lineaments identified in remote sensing imagery.

Georgian Bay Linear Zone

The Georgian Bay Linear Zone is delineated by northwest-trending aeromagnetic lineaments, lineaments identified by satellite imagery, and structures identified in surficial bedrock and lake sediments (URS 2002b).

3.2.7.4.2 Seismic Hazard Analysis

A range of seismic hazard assessments has been conducted for the West Valley Site over the last five decades—the history and results of these studies are described in Wong et al. (2004) and are briefly summarized in the FEIS (DOE 2010a). The most recent study (Wong et al. 2004) used modern methods of probabilistic seismic hazard analysis (PSHA) that have evolved from the pioneering work of Cornell (1968) and have been formalized in the report by the Senior Seismic Hazard Analysis Committee (Budnitz et al. 1997). The goal of a PSHA is to estimate the levels

of horizontal ground motion that could be exceeded at specified annual frequencies for a specific site. These studies are conducted in sequential steps:

1. Identify specific seismic sources for a region surrounding a site.
2. Develop probabilistic seismic parameters for the seismic sources (location, geometry, orientation, maximum earthquake magnitude, and earthquake recurrence rates).
3. Evaluate ground accelerations based on the surface and subsurface geology at a site.
4. Estimate horizontal ground motions for selected annual probabilities of exceedance using established methods of PSHA.

Historical Seismicity

Historical seismicity in the northeastern U.S. was compiled using the earthquake catalog of the U.S. Geological Survey for the National Seismic Hazard Maps, supplemented by data from the National Earthquake Information Center through 2003 (Wong et al. 2004). Noteworthy historic earthquakes include the 1929 Attica earthquake (MM IV on the Modified Mercalli Intensity Scale), the 1944 Cornwall, Ontario-Massena earthquake (5.8 M), and the 1986 Leroy earthquakes in northeast Ohio (5.0 M). Historical earthquakes within 100 km of the West Valley Site are listed in Table 3 of Wong et al. (2004), showing a record for calendar years 1786 through 2003. Seismicity within 50 km (31 mi) of the Site has been sparse for detection thresholds. Twenty-three events within 100 km (62 mi) of the Site are included in Table 3 of Wong et al. (2004) for magnitudes up to 4.7. Figure 33 and Figure 34 are maps of compiled seismicity for the northeastern United States.

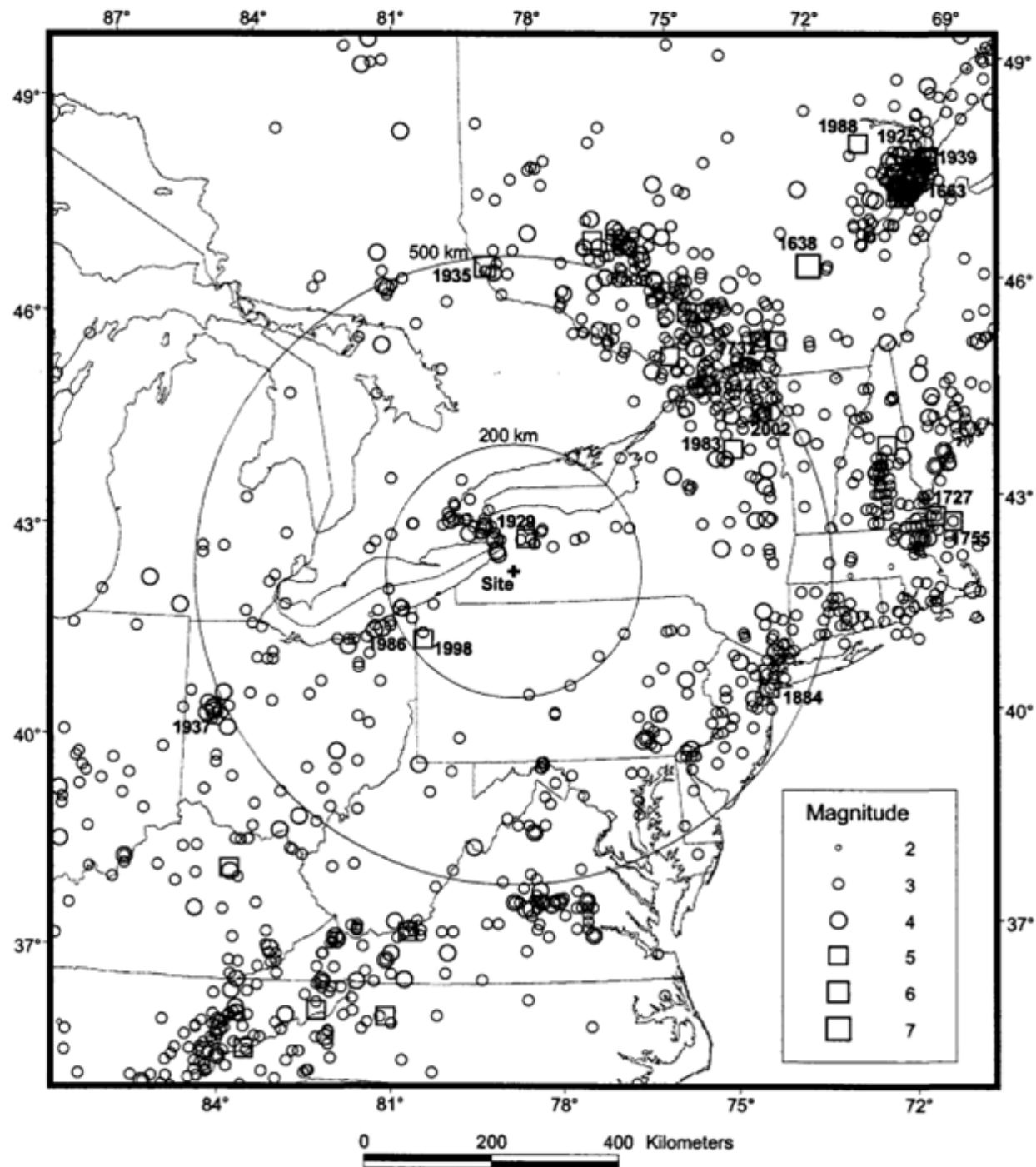


Figure 33. Historical seismicity ($M > 2.0$) of the northeastern United States centered around the West Valley Site for the period from 1638 to 2003. (From Wong et al. (2004), Figure 3.)

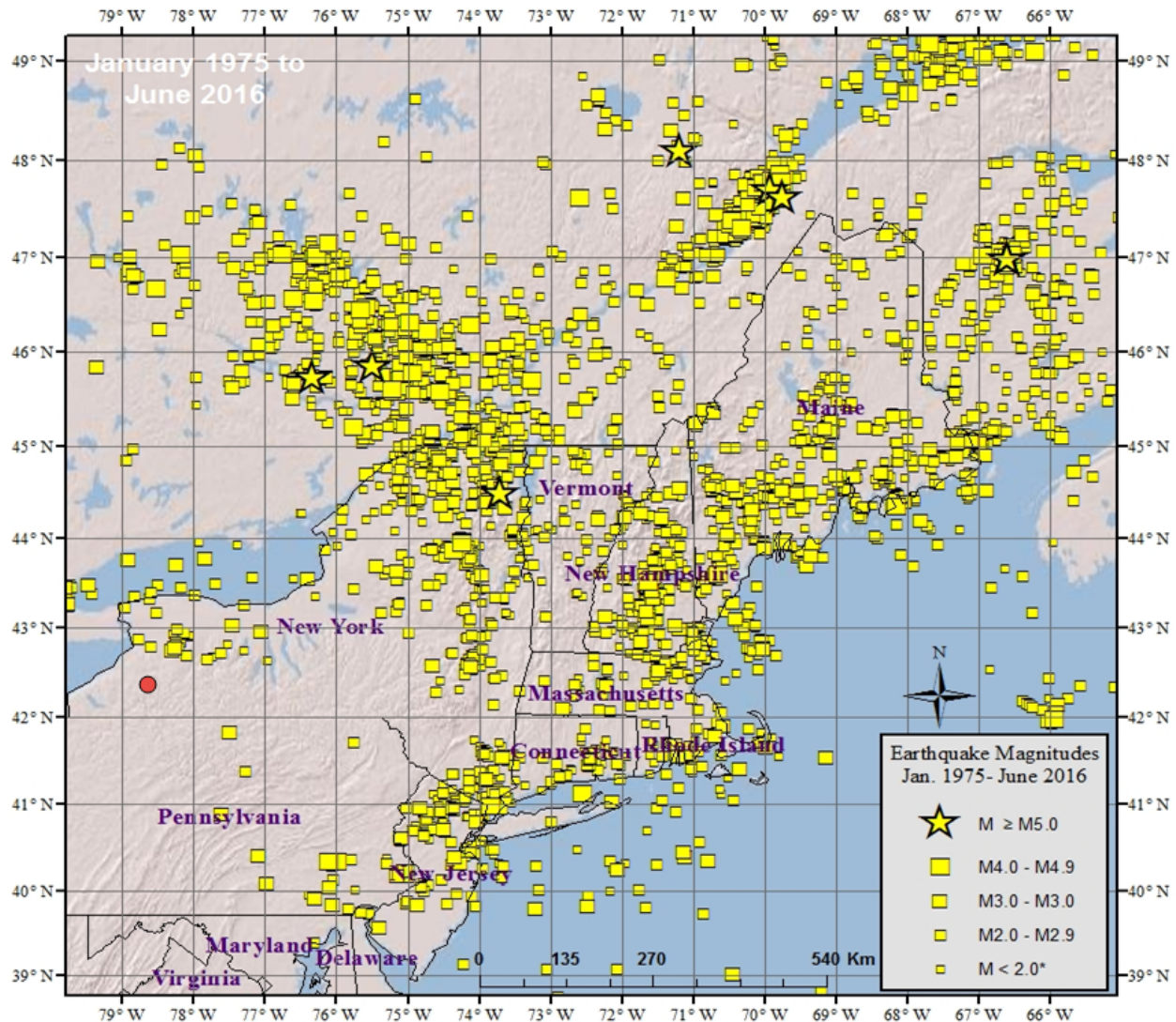


Figure 34. Earthquake locations and magnitudes for 1975 to June 2016 from the seismic network of the Weston Observatory (from http://www.bc.edu/content/dam/files/research_sites/westonobservatory/jpg/Research_Folder/NEUS_Map_1975_2016.jpg accessed November, 2016). The red circle marks the location of the West Valley Site.

Seismic Sources and Parameters

Eastern North America is a passive continental margin well removed from active plate tectonic boundaries. There are no identified Quaternary faults in the West Valley Site (see the current Quaternary fault and fold database of the United States maintained by the U.S. Geological Survey; <http://earthquake.usgs.gov/hazards/qfaults/map/#qfaults>). The current preferred explanation of patterns of seismicity in the northeastern U.S. is reactivation of Precambrian basement structures (Wong et al. 2004). Dineva et al. (2004) note, for the Great Lakes area, an association of seismic clusters with linear magnetic anomalies (see also Jacobi (2002)) that are probably correlated with Precambrian basement structures of the Grenville complex. They

recognize clusters beneath Lake Ontario, Niagara Falls, and the south shore of Lake Erie. Dineva et al (2004) argue that correlation of earthquake clusters with specific aeromagnetic lineaments is uncertain and that both surface water and pre-existing basement structures probably control intraplate seismicity in the Great Lakes region. The most prominent fault system in western New York is the seismically active CLFS (Jacobi and Fountain 2002). Seeber and Armbruster (1993) recognize seismic zones in the Lake Erie–Lake Ontario region associated with the Akron magnetic lineament (within the Georgian Bay Linear Zone) and the CLFS. Jacobi (2002) argues that there is a spatial correlation between epicenter locations and fault/lineament maps and that many of these systems could be considered seismically active. Wong et al. (2004) notes that, while seismicity on multiple fault/lineament systems is possible, definitive evidence of active seismicity has only been demonstrated for the CLFS.

Two types of earthquake sources are used in the PSHA (Wong et al. 2004): fault sources and areal source zones. Uncertainties in the source parameters are incorporated in the hazard models using logic trees. Input parameters are represented by three-point probability distributions centered around a best estimate. Recurrence rates for seismic sources use the exponentially truncated Gutenberg-Richter approach for the characteristic earthquake and maximum earthquake magnitude. Attenuation relationships for the eastern U.S. were developed primarily using seismological-based numerical models (Wong et al. 2004).

Four fault systems or fault zones were included for the fault sources in the PSHA; the dominant fault system for almost all ground motion estimations is the CLFS (fault parameters are listed in Table 4 of the Wong et al. (2004) report and recurrence interval data for the CLFS are in Table 5). Areal source zones were developed from the fourth generational Canadian national seismic hazard maps—the fifth generational seismic hazards models are now available (Allen et al. 2015). Source zone parameters for 15 seismic source zones used in the PSHA are listed in Table 6 of Wong et al. (2004).

Results of Probabilistic Seismic Hazard Assessments

Ground motion estimations as a function of annual exceedance probability were developed for hard rock Site conditions (Table 2) and for soil conditions (local Site stratigraphy) for the North and South Plateaus (Table 3). Source data for both tables are from Wong et al. (2004) and are summarized in DOE (2010a).

Table 2. Site-specific mean spectral accelerations on hard rock.

Return Period	Peak Horizontal Ground Acceleration	0.1 Second Spectral Acceleration	1.0 Second Spectral Acceleration
(yr)	(g)	(g)	(g)
500	0.04	0.07	0.02
1,000	0.05	0.11	0.03
2,500	0.10	0.20	0.06

Table 3. Site-specific mean spectral accelerations on soil for North and South Plateaus.

Return Period	Peak Horizontal Ground Acceleration	0.1 Second Spectral Acceleration	1.0 Second Spectral Acceleration
(yr)	(g)	(g)	(g)
500	0.05/0.03	0.09/0/08	0.04/0.05
2,500	0.14/0.11	0.24/0.22	0.11/0.14

The largest contributor to the mean peak horizontal ground acceleration at the Site is the CLFS (fault source zone) for almost all return periods; the Southern Great Lakes seismic source zone is the second leading contributor to the mean peak horizontal ground acceleration (DOE 2010a). For comparison, the peak horizontal ground acceleration using the 2002 National Seismic Maps of the U.S. Geological Survey is 0.11 g for a 2,500-year return period (assumed hard rock site). The West Valley Site adopted a design-basis earthquake with a peak horizontal ground acceleration of 0.10 g and a return period of 2,000 yr (DOE 2010a).

The modest estimated ground accelerations from the PSHA support limited direct impacts on waste disposal systems at the West Valley Site for future seismic activity. Moreover, the absence of surface Quaternary faults in the region indicates a very low risk of surface propagation of seismic energy and disruption of near-surface facilities. Potential seismic impacts are primarily from the secondary effects of ground shaking and seismically induced ground failure.

Garrick et al. (2010) show that seismic and other landslide processes are potentially significant contributors to risk in a quantitative risk assessment for the New York State–operated radioactive waste disposal area at the West Valley Site. Jibson and Harp (2012) suggest that the unexpectedly long distances of landslides triggered by the 2011 Mineral, Virginia, earthquake require reduced attenuation of ground shaking in the eastern U.S. compared to earthquakes at plate-tectonic boundaries. Peak ground accelerations at the landslide distance limits of the

Virginia earthquake are within the range of peak ground accelerations estimated in the PSHA for the West Valley Site. Note that the U.S. Geological Survey 2014 seismic hazards maps for the United States raised the map values of the 2% probability of exceedance in 50 years of peak ground acceleration in western New York to 0.06 to 0.14 g (hard rock acceleration) partly as a result of the 2011 Mineral, Virginia earthquake event (see 2014 seismic hazard maps and site-specific data at <http://earthquake.usgs.gov/hazards/hazmaps/>; accessed November, 2016). New methods have been developed for identifying seismic landslide hazards that could be used at the West Valley Site (Gorum 2009; O'Banion and Olsen 2014; Wilson et al. 2008). The EWG (Wilson and Young 2016 [in preparation]) provides a preliminary draft of an overview of geomorphic and hydrologic processes affecting the Buttermilk Creek Watershed. Landsliding of various forms and origins is identified as a common erosional process on the steep slopes of Buttermilk Creek. Multiple conditional events are required for significant impacts from seismic slope failure, including:

1. Future shallow earthquake activity on a local fault or faults of sufficient magnitude ($> M 5.2$ to 6.0) (Tuttle et al. 2002) to cause significant ground shaking.
2. Location of the earthquake epicenter near the West Valley Site and flanking slopes of Buttermilk Creek. Jibson and Harp (2012) (their Figure 1) document the exceptionally large size of the 2011 Mineral, Virginia earthquake landslide limits compared to established maximum distances of landslides for typical plate boundary $M 5.8$ earthquake events.
3. Significant landslide events on slopes near disposal facilities and/or where landslide features could couple with surface erosion and affect disposal facilities. Note that Jibson and Harp (2012) did not observe any large landslides with the 2011 earthquakes and that the landslide limits are based on observations of rock and soil falls from steep slopes.

Induced Seismicity

Induced seismicity from either salt mining and/or fluid injection/extraction may potentially be of importance for the western New York region. Wong et al. (2004) note that induced seismicity has not been explicitly incorporated into the PSHA but is likely accommodated through use of uncertain recurrence parameters in the hazard assessment. Future monitoring of the issue of induced seismicity may require future evaluations for potential impact on seismic source zones and/or model parameters used in the PSHA.

Liquefaction

No evidence of seismically induced ground failure has been observed within the West Valley Site or region (DOE 2010a). However, it is unclear whether this conclusion is based on recent assessment methods for seismic-induced landslide hazards. Tuttle et al. (2002) document the absence of seismic-induced liquefaction features in Late Pleistocene and Holocene sediments in exposures near the Clarendon-Linden Fault System. They compiled geotechnical data, assessed the liquefaction potential of saturated sandy sediments, and conclude that the 1929 $M 4.9$ Attica earthquake probably did not cause liquefaction in the earthquake epicentral area. They conclude that the Clarendon-Linden Fault System is unlikely to have produced large earthquake events in post-Late Pleistocene time. The probability of significant future liquefaction effects at the West Valley Site is low and liquefaction is not included in the CSM.

3.2.7.5 Volcanic and Igneous Activity

There are no Quaternary igneous or volcanic rocks in the northeastern U.S. The eastern edge of the North American continent in the northeastern U.S. is a passive-margin tectonic setting. There are no tectonic processes that are likely to generate magmatic activity in the region. Future igneous and volcanic activity is not an issue for the West Valley Site.

3.2.8 Hydrology

The purpose of this section is to describe the hydrological processes at the West Valley Site that are potentially relevant to the West Valley PPA Model. Final development of the PPA unsaturated and saturated zone hydrological models and surface water effects will be based on information in this CSM, other supporting documents, and future research.

3.2.8.1 Surface Water Hydrology

Surface water sources at the West Valley Site include precipitation in the form of rain and snow, surface runoff from higher elevations, and groundwater flow from areas of higher hydraulic head (Bergeron et al. 1987; DOE 2010a). This section covers the occurrence, locations, types, and movement of surface water.

3.2.8.1.1 Surface Water Occurrence

Surface water at the Site occurs as creeks, seeps, wetlands, reservoirs, and lagoons.

Creeks

The surface water drainage network at the Site is described by DOE (2010a) and WVNS (2006). Near the facilities, the network is composed of three small intermittent streams—Erdman Brook, Quarry Creek, and Frank’s Creek—that carry flow from the Project Premises and the SDA as shown in Figure 35. Erdman Brook and Quarry Creek are tributary to Frank’s Creek (Figure 35), which flows into the perennial stream, Buttermilk Creek (Figure 8). Buttermilk Creek flows northwest to its confluence with Cattaraugus Creek at the northernmost extent of the Site. Cattaraugus Creek, also perennial, flows west and then turns northwest to flow into Lake Erie northwest of Gowanda, NY (Figure 8).

Erdman Brook is a northeastward flowing tributary in the Frank’s Creek system (WVNS 1993a). This tributary is the smallest of the three and drains the central and largest area of the Project Premises and the SDA. Treated WVDP waste water from the LLWTF is discharged from the SPDES-permitted Lagoon 3 outfall to Erdman Brook (DOE 2010a; WVNS 2006). The elevation of Erdman Brook west of Rock Springs Road (Figure 35) is about 427 m (1,400 ft), where it flows to the northeast for about 910 m (3,000 ft) though the Project Premises to its confluence with Frank’s Creek at an elevation of 398 m (1,305 ft) (WVNS 2006). The area of the Erdman Brook drainage basin is approximately 57 ha (140 ac) (WVNS 1993a).

Quarry Creek drains the largest area of these three streams. This stream captures runoff from the High-Level Radioactive Waste Tank Farm and vitrification area, a portion of the northern parking lot, and the waste storage area (DOE 2010a; WVNS 2006). Quarry Creek flows from

west of Dutch Hill Road at an elevation of 588 m (1,930 ft) to an elevation of 379 m (1,245 ft) at the confluence with Frank's Creek (WVNS 2006). An approximately 914 m (3,000 ft)–long segment of the creek is adjacent to the north side of the Project Premises. The area of the Quarry Creek drainage basin is approximately 300 ha (740 ac) (WVNS 1993a).

Frank's Creek receives drainage from the east side of the Project Premises, including the Drum Cell and the SDA (DOE 2010a; WVNS 2006). Approximately 610 m (2,000 ft) downstream from its confluence with Quarry Creek, Frank's Creek flows into Buttermilk Creek (Figure 8). Frank's Creek flows from west of Rock Springs Road (Figure 35) at an elevation of 546 m (1,790 ft) to elevations of 379 m (1,245 ft) at the confluence with Quarry Creek and 360 m (1,180 ft) at the confluence with Buttermilk Creek (WVNS 2006). The area of the Frank's Creek drainage basin is approximately 120 ha (295 ac) (WVNS 1993a). The Frank's Creek system consists of these three creeks and their drainage basins.

The West Valley Site area is also drained by two perennial streams, Buttermilk Creek and Cattaraugus Creek. Buttermilk Creek is a high gradient stream in a steep, narrow stream channel that bisects the West Valley Site (WVNS 1993a). The stream is deeply incised mainly within the KRS with an upstream segment flowing through the Kent till (DOE 2010c).

Headwaters form into a main channel in the vicinity of the southeastern end of the West Valley Site boundary, where Buttermilk Creek flows to the northwest to the confluence with Cattaraugus Creek (WVNS 1993a). The elevation ranges from 400 m (1,310 ft) at the southern Site boundary to 338 m (1,110 ft) at the confluence with Cattaraugus Creek (WVNS 2006). The area of the Buttermilk Creek drainage basin was estimated to be 7,842 ha (19,378 ac) (Boothroyd et al. 1982). The Project Premises and SDA are located entirely within the Buttermilk Creek drainage basin (DOE 2010a). Cattaraugus Creek flows west and then northwest from the confluence with Buttermilk Creek for about 78 km (48 mi) downstream from the Site to Lake Erie (WVNS 1993a).

Seeps

Groundwater flow from seeps located on three sides of the North Plateau has been documented and measured (Bergeron et al. 1987; Kappel and Harding 1987). The seepage faces are described by Bergeron et al. (1987) as occurring in zones of 1.5 to 18 m (5 to 60 ft) long downslope from the contact between the sand and gravel at the surface and the till. Locations of the seeps are shown in Figure 52 of Section 3.2.8.2.

Wetlands

Wetlands are defined by 40 CFR 230.3 as “those areas that are inundated or saturated by surface- or groundwater at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.” The most recent wetland delineation of a portion of the West Valley Site identified 13.8 ha (34.09 ac) of wetlands as “part of an ecological continuum constituting a surface water tributary system of Buttermilk Creek, Cattaraugus Creek, and Lake Erie” (DOE 2010c). Following this the DOE has included the 12 isolated wetlands as part of the jurisdictional wetland total, increasing the regulated wetland area to 14.78 ha (36.52 ac) (DOE 2010c). Wetlands in the vicinity of the Project Premises are shown in Figure 36.



Figure 35. The West Valley Demonstration Project Premises showing Quarry Creek to the north, Erdman Brook bisecting the North and South Plateaus, and Frank's Creek to the east and south. (Figure 3 from DOE (2010b).)

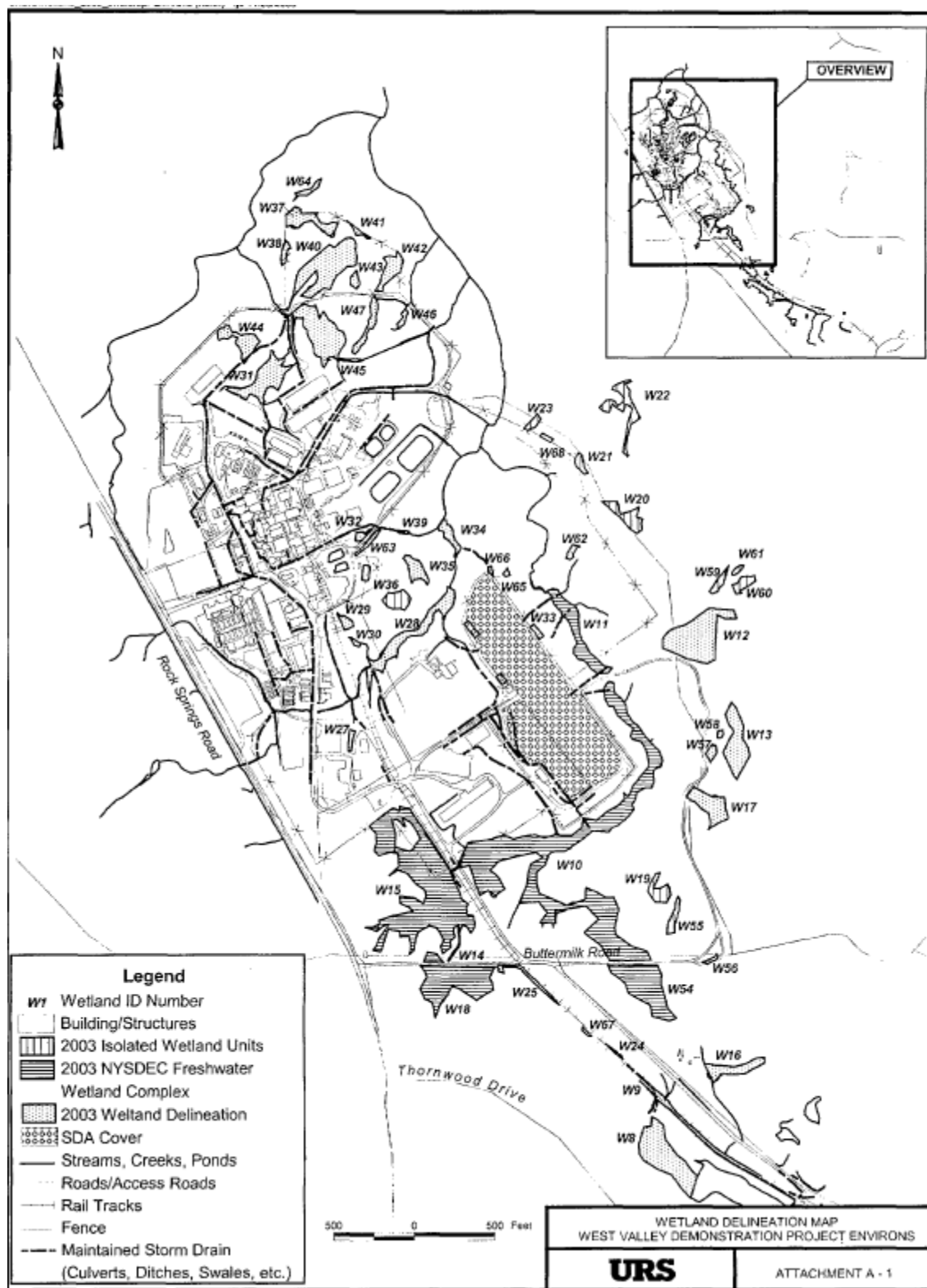


Figure 36. Wetland delineation in the vicinity of the Project Premises (Wierzbicki 2006).

Reservoirs

There are two water supply reservoirs located 2.4 km (1.5 mi) southeast of the MPPB (Figure 37). The reservoirs are connected by a canal and were formed by blocking two intermittent tributaries of Buttermilk Creek with earthen dams. The south reservoir drains to the north reservoir, which drains to Buttermilk Creek through a control structure. The reservoirs capture drainage from an area of 1,255 ha (3,000 ac) (DOE 2010a). In addition to the reservoirs, two bedrock groundwater extraction wells now supply water to the WVDP.

Lagoons

There are four currently active lagoons located on the southeast side of the North Plateau (Figure 38). Lagoon 2 is an unlined pit excavated through the TBU and into the top 0.6 to 2.1 m (2 to 6.9 ft) of the ULT. It is used to hold wastewater temporarily before transfer to the Low-Level Waste Treatment Facility (LLWTF) (DOE 2010c). Treated waste water is transferred from the LLWTF to Lagoons 4 and 5, which are excavated into the TBU and are lined with a geomembrane liner. Waste water from Lagoons 4 and 5 is transferred to Lagoon 3, which is an unlined pit excavated through the TBU into the upper portion of the ULT. Waste water is batch discharged from Lagoon 3 to Erdman Brook through a SPDES-permitted outfall.

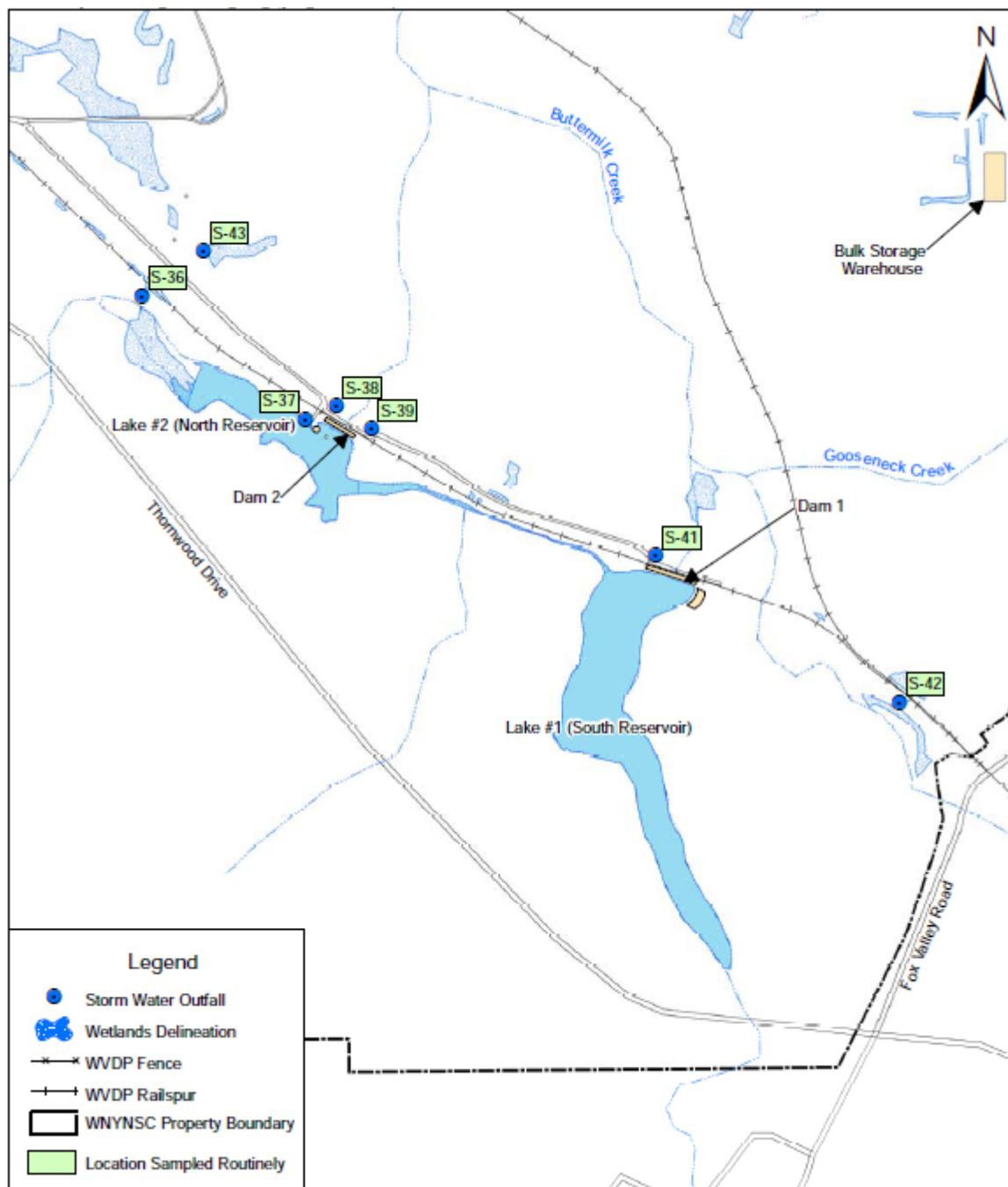


Figure 37. Water supply reservoir locations. (Figure A-4 from DOE (2015).)

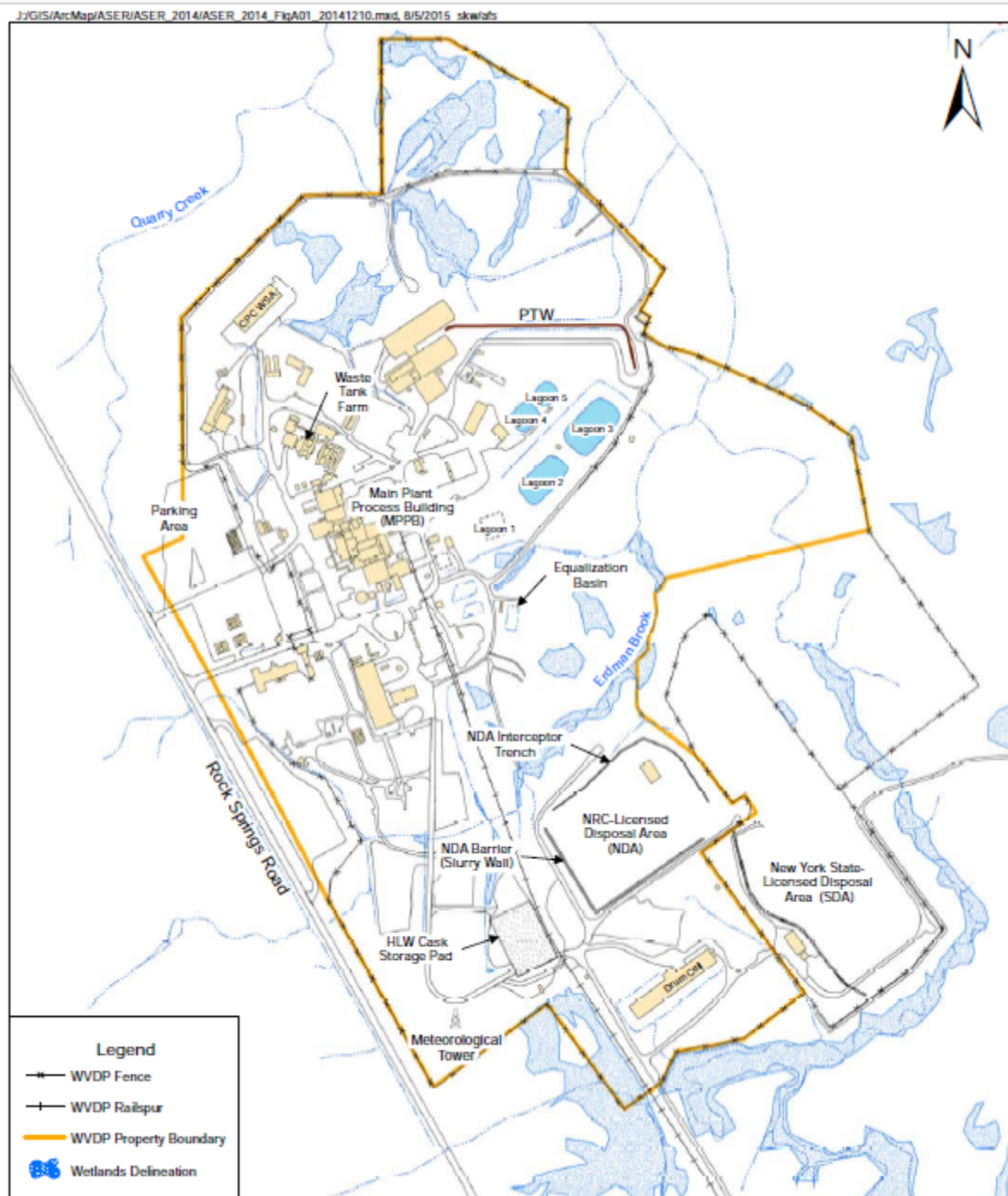


Figure 38. Location of lagoons on North Plateau. (Figure A-1 from DOE (2015).)

3.2.8.1.2 Discharge

The variation of surface water runoff throughout the year at the West Valley Site is described by Prudic (1986) as being typical of streams in the northeastern U.S. Snowmelt, low evapotranspiration rates, and high groundwater levels in March and April produce high runoff, while increased evapotranspiration and lower groundwater levels in summer result in low runoff. The water budget for the Site, which includes the interaction between surface and groundwater, is discussed in Section 3.2.8.2 of the CSM.

The New York State Geological Survey and the U.S. Geological Survey (USGS) conducted a three-year monitoring program from 1981 through 1983 at the West Valley Site to characterize the relationships between precipitation and surface-water runoff on the North and South Plateaus (Kappel and Harding 1987). Stream discharge data was collected at three continuously recording stations: on Lagoon Road Creek, a tributary to Erdman Brook just below the NDA (Lagoon Road); on an unnamed tributary draining the west side of the North Plateau that is tributary to Quarry Creek (NP-1); and on another unnamed tributary draining the center of the North Plateau that is tributary to Frank's Creek (NP-3). Peak flow data was also recorded at a station located on a channel that was an outlet of a portion of a wetland area (NP-2) (Bergeron et al. 1987). The locations of the gauging stations are shown in Figure 39.

Analysis of the gauging data indicated that the runoff characteristics of the North and South Plateaus differed. The data demonstrated that base flow measured at the NP-1 and NP-3 stations on the North Plateau is much greater than the South Plateau due to the flow from the sand and gravel deposits that cover the surface. At the North Plateau stations, 70 percent of the total runoff was determined to be base flow, while 30 percent was attributed to stormflow. At the Lagoon Road site on the South Plateau, 20 percent of the total runoff measured was base flow, and the remaining 80 percent stormflow. This difference is attributed to the presence of the permeable sand and gravel layer (TBU) on the North Plateau that allows precipitation to infiltrate. The low permeability till with large percentages of clay and silt on the South Plateau limits infiltration and directs a greater portion of precipitation to run off directly to stream channels.

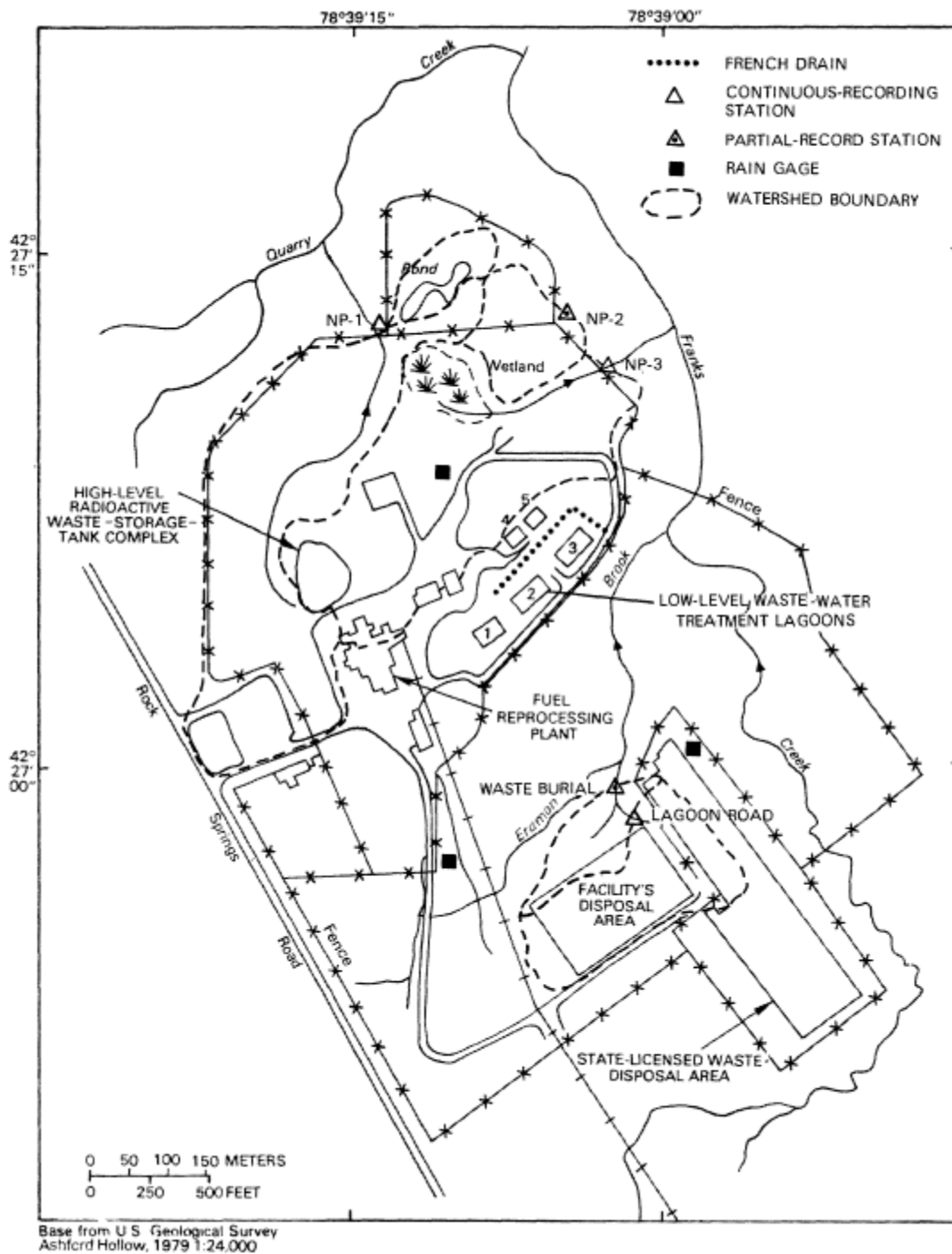


Figure 39. Location of surface water gauging stations. (Figure 8 from Bergeron et al. (1987).)

