National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
White Sands Test Facility
P.O. Box 20
Las Cruces, NM 88004-0020

February 12, 2020

RECEIVED
FEB 13 2020
NMED
Hazardous Waste
Bureau

Reply to Attn of: RE-20-028

Mr. Kevin Pierard, Bureau Chief
New Mexico Environment Department
Hazardous Waste Bureau
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505

Subject: NASA WSTF Groundwater Monitoring Plan Update for 2019

NASA White Sands Test Facility (WSTF) received NMED's December 12, 2019, *Approval with Modifications Groundwater Monitoring Plan*, in which NMED provided one comment related to NASA's April 30, 2019 *NASA WSTF Groundwater Monitoring Plan*. NMED directed NASA to respond to the Approval by April 28, 2020 with a response letter that cross-references where NMED's modifications were addressed, as well as respective replacement and electronic redline-strikeout pages indicating where changes were made.

Enclosure 1 provides a response table that addresses the modifications. Enclosure 2 provides printed replacement pages of the Groundwater Monitoring Plan. Enclosure 3 provides an electronic copy of the table, redline-strikeout version report, and the final report in PDF format on CD-ROM.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

If you have any questions or comments, please contact Antonette Doherty of my staff at 575–524–5497.

Timothy J. Davis
Chief, NASA Environmental Office

2 Enclosures

cc:
Mr. Gabriel Acevedo
New Mexico Environment Department
Hazardous Waste Bureau
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505

Comments for Approval with Modifications of the Groundwater Monitoring Plan 2019 Update

NMED Comment Number	NMED Comments	NASA Revisions/Responses/Discussion
1. Figure 3, Distribution of NDMA [N-nitrosodimethylamine] in WSTF [White Sands Test Facility] Groundwater, Page 92	**NMED Comment:** An NDMA contamination distribution map was not provided in the Monitoring Plan. The figure "Site-Wide Groundwater Elevations for Fourth Quarter 2018" followed the Figure 3 cover page. Revise the Monitoring Plan to include the NDMA contamination distribution map and provide a replacement figure.	The figure "NDMA Maximum Concentrations in Groundwater for Fourth Quarter 2018" has been substituted into the document.
2. Requirement for Initial Groundwater Screening for Aqueous Film-Forming Foam (AFFF) Chemicals of Concern at WSTF	**NMED Comment:** Use of AFFF at WSTF was documented in NASA's July 2014 SWMUs [Solid Waste Management Units] 1, 3, and 15 Historical information Summary (HIS). The HIS indicated that AFFF was intermittently used during fire training exercises conducted at WSTF 100 and 200 Areas from the late 1960s to at least 1995. AFFFs are known to contain poly and per-fluoroalkyl compounds (PFAS) such as perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) and are emerging contaminants of concern due to their toxicity, high mobility, and persistence in the environment. Given the reported history of use and release of AFFF to the environment at WSTF 100 and 200 Areas, and potentially other areas, an initial groundwater screening sampling event for PFAS chemicals must be proposed in the 2020 WSTF Groundwater Monitoring Plan. Groundwater samples must be collected at select existing WSTF monitoring wells proximal to any former and currently existing WSTF fire training areas and other potential PFAS release source areas, such as fire or fuel spill incident locations where AFFF was used, wastewater treatment system locations that potentially received AFFF laden waste water, or landfills where waste containing PFAS may have been disposed. The proposed groundwater sample analysis suite must address all PFAS chemicals listed in NMED's June 2019 Risk Assessment	Acknowledged. The Executive Summary of the HIS states that the 200 Area burn pits were used for fire extinguisher practice and that these extinguishers did not contain AFFF. Section 7.4 of the HIS indicates that prior to the availability of AFFF, protein-based foams had been used at 200 Area burn pits. That section documents the use of AFFF at the 100 Area burn pit for firefighter training only and indicates that AFFF was used only at the burn pit and may have been discharged to the adjacent overflow area (identified as an area of interest in the HIS and associated investigation work plan). Appendix A of the HIS includes employee statements that fire extinguishers did not use AFFF and that AFFF was not used at 200 Area burn pits. Appendix A also includes employee statements that no "real" (non-training) fires were extinguished with AFFF. Based on the available information, NASA concluded in the HIS that AFFF was discharged to the ground at the 100 Area burn pit and 150 Area fire training area. AFFF-laden water may have also discharged to the adjacent surface when the 100 Area burn pit overflowed. The AFFF in use at the time of training at the 100 Area may have contained PFOS and PFOA. There is no evidence that AFFF was used at the 200 Area burn pits or discharged to any other location at WSTF. NASA analyzed soil samples collected at the 100 Area burn pit (SWMU 1), adjacent overflow area, and 600 Area burn pit (SWMU 15) during the 2015 investigation of those SMWUs. PFOA and PFOS were not

Comments for Approval with Modifications of the Groundwater Monitoring Plan 2019 Update

NMED Comment Number	NMED Comments	NASA Revisions/Responses/Discussion
	Guidance for Site Investigations and Remediation (RA Guidance), Section 5.3, PFAS (See Table 5-2, PFAS Analyte List). A preliminary Tap Water screening level (0.07 micrograms per liter) for PFOA, PFOS, and perfluorohexanesulfonic acid (PFHxS) is provided on RA Guidance Table 5-3, Preliminary Screening Levels for Select PFAS (PFOA, PFOS, and PFHxS). The results of the groundwater sampling event must be reported in the comprehensive fourth quarter 2020 periodic groundwater monitoring report. No changes to the 2019 Monitoring Plan are necessary in response to this comment.	detected in soil samples above the practical quantitation limit of 1.0 mg/kg and 2.0 mg/kg, respectively. NASA also analyzed soil samples collected at a former historical burn pit on the southeast side of the 200 Area as requested by NMED during the investigation in 2014. PFOA and PFOS were not detected in soil samples above the practical quantitation limit of 0.89 mg/kg. NASA has also collected several groundwater samples for the analysis of some PFAS at groundwater monitoring wells between the potential 100 Area source and the WSTF potable water supply wells. Those sampling events did not include all the PFAS listed in NMED's June 2019 Risk Assessment Guidance, so additional sampling is necessary to comply with NMED's requirement in this approval with modifications. A plan for additional groundwater screening for PFAS will be included in the 2020 WSTF Groundwater Monitoring Plan. In order to comply with NMED's requirement that PFAS results be provided in the comprehensive 2020 PMR, NASA must collect groundwater samples for analysis of PFAS by October 31, 2020. To achieve this, PFAS sampling may begin prior to submittal of the 2020 GMP and is likely to be well underway prior to approval by NMED, which is expected in the fall of 2020. NASA expects to sample groundwater monitoring wells located near and downgradient of potential PFAS sources at the 100 Area burn pit and 150 Area fire training area, as well as near potential but unlikely sources in the 200 Area.

National Aeronautics and Space Administration

White Sands Test Facility

Groundwater Monitoring Plan

April 2019

Revised February 2020

NM8800019434

NASA Johnson Space Center White Sands Test Facility

Groundwater Monitoring Plan

April 2019

Revised February 2020

NM8800019434

Certification Statement

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Timothy J. Davis
Chief, NASA Environmental Office

2/12/2020
Date

National Aeronautics and Space Administration

Johnson Space Center
White Sands Test Facility
12600 NASA Road
Las Cruces, NM 88012
www.nasa.gov/centers/wstf

www.nasa.gov

Executive Summary

This Groundwater Monitoring Plan (Plan) provides information related to routine groundwater monitoring performed at the NASA (National Aeronautics and Space Administration) WSTF (White Sands Test Facility). Groundwater monitoring is conducted in accordance with NASA WSTF's Hazardous Waste Permit (Permit), issued by the NMED (New Mexico Environment Department) in November 2009 and modified in November 2016. Permit Section VII.B requires that NASA develop a facility-wide Groundwater Monitoring Plan to set forth detailed methods, procedures, and schedules. This plan meets the requirements of the Permit and satisfies the regulatory requirements of 40 CFR 264.90(f) as directed by NMED.