USGS gauging data shown in Figure 40 (from the gauging station on Buttermilk Creek near the Bond Road Bridge) was presented for water year 1962 in Boothroyd et al. (1979).

The sharp peaks in the discharge response associated with high flow events of only one to two days duration was noted by Boothroyd et al. (1979). These authors describe Buttermilk Creek

discharge as rising rapidly from base flow conditions to flood stage in only a few hours and then subsiding quickly. The behavior of the stream hydrograph was attributed to the low permeability of the till covering the drainage basin. The high effective runoff is believed to enhance sediment transport in the creek, possibly because the high stream stages cover more of the bar surface area, providing more bedload for transport (Boothroyd et al. 1979).

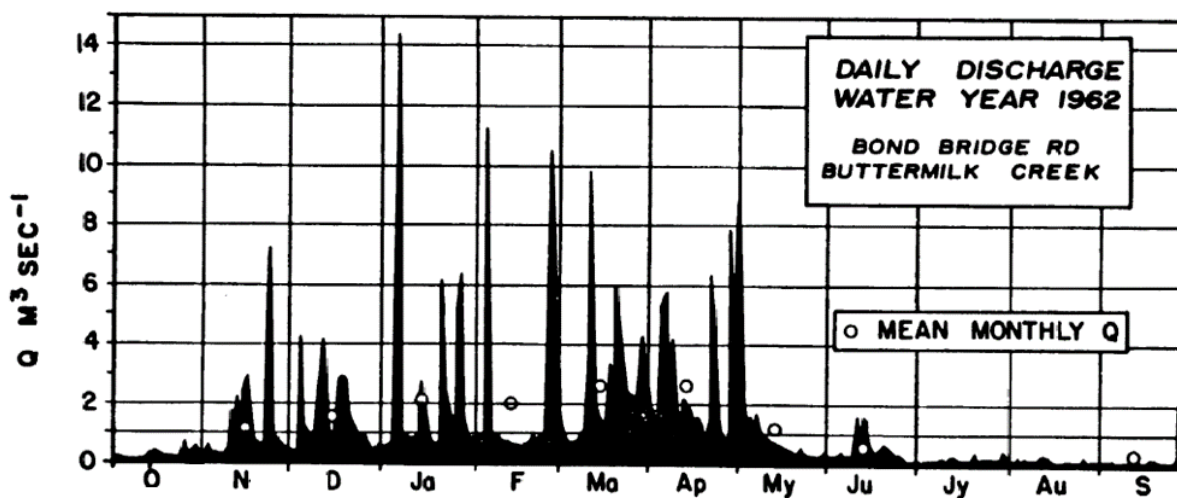


Figure 40. Daily discharge of Buttermilk Creek at Bond Road Bridge for water year 1962. (Figure 17 from Boothroyd et al. (1979).)

Peak discharges during the period 1990–1991 were measured at gauging stations located at the Frank’s Creek–Quarry Creek confluence, the Erdman Brook–Frank’s Creek confluence, and Erdman Brook just downstream of the SDA. Peak flows measured on March 27, 1991 were 9.636 cubic meters per second (m^3/s) (340.3 cubic ft per second [cfs]) at the confluence of Quarry Creek and Frank’s Creek; 4.56 m^3/s (161 cfs) at the confluence of Erdman Brook and Frank’s Creek; and 1.7 m^3/s (60 cfs) at Erdman Brook downstream of the SDA (WVNS 2004).

The peak flow measured at the Bond Road Bridge over Buttermilk Creek was 111 m^3/s (3,910 cfs) on September 28, 1967 (WVNS 2004). For comparison, see the daily discharge measurements at the same station for 1962 in Figure 40, which show a maximum for the year of only slightly over 14 m^3/s (494 cfs).

Discharge from the 19 seepage faces identified on the North Plateau were measured by Kappel and Harding (1987) and Bergeron et al. (1987) on three dates during the spring, summer, and fall of 1983. These results are plotted in Figure 41. Measurements in the spring (Figure 41a) show discharge of one seep as high as 287 cm^3/s (0.000287 m^3/s or 0.010 cfs), with a total discharge of 640 cm^3/s (0.00064 m^3/s or 0.023 cfs) for all 19 seeps. As the water table lowers and evapotranspiration losses increase in summer (Figure 41b), seepage discharge decreases, with the maximum discharge observed of 215 cm^3/s (0.000215 m^3/s or 0.0076 cfs) and a total discharge of 306 cm^3/s (0.000306 m^3/s or 0.0108 cfs). Measurements in the fall (Figure 41c) followed a rainfall event of 2.41 cm (0.95 in) within 24 hours of the measurements and show the response of the seepage faces to the event. The maximum discharge for this sampling date was 312 cm^3/s (0.000312 m^3/s or 0.011 cfs), and the total discharge from all seepages faces was 717 cm^3/s (0.000717 m^3/s or 0.025 cfs).

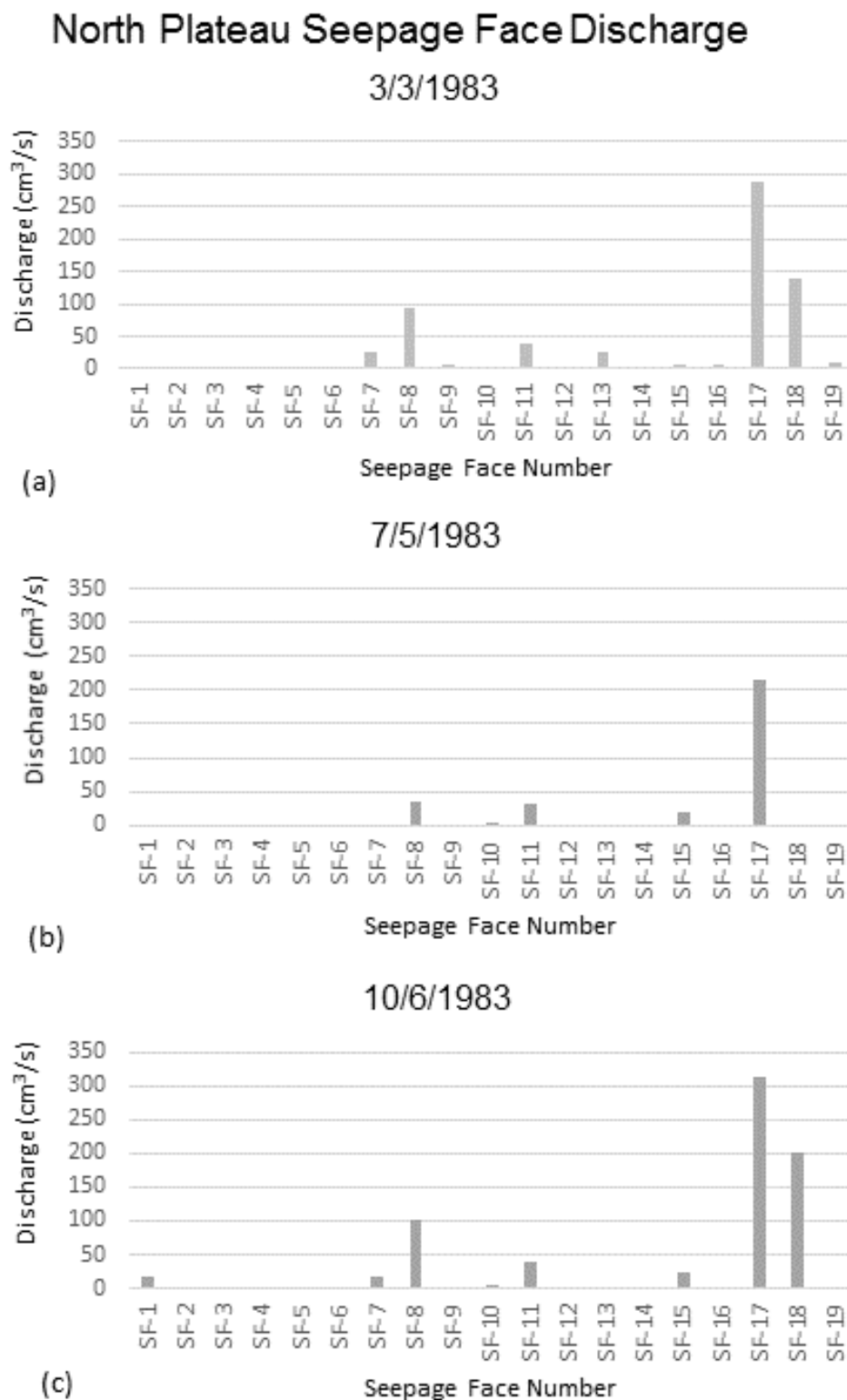


Figure 41. North Plateau seepage face discharge measurements. (Table A-1 from Bergeron et al. (1987).)

3.2.8.1.3 Flooding

Floodplain Analyses

The history of flooding in the vicinity of the West Valley Site, described in WVNS (2006), suggests that direct effects of flooding would be negligible on the Project Premises. The location of Cattaraugus, Buttermilk, Frank's, and Quarry Creeks and Erdman Brook in deep narrow valleys limits the possibility of inundation. Indirect effects, however, resulting from high discharge including erosion and high slope saturation, do occur.

Floodplain analyses can be conducted for various recurrence intervals as described in Appendix M of DOE (2010c). A 100-year flood is a flood with a probability of 1 percent of being equaled or exceeded in any given year. The ground surface area that is inundated by the 100-year flood is referred to as the 100-year floodplain. The 500-year flood is a flood event with a 0.2 percent probability of being equaled or exceeded in any given year; the area flooded is the 500-year floodplain. The probable maximum flood (PMF) has somewhat different assumptions in that this analysis represents the flood expected from the combination of meteorological and hydrological conditions possible in the drainage area that would result in the highest stream stages. A PMF analysis can be done using the probable maximum precipitation (PMP). The PMP is defined in Appendix M of DOE (2010c) as the "theoretically greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographic location at a particular time of year."

Floodplain analyses of the West Valley Site area conducted using the U.S. Army Corps of Engineers HEC-2 software were described in WVNS (2006). Simulations were conducted for storm return frequencies of 2, 10, and 100 yr. The results of the 100-year simulation are shown in Figure 42. These results (Boothroyd et al. 1982) show the control of the narrow and deep tributary valley cross sections of the streams on flooding; they act to constrain the floodplain to the area near the streams. These results show that no existing facilities are located in the 100-year floodplain (DOE 2010b, Appendix M).

A PMF analysis was conducted by URS (2008) for the West Valley Site area using PMP meteorological conditions. URS (2008) described the primary objective of the PMF Inundation study as being to determine the extent to which any critical facilities of the WVDP would be affected due to a PMP event. Comparison of the PMP results shown in Figure 43 with the 100-year floodplain (Figure 42) indicates that the PMF floodplain is only wider than the 100-year floodplain in relatively flatter areas, such as in the upper reaches of Erdman Brook and Frank's Creek downgradient from Rock Springs Road, largely between the road and the railroad tracks (DOE 2010a; URS 2008). In other areas of the Site, including existing facilities and waste burial locations, the PMF floodplain is similar to the 100-year floodplain (DOE 2010a; URS 2008).

The PMF has a peak discharge almost eight times that of the 100-year flood. Hydrologic modeling conducted by WVNS (2006) demonstrated that, in a hypothetical PMF event, culvert headwaters would overtop Rock Springs Road and some fraction of the floodwaters would likely flow across the plant area. Shallow flows of moderate velocity would be expected across some sections of the Site. However, these flows would be expected to quickly recede due to the

existing drainage ditch network. WVNS (2006) stated that the effects of such an extreme event were difficult to quantify. This is likely due to the limitations of their model to account for uncertainty regarding how the interconnections and flow paths between drainages would evolve during the event.

The TR-20 model used to simulate the PMF by WVNS (2006) is a storm event surface water hydrologic model developed by the Natural Resources Conservation Service (<https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042924>). In this model, direct runoff from rainfall in each subarea of a watershed is routed through pre-defined stream reaches and structure reaches to the watershed outlet. This model provides estimates of runoff and peak discharges. This is a surface water model only and does not consider hillslope or channel erosion processes due to overland flow or stream flow. Erosion effects from surface flows are described in Section 3.2.7.2.2, and the conceptual model for surface water transport is described in Section 5.5.

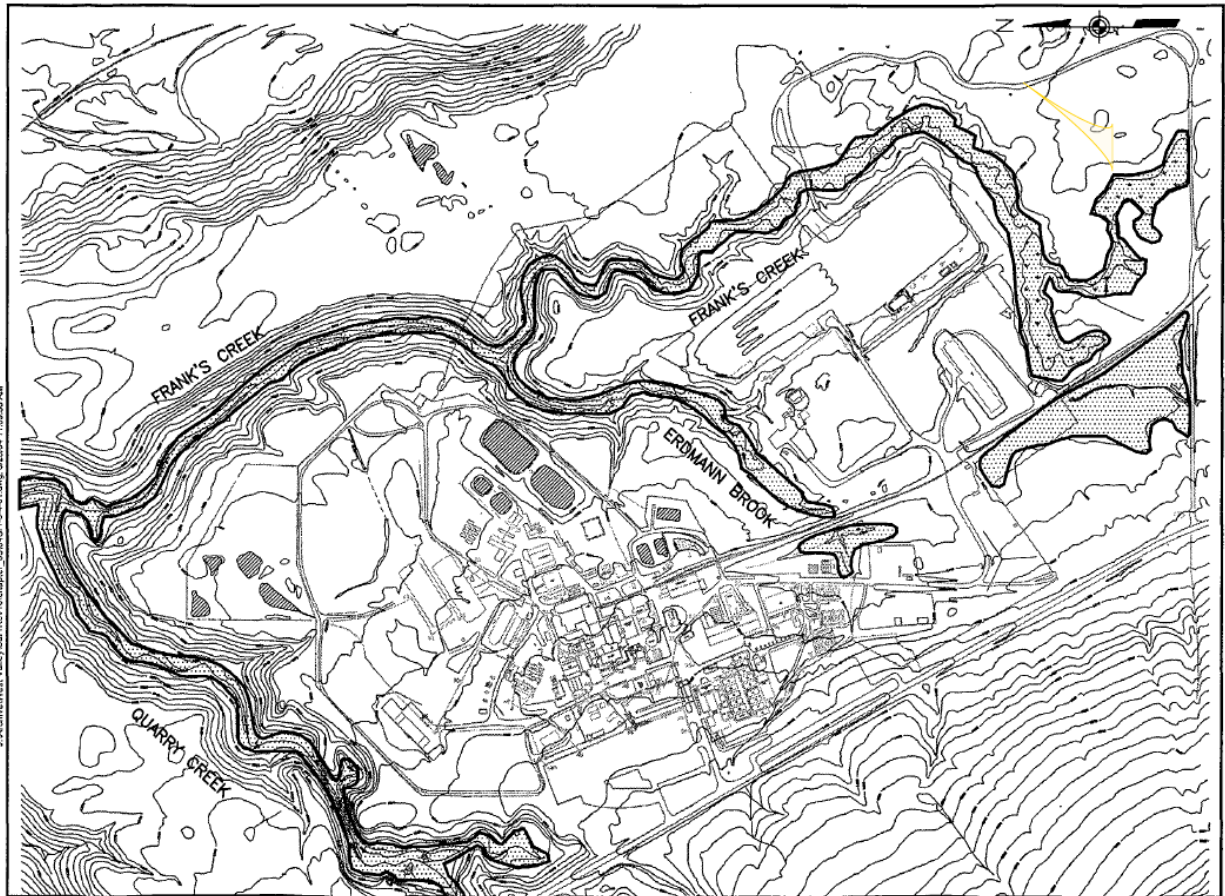


Figure 42. The 100-year floodplain is shown as the area between bold lines. (Figure 3.4-1 from WVNS (2006).)

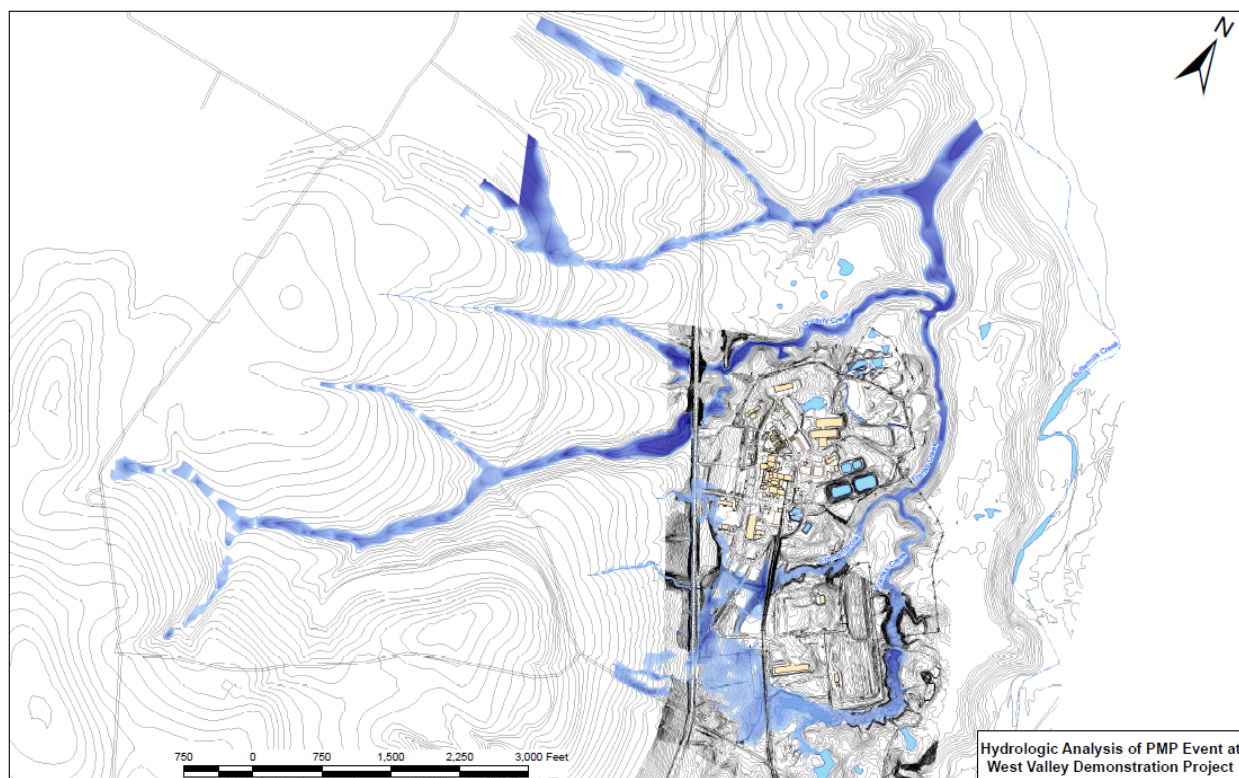


Figure 43. Inundation areas due to probable maximum flooding (PMF) event (URS 2008).

Effects of Local Intense Precipitation

Other effects beyond inundation can occur as a result of locally intense precipitation events. The *Safety Analysis Report for Waste Processing and Support Activities* (WVNS 2006) notes that erosion resulting from intense precipitation events is particularly significant for the Site. This report describes the effect of a PMP event as capable of overwhelming the Site drainage system. Ditches along open section roadways would be expected to overflow and the capacities required of storm drain inlets at grade and in sumps exceeded. Culverts within the watershed would not be able to prevent overtopping of the embankments. While culvert embankment failures would not be expected to impact critical facilities, the analysis indicated that erosion resulting from a failure-induced flood wave at the railroad embankment could possibly effect the stability of the northern slopes of the SDA and NDA (WVNS 2006).

In the late evening of August 9, 2009, two storm systems converged over western New York, producing heavy rainfall leading to severe flash flooding in portions of Cattaraugus, Chautauqua, and Erie Counties in the early hours of August 10 (Szabo et al. 2010). This storm event had a significant impact at the West Valley Site.

Daily totals and assigned recurrence intervals for the storm were reported by Szabo et al. (2010). Radar-derived precipitation estimates showed a daily total of 17.9 cm (7.06 in) at Gowanda, located 23 km (14.3 mi) west of the West Valley Site. A National Weather Service (NWS) cooperative weather observer located in Perrysburg, 29 km (18 mi) west of the West Valley Site,

reported a daily total of 18.5 cm (7.27 in), with 15.2 cm (5.98 in) recorded in the 90 minute period between ten-thirty in the evening and midnight August 9. A recurrence interval of 200 to 500 yr was assigned to this daily total by the Northeast Regional Climate Center (Szabo et al. 2010).

Impacts of the storm at the West Valley Site included increased stream erosion within Erdman Brook adjacent to the SDA and flood damage to portions of the spillways of the two dams (DOE 2010d).

3.2.8.2 Groundwater Hydrology

The hydrologic conceptual model presented in the following sections is intended to lay the groundwork for subsurface numerical modeling of fluid flow and contaminant transport. An overview of the hydrogeologic setting is presented in Section 3.2.8.2.1. The stratigraphic units, introduced in Section 3.2.7.3, are described further for hydraulic properties that relate to flow characteristics in Section 3.2.8.2.2. Vadose zone flow and transport, including infiltration and evaporation, are discussed in Section 3.2.8.2.3. The depths and occurrence of groundwater beneath the Site are presented in Section 3.2.8.2.4, and the nature of groundwater movement is found in Section 3.2.8.2.5.

3.2.8.2.1 Regional Hydrogeologic Setting

As described in Section 3.2.7.2, the Site is situated in a steep-walled bedrock valley filled with glacial deposits of Pleistocene to Holocene age (WVNS 1993b). Regional groundwater flow at the Site is shown schematically in Figure 44, although many factors contribute to local changes in water table elevation and groundwater flow direction, including hydraulic conductivity of individual units, heterogeneity, fracturing, seasonal effects (including precipitation and snow cover), and engineered features, as discussed in greater detail in the sections below. Recharge generally moves from highlands down and laterally towards streams and creeks, where it flows upwards to discharge into surface waters or, in the case of the bedrock valley containing the Site, into the relatively higher-permeability units within the glacial deposit fill (as discussed in Section 3.2.8.2.5). Seeps and springs in higher-permeability units at the intersection with stream valleys are common. The hills to the west of the Site are a highland recharge area (DOE 2010c). The majority of subsurface flow is near the surface and roughly parallel to it, with only a small component of flow in the regional system moving from the highlands to streams further than a few kilometers away (Prudic 1986). Bedrock in the vicinity of the Site is relatively impermeable (Section 3.2.8.2.2), with flow primarily in the upper 3 m of fractured, weathered material, and to a lesser extent along other fractures and bedding planes in the unweathered bedrock (Zadins 1997).

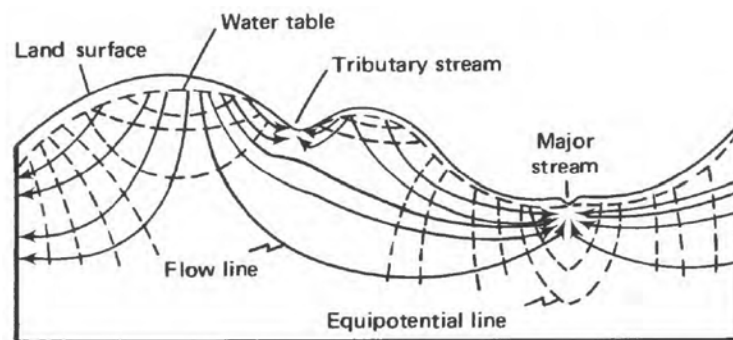


Figure 44. Schematic of general groundwater flow patterns in hydrogeologic settings similar to the Site. (From Prudic (1986), Figure 6.)

The Site is situated in the Cattaraugus Creek Basin Aquifer system, which is designated as a sole source aquifer by the EPA (Section 3.2.4). No concrete evidence suggests that Site groundwater is connected hydraulically with the Springville aquifer north of Cattaraugus Creek by way of the weathered bedrock stratigraphic layer or other stratigraphic units (DOE 2010c) (Section 3.2.8.2.5). Geochemical evidence in the form of low chloride concentration also suggests that regional flow in the bedrock does not discharge along the reaches of Buttermilk Creek adjacent to the Site (Prudic 1986).

Generally, domestic well production yields in the Buttermilk Creek Valley region are low. Pockets and lenses of coarse material between 12–120 m (39–394 ft) below ground surface can sometimes support wells with yields of 38–190 L/min (10–50 gal/min) (Prudic 1986). The fractured weathered bedrock layer is penetrated by wells yielding 40–60 L/min (11–16 gal/min), while unweathered bedrock frequently produces 0–25 L/min (7 gal/min) (Prudic 1986). However, there are two unweathered bedrock supply wells on the Site that can produce over 190 L/min (50 gal/min) each in the short term and likely up to 150 L/min (40 gal/min) total (both wells together) in the long term (GEI Consultants 2014).

3.2.8.2.2 Hydrogeologic Properties of the Units

Geologic properties of the stratigraphic units at the Site are discussed in Section 3.2.7.3. This section focuses on hydrogeologic properties that influence fluid flow and contaminant transport. Some geologic units have been reorganized by different authors into hydrostratigraphic units of similar characteristics. For example, in some references, the TBU and SWS are further combined into one hydrostratigraphic unit denoted as the surficial “Sand and Gravel” (S&G) unit, but that notation will not be used here (WVES 2007).

Table 4 lists the units found beneath all or parts of the North and South Plateaus and gives estimates of important hydraulic parameters from several sources. Development of distributions of these parameters for strata represented in the West Valley PPA Model will happen in the future following a thorough literature review of all available data and a rigorous statistical approach. The earthen covers of the NDA and SDA, which have hydraulic properties different than the weathered and unweathered Lavery till, will also need to be considered in the Model. The upper silty, coarse-grained layers have comparatively high permeability (colluvium, TBU,

SWS), followed by the three glacial till materials, which are of low permeability (Lavery, Kent, Olean), except where fractured. The three tills are separated by two fluvio-lacustrine deposits of only slightly higher permeability (KRS, ORS). The bedrock surrounding the valley ranges from weathered (higher permeability) to competent (lower permeability). Compacted backfill material is generally lumped with the TBU, but it may have lower permeability (WVNS 1993b).

Table 4. Average hydrogeologic parameters for the Upper and Lower Aquifers.

Hydro-stratigraphic Unit	Description (from reference ^a unless otherwise noted)	Saturated Hydraulic Conductivity (K_h , K_v)	Porosity
Backfill	Recompacted original sediment present in some places ^b . Can be considered similar to the TBU.	–	–
Colluvium	Soft pebbly silt on slopes, blocks up to several m in size. 0 to 0.9 m thick	–	–
Thick-bedded unit (TBU)	Average 41% gravel, 40% sand, 11% silt, 8% clay. ^b 0 to 12.5 m thick	$K_{h,v} = 10^{-5}$ to 10^{-3} cm/s ^b $K_{h,v} = 10^{-4}$ to 3.8×10^{-2} cm/s ^g	Average 21.9% ^b 22.6% ^e Effective porosity 25% ^f
Slack-Water Sequence (SWS)	Clay, silt, sand, fine-grained gravel in thin beds. Occurs over limited area at base of TBU, separated from the TBU by a clay-rich deposit. ^d 0 to 4.6 m thick	$K_h = 5.29 \times 10^{-3}$ cm/s, $K_h/K_v = 20$ ^e	35% ^e
Weathered Lavery Till (WLT)	Fractured till composed of clay & silt. Horizontal & vertical fractures; penetrated by root holes and burrows. ^b Exposed at the surface on the South Plateau; thinner layer below the TBU on the North. Average 47% clay, 29% silt, 20% sand, 4% gravel. ^b 0 to 4.9 m thick	$K_{h,v} = 10^{-8}$ to 10^{-5} cm/s ^b $K_{h,v} = 4.65 \times 10^{-5}$ cm/s ^e	Average 40.7% ^b 32.4% ^e
Unweathered Lavery Till (ULT)	Clayey and silty till with discontinuous sand lenses; considerable textural variation in shallow portions. May be locally more permeable at shallow depths. ^c Average 50% clay, 30% silt, 18% sand, 2% gravel. ^b 1 to 34 m thick	$K_{h,v} = 6 \times 10^{-8}$ cm/s (>3 m depth from top of ULT); $K_{h,v} = 1 \times 10^{-6}$ cm/s (<3 m depth) ^e $K_{h,v} = 10^{-8}$ to 10^{-7} cm/s ^b	41.7% ^b 32.4% ^e
Lavery Till Sand (LTS)	Fine to coarse sand within ULT. Average 46% sand, 19% gravel, 18% silt, 17% clay. ^b 0 to 4.9 m thick	$K_{h,v} = 6.2 \times 10^{-5}$ cm/s ^b $K_h = 1.85 \times 10^{-3}$ cm/s, $K_h/K_v = 10$ ^e	25% ^b 22% ^e

Hydro-stratigraphic Unit	Description (from reference ^a unless otherwise noted)	Saturated Hydraulic Conductivity (K_h , K_v)	Porosity
Kent Recessional Sequence (KRS)	Gravel, cobbles, sand, clay, clay-silt. Coarse-grained deposits: Average 44% sand, 23% silt, 21% gravel, 12% clay. ^b Fine-grained deposits: Average 57% silt, 37% clay, 5.9% sand, 0.1% gravel. ^b 0 to 21 m (23 m) ^b thick	$K_h = 1.6 \times 10^{-4}$ cm/s, $K_h/K_v = 10^e$	22% ^e
Kent Till	Clayey and silty till, similar to Lavery Till	$K_{h,v} = 6 \times 10^{-8}$ cm/s ^e	32.4% ^e
Olean Recessional Sequence (ORS)	Clay, clayey silt, silt; similar to KRS	$K_h = 1 \times 10^{-4}$ cm/s, $K_h/K_v = 10^e$	22% ^e
Olean Till	Clayey and silty till, similar to Lavery Till	$K_{h,v} = 6 \times 10^{-8}$ cm/s ^e	32.4% ^e
Weathered Bedrock (WB)	Shale and interbedded siltstone. Abundant fractures, decomposed rock. ~3 m thick ^b	$K_{h,v} = 10^{-5}$ cm/s ^b $K_h = 1 \times 10^{-5}$ cm/s, $K_h/K_v = 10^e$	40% ^e
Unweathered Bedrock (UB)	Shale and interbedded siltstone. Regionally, bedding dips ~0.5 to 0.8° south. ^{a,b}	$K_{h,v} = 10^{-7}$ cm/s ^b $K_h = 1 \times 10^{-7}$ cm/s, $K_h/K_v = 10^e$	5% ^e

^a DOE (2010c).^b WVNS (1993b).^c Garrick et al. (2008).^d WVNS (2007).^e Based on Tables E-3 and E-4 of DOE (2010c); values used in site-wide FEHM model.^f WVNS (1993c).^g WVNS (2009a).

The layout and distribution of these units across the Site is complex (Figure 30). The NDA and SDA on the South Plateau are situated in the Lavery till, with a weathered layer (WLT) generally present with a thickness of 0.9–4.9 m (3.0–16.1 ft) (average 3 m [9.8 ft] thick) (DOE 2010c). A soil layer of around 23–25 cm (9–10 in.) depth is present in some areas, with exposed WLT in others. Figure 45 shows a conceptual model of the WLT to ULT interface based on test pits (representative of the WLT/ULT in undisturbed areas outside of the NDA and SDA). Fracture data from a 5.2-m (17-ft) trench in the NDA (WVNS 1993c) had poorly developed soil to 23 cm (9 in.). Fracture density is correlated with degree of weathering of the till and moisture content (increased density with dry soil and till; WVNS (1993e)). The longest fractures (vertical length) were observed in the ULT with higher moisture contents. Fracture densities decreased with depth from 13.4 fractures/m (4.1 fractures/ft) at 23 cm (9 in) bgs to 3.0 fractures/m (0.9 fractures/ft) at 3.2 m (10.5 ft) bgs, and there was generally an east-west trend for vertical fractures at depths below 1.7 m (5.6 ft) bgs (WVNS 1993c). Horizontal fracture density decreased between 2.1 and 3.2 m (6.9 and 10.5 ft) depth. Between 3.2 and 5.2 m (6.9 and 17.1 ft), the vertical fracture

density was 2.0 fractures/m (0.6 fractures/ft). Below the weathered zone, fractures of 4 to 8 m (13 to 26 ft) in length may extend into the ULT and can be hydraulically connected to sand lenses (DOE 2010c; WVNS 1993c).

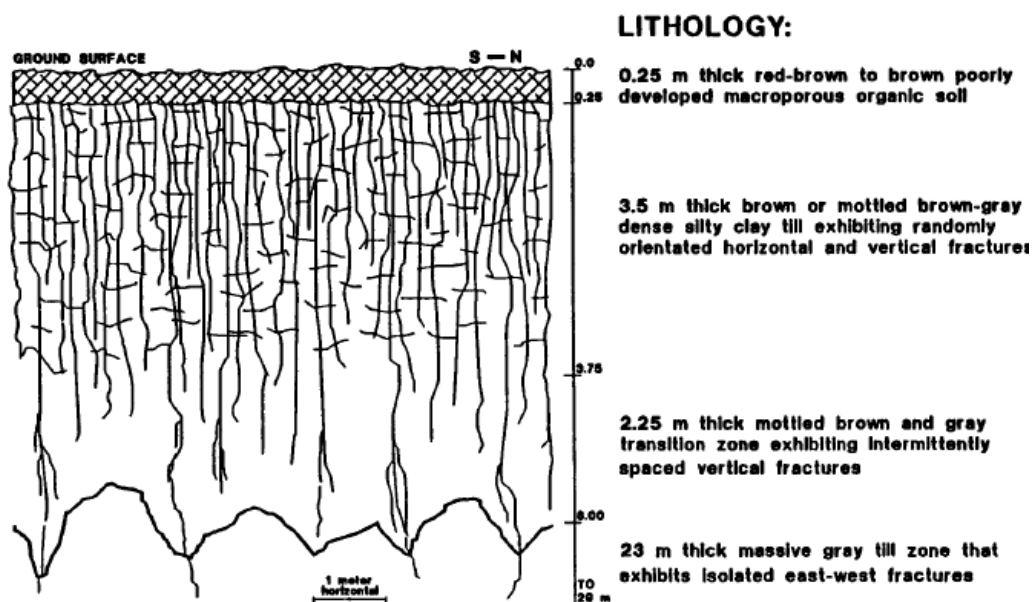


Figure 45. Conceptual cross section of South Plateau test pits from the WLT to ULT depths. (From WVNS (1993c), Figure 17.)

Prudic (1986) notes that oxidized zones border till fractures, that the fractures locally contain thin coatings of manganese or iron oxides and calcite, and that there are thin reduced zones on inner surfaces. He suggests these composite features support a history of water movement along and through the fractures.

On the North Plateau, the TBU and construction backfill form the surface unit, with depths ranging from 12.5 m (41.0 ft) in the center of the plateau and pinching out at creeks on the north, east, and south edges and against the bedrock valley slope to the west (WVNS 1993b). A soil layer of 22–30 cm (8.7–11 in.) is present in some undisturbed areas (WVNS 1993c). The TBU is underlain in places by the SWS unit, which has limited extent (Figure 29). The clay layer separating the SWS and TBU ranges in thickness from 0 to 2.1 m (7 ft), causing a potentiometric head difference between the SWS and TBU where it is thicker (WVES 2007). Below the SWS there is weathered to unweathered Lavery till, as on the South Plateau, but the weathered zone is generally much thinner, at less than 0.3 m (1.0 ft) (DOE 2010c).

There is some disagreement about the overall effective permeability of the ULT, particularly between the FEIS (DOE 2010c) and the Independent Expert Review Team (Garrick et al. 2008). The former treat the ULT as unfractured with low hydraulic conductivity (6×10^{-8} cm/s) at depths greater than 3 m (10 ft), while the latter suggest it is more fractured, contains higher-permeability inclusions, has been disturbed by holes and trenches deeper than 3 m, and includes reworked sediments.

3.2.8.2.3 Vadose Zone Flow

The vadose zone at the Site comprises the unsaturated parts of the TBU (“surficial sand and gravel”) on the North Plateau and the WLT (fractured, weathered till) on the South Plateau. These two areas generally have very different flow characteristics and are described separately below. Key processes discussed in this section include conceptual models of infiltration and multiphase flow. Seasonal effects strongly influence vadose zone conditions at the Site; weather, precipitation, and evapotranspiration were discussed in Section 3.2.5.

On the North Plateau, the vadose zone thickness varies widely due to topography (Section 3.2.1), but ranges from 0 m (at swamps and seeps) up to 6 m (20 ft) (DOE 2010c). The nature of vadose zone flow depends on the antecedent soil moisture conditions, but generally the coarse-grained TBU is conducive to fingering flow (WVNS 1993c). During driest months, evapotranspiration produces an upward gradient from the surface to 2.1 m (6.9 ft) depth (WVNS 1993c). During the wetter season (November through May), a downward matric potential gradient exists from the surface to an average of 3.0 m (9.8 ft) depth.

On the South Plateau, the water table in the WLT fluctuates between 0.3–3.3 m (1.0–10 ft) from the surface (WVNS 1993c) and different conceptual models for flow may be used to represent the vadose zone across the seasons. Maximum saturation occurs in January or February, around the time the upper ground surface approaches freezing. In the soil layer of ~25 cm (10 in.) thick (Figure 45), piston flow is the mode of moisture movement (in undisturbed WLT/ULT outside of the NDA and SDA). Below that, moisture is routed to the fracture network. During wetter months, soil and clay swelling causes reduced conductivity of fractures, and nearly the entire fractured WLT can be treated as an equivalent porous medium with horizontal and vertical flow; infiltration rate is lower and is governed by saturated hydraulic conductivity. The water table is so close to the surface that the capillary fringe may cause ponding. In drier seasons, on the other hand, fractures and macropores are reopened and the process is better represented by fracture flow. Matric potential produces an upward gradient from the surface to 1.5 m (4.9 ft) (WVNS 1993c). During large-volume summer rainfall events that dwarf evapotranspiration rates, infiltration volume is high and horizontal flow to discharge regions (discussed in Section 3.2.8.2.5) is possible. Figure 46 illustrates average saturation values and water table depth in the WLT.

Estimated seasonal infiltration rates vary based on location around the Site and the technique used to model or calculate it; a few examples are provided here. Engineered structures, water catchment, and other facilities constructed around the Site also have local influence on infiltration rates and hence recharge (DOE 2010c). (In some areas infiltration is mitigated through the use of covers; see Section 3.1.2.3.) The average rainfall and evapotranspiration values at the Site are discussed in Section 3.2.5.4. Between December and April, runoff and infiltration dominate the precipitation water budget while, during the rest of the year, evapotranspiration and infiltration are greater than runoff (WVNS 1993c). For the WLT on the South Plateau, late Fall rains (late October–December) are thought to contribute more to groundwater than Spring rains due to antecedent soil moisture conditions: soil swelling is reduced, and root shrinkage and desiccation cracks provide more open pathways to infiltration, as described above.

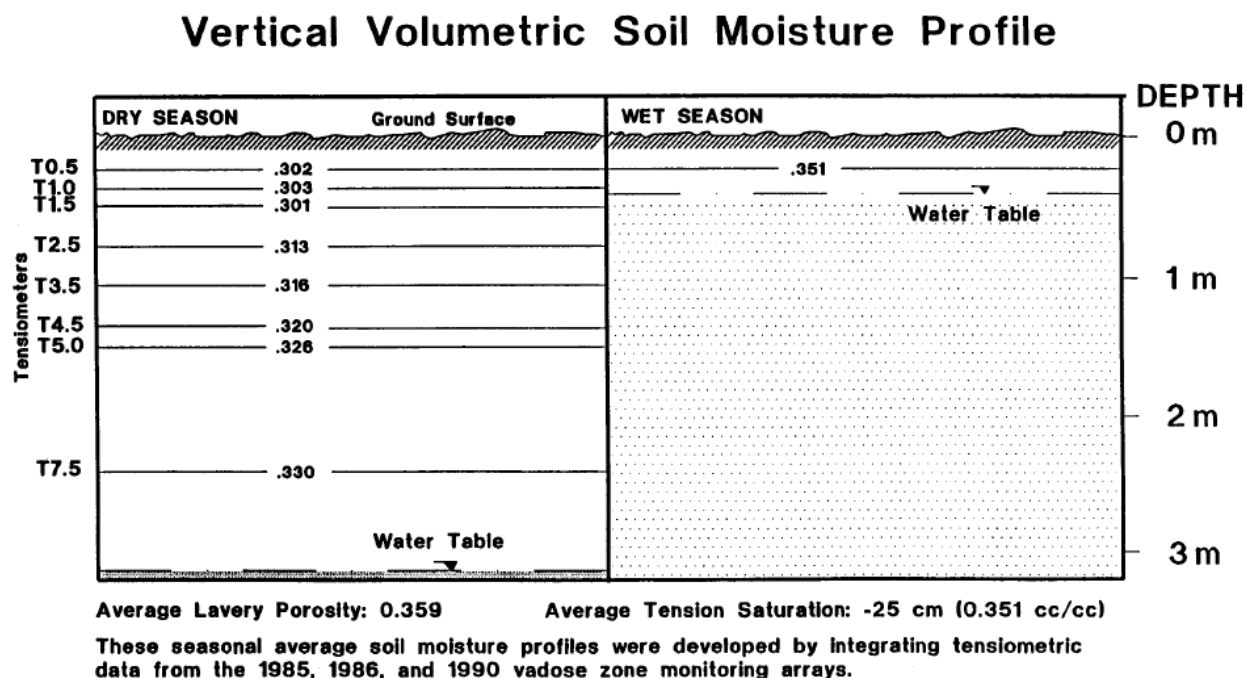


Figure 46. Conceptual model of seasonal variation in vadose zone soil moisture for the WLT on the South Plateau. (From WVNS (1993c), Figure 11.)

Vadose zone modeling of infiltration with calibration to measured moisture content is described in WVNS (1993c). One estimate of the annual water budget at the Site is that 101 cm (40 in.) of yearly rainfall is partitioned into 57 cm (22 in.) of evapotranspiration, leaving 44 cm (17 in.) for runoff and infiltration (WVNS 1993b). The spatially averaged infiltration rate was estimated at 7.4 cm/yr (2.9 in./yr) for the South Plateau and 17.3 cm/yr (6.8 in./yr) for the North Plateau. Estimates of spatially distributed recharge across the TBU in the North Plateau due to precipitation range from 7.7–42 cm/yr (3.0–16 in./yr) with an average of 17 cm/yr (6.7 in./yr) (WVNS 1993c), but estimates vary based on method of analysis. Another study by Yager (1987) estimated the water budget for the TBU, with 50 cm/yr (20 in./yr) of recharge from precipitation, but WVNS (1993b) notes that the greater values from Yager were due to an order-of-magnitude higher estimate for the hydraulic conductivity of the TBU. For the site-wide FEHM model (DOE 2010c), spatially heterogeneous infiltration rates were varied during model calibration, with measured water levels as the target for comparison between observed and predicted values. Their estimated infiltration rates depend sensitively on model assumptions and calibration techniques.

Unsaturated flow parameters have been estimated using experimental soil moisture content and tension data (WVNS 1993c). A van Genuchten model for soil moisture as a function of capillary suction, $\theta(\psi)$, was fit to the data. The resulting parameters (α , n) are given in Table 5.

A relationship for unsaturated hydraulic conductivity (K) as a function of suction, saturated K_s , and a fitting parameter, also denoted α , was also developed (WVNS 1993c). In that case, $K(\psi) = K_s \exp(-\alpha\psi)$, with best-fit parameters $\alpha = 2.35 \times 10^{-3} \text{ cm}^{-1}$ and $K_s = 1.07 \times 10^{-8} \text{ cm/s}$.

A capillary fringe zone holds water under tension at nearly saturated levels (90+%) above the water table in both the surficial units: the TBU on the North Plateau and the WLT on the South Plateau. The former is expected to have a capillary fringe from 21–42 cm (8–17 in.) thick, while the latter may be up to 2.1 m (6.9 ft) (WVNS 1993c).

Table 5. Van Genuchten retention curve fitting parameters.

	α	n
Lavery till	Average: 9.5×10^{-3} Range: 9.2×10^{-4} to 0.73	Average: 1.23 Range: 1.03 to 2.35
TBU	Average: 1.2×10^{-2} Range: 8.6×10^{-3} to 2.1×10^{-2}	Average: 1.31 Range: 1.13 to 2.35

Values from WVNS (1993c).

3.2.8.2.4 Groundwater Occurrence

Saturated regions are present to some extent in all of the stratigraphic units discussed in Section 3.2.8.2.2. In both the North and South Plateaus, two aquifer systems are present, an upper and a lower system, separated by unsaturated conditions in the KRS. In the surficial TBU at the North Plateau, groundwater is unconfined and water table depth can vary by a few meters seasonally, with a maximum in April following snowmelt, and a minimum in July when the ratio of precipitation to evapotranspiration is relatively low (WVNS 1993b). There is an average of 77 cm (30 in.) annual variation in water table depth in the TBU (WVNS 1993c). Unusually dry weather (e.g., from April to October 1991) can affect average water levels by even greater amounts than typical seasonal variation (WVNS 1993b). Across the North Plateau, depth to the water table ranges from 0–6 m (20 ft) below ground surface, with the greatest depth to groundwater in the thickest part of the unit, near the MPPB (DOE 2010c; WVNS 2009a). Measuring from the base of the TBU, saturated thickness ranges from 0.4–9.3 m (1.3–30.4 ft). Figure 29 shows a generalized cross-section view of the units beneath the North Plateau, with approximate water table depths indicated. Figure 47 shows plan view groundwater elevation contours taken in Third Quarter 2016 monitoring (CHBWV 2016).

Locally confined aquifer conditions exist in the SWS beneath the North Plateau (DOE 2010c), due to the low hydraulic conductivity of the ULT below and the clay-rich layer above (WVNS 2007). Groundwater contours in the SWS from Third Quarter 2016 monitoring are shown in Figure 48 (CHBWV 2016). In the LTS contained within the ULT, confined and artesian conditions generally exist (WVNS 1993b).

Figure 31 shows a cross-section view of the units beneath the South Plateau, with approximate water table depth indicated. Figure 49 shows plan view groundwater elevation contours (AECOM 2016a). On the South Plateau, the water table fluctuates widely in the WLT (up to 4.6 m [15 ft]) (WVNS 1993b), and the ULT is perennially saturated (WVNS 1993c). However, in the ULT, not all piezometers contain groundwater, suggesting local tension-saturated conditions that limit entry of water into the piezometers (WVNS 1993b).

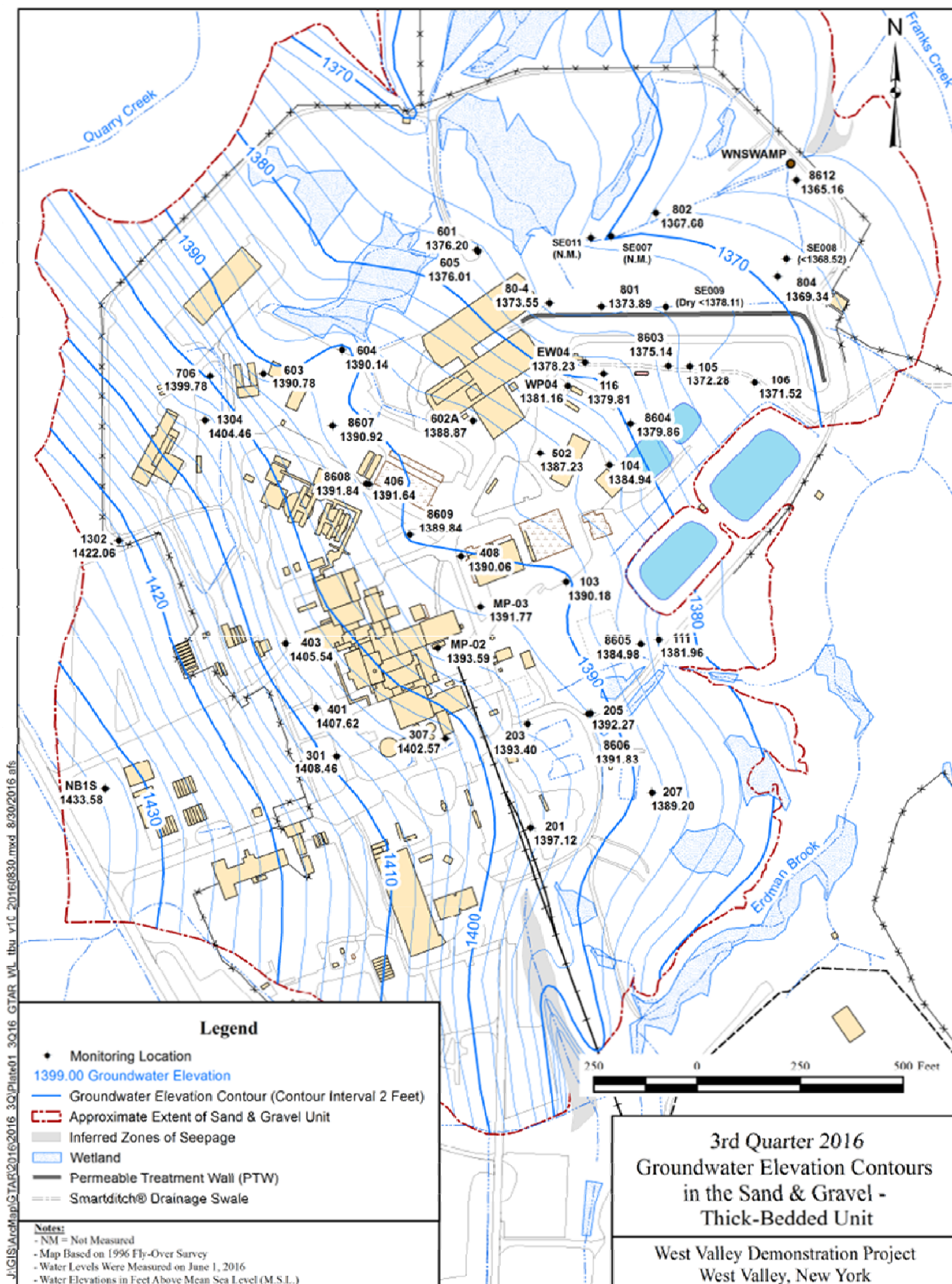


Figure 47. North Plateau groundwater elevations in the TBU, from Third Quarter 2016 monitoring data. (From CHBWV (2016), Figure 5.)

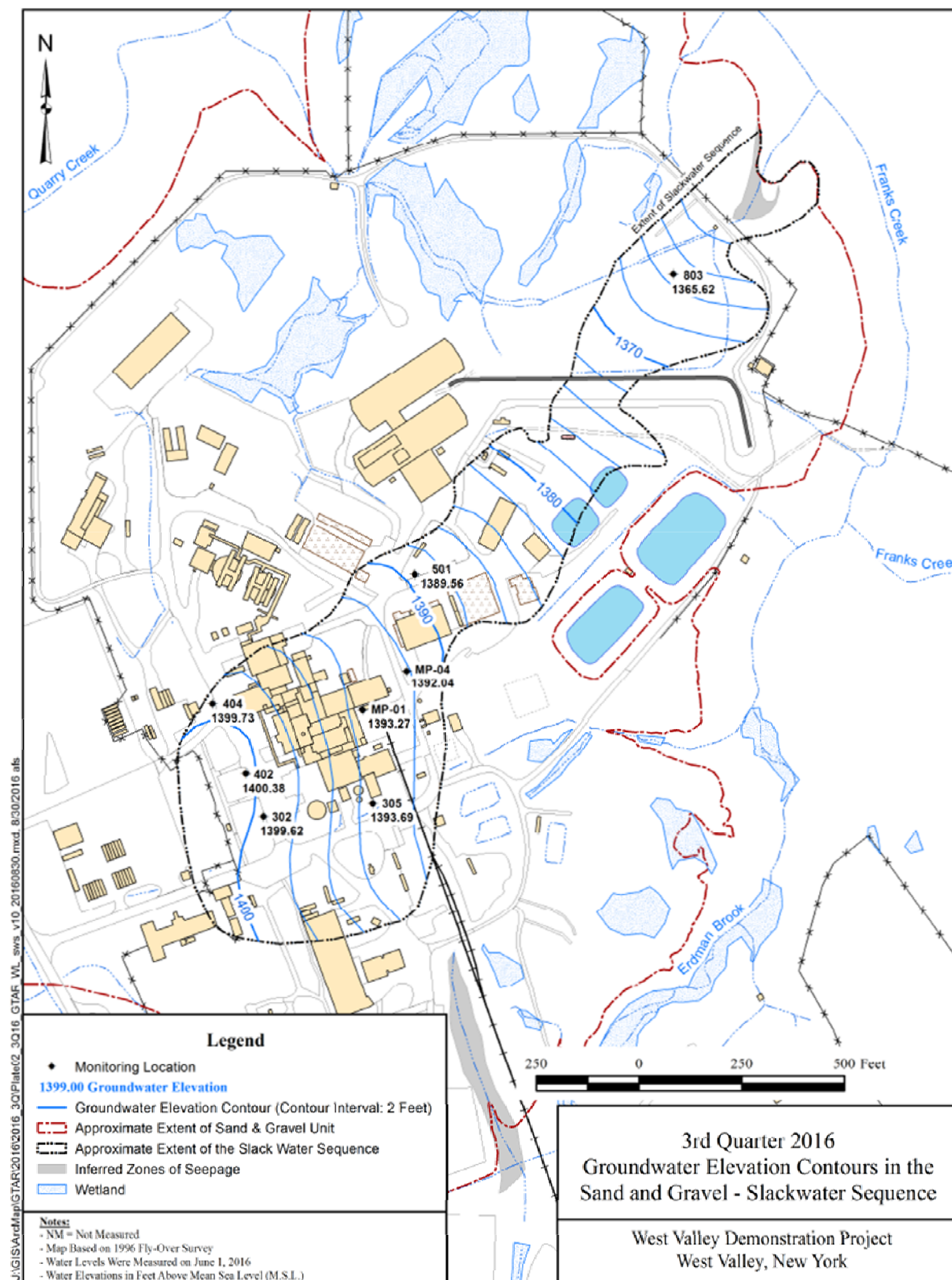


Figure 48. North Plateau groundwater elevations in the SWS, from Third Quarter 2016 monitoring data. (From CHBWV (2016), Figure 6.)

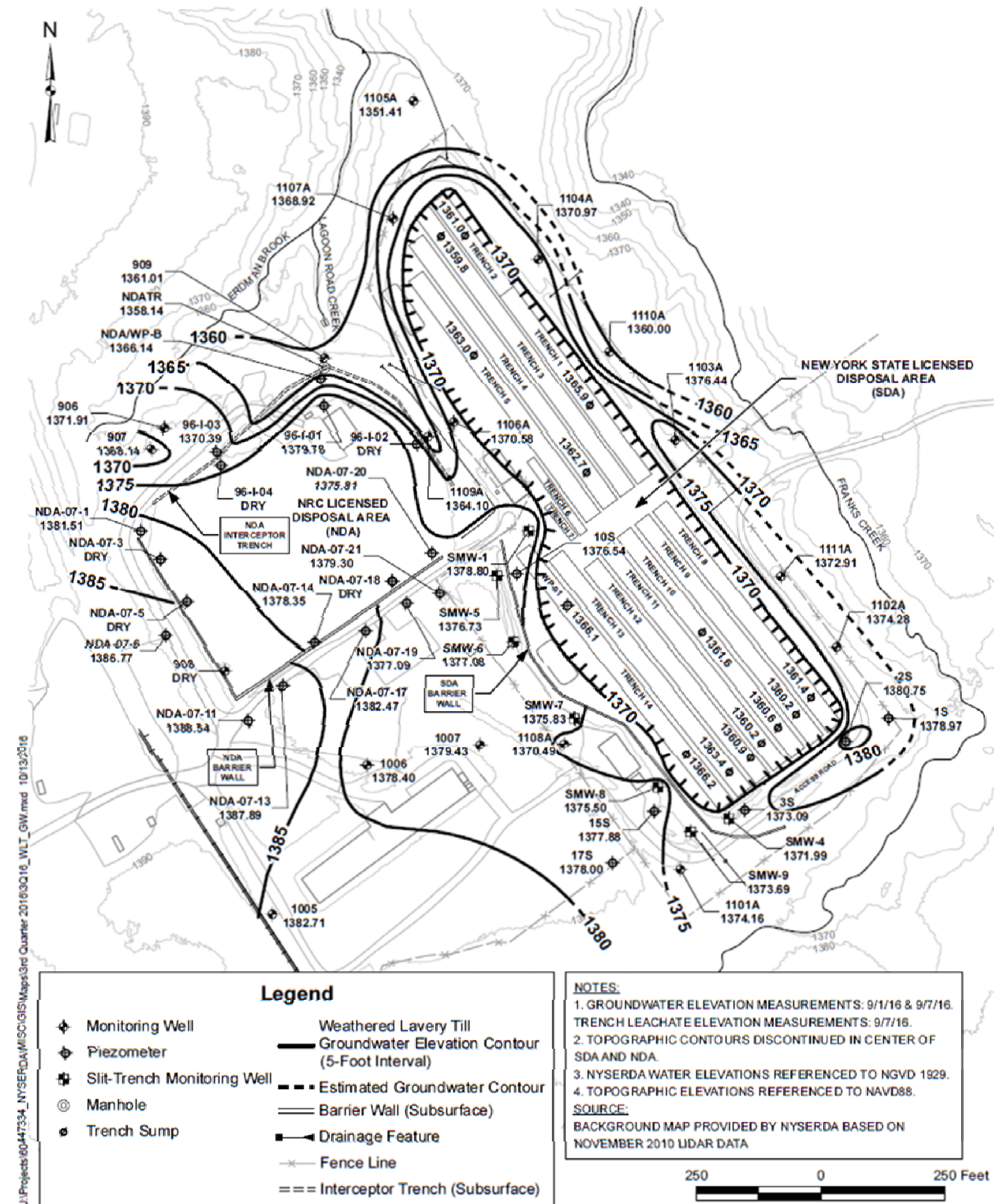


Figure 49. South Plateau groundwater elevations in the WLT, from Third Quarter 2016 monitoring data. (From AECOM (2016a).)

The upper parts of the KRS beneath both plateaus are unsaturated due to low quantity of recharge from above (low vertical permeability of the ULT) (WVNS 1993b), as shown in Figure 29 and Figure 31. The deeper parts tend to be saturated. Below the lower KRS, all units are saturated (DOE 2010c).

Rising water levels were observed in most of the disposal trenches at the SDA on the South Plateau (Figure 50 shows Trench 14) (AECOM 2016b). The water in the trenches is described as “leachate,” and is a mixture of fresh water and materials leached from buried wastes. Various strategies were employed to mitigate leachate rise in these trenches, including multiple cover materials, bioengineered covers (juniper plantings at Trench 9), runoff management, removal of leachate into a storage tank, and a slurry wall. The slurry barrier wall (Section 3.1.2.2) prevents infiltration of groundwater into the western side of Trench 14 (Figure 4). Geomembrane covers have been installed to reduce infiltration (Section 3.1.2.3), including the VLDPE and XR-5 covers (Figure 6). Recent and ongoing analyses have been performed to evaluate the effectiveness of the mitigation measures and to understand the observed trends (e.g., Ecology and Environment (2010), AECOM (2016b)).

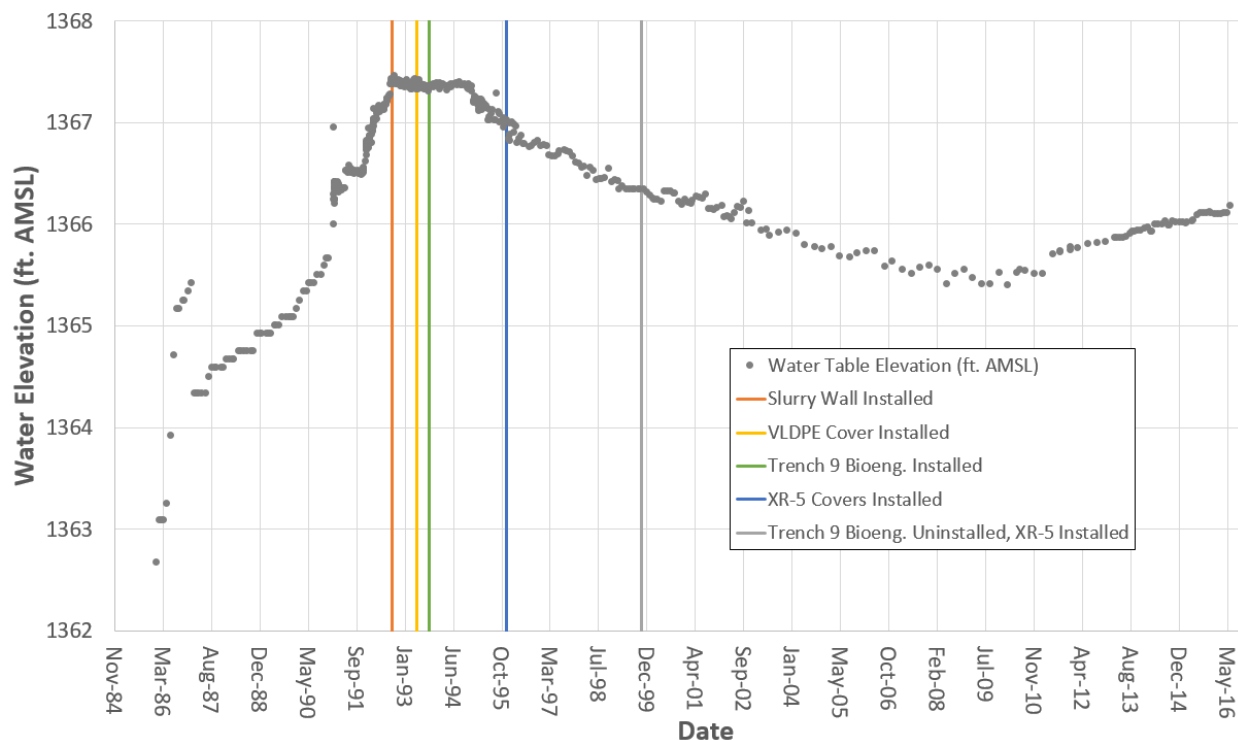


Figure 50. Trench 14 leachate levels, Jan 16, 1986–June 6, 2016. (From AECOM (2016b), p. A-15.)

3.2.8.2.5 Groundwater Movement

In general, for hydrogeologic regimes such as those at the Site, recharge at topographic highs migrates downwards and horizontally as shown schematically in Figure 51. Figure 29 and Figure 31 also show general groundwater flow direction in the layers below the North and South Plateaus, respectively. The inference of flow direction comes from water levels in wells, observed contaminant transport at the Site (e.g., the North Plateau groundwater plume), and other geochemical evidence (Section 3.2.8.3). Groundwater flow directions are locally impacted by interfaces between adjacent units with differing hydraulic conductivities, by layers or lenses contained within the units, and by disposal area trenches, lagoons, waste ponds, discharge drains, and other engineered features (WVNS 1993b). From 1995 to 2013, three extraction wells were in operation on the North Plateau to help mitigate the ^{90}Sr plume (Geomatrix 2007). Each unit is discussed separately below.

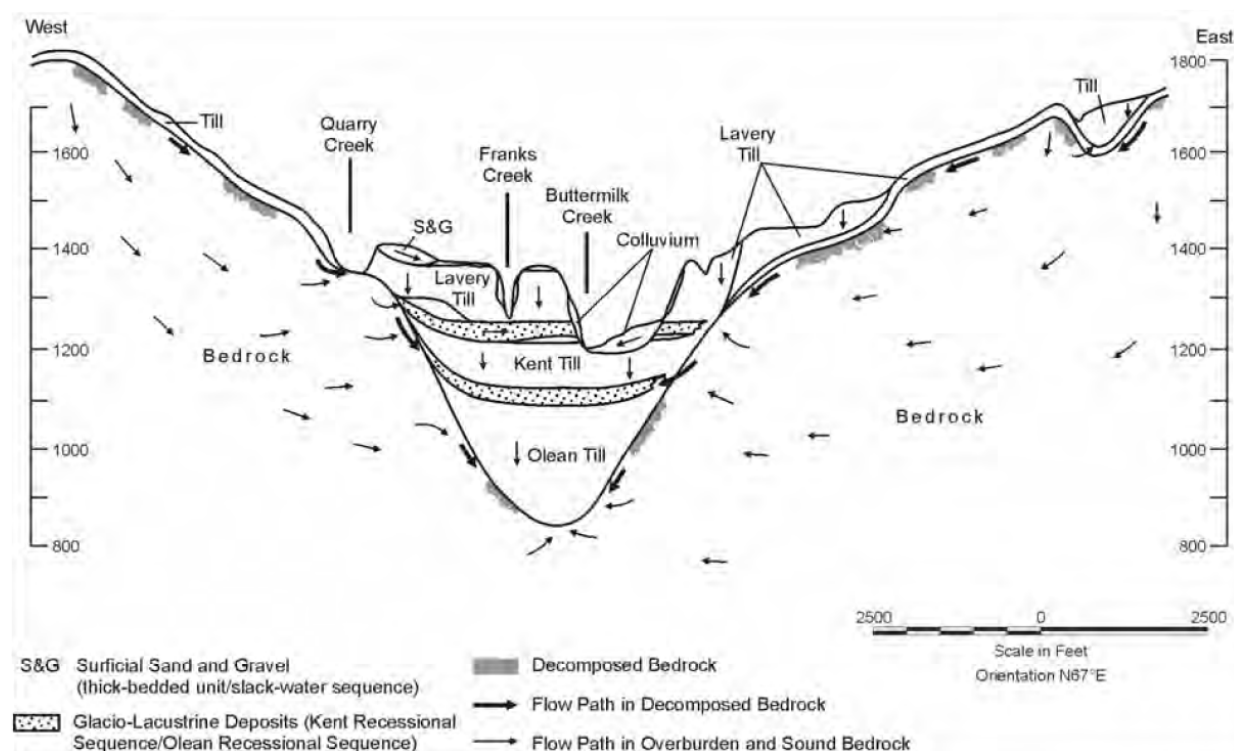


Figure 51. Schematic cross section of the region showing conceptual groundwater flow directions. (From DOE (2010c), Figure E-4.)

TBU (denoted “S&G” in Figure 51): Recharge of groundwater in this layer occurs primarily from precipitation and bedrock underflow, with annual average recharge estimates ranging widely from 17.3–66 cm/yr (6.8–26 in./yr) (WVNS 1993b). DOE (2010c) provides a summary of multiple studies that make attempts to estimate the water budget with allocations to recharge from precipitation and inflow from the bedrock, and loss by runoff and evapotranspiration (p. E-25). Yager (1987), for example, estimated total recharge to the TBU over one time period (Fall 1982–Fall 1983) as 66 cm/yr (26 in./yr), with 50 cm/yr (20 in./yr) from precipitation (as described in Section 3.2.8.2.3), 12 cm/yr (4.7 in./yr) as underflow from bedrock, and 4 cm/yr (2 in./yr) as “leakage from main plant’s outfall channel” (p. 21).

Groundwater flow in the TBU is generally from southwest to northeast, toward Frank’s Creek and along the topographic and hydraulic gradient (Figure 47). Average groundwater velocity is approximately 18.6 m/yr (61.0 ft/yr) (WVNS 1993b). However, groundwater at the northwestern boundary of the TBU flows towards Quarry Creek and, at the southeastern margin, towards Erdman Brook. Near the lagoons (Figure 47), lower groundwater velocities were estimated at 4.9 m/yr (16.0 ft/yr) (WVNS 1993b). Discharge from the unit is by evapotranspiration, into springs and streams, and seepage at the edges of the plateau. Figure 52 shows the estimated extent of the TBU on the North Plateau and the locations of seeps. In the TBU, evapotranspiration is thought to contribute to about 30% of the groundwater discharge (WVNS 1993b). Vertical leakage also occurs downwards into the SWS where present (DOE 2010c), with only negligible leakage to the underlying Lavery till (WVNS 1993b). Yager (1987) estimated discharge proportions over the same one-year time period above (Fall 1982–Fall 1983) as 13 cm/yr (5 in./yr) into stream channels, 21 cm/yr (8 in./yr) into stream and seepage faces, 2 cm/yr (0.8 in./yr) into the former French drain, 1 cm/yr (0.4 in./yr) in vertical leakage to the Lavery till, and 4 cm/yr (2 in./yr) as change in storage.

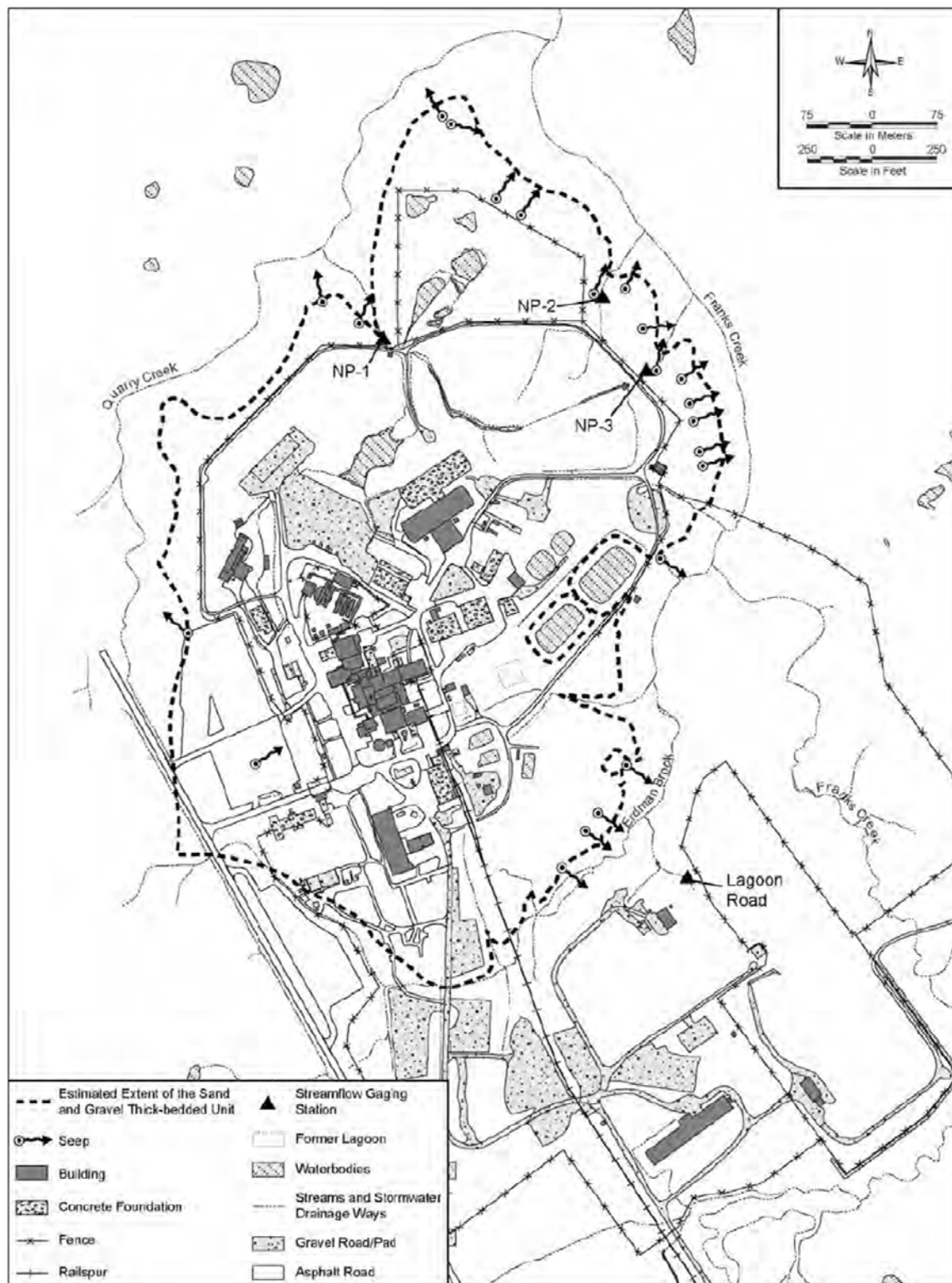


Figure 52. Locations of North Plateau seeps from the TBU. (From DOE (2010c), Figure E-10.)

A plume of ^{90}Sr emanating from the former MPPB area is found in the TBU and the SWS below it. The plume is discussed in greater detail in Section 3.2.8.3. Time series data collected for monitoring ^{90}Sr migration provides further information to validate models for groundwater flow, discharge, and transport in these units (Geomatrix 2007). The full-scale PTW (Section 3.1.2.1) filters some ^{90}Sr from groundwater, but it does not substantially affect groundwater flow direction (CHBWV 2012). Operation of the PTW is discussed in Section 3.2.8.3.3.

SWS: The SWS is hydraulically connected with the TBU, although it has more stratification and locally semi-confined conditions (Geomatrix 2007). Recharge to the SWS is from the TBU above; discharge is at seeps along Frank's Creek and downward into the Lavery till (DOE 2010c). Flow direction is to the northeast, as evidenced by the migration of the North Plateau groundwater plume (Section 3.2.8.3.1).

WLT (South Plateau): The surface-exposed WLT on the South Plateau is recharged by precipitation, averaging approximately 7.4 cm/yr (2.9 in./yr), as discussed in Section 3.2.8.2.3 above (WVNS 1993c). Runoff on this layer is estimated at 36.6 cm/yr (14.4 in./yr). Discharges are minor to the ULT below, estimated at 1.3 cm/yr (0.5 in./yr). Seepage into stream valleys and marshes, which remain saturated in the summer when the streams are not flowing (WVNS 1993b), is estimated at 6.1 cm/yr (2.4 in./yr).

Horizontal discharge in the WLT is generally restricted to conditions of high soil moisture in the fall and early winter, as well as during high-volume summer rainfall events (WVNS 1993c). Lateral flow is to the north-northeast, controlled by South Plateau topography, which slopes gradually to the northeast (WVNS 1993b). Minimum groundwater velocity was estimated from migration of a contaminant mixture at 1.4 m/yr (4.5 ft/yr) (WVNS 1993b). However, disposal areas (NDA and SDA) locally affect lateral flow significantly. In the SDA, the slurry wall and trenches intercept groundwater flow and generally prevent horizontal flow through that part of the facility (Ecology and Environment 1994) (Figure 4). As described in Section 3.1.2.2, a similar barrier wall composed of bentonite, soil, and a geomembrane cover was constructed in the NDA (Figure 53). These slurry walls of soil and bentonite are intended to be long-lasting and crack-resistant (Mann et al. 2009).

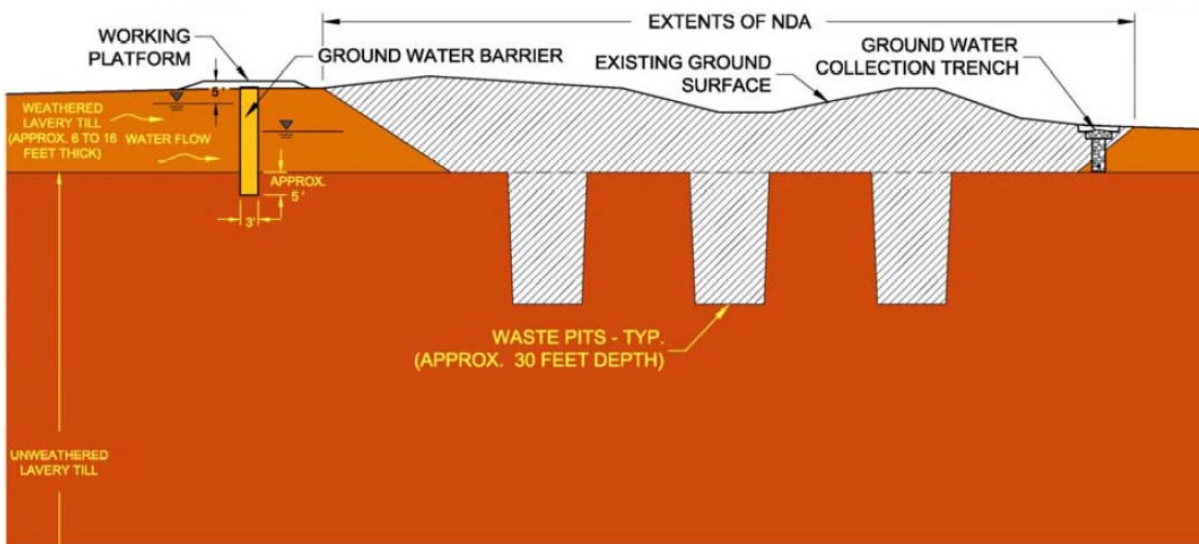


Figure 53. Schematic of the groundwater barrier wall in the NDA (note that Deep Holes extend to 55 ft). (From Mann et al. (2009), Figure 8.)

ULT: As the WLT transitions to the ULT, fractures become less frequent (Figure 45). The flow regime in the WLT, described in Section 3.2.8.2.3, transitions to generally vertical matrix flow in the ULT (WVNS 1993c). Recharge water may pond at the WLT/ULT boundary due to the lower hydraulic conductivity of the lower unit, but horizontal fissures and fractures (depicted in Figure 45) may also allow migration in this transition zone and discharge to surrounding lowlands. Otherwise, at the base of the ULT, discharge is primarily vertically downward to the KRS below (WVNS 1993b). The low hydraulic conductivities of the ULT also imply that contaminant transport in this unit may be dominated by diffusion (WVNS 1993b). However, as described above in Section 3.2.8.2.2, there is some disagreement about the extent of fracturing, high-permeability inclusions, and anthropogenic influences in the ULT (e.g., reworked sediments) that may lead to a higher-permeability flow regime (Garrick et al. 2008).

LTS: This unit is located in the North Plateau within the ULT, and recharge and discharge in the LTS appear to be controlled by the lower hydraulic conductivities of that unit.

KRS: Recharge into the KRS may be from above from the ULT, and from bedrock to the west (WVNS 1993b). However, Garrick et al. (2008) posit that groundwater may also be leaking upwards from the Kent Till, while WVNS (1993b) suggest that such a situation may have previously existed prior to the incision of Buttermilk Creek. In particular, in Garrick et al. (2008), S. Neuman of the Independent Expert Review Team (IERT) writes:

Considering the regional setting of the site it is, in my opinion, much more likely that water is in fact leaking upward from the Kent Till into the KRU. (Page A-3)

The regional hydrogeologic conceptual model, as depicted in Figure 44, shows why upward flow may be possible in these units, with recharge from topographic highs converging and flowing upwards at valley locations such as the Site. The downward arrow in the Kent Till in Figure 51

should be considered potentially incorrect per Garrick et al. (2009a), while the arrows in the bedrock in Figure 51 depict the model of upward flow towards the valley, as well as the possibility of lateral seepage from the bedrock into the KRS. Figure 31 also depicts this uncertainty.

Slow, northeast-trending lateral discharge occurs through the lower, saturated portions of the KRS (in the finer-grained lacustrine deposits, generally) to bluffs along Buttermilk Creek (DOE 2010c; WVNS 1993b). Groundwater velocities have been estimated at 13 cm/yr (0.4 ft/yr) to 1.7 m/yr (5.5 ft/yr) (WVNS 1993b).

Kent Till: Recharge into the Kent Till is from the KRS above, and flow in this low-permeability unit is likely vertical (DOE 2010c).

ORS and Olean Till: Less is known about the groundwater flow patterns in these units. Similar to the KRS and Kent Till pair, recharge into the ORS may occur from the bedrock and there may be discharge to surface water (DOE 2010c), although the latter is not supported according to Garrick et al. (2009a). Upwards discharge into the Kent Till or recharge from below are also uncertain (DOE 2010c). The Olean Till may discharge to the WB below.