This plan provides specific information related to groundwater monitoring at WSTF, including:

- Background information on the facility, operations performed, hazardous constituents and hazardous wastes managed and released, the nature and extent of groundwater contamination resulting from those operations and releases, potential receptors of contaminated groundwater, pertinent previous investigations related to groundwater, and surface and subsurface conditions.
- Applicable regulatory criteria.
- A detailed description of the existing WSTF groundwater monitoring system.
- Descriptions of the sampling equipment utilized for groundwater monitoring.
- Descriptions of pre-sampling activities such as equipment decontamination, sampling records, determination of groundwater elevations and indicator parameters, and purging of groundwater monitoring wells.
- Discussion of sampling procedures for WSTF groundwater monitoring wells.
- Descriptions of post-sampling activities such as sample management (identification, storage, custody, and shipment), IDW (investigation-derived waste) management, and the determination of groundwater flow direction and rate.
- A summary of the chemical analytical methods utilized by contracted analytical laboratories to analyze for hazardous constituents and other analytes in WSTF groundwater.
- An introduction to the WSTF QA/QC (quality assurance/quality control) program, including a discussion of requirements for contracted analytical laboratories, QC samples, data quality indicators, analytical data quality exceptions, and analytical data management processes.
- The schedules for various activities presented in the Plan.

Table of Contents

History of Revisions

Data of Revision	Summary of Revision
June 2010	Original Groundwater Monitoring Plan
April 2012	Annual revision/update. Significant revisions in the annual update include: an evaluation of hazardous constituents and subsequent revision of text and tables in affected sections; reference to off-site sampling performed in accordance with Permit Section VII.G.2; inclusion of the results of an evaluation of groundwater background concentrations are required by Permit Section 17.5; and the addition of new groundwater monitoring wells to affected sections and tables.
April 2013	Annual revision/update. Significant revisions in the annual update include: removal of text and tables discussing groundwater background sampling and statistical evaluations; addition of new groundwater monitoring wells to the affected sections and tables; update of cleanup levels; and update of sampling frequencies.
April 2014	Annual revision/update. Significant revisions in the annual update include: modification of groundwater monitoring parameters and frequencies; revision of tables and text to reflect well changes since last GMP update; and review/update of cleanup levels.
April 2015	Annual revision/update. Significant revisions in the annual update include: modification of groundwater monitoring parameters and frequencies; revision or addition of tables and text to reflect well changes since the last GMP update; and review and update of cleanup levels.
May 2016	Annual revision/update. Significant revisions in the annual update include: modification of groundwater monitoring parameters and frequencies; revision of tables and text to reflect changes in monitoring wells and sampling equipment since last GMP update; and review and update of groundwater cleanup levels, including a discussion and figure showing historical cleanup levels to support periodic reporting.
April 2017	Annual revision/update. Significant revisions in the annual update include: addition of new groundwater monitoring wells to text and tables; revision of tables and text to reflect changes in monitoring wells and sampling equipment since last GMP update; addition of monitoring well inspection requirements and monitoring wells that require attention in 2017; and review and update of groundwater cleanup levels. Certain sections of the text and tables were also updated to address NMED comments provided in the October 6, 2016 Approval with Modifications Groundwater Monitoring Plan May 2016 (resolved in NASA's December 22, 2016 response to that Approval) and NMED's April 12, 2017 NMED Response to Permittee Comments on the Approval with Modifications of 2016 GMP Update.
April 2018	Annual revision/update. Significant revisions in the annual update include: inclusion of monitoring for 1,4-dioxane as directed by NMED on December 19, 2017; inclusion of analysis of groundwater samples from certain wells by SW-846 Methods 8015 and 8270 as indicated in NASA's IWP for the TDRSS diesel release (SWMU 50), approved by NMED on January 17, 2018; revision of tables and text to reflect changes in monitoring wells and sampling equipment since last GMP update; update on monitoring wells that required attention in

Data of Revision	Summary of Revision
	2017 and additional work for 2018. Certain sections of the text and tables were also updated to address NMED comments provided in the December 19, 2017 Approval with Modifications of the 2017 Groundwater Monitoring Plan.
April 2019	Annual revision/update. Significant revisions in the annual update include: updated text in Section 4.4 to reflect current status of groundwater well evaluation and maintenance activities; revision of tables and text to reflect changes in monitoring wells, sampling equipment, and sampling frequencies since last GMP update; and, updates to certain sections of the text and tables to address NMED comments provided in the September 13, 2018 Approval with Modifications Groundwater Monitoring Plan.

List of Acronyms and Abbreviations

%R	Percent recovery
µg/L	Micrograms per liter
AD	Analyst Duplicates
bgs	Below ground surface
BLM	Bureau of Land Management
CAS	Chemical Abstract Service
CFR	Code of Federal Regulations
COC	Contaminant of Concern
DMN	N-Nitrodimethylamine
DO	Dissolved oxygen
DP	Discharge Plan
DQI	Data quality indicator
DRO	Diesel range organics
EAR	Environmental Activities Report
EPA	U.S. Environmental Protection Agency
FBR	Flow-banded rhyolite
ft	Feet
GRO	Gasoline range organics
HWMU	Hazardous waste management unit
IDW	Investigation -derived waste
in.	Inch(es)
JDMB	Jornada del Muerto Basin
JER	Jornada Experimental Range (U.S. Department of Agriculture)
JP	Jet Propellant Test Area (used in alphanumeric well identification)
K	Hydraulic conductivity
L	Liter
LCS	Laboratory control sample
LCSD	Laboratory control sample duplicate
MB	Method blank
MCL	Maximum Contaminant Level
MDL	Method detection limit
mi	Mile(s)
mL	Milliliters
mm	Millimeter
MPCA	Mid-plume Constriction Area
MPITS	Mid-plume Interception and Treatment System
MS	Matrix spike
MSD	Matrix spike duplicate
NASA	National Aeronautics and Space Administration
NDMA	N-Nitrosodimethylamine

NELAC	National Environmental Laboratory Accreditation Conference
ng/L	Nanograms per liter
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMOSE	New Mexico Office of the State Engineer
ORP	Oxidation reduction potential
PCB	Polychlorinated Biphenyl
PCC	Post-Closure Care
PCE	Tetrachloroethene
PEST	Automated parameter estimation software
PFTS	Plume Front Treatment System
PL	Private land (used in alphanumeric well identification)
PMR	Periodic Monitoring Report
PPE	Personal protective equipment
PQL	Practical quantitation limit
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
QAR	Quality Assurance Report
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RPD	Relative percent difference
RSL	EPA Regional Screening Level
SA	Sample
SAM	San Andres Mountains
SOP	Standard operating procedure
ST	State (used in alphanumeric well identification)
SVOC	Semi-volatile organic compounds
SWMU	Solid waste management unit
T	Transmissivity
TCE	Trichloroethene
TDRSS	Tracking and Data Relay Satellite System
TP	Toxic pollutant
TPH	Total petroleum hydrocarbons
UDMH	1,1-Dimethylhydrazine
VOC	Volatile organic compounds
WB	Westbay (used in alphanumeric well identification)
WBFZ	Western Boundary Fault Zone
WQCC	NM Water Quality Control Commission
WSTF	White Sands Test Facility

1.0 Introduction

WSTF (White Sands Test Facility) currently operates as a field test installation under the NASA (National Aeronautics and Space Administration) Lyndon B. Johnson Space Center in Houston, Texas. WSTF is a restricted access site and all activities are industrial in nature. Although the primary purpose of the facility is to provide test services and support to NASA for the United States space program, services are also provided for the Department of Defense, Department of Energy, private industry, and foreign government agencies. WSTF operates several laboratory facilities that conduct simulated use tests for space vehicles and space station materials and compatibility testing.