Bedrock: The ~3 m (10 ft) thick fractured weathered bedrock zone has a much higher hydraulic conductivity than the competent bedrock below (Table 4). Preferential flow would occur in this weathered zone, as depicted in Figure 51 (“Flow Path in Decomposed Bedrock”). Flow is also possible along high-angle fractures and bedding planes in the unweathered bedrock (Zadins 1997). However, this is not a major conduit for subsurface flow (Prudic 1986), which contributes to the relative isolation of the aquifers supplying drinking water for nearby municipalities such as at Springville.

In addition to the installed engineered systems discussed above that impact groundwater movement, other possible hydraulic barriers may be installed under certain decommissioning alternatives (discussed in Section 3.1.2.2).

The flow of groundwater, in both unsaturated and saturated zones, for each facility modeled in the West Valley PPA Model will be based on local heads, flow patterns, gradients, and velocities as determined in the 3-D groundwater flow process modeling. The flow of water through GoldSim compartments is necessarily simple, though in some cases it could be modeled to flow out in more than one direction, splitting inflow into multiple outflow paths.

3.2.8.3 Geochemistry

In-situ groundwater chemistry affects contaminant behavior through radionuclide transport parameters such as K_d , solubility, and diffusivity. Natural and anthropogenic constituents observed in groundwater are discussed in Section 3.2.8.3.1. Section 3.2.8.3.2 covers geochemical considerations important for modeling the Site, including parameter development and inferred hydrogeologic behavior. The chemistry of engineered barriers and other materials present or proposed for the Site is discussed in Section 3.2.8.3.3, including performance characteristics as well as the impact of degradation.

3.2.8.3.1 Groundwater Quality

Results of chemical and radiological groundwater analyses performed by the WVDP Environmental Laboratory from 1982 to 1993 were described in Volume III of the *Environmental Information Document* (WVNS 1993b). Although samples were initially analyzed only for radiochemical constituents, the analytical suite was expanded in 1991 to more fully characterize Site groundwater. Groundwater in all lithologies was identified as a calcium-bicarbonate type. Localized variations in groundwater quality not attributable to Site activities likely result from dissolution of minerals in the subsurface; several anomalies are detailed in Section 3.2.8.3.2. Major components of the groundwater, by layer, are shown in Table 6.

Table 6. Major groundwater components by layer¹.

Analyte	Units	Surficial Units (TBU/SWS)	Weathered Lavery Till (WLT)	Unweathered Lavery Till (ULT)	Lavery Till Sand (LTS)	Kent Recessional Sequence (KRS)
Calcium	% of cations	62	60	60	64	41
Magnesium	% of cations	15	34	34	20	25
Sodium	% of cations	23	6	6	16	32
Bicarbonate	% of anions	47	55	55	57	73
Chloride	% of anions	36	3	2	27	<8
Sulfate	% of anions	17	42	42	16	19
pH ²	Mean: s.u.	7.04	7.04	7.18	8.05	7.74
	Range: s.u.	5.96 to 8.14	6.35 to 8.77	6.58 to 7.99	6.61 to 12.61	6.88 to 9.88
Specific Conductance ²	Mean : µmhos/cm	777	1142	1042	912	615
	Range: µmhos/cm	292 to 4018	417 to 2810	395 to 1544	22 to 3220	253 to 1383
Total organic carbon	Mean: mg/L	6.5	7.1	6.4	7.2	-
	Range: mg/L	1.0 to 85.0	1.0 to 49.0	<1.0 to 110	<1.0 to 84	-

Analyte	Units	Surficial Units (TBU/SWS)	Weathered Lavery Till (WLT)	Unweathered Lavery Till (ULT)	Lavery Till Sand (LTS)	Kent Recessional Sequence (KRS)
Total organic halogens	Mean: mg/L	0.028	0.013	0.009	0.012	-
	Range: mg/L	0.005 to 0.960	0.010 to 0.005	0.005 to 0.130	0.005 to 0.034	-

¹ Data from Volume III of the Environmental Information Document (WVNS 1993b). Means presented unless otherwise noted.

² Excluding well 0103 which is within a sodium hydroxide spill radius of influence.

Data used to compute background values in the TBU/SWS are taken from wells 301, 401, 706, and 1302 from 1991 to September 2009. Groundwater screening levels for radiological constituents are set to the higher of either: (1) the upper limit of the 95% confidence intervals from those data or (2) the NYSDEC TOGS 1.1.1 Class GA Groundwater Quality Standards (DOE 2016). Groundwater chemistry in these surficial sand and gravel units in Well NB-1S is compared to samples from 41 wells on the Site in Table 7. Mean chemical concentrations are higher in the wells on-site compared to NB-1S (WVNS 1993b). Inferences about groundwater behavior and contaminant transport based on observed chemical concentrations at the Site are discussed in Section 3.2.8.3.2.

Table 7. Chemical constituents in the TBU/SWS and Well NB-1S¹ Data.

Analyte	Units	Surficial Units (TBU/SWS)	NB-1S Concentrations
Calcium	mg/L	107	73
Magnesium	mg/L	14.7	7.9
Sodium	mg/L	61	41
Bicarbonate	mg/L	199	132
Chloride	mg/L	157	75
Sulfate	mg/L	76	13
Total organic carbon	Mean: mg/L	6.5	7.2
	Range: mg/L	<1.0 to 85.0	-
Total organic halogens	Mean: mg/L	0.028	0.010
	Range: mg/L	0.005 to 0.960	-

¹ Data from Table 2-9 of WVNS (1993b). Means of 41 wells for 2 sampling events in 1991.

Groundwater monitoring at the Site has generally continued and expanded. Collection points at groundwater seeps and more monitoring wells have been added, analytical lists have been tailored to each sampling location, and, in some cases, the sampling frequencies have been reduced (based on regulatory requirements, current and historical activities, and continual evaluation of groundwater data). The complete set of available geochemical results to date will be used to inform parameter distribution development.

The groundwater monitoring program identified several areas where groundwater has been affected by Site activities. In 1983, n-dodecane and tributyl phosphate were observed in a monitoring well at the perimeter of the NDA; the contamination source was spent extractant from fuel reprocessing operations disposed in the NDA Special Holes. In 1993, elevated gross beta results were found in TBU surface water in the northeastern portion of the North Plateau. The activity, confined primarily to the TBU, was attributed to ^{90}Sr . Subsequent subsurface investigations traced the source to the southwest corner of the MPPB and identified a smaller lobe of ^{90}Sr within, and downgradient of, former Lagoon 1 (Figure 54).

Routine gross beta monitoring results, supported by periodic measurement of ^{90}Sr , were evaluated to assess plume conditions. In June 2015, the highest gross beta activities were in the wells northeast of the MPPB, closest to the source area, at levels up to $5.23\text{E-}04 \mu\text{Ci/mL}$ (DOE 2015). The ^{90}Sr derived concentration standard (DCS) of $1.0\text{E-}06 \mu\text{Ci/mL}$ is used to delineate and map the plumes. Upgradient expansion has been minimal, as has downgradient expansion of the Lagoon 1 lobe. In the 20 yr since its discovery, the main plume has split into three lobes, which have expanded northeast and east (Figure 54). The effect of the PTW on plume mitigation is discussed in Section 3.2.8.3.3.

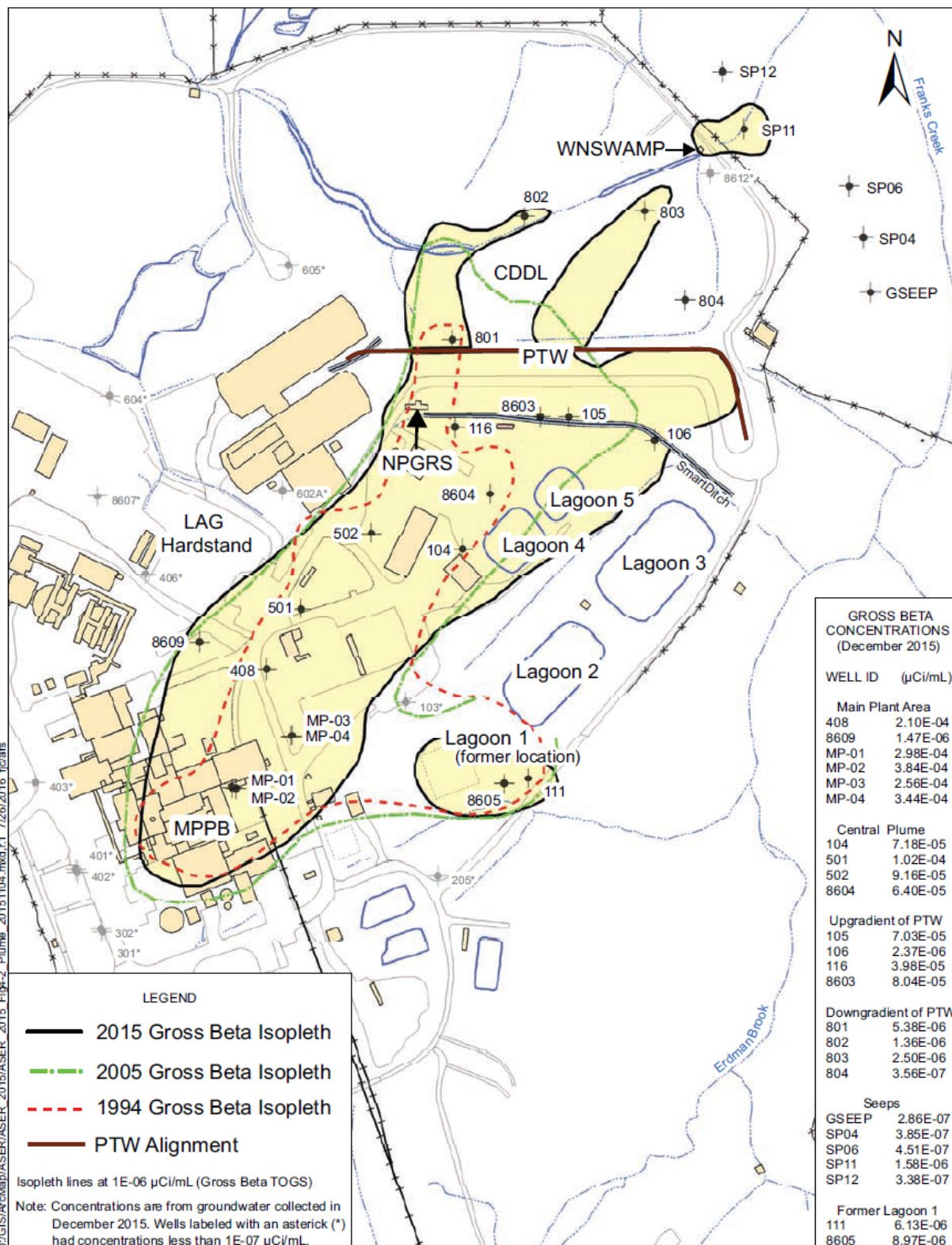


Figure 54. Migration of the strontium-90 plume over time. Yellow shading indicates gross beta concentrations above $2015\ 1\text{e-}6 \mu\text{Ci/mL}$. (From DOE (2016), Figure 4-2.)

3.2.8.3.2 Geochemical Considerations

A key uncertainty in developing transport parameters for the constituents of concern is the effect of local geochemical conditions, as determined by the water, the sediments, and the interaction between the two. Some Site-specific data have been collected for select radionuclides for important parameters, including K_d (Dames & Moore 1995a, 1995b; WVNS 1993b). For constituents without Site-specific data, inferences must be made based on a thorough review of the geochemical conditions, e.g., pH, redox potential, ionic strength, and dominant ions present. Many of these geochemical factors depend on the hydrogeologic setting, with issues such as groundwater/vadose zone pore water residence time, infiltration of meteoric water, and mixing all affecting the natural concentrations of chemicals in aqueous solution. Furthermore, interactions between waste, grout, concrete, construction materials, and the water may also be factors for parameter development at the Site.

Redox conditions at the Site are varied. In the TBU, with its shallow unconfined water table and recharge from oxygenated precipitation, conditions are aerobic. Similarly, at the South Plateau, conditions in the brown-colored WLT are oxidizing. Below both areas, the ULT is generally gray-colored and reducing, except at small, minute fractures where groundwater flow is oxidized. Water in the South Plateau disposal holes and trenches is typically anoxic (WVNS 1993b).

Many anomalous localized chemical concentration results are a result of Site operations. For example, elevated chloride measured in wells in the surficial units and the underlying ULT at the North and South Plateaus may be related to salting of roads and parking lots. Other elevated chloride concentrations in the TBU on the North Plateau may be from sludge ponds that received brine solutions. A 1984 NaOH leak was thought to be the source of elevated sodium and hydroxide concentrations in one well, but this well has returned to a normal range. Measured specific conductivities are higher in areas around the MPPB, the LLWTF lagoons, and the sludge ponds. On the other hand, in the WLT beneath the South Plateau, differences in sulfate, bicarbonate, magnesium, and sodium concentrations may be a result of natural mineralogical differences in the unit (WVNS 1993b). Construction activities on the South Plateau may have influenced aqueous concentrations of calcium, magnesium, and sodium, which may have originated in crushed limestone used for the base of the drum cell building.

Despite the complex distribution of aqueous chemical concentrations as a result of operations, some observations may be used to infer local hydrogeologic behavior at the Site. For example, it had been inferred from soil core data around the South Plateau trenches that transport in the WLT was governed by molecular diffusion (Prudic 1986), due to the apparently slow nature of tritium migration. However, more recent data supports the dominance of horizontal fracture flow in the WLT based on the migration of tritium from Trench 14 to a borehole 9.1 m (29.9 ft) to the west (WVNS 1993b).

Transport and geochemical conditions in the North Plateau can also be understood through the migration of the ^{90}Sr plume. Based on estimates of groundwater flow velocity in the TBU (Section 3.2.8.2.5), the plume has migrated at about 1/3 the speed expected based on advection alone (Geomatrix 2007). This is important validation data for transport models that include retardation and dispersion within the TBU.

Natural chloride concentration in wells at the Site has been used to infer regional hydrogeologic patterns. Shallow wells average around 2–25 mg/L chloride (Prudic 1986), while deeper water in the bedrock has much higher concentrations. At the valley floors, depth to high-chloride water is shallower than elsewhere in the landscape (Figure 44), suggesting water is coming from the deeper regional flow system. However, lower chloride (21 mg/L) in a well between the Site and Buttermilk Creek provides some evidence that regional groundwater flow does not discharge to the surface water at this location (Prudic 1986).

3.2.8.3.3 Barrier Chemistry

Several types of barriers against radionuclide migration are in place at the Site, and additional types of barriers may be considered for some of the Phase 2 decommissioning alternatives to be evaluated in the SEIS. Methods include grout, clay, or bentonite fill around individual waste forms; slurry walls; and the PTW on the North Plateau (Section 3.1.2). The effects of physical barriers to divert groundwater flow are discussed in Section 3.2.8.2.5. Here, the geochemical aspects of these barriers are discussed.

Grout/Cement/Concrete

Cementitious materials have been used at the Site to stabilize waste and line lagoons, and may be considered in the Phase 2 decommissioning alternatives to be evaluated in the SEIS. Models of waste areas, if they contain cementitious materials, will need to consider the effect of cement on transport parameters and the timescales for degradation of the materials to their “naturalized” state. The chemical stability of the materials is independent of their structural stability; that is, even if the grout or cement has cracked, it continues to control the aqueous chemistry. Thus, timescales for physical degradation of these materials may not correspond to timescales for chemical degradation.

Cement weathering models have been developed to describe the changes in mineralogy and aqueous chemistry over long time scales (Bradbury and Sarott 1994; Krupka and Serne 1998; Wang et al. 2009). In these models, the primary variable is the number of pore volumes of fresh water that passes through the material. At first (less than 5 pore volumes), pH drops from its initial value in the cementitious material. Next, the “young concrete” phase (stage II) is saturated with respect to portlandite, which buffers pH to around 12.5. This stage may last for around the time it takes for 2000 pore volumes of fresh water to infiltrate (SRS 2010). In the third stage, pH drops again to around 11, where it stays stable until the material rapidly degrades such that the aqueous chemical environment resembles the natural groundwater and the remaining material is essentially sand and gravel. The effect of pH on parameters such as K_d and solubility will be considered in the modeling, with each of these stages represented by appropriate parameter distributions and the timing of degradation from phase to phase determined by a thorough analysis. The previous approach of the FEIS (assigning so-called “degraded” values and maintaining them for the 100,000 yr span of the model) will be re-evaluated (DOE 2010a).

Other materials, such as natural clays and bentonite, have also been used at the Site and may be considered for some of the Phase 2 decommissioning alternatives to be evaluated in the SEIS. Depending on the modeled scenario, the geochemical behavior of these materials will need review.

PTW

Permeable treatment systems are designed to allow groundwater throughflow while capturing undesirable contaminants through ion-exchange reactions within the wall. The design used at the Site is a trench backfilled with clinoptilolite, a zeolitic material that sorbs ^{90}Sr (Bellis et al. 2010). A schematic of PTW operation is shown in Figure 55. The final PTW (3.1.2.1) is keyed into the Lavery till below the TBU/SWS (CHBWV 2012). A monitoring network of 66 new wells was added to 22 pre-existing relevant wells in order to assess the performance of the PTW.

The zeolitic material selected for the PTW was based on high cation exchange capacity (CEC), minimal clay, and low friability (Chamberlain et al. 2011). The friability concern relates to the degradation timescales of the barrier. The clinoptilolite was obtained from the Bear River Mine in Preston, UT. Early results from the monitoring network indicate good performance of the PTW; Figure 56 shows ^{90}Sr concentrations near the PTW in 2011 and 2014 (Steiner 2015).

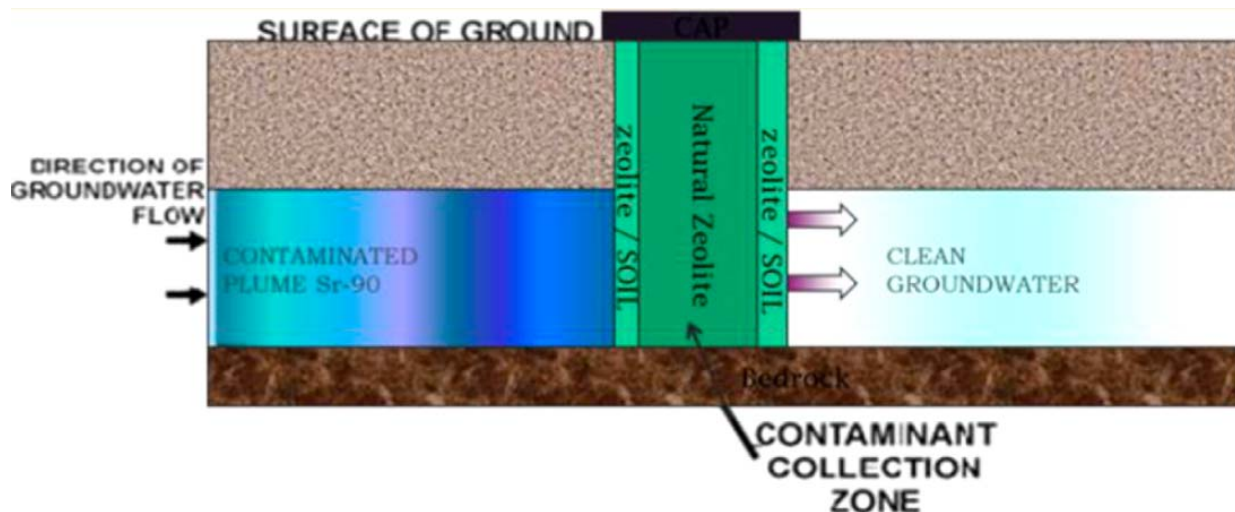


Figure 55. The PTW operates by passive removal of contamination from groundwater by ion exchange onto natural materials. (From Seneca and Rabideau (2013).)

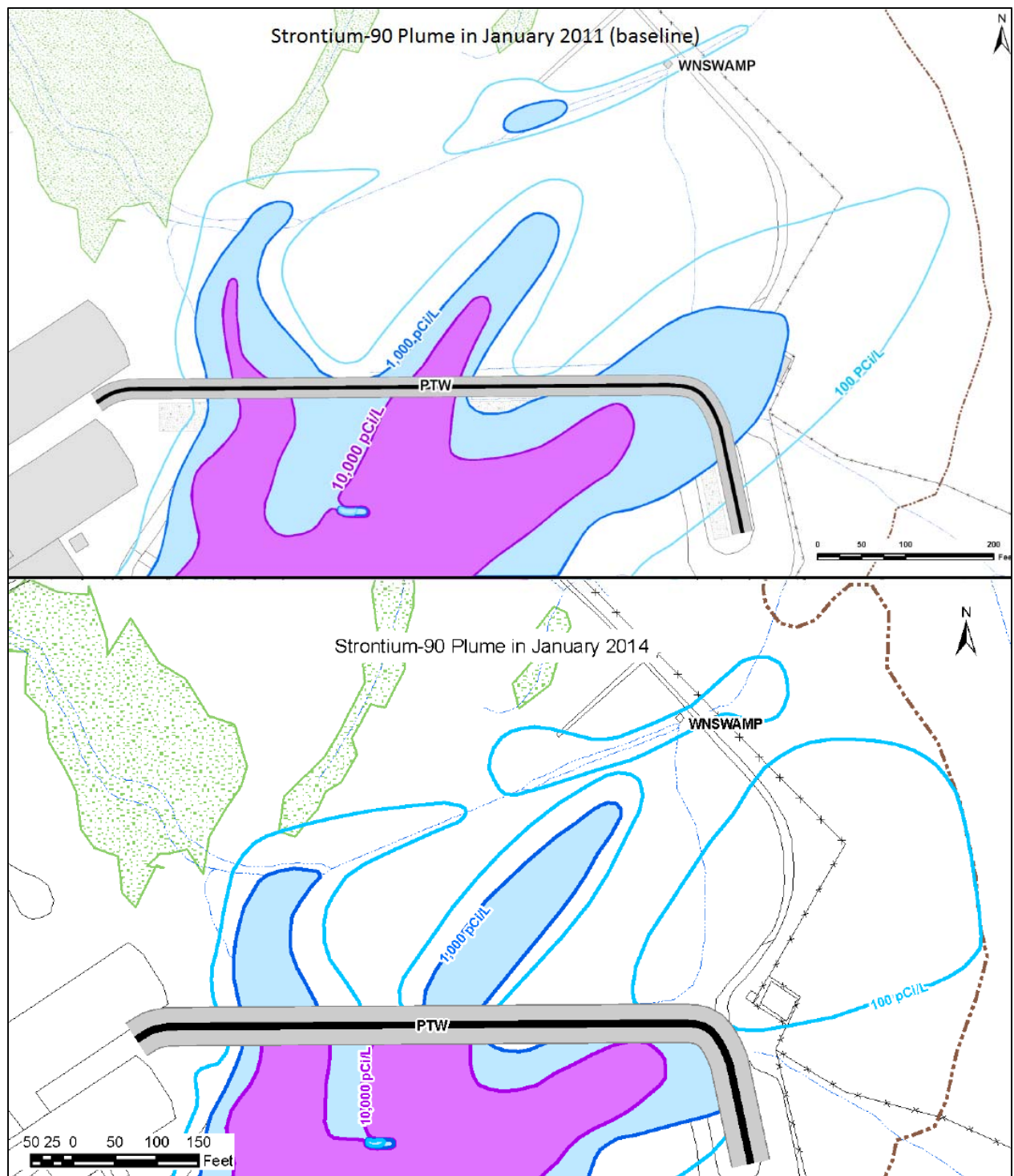


Figure 56. ^{90}Sr plume contours in January 2011 (baseline, top) and January 2014 (bottom). (Adapted from Steiner (2015).)

Slurry Walls

Several slurry walls composed of compacted soil mixed with bentonite have been installed at the Site (Section 3.1.2.2). The primary purpose is physical diversion of groundwater flow, as discussed in Section 3.2.8.2.5. However, the soil/bentonite mixture will have different geochemical properties than the surrounding undisturbed rock, including K_{ds} for adsorption of radionuclides. The influence of these barrier materials on geochemical parameters will be studied and included in distribution development.

3.2.9 Natural Background Radiation

The National Nuclear Security Administration's (NNSA) Remote Sensing Laboratory (RSL) conducted an aerial radiological survey over the WNYNSC and Cattaraugus Creek at the request of DOE and NYSERDA between September 22 and October 2, 2014 (NNSA 2015). Nineteen flights were completed to survey an area of approximately 23,310 ha (90 mi²) and 25 fixed ground measurements were made for verification. Exposure rates at 1 m (3 ft) above ground due to terrestrial sources were calculated. These exposure rates did not include cosmic radiation and airborne radon. The exposure rates over the survey area were given in units of microroentgen per hour ($\mu\text{R/h}$). Roentgens are a unit of radiation density (the SI equivalent being coulombs/kilogram, or C/kg), but are often equated with rem, which is an abbreviation for "roentgen equivalent man," which is a unit of radiation dose. One μR corresponds to 1 μrem , which in SI is 0.01 μSv .

Results for the entire survey area are shown in Figure 59 and are shown with more detail in the vicinity of the WNYNSC in Figure 60. The authors note that background exposure rates over the full survey area in areas apart from those with radioactive contamination (other than from historical nuclear testing) are in the range of 2-5 $\mu\text{R/h}$. Exposure rates due to cosmic radiation and airborne radon measured by data collection on flights over Lake Erie were estimated to contribute on average an additional 4.8 $\mu\text{R/h}$ to the total exposure rate from natural background radiation.

Radiation levels in the vicinity of the Site have been measured at off-site locations in a network of environmental thermoluminescent dosimeters (TLD). The locations of perimeter TLDs within 5 km (3.1 mi) of the Site (DOE 2015) are shown in Figure 57. The trend in exposure rate over a ten year period for the perimeter TLDs and a background TLD located approximately 30 km (18 mi) from the Site are shown in Figure 58. Inferred exposure rates are shown in Figure 59 and Figure 60. Annual averages of the perimeter TLDs range from approximately 6.5 to 8.5 $\mu\text{R/h}$, which is consistent with the sum of the background exposure rates and exposure rates due to cosmic radiation and airborne radon (6.8 to 9.8 $\mu\text{R/h}$) measured by NNSA (2015).

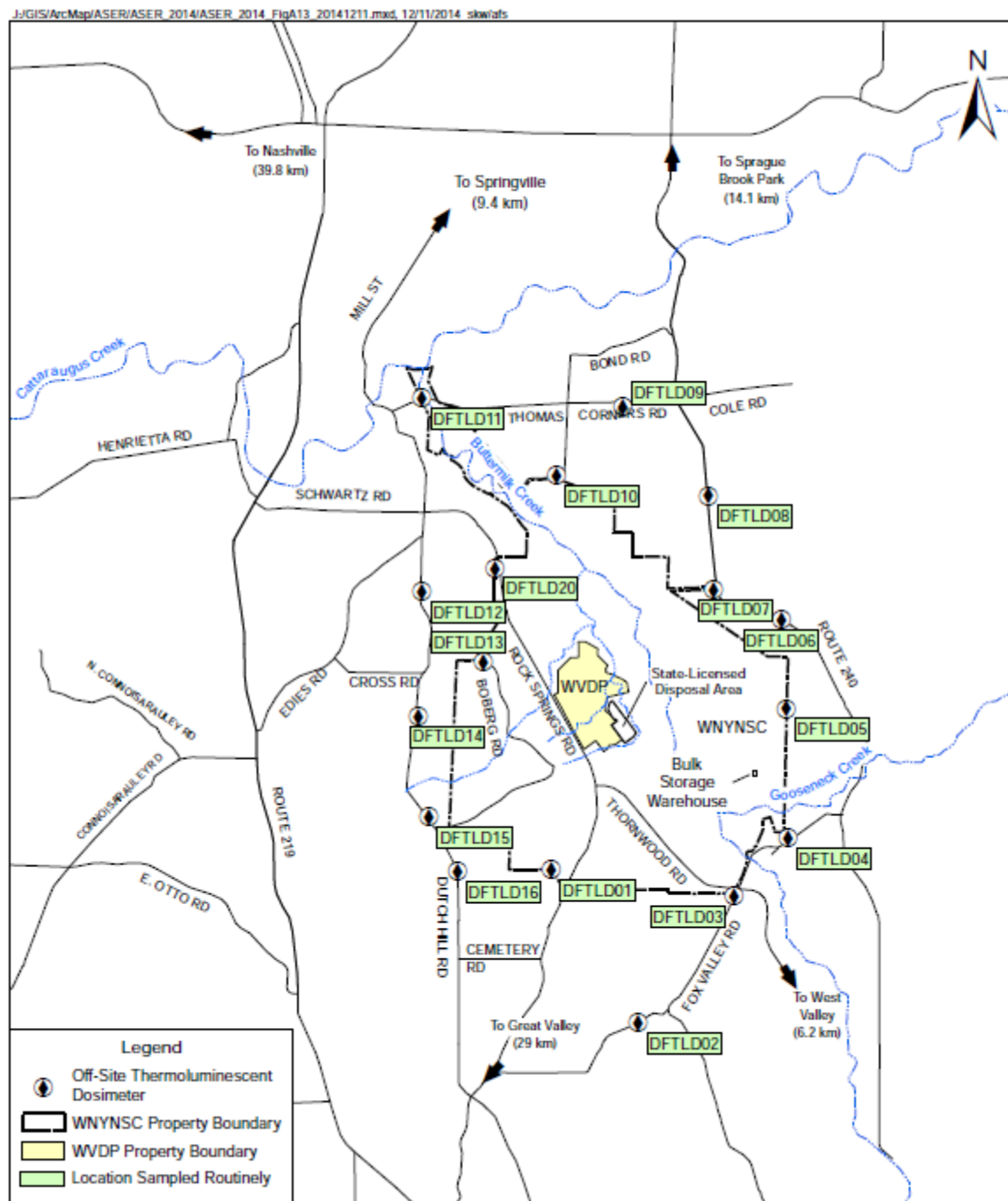


Figure 57. Off-site thermoluminescent dosimeters (TLDs) within 5 km (3.1 mi) of the Site. (Figure A-13 of DOE (2015).)

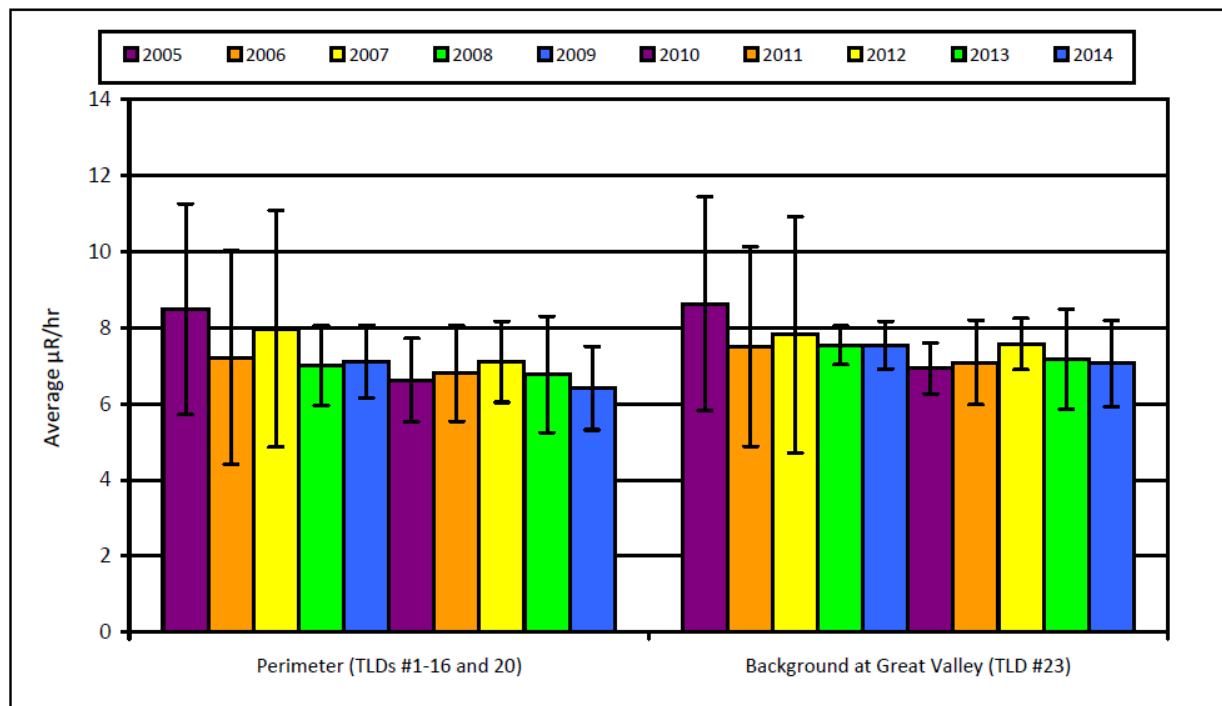


Figure 58. Ten year trends in exposure rates for the perimeter TLDs and a background TLD (#23) located approximately 30 km (18 mi) from the Site. (Figure 2-3 of DOE (2015).)

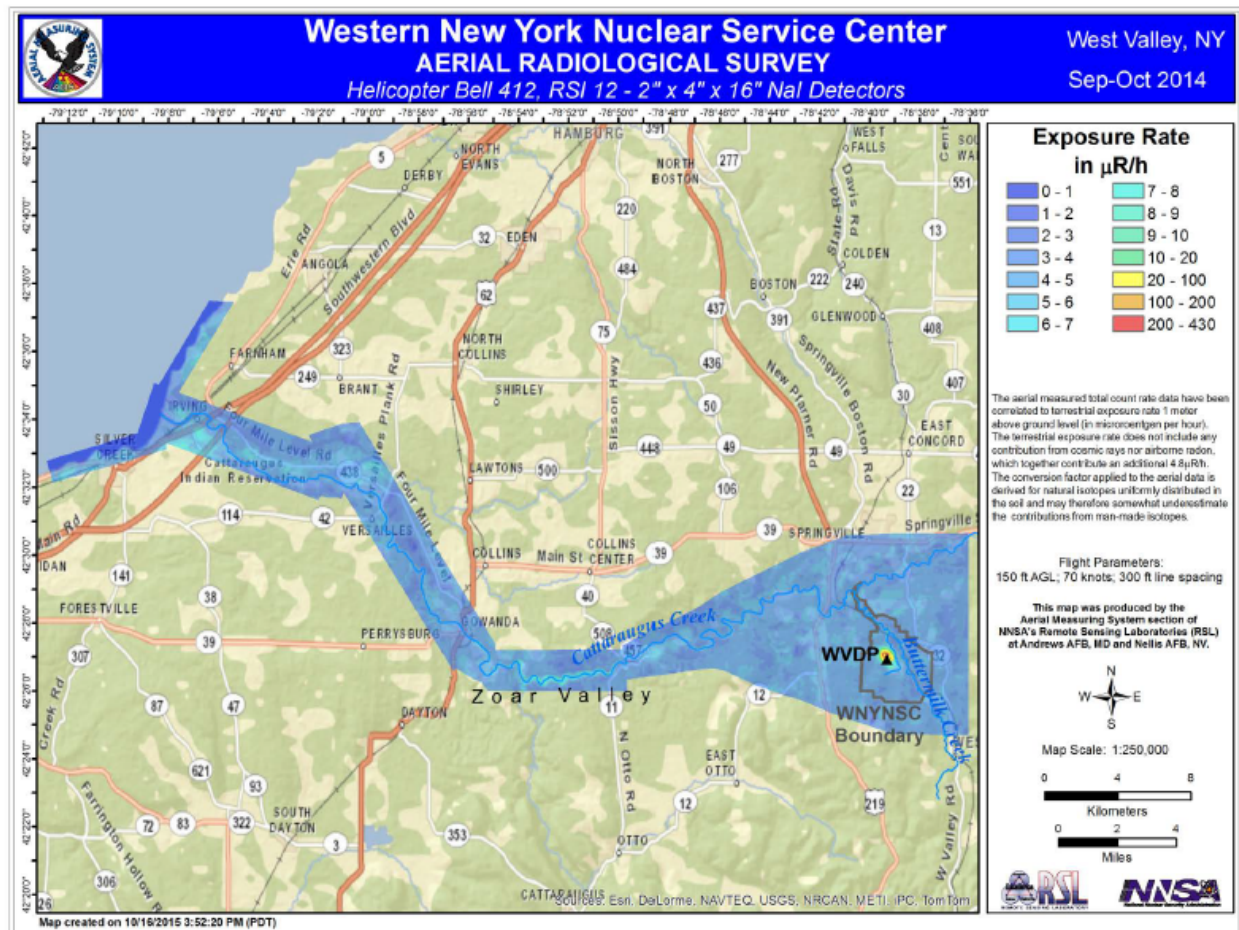


Figure 59. Inferred exposure rates ($\mu\text{R/h}$) at 1 m above ground surface over the full survey area due to terrestrial sources. (Figure 14 from NNSA (2015).)

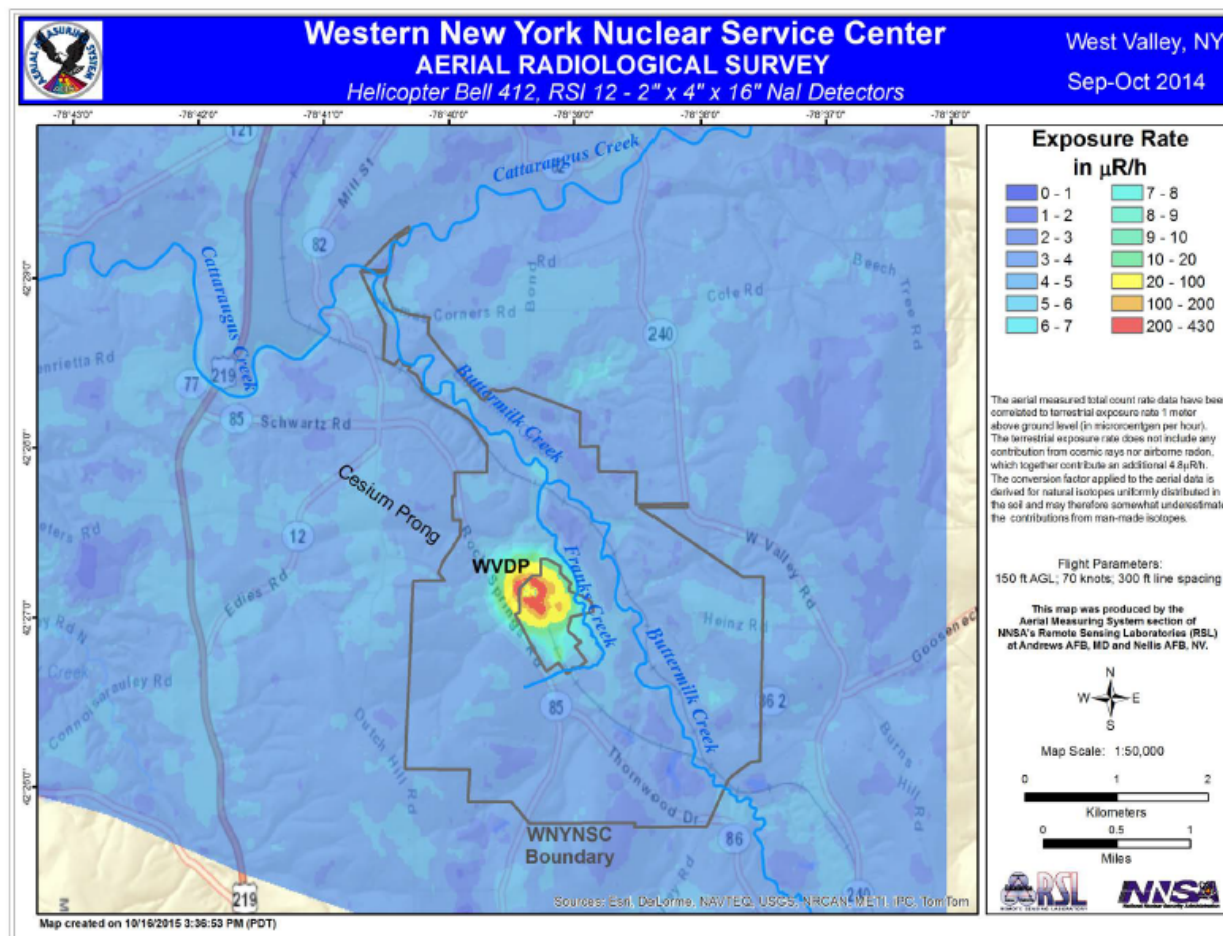


Figure 60. Inferred exposure rates ($\mu\text{R/h}$) at 1 m above ground surface in the vicinity of the WVNSC due to terrestrial sources. (Figure 15 from NNSA (2015).)

3.2.10 Climate Change

3.2.10.1 Introduction

This section examines the approach used to implement future climate in the West Valley PPA Model and in erosion studies for the West Valley Site (DOE 2010a, 2010c) with respect to the current scientific literature on climate change. The FEIS assumes current conditions for future climate but acknowledges incomplete or unavailable information with respect to incorporation of climate variability (both natural and anthropogenic) in assessment of human health impacts from release and transport of contaminants (DOE 2010a). Uncertainty for future climate is “accommodated through sensitivity analysis and more conservative erosion predictions” (p. 4-141). Non-inclusion of anthropogenic climate change is based on cited NRC guidance.

Erosion studies described in the FEIS assumed a constant climate during the calibration period, arguing that the uncertainty of *not* including climate variations is approximately equal to the uncertainty of estimating future climate impacts for rainfall statistics (DOE (2010c); p. F-23 of

Appendix F). The Channel-Hillslope Integrated Landscape Development (CHILD) erosion model uses a stochastic representation of rainfall and runoff. Rainfall was modeled in simulations through an average storm intensity, P , average fraction precipitation time F_p (between 0 and 1), and through the model time step, T_g , that was the average duration of storm and inter-storm intervals. A “wetter” climate was represented in erosion modeling by doubling the mean precipitation intensity and using a minimum calibration value for the soil infiltration capacity (DOE 2010c). Climate data were collected at a meteorological tower at the West Valley Site, operational since 1983. A baseline dataset was established from a 5-year, Site-specific dataset for the years 1998–2002 (DOE 2010a).

Definitions used in the following sections are presented in Section 3.2.10.2.1. The most recent climate literature is used to assess three topics: characteristics of interglacial intervals and climate processes associated with glacial-interglacial transitions (Section 3.2.10.3), modeling studies assessing the timing of the next glacial transition (Section 3.2.10.3.3), and a revised conceptual model for climate change at the West Valley Site (Section 3.2.10.4).

3.2.10.2 Climate Perspectives

A standard approach for climate studies of contaminated sites is to evaluate bounding or worst-case impacts of future climate states. For disposal of TRU at the Waste Isolation Pilot Plant (WIPP) in southeast New Mexico, climate change is treated as a future disruptive event. Paleoclimate data are used to establish variability in temperature and precipitation during past glacial and interglacial cycles as described by the National Research Council (1996) and Swift (1992). Climate inputs in groundwater and performance assessment models assume that variations in past precipitation and infiltration coincide with maximum advances and minimum retreats in the North American ice sheets. Future climate states are driven by Milankovitch cycles (see Section 3.2.10.2.1, Definitions) and are assumed not to exceed patterns from past glacial cycles (Swift 1992). Anthropogenic climate impacts are acknowledged but are not expected to disrupt future glacial and interglacial cycles.

Climate studies for the Yucca Mountain Project in Nevada (YMP; disposal of high-level waste) assume model simulations of future climate states are not credible given current scientific knowledge and the significant natural variability in global climate (Campbell 2004). Paleoclimate data were used in YMP climate studies to establish variability in temperature and precipitation during past climates. Modern analog climates in the U.S. were selected that match precipitation and infiltration minimums and maximums from past glacial cycles. Three future analog climates were selected (Campbell 2004; Sharpe 2003): the modern interglacial climate, a future monsoonal climate, and a future glacial transition climate.

The Intergovernmental Panel on Climate Change (IPCC) was established by the world Meteorological Organization and the United Nations Environmental Program in 1988 to assess “scientific, technical socio-economic information produced worldwide relevant to the understanding of climate change” (<https://www.ipcc.ch/organization/>). They have produced five assessment reports, with the sixth report scheduled for 2022. The second through the fifth assessment reports provide progressively stronger statements on the likelihood of anthropogenic effects on multi-decadal climate change and its role in global warming since the twentieth century (Henson 2014). The fifth assessment report concludes that a glacial inception (end of the

current interglacial conditions) is not expected within the next 50 ka (ka is one thousand years) as long as CO₂ concentrations exceed 300 parts per million (ppm) or cumulative carbon emissions exceed 1000 PgC (one trillion tonnes of carbon) (p. 435 of IPCC (2013)). Further, they conclude that atmospheric CO₂ concentrations under the lowest emission scenario will exceed 300 ppm through calendar year 3000 and it is *virtually certain* (> 99% probability) that there will not be a return to glacial conditions before the end of the next millennium.

Given the strength of the IPCC conclusions and the recognition by the majority of climate-change researchers that climate forcings from anthropogenic greenhouse gases (GHG) will profoundly impact future global climate states, it is imperative that climate change studies for contaminant waste disposal be upgraded for consistency with the current climate literature.

3.2.10.2.1 Definitions

The IPCC definition of *global climate change* is “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.” Climate change may be due to “natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use” (IPCC 2013). The phrase “global climate change” is used to identify changes that occur on a global scale versus regional or local changes. Multiple modeling studies have shown that observed changes in the energy balance of the earth since the mid-twentieth century cannot be reproduced solely by internal climate variability (< 5% probability); anthropogenic contributions must be included to match observations (for example, Huber and Knutti (2012) and Huber and Knutti (2014)).

Global warming is a subset of multiple changes associated with global climate change. The definition of *abrupt climate change* is from the National Research Council report (National Research Council 2002) and includes both abrupt climate change and abrupt climate impacts. Abrupt climate change occurs when some part of the climate system (regional, continental, or global) passes a threshold or tipping point resulting in rapid change that lasts decades or longer. Abrupt climate change can include abrupt changes in the physical climate system or abrupt climate impacts in the physical, biological, or human systems triggered by a gradually changing climate.

Milankovitch cycles include any of three cyclic variations in the orbit of the Earth around the Sun, including the obliquity of its axis, the precision of the equinoxes, and the eccentricity of its orbit.

Glacial and Interglacial cycles refer to phases in Earth’s history, particularly during the Pliocene and Quaternary, marked by large variations in the continental and sea ice volume and global sea level (IPCC 2013). A *glacial period* or *ice age* refers to intervals characterized by long-term reduction in global temperature, reduction in atmospheric CO₂, and growth of ice sheets and glaciers resulting in falling sea levels. Glacial periods tend to be longer (approximately 100,000 yr) than interglacial periods (approximately 10,000 to 20,000 yr), which are warmer periods between glacials with sea levels close to current sea levels.

3.2.10.3 Glacial and Interglacial Cycles

Global paleoclimate data show that the Earth, throughout geologic time, has had two fundamental climate states: 1) a cool or “icehouse” state characterized by bipolar glaciation and waxing and waning of continental ice sheets in the high latitudes of the Northern Hemisphere, and 2) a “greenhouse” state characterized by warm temperatures on a global scale with limited or no ice sheets (National Academy of Sciences 2011). Figure 61 shows reconstructed global surface temperatures for the Cenozoic Era (last 65 Ma), with a systematic decline in temperature from the Paleocene-Eocene Thermal Maximum ~50 Ma until the cyclic glacial and interglacial intervals of the Quaternary (Pliocene and Pleistocene). Notable features include:

- the Paleocene-Eocene Thermal Maximum, the last major greenhouse global climate state,
- gradual decline in the CO₂ content of the atmosphere that coincides with decreasing global surface temperatures for the last 50 Ma,
- development and persistence of Antarctic ice sheets starting in the Late Eocene-Early Oligocene, and
- development of Northern Hemisphere ice sheets in the Late Miocene-Pliocene.

The causes of the long Cenozoic cooling trend are multiple and are topics of continuing debate; for example, see Allen and Armstrong (2008), Pagani et al. (2005), Livermore et al. (2007), and De Boer et al. (2010). The Plio-Pleistocene climate record includes two additional patterns: the onset of cyclical glacial and interglacial intervals in the Northern Hemisphere at about 2.7 Ma (asymmetrical sawtooth cycles) and a transition in the periodicity of glacial cycles from 41 ka to 100 ka in the Middle-Pleistocene (Lisiecki and Raymo (2005); see Figure 62). Note the progressive cooling trend, the increased amplitude of the cyclical patterns, and the transition from the 41 ka to 100 ka glacial cycles since the onset of Northern Hemisphere glaciation at 2.7 Ma. Climate investigations continue to seek unifying explanations for these patterns. The latter change was also accompanied by increased severity and duration of cold glacial states and increased global ice volume (Head and Gibbard 2005).

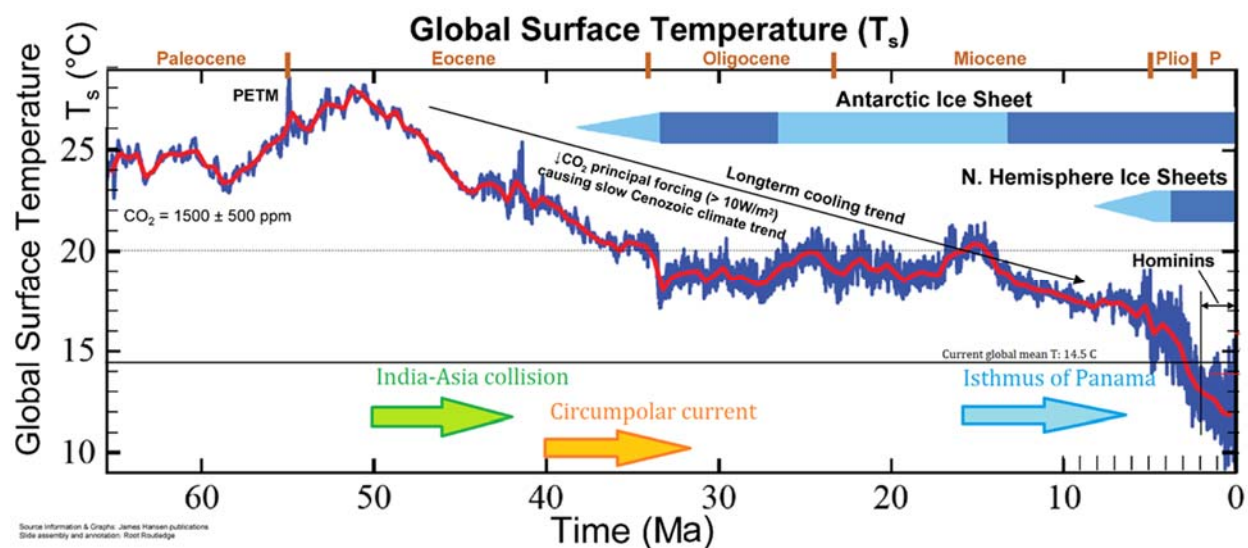


Figure 61. Global surface temperature for the Cenozoic era. (Figure from Steven Earle (<https://opentextbc.ca/geology/chapter/16-1-glacial-periods-in-earths-history/>).)

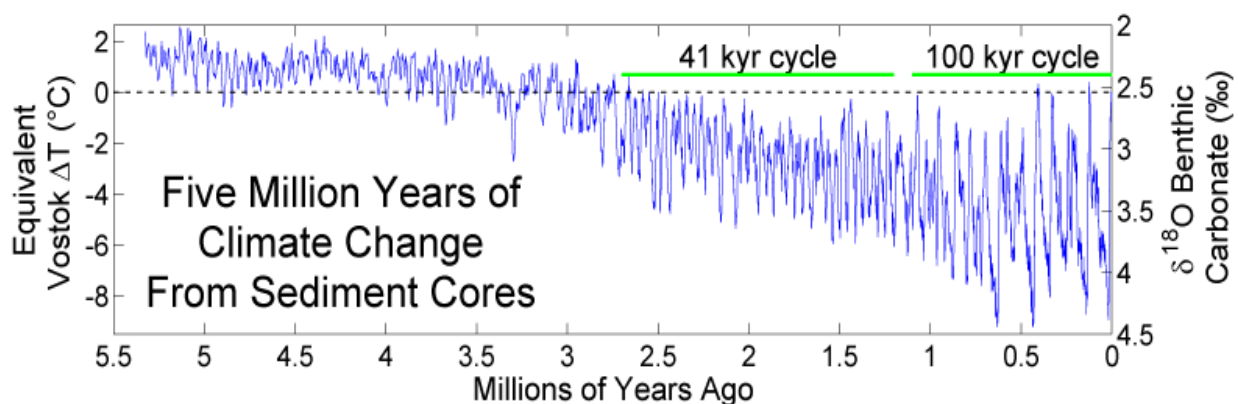


Figure 62. Plot of ΔT and $\delta^{18}O$ for the last 5.3 million yr. (Plot from the glacial cycle discussion of the Azimuth Project (<http://www.azimuthproject.org/azimuth/show/Glacial+cycle>) using the benthic $\delta^{18}O$ data from Lisiecki and Raymo (2005).)

3.2.10.3.1 Interglacial Intervals

On a large scale, the glacial and interglacial cycles are mostly explained by the progression of Milankovitch orbital parameters. There is a consensus that the initiation of interglacial cycles tends to be associated with maximum summer (June) insolation (incoming solar radiation) in the higher latitudes of the Northern Hemisphere (Masson-Delmotte et al. 2013). However, the global energy budget of orbital variations is insufficient to fully drive the documented large magnitude changes in glacial cycles or to cause the observed rapid climate transitions (Sigman and Boyle 2000).

The timing and characteristics of short duration climate variations during interglacial cycles remain difficult to explain (Crucifix 2011, 2013). This is attributed to three problems. First, the onset and terminations of interglacial cycles are difficult to define. Interglacials are typically identified by significant temporal changes in global temperature, sea level, atmospheric CO₂, and ice volume. All of these climate parameters show significant decadal, centennial, and millennial variations that are difficult to resolve using paleoclimate data. Second, the chronology of glacial events is more difficult to refine with increasing age. Govin et al. (2015) evaluate the limitations in chronology data used for paleoclimate studies for the Last Interglacial (Marine Isotope Stage (MIS) 5e). They note that limitations in correlating regional versus global paleoclimate records complicate interpretations of climate data and applications in climate model simulations. Third, recent data reveal the complexity of global climate patterns during glacial-interglacial transitions (Shakun et al. 2012). Paleoclimate proxy data must be integrated for both the Northern and Southern Hemispheres. Temperature and CO₂ variations in both hemispheres are strongly affected by the strength of the Atlantic meridional overturning circulation (AMOC) (Shakun et al. 2012). Ganopolski and Roche (2009) argue that temporal analysis of leads and lags in climate parameters cannot be used to infer causative relationships in climate without a global scale understanding of climate processes. They note that local ice core data can contradict global CO₂ and temperature variations.

Tzedakis et al. (2012a) and Tzedakis et al. (2012b) attempted to compile data on the length of interglacial cycles during the Quaternary by examining patterns of sea-level changes. However, defining sea-level highs in paleoclimate data on a global scale can be difficult. Instead, they use the interval between early and late oscillations of the bipolar seesaw (out of phase temperatures in the North Atlantic and South Atlantic oceans) to define the boundaries of past interglacials. They note that the onset of interglacials occurs within 2 ka of a summer insolation maximum and precession minimum; glacial inception always takes place when obliquity is decreasing and never after the obliquity minimum.

Tzedakis et al. (2012b) recognize two patterns of interglacial durations—shorter (~13 ka) and longer (~28 ka; see Figure 63). They suggest that the current interglacial should be categorized with the short-duration interglacials if the effects of greenhouse gases are ignored. Using this assumption, the current interglacial (~12 ka) should be near its end.

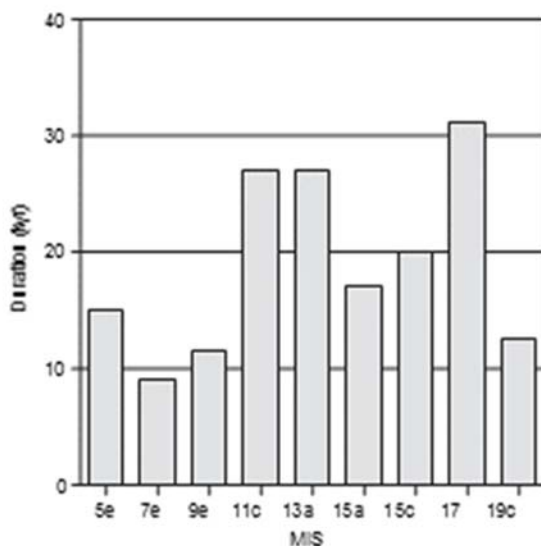


Figure 63. Diagram of the interglacial duration during glacial cycles for the last 800 ka. (From Tzedakis et al. (2012b), their Figure 8.) Duration is in thousands of yr and MIS is the marine isotope stages.

3.2.10.3.2 Atmospheric CO₂ Variations with Glacial Cycles

Ice core studies show cyclic variations in atmospheric CO₂ during glacial and interglacial intervals (Sigman and Boyle (2000); see Figure 64). This CO₂ record is based on Vostok ice core studies in Antarctica. The δD (‰) is the ratio of deuterium to hydrogen in ice and is a proxy for air temperature where negative values correlate with decreased temperatures. Ice volume is based on oxygen isotope data for benthic foraminifera from ocean sediment cores. Atmospheric concentration of CO₂ is typically near 280 ppm during interglacial periods and about 180 to 200 ppm during glacial intervals. A consensus has not been achieved on the mechanisms controlling the cyclic variations in atmospheric CO₂. Sigman and Boyle (2000) summarized explanations for the CO₂ variability based on sequestration of carbon in the ocean by the sinking of organic carbon at the surface of the ocean and burial in marine sediments (biological pump). They examined two mechanisms to explain the variations in atmospheric CO₂ with glacial cycles: 1) larger reservoirs of algal nutrients during glacial times increasing the biological pump at low latitudes, and 2) increased utilization of algal nutrients at high latitudes during glacial times.

Schmitt et al. (2012) obtained high-resolution stable carbon isotope ratios of atmospheric CO₂ ($\delta^{13}C_{atm}$) for Antarctic ice cores from locations using three independent analytical methods at two laboratories. They suggest that a decrease in $\delta^{13}C_{atm}$ during the last deglaciation can be explained by upwelling of deep carbon enriched waters in the Southern Ocean driven by changes in sea surface temperature and ocean circulation. Anderson et al. (2009) argue that wind-driven upwelling in the ocean around Antarctica regulates the exchange of CO₂ between the deep sea and the atmosphere. They note two intervals of increased upwelling that coincide with intervals of rising atmospheric CO₂ during the Late Pleistocene deglaciation.

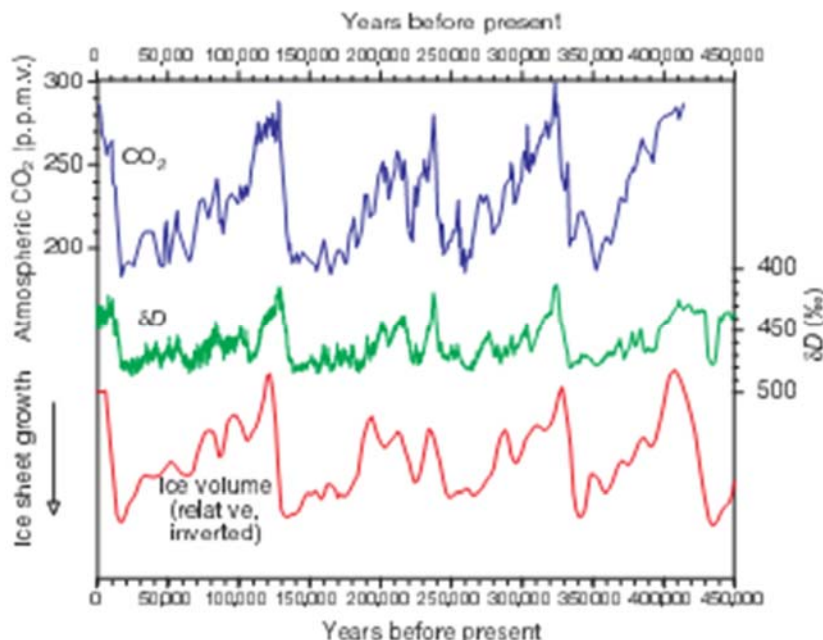


Figure 64. Atmospheric CO₂ for the last 420 ka. (Figure 1 from Sigman and Boyle (2000).)

There are multiple remaining challenges regarding the reliability of attempts to match paleoclimate data and model simulations to the detailed climate variations observed in glacial cycles. These challenges limit confidence in attempts to predict future climate conditions. Some of the major issues include:

- The glacial and interglacial intervals follow asymmetric sawtooth patterns with longer glaciations and shorter interglacials. These patterns are not easily reproduced in modeling studies without adding additional internal climate forcing components (Cane et al. 2006; Sigman and Boyle 2000). Crucifix (2013) argues that many of the problems explaining the stability patterns of glacial cycles arise from attempts to apply statistical inferences to dynamical climate systems that are hampered by sparse data sets with large interpretative and chronological uncertainties.
- Lisiecki (2010) uses statistical analyses (cross-wavelet analysis) of insolation and climate over the last 5 Ma to evaluate the linkage between orbital eccentricity and the 100 ka glacial cycles. The author argues that eccentricity is unlikely to force 100 ka glacial cycles directly and that, instead, cyclic patterns probably result from internal feedbacks of the climate system that are phase locked to eccentricity.
- Modeling studies of glacial inception (Calov et al. 2005) show that the models must integrate all major components of a climate system as well as nonlinear feedbacks between components. Climate models require amplifying feedbacks in combination with insolation forcing to trigger glacial-interglacial transitions (Archer and Ganopolski 2005).
- Paleoclimate data show that global changes during the last glacial transition were complex and involved dynamic and non-linear processes operating across both hemispheres (Shakun et al. 2012). Orbital changes must be coupled to other dynamic processes, particularly snow-albedo feedbacks and atmospheric CO₂ contents, as well as other processes (variations in the AMOC, vegetation changes with feedbacks, carbon variations in the ocean and atmosphere).

3.2.10.3.3 Climate Models and Glacial-Interglacial Transitions

The series of reports by the IPCC continually updates the knowledge state of climate studies, including the use of modeling (IPCC 2013); the most current assessments of climate models are in Chapter 9, *Evaluation of Climate Models* (Flato et al. 2013). Climate models are divided into two general categories depending partly on their intended use. Coupled atmosphere-ocean General Circulation Models (GCMs) are the standard models. They tend to be high-resolution process-based models used for simulating seasonal to decadal variations in climate systems. Earth System Models (ESMs) have become the state-of-the-art models that expand on GCMs by adding numerical representation of feedbacks for biological and geochemical systems. Earth System Models of Intermediate Complexity (EMICs) are a subset of ESMs that include multiple components of ESMs, but at higher levels (top-down) or lower resolutions. These simplified models allow simulations on millennial time scales with exploration of sensitivities of model components using ensemble and/or Monte Carlo simulation methods. The main features of the three different model types are summarized in Tables 9.1 and 9.2 of Flato et al. (2013). The EMICs have been used more extensively in evaluations of glacial-interglacial transitions and/or long-term projection of future climate states.

Climate studies with both GCMs and EMICs have evolved dramatically over the last decade with sequential modeling studies building on the progress of past modeling studies. Mysak (2008) and Cane et al. (2006) reviewed progress in model simulations of the last glacial inception. Early simulations used GCMs that incorporated seasonal atmospheric variations coupled with Northern Hemisphere insolation and atmospheric CO₂ from paleoclimate records. The models failed to produce snow and ice build-up in the Northern Hemisphere, leading to the recognition that amplifying feedbacks were needed (for example, vegetation, sea ice, and polar surface energy balance). Subsequent GCM modeling used ocean feedback to increase polar moisture and snow buildup in the northern latitudes. However, the models could not sustain ice buildup over thousands of years.

Four- and five-component EMICs were developed and coupled to ice sheet models, including a zonally latitude-depth dependent model for the thermohaline circulation of the ocean. These models allow climate simulations over time periods of glacial transitions that were not possible with GCM models (Cane et al. 2006). Simulations with multicomponent EMICs produced buildup of Northern Hemisphere ice sheets and also showed intensified thermohaline circulation during ice buildup. Some EMIC models also incorporated dynamic vegetation components. These models show that vegetation changes over North America amplify insolation cooling and initial ice sheet buildup. The model simulations do not show similar processes over Eurasia because of warmer initial conditions and differences in vegetation patterns (Mysak 2008). Mysak (2008) concludes that, during a glacial inception, multiple feedbacks influence build-up of large ice sheets including ice-albedo, vegetation-albedo, and elevation cooling effects. Cane et al. (2006) note the important role of hydrological-cycle changes during glacial-interglacial cycles. Northward moisture transport amplifies high-latitude cooling and ice accumulation through complex feedbacks involving sea ice, oceans, and atmosphere moisture.

Timing of the Next Glacial Inception

Mysak (2008) surveyed climate literature on the timing of the next glacial inception and concluded that the present interglacial could last longer than 100 ka, as long as CO₂ concentrations remain above pre-industrial levels.

Archer and Ganopolski (2005) used the CLIMBER-2 EMIC coupled with the SICOPOLIS ice sheet model to simulate the past five glacial cycles. They evaluated the stability of the climate-cryospace system under orbital and CO₂ atmosphere forcings and explored a threshold curve in the Northern Hemisphere insolation values as a function of CO₂. The rate of ice growth in the Northern Hemisphere in the CLIMBER-2 model depends both on the duration of an insolation minimum and on how far the minimum falls below the threshold curve. When the baseline CO₂ is raised, a deeper minimum in summertime insolation is required to initiate ice growth. Archer and Ganopolski (2005) note that the Earth's orbit is entering a period of low eccentricity with low variability in the summer insolation. An assumed release of 1000 Gt (gigaton) of carbon (or GtC) during the 21st century would prevent a new cycle of glaciation until 130 ka from the present.

Ganopolski et al. (2016) updated the critical insolation-CO₂ relationships for assessing future glacial inceptions. They compared earth orbital configurations for the present interglacial (MIS 1) with other interglacial intervals that transitioned to glacial intervals (MIS 11 and MIS 19). The CO₂ concentrations for MIS 11 and MIS 1 are about the same (approximately 280 ppm pre-industrial era for MIS 1) but are lower for MIS 19 (approximately 250 ppm). The CLIMBER-2 EMIC model with the SICOPOLIS ice sheet model was again used to run multiple model simulations exploring orbital configurations and CO₂ concentrations for the three interglacial intervals. Simulations were screened consistent with the observation that MIS 11 and MIS 9 transitioned to a glacial interval (simulations with at least an ice-buildup equivalent to a 5 m decrease in sea level were included), and MIS 1 has not transitioned (simulations with more than a 1 m equivalent of ice-volume change were not included). Four realizations passed their screening constraints. At 280 ppm none of the screened model versions simulate significant ice sheet growth within the next few thousands of years. At 240 ppm of CO₂, all four model realizations simulate rapid ice growth within several thousand years. Ganopolski et al. (2016) speculate that the earth may have escaped a Holocene glacial inception with only a 40 ppm difference in initial CO₂ contents.

Ganopolski et al. (2016) explored the threshold values of CO₂ levels versus the maximum summer insolation at 65 degrees North, expanding the initial work by Archer and Ganopolski (2005). Points in insolation-CO₂ space are clustered along a logarithmic curve consistent with radiative forcing of CO₂ being proportional to the logarithm of CO₂ concentration and a linear temperature response within the range of the modeled CO₂ concentrations (Figure 65a). This shows the best-fit logarithmic relation between maximum summer insolation at 65 degrees N and the CO₂ threshold for glacial inception. Blue and red dots are the coldest and warmest model version in the CLIMBER-2 simulation runs used to explore the threshold relationship. The shaded area is one standard deviation of the threshold curve.

Past glacial inceptions all plot below the critical insolation-CO₂ line (Figure 65b). This shows the location of the Quaternary glacial inceptions (MIS numbers) for the best-fit curve from Figure

65a. Glacial inception in the model simulations is only possible below the insolation- CO_2 curve. The current interglacial (MIS 1) plots above the insolation curve at the pre-industrial CO_2 value of 280 ppm. The Holocene interglacial (MIS 1) plots above the threshold value using the pre-industrial CO_2 content of 280 ppm. Ganopolski et al. (2016) conclude that the current Holocene interglacial has no analog within past interglacials for the last 1 Ma. They simulated the onset of a new glaciation by running the four screened model realizations for 100 ka (after present) using different carbon emission scenarios. For a 1,000 Gt carbon scenario projected in 2100, the model simulations show that a glacial inception is impossible over a time period comparable to the duration of previous glacial cycles, approximately 100 ka (Ganopolski et al. (2016); p. 203).

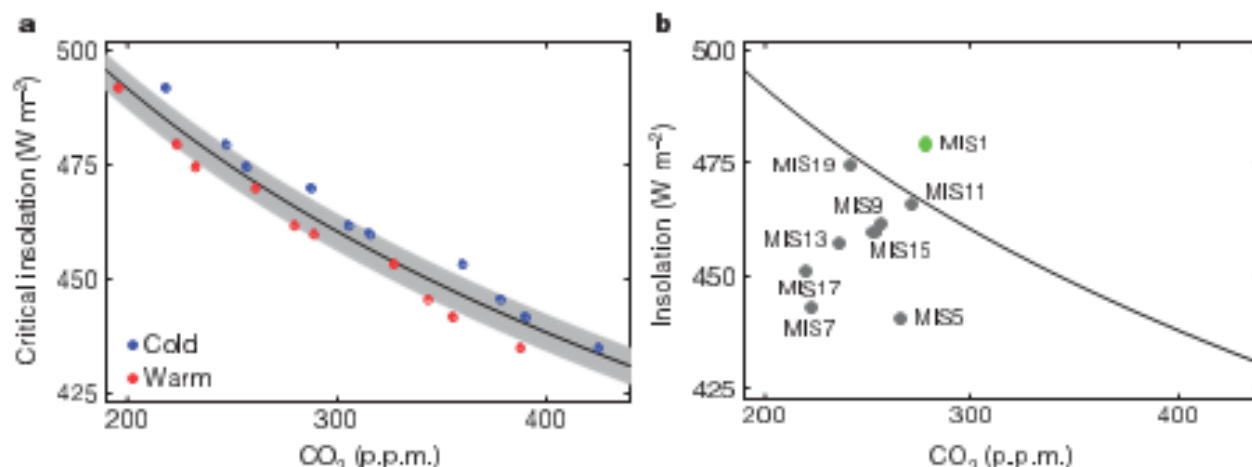


Figure 65. Relationships of CO_2 concentrations and (a) insolation (Figure 3 from Ganopolski et al. (2016)) and (b) location of the Quaternary glacial inceptions (MIS numbers) (Figure 3 from Ganopolski et al. (2016)).

3.2.10.4 Conceptual Model for Future Climate Change at the West Valley Site

Integration of paleoclimate studies, climate modeling studies, and the combined effects of Milankovitch cycles and interacting climate processes that respond to orbital forcing provide a foundation for forecasting future climate at the West Valley Site. Figure 65b illustrates an important breakthrough in understanding the relationship between insolation and atmospheric CO_2 contents. Past glacial-interglacial transitions show systematic relationships in insolation- CO_2 phase space and strongly support the temporal persistence of the current interglacial interval (MIS 1). The impact of atmospheric CO_2 is profound when dynamically linked to other climate components. Figure 66 is a plot of the most recent data for mean atmospheric CO_2 measured at the Mauna Loa Observatory in Hawaii. The dashed red line is the monthly mean values centered on the middle of each month; the black line is the same data corrected for the average seasonal cycles. The last year of data are preliminary and have not been calibrated for reference gases and quality control. Current atmospheric CO_2 contents (> 400 ppm) exceed concentrations measured in ice cores for the last 800 ka (IPCC 2013). Estimated CO_2 concentrations for the next century will exceed the highest estimated CO_2 concentrations in the last 30 Ma of the Earth's history (National Academy of Sciences 2011).

More recent research has provided a much improved understanding of the longevity of CO₂ in the atmosphere (Archer and Brovkin 2008; Clark et al. 2016). Twenty to fifty percent of the anthropogenic CO₂ released within the next 100 yr will remain in the atmosphere after 1000 yr, and a return to pre-industrial CO₂ concentrations may require hundreds of thousands of yr (Clark et al. 2016). Given the current high atmospheric CO₂ contents and the long-term persistence of CO₂, the most likely scenario for the future climate at the West Valley Site is the continuation of the current interglacial climate under conditions of variable but progressive global warming.

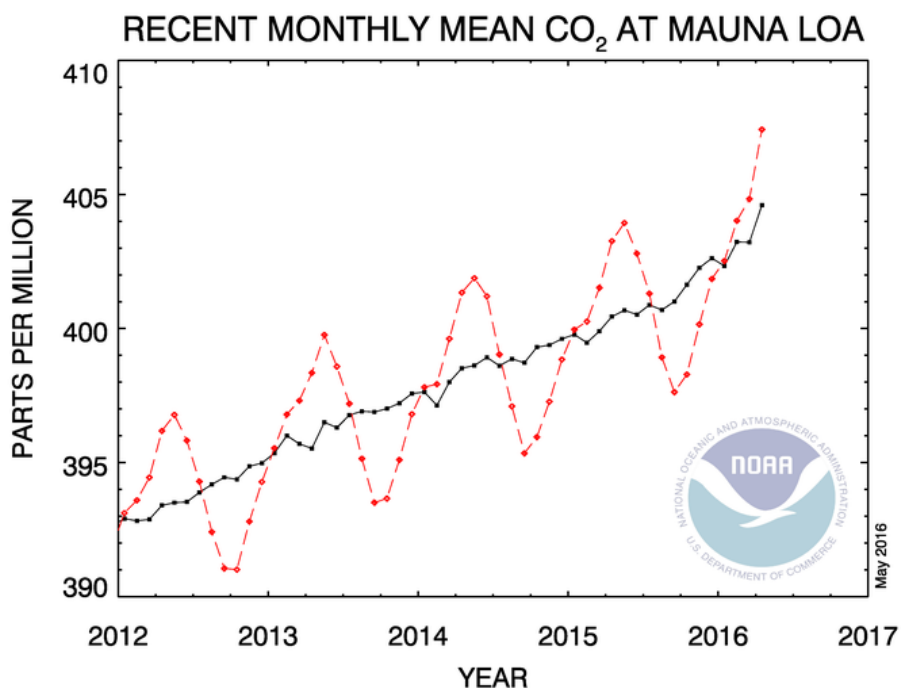


Figure 66. The monthly average mean CO₂ at the Mauna Loa Observatory, Hawaii
(<http://www.esrl.noaa.gov/gmd/ccgg/trends/> accessed June 2016).

Important highlights of the IPCC (2013) report of changing patterns in the climate system include:

- Annual mean surface warming since the 20th century has reversed long-term cooling trends of the past 5 ka.
- Global circulation features have migrated poleward since the 1970s, including a poleward shifting of storm tracks, jet streams, and contraction of the northern polar vortex.
- Arctic sea ice extent has decreased over the period 1972–2012, and glacier length, area, volume, and mass are shrinking on a world-wide basis.
- The number of cold days and nights has decreased and the number of warm days and nights has increased on a global scale between 1951 and 2010.
- The frequency and intensity of maximum precipitation events has likely increased despite significant seasonal and regional variability.

Brown et al. (2010) show strong warming of the northeastern U.S. for the period 1870–2005, with increases in the frequency of warm events and decreases in the frequency of cold events. Maximum temperature indices show strong warming over much of the period, but limited changes and possible cooling since 1950. Precipitation trends are less clear but they show a tendency toward wetter conditions. Hayhoe et al. (2006) and Huntington et al. (2009) examined past and future changes in key climate, hydrological, and biophysical indicators for the northeast U.S. They used multiple global climate models to forward project 20th century climate data. Patterns in future climate are variable and dependent on emission scenarios but generally show increases in high spring streamflow, decreases in snow depth, and extended growing seasons. Model results show consistent increases in temperature and precipitation across the northeast U.S. over the next century.

The issue of abrupt climate change (see Section 3.2.10.2.1 for definitions) has been summarized in recent reports (IPCC 2013; National Academy of Sciences 2013; National Research Council 2002; USGS 2008). Major topics of interest to climate studies at the West Valley Site include changes in the AMOC, variations in sea ice (particularly the ocean warming and decline in the volumes of sea ice in the Arctic), changes in atmospheric circulation, systematic changes in weather and climate extremes, abrupt changes in ecosystems, and widespread changes to the hydrologic cycle.

The AMOC strongly affects the transport of cold, deep waters toward the equator and the poleward flux of warm, near-surface waters. The stability of the AMOC and its role in climate transitions are important topics of ongoing discussion (for example, Lozier (2012)). The National Academy of Sciences (2013) summarized data supporting stability of the AMOC during at least the next century based on modeling of the current system. There is, however, controversy over the seasonal and inter-annual variability of the AMOC compared to variations observed in climate models (Rayner et al. 2011; Srokosz and Bryden 2015). Monitoring of variations in the strength and stability of the AMOC, and evaluations of potential climate impacts on the northeast seacoast including the West Valley Site, should be an ongoing part of Site studies. Arctic amplification—the enhanced warming in high northern latitudes relative to the Northern Hemisphere—could cause weather patterns in mid-latitudes to be more persistent (Francis and Vavrus 2012). They suggest these effects are one of the causes of model projections of increased

frequency and intensity of extreme weather from the global increase in GHG (for example, record-breaking rains in the northeast U.S. during the summer of 2011; Francis and Vavrus (2012), p. 5).

A climate change workshop was convened for Phase 1 Studies of the West Valley Demonstration Project in 2012 (ECS 2012a). These studies impact future climate inputs for forecasts of human health and safety and erosion studies for the West Valley Site. Key observations from this workshop include:

- Presentation by Vasilii Peetrenko, Earth and Environmental Sciences at the University of Rochester, New York:
 - A transition from the current interglacial climate to a future glacial state is extremely unlikely to occur in the next 100 ka.
 - Abrupt climate events associated with the last glacial maximum are unlikely today.
 - Analog climates to the current interglacial cycle include the previous warm interglacial (MIS 5) and the Paleocene-Eocene Thermal Maximum.
- Presentation by Xuebin Zhang, Climate Research Division, Environment Canada:
 - Warming of the climate system is unequivocal.
 - Changes associated with warming include increase in precipitation in the high latitudes, increase in atmospheric moisture, decrease in coldest temperature, and increase in hottest temperature.
 - Science data support the conclusion that the dominant cause of climate change over the last half century is the increase in anthropogenic GHG.
- Presentation by Kenneth E. Kunkel, Department of Marine Earth and Atmospheric Science, North Carolina State University:
 - Probable Maximum Precipitation (PMP) is a forecast of the greatest amount of rain that can fall at a specific location.
 - Methods for estimation PMP have not changed over the last 30 to 40 yr.
 - PMP values can be expected to change because of potential changes in atmospheric water vapor associated with global warming.
 - Observed difference in extreme event precipitation (+ 4.7 mm) for the northeast U.S. (calendar yr 1982 to 2009 versus 1961 to 1981).
- Presentation by Art DeGaetano, Department of Earth and Atmospheric Science, Cornell University, New York:
 - An increase in heavy rainfall for the northeast U.S. over the last 50 yr.
 - Storm data for the northeast U.S. show that the 100-year storm is now expected to occur every 66 yr. There is a similar decrease in the return frequency of the 50-year and 2-year storms.
 - Intensity of rainfall determines the magnitude of storm runoff and the daily total rainfall; climate models show that daily rainfall will continue to become more intense in the future.

3.2.10.5 Conclusions of the Climate Section of the CSM

Based on the climate research and analysis presented above, the following relevant conclusions are drawn for the CSM:

- Assumptions of continuous future climate conditions in the FEIS based on Site meteorological data are not consistent with current understanding of global and regional climate patterns.
- The most likely future climate state at the West Valley Site is the continuation of the current interglacial climate accompanied by persistent but variable global warming.
- Global warming is likely to increase atmospheric moisture and to increase storm frequency and intensity. These changes require modification of the climate parameters used in erosion studies (for example, estimates of Probable Maximum Precipitation).
- Continuing global warming may additionally affect the strength and stability of the AMOC and storm patterns affected by processes of arctic amplification. Future climate studies involving the latter topics should be monitored for impacts on the West Valley Site.
- Climate assumptions and approaches need to be updated for human health assessments and for erosion studies presented in the FEIS (DOE (2010a) and DOE (2010c); Appendices F and G).

3.3 Radioactive Contamination

Many forms of radioactive contamination are present at the West Valley Site, ranging from disposed spent nuclear fuel in the NDA to unintended releases of ⁹⁰Sr in the North Plateau groundwater plume to suspected but unconfirmed near-surface contamination along the Rail Spur. These are discussed below in terms of intentional disposals and other contamination.

Several other discrete facilities, as listed in the table of modeled facilities later in this CSM (Table 10), have reports assessing their inventories based on disposal records (WVNS 1994b, 1995a, 1996b, 1997; WVNS and Dames & Moore 1996a, 1996b, 1997a, 1997b, 1997c, 1997d). A significant campaign was also executed in 1996 to characterize soil contamination across the Site (WVNS 1996c).