WSTF is located approximately 18 mi (miles) northeast of Las Cruces, New Mexico. Figure 1 provides a vicinity map that shows the general location of WSTF relative to other dominant features and major properties in southern Dona Ana County. Historical operations at WSTF have resulted in a groundwater plume requiring extensive investigation activities and associated corrective actions. The nature and extent of groundwater contamination at WSTF is discussed in further detail in Section 2.0.

The groundwater assessment program at WSTF was established to determine the nature and extent of groundwater contamination present at WSTF as a result of historical releases of hazardous waste and/or hazardous constituents. Prior to issuance of the current Hazardous Waste Permit (Permit; NMED, 2016b), groundwater sampling was performed as required by NASA’s former Hazardous Waste Operating Permit, PCC (Post-Closure Care) Permit, 3008(h) Consent Order (EPA, 1989), the requirements of RCRA (Resource Conservation Recovery Act), and site-specific project plans. Routine groundwater monitoring has enabled NASA to delineate WSTF’s groundwater contaminant plume and has provided a thorough understanding of the nature and extent of groundwater contamination. This has allowed NASA to design, construct, and operate state of the art pump and treat systems for corrective actions at the Plume Front and Mid-plume areas. The primary objective of the PFTS (Plume Front Treatment System) is to prevent further migration of the WSTF groundwater contaminant plume. The MPITS (Mid-plume Interception and Treatment System), another voluntary interim measures presumptive remedy, is intended to significantly reduce groundwater contamination through removal and treatment of groundwater in the MPCA (Mid-plume Constriction Area). NASA monitors the effectiveness of the PFTS and MPITS in accordance with the Remediation System Monitoring Plan (NASA, 2018c) and operates and maintains the systems as specified in project-specific plans and other documentation submitted to and approved by NMED (New Mexico Environment Department).

1.1 Purpose

This Plan satisfies the requirements of the Permit to develop a comprehensive facility-wide groundwater monitoring plan. It serves as a procedural outline for personnel engaged in routine groundwater sampling and analysis activities at WSTF. It is used in conjunction with site-specific procedural documentation and specific equipment operations and maintenance manuals. Procedures outlined are consistent with those specified for use at sites subject to the requirements of RCRA, and have been adapted to meet WSTF groundwater monitoring program and Permit requirements. This Plan introduces the methods, procedures, and schedules for conducting routine groundwater monitoring at WSTF. Adherence to the protocols presented in this document assures that samples are collected in a consistent manner, representative of actual groundwater conditions, managed efficiently and effectively, and analyzed by appropriate analytical methods. This Plan outlines the process for reviewing chemical analytical data to ensure that only the highest quality data are generated and available for use in other WSTF projects (corrective action, reporting, etc.).

1.2 Scope

This Plan directs activities related to routine groundwater monitoring throughout WSTF in accordance with Section VI.B of the Permit. It is intended for use as an aid for training technical staff and as an informational guide for trained personnel involved in the collection and processing of WSTF groundwater samples and in the management of chemical analytical data generated from the analyses of those samples. It is also used by NMED to ensure that NASA is performing groundwater monitoring in accordance with applicable federal and state regulations and the Permit. The requirements of this Plan are applicable to all groundwater sampling events performed to accomplish the objectives of this Plan. A WSTF groundwater sampling event consists of specific activities and relevant documentation associated with the collection, management, and analysis of groundwater samples from a distinct groundwater source. A sampling event is performed at a specific groundwater source, typically an individual monitoring well or zone of a multiport well that has been completed in accordance with the Permit and applicable site-specific documentation. Specific requirements and procedures for performing sampling are provided in later sections of this Plan.

1.3 Objectives

The current objective of the groundwater monitoring program is to collect and manage groundwater chemical analytical data to:

- Provide a consistent, accurate representation of actual concentrations of hazardous constituents in the groundwater.
- Monitor the distribution, extent, and movement of hazardous constituents in the groundwater.
- Determine potential threats to human health and the environment from hazardous constituents in the groundwater.
- Monitor the effectiveness of corrective measures used to remediate hazardous constituents released from hazardous waste management units to the groundwater as a result of historical operations.
- Detect the presence of hazardous constituents not previously detected in the groundwater.
- Determine when the corrective measures have reduced the concentrations of hazardous constituents in the groundwater to less than the cleanup levels established according to Permit guidance.

The on-site contractor environmental organization is tasked with the management and implementation of groundwater monitoring activities. This organization is staffed with groundwater, hydrogeological, engineering, and environmental compliance personnel. Groundwater personnel are primarily involved in the collection and analysis of groundwater samples for assessment and remediation activities. Hydrogeological personnel are primarily involved in the installation, development, and maintenance of groundwater monitoring and remediation wells and the hydrogeologic interpretation of contaminant distribution and migration. Engineering personnel are responsible for the design, construction, and implementation of corrective actions and successful operation of environmental remediation systems. Compliance personnel are responsible for overseeing the numerous facets of compliance with multiple permits, plans, and other regulatory requirements applicable to WSTF.

2.0 Background

WSTF was established in the early 1960s to support the NASA Apollo Space Program. Primary site activities serve to: develop, qualify, refurbish, and test spacecraft propulsion systems, subsystems, and ground support equipment; investigate flight hardware anomalies; test materials and components; and perform hazard and failure analyses.

Hazardous wastes generated at WSTF during testing and evaluation procedures were historically managed in surface impoundments and underground storage tanks that leaked, subsequently contaminating groundwater. From the early 1960s through the mid-1980s, tanks or waste impoundments in the 200, 300, 400, and 600 industrial areas contributed to groundwater contamination. To minimize further releases of contaminants, these impoundments and tanks were closed under RCRA, and approved by NMED in 1989. The closures were permitted under a PCC Permit in the early 1990s and continue to be monitored in accordance with the Permit and related plans. The locations of these closures, as well as other pertinent WSTF features, are provided in Figure 2.

2.1 Wastes Managed and Released

This section provides a brief description of the primary wastes managed and released at the facility during historical operations, and discusses the releases as sources of contamination in the groundwater.

The primary hazardous constituents in groundwater originated from historical waste management operations within the WSTF industrial area (NASA, 1996a). Sources within these industrial areas are shown on Figure 2. NDMA (N-Nitrosodimethylamine) contamination primarily originated from operations in the 300 and 400 Areas. Most of the halogenated volatile contaminants (TCE [trichloroethene], PCE [tetrachloroethene], Freon®[1] 11 [trichlorofluoromethane], and chloroform) originated from the 200 Area with lesser contributions from the 100, 300, 400, and 600 Areas. Four of these hazardous constituents – NDMA, PCE, TCE, and Freon 11 – are considered the primary COC (contaminants of concern) in WSTF groundwater.

Additional hazardous constituents, discussed in later sections of this Plan, were also managed and released from activities in the WSTF industrial area. Several other chemicals, which do not meet the criteria to be designated as hazardous constituents, were also managed and released to the groundwater at WSTF. While not of primary concern to the groundwater monitoring program, these constituents are routinely sampled for and are discussed in many NASA documents, both current and historical. These chemicals include DMN (N-Nitrodimethylamine), Freon 21 (dichlorofluoromethane), and Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane). Freon 113 had historically been considered a hazardous constituent, but was reassessed in 2012 in accordance with the process described in Section 3.1, which resulted in it being removed as a hazardous constituent. However, because it was used in large quantities at WSTF, and is prevalent throughout the groundwater contaminant plume, it is frequently considered a COC within the groundwater assessment program and is included in specific sections of this document.