3.3.1 Radioactive Waste Disposal and Storage

Solid and liquid radioactive waste was disposed of in the SDA and NDA and liquid HLW stored in the WTF (Sections 3.1.1.2 and 3.1.1.3). The inventories of these facilities are documented for the SDA (URS 2002a; Wild 2002), the NDA (URS 2000), and the WTF (WVNS 2005).

ECS (2016a) contains 31 tables of radionuclide inventories for the SDA and NDA, reported variously in units of activity or mass. These tables list 44 specific radionuclides, as well as categories of “mixed fission products” (MFPs), “fission products,” “actinides,” “activation products,” “material unaccounted for” (MUF), “byproduct materials” (BPM), “special nuclear materials” (SNM), “source material” (SM), “total U, Pu, and Th,” “thorium,” “total Pu,” “total U,” “natural uranium,” and mixed and miscellaneous materials. None of these is radionuclide-

specific, so each must be converted into collections of specific radionuclides, with uncertainty accounted for.

3.3.2 Other Radioactive Contamination

Several other sources of radioactive contamination are present at the Site. Perhaps the most significant of these in terms of potential future risk is the WTF. The inventory of the WTF is examined in ECS (2016a); it is presented in a collection of 12 tables. The WTF inventory tables provide estimates of total activity for various tank contents for about two dozen radionuclides, but include neither progeny nor the fission product radionuclides that would be expected. For example, Table C-8 in Appendix C of DOE (2010c) contains the footnote, “Activity excludes progeny,” and is prefaced by the comment, “Data are presented in this appendix for radionuclides identified for detailed analysis rather than for all radionuclides that may be present on the site.”

The North Plateau Groundwater Plume consists of a plume of ^{90}Sr emanating from the former MPPB area (WVES 2009b). The plume is discussed in greater detail in Section 3.2.8.3.

Other sources of radioactive contamination from facilities that were not intended to be disposal units are discussed in Section 5.1. These include nearly three dozen separate facilities, many of which are discussed in Appendix C of DOE (2010c). However, many of these facilities will be removed during Phase 1 decommissioning and thus will be considered only as sources of residual contamination. In many cases, the identification of contamination reported in Appendix C is limited to vague statements such as, “[t]he New Interceptors are radiologically contaminated” or “[a]n order-of-magnitude estimate of the residual radioactivity in a removed pump in 1998 was approximately 220 curies.”

For all of these facilities that are not disposal units, inventories will be developed for the West Valley PPA Model from original data, where available.

3.3.3 Decay and Ingrowth of Radionuclides

All radionuclides decay to other nuclides. Some progeny may be stable, as in the case of ^3H decaying to He, or ^{14}C decaying to N. In these cases, there is no ingrowth of radioactivity. Most of the radionuclides present in contamination at the Site, however, decay to other radionuclides, which may or may not present greater risks than their parents. A classic example of this process is the decay chain from ^{238}U , which by itself presents a greater health risk as a toxic metal than as a radionuclide. The progeny from the decay of ^{238}U contain the risk as providers of dose.

As mentioned above, the documentation of radionuclides present in the Site inventory does not include all radioactive progeny. The development of a complete list of progeny from the decay and ingrowth of parents is part of model development. The decay chain for ^{238}U is provided as an example in Figure 67. This is the complete decay chain for ^{238}U , showing all 19 radioactive progeny, including the decay modes and the branching fractions for each decay transition.

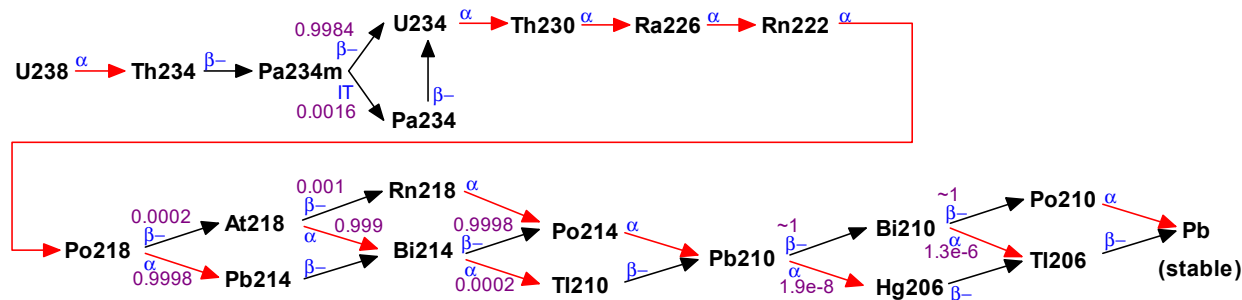


Figure 67. Decay chain for ^{238}U , showing decay modes and branching fractions.

Decay modes are shown in the blue text, with alpha (α), beta (β^-), and isomeric transition (IT) represented. Other modes such as electron capture occur in other decay chains. The branching fractions are shown in purple text unless they are equal to 1. For example, all ^{238}U decays by emission of an alpha particle (a He nucleus, with two protons and two neutrons) to ^{234}Th , so the branching fraction is 1. All ^{234}Th in turn decays via beta decay (emission of an electron) to $^{234\text{m}}\text{Pa}$. The “m” indicates that this is a metastable form. The $^{234\text{m}}\text{Pa}$ decays by two different modes. A small fraction (0.0016, or 0.16 percent) decays to ^{234}Pa via isomeric transition, but most of the $^{234\text{m}}\text{Pa}$ decays via beta to ^{234}U , with a branching fraction of 0.9984, or 99.84%. The ^{234}Pa produced by IT from $^{234\text{m}}\text{Pa}$ also decays via beta to ^{234}U , but the step through ^{234}Pa is important to account for, since the energies of each decay are different, and produce different doses.

Each of these decay steps also has a unique half-life ($T_{1/2}$), which represents the amount of time needed for half of the parent to decay to its progeny. These half-lives are extremely variable, from about 4.5×10^9 yr for ^{238}U to 164 μs (5.2×10^{-12} yr) for ^{214}Po , within this decay chain.

At the one extreme, very short-lived radionuclides do not exist long enough to undergo appreciable transport in the environment before they are transformed to the next nuclide in the chain. In such cases, there is no point in modeling contaminant transport, so these are assumed to be transported with a sufficiently long-lived parent, and to remain in place as they undergo decay. These short-lived radionuclides must be accounted for in the modeling of dose, however, since doses from short-lived species may be significant, outshining doses from the long-lived parent. An example of this is the decay of ^{137}Cs to $^{137\text{m}}\text{Ba}$ and then to stable Ba, as illustrated in Figure 68. The IT decay mode from $^{137\text{m}}\text{Ba}$ to Ba produces about 10,000 times the external dose as the beta decay of ^{137}Cs to $^{137\text{m}}\text{Ba}$, so that is where the bulk of the dose is coming from. Even though the contaminant transport of $^{137\text{m}}\text{Ba}$ is ignored due to its half-life of only 2.5 minutes, the dose must be accounted for. In such cases, the dose from the progeny is combined with the dose from the parent. The half-life below which radionuclides are not included in contaminant transport calculations is generally on the order of 1 to 5 yr, with the notable exceptions of ^{222}Rn , which is a special case as a noble gas in the midst of a significant decay chain, and of ^{228}Th , which has an animal transfer factor significantly different from that of its parents, ^{232}U and ^{228}Ra (through ^{228}Ac).



Figure 68. Decay chain for ^{137}Cs through $^{137\text{m}}\text{Ba}$.

At the other extreme, radionuclides with extremely long half-lives behave much like stable nuclides. In a case like ^{148}Sm , a progeny of the fission product ^{152}Eu with a half-life of 7×10^{15} yr, dose conversion factors are not even developed (Eckerman et al. 1988), since doses would be immeasurably low. For these, a half-life value above which radionuclides are not included in the Model is established. This is generally taken to be 1.5×10^{10} yr, which is large enough to allow for modeling of ^{232}Th , but not the longer lived rare earths that are of no consequence.

A final consideration of which radionuclides to include in the West Valley PPA Model is the case where a radionuclide is reported in an inventory, but has a short half-life. If the radionuclide decays quickly to some stable nuclide, then the inventory of that radionuclide is simply ignored, because by the time the radionuclide could become part of an exposure pathway, it will have decayed to inconsequence. This would be the case, for example, for ^7Be , which decays to stable Li with a half-life of only 53 days. If the short-lived radionuclide reported in an inventory decays to some other longer-lived progeny, however, it cannot be ignored. In such a case, the activity attributed to the short-lived parent is simply added to the reported activity of the progeny. For example, ^{242}Cm has a half-life of 163 days, and so will decay before it has a chance to contribute to risk. It decays to ^{238}Pu , which is a significant radionuclide. In order to account for the ^{242}Cm , each activity unit (e.g. Bq or Ci) of ^{242}Cm is converted to a Bq (or Ci) of ^{238}Pu and is added to the reported ^{238}Pu inventory.

3.3.4 Scope of Radionuclide Inventory: Contaminants

A list of radionuclides to be included in the modeling is developed from the list of reported radionuclides, subject to the process discussed in the previous section. This process is summarized as follows:

1. Collect a list of all radionuclides reported as disposed, measured, or otherwise present as residuals.
2. Add to this list all progeny resulting from decay and ingrowth.
3. Screen out those progeny with very low branching fractions, since they are assumed to not have significant contributions to dose due to very low abundance.
4. Determine which reported radionuclides, if any, have short half-lives (typically below 5 yr) and long-lived progeny, and reassign all reported activity to the next long-lived progeny in the decay chain.
5. Apply the short half-life cutoff value below which radionuclides are modeled as contributors to dose, but are not included in contaminant transport calculations.
6. Apply a long half-life value to remove those radionuclides that have such long half-lives they do not contribute to dose, or otherwise contribute to modeling or decision making.

The resulting list of radionuclides constitutes the radionuclides included in the “Species” list for modeling in GoldSim.

As a starting point, the list of all radionuclides mentioned in tables and text in Appendix C of DOE (2010c) and in ECS (2016a) includes:

^3H , ^{14}C , ^{54}Mn , ^{55}Fe , ^{59}Fe , ^{58}Co , ^{60}Co , ^{59}Ni , ^{63}Ni , ^{65}Zn , ^{90}Sr , ^{90}Y , ^{93}Zr , ^{95}Zr , ^{94}Nb , ^{99}Tc , ^{103}Ru , ^{106}Ru , ^{110}Ag , $^{110\text{m}}\text{Ag}$, ^{125}I , ^{129}I , ^{131}I , ^{137}Cs , $^{137\text{m}}\text{Ba}$, ^{154}Eu , ^{226}Ra , ^{232}Th , ^{232}U , ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{237}Np , ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{242}Pu , ^{241}Am , ^{243}Am , ^{242}Cm , ^{243}Cm , and ^{244}Cm .

Another list of radionuclides is provided by the SDA inventory work from Wild, in a spreadsheet accompanying URS (2002a):

^3H , ^{10}Be , ^{14}C , ^{32}Si , ^{32}P , ^{36}Cl , ^{54}Mn , ^{55}Fe , ^{57}Co , ^{60}Co , ^{59}Ni , ^{63}Ni , ^{65}Zn , ^{79}Se , ^{85}Kr , ^{87}Rb , ^{90}Sr , ^{90}Y , ^{93}Zr , ^{92}Nb , $^{93\text{m}}\text{Nb}$, ^{94}Nb , ^{93}Mo , ^{98}Tc , ^{99}Tc , ^{106}Ru , ^{106}Rh , ^{107}Pd , ^{108}Ag , $^{108\text{m}}\text{Ag}$, $^{110\text{m}}\text{Ag}$, ^{109}Cd , $^{113\text{m}}\text{Cd}$, ^{115}In , $^{119\text{m}}\text{Sn}$, ^{126}Sn , ^{125}Sb , ^{126}Sb , $^{126\text{m}}\text{Sb}$, ^{123}Te , $^{125\text{m}}\text{Te}$, ^{129}I , ^{134}Cs , ^{135}Cs , ^{137}Cs , $^{137\text{m}}\text{Ba}$, ^{144}Ce , ^{144}Pr , $^{144\text{m}}\text{Pr}$, ^{146}Pm , ^{147}Pm , ^{147}Sm , ^{151}Sm , ^{152}Eu , ^{154}Eu , ^{155}Eu , ^{152}Gd , $^{166\text{m}}\text{Ho}$, ^{171}Tm , ^{187}Re , ^{193}Pt , ^{204}Tl , ^{207}Tl , ^{208}Tl , ^{209}Tl , ^{209}Pb , ^{210}Pb , ^{211}Pb , ^{212}Pb , ^{214}Pb , ^{208}Bi , ^{210}Bi , ^{211}Bi , ^{212}Bi , ^{213}Bi , ^{214}Bi , ^{210}Po , ^{211}Po , ^{212}Po , ^{213}Po , ^{214}Po , ^{215}Po , ^{216}Po , ^{218}Po , ^{217}At , ^{219}Rn , ^{220}Rn , ^{222}Rn , ^{221}Fr , ^{223}Fr , ^{223}Ra , ^{224}Ra , ^{225}Ra , ^{226}Ra , ^{228}Ra , ^{225}Ac , ^{227}Ac , ^{228}Ac , ^{227}Th , ^{228}Th , ^{229}Th , ^{230}Th , ^{231}Th , ^{232}Th , ^{234}Th , ^{231}Pa , ^{233}Pa , ^{234}Pa , $^{234\text{m}}\text{Pa}$, ^{232}U , ^{233}U , ^{234}U , ^{235}U , ^{236}U , ^{237}U , ^{238}U , ^{240}U , ^{235}Np , ^{236}Np , ^{237}Np , ^{238}Np , ^{239}Np , ^{236}Pu , ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{242}Pu , ^{244}Pu , ^{241}Am , ^{242}Am , $^{242\text{m}}\text{Am}$, ^{243}Am , ^{242}Cm , ^{243}Cm , ^{244}Cm , ^{245}Cm , ^{246}Cm , ^{247}Cm , ^{248}Cm , ^{249}Cf , ^{250}Cf , and ^{251}Cf .

The radionuclides identified in other sources, such as RCRA Facility Investigations (RFIs) and Environmental Information Documents (EIDs), include:

^3H , ^7Be , ^{14}C , ^{40}K , ^{51}Cr , ^{54}Mn , ^{57}Co , ^{60}Co , ^{65}Zn , ^{89}Sr , ^{90}Sr , ^{95}Zr , ^{99}Tc , ^{106}Ru , ^{110}Ag , ^{125}Sb , ^{129}I , ^{131}I , ^{134}Cs , ^{137}Cs , ^{133}Ba , ^{144}Ce , ^{154}Eu , ^{208}Tl , ^{212}Pb , ^{214}Pb , ^{214}Bi , ^{224}Ra , ^{226}Ra , ^{228}Ra , ^{228}Ac , ^{230}Th , ^{232}Th , ^{234}Th , ^{232}U , ^{233}U , ^{234}U , ^{235}U , ^{236}U , ^{238}U , ^{237}Np , ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{241}Am , ^{243}Cm , and ^{244}Cm .

A list of WTF residuals is provided in WVNS (2005):

^3H , ^{14}C , ^{60}Co , ^{63}Ni , ^{79}Se , ^{90}Sr , ^{99}Tc , $^{113\text{m}}\text{Cd}$, $^{121\text{m}}\text{Sn}$, ^{126}Sn , ^{125}Sb , ^{129}I , ^{137}Cs , ^{147}Pm , ^{151}Sm , ^{154}Eu , ^{207}Tl , ^{208}Tl , ^{209}Pb , ^{210}Pb , ^{211}Pb , ^{212}Pb , ^{214}Pb , ^{210}Bi , ^{211}Bi , ^{212}Bi , ^{213}Bi , ^{214}Bi , ^{210}Po , ^{213}Po , ^{214}Po , ^{215}Po , ^{216}Po , ^{218}Po , ^{217}At , ^{219}Rn , ^{220}Rn , ^{222}Rn , ^{221}Fr , ^{223}Ra , ^{224}Ra , ^{225}Ra , ^{226}Ra , ^{228}Ra , ^{225}Ac , ^{227}Ac , ^{228}Ac , ^{227}Th , ^{228}Th , ^{229}Th , ^{230}Th , ^{231}Th , ^{232}Th , ^{234}Th , ^{231}Pa , ^{233}Pa , $^{234\text{m}}\text{Pa}$, ^{232}U , ^{233}U , ^{234}U , ^{235}U , ^{236}U , ^{238}U , ^{237}Np , ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{241}Am , ^{243}Cm , and ^{244}Cm .

The initial list of radionuclides in the inventory, then, is the superset of these lists. In addition, the miscellaneous waste codes and radionuclides are to be broken down into individual radionuclides, which will include more than the above list, especially in the area of fission products. Once the master list of all radionuclides extant at the West Valley Site is complete, the screening on branching fraction and half-life can be done and the final list of modeled radionuclides can be assembled.

3.3.5 Scope of Radionuclide Inventory: Facilities

The West Valley PPA Model includes all contaminated facilities at the Site. Those that have undergone remediation under Phase 1 will leave residual amounts of radioactivity behind, and this is to be accounted for in the Model so that contributions to dose and risk from these residuals are evaluated.

All facilities that are subject to Phase 2 decision making are also included, and are the principal focus of the modeling effort. Each of the facilities to be included for remediation alternatives has a current inventory, and inventories that would result from the various remediation alternatives.

The list of radionuclides to be included in the Model is the superset of all radionuclides reported in any inventory at the Site, subject to the screening outlined in the previous section.

3.4 Chemical Contamination

In addition to radioactive contamination, the West Valley PPA Model will evaluate chemical contaminants and their risks to receptors. Like the radioactive wastes, some of these were disposed intentionally in the SDA and NDA, but others are due to industrial processes (e.g. the WTF) and inadvertent releases and spills (e.g. the CDDL). Historical chemical analytical data is available for environmental media around the site. The complete list of chemicals to be modeled is assembled from these and other data sources. These are grouped into those of similar fate and transport characteristics, as well as aspects contributing to risk.

3.4.1 Disposed Chemical Wastes

Appendix C of DOE (2010c) outlines contamination found at each West Valley Site facility. Within the NDA, the following chemical constituents are mentioned in the text or tables: tributyl phosphate, n-dodecane, phenol, 1,4 dioxane, bis (2-ethylexyl) phthalate, di-n-butyl phthalate, 1-butanol, acetone, 2-hexanone, 2-methylnaphthalene, isobutyl alcohol, and 1,2-dibromo 3-chloropropane. Nicholson and Hurt (1985) report that free product kerosene, contaminated with other chemical and radioactive constituents, was encountered in the NDA, but WVNS (1995a) states that this was likely a misnomer, and that “the word ‘kerosene’ was used as a layman’s term during public meetings to describe the TBP/n-dodecane, but it is not a true description of the process diluent.”

For the SDA, RCRA chemicals include: benzene, ethylbenzene, toluene, xylene, 1,1-dichloroethane, 2-chlorophenol, 2,4-dichlorophenol, chloroform, 3,4-methylphenol (cresol), and methylene chloride (DOE 2010c).

Metals associated with radioactive wastes, such as Pb and U, would also be expected in the NDA and SDA.

3.4.2 Other Chemical Contamination

The MPPB and Vittrification Facility also contain chemical constituents, including asbestos and polychlorinated biphenyls (PCBs), and the metals Sb, As, Ba, Be, Cd, Cr, Pb, Hg, Ni, Se, Ag, and Tl (DOE 2010c). Most of these metals are also associated with the WTF.

3.4.3 Decay and Ingrowth of Chemical Constituents

Some chemicals degrade in the environment, depending on conditions such as the presence of oxygen or certain microbes. Some degradation processes lead to the production of decay products, similar in some ways to the decay and ingrowth of radionuclides.

3.4.4 Scope of Chemical Waste Inventory: Contaminants

The comprehensive list of chemical constituents to be examined in the West Valley PPA Model includes at a minimum the following organics:

tributyl phosphate, n-dodecane, phenol, 1,4 dioxane, bis (2-ethylexyl) phthalate, di-n-butyl phthalate, 1-butanol, acetone, 2-hexanone, 2-methylnaphthalene, isobutyl alcohol, and 1,2-dibromo 3-chloropropane, benzene, ethylbenzene, toluene, xylene, 1,1-dichloroethane, 2-chlorophenol, 2,4-dichlorophenol, chloroform, 3,4-methylphenol (cresol), and methylene chloride,

and inorganics:

asbestos, Sb, As, Ba, Be, Cd, Cr, Pb, Hg, Ni, Se, Ag, Tl, and U,

all of which are reported in Appendix C of DOE (2010c).

3.4.5 Scope of Chemical Waste Inventory: Facilities

While most facilities at the West Valley Site have some sort of chemical contamination, some are strictly radiological. An example is the Cesium Prong, with ¹³⁷Cs. The nature and extent of chemical contaminants at other facilities depends on the results of sampling and analysis, both those already performed and those planned.

4.0 Modeling of Human Exposure and Effects

Several aspects of the PPA modeling framework crucial to the identification and application of human exposure models are under development. A hierarchical decision-making structure will be designed to help focus the scope and endpoints for the West Valley PPA Model. Although such a structure is largely a matter of decision makers defining the basis for selecting among different management options, there is a role for a hierarchical PPA to provide pertinent technical information to support that basis. For example, high-level modeling can support resolution of issues such as the following:

- Are chemical risks potentially important relative to radiological risks?
- Are acute radiological exposures of concern for high-activity waste packages in situations and time frames when erosion could expose such packages?
- Are potential post-closure risks for individual facilities or WMAs either obviously negligible or obviously unacceptable based on simple screening models?

To answer these and other scoping questions, key boundaries that must be defined include the time frame of the PPA modeling (temporal boundaries, Section 4.2.2) and where future human receptors may be located (spatial boundaries, Section 4.2.3). High-level transport and exposure models may be useful in helping stakeholders and decision makers establish such boundaries by revealing the consequences of selecting different bounds. Using simple initial modeling to help define the appropriate scope and complexity of the system-level PPA in a hierarchical fashion also promotes efficiency and model parsimony (i.e., keeping the model as simple as possible, while representing the system in an accurate fashion).

Conversely, the definition of specific assessment endpoints (Section 4.1) can strongly influence the development of the West Valley PPA Model. For example, the spatial domain of a model that evaluates population-level exposures and effects is likely to be much larger than that of a model focused on quantifying exposures and effects for a reasonably maximally exposed individual who is present on-site.

The description of potential future land use scenarios and activities is kept at a high level in this CSM, as is suited to the relatively simple modeling foreseen at the initiation of the hierarchical PPA to support development of a decision-making structure. As the hierarchical PPA modeling framework is developed and the scope and boundaries are better defined, more detailed human exposure scenarios will be developed as required to support decision making.

4.1 Human Health Effects Endpoints

Human health effects from contamination present at the Site, evaluated as part of the West Valley PPA Model, will include radiological effects related to ionizing radiation, and possibly non-radiological chemical toxicity effects. The general term “contaminant” is employed here to refer to either or both radionuclides and non-radionuclides that may pose risks to humans. Receptors are defined as hypothetical individuals who may encounter contaminants attributable to the Site, at different points in the future.

The specific assessment endpoints and associated criteria related to human health effects are described below.

4.1.1 Radiological Dose

Adverse health effects from radiation exposure are typically evaluated by the proxy measure of radiological dose, using radiation dose conversion factors (DCFs). These DCFs incorporate weighting factors for the biological effectiveness of different types of radiation as well as weighting factors for the sensitivity of different organs and tissues to the detrimental effects of ionizing radiation. The health effects of radiation exposure (primarily cancer risk) are implicit in the basis of these weighting factors. Also implicit in the dosimetry underlying the DCFs are assumptions regarding the duration of exposure. These doses are referred to as total effective dose (TED) in DOE O 458.1 (Section 2.2) and in 10 CFR 20 (CFR 2014a), and as committed effective dose by EPA. The associated DCFs were derived for the purpose of radiation protection in a regulatory context where criteria are expressed in terms of permissible annual dose. The term TED is employed here. Specific dose-related performance criteria for different regulations are outlined in Section 2.0.

The dose conversion factors used in the FEIS (DOE 2010c) were taken from Federal Guidance Report (FGR) 11 (Eckerman et al. 1988) and FGR 12 (Eckerman and Ryman 1993). The radiation dosimetry underlying the internal DCFs (ingestion and inhalation pathways) in FGR 11 was published by ICRP in ICRP Publication 30 and is targeted to worker protection (Eckerman et al. 1988). The EPA has subsequently made use of more recent age-specific dosimetry underlying the DCFs published in ICRP Publication 72 (ICRP 1996) to estimate radionuclide cancer “risk coefficients” (described below) in FGR 13 (Eckerman et al. 1999). Internal DCFs for different age groups are also published in FGR 13 based on the ICRP 72 dosimetry.

More recently, DOE has derived age-dependent internal dose coefficients based on ICRP Publication 72 (ICRP 1996), using revised gender-specific physiological parameters for members of the public described in ICRP Publication 89 (ICRP 2002). These DCFs, published in DOE’s *Derived Concentration Technical Standard* (DOE 2011), are time-weighted for each of the six age subgroups described in ICRP (1996) by their fractional representation in the U.S. population and their inhalation and drinking water ingestion rates. Additionally, these DCFs are calculated employing the most current nuclear decay data from ICRP Publication 107 (ICRP 2008). DOE (2011) notes that the practical difference in applying the age-weighted versus adult DCFs for dose calculations is not substantial because “the higher dose coefficients at the younger ages are tempered by their lower daily intakes and the U.S. population distribution for which 74 percent of the population falls into the adult subgroup.” Regardless, Neptune will employ these DCFs in the PPA.

4.1.2 Radionuclide Risk

The primary human health endpoint of concern related to chronic exposure to ionizing radiation from radionuclides is cancer. Cancer risk may be expressed as either the risk of cancer mortality, or as the risk of cancer morbidity (i.e., getting cancer, whether fatal or nonfatal). Additionally, this risk may relate either to potential cancer risks to a hypothetical individual, or to population level risks for the exposed populations in the foreseeable future.

Eckerman et al. (1999) derived risk coefficients for both mortality and morbidity, for given radionuclides and exposure modes (inhalation, ingestion, or external exposure). A mortality risk coefficient is an “estimate of the risk to an average member of the US population, per unit activity inhaled or ingested for internal exposures or per unit time-integrated activity concentration in air or soil for external exposures, of dying from cancer as a result of intake of the radionuclide or external exposure to its emitted radiations. A morbidity risk coefficient is a comparable estimate of the average total risk of experiencing a radiogenic cancer, whether or not the cancer is fatal” (Eckerman et al. 1999). Note that these risk coefficients are likely conservative (i.e., they overestimate risk, and thus increase protectiveness) as they assume no threshold of effect (i.e., there is no level of radiation exposure that is not associated with an increased risk). Also note that if risks are summed across individuals to result in a population dose, such a population dose will not include variability across individuals in terms of susceptibility to cancer.

Risk coefficients are multiplied by estimated exposure levels to result in dimensionless risks. The cancer risk criterion addressed in the FEIS is the 1E-04 to 1E-06 incremental (or excess) lifetime cancer risk (ILCR) range associated with exposure to carcinogens that is suggested by CERCLA, the Comprehensive Environmental Response, Compensation, and Liability Act. The New York State Department of Environmental Conservation (NYSDEC 2006) states “the risk presented by residual contamination as defined at ECL 27-1405.28 at a site shall not exceed an excess cancer risk of one in one million for carcinogenic end points.” Specific risk-related performance criteria are discussed in Section 2.0.

By way of context, the lifetime cancer risk in the US is 0.42 for men, and 0.38 in women (ACS 2015). Therefore, for males, an ILCR of 1E-04 due to radiation exposure corresponds to a total lifetime risk of 0.4201, and an ILCR of 1E-06 corresponds to 0.420001. Note that these levels of increased risk in the population would not be detectable in any epidemiological study. They are simply a regulatory means to ensure that risks at contaminated sites are kept at a minimal level.

4.1.3 Chemical Contaminant Health Effects

Toxicity values used to assess cancer and non-cancer effects of chemical contaminants are published by EPA as well as other federal agencies and individual states. EPA’s Superfund program has published a hierarchy of sources for human health chemical toxicity values, providing three tiers of sources beginning with the Integrated Risk Information System (IRIS) followed by the provisional peer-reviewed toxicity values published by the Superfund Health Risk Technical Support Center (EPA 2003b). More recently, EPA has developed a hierarchy for sources in order to support publication of Regional Screening Levels for soil, drinking water, and air (EPA 2014). The most appropriate sources, on a chemical specific basis, will be reviewed and employed in the West Valley PPA Model.

The risk-related performance criteria discussed in relation to radionuclide risk (Section 4.1.2) is also applicable to carcinogenic chemical contaminants. Instead of the risk coefficients employed for radionuclides, slope factors (SFs) are employed to estimate risks. Functionally, these are similar to risk coefficients; the major difference is that for all radionuclides the risk coefficients are based on human data, whereas for chemical contaminants most SFs are based on animal data (as reliable epidemiological data do not exist for most chemical carcinogens). Therefore, there

may be considerably more uncertainty in estimated human health cancer risks associated with the use of SFs. Regardless, SFs are used in a similar fashion as radionuclide risk coefficients to estimate ILCRs. The assumption of no threshold of effect is also typically applied.

For chemical contaminants that are not thought to be carcinogenic, EPA and others typically view non-cancer toxic effects as having thresholds, i.e., levels below which adverse effects would be unlikely. Reference doses (RfDs) and reference concentrations (RfCs) essentially amount to such thresholds, and commonly include safety factors to bias the values in a protective manner accounting for different types of uncertainty.

Radioactive metals can also be associated with toxicological effects that are independent of radioactive properties and carcinogenic effects. Uranium is the only radioactive metal for which EPA currently publishes toxicity values for non-cancer effects (kidney toxicity). Other radionuclide metals may have toxic effects as well, but without published toxicity values it is difficult to evaluate these effects.

4.1.4 Other Criteria

Depending on the final scope and endpoints of the West Valley PPA Model, other health-based criteria may be applied. For example, EPA Maximum Contaminant Levels (MCLs), applied under the Clean Water Act, are legally enforceable water quality standards for municipal water supplies (e.g., municipal wells for Gowanda, New York, and Lake Erie municipal inlets).

4.2 Bounding Assumptions Regarding Future Exposure Scenarios

4.2.1 Site Waste Management Areas

The Site is being remediated and decommissioned in two Phases. Phase 1 is ongoing. Facilities to be decommissioned during Phase 1 will not be evaluated in the West Valley PPA Model, with the exception of residual contamination (Section 3.3.5). The specific WMAs and “facilities” that have been defined as part of Phase 2 decision-making at the Site and that are evaluated in the Model are provided in Section 5.1.

4.2.2 Time Frame

DOE and NYSERDA have directed that the West Valley PPA Model’s time frame will begin in 2020. Potential operational worker and public exposures and doses prior to this date are out of the Model’s scope. The radionuclide and chemical contaminant inventories present at the end of Phase 2 decommissioning, including any residuals from Phase 1, are to be evaluated for as long as necessary in order to determine the value and timing of peak doses and risks.

It is unclear at this time in what situations and at what specific time loss of IC and Site knowledge may occur. Typically, PAs assume that as soon as IC is lost Site knowledge is also lost (i.e., no one will know that contamination is present at the Site). The relationship between loss of IC and post-closure exposure assumptions is discussed in Section 4.3. The specific duration of the modeling performance period will follow development of a decision-making structure to help focus the scope and endpoints of the Model.

4.2.3 Spatial Scale

In general, the FEIS evaluated impacts to a 50-mi (80-km) “radius of interest” around the Site, which includes Lake Erie and Buffalo, New York (Figure 10). This radial distance is discussed in DOE O 458.1 in the context of evaluating population dose for active DOE facilities.

Practically, the application of a radial distance around a source of radiological emissions is a generic guideline for assessing exposures due to air dispersion of radionuclides, such as from one or more permitted emissions sources. In the context of releases from the Site, where infiltration and erosion processes are likely to dominate releases, the spatial scale of interest may be more appropriately defined by consideration of watersheds (e.g., the Cattaraugus Creek watershed). Identification of the spatial bounds of the Model will follow development of a decision-making structure to help focus the scope and endpoints of the Model.

4.2.4 Modeling of Intrusion and Exposure to Contaminated Materials

As discussed in Section 2.0, NRC regulations distinguish between off-site exposures of hypothetical future receptors (members of the public, or MOPs) and exposures of on-site MOPs and inadvertent human intruders (IHIs) on a closed disposal facility, although DOE O 458.1 makes no such distinction. In this context, the definition of on-site receptors encompasses the exposure of receptors who engage in activities at the Site after the loss of IC, and without knowledge of the disposal facility and wastes. A summary of issues related to human intrusion into contaminated materials and exposures subsequent to erosive exposure of these materials to the ground surface is included below. Application of this information in the West Valley PPA Model will follow detailed development of the scope and endpoints of the Model. Simplified models for evaluating the time frame of erosive exposure of contamination and possible radiological effects of receptor exposure may be useful in guiding whether and how to include these scenarios in the Model.

Inadvertent intrusion into the WMAs and direct exposures to contamination may occur as a consequence of drilling for water for domestic use. According to the FEIS (DOE 2010a), a 1985 survey of off-site groundwater use indicated 151 private wells located in the vicinity of the Site. The types of well installations found in the survey included dug wells, drilled wells, augered wells, well-points, and springs. Wells are screened in both the shale bedrock and in alluvial gravel deposits. The main consequence of intrusion via a water supply well is the potential for drillers or post-drilling receptors to be exposed to drill cuttings containing contaminants originating in the WMAs, in addition to contaminated groundwater. There are also over 2300 currently producing oil and/or gas wells in Cattaraugus County (see Section 3.2.4). A secondary consideration pertaining to impacts of drilling activities may be the effect of an improperly sealed borehole on infiltration of surface water and development of a preferential pathway for migration of contaminants in disposed wastes to the aquifers.

Inadvertent direct exposures could also result from construction of subfloors or basements. Depending on closure cover thickness, a typical residential basement may not reach contaminated materials, but excavations for a commercial or industrial building might be deeper. The thickness of cover materials can also decrease over time due to surface erosion. Activities other than drilling and construction may also result in inadvertent exhumation of contaminated material, or disturbance of the overlying cover. For example, there are 195 permitted, non-

permitted, and reclaimed sand/gravel mines in the County, as well as clay and peat mines (see Section 3.2.4).

Inadvertent, direct exposure to wastes could also follow a sufficient degree of Site erosion (Section 3.2.7.2.2). Although the rate of erosion is uncertain at this time, and the susceptibility of contaminated materials to erosion exposure will vary for specific materials and WMAs, at some point in the future after IC is lost contaminated materials will begin to be exposed. Contamination will eventually migrate toward the Cattaraugus Creek watershed and eventually to Lake Erie. At such time, if humans are present, exposure to these contaminants will occur over a broad spatial area.

As discussed in Section 2.0, DOE and EPA regulation and guidance regarding radioactive materials do not require assessment of the consequences of deliberate human intrusion into contaminated materials (e.g., for the purpose of retrieval). A practical consideration is the degree of speculation that would be required in defining plausible chains of events and related probabilities to model deliberate intrusion. Relevant information would include the intruder's state of knowledge about the disposal system and its contents, the rationale for intrusion, the method of intrusion, the specific materials targeted, and the exposure routes and exposure intensities for the intruder. An additional set of assumptions related to post-intrusion events and consequences would be required to assess potential exposures to the public subsequent to the deliberate intrusion. For these reasons, scenarios related to deliberate intrusion are not proposed for the PPA.

4.3 Future Exposure Scenarios

This CSM considers exposures to humans who may inhabit or otherwise occupy the Site and surrounding areas in the future. The determination of who these receptors are, with respect to land use scenarios, activities, and behaviors, is necessarily based on historical and present-day land uses as indicators of potential future land uses. As indicated in Section 3.2.3, the predominant land use in the vicinity of the Site is agricultural (i.e., small farms), but there is also appreciable residential, commercial, and industrial development, as well as forested and recreational areas.

People may be exposed to contaminants transported in various environmental media such as water, soil, sediment, air, and biota. Environmental transport pathways pertaining to these media are discussed further in Section 5.0. The degree of human exposure depends on the following:

- presence of people at the Site and in areas that may be affected by Site contaminants,
- human behaviors and activities,
- concentrations of contaminants in different exposure media, and
- the stability and toxicity over time of those contaminants.

Contaminated exposure media may exist on-site due to movement of contaminants in the environment, and in cases of sufficient erosion will include the contaminated materials themselves. Contaminated media may also exist off-site following migration of air, water, and soils due to natural transport processes.

4.3.1 Possible Site Exposure Scenarios between the End of Phase 1 Decommissioning and Site Closure

During the period of active NYSERDA and DOE control, radiological doses will be evaluated by a health and safety program with personal radiation monitoring. Therefore, modeling of radiological exposure and effects for Site personnel during the period of active institutional operations is not proposed.

4.3.2 Possible Post-Closure Site Exposure Scenarios

There are numerous land uses, activities, and receptor types that could occur both on- and off-site post-closure. The FEIS evaluated a limited set of these exposure scenarios, but it is conceivable, for example, that the following types of post-IC development scenarios on the Site could occur based on current regional land uses (Section 3.2.3):

- Rural residential (with or without gardening/farming and ranching)
- Suburban residential
- Urban residential
- Commercial (e.g., shopping center)
- Industrial (e.g., manufacturing)
- Resource-extraction industrial (e.g., gravel pits, oil wells)
- Recreational (e.g., hiking, horseback riding, hunting, off-highway vehicle use, etc., including fishing on-site or in surrounding streams)
- Farming (without residence)
- Ranching (without residence)
- Subsistence lifestyles (e.g., Native American)
- Commercial fishing (e.g., Lake Erie)

Any of the development scenarios involving building or resource extraction could involve exposures of workers, as well as exposures of other receptors to contaminants released to the environment during these activities.

4.3.3 FEIS Site Exposure Scenarios and Modeling

Two broad analyses were performed in the FEIS. The first time period reflects the shorter-term decommissioning period (DOE 2010c). The deterministic GENII computer code, developed by Pacific Northwest National Laboratory, was used to estimate radiation doses and cancer fatalities to workers, maximally exposed individuals (MEIs) at the site boundary, and the population within an 80-km (50-mi) radius of the Site (approximately 1.7 million individuals). The GENII code includes air, water, crops, animal products, and external exposure pathways. Cancer fatalities were estimated as follows:

DOE recommended that 0.0006 fatal cancers per rem be used for both workers and members of the public ... Numerical fatal cancer estimates presented in this EIS were obtained using a linear no-threshold extrapolation from the nominal risk estimated for lifetime total cancer

mortality that results from a dose of 0.1 gray (10 rad) ... The risk factor of 0.0006 fatal cancers per rem [(0.06 per Sv)] was used as the conversion factor for all radiological exposures up to [0.2 Sv, or] 20 rem per individual due to accidents, including those in the low-dose region. A risk factor of 0.0012 [fatal cancers per rem, or 0.12 per Sv], was used for individual doses of [0.2 Sv, or] 20 rem or greater. For normal operations public radiological exposure, lifetime fatal cancer risk was calculated using radionuclide-specific risk factors [from FGR 13, discussed above]. Worker normal operations radiological exposure was calculated using the risk factor of 0.0006 fatal cancers per rem [(0.06 per Sv)].

A second “long-term” analysis utilized a different methodology. The calculations presented in the FEIS consist of a loosely coupled series of models at a variety of scales (site-scale to location-specific) using several numerical computer models. There are three primary models: the groundwater model, which tracks releases from sources across the Site to various receptors in the area, the erosion model, and the direct intruder model. Details about the models are provided in the 2010 FEIS appendices (DOE 2010c), in document files provided along with the models and codes, and in code comments.

For reference, the points of exposure for the receptors defined in the FEIS long-term dose assessment are shown in Table 8, which is Table D-4 from Appendix D of DOE (2010c).

Table 8. Summary of long-term receptors and exposure points from the 2010 FEIS.

Release and Transport Mode, Receptor Location	Exposure Mode						Worker Inhalation & External Exposure
	Drinking Water Consumption	Fish Consumption	Residential with Agriculture ^b	Residential without Agriculture	Deer Consumption	Recreational Hiking	
Groundwater to groundwater							
North Plateau	Y	N	Y	N	Y	Y	N
South Plateau	N	N	Y	N	Y	Y	N
Groundwater to groundwater and surface water							
Buttermilk Creek	Y	Y	Y	N	N	N	N
Cattaraugus Creek	Y	Y	Y	N	N	N	N
Seneca Nation of Indians	Y	Y	Y	N	N	N	N
Sturgeon Point	Y	Y	Y	N	N	N	N
Niagara River	Y	Y	Y	N	N	N	N
Erosion to surface water							
Buttermilk Creek	Y	Y	Y	N	N	N	N
Cattaraugus Creek	Y	Y	Y	N	N	N	N
Seneca Nation of Indians	Y	Y	Y	N	N	N	N
Sturgeon Point	Y	Y	Y	N	N	N	N
Niagara River	Y	Y	Y	N	N	N	N
Erosion with adjacent residence							
North Plateau	N	N	N	Y	N	Y	N
South Plateau	N	N	N	Y	N	Y	N
Intrusion							
Home construction worker	N	N	N	N	N	N	Y
resident	Y	N	Y	N	N	N	N
Well-drilling worker	N	N	N	N	N	N	Y
resident	Y	N	Y	N	N	N	N

^a Y = Yes, combination of release, transport, and exposure modes and receptor location occurs.