Little historical data are available describing the exact nature and amounts of chemical wastes that were contained or released at WSTF. COC release estimates were derived from numerical models. Table 1 provides a list of potential COC released from individual WSTF areas. Subsequent sections describe sources at the industrial areas at which contaminants were introduced to the surface and subsurface.

2.1.1 Wastes Managed and Released in the 100 Area

The 100 Area Burn Pit (Figure 2) is a potential minor source of contamination to the subsurface. This pit, in operation from 1969 to 1983, was used for fire-suppression training. Flammable liquid wastes were poured onto the water surface in the pit and ignited. An estimated 1,000 gallons of flammable liquids was

[1] The trade name Freon is a registered trademark of E.I. du Pont de Nemours & Company Corporation (DuPont).

burned each year during operation. This pit was excavated and residual fluids and soils were removed in 1984. Five other SWMU (solid waste management units), the Container Storage Area, Container Storage Unit, wastewater lagoon, Drum Storage Facility, and Temporary PCB (Polychlorinated Biphenyl) Storage Area, are located in the 100 Area. These SWMU are not considered to be significant sources of COC to groundwater at WSTF.

2.1.2 Wastes Managed and Released in the 200 Area

Several contaminant sources were identified in the 200 Area (Figure 2). The two major sources of contamination in the 200 Area, the Chemistry Lab Tank and the Clean Room Tank, are considered the primary source of TCE in WSTF groundwater. The Chemistry Lab Tank had a storage capacity of 1,500 gallons. This tank was installed in 1964 and received wastes from metallurgical and etching laboratory operations. These wastes were periodically transferred to the 600 Area impoundments. Wastes discharged to the Chemistry Lab Tank included aerospace propellants, organic solvents, oils, spent cutting fluids, spent x-ray developer solutions, cooling water, and other liquids. Closure activity was completed in June 1989.

The Clean Room Tank was a 4,000-gallon tank used from 1964 to 1979 to accumulate wastes generated by precision cleaning of flight hardware. Chemicals disposed to this tank included Freon 113, Freon 11, TCE, chromic acid, isopropyl alcohol, and other solvents. These accumulated wastes were periodically transferred to the 600 Area impoundments. In 1979, the severely corroded tank was removed and was replaced by a new tank installed approximately 50 ft (feet) to the west. The replacement tank was removed from service in 1986 and was found to be extensively corroded upon its removal.

Other potential sources for minor groundwater contamination at the 200 Area included the Clean Room Discharge Pipe, Scape Room Discharge Pipe, Building 203 Discharge Pipe, South Highbay Discharge Pipe, and several other areas of concern identified during historical information research performed prior to the 200 Area investigation (NASA, 2012a). The exact quantities or types of waste discharged to grade at these locations are not known.

2.1.3 Wastes Managed and Released in the 300 Area

The 300 Area surface impoundments (Figure 2) are a primary source for release of NDMA to the subsurface. Operation of these impoundments, located in the 300 propulsion testing area of WSTF, began in 1965. The impoundments provided emergency spill containment and fuel treatment systems for discharges of hypergolic rocket fuels, including hydrazine, monomethylhydrazine, unsymmetrical dimethylhydrazine, Aerozine 50, and nitrogen tetroxide. Treatment of rocket fuels consisted of oxidation with calcium hypochlorite followed by discharge to grade to adjacent arroyos. Freon 113 and isopropyl alcohol also were used as referee propellants until 1972. TCE was also used as a cleaning solvent in 1964. Freon 113, isopropyl alcohol, and TCE were discharged to the surface impoundments and, in some instances, to grade.

Additionally, TCE was used to clean pipelines during facility construction of the 300 Propulsion Area during the early 1960s. TCE waste derived from this cleaning activity is suspected to be a source for TCE contamination in groundwater.

2.1.4 Wastes Managed and Released in the 400 Area

The 400 Area Surface Impoundments (Figure 2) in the propulsion testing area are a primary source for release of NDMA to the subsurface. These impoundments became operational in 1964. The impoundments provided emergency spill containment and fuel treatment systems for discharges of hypergolic rocket fuels, including hydrazine, monomethylhydrazine, unsymmetrical dimethylhydrazine, Aerozine 50, and nitrogen tetroxide. Treatment of rocket fuels consisted of oxidation with calcium hypochlorite followed by discharge to grade in adjacent arroyos. Freon 113 and isopropyl alcohol also were used as referee propellants until 1972. Freon 11 and Freon 21 were also used as cleaning solvents. Freon 11, Freon 113, and isopropyl alcohol were discharged to the surface impoundments and, in some instances, to grade.

Additionally, TCE was used to clean pipelines during facility construction at the 400 propulsion area during the early 1960s. TCE waste from this cleaning activity is suspected to be a source for TCE contamination in groundwater.

2.1.5 Wastes Managed and Released in the 500 Area

The 500 Area Fuel Storage Area (Figure 2) is a potential minor source of NDMA in the subsurface. This area consisted of a 20,000-gallon storage tank with secondary containment that was used to store hydrazine fuel. Treatment of fuel and release to grade may have taken place at this potential source. NASA performed a preliminary investigation at the 500 Area Fuel Storage Area in 2000 and 2001 and submitted a summary of the results in the 500 Fuel Storage Area Historical Information Summary (NASA, 2011). NASA recently recommended additional investigation at this area (NASA, 2018d).

2.1.6 Wastes Managed and Released in the 600 Area

NASA operated the 600 Area Surface Impoundments (Figure 2) from 1968 to 1986. These impoundments were designed to contain saltwater backwash from the facility's water softening plant. They also received an undetermined amount of hazardous waste from the 200 Area Chemistry Lab Tank and Clean Room Tank. The impoundments were lined with an 8-mm PVC (polyvinyl chloride) liner and had a combined capacity of 2 million gallons. NASA closed this unit in 1989, performed an investigation at the 600 Area Closure in 2009 and 2010, and subsequently performed a soil vapor extraction pilot test in 2012. After completing the pilot test, NASA concluded that the vadose zone beneath the Closure is not a source of continuing contamination to the groundwater (NASA, 2012c). Contaminated perched groundwater is being extracted from beneath the 600 Area Closure and transported to and treated by the MPITS (NASA, 2018b).

2.1.7 Wastes Managed and Released in the 700 Area

The 700 Area Landfill (Figure 2) is a potential minor source of groundwater contamination. NASA used this 24-acre landfill for the disposal of solid waste between 1964 and 1997. Hazardous wastes may have been disposed to this landfill prior to 1987, when weekly inspections were implemented. Hazardous wastes may have included spent solvents, waste paints, and soft goods contaminated with hydrazine and oxidizer. The landfill was closed in 1998 and is monitored under a PCC Plan (NASA, 1996b) approved by the NMED Solid Waste Bureau. Routine groundwater monitoring is performed in accordance with that plan, and additional investigation has been proposed (NASA, 2017f).

2.2 Extent of Contamination

This section briefly describes the spatial distribution of the five primary COC in groundwater at WSTF. The approximate extent and thickness of COC plumes are derived primarily from maps constructed using 2018 concentration data, cross sections constructed in the draft RCRA Facility Investigation (NASA, 1996a), and concentration data from wells with multiple completion depths. The distribution of other hazardous constituents present in WSTF groundwater does not exceed that of the COC presented in this section. Those hazardous constituents are discussed in more detail in later sections of this Plan.