N = No, combination of release, transport, and exposure modes and receptor location does not occur.

^b Inhalation and direct exposure are subpaths for the residential agriculture scenario.

Table 9 is an overview of the human exposure portion of the long-term analysis, which is presented here for comparison to the current CSM. Both radionuclides and chemical contaminants were evaluated. Due to unclear documentation and inconsistencies between the FEIS (DOE 2010c) and the computational model code, this table should be viewed as a rough guide only.

Table 9. Summary of long-term receptors and pathways discussed in the 2010 FEIS, Appendix H.

Receptor	Exposure pathways	Location
Home construction worker	Dust inhalation External irradiation	On top of facilities and waste units
Well drilling worker	Dust inhalation External irradiation to contaminated water over a drill cuttings pond (mud pit)	On top of facilities and waste units
Recreational hiker	Dust inhalation Inadvertent soil ingestion External irradiation	Along an active erosion front (Table H-62), not the creek bank
Resident farmer (includes hiking and hunting of deer)	Inadvertent soil ingestion Dust inhalation Ingestion of produce and animal products (meat and milk), garden is irrigated with groundwater and/or surface water Groundwater and/or surface water ingestion External irradiation Fish ingestion from Buttermilk Creek Deer meat ingestion	On top of facilities and waste units, and other locations
Off-site resident farmer	Surface water ingestion Ingestion of produce and animal products (meat and milk), garden is irrigated with groundwater and/or surface water Fish ingestion	Cattaraugus Creek
Off-site resident farmer: Cattaraugus Territory of the Seneca Nation of Indians	Identical to off-site resident farmer above, but with additional fish consumption.	Cattaraugus Creek, in Seneca Nation land
Off-site receptor for drinking water from Sturgeon Point (Lake Erie)	Municipal drinking water ingestion Fish ingestion	Sturgeon Point, Lake Erie shoreline
Off-site receptor for drinking water from Niagara River	Municipal drinking water ingestion Fish ingestion	Niagara River
Receptor exposed to eroded stream banks, from a distance, who is also a hiker	External irradiation Inadvertent soil ingestion Dust inhalation External irradiation	E bank of Frank's Creek, N bank of Erdman Brook, and one near lagoons

Neither the short-term nor the long-term assessments evaluated direct exposure to contaminated materials exposed after erosion, or after resource extraction activities. The closest such scenario was external exposure of a receptor situated near eroded stream banks.

A critique of the FEIS exposure models and results is not presented here, because the present CSM is substantially different and exposures/risks will be modeled in a different fashion in the West Valley PPA Model. However, the FEIS analysis in conjunction with simple initial PPA modeling can serve as a guide for what types of scenarios may be most important for decision-making.

4.3.4 Proposed PPA Exposure Scenarios

As long as IC is in place, there are no applicable on-site scenarios except those pertaining to Site workers. Any of the scenarios in Section 4.3.2 could occur off-site. After IC and loss of institutional knowledge, any of these scenarios could potentially occur on-site as well.

A challenge associated with a complex site that has multiple possible land uses is focusing on the exposure scenarios that are likely to influence decisions the most. The FEIS provides a guide in this regard, with modifications described below. The intent here is to simplify the exposure/dose/risk analysis for the relatively simpler modeling foreseen at the initiation of the West Valley PPA Model. As the PPA modeling framework is developed and the scope and boundaries are defined, more detailed human exposure scenarios may be developed as required to support decision making.

Note that dermal absorption is indicated as an exposure pathway below. With specific exceptions such as tritium, dermal absorption of radionuclides is considered to be a negligible contributor to dose and is not typically evaluated for radionuclide exposure. However, it is a relevant pathway for certain chemical contaminants, thus it is included here for those contaminants.

4.3.4.1 On- and Off-Site Resident Farmer

Post-IC, the results of the FEIS analyses indicate that a rural home, with gardens, animals, and water wells, likely defines a scenario of greatest exposure (aside from direct exposure to wastes exposed via erosion or resource extraction). This scenario focuses on home-produced foods, although it is possible that residents of such homes could fish in local streams (e.g., Buttermilk Creek) and hunt deer and other game. Thus, the “Resident Farmer” scenario, similar to that in the FEIS, is a reasonable scenario to define for upper bounding of exposures and effects for both on- and off-site scenarios.

Possible exposure routes for both children and adults for this scenario include the following:

- Incidental soil, sediment, dust ingestion (e.g., via hand-to-mouth transfer)
- Groundwater ingestion (i.e., from a well)
- Vegetable ingestion
- Fruit ingestion
- Livestock ingestion

- Milk ingestion
- Chicken ingestion
- Egg ingestion
- Fish and game meat ingestion
- Gas inhalation
- Dust inhalation
- Dermal absorption from surface water
- Dermal absorption from soil and sediment
- External exposure from soil and sediment

For the on-site application, exposure pathways related to home produce and domestic meat consumption can include use of well water for irrigation, whereas for off-site residents these pathways may involve the use of either well or surface water. An important on-site residential exposure pathway for gas inhalation involves intrusion of radon gas into a home if the building is situated above a facility containing radionuclides that decay to radon gas. It is also possible that an on-site Resident Farmer may be exposed to contaminants in disposed wastes if radionuclides are released to the environment via one or more of the inadvertent intrusion mechanisms described in Section 4.2.4. This scenario may be combined with hunting and fishing pathways below, if further investigation reveals that these practices are common in local rural situations.

4.3.4.2 On- and Off-Site Recreational User

Recreational use of the Site and surrounding areas, including hunting and fishing, is proposed as an exposure scenario to evaluate nonresidential exposures. This scenario provides a second possible future land use state to complement the resident farmer. These scenarios are intended to capture a practical range of potential future exposure intensity. At present, there are fish in Buttermilk Creek, Cattaraugus Creek is a destination fishing stream, and Lake Erie is a major commercial fishery (see Section 3.2.4). Because Buttermilk or Cattaraugus Creek will experience higher concentrations of contaminants than Lake Erie, this scenario will focus on a recreational receptor who fishes Cattaraugus Creek and Buttermilk Creek. The recreational receptor is also assumed to access the Site in the post-IC time period, when he or she may hike and hunt.

Possible exposure pathways for this scenario include the following:

- Incidental soil, sediment, dust ingestion (e.g., via hand-to-mouth transfer)
- Surface water ingestion
- Fish and game meat ingestion
- Dust inhalation
- Dermal absorption from surface water
- Dermal absorption from soil and sediment
- External exposure from soil and sediment

Recreational fishing and hunting are considered an applicable activity for older children and adults, but ingestion of fish and game meat is potentially applicable to younger children as well.

4.3.4.3 Off-Site Municipal Water Use

The nearest municipal groundwater wells serving a community are in Gowanda, New York, but these wells are not expected to be impacted by groundwater contamination from the Site due to the isolation of these aquifer systems (Section 3.2.8.2.1). Therefore, the FEIS did not evaluate impacts to these wells, but did evaluate a Seneca Nation receptor drinking surface water and eating fish from Cattaraugus Creek, plus the Sturgeon Point municipal intake on Lake Erie (which is the nearest surface water intake to the Site). Municipal water supplies are subject to EPA and State of New York water quality regulations such as MCLs. The West Valley PPA Model will evaluate impacts to municipal water supplies where appropriate. The specific assessment endpoints could be comparison of modeled water concentrations to MCLs, and/or application of the effects-based endpoints described in Section 4.1 to the following exposure routes:

- Groundwater ingestion and
- Dermal absorption from groundwater

4.3.4.4 Other Scenarios

The FEIS evaluated a number of additional scenarios, including a home construction worker, a well drilling worker, a recreational hiker, and a fisher receptor located in the Seneca Nation of Indians. These and other scenarios, including a variety of natural resource uses, could be developed for the Site based on the present-day land use and activities described in this CSM. Aside from direct or close-proximity exposures to wastes, it is likely that none of these scenarios would result in greater exposures than the Resident Farmer, as defined above. Therefore, it is not useful to specifically define these scenarios in the CSM. As the PPA modeling framework is developed and the scope and boundaries are defined, more detailed human exposure scenarios may be developed as required to support decision-making.

4.3.4.5 Scenario Application

All off-site receptors are evaluated for all times during the model calculations. It is assumed that any on-site receptor exposures would only be possible after IC is lost.

The Off-Site Resident Farmer is assumed to be located near the Site property boundary that is defined for IC, at a location topographically suitable for farming where the highest multi-media concentrations would be expected to occur based on existing and initial PPA transport modeling.

The On-Site Resident Farmer will be modeled for the facilities defined in Section 5.1 as appropriate. The assessment of on-site resident farming activities invokes spatio-temporal considerations, as each individual facility has unique characteristics in terms of the following (any of which may change over time):

- Topography
- Surface area
- Waste types
- Mobility of wastes
- Current and proposed cover characteristics

The Site covers 1351 ha (3338 ac). The average size of a farm in Cattaraugus County is 76 ha (190 ac) (USDA 2012). Thus, it is possible that 17 or 18 farms could be located on the Site in the future. Specific aspects of modeling spatio-temporal considerations will be further discussed in a future report on PPA model design.

4.4 Modeling of Ecological Exposure and Effects

This CSM follows the *Guidelines for Ecological Risk Assessment* (EPA 1998) as the basic framework to determine the potential for ecological exposure risks at the Site and its environs. The ecological framework is similar to that used to assess adverse effects on humans, with the major phases of problem formulation, analysis, and risk characterization. One of the major differences of the ecological framework from the human methods is the wide range of potential ecological assessment endpoints. For example, protected special species exist at the Site (Section 3.2.6.6), and the ecological risk assessment should include endpoints that evaluate the potential for adverse effects on individuals of these species. Ecological assessment endpoints are among the components of the ecological risk assessment currently under development. The ecological risk assessment builds upon the current day assessment of ecological risks, the potential for changes to exposure and ecological communities under future conditions, and methods to evaluate risks to biota for the predicted future conditions.

4.4.1 Current Day Ecological Risk Assessment Methods

To assess current day ecological risks for radionuclides, the Site uses the *DOE Standard, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2002). DOE (2002) provides methods and guidance to be used in evaluating doses of ionizing radiation to populations of aquatic animals, riparian animals, terrestrial plants, and terrestrial animals. An overview of the methods employed in this standard is represented in Figure 69.

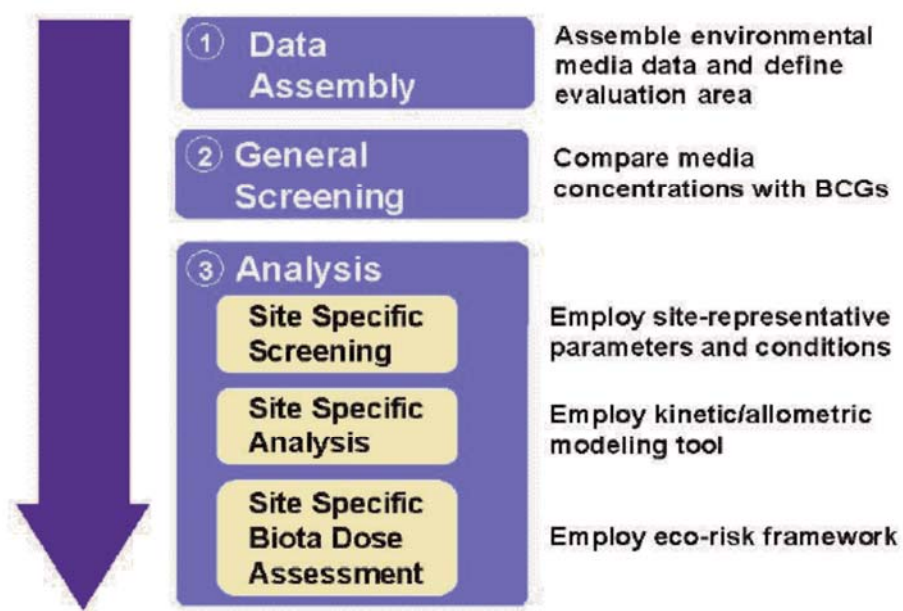


Figure 69. Overview of the DOE graded approach for evaluating radiation doses to aquatic and terrestrial biota. (From DOE (2002), Figure 2.1.)

This approach was employed in the 2014 *West Valley Demonstration Project Annual Site Environmental Report* (ASER) (DOE 2015) to evaluate radiation doses to aquatic and terrestrial biota within the confines of the Site. The biota assessed for dose broadly represent terrestrial plants and animals, riparian animals, and aquatic animals found at the West Valley Site. Doses were assessed for compliance with the limit in DOE Order 458.1 for native aquatic animal organisms (1 rad/day), and for compliance with the thresholds for terrestrial plants (1 rad/day) and for terrestrial animals (0.1 rad/day), as proposed in DOE (2002). RESRAD-BIOTA for Windows® (DOE 2004) was used to compare existing radionuclide concentration data from environmental sampling with biota concentration guide (BCG) screening values and to estimate upper bounding doses to biota.

For the West Valley PPA Model, a broader approach is necessary. The following major differences exist between the 2014 ASER approach and the proposed West Valley PPA Model approach:

1. Both radionuclide and non-radionuclide chemical contamination will be assessed.
2. Ecological assessment endpoints will reflect an appropriate variety of terrestrial, riparian, and aquatic animals, including sensitive species or populations.
3. Future as well as past and current releases will be evaluated.
4. The ecological risk assessment will not be limited to the Site itself, but will be expanded to include areas potentially affected by future releases such as the Cattaraugus Creek watershed and Lake Erie.
5. Sources and methods to develop screening levels for both on-site and off-site media will be needed to determine *de minimus* risk thresholds for ecological receptors.

4.4.2 PPA Ecological Risk Assessment Problem Formulation

The nature of the contaminants to be addressed in the ecological risk assessment is covered in Sections 3.3 and 3.4. Both radionuclide and non-radionuclide chemical contamination are included. For the purposes of ecological risk evaluations, the important distinctions among these analytes are the potential for bioaccumulation into terrestrial or aquatic food webs and the sensitivity of various biota to these chemicals.

For radionuclides, we use the Biota Dose Assessment Committee (BDAC) guidance (DOE 2002) as well as any updates provided in the RESRAD-BIOTA software for information on bioaccumulation potential. The BDAC uses a “lumped parameter” to model internal dose associated with radionuclides. The lumped parameter is available for terrestrial environments to assess uptake from soil into tissues and for aquatic environments to measure uptake from water into tissues. The lumped parameter approach is a simplification of the actual relationship of tissues to abiotic media; for radionuclides and inorganic chemicals a log-linear relationship has been shown. Log-linear models mean that the bioaccumulation factor is not a constant across abiotic medium concentrations. Instead, the amount of uptake decreases as concentration in soil (for example) increases.

There are a number of sources of bioaccumulation information for chemicals. One resource is the compilation of Eco-SSLs or ecological soil screening levels (EPA 2005). EPA developed Eco-SSLs for nationwide ecological risk assessments of contaminated soils. Bioaccumulation information was reviewed and developed for uptake into plants, soil invertebrates, and wildlife. Another national resource for bioaccumulation information is from the assumptions used for the assessment of human health criteria based on water to fish uptake (EPA 2016a). For the Great Lakes, bioaccumulation factors for the protection of fish and wildlife have been developed (Cook and Burkhard 1998). If bioaccumulation information is not available for a chemical and feeding group (e.g., herbivore, carnivore), then other compilations such as the Los Alamos National Laboratory ECORISK Database will be used (LANL 2015).

The conclusion of a review of the analytes identified for ecological risk assessment is that there is a range of bioaccumulation potential. Some radionuclides have high potential for bioaccumulation in terrestrial or aquatic environments (e.g., ⁹⁰Sr, ¹³⁷Cs, and isotopic uranium). Some of the chemicals also have high bioaccumulation potential (e.g., phthalates, Hg, Se), but others are not likely to bioaccumulate (e.g., volatile organic chemicals). To address this range of uptake into the food web, a functional food web addressing terrestrial, riparian, and aquatic receptors is under development.

Ecological assessment endpoints are under development based on the EPA General Ecological Assessment Endpoint framework (EPA 2016b). This framework begins with management goals and converts these goals into specific endpoints with an entity (e.g., species), attribute (e.g., reproduction), and direction of change (e.g., decrease) identified. Management goals are sometimes spelled out in laws, regulations, or guidance. For example, the DOE Order 458.1, Section 4.j “Protection of Biota” states:

- (1) Radiological activities that have the potential to impact the environment must be conducted in a manner that protects populations of aquatic animals, terrestrial plants, and terrestrial animals in local ecosystems from adverse effects due to radiation and radioactive material released from DOE operations.

(2) When actions taken to protect humans from radiation and radioactive materials are not adequate to protect biota then evaluations must be done to demonstrate compliance with paragraph 4.j.(1) of this Order in one or more of the following ways:

- (a) Use DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*.
- (b) Use an alternative approach to demonstrate that the dose rates to representative biota populations do not exceed the dose rate criteria in DOE-STD-1153-2002, Table 2.2.
- (c) Use an ecological risk assessment to demonstrate that radiation and radioactive material released from DOE operations will not adversely affect populations within the ecosystem.

Based on DOE Order 458.1, one management goal is to protect “populations of aquatic animals, terrestrial plants, and terrestrial animals in local ecosystems from adverse effects due to radiation and radioactive material released from DOE operations.”

Protected species represent a special category of biota that was discussed in Section 3.2.6.6. Under current conditions there are few threatened or endangered species potentially impacted by the Site. If radionuclides or non-radionuclide chemical contamination were to be distributed off-site in the future, then other threatened and endangered species might be impacted. Migratory birds are also protected from taking or killing. Federally listed threatened or endangered species are also protected from takings or activities that may jeopardize their continued existence. For these reasons management goals for protected species are stated in terms of protecting against adverse effects on individuals.

Management goals for the Site are under development but at this point include protection of biota populations for all species and security of individuals of protected species. The species listed in Section 3.2.6 provide a starting point for ecological assessment endpoint entities.

4.4.3 PPA Future Conditions and Assessment Scale

The time frame for the ecological risk assessment will parallel that selected for the human health risk assessment. As one goes further into the future there is greater potential for significant off-site transport from the Site proper to areas possibly affected by future releases. There will also be opportunities for changes to the type and distribution of biota based on natural and anthropogenic changes to the landscape and climate. The relationship between the current biota and those expected at various points in time and space are currently in development.

Although the management goals and ecological assessment endpoints are under development, the available information suggests that the ecological risk assessment should assess the potential for adverse effects on biota at a range of spatial scales. This range is needed to address the natural differences in areas used by species for foraging as well as variation in the type of habitat generally used by biota. We also expect that, while impacts on populations are desired for ecological risk assessment entities, protected species require information at the scale of individuals.

Spatial scales should reflect the assessment population areas for the entities selected for the ecological risk assessment. For special status species, information on the home range is used to define the spatial scale. Habitat suitability index (HSI) models

(<http://www.nwrc.usgs.gov/wdb/pub/hsi/hsiintro.htm>) can assist with determining the likelihood of a species using part of the landscape. HSI models are available for several wildlife species.

Based on the time frames identified for the ecological risk assessment, relevant spatial scales are the Site proper, Buttermilk Creek, Cattaraugus Creek, and Lake Erie. The appropriate representative biota species for these scales is based on the home range or assessment population area. Wildlife home range is available from both national and regional literature compilations.

As discussed in problem formulation, wildlife species are selected to represent a range of exposures based on their position in the food web. These species differ taxonomically (e.g., bird, mammal, reptile) and are based on their spatial and temporal interactions with contaminants in soil and in their food. Although temporal variations in food webs can be significant (Preziosi and Pastorok 2008), this assessment focuses on spatial variation in exposure through the food web. Variations in spatial exposures are commonly addressed by adjusting contaminant intake by the area use factor (AUF), which is the ratio of the area of the contaminated site(s) to an individual animal's home range. The AUF considers how exposure from a contaminated site might be evaluated for individual animals; it does not readily assess impacts on populations or address cumulative risk from multiple contaminant source areas.

To consider animal populations, Ryti et al. (2004) proposed an approach for defining an assessment population for wildlife based on dispersal distance; i.e., the distance an animal moves from its birthplace. This approach assumes that animals within the typical dispersal distance have greater potential for interbreeding and thus can fulfill one of the requirements for a biological population. The population area use factor (PAUF) was developed using published information for animal dispersal distances and the statistical relationship between dispersal and home range size (Bowman et al. 2002). Dispersal distance is related to home range because both scale allometrically with body weight. Dispersal distance information is presented in Sutherland et al. (2000), Appendix 1, for both birds and mammals.

The PAUF is the proportion of a receptor's assessment population area that is represented by a contaminated site. This approach is similar to that developed by the State of Oregon to evaluate adverse effects on populations by estimating the area inhabited by a local population that overlaps a potentially contaminated site (Fuji et al. 2000; Hope and Peterson 2000). The PAUF provides information on the appropriate spatial scale for the assessment and directly addresses cumulative risk from multiple contaminant source areas for an ecological population.

Information on the critical patch size required for plants and wildlife might also be useful in selecting receptors and in defining the assessment population area. There are various ecological data compilations with information on receptor home range, critical patch size, and dispersal distance (e.g., (Bowman et al. 2002; Carlsen et al. 2004; Sutherland et al. 2000)). For bird and mammal wildlife receptors in particular, there is likely directly relevant information available, or population-relevant spatial estimates can be made from allometric relationships. Carlsen et al. (2004) compiled information on the minimum home range and the critical patch size for mammals, birds, reptiles, and amphibians. The critical patch size is the minimum area of habitat required for persistence of a species. This area can be based on the calculation of a minimum viable population size and information on animal density.

4.4.4 PPA Ecological Risk Assessment Thresholds

Risk assessment thresholds are commonly used as an initial tier of screening for adverse effects on biota. These screening values provide *de minimus* risk thresholds for ecological receptors, and are available from national and regional compilations.

For radionuclides, we use medium- and radionuclide-specific BCGs (discussed in Section 4.4.1), as risk-screening thresholds. As the BCGs are used to sum effects over radionuclides and pathways, the Tier 1 BCGs are divided by 100 to account for these calculations and to be protective of terrestrial, riparian, and aquatic receptors at both the population and individual levels. As discussed in Section 4.4.3, the ecological risk assessment should ultimately be protective of risks for the Site proper, Buttermilk Creek, Cattaraugus Creek, and Lake Erie. The modeled radionuclide concentrations in soil, sediment, and water would be compared to the relevant BCG. If a media concentration is greater than 1% of the BCG, then further calculations based on the sum of fractions (SOF) would be conducted. Receptors and spatial averages appropriate for individual or population effects would also be calculated if the SOF is greater than 1. As necessary, a distribution of radiological dose estimate for ecological assessment endpoint entities would be calculated.

For chemical contamination, we use medium-specific screening values from national or regional sources. These screening values are generally based on no effect concentrations for a single chemical. In some cases, analytes in a class of compounds are summed for additive effects. However, this is not generally the case. Therefore, as an initial screen of *de minimus* risk, we use 10% of the screening value as a threshold. This increases the likelihood that the chemical has no adverse effects at this lower threshold. If any chemicals are identified in the initial screen, then the probability of adverse effects is calculated for the endpoint based on dose-response information and the distribution of exposures for a specific assessment zone at that time (Site proper, Buttermilk Creek, Cattaraugus Creek, or Lake Erie). Sources for chemical screening values are as follows:

- Soil: EPA Eco-SSLs, supplemented as needed by the LANL ECORISK Database and the EPA ECOTOX Database (https://cfpub.epa.gov/ecotox/quick_query.htm)
- Sediment: NY State sediment screening values (NYSDEC 2014), supplemented as needed by the LANL ECORISK Database and the EPA ECOTOX Database (https://cfpub.epa.gov/ecotox/quick_query.htm)
- Water: NY State ambient water quality criteria (NYSDEC 1998), supplemented as needed by the LANL ECORISK Database and the EPA ECOTOX Database (https://cfpub.epa.gov/ecotox/quick_query.htm)

5.0 Contaminant Fate and Transport Modeling

5.1 Modeled Facilities

This section discusses the implementation of West Valley Site facilities (Section 3.1) as discrete entities in the West Valley PPA Model.

5.1.1 Areas of Residual Contamination

The expected state of contamination at the end of Phase 1 decommissioning activities is documented by DOE (2009). The residual contamination remaining after the completion of Phase 1 decommissioning needs to be included in the consideration of which facilities are slated for remediation under Phase 2 decision making, and to what degree that remediation should occur.

The West Valley PPA Model represents each facility with Phase 1 residuals and each facility that is to be considered for Phase 2 decommissioning, including its source term of contamination, the engineered and natural environment that governs the release of contaminants to the larger environment, and the fate and transport of contaminants from the facility to exposure media that will contribute to future risk to people and the environment. In some cases, it is prudent to group several discrete facilities together in order to simplify the Model. This is especially true for remediated facilities, where additional removal is not considered in the initial West Valley PPA Model.

The identification of contaminated areas is based on discussions and data provided in several documents (DOE 2009, 2010a, 2010c; ECS 2015). A summary of the collection of modeled areas (Section 5.1.1.3) follows a discussion of their inclusion in Phase 1 (Section 5.1.1.1) and Phase 2 (Section 5.1.1.2) decision making efforts. Details about each area and how it will be represented in the Model are provided following the summary.

Since the Phase 1 decommissioning activities are still underway, estimates of residual soil contamination must be relied upon until sampling of the excavated areas can be accomplished. For those facilities and contaminated areas that are subject to Phase 2 work, the West Valley PPA Model will also have to rely on estimated residual concentrations that would be expected were the facilities to be removed. That is, in order to determine the reduction in risk that would be gained by removal of a particular facility, estimates of contaminant inventory are needed both for the case of leaving the facility in place, and for removing the facility, leaving only residual contamination in place.

5.1.1.1 Residuals from Phase 1 Actions

Phase 1 decommissioning of contaminated structures and soils includes removal of highly contaminated structures and materials, but stops short of leaving the area pristine. Even under unrestricted use criteria, some MDC of contaminants is left behind, often at depth. As a background for Phase 2 decision making, the residuals from Phase 1 efforts must be accounted for in the modeling of fate and transport, as well as their contributions to dose and risk.

All of the facilities in WMA 1 are slated for removal under Phase 1. These include the MPPB (including the “sealed rooms”), Vitrification Facility, 01-14 Building, Fuel Receiving and Storage Building, Load-In/Load-Out Facility, Utility Room and Expansion, Fire Pumphouse and Water Storage Tank, Plant Office Building, Electrical Substations, underground lines and tanks, Source Area of the North Plateau Plume, and Vitrification Off-Gas Line and Trench. Although these will all have been removed during Phase 1, each will have residual contamination left behind, to be accounted for in the West Valley PPA Model. In addition, as for all the WMAs, there are local surface soils, subsurface soil, and groundwater that will also contain residual contamination.

Aside from the PTW, the fate of which is to be evaluated under Phase 2, most of the facilities in WMA 2 are to be removed under Phase 1. These include the LLW Treatment Facility, Lagoons 1 through 5, Neutralization Pit, Old and New Interceptors, Solvent Dike, wastewater lines, and all associated foundations, concrete, and gravel pads. Some may have residual contamination at the time of closure.

Some of the facilities in WMA 3 are slated for removal under Phase 1. These include the HLW Transfer Trench Piping, the waste tank pumps, the Equipment Shelter and associated condensers, and the Con-Edison Building. Foundations, pads, and some subsurface contamination are expected to remain. Other tanks and structures will be addressed under Phase 2.

Nothing in WMA 4 is addressed in the Phase 1 work.

All of the facilities in WMA 5 are slated for removal during Phase 1, although radiological contamination is expected to remain. This includes the Remote-Handled Waste Facility, the Chemical Process Cell Waste Storage Area (CPCWSA), Lag Storage Area 3, Lag Storage Area 4, and all associated foundations, concrete, and gravel pads. Although the Lag Storage Area 3 and the CPCWSA were expected to be removed before the start of Phase 1, as of May 2017, those facilities are still standing and in use.

All of the facilities in WMA 6, with the exception of the Rail Spur, are slated for removal under Phase 1, including the Sewage Treatment Plant, Demineralizer Sludge Ponds, the Equalization Basin and Tank, and all associated foundations, concrete, and gravel pads. Some subsurface contamination is expected to remain. The Rail Spur, some of which is in WMA 6, has documented ¹³⁷Cs contamination near the former Old Warehouse (DOE 2010c), but contamination along the rest of the rail line is yet to be examined.

All of WMA 7 is occupied by the NDA, and all of WMA 8 is the SDA. Neither of these is addressed in Phase 1.

All of the facilities in WMA 9 are slated for removal under Phase 1. These include the Integrated Radwaste Treatment System Drum Cell, Trench Soil Container Area Pad, and the Subcontractor Maintenance Area. Some residual contamination is expected to remain.

All of the facilities in WMA 10 are addressed under Phase 1. This is the Support and Services Area, including the New Warehouse, Security Buildings, and parking lots.

Nothing in WMA 11 is included in the Phase 1 work. Radionuclides present at the Bulk Storage Warehouse are either consistent with background or are below the screening levels or DCGLs for the unit.

Nothing in WMA 12 is considered in the Phase 1 work.

The source of the North Plateau groundwater plume is the MPPB, which is to be removed in Phase 1. The remainder of the plume will be addressed in Phase 2.

Other contaminated areas are not considered in Phase 1.

5.1.1.2 Areas Subject to Phase 2 Decision Making

Phase 2 decision making addresses the alternatives of closing each contaminated facility in place, or performing remediation to reduce risk by removing the bulk of the contamination. A central role of the West Valley PPA Model in Phase 2 decision making is the estimation of the reduction of risk achieved by removing a given facility, as opposed to leaving it in place. This analysis will help to prioritize cleanup actions.

For each facility under consideration for Phase 2, two inventories of radiological and hazardous chemical constituents must be developed: One is the inventory of contaminants that are known to be present currently—these would be sources of contamination left behind for facilities closed in place. The alternative is to remediate a given facility, with an inventory representing MDC levels.

No facilities in WMA 1 are considered for Phase 2 decision making, since they all will have been removed. However, residual contamination remaining in WMA 1 is included in the West Valley PPA Model since it may influence Phase 2 decisions at other locations.

Most of the WMA 2 facilities will also have been removed, but the PTW will not be removed, and so is subject to Phase 2 decision making.

Several facilities in WMA 3 are under consideration in Phase 2. These include the four waste tanks (8D-1, -2, -3, and -4), the HLW Transfer Trench itself, the Permanent Ventilation System Building, and the Supernatant Treatment System Support Building.

The Construction and Demolition Debris Landfill (CDDL) is the only facility in WMA 4, and it is in the path of the North Plateau groundwater plume, so its contents are presumed to be contaminated, principally with ⁹⁰Sr. The CDDL is to be evaluated under Phase 2.

Like WMA 1, no facilities in WMA 5 are considered for Phase 2 decision making, since they all will have been removed. Residual contamination remaining is likewise included in the Model.

The only facility in WMA 6 to be considered under Phase 2 is the Rail Spur.

The entire WMA 7 consists of the NDA, which has several subareas to be considered in Phase 2. These include about 130 NFS Special Holes, about 100 NFS Deep Holes, 12 WVDP Trenches, 4 WVDP Caissons, the NDA Interceptor Trench, the Leachate Transfer Line, and the NDA Lagoon. These are evaluated in the West Valley PPA Model.

Similarly, all of WMA 8 consists of the SDA, which also has several subareas to be considered in Phase 2. These include the SDA North Disposal Area, SDA South Disposal Area, the Mixed Waste Storage Facility, and the SDA Lagoons. These are evaluated in the West Valley PPA Model.

No facilities in WMA 9 or WMA 10 are considered for Phase 2 decision making, since they all will have been removed. Residual contamination remaining is included in the Model.

All of the facilities in WMA 12 are evaluated as part of Phase 2. This includes the reservoirs and dams south of the plant, all of Buttermilk Creek downstream of the Site, and other surface waters and stream sediments within WMA 12.

The non-source area of the North Plateau groundwater plume located in WMAs 2, 4, and 5 is to be addressed in Phase 2, the source having been removed under Phase 1. Cleanup of the plume will result in some residual contamination in the North Plateau sand and gravel unit.

The PTW will be modeled as a contaminant source, since it will slowly leach contaminants into the environment in the desorption process, complementary to adsorption. Given the 30-yr half-life of ^{90}Sr , however, the process of desorption may be outpaced by radioactive decay, so the future risk attributed to the contaminants in the PTW is difficult to anticipate. This is evaluated in the Model. It may be that the ^{90}Sr will decay to very short-lived ^{90}Y and then to stable (non-radioactive) zirconium before much of it is released.

Off-site areas considered in the Model include the Cesium Prong and the waters and sediments of Cattaraugus Creek and points downstream.

Air dispersion is considered out to a much larger area, as discussed in Section 5.6.

5.1.1.3 Summary of Modeled Source Areas

Discrete regions that are sources of contamination and are included in the West Valley PPA Model are listed in Table 10. In this discretization of facilities, those that represent residuals following Phase 1 cleanup are grouped together within a given WMA. Those that are discussed individually in Appendix C of DOE (2010c) are listed individually in the table. Both of these organizational approaches could be modified, however, in future iterations of the Model. If needed, individual facilities with Phase 1 residuals could be broken out on their own. Conversely, facilities may be grouped together for the purposes of modeling contaminant transport and human exposures. For example, multiple facilities could be grouped into one in order to evaluate how they influence risk collectively. If it becomes apparent that a higher resolution of facilities is needed, then they can be broken apart in a future version of the West Valley PPA Model.

Table 10 enumerates the West Valley Site facilities that are proposed to be individually modeled in the West Valley PPA Model. For each facility remediated under Phase 1, an estimate of residual radionuclide and hazardous chemical contamination is needed, so that these may be properly accounted for in the estimations of risk from the entire Site. For each facility to be addressed under Phase 2, contaminant inventories are needed for the unremediated state (i.e. for the No Action Alternative), for the completely remediated state (complete excavation), and for

any other alternative in between that is to be evaluated. This level of detail is needed so that the effect in risk reduction to any receptor may be discerned for any alternative applied to any individual facility.

As a general note, Soils underlying removed slabs and other excavation footprints will be characterized as part of Remedial Action and Final Status Survey sampling as described in the *Phase 1 Characterization Sampling and Analysis Plan* (CSAP) (ANL 2011b) and the *Phase 1 Final Status Survey Plan* (FSSP) (ANL 2011a).

Table 10. West Valley Facilities to be included in the West Valley PPA Model.

facility name¹ [short name]	description	nature of contamination	decision alternatives	data sources²
WMA 1 Residuals [WMA1res]	Residuals remaining after Phase 1 cleanup of WMA 1. This includes the Main Plant Process Building (including the “sealed rooms”), Vitrification Facility, 01-14 Building, Fuel Receiving and Storage Building, Load-In/Load-Out Facility, Utility Room and Expansion, Fire Pumphouse and Water Storage Tank, Plant Office Building, Electrical Substations, underground lines and tanks, Source Area of the North Plateau Plume, and Vitrification Off-Gas Line and Trench, plus surface soils, subsurface soil, and groundwater.	Residual radioactive contamination in Lavery Till and downstream (above background radioactivity).	All WMA 1 facilities to be removed under Phase 1, but residual contamination will remain.	WVDP-RFI-016 (WVNS 1994b) for insight about materials sent to the NDA, tanks, LWTS, LAG storage, solvent dike, and the lagoons (and subsequently to Erdman Brook). WTF Radionuclide Residuals Supplemental Report (WVNS 2005), WVDP-RFI-026 (WVNS and Dames & Moore 1997b)
WMA 2 Residuals [WMA2res]	Residuals remaining after Phase 1 cleanup of WMA 2. This includes the LLW Treatment Facility, Lagoons 1 through 5, Neutralization Pit, Old and New Interceptors, Solvent Dike, wastewater lines, and foundations and slabs.	Residual rad and chem contamination; includes contents of PTW.	All WMA 2 facilities to be removed under Phase 1, but residual contamination will remain.	WVDP-RFI-020 (WVNS and Dames & Moore 1997d), WVDP-RFI-021 (WVNS and Dames & Moore 1997a), WVDP-RFI-025 (WVNS 1997), and WVDP-RFI-026 (WVNS and Dames & Moore 1997b).
WMA 2 Maintenance Shop leach field, [MSLF]	Within WMA 2.	"	"	WVDP-RFI-025 (WVNS 1997).
WMA 2 Permeable Treatment Wall [PTW]	Within WMA 2.	Rad and chem contamination; If removed: Residual rad and chem contamination.	Subject to Phase 2.	Data sources not yet identified.

facility name ¹ [short name]	description	nature of contamination	decision alternatives	data sources ²
WMA 3 Residuals [WMA3res]	Residuals remaining after Phase 1 cleanup of WMA 3. This includes the Equipment Shelter and condensers, Con-Edison Building.	Residual rad and chem contamination.	Some WMA 3 facilities to be removed under Phase 1, but residual contamination will remain.	Data sources not yet identified.
Tank 8D-1 (and its supernatant treatment system) [T8D1] Tank 8D-2 [T8D2] Tank 8D-3 [T8D3] Tank 8D-4 [T8D4]	This is within WMA 3.	Rad and chem contamination; If removed: Residual rad and chem contamination.	Subject to Phase 2; and could be modeled individually if different alternatives might be applied to different tanks.	WTF Radionuclide Residuals Supplemental Report (WVNS 2005), WVDP-RFI-024 (WVNS and Dames & Moore 1997c). Residuals estimated for cleaned tanks and associated structures.
HLW Transfer Trench [HLWTT]	"	Need to confirm if clean.	"	Data sources not yet identified.
Permanent Ventilation System Building [PVS]	"	Confirmatory sampling needed.	"	Rough total activity (Ci) estimates are provided in the FEIS (DOE 2010c), but confirmatory sampling is needed.
Supernatant Treatment System Support Building [STSSB]	"	Uncontaminated with the exception of the Valve Aisle. Confirmatory sampling needed.	"	WTF Supplemental Report (WVNS 2005) and the Exhumation Working Group (ECS 2016a, 2016b). Additional data sources not yet identified.
Construction and Demolition Debris Landfill [CDDL]	This is the only facility within WMA 4.	Radioactive contamination from NPGP; If removed: Residual rad contamination.	Subject to Phase 2.	WVDP-EIS-008 (WVNS 1996c), and WVDP-RFI-019 (WVNS 1996b).

facility name ¹ [short name]	description	nature of contamination	decision alternatives	data sources ²
WMA 5 Residuals [WMA5res]	Residuals remaining after Phase 1 cleanup of WMA 5. This includes the Remote Handled Waste Facility, Lag Storage Areas, Chemical Process Cell Waste Storage Area, and foundations and pads in WMA 5.	Residual rad and chem contamination.	All WMA 5 facilities to be removed under Phase 1, but residual contamination will remain.	WVDP-EIS-008 (WVNS 1996c), WVDP-RFI-022 (WVNS and Dames & Moore 1996a), and WVDP-RFI-023 (WVNS and Dames & Moore 1996b).
WMA 6 Residuals [WMA6res]	Residuals remaining after Phase 1 cleanup of WMA 6. This includes the Sewage Treatment Plant, Demineralizer Sludge Ponds, Equalization Basin and Tank, and foundations and pads in WMA 6.	Residual rad and chem contamination.	To be removed under Phase 1, but residual contamination will remain.	WVDP-EIS-008 (WVNS 1996c), WVDP-RFI-020 (WVNS and Dames & Moore 1997d), and CSAP (ANL 2011b).
Rail Spur [Rail]	This is within WMA 6.	Rad contamination; If removed: Residual rad contamination.	Subject to Phase 2.	WVDP-EIS-008 (WVNS 1996c), WVDP-RFI-020 (WVNS and Dames & Moore 1997d), WVDP-RFI-023 (WVNS and Dames & Moore 1996b), Additional data sources not yet identified.
NFS Special Holes [NDASpec]	This is within WMA 7, the NDA.	Rad and chem contamination; If removed: Residual rad and chem contamination.	Subject to Phase 2; these holes could be grouped or subdivided if different alternatives might be applied to different holes.	(DOE 2010c); ECS (2016a); (Prudic 1986; URS 2000; WVNS 1996a), and WVDP-RFI-018 (WVNS 1995a).
NFS Deep Holes [NDADeep]	"	"	Subject to Phase 2; these holes could be grouped or subdivided.	"
WVDP Trenches [NDATrench]	"	"	Subject to Phase 2; these trenches could be grouped or subdivided.	"
WVDP Caisson (1 of 4) [NDACaisson]	"	"	Subject to Phase 2; only 1 of 4 caissons is contaminated.	"

facility name ¹ [short name]	description	nature of contamination	decision alternatives	data sources ²
NDA Interceptor Trench and Liquid Pretreatment System [NDAIT]	"	"	Subject to Phase 2.	
Leachate Transfer Line [NDATransfer]	"	"	"	"
NDA Lagoon [NDALagoon]	"	"	"	"
foundations and pads in WMA 7 [WMA7pads]	"	"	"	"
SDA North Disposal Area [SDAN]	This is within WMA 8, the SDA.	Rad and chem contamination; If removed: Residual rad and chem contamination.	Subject to Phase 2; the trenches could be grouped or subdivided if different alternatives might be applied to different trenches.	SDA Radiological Characterization Report (Wild 2002) and Data Package (URS 2002a), Excel workbook "SDA Inventory Wild 2000 by Interval - New Method.xlsx" (Wild 2000).
SDA South Disposal Area [SDAS]	"	"	"	"
SDA Lagoons (3) [SDALagoon]	"	"	Subject to Phase 2; the lagoons could be grouped or subdivided.	" NYSERDA SDA RFI (Ecology and Environment 1994).
WMA 9 Residuals [WMA9res]	Residuals remaining after Phase 1 cleanup of WMA 9. This includes the Radioactive Waste Treatment System Drum Cell and the Trench Soil Container Area.	Possible residual rad and chem contamination. Confirmation survey needed.	All WMA 9 facilities to be removed under Phase 1, but residual contamination will remain.	Data sources are needed to verify clean state.

facility name ¹ [short name]	description	nature of contamination	decision alternatives	data sources ²
WMA 10 residuals [WMA10res]	Residuals remaining after Phase 1 cleanup of WMA 10. This includes the New Warehouse, Security Buildings, and parking lots.	Residual rad and chem contamination.	All WMA 10 facilities to be removed under Phase 1, but residual contamination will remain.	Data sources not yet identified.
Soils and Stream Sediments [SoilSed]	WMA 12 is the Balance of Site Facilities (BoSF). This includes Quarry Creek, Frank's Creek, Erdman Brook, and Buttermilk Creek downstream of the Site. Additional downstream contamination would extend into Cattaraugus Creek, Lake Erie, and beyond.	Rad and chem contamination; If removed: Residual rad and chem contamination.	Subject to Phase 2; subdivisions will be needed. The soils and stream sediments will be continually contaminated from "upstream" sources.	EID Vol. VI WVNS (1996c). Source terms for future surface water transport are developed internally to the model.
North Plateau Groundwater Plume source area [NPGPS]	Within WMA 1.	Residual rad and chem contamination in the North Plateau sands and gravels.	Source to be removed under Phase 1, but residual contamination will remain.	(WVES 2009b; WVNS 1995c, 1998, 1999).
North Plateau Groundwater Plume non- source area [NPGPNS]	Intersecting WMAs 1 through 6.	Rad and chem contamination; If removed: Residual rad and chem contamination.	Subject to Phase 2.	
Cesium Prong	On-site portions are to be included in the Model.	Rad contamination; If removed: Residual rad contamination. Off-site areas are shown to be free-release.	Subject to Phase 2.	

facility name ¹ [short name]	description	nature of contamination	decision alternatives	data sources ²
Areas affected by air dispersion	Potential future atmospheric dispersion would extend off-site and outside the WNYNSC boundary.	Rad and chem contamination.	Sources are subject to Phase 2; larger contaminated areas are not considered for cleanup.	Source terms for future atmospheric dispersion are developed internally to the Model.