2.2.1 N-Nitrosodimethylamine

NDMA is believed to have been released to the environment due to its creation during chemical oxidation of UDMH (1,1-dimethylhydrazine) by calcium hypochlorite. An estimated 34 kg of contaminant mass was released to the environment (NASA, 1996a). Figure 3 shows a manual interpretation of the NDMA conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. The NDMA plume extends westward approximately 20,400 ft from sources at the 300 and 400 Areas; is located entirely within WSTF boundaries; and, is as much as 6,100 ft wide in the area upgradient from the MPCA. The highest concentration in this area occurs within well 400-HV-147 installed through the 400 Area Closure at 59,000 ng/L. Downgradient of the 400 Area, concentrations reach 10,000 ng/L within the main mass of NDMA along the plume axis. The width of the NDMA plume narrows to less than 2,800 ft within the MPCA where observed concentrations are between 260 and 13,000 ng/L. A northwest trending plume arm extends approximately 7,000 ft from the MPCA with NDMA concentrations between 1.1 and 170 ng/L. Within the Plume Front area downgradient from the MPCA, the plume widens to approximately 6,700 ft with maximum observed concentrations between 720 and 1,400 ng/L. The vertical extent of NDMA, inferred from measured NDMA concentrations in water from wells with multiple-depth sampling points, is estimated to range from less than 325 ft bgs (below ground surface) to approximately 750 ft bgs.

2.2.2 Trichloroethene

An estimated 4,663 kg of TCE contaminant mass was released to the environment (NASA, 1996a). Figure 4 shows a manual interpretation of the TCE conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. The TCE plume extends westward approximately 18,500 ft from primary sources at the 200 Area and is located within WSTF boundaries. The maximum width of the TCE plume is approximately 4,400 ft upgradient from the MPCA in the industrial 200 Area. Downgradient, the width of the TCE plume decreases to approximately 1,600 ft in the vicinity of the MPCA. Observed maximum TCE concentrations in MPCA groundwater are between 100 and 180 µg/L. A northwest trending plume arm extends approximately 7,000 ft from the MPCA with TCE concentrations between 17 and 22 µg/L. Within the Plume Front, west of the MPCA, the TCE plume is approximately 7,000 ft wide. Concentrations in the Plume Front range from the detection limit to approximately 230 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of TCE in WSTF groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.2.3 Tetrachloroethene

An estimated 80 kg of PCE contaminant mass was released to the environment (NASA, 1996a). Figure 5 shows a manual interpretation of the PCE conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2087. The PCE plume originating from sources at the 100, 200, and 600 Areas, contains two separate portions, extends westward approximately 20,000 ft from the original release location in the WSTF test areas, and is located entirely within WSTF boundaries. In the MPCA, the PCE plume occurs as a small lobe approximately 1,500 ft in length by 400 ft in width before pinching out. Observed concentrations are between 2.2 and 7.1 µg/L within the Mid-plume area, although the plume is defined by the PCE cleanup level of 5 µg/L and centered on well BLM-39. Within the Plume Front, downgradient from the MPCA, a second plume lobe is centered on the ST-1 well cluster with an observed concentration of 8.0 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of PCE in groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.2.4 Freon 11

An estimated 2,766 kg of Freon 11 contaminant mass was released to the environment (NASA, 1996a). Figure 6 shows a manual interpretation of the Freon 11 conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. The Freon 11 plume extends westward approximately 23,000 ft from sources at the 200, 300, 400, and 700 Areas and is entirely located within WSTF boundaries. The plume is as much as 7,000 ft wide upgradient from the MPCA in the WSTF industrial area. The highest concentrations range from 470 to 630 µg/L in the 300 Area, with concentrations from 180 to 560 µg/L existing throughout much of the area upgradient from the MPCA. The width of the Freon 11 plume narrows to approximately 1,200 ft within the MPCA where observed concentrations are between 30 and 230 µg/L. A northwest trending plume arm extends approximately 7,000 ft from the MPCA with maximum Freon 11 concentrations between 4.9 and 63 µg/L. Within the Plume Front, downgradient from the MPCA, the plume widens to approximately 5,500 ft with maximum observed concentrations between 24 and 220 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of Freon 11 in groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.2.5 Freon 113

Though not designated as a hazardous constituent, Freon 113 remains of interest to NASA for groundwater monitoring purposes. An estimated 4,621 kg of Freon 113 contaminant mass was released to the environment (NASA, 1996a). Figure 7 shows a manual interpretation of the Freon 113 conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. Coalescing Freon 113 plumes originating from sources at the 100, 200, 300, and 400 Areas extend westward approximately 19,000 ft. The coalesced plume is entirely located within WSTF boundaries. The plume is as much as 7,000 ft wide in the area upgradient from the MPCA. The highest concentrations are 140, 510, and 410 µg/L in the 200 Area, MPCA, and Plume Front areas, respectively. The width of the Freon 113 plume narrows to approximately 1,600 ft within the MPCA where observed concentrations are between 16 and 510 µg/L. A northwest trending plume arm extends approximately 4,000 ft from the MPCA with a maximum Freon 113 concentration of 47 µg/L. Within the Plume Front downgradient from the MPCA, the plume widens to approximately 8,500 ft with observed concentrations between 12 and 410 µg/L. A confined secondary plume centered on well 700-D-186 is present near the 700 Area with a Freon113 concentration of 27 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of Freon 113 in groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.3 Potential Receptors

Under current and future conditions, NASA maintains administrative control of lands below which groundwater has been contaminated by historical activities at WSTF. No expansion of water use will occur on lands within NASA's administrative control. Thus, conservatively, the nearest location where a water use well may be installed by an outside entity is at the property boundary directly downgradient of the plume.

Currently, there are no complete exposure pathways or human or ecological receptors of contaminated groundwater. Downgradient public and WSTF water supply wells comprise potential future pathways for exposure to groundwater contamination. Under current conditions, the nearest downgradient water wells are NASA WSTF water supply wells. The distance between the edge of the conceptualized groundwater contaminant plume and the property boundary is approximately 7,300 ft. The locations of the WSTF water supply wells relative to other pertinent site features are shown in Figure 2. Routine sampling of drinking water from the NASA supply wells indicates that the WSTF water supply has not been impacted by WSTF groundwater contaminants. NASA also performed groundwater sampling at six off-site water supply wells in 2010. There was no evidence that these wells had been impacted by NASA's groundwater contaminant plume (NASA, 2010).

2.4 Previous Investigations

NASA has performed numerous environmental investigations at WSTF, including soil sampling, soil gas sampling, air monitoring, and groundwater monitoring. Historical and ongoing groundwater monitoring are most applicable to this Plan. A detailed discussion of the results of routine groundwater monitoring at WSTF is provided in the PMR (Periodic Monitoring Reports) submitted regularly to NMED. PMR include a comprehensive database of historical chemical analytical data from groundwater monitoring.

2.5 Surface Conditions

This section provides a brief description of the surface conditions as they relate to routine groundwater monitoring. Specific information on site conditions was provided in the WSTF RFI (RCRA Facility Investigation; NASA, 1996a).

2.5.1 Climate

The climate at WSTF is characterized by abundant sunshine, wide diurnal variation in temperature, low relative humidity, and variable precipitation. WSTF typically receives an average of 10 in. (inches) of rain per year, with the majority of rainfall events occurring in intense, brief, and localized thunderstorms during the late summer.

2.5.2 Surface Water Bodies

The major perennial surface water body in the region is the Rio Grande River, located approximately 15 mi west of WSTF within the Mesilla Valley. There are no natural surface water bodies at WSTF. The natural surface water body closest to the facility is Isaacks Lake, an ephemeral playa lake located approximately 8 mi southwest of the site at the lowest elevation in the JDMB (Jornada del Muerto Basin), a hydrologically closed basin (Figure 8) that is separated from the Mesilla Valley to the west by an uplifted horst block represented by the Doña Ana Mountains. Water is typically present in the playa only in years with above-average precipitation.

In certain areas, man-made channels or structures have been constructed to facilitate drainage and prevent erosion during high flow events. The only permanent surface water bodies at WSTF are the Test Stand 302 Cooling Water Discharge Pond and the 400 Area discharge ponds.

2.5.3 Surface Drainage

WSTF is characterized by high evaporation and infiltration rates, which are typical of a desert climate. Precipitation from the brief intense thunderstorms that falls upon the mountain range and alluvial fans cannot evaporate or infiltrate immediately and is transported downstream via arroyos. Arroyo surface flow generally terminates within minutes to hours after the end of a precipitation event. Topographic maps of the area indicate that numerous well-developed arroyos from WSTF terminate northeast of Isaacks Lake, and sheet flow drainage patterns characterize the western half of WSTF.

2.6 Subsurface Conditions

This section provides a brief description of the surface conditions as they relate to routine groundwater monitoring. Specific information on site conditions was provided in the WSTF RFI (NASA, 1996a).

2.6.1 Site-Wide Stratigraphy

Outcrops of Pennsylvanian limestone, sandstone, and siltstone bedrock that dip at approximately 22 degrees to the west occur adjacent and east of the WSTF 200 and 300 Areas. Exposed bedrock, or shallow bedrock covered by a thin (0 ft to 100 ft) veneer of alluvial sediments characterizes the fractured bedrock aquifer in the source areas. Figure 9 shows the geologic features of the eastern areas of WSTF. Bedrock west of the source areas is comprised of more gently westward dipping Tertiary volcanics overlain by a thicker alluvial sequence. Pennsylvanian and Tertiary bedrock lithologies are juxtaposed in the subsurface along the regional northwest- trending Hardscrabble Hill Fault that is exposed 2 mi south of WSTF on Hardscrabble Hill. West of the WSTF source areas, the alluvium thickness increases from approximately 100 ft to 350 ft within the MPCA. Immediately west of the MPCA, a structural feature known as the WBFZ (Western Boundary Fault Zone) displaces bedrock and the thickness of the alluvial unit increases significantly to over 2,500 ft within the JDMB. Alluvium consists of unconsolidated Quaternary alluvial fan deposits of the Santa Fe Group derived from the SAM (San Andres Mountains), located to the east of WSTF. Figure 10 shows additional geological features of the western areas of WSTF, with emphasis on the MPCA where the predominant WSTF geological features coexist. A detailed description of site geology is available in the Draft RFI Report, Volume Two, Chapter Four (NASA, 1996a).

2.6.2 Site-Wide Structural Geology

Two types of geologic deformation of the alluvium/bedrock stratigraphic section are recognized near WSTF. The oldest and least prevalent deformation consists of west-trending folds and faults associated with the Late Cretaceous to Early Tertiary Laramide Orogeny (Seager, 1981). This deformation is confined to the western SAM, and is exposed within the Bear Peak Fold and Thrust Zone located 1 mi northeast of the eastern limit of the groundwater plume in the 300 Area.

Younger and more widespread deformation is attributable to regional Late Tertiary Basin and Range normal faulting and directly affects the stratigraphy within the contaminated portion of the aquifer. East-west extensional forces across the southwestern United States resulted in the formation of northwest-trending structural depressions and adjacent fault-bound mountains. WSTF is located partially on the pediment slope of the SAM (bounding the JDMB on the east) and partially in the downfaulted JDMB, which is bounded on the west by the Doña Ana Mountains. Numerous subsurface half-graben normal faults within the western pediment slope of the SAM below WSTF have been identified from shallow seismic reflection and well log data. Regional structural features displaying the predominant northwest trend include the WBFZ and the Tertiary Hardscrabble Hill fault. The Hardscrabble Hill fault which lies to the east of the Mid-plume and passes through the WSTF 100 Area has an inferred displacement of several thousand feet. The WBFZ is a northwest-trending, regional-scale series of normal half-graben faults that offset the top of the bedrock from a depth of 400 ft in the MPCA pediment to >2,500 ft within the JDMB to the west over a horizontal distance of 2,000 ft.

2.6.3 Groundwater Hydrostratigraphy

Groundwater below the WSTF industrial areas is hosted within a fractured bedrock aquifer comprised of Pennsylvanian sedimentary rocks and Tertiary volcanic rocks at depths between approximately 100 ft and 200 ft bgs. The water table is relatively coincident with, and just below the contact between bedrock and the overlying alluvium. In the MPCA, groundwater occurs at a depth of approximately 300 to 450 ft bgs in an unconfined to semi-confined fractured bedrock aquifer. In the Plume Front area west of the WBFZ, groundwater occurs in an alluvial aquifer as a result of bedrock being displaced to inferred depths of up to 2,500 ft bgs toward the center of the JDMB. This aquifer yields relatively large quantities of potable water. At the Plume Front, the elevation of the water table within the upper aquifer of the JDMB ranges from 390 to 475 ft bgs and has been relatively consistent (within 3 to 6 ft) over a historical monitoring period of 40 years. Aquifer conditions in the vicinity of the Plume Front vary from unconfined to leaky confined due to the presence of discontinuous confining layers of clay or cemented alluvial horizons. Leaky confined conditions are generally prevalent within and to the west of the WBFZ. Figure 11 shows a cross-sectional view of WSTF's geology. The location of the cross-section is shown in Figure 2.

2.6.4 Groundwater Flow System

Groundwater beneath WSTF generally originates as recharge through precipitation in the southern SAM immediately east of the facility. As shown in Figure 11, groundwater flows generally to the west through fractured bedrock and the lower portion of the overlying alluvium down the pediment slope on the western flank of the SAM, and merges with the groundwater flow system of the JDMB alluvial aquifer west of the WBFZ.

Groundwater recharge to the bedrock and alluvial aquifers occur primarily through precipitation infiltrating into exposed bedrock fractures and faults. Annual mountain-front recharge is estimated to be 50 to 200 acre-ft per mi of mountain front (Wilson et al., 1981; NASA, 1996a, 1999). Recharge from the SAM catchment areas infiltrates the aquifer within the source areas and moves across the MPCA into the Plume Front area. West of the WSTF site boundary in the vicinity of the axis of the JDMB, recharge is more limited. This is a result of reduced precipitation, higher evaporation rates, an increased depth to groundwater, and the presence of shallow and relatively thick lacustrine clay deposits within the alluvial section.

Minor artificial recharge areas are present on the pediment slope adjacent to the 300 and 400 Areas where WSTF has discharged excess test water relatively continuously over the last 30 years. Spent test water, discharged to grade, infiltrates in the adjacent arroyo and recharges the groundwater system. Annually, approximately 90 acre-ft are estimated to recharge the aquifer over a distance of 7,000 ft downgradient of the 300 Area in the 300/400 Area arroyo (NASA, 1996a, 1999, 2013a). Water used in testing activities at WSTF is supplied by production wells completed in the JDMB aquifer in the western portion of WSTF. Hence, this artificial recharge simply recycles groundwater from one part of the flow system to another and does not represent a net increase in aquifer recharge.

Groundwater flow from east to west in the fractured bedrock aquifer below WSTF is a result of a hydraulic gradient between the higher topographic elevations in the SAM-front recharge area and the lower elevations of the WSTF Plume Front in the JDMB. Horizontal hydraulic gradients at WSTF are steep in the source area and MPCA bedrock pediment aquifer (0.05 ft/ft or 250 ft/mi), where small-scale, interconnected fractures promote localized irregular downgradient groundwater movement. The rates of movement through the fractured bedrock are highly variable, but are inferred to reach velocities of up to 750 ft per year. West of the WBFZ, horizontal hydraulic gradients are significantly lower within the alluvial aquifer of the JDMB (0.0002 ft/ft or 1 ft/mi).

Figure 12 provides a basic groundwater elevation map of WSTF.