¹ Facilities that are grouped together are modeled as a single virtual facility. Each listed facility is a discrete modeled source term with its own contaminant transport and human and ecological exposure calculations. Grouping facilities reduces the burdens of constructing and running the West Valley PPA Model. Evaluating facilities individually allows for finer granularity in decision making alternatives.

² Data need to be radionuclide-specific and hazardous chemical-specific (this applies to *all* data to support inventories in this table.)

5.2 Spatial and Temporal Model Domain

This section develops the spatial and temporal boundaries of the West Valley PPA Model, written in GoldSim. It does not document the boundaries of other models, such as the groundwater or regional air dispersion models *per se*, though the results of those models are incorporated into the GoldSim platform, so their domains are essentially accounted for by reference.

5.2.1 Spatial Considerations

Several independent criteria are used to help in defining the spatial extent of the West Valley PPA Model. These are categorized as the locations of contaminant sources, an evaluation of the contaminant transport processes and how they govern migration of the contaminants into the environment, and the locations of receptors.

5.2.1.1 Locations of Contaminant Sources

Contaminant sources are scattered across the West Valley Site (Figure 1), though most are located in the vicinity of the WVDP and most are within 30 m (100 ft) of the ground surface. There are sources of contamination in all WMAs, either as Phase 1 residuals, Phase 2 residuals, or other contamination left in place. Other sources of contamination are more widespread, including the North Plateau groundwater plume, the Cesium Prong, and currently contaminated stream sediments. The West Valley PPA Model considers all of these sources, enumerated in Table 10. Source areas and depths define a minimum spatial domain for the Model.

5.2.1.2 Processes for Contaminant Redistribution

Following the spatial definitions of contaminant sources, consideration is next given to the spatial extent of where contaminants might migrate to within the Model. This depends on the processes that are modeled, and to what extent each of these might move contaminants.

Groundwater advective transport will pick up contaminants as groundwater flows through contaminated source volumes. Groundwater flow at the Site is discussed in Section 3.2.8.2.5. Most flow is in the upper several meters or tens of meters from the surface. This is where the contaminant sources are encountered, some in trenches or in holes that might allow the groundwater to flow deeper. Irrespective of the exact paths of groundwater flow, all the local groundwater eventually drains into Buttermilk Creek and its tributaries Frank's Creek, Quarry Creek, and Erdman Brook. In order to account for groundwater flow, then, the spatial domain will include contributions to these surface water drainages. The spatial domain of groundwater diffusive transport is essentially coincident with the advective transport domain.

Surface water transport continues from there, flowing downstream to Cattaraugus Creek and into Lake Erie. All of these creeks are included in the West Valley PPA Model.

Airborne contaminant transport includes diffusion in air within subsurface porous media as well as atmospheric diffusion and transport above ground. Subsurface air diffusive transport starts with the underground source volumes, and proceeds most quickly in the direction of the

overlying atmosphere, which acts as a large sink for subsurface air transport. This means that the concentration gradients that drive diffusion in air are generally upwards, to the ground surface. The air diffusion pathway, then, is upwards from each contaminant source to the area of that source projected up to the ground surface. This is included in the column representing each contaminated facility.

Atmospheric dispersion transports contaminants emanating from that ground surface area to the surrounding atmosphere. These airborne contaminants are distributed upwards and laterally depending on atmospheric conditions. The upper bound of the model is defined by the atmospheric mixing height above the Site (Section 3.2.5.6). Laterally, the boundaries depend on the results of the atmospheric dispersion model that is used to estimate contaminant concentrations in the region. In reality, the contaminants are dispersed endlessly within the atmosphere, but in practical terms the concentrations in the air mix with contaminants from other sources, and the “trace” of the West Valley airborne contaminants is lost. Other sources include naturally occurring radon and a host of organic pollutants originating from the exhaust of internal combustion engines, the application of agricultural chemicals, and the like. The risk from West Valley Site sources is quickly masked by that from other sources. For the purposes of modeling atmospheric dispersion, it is more practical to use receptor locations to define where in the atmospheric dispersion plume to estimate concentrations, rather than to attempt to define some domain outside of which the atmospheric concentrations no longer are relevant.

Plants and animals also provide transport mechanisms, but these are limited to the contaminated volume that is reachable by plant roots or animal burrows, and the projected volume above it to the ground surface. This biotically induced transport operates at essentially the same spatial domain as the air phase diffusive processes.

Erosion as a contaminant transport mechanism covers a wide area. Surface erosion will transport contaminated soils from the ground surface above a contaminated facility to the nearest surface water body. Mass wasting will transport contaminated soils and materials (including wastes) in bulk from the top to the bottom of a slump. Sediment transport in the creeks can be thought of as a sort of erosional process, so the creeks are to be included as well.

The final consideration about the spatial extent of the West Valley PPA Model is the various locations of receptors. More specifically, the Model must include the exposure media (soil, sediment, water, air) to which a receptor would be exposed. For example, Section 4.2.3 addresses spatial considerations for future human exposures. That section identifies a “radius of interest,” within which locations of people are considered for modeling.

5.2.1.3 Spatial Domain of the West Valley PPA Model

Unlike many process models (e.g. for groundwater flow or atmospheric dispersion), GoldSim is not explicitly spatial—rather, spatial relationships are implied by the connections between model elements. The West Valley PPA Model, as a GoldSim model, also has these relationships implied. On one scale, the spatial relationships between the modeled cells that act as finite difference elements are tight: one cell is connected to the next, in a 1-dimensional columnar arrangement, with advective and diffusive flux connections. These columns are connected to the atmosphere at the ground surface, and to groundwater and surface water seeps in the subsurface.

Further, erosion will intrude into the contaminated columns, releasing more contamination into the surface water system. This system subsequently transports contamination downstream to Lake Erie and receptors in Buffalo, for example.

The spatial domain of the Model can be thought of as a concentrated collection of model elements in the near field at the West Valley Site, with streams defining additional 1-D transport pathways to downstream people. Atmospheric dispersion is reduced to concentrations at human receptor locations that are functions of the contaminant flux atop the various facilities and the distance of the people from the facilities.

5.2.2 Temporal Considerations

The West Valley PPA Model establishes a chronology for modeling purposes. This specifies when important things happen for the Model. Some events in the chronology are related to near-term Site operations, and others are related to the distant future. Both of these are discussed in this section.

5.2.2.1 Operational Chronology

From a radiological standpoint, the West Valley Site began operations in 1963 as NFS began accepting low level waste for disposal in the SDA. Waste disposals began in 1963 and continued into 1986. Releases to the environment are ongoing, though many sources will be removed as part of Phase 1 decommissioning. The degree to which these details need to be captured is uncertain, and is decided during model development.

5.2.2.2 Site Closure

The time of Site closure is indeterminate, though Phase 1 decommissioning is planned to be complete by the year 2020. This would be followed by Phase 2 activities, followed by Site closure. The Model is constructed to include the time of closure as an uncertain variable.

5.2.2.3 Loss of Institutional Control

Following Site closure, there is a period of time during which institutional control is active and effective. The effectiveness of IC is expected to degrade, as is typical of long-term care programs of legacy waste sites and other industrial properties. At some point in the future, IC is expected to be lost completely, and the assumption is made for modeling purposes that there are no longer any institutional barriers to Site occupation.

The timing of the loss of IC is important, since it defines when on-site receptors may have access to the Site. This is discussed in Section 4.2.2. In accordance with regulations from NRC and DOE orders (Section 2.0), the West Valley PPA Model is set up to record doses and risks to people at specific times in the future, such as 1000 or 10,000 yr post-closure. These values are used principally to evaluate compliance, but are also useful benchmarks for evaluating the effectiveness of various approaches to keeping doses ALARA. Refer to Section 2.1 for additional details regarding IC, unrestricted use, and restricted conditions.

5.2.2.4 Time of Peak Risk

Both NRC regulations and DOE Orders state that the Model should be run into the future in order to determine the peak values of dose and risk and the time at which these peaks occur. The time of peak dose and risk will be different for different receptors, but each of these is recorded in the Model.

5.2.2.5 Temporal Domain of the West Valley PPA Model

The start time of the Model will account for previous contaminant releases to the environment. Contaminant migration begins with the early introductions of contamination, and not at the time of Site closure. At Model time zero (year 2020), the locations and concentrations of contamination previously released will be in place.

The duration of the Model can be easily extended to any arbitrary time in order to determine the timing of peak dose and risk. This model duration is not a predetermined value. Extended calculations are readily performed by GoldSim, although they obviously increase the size of model results.

5.3 Contaminant Release

The West Valley PPA Model calculates the fate and transport of contaminants, whether they are disposed as waste, remediated in place, or left as residuals following cleanup. At the beginning of the model calculations, contaminants are represented as radionuclides and chemicals with inventories in discrete modeled source volumes. Some of these may be associated with contaminated soils, and others with contained materials, such as grouted wastes or discrete objects. These are modeled using two different modeling techniques, as described in this section.

5.3.1 Instantaneous Release

Much of the waste in the NDA and SDA waste disposal units was emplaced in cardboard boxes, thin-walled steel drums, and other containers that are assumed to not retain structural integrity in the disposal unit environment. Much of the other inadvertent contamination around the Site is in bulk media such as soils and other geologic materials.

All of these contaminated materials are assumed to allow instantaneous release of contaminants to the surrounding environment. That is, no containment is assumed. Contaminants are subject to partitioning between water and solids (soils, till, etc.), and water and air. They will migrate into the environment immediately, driven by the contaminant processes that are present at the Site, as discussed below (Sections 5.4 to 5.7).

5.3.2 Moderated Release

Some disposed wastes and contaminated structures, however, may release more slowly. A piece of irradiated hardware, for example, would contain activation products throughout its volume, releasing them through diffusion through the metal and directly as the metal itself corrodes. Some wastes may be mixed in with a grouted or vitrified matrix, which would have similar release mechanisms. The waste release modeling tools available natively in GoldSim can be used

to approximate these various release mechanisms in the West Valley PPA Model. The specifics of this modeling technique, including uncertain rates of degradation and fractions of released contaminants, are determined and documented as part of fate and transport model development.

5.4 Subsurface Transport

The following sections describe the transport processes that affect the underground movement of contaminants at the Site. Contaminants in the subsurface are found in varying concentrations in air, water, and sorbed onto solid materials according to their partitioning coefficients and solubilities (Section 5.4.1). This controls the quantity of contaminant available to migrate by advection (Section 5.4.2) and diffusion (Section 5.4.3).

5.4.1 Partition Coefficients

This CSM accounts for partitioning between solid and water phases via adsorption, solubility in water, and partitioning between interstitial air and water phases. As a set of simplifying assumptions, partitioning is often modeled as a reversible, linear, equilibrium process, whereby concentrations are instantaneously allocated between the phases in amounts proportional to the quantity of contaminant present, with proportionality coefficients specific to each contaminant and independent of radioisotope. Some of these coefficients depend sensitively on local geochemical conditions, rock mineralogy, and temperature. This section discusses the geochemical relationships between the contaminant concentrations in the various media to be modeled at the Site.

5.4.1.1 Air/Water Partitioning

In the absence of other processes, a volatile solute will partition between air and water phases in a given proportion (for a given temperature), following Henry's Law. The ratio of the concentration of a contaminant in water to its concentration in air is known as its Henry's Law coefficient (K_H), which can have many functional forms. Possible volatile radionuclides of interest in the modeling of radioactive wastes at the Site are ^3H , ^{14}C , ^{129}I , and the isotopes of radon (^{222}Rn in particular) (Section 3.3.4). Nonradioactive volatile contaminants that are part of the inventory (Section 3.4.4), such as acetone and chloroform, will also have stochastic Henry's Law coefficients. Nonvolatile solutes have a K_H of 0.

5.4.1.2 Adsorption

Adsorption is the partitioning of ions or compounds from water onto the surface of solid phases. The minerals that compose a soil or other subsurface solids often have surfaces with charges or partial charges that attract molecules in solution. Clay surfaces typically have more surface charge, which encourages more adsorption (EPA 1999). Sorption consists of several physicochemical processes including ion exchange, adsorption, and chemisorption. The most common simplified model for these complex processes is a linear relationship expressed by the water/rock partition coefficient K_d , which is the proportion of the mass of an element adsorbed onto the solid phase compared to the mass in solution. Contaminants that do not adsorb onto solids have a K_d of 0.

The major solid material groupings that will be considered for their sorptive behavior at the Site are sands and gravels, clays and tills, bedrock, and cementitious materials.

5.4.1.3 Solubility

Aqueous solubility is a chemical property that quantifies the concentration of a contaminant in water in equilibrium with solid minerals. The solubility limit is the maximum aqueous concentration attainable for a given contaminant. In general, the solubility of any element depends on water composition, temperature, and which solid minerals are present. The CSM adopts simplified assumptions for solubility modeling that do not take these variables into account as a function of time, but rather assumes a constant (stochastic) value for solubility limit for each contaminant.

5.4.2 Advective Transport

Advection is the process of mass transport due to the bulk flow of a fluid. For contaminants in the aqueous phase, advective transport is controlled by the velocity of water. Contaminants may be transported towards the water table with infiltrating water in the vadose zone when fluxes are directed downward. Movement of water in this zone is governed by multiphase flow parameters, including retention characteristics (capillary suction as a function of saturation) and relative permeabilities of air and water. Contaminants may also be retained in immobile zones within pore spaces and fractures, although they may still participate in diffusive transport (Section 5.4.3) while immobilized to advection if enough aqueous interconnectedness exists between pores. This process can lead to late-time tailing behavior in breakthrough curves for solute transport through the vadose zone, as well as earlier than expected arrival times due to a smaller available porosity for flow (Stephens 1995). The conceptualization of advective transport is simplified for modeling purposes, but these effects may be included through simplified models and adjusted parameters (e.g., effective porosity). In groundwater, assuming isotropic and homogeneous materials, advective transport follows the hydraulic gradient with average pore velocities determined by Darcy's Law and effective porosity. During advective transport from a source region of contamination into fresh material, transport velocities for some contaminants may be effectively slowed by retardation due to sorption onto the solid phase (Section 5.4.1.2 above). Key elements related to advective transport from the hydrologic system described in Section 3.2.8 include:

- Infiltration and evapotranspiration: estimated rate and seasonality of water flux through the vadose zone (Section 3.2.8.2.3); differences between the North and South Plateau surficial units (Section 3.2.8.2.2).
- Fracture transport: whether the fractured WLT is better modeled as an equivalent porous medium or by a multiple overlapping continuum model (matrix and fracture) may depend on the season (Section 3.2.8.2.3); preferential flow in the fractured weathered bedrock (Section 3.2.8.2.5).
- Direction of flow in the units present beneath the Site ranges from generally northeasterly in the higher-hydraulic conductivity units to vertical from one unit to the underlying or overlying unit in the lower-hydraulic conductivity units (Section 3.2.8.2.5); velocities of flow in these units have been estimated.

- An additional unsaturated region is present in the upper part of the KRS (Section 3.2.8.2.4).
- The locations and nature of recharge and discharge from groundwater (Section 3.2.8.2.5), the presence of pumping wells, and subsurface barriers can all affect advective transport.
- Geochemical factors that affect sorption (Section 3.2.8.3), including engineered structures such as the PTW, affect the rate of advective transport by way of retardation coefficients.

Mechanical dispersion is also included in the Site CSM. This is a process that spreads out an advecting solute front as it migrates through a porous material. It arises from (1) differing pore sizes with correspondingly different flow velocities, (2) differing solute speeds within individual pores due to the no-slip boundary condition, and the existence of mobile and immobile zones to flow, (3) different path lengths for different tortuous routes taken through the pores, and (4) heterogeneity in the material (Fetter 1994). Dispersion produces an apparent diffusive-like distribution of solutes, which is typically combined with diffusion coefficients (Section 5.4.3) into a single effective diffusivity term. The term “dispersivity” is used to describe a coefficient (α) with units of length that, when multiplied by solute advective velocity, can be directly added to the molecular diffusion coefficient. Dispersivities are typically larger in the longitudinal (same direction as flow) direction than transverse (perpendicular to flow) directions. Dispersivities are scale-dependent (Fetter 1994) and are a function of the material properties (e.g., homogeneity of pore sizes) and saturation. Their relative importance in a given transport situation depends on the Péclet number, a dimensionless ratio that compares the effectiveness of advective to diffusive transport (Fetter 2008).

Advective transport of volatile contaminants in air is not a significant process at the Site. Possible mechanisms of air-phase advection include barometric pumping, density-driven flow, and winds, but these are generally more predominant for transporting contaminants at drier sites with thick vadose zones and extensive, well-connected fractured or rubblized rock (Stephens 1995). Although the WLT on the South Plateau is fractured, the water table is close to the surface (Section 3.2.8.2.3) and transport in the aqueous phase is the greater concern. On the North Plateau, where the surficial TBU is unfractured, effects of barometric pumping would not be expected to penetrate to more than about a meter (Stephens 1995).

5.4.3 Diffusive Transport

Diffusion is the movement of a contaminant within air or water by its own kinetic motion, independent of the movement of the fluid (air or water). Transport in air and water by diffusion is included in the Site CSM. Diffusion is commonly modeled using Fick’s Laws, which state that diffusive flux is proportional to the concentration gradient, and the time rate of change of concentration is proportional to the second derivative of concentration with respect to spatial coordinates. The proportionality constant is known as the molecular diffusion coefficient, D_i , for constituent i . It depends on factors such as temperature, pressure, and molecular size.

Since the direction of diffusion is driven only by the concentration gradient, diffusion is independent of gravity and can move radionuclides in all directions in response to a concentration gradient including upward toward plant roots and the ground surface. In general, transport will be away from the waste zones where the concentration is highest.

In free space (i.e., not confined by porous material such as soil or rock), the diffusion coefficient is referred to as $D_{i,air}$ or $D_{i,water}$ for the two media. The effective diffusivity in subsurface porous material is modified (reduced) due to the tortuosity (τ) of the pore space, which depends in turn on the porosity of the material and its saturation. Aqueous diffusion occurs through pores in the material that are interconnected with water, with increasing water contents leading to higher effective diffusivity. For diffusion in air, the relationship between diffusion rate and water content is reversed. Increasing water content reduces the interstitial air space available and reduces the effective diffusivity.

Air phase diffusion can move volatile contaminants up to the ground surface where they are released to the atmosphere (Section 5.6).

5.5 Surface Water Transport

Contaminants from the Site may enter the stream network and move off-site in different modes and at different rates dependent on contaminant-specific factors. The CSM considers the following sources of dissolved contaminants entering surface water:

- groundwater seepage,
- storm water runoff across surfaces bearing residual contamination,
- dissolution from contaminants in stream channel sediment storage (including floodplain and bar deposits),
- leachate from overtopping disposal trenches, and
- leachate from disposal trenches breached by erosion processes.

The CSM considers the following sources of particle-bound contaminants to surface water:

- residual contaminants from soil and fill material erosion by sheet flow, rilling, and gullyng,
- residual contaminants from soil and fill material erosion by mass wasting and landsliding,
- remobilization of contaminated sediment in stream channel sediment storage (including floodplain and bar deposits), and
- waste material exposed in trenches breached by erosion processes.

Models with a wide range of chemical, biological, and hydraulic complexity have been developed to predict fluvial transport of contaminants. The appropriate level of detail to adopt will be determined by the temporal and spatial scales incorporated into the West Valley PPA Model.

5.5.1 Surface Waters

The distribution of contaminants among water, air, and sorbed to particles in soils and sediments is described by partition coefficients specific to a given substance, as with groundwater (Section 5.4.1). Due to complexities resulting from larger rates of water flow and a wide range of environmental conditions present in the stream network, the CSM includes constant (stochastic) values for K_H , K_d , and solubility limits for each contaminant.

Contaminants are subject to physical, chemical, and biological processes as they move down the stream network, including, but not limited to, advection, dispersion, volatilization, sorption, radioactive decay, oxidation, microbial degradation, and biotic uptake. Volatilization in rapid, shallow flows is significant for many of the organic compounds listed in Section 3.4.2, such as the benzenes and methylene chloride. Volatilization half-lives are longer in wetland ponds or Lake Erie, and adsorption to suspended sediments might drastically increase their resident half-lives in either setting (Rathbun 1998). Microbial degradation is important for many as well, including cresol and acetone (NIH 2016). Where appropriate, the CSM incorporates storage and decay rates ascribed to these and other potentially significant processes.

Increased travel times and altered geochemical conditions in hyporheic waters associated with channels and bankforms might promote increased rates or efficiency of sorption/desorption, oxidation, and microbial degradation processes. The CSM provisionally includes this pathway.

5.5.2 Sediment Transport

The CSM includes erosion and sediment transport with transient deposition as processes affecting contaminated soil and/or disaggregated waste materials. The characteristics of the releases are dependent on the erosional processes leading to exposure and transport of contaminants, the specific breached site (contaminant source areas are distributed across the North and South Plateaus), and the Phase 2 decommissioning alternatives to be evaluated in the SEIS.

The sequence of erosional processes associated with release and sediment transport of contamination includes:

1. *Breaching of contaminant sites by processes of erosion including gully migration, channel undercutting, and hillslope processes.* Higher probability sites for erosion are associated with Quarry and Frank's Creek and Erdman Brook; landscape evolution modeling identified four higher priority sites of unmitigated erosion including NP-1, NP-2, NP-3, and the NDA gullies (DOE (2010c), Appendix F).
2. *Downslope migration of surface contaminants to creeks.* Transport processes include surface-water flow in areas of topographic convergence, hillslope erosion, and slope failure. Erosion and transport processes associated with gully to stream channel transition are illustrated in Figure 25.
3. *Ephemeral transport of contaminated bed-load sediments in creeks and stream channels.* Space-time variations are expected in sediment grain size and cover fraction with stream flow and downcutting. Sediment load will vary seasonally dependent on storm events, snow cover, and vegetation. Transport properties are unique to the upper reaches of the

drainage channels but will normalize below the intersection of Quarry and Frank's Creek and Buttermilk Creek. Bed sediments in Buttermilk Creek are predominantly gravel- and cobble-size with sand and minor silt fractions. Sediment grain size and transport rates will vary with different frequencies of flood events. Sediment studies in Buttermilk Creek show that large sediment clasts are mobilized in one-year equivalent flows with exchange of sediment between active channels and sites of transient deposition (for example, point bars, levees, floodplains, and terraces).

In the surface water environment, stable and radioactive heavy metals have high affinity for adsorbing to fine particles, organic materials, and hydrous oxides of iron so that contaminant loads are dominated by sediments (Graf 1994). Organic contaminants such as PCBs and 1,4-dioxane also adsorb strongly to soils and sediments (NIH 2016). The CSM includes downstream transport of contaminants by adsorption to clay-, silt-, and sand-sized particles in suspension and as a component of bedload (Walters et al. 1982b). The CSM includes exchange between stream flow and temporary storage in channel, point bar, and floodplain deposits, and in sediments trapped by Scoby Hill Dam (USACE 2014).

5.6 Transport in Air

Contaminants accumulating on or at the ground surface above the wastes due to plant and animal activity and diffusion of soluble and gas-phase contaminants exiting soil pore space can be mixed with the atmosphere near the surface and transported downwind from the source. Physical and chemical processes in the atmosphere control the entrainment of gases and mineral aerosols, as well as mixing, transport by atmospheric advection, dispersion, and deposition at locations distant from the source. These processes are described by Samson in National Academy of Sciences (1988). Transport is the movement of contaminants due to average wind speed. Dispersion is mixing produced by local turbulence. Deposition is the return of the contaminant to the surface; it occurs through a number of processes. Conceptualization of atmospheric dispersion includes transport. As the surface soils collect contaminants migrating upwards from the buried wastes, diffusion of gases and resuspension of particulates (dust) into the atmosphere are sources for atmospheric dispersion in the region. As gas and suspended dust, contaminants are carried downwind, where they remain in the air in some concentration, and are deposited back onto the ground in less turbulent areas through settling of the larger particles and wash-out of the finer ones.

Processes in this lowest layer of the atmosphere, known as the atmospheric boundary layer (ABL), are strongly influenced by heating and cooling of the air by the ground surface and frictional effects. The thickness of the ABL depends on geographic location and time of day. The thickness over land surfaces varies from several hundred meters at night under clear calm conditions that produce a stable layer to several kilometers during the afternoon due to vertical mixing that produces an unstable layer. The ABL during daytime hours is also referred to as the mixed layer. Average mixing heights for Buffalo, NY, shown in Figure 19 of Section 3.2.5, range over similar distances depending on time of day and season.

Under conditions of clear skies and warm temperatures, heating of the air near the surface leads to the warmer, lighter air rising, resulting in vertical turbulence. Cooling of the surface air layer at night increases the air density, resulting in the suppression of turbulence (Campbell 1977). Air

movement begins to be influenced by friction as it interacts with a flat terrain surface at a height of about 500 m, with the mean wind speed decreasing exponentially as the surface is approached (Barry and Chorley 2003). Air movement and mixing near the surface is influenced by surface roughness created by topographic features, surface reflectivity, vegetation, and structures.

The influence of these complex and interacting processes on atmospheric dispersion is conceptualized as being represented by a steady-state Gaussian plume in both the vertical and the horizontal. The conceptual model accounts for vertical variations in wind, temperature, and turbulence and considers the influence of complex terrain.

This is a simplified approach to representing the spatial distribution of contaminant concentrations in air with time. Modeling provides annual average values of the ratio Chi/Q , where Chi/Q is the concentration of a contaminant material in air at a downwind location, divided by the resuspension rate from the source (PNNL 2010).

This approach to dispersion modeling is not able to predict short-term variations in concentrations, or the effects of spatial variability in wind shear and terrain, and cannot respond to changing meteorological conditions in the short term. However, it does provide time-averaged contaminant concentrations appropriate for PA.

5.7 Contaminant Transport—Biota

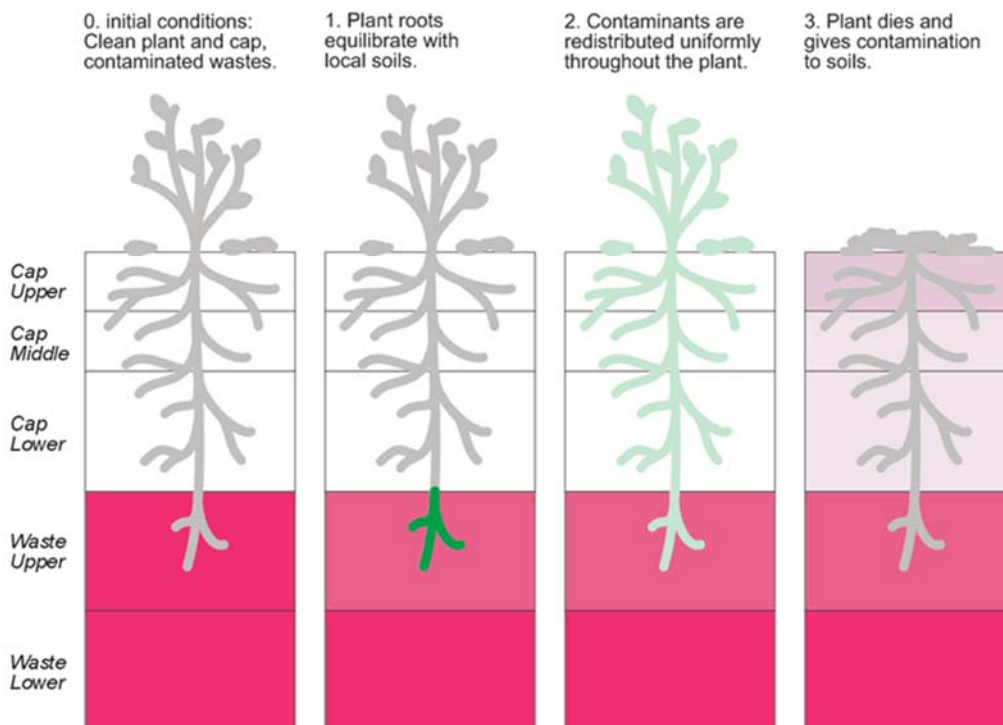
Two forms of biological contaminant transport from the subsurface to the surface are considered in the West Valley PPA Model. This Model addresses biological transport on-site. If there is significant transport off-site, then other pathways, including those into the aquatic food web (e.g., contaminant uptake into fish), should be considered. Plants uptake contaminants in their roots, redistribute them around their various plant parts, and leave them behind upon death or senescence—some on the ground surface. Burrowing animals (mammals, earthworms, and ants to varying degrees) are conceived to move bulk materials, including soils and the water and air contained within them, from various depths to the ground surface. As excavated areas are abandoned, it is assumed that the same volumes of materials collapse into the open spaces, preserving a balance of materials overall. Each of these forms of transport is discussed in more detail below. A third pathway that is not considered to be significant is bioconcentration into fauna and redistribution both laterally and with depth via excrement and decomposition of animal tissues. The biological transport model does not directly address microbial or other processes that can change the bioavailability of radionuclides and other inorganic contaminants and can degrade organic chemicals.

5.7.1 Plant Conceptual Model

With the exception of tree throw, plants do not move bulk soils, but rather selectively take up chemicals from the soil, either as nutrients or incidentally, and move these chemicals to various plant parts. Some plant species are known to hyper-accumulate and can be used as part of phytoremediation of contaminated sites (Entry et al. 1999). Phytoremediation takes advantage of plant uptake; the aboveground parts of the plants are harvested and removed from the contaminated site. At the West Valley Site, it is assumed that there is no such active management. When a plant dies or senesces, nutrient cycling processes return its mineral

components to surface and subsurface soils, and the various contaminants associated with them, as illustrated in Figure 70. Different types of plants have different characteristic plant rooting depths and shapes of the root mass, and the plant in the figure is simply a schematic depiction of a single plant, or rather a representation of all plants of a single type. Canadell et al. (1996) present a review of maximum plant rooting depths for global biomes. The range of maximum rooting depths for trees in the temperate deciduous forest biome was reported to be 1.8 m to 4.4 m. The range of maximum rooting depths reported for the temperate grassland biome was 1.2 to 6.3 m. In contrast to the reported maximum rooting depths, Jackson et al. (1996) reviewed the root biomass distribution by depth. They reported that 65% of the root biomass was in the top 30 cm in the temperate deciduous forest biome and 83% of the root biomass was in the top 30 cm in the temperate grassland biome (Jackson et al. 1996). Given the root depth and root mass shape, each depth increment is assumed to contain a certain mass of roots, and that mass of roots interacts with the mass of solids in that same increment. Contaminant transport rates depend on plant biomass production rates, root to shoot ratios, maximum root depths, and biomass shape.

Plant Conceptual Model for GoldSim Modeling



Plant Conceptual Model for GoldSim Modeling, cont'd

The following processes can be thought of as happening each time step (two time steps are shown below):

1. The plant roots absorb contaminants, equilibrating with the contaminant concentration in each layer. Additional contaminants are absorbed and transported to the aboveground parts of the plant in proportion.
2. The plant redistributes all the contamination taken up uniformly throughout the plant.
3. The plant dies (senescence), giving up all contamination to the neighboring soils. The aboveground parts of the plant join the uppermost soil layer as litter.

Note how the biotically-accessible upper waste layer is gradually depleted in contamination, while the cap layers become more contaminated. The uppermost cap layer receives the most contamination.

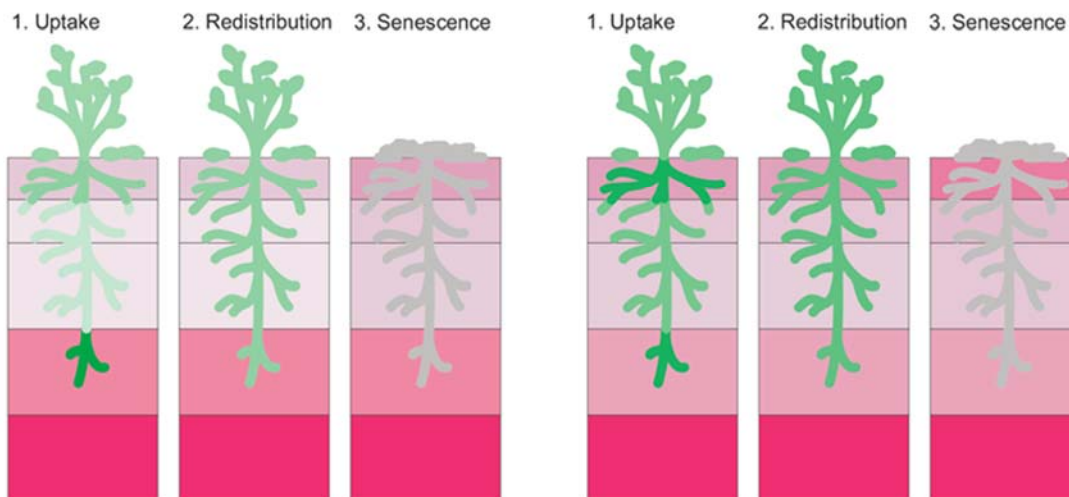


Figure 70. Conceptual model of contaminant uptake and redistribution by plants.

The process of contaminant uptake in the roots is modeled similarly to the air/water and solid/water partition coefficients described above (Section 5.4.1). A plant/soil concentration ratio *CR* is defined that is the ratio of the mass/mass concentration of the contaminant in the plant to that in the surrounding soils, and it varies by contaminant. For a particular depth increment in the soil, there is a known mass of soil and of plant roots, and the partitioning of each contaminant into the roots is simply a function of the concentration in the soils times the *CR*.

Once the total amount of all plant parts in each layer has acquired the proper mass of contaminants, it is assumed that the total mass of contaminants in the entire plant is redistributed evenly in all plant tissues. When the plant dies or senesces, nutrient cycling processes return the contaminants within each layer to the other materials in that layer. In this way, plants gradually redistribute contaminants in the near surface soils, generally increasing the concentrations in the top layer where the aboveground plant parts fall and are mixed into the upper soil layers.

Transport by plants is assumed for the CSM to depend on the dominant plant species, the net annual primary productivity, root to shoot mass ratios, relative abundance of plants or plant groups, and the root mass shape and maximum depth. Tree throw, which is the transport of soil and rock via roots when a tree is blown over or dies and falls over causing the root ball to be pulled to the ground surface, is not explicitly modeled in the West Valley PPA Model. However, it is included among other processes that contribute to erosion at the Site.

5.7.2 Burrowing Mammals Conceptual Model

Animal burrows are also characterized by a depth and burrow shape and vary by taxonomic groups and species (Zaitlin and Hayashi 2012). Among the burrowing mammals observed at the West Valley Site are opossum, voles, mice, red fox, gray fox, woodchuck, porcupine, Eastern chipmunk, and Eastern cottontail (Section 3.2.6.2). As with the plants, there is a certain amount of burrow (in this case, a volume) that exists in each subsurface layer. The rate of burrowing is defined by the age of the nest or colony, the total volume of soils excavated by each burrow per unit time, and the number of burrows for each type of animal present on the Site. All subsurface excavations are assumed to be brought to the ground surface, and a cascade of burrow collapses follows as burrows are abandoned. The burrow collapse is necessary to preserve the mass balance of materials in the system.

Burrowing animals may not move all materials to an equal degree. In some cases finer or coarser materials are moved, and this can lead to stratification over time. For examples of the resulting distributions vertically over the soil profile, see Figure 3 in Johnson and Schaetzl (2015). Burrowing animals can also lead to mounding horizontally for highly territorial animals (Johnson and Schaetzl 2015).

For the CSM, radionuclide transport by mammals is assumed to depend on burrowing mammal species present at the West Valley Site, volume of soil excavated per year, maximum burrow depth, and the areal density with depth of mammal burrows.

Once contaminants have been transported into nearby streams, beavers play an important role in the retention and transport of contaminants. Beaver ponds can act to delay and store contaminants, while beaver movement can transport contaminants out of beaver ponds and into

surrounding areas. Beaver activity will be considered in the development of surface water and sediment transport models for the PPA.

5.7.3 Soil Invertebrate Conceptual Model

For contaminant transport by soil invertebrate species, the CSM considers that earthworms, ants, and other invertebrates move materials from below ground to the ground surface while excavating chambers and tunnels within a nest. At the West Valley Site, earthworms are more significant than other invertebrate taxa for moving and modifying soil contaminants (Section 3.2.6.4).

Earthworms have been long recognized for their importance in nutrient cycling and bioturbation of temperate soils (Darwin 1881). Across several environments, earthworms were found on average to deposit about 0.5 cm/yr of new material on the ground surface. For this reason, they have been one of the major factors leading to the burial of ancient ruins. Several studies have documented the depth of burrowing for various types of earthworms, with one study reporting depths up to 2.5 m (Kobel-Lamparski and Lamparski 1987). Earthworms can also modify chemical properties. For example, Covey (2008) showed changes in arsenic bioavailability when soil passed through the earthworms' digestive tracts. In summary, earthworms move and transform large amounts of temperate zone soils and act over a large fraction of the soil profile.

The CSM assumes that chambers and tunnels collapse over time and return soil from the upper part of the soil profile back to lower parts. Through this process the balance of materials is preserved. Contaminant transport by invertebrates is conceptualized as depending on the species, nest volume, maximum nest depth, lifespan, density, and variation of burrow density with depth.

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