2.6.5 Hydraulic Properties

Hydraulic conductivity (K) and transmissivity (T) values are typically several orders of magnitude greater in the alluvial aquifer than in the fractured bedrock aquifer. Recent groundwater flow modeling was accomplished by adjusting hydraulic conductivity to best match observed hydraulic heads. Figure 13 presents the calibrated horizontal hydraulic conductivity values used in the model, which match the range of hydraulic conductivities measured during aquifer pumping and slug tests.

Hydraulic conductivity zones were delineated across the WSTF model domain based on distribution of geologic units. Those units included fractured rocks (limestone, rhyolite, and andesite) and alluvial fan deposits. Figure 13 shows the distribution of these zones. Table 2 identifies these zones, geologic units they represent, distribution, K values derived from model calibration, and the range and geometric mean values for K derived from aquifer tests. The large number of significant digits indicated for hydraulic conductivities in Figure 13 and Table 2 were calculated by automated PEST (parameter estimation software). While measuring hydraulic conductivity to this level of accuracy is impossible, the software resolves hydraulic conductivity within the range of acceptable values specified by the user so that model calibration errors are minimized. These hydraulic conductivities are not field measured; however, they lie within the range of conductivities observed during field testing and result in a best fit match to observed hydraulic heads when paired with the other model hydraulic parameters.

The low permeability rhyolite and andesite unit, representing areas of dry holes and extremely small well yields, was assigned a very low K to represent these low permeability rocks. No test data are available to verify the calibrated value.

With one exception, calibrated horizontal K of zones representing other fractured rock units fell within the range of measured K derived from aquifer pumping and slug tests. These tests represented point values in an extremely heterogeneous system and the range was correspondingly large. Calibrated K of the representing fractured rhyolite east of the flow-banded rhyolite was lower than the observed range. That range was obtained from only three slug tests and may not be representative of the bulk hydraulic properties of this fractured rhyolite. In the case of several of the fractured rock units, the calibrated vertical K exceeds the horizontal K. This is a reasonable result given that fracture permeability dominates and near-vertical normal faults are known to exist in the fractured bedrock units.

The K of the alluvium was calibrated to observed distance-drawdown relationships observed during pumping tests at Well J (for the distal basin-fill deposits) and NASA-PT (alluvium in zone). The actual rates of groundwater flow at the Plume Front and similar areas of the JDMB alluvium are inferred to vary between 17 and 50 ft per year.

3.0 Regulatory Criteria

3.1 Hazardous Constituents and Cleanup Levels

The Permit requires that NASA establish cleanup levels for hazardous waste and hazardous waste constituents (Permit Attachment 15), as well as several site-specific contaminants identified in the Permit Section I.J (perchlorate, methyl tert-butyl ether, and munitions constituents). In accordance with the definition provided in Permit Section I.J, NASA identified hazardous constituents as those compounds specified in 40 CFR Part 261 Appendix VIII and 40 CFR Part 264 (2014) Appendix IX which have been consistently detected at the facility and “are reasonably expected to be in or derived from waste contained in a regulated unit” as indicated in 40 CFR 264.93 (2014). Cleanup levels were assigned to groundwater contaminants listed in Appendix VIII in 40 CFR Part 261 (2011) and/or Appendix IX in 40 CFR Part 264 (2014). The following steps were followed to develop cleanup levels:

1. Each hazardous constituent was evaluated individually to determine if an EPA (United States Environmental Protection Agency) Drinking Water MCL (Maximum Contaminant Level; 40 CFR Part 141 [2013]) exists.
2. Each hazardous constituent was evaluated to determine if a New Mexico WQCC (Water Quality Control Commission) numeric standard existed in Paragraphs (1-33) of Subsection A; Paragraphs (1-10) of Subsection B; and, Paragraphs (1-5) of Subsection C 20.6.2.3103 NMAC (New Mexico Administrative Code).

3. Each hazardous constituent was evaluated to determine if it is listed as a TP (toxic pollutant) in Paragraphs (1-54) of Subsection WW 20.6.2.7 NMAC.
4. If the hazardous constituent is NOT listed as a TP and has:
    a. Either an MCL or a WQCC standard, that value was assigned.
    b. Both an MCL and a WQCC standard, the lower of the two values was assigned.
    c. Neither an MCL nor a WQCC standard, an RSL (Regional Screening Level) was determined in accordance with Permit Attachment 15.1.1.c (Step 7) and assigned as the cleanup level.
5. If the contaminant is listed as a TP in paragraphs (1-54) of Subsection WW 20.6.2.7 NMAC, the RSL was determined according to Step 7.
6. Then, for each hazardous constituent listed as a TP, the lowest value of the existing drinking water MCL, the WQCC numeric standard, or the EPA RSL was assigned as the cleanup level.
7. For each hazardous constituent falling into the category of Step 4c or Step 5, above, the EPA RSL for tap water was determined as follows:
    a. For carcinogenic hazardous constituents, the RSL corresponding to a cancer risk level of 1.0E-05 was assigned. Note that the EPA RSLs for carcinogens are equivalent to a 1.0E-06 excess cancer risk. Therefore, for carcinogens, the RSL must be increased by an order of magnitude to meet Permit Attachment 15 requirements (NMED, 2016b).
    b. For each non-carcinogenic hazardous constituent, the RSL for tap water corresponding to a hazard index of 1.0 was determined (EPA, 2017).

Hazardous constituents are classified into the following categories to facilitate their analysis: VOC (volatile organic compounds); nitrosamines; metals; inorganics; SVOC (semi-volatile organic compounds); and miscellaneous hazardous constituents. Table 3 provides the current cleanup levels for hazardous wastes and hazardous constituents detected in groundwater at WSTF. In each PMR submitted to NMED, NASA compares the results of groundwater monitoring to the current established cleanup levels. Groundwater cleanup levels tend to fluctuate over time as the understanding of health risk evolves. To illustrate this variability, Figure 14 summarizes the cleanup levels for the four primary hazardous constituents in WSTF groundwater (NDMA, TCE, PCE, and Freon 11) between November 2009, when the current RCRA permit was issued by NMED, and the present. Table 4 identifies several other constituents that have been detected in WSTF groundwater that are of interest to NASA. These analytes are not hazardous constituents and thus do not have cleanup levels. However, NASA believes these analytes may be associated with historical or other activities at WSTF and has determined that they should be included in routine groundwater monitoring at WSTF.

3.2 Background Concentrations

NASA performed groundwater sampling at four upgradient monitoring wells and provided a statistical evaluation of background concentrations in Appendix A of the 2012 GMP Update (NASA, 2012b). However, the data set was not sufficient to perform all required statistical evaluations (NMED, 2012), so additional sampling is required. NASA anticipates the collection of additional groundwater samples from locations appropriate for the determination of background concentrations and expects a subsequent statistical evaluation will be performed when an adequate data set can be compiled.

3.3 Detection Monitoring

Detection monitoring will be performed at WSTF as required by Permit Section VI.D.2, which requires NASA to report new detections and refers to the requirements of this Plan and incorporates the requirements of 40 CFR 264.101 (2014). This section discusses these requirements and provides procedures for conducting detection monitoring at WSTF.

3.3.1 Detection Monitoring at HWMU (Hazardous Waste Management Units)

40 CFR 264.101 (2014) does not specifically address requirements related to detection monitoring at HWMU the (hazardous waste management units). In order to determine potential requirements for detection monitoring, NASA consulted 40 CFR 264.98 (2014), which requires the collection of samples for analyses of Appendix IX constituents at the compliance point. Because NASA has entered corrective action and is not specifically subject to these requirements, specific compliance points have not been identified for the facility or closed HWMU. However, in order to ensure that additional hazardous constituents are not released to the groundwater from the closed HWMU or current activities in the operational areas of the facility, groundwater samples from several locations will be analyzed for Appendix IX constituents. Appendix IX constituents that have been detected at WSTF are included in Table 4. Wells that are utilized for detection monitoring near HWMU are identified in Section 4.1 and Table 5. Detections of new Appendix IX constituents are managed as indicated in Section 3.3.3.

3.3.2 Facility-wide Detection Monitoring

As indicated in the Permit, a "new detection is any incidence of a constituent being detected in a groundwater sample collected from a monitoring well that has never been detected in prior samples obtained from that monitoring well." NASA samples groundwater monitoring wells at WSTF for a variety of hazardous constituents in accordance with this Plan. Chemical analytical data are reviewed to determine if new hazardous constituents have been detected. New detections are managed as indicated in the following section.

3.3.3 Management and Reporting of New Detections

If detection monitoring at WSTF results in the detection of previously undetected hazardous constituents, NASA will determine the reporting and monitoring requirements for that constituent as follows:

- The chemical analytical data and related laboratory reports will be evaluated by project chemists in accordance with the quality requirements specified in Section 10.0 to determine if the detection is reliable.
- If the detection is not validated, or is an estimated value, no further action is required.
- If the detection is validated, resampling will be performed for the constituent during the next scheduled sampling event at that monitoring well or zone. NASA will report the detection and scheduled confirmatory resampling in the subsequent PMR.
- If the constituent is not detected in the resample, NASA will report the resampling results to NMED in the subsequent PMR. No additional further action is required.
- If the detection is confirmed in the resample, NASA will report the detection to NMED in the subsequent PMR and propose a course of action related to the detection.

New or reconfigured groundwater monitoring wells will not be subject to facility-wide detection monitoring and related reporting until they have been sampled for at least one year as specified in Section 11.3.

4.0 Groundwater Monitoring System

This section describes the groundwater monitoring system in use at WSTF. It provides general information related to the groundwater monitoring wells in use, including: a list of the monitoring wells and their designations; a discussion of well drilling activities and basic procedures; a summary of well construction information; a description of well security practices; a summary of well maintenance activities; and a brief description of the procedures for well abandonment.

4.1 Groundwater Monitoring Well Identification and Designation

In general, groundwater monitoring wells are identified by a three-part alphanumeric code stenciled on the protective outer casing or on one of the well's protective barrier posts. The exception to this are those monitoring wells that were installed as part of the original RCRA groundwater detection program, which are designated as NASA 3 through NASA 10. The designations of wells installed after March 1987 are determined by location of the well site or other unique descriptor, an alphanumeric identification digit, and the depth (in feet below ground surface) to the top of the screened interval or to the discreet location of a multiport monitoring well. Multiport wells, in their entirety, are designated only by the location of the well site or other unique descriptor and the alphanumeric identification digit. The designation of a specific sampling zone in a multiport well incorporates the depth to that zone for three-part well zone designation and unique identification.

Groundwater monitoring wells at WSTF have been installed to monitor various areas of the groundwater plume or to serve specific functions in the groundwater monitoring program. The functional groups into which WSTF groundwater monitoring wells have been assigned are described below. A summary of WSTF's active groundwater monitoring wells is provided in Table 5. The location of groundwater monitoring well are provided in Figure 2.

4.1.1 Background Wells

Background monitoring wells are installed in the aquifer upgradient of the facility and HWMU at which hazardous waste was released to the groundwater. These wells are reasonably expected to be free of contamination resulting from activities at WSTF. In general, groundwater samples collected from these well can be considered representative of the background conditions at eastern WSTF. Due to the size and geological complexity of the facility, upgradient wells may not be fully representative of background conditions at some locations to the west of the WSTF industrial area.

4.1.2 Source/Industrial Area Wells

Numerous groundwater monitoring wells have been installed in the vicinity of or adjacent to closed HWMU at WSTF and in nearby sections of the industrial area. These wells were originally intended to monitor groundwater downgradient of the closures, determine if the HWMU were continuing sources of contamination to the groundwater, and/or determine the nature and extent of groundwater contamination in the industrial area. Several of these wells or zones were previously designated as PCC monitoring wells (Points of Compliance or Supplemental) and were subject to semi-annual replicate sampling for a variety of hazardous constituents (NASA, 1996a). Historical and current chemical analytical data indicate that groundwater in these areas remains contaminated, but show no evidence of additional releases of hazardous constituents to the groundwater (NASA, 2019). Typical PCC monitoring is not required by the

Permit. Source/industrial area groundwater monitoring wells are now primarily used on a less frequent basis to continue monitoring groundwater contaminant behavior in the vicinity of the HWMUs in order to support characterization of the contaminant plume, assist with source are investigations, and, if required, provide data for the development, implementation, and monitoring of corrective actions in these areas. Source/industrial area monitoring wells are installed in the thin veneer of alluvial sediments or the fractured bedrock underlying the thin alluvium in the WSTF industrial area.

Source/industrial area wells are divided into three subcategories: 100/600 Area wells; 200 Area wells; and 300/400 Area wells. Among these are five wells designated for detection monitoring as indicated in Section 3.3.1: 200-B-240; 200-SG-1; 300-A-120; 400-C-118; and BLM-3-182.

4.1.3 Northern Boundary Wells

Groundwater monitoring wells installed to the north and west of the WSTF industrial area serve primarily to bound the conceptualized groundwater contaminant plume in that region. Chemical analytical data collected from these wells provide information related to the migration of hazardous constituents along the northern limit of the plume. Included in this group of monitoring wells are those designated for groundwater monitoring in the vicinity of the closed 700 Area Landfill. Sampling of these monitoring wells is performed in accordance with a Closure and Post-closure Care Plan (NASA, 1996b) approved by the NMED Solid Waste Bureau.

4.1.4 Southern Boundary Wells

Groundwater monitoring wells installed to the south and west of the WSTF industrial area are also utilized to bound the conceptualized groundwater contaminant plume in that region. Chemical analytical data collected from these wells provide information related to the migration of hazardous constituents along the southern limit of the plume. Historical analytical data indicate very little plume activity in this area, thus monitoring of wells to the south of the industrial boundary is typically performed less frequently than at other more critical locations in and around the plume.

4.1.5 Mid-plume Constriction Area Wells

The MPCA is of great interest to NASA because of the potential for intercepting significant concentrations of groundwater contaminants in the area. As a result, numerous groundwater monitoring wells have been installed both upgradient and downgradient of the MPCA to characterize groundwater and contaminant movement in that region of the plume. These wells are installed at varying depths in both alluvium and fractured bedrock.

4.1.6 Plume Front Wells

Groundwater monitoring wells installed in the Plume Front area are used to characterize the conceptualized groundwater contaminant plume, identify and monitor the leading edge of the plume, and monitor the effects of the PFTS, NASA’s voluntary interim measures to prevent further westward migration of the plume. These wells are installed at varying depths in the alluvium west of the WBFZ and provide horizontal and vertical delineation of the plume.

Plume Front groundwater monitoring wells are further divided into two subcategories: wells within the main portion of the contaminant plume that are used to determine the impacts of the PFTS on groundwater contamination and those installed near the leading edge of the plume that are used to effectively monitor the horizontal and vertical extent of the contaminant plume and ensure the overall effectiveness of the PFTS.

4.1.7 Sentinel Wells

Sentinel wells are those groundwater monitoring wells installed beyond the leading edge of the conceptualized contaminant plume that have not been impacted by historical or current operations at WSTF. Sentinel wells provide monitoring points at depths within the aquifer where contaminant migration is a concern. Evidence of WSTF COC at these wells or zones indicate uncontrolled migration of contaminants beyond a defined spatial limit (such as a capture zone) and may initiate changes in remediation system operation or other actions to prevent further contaminant migration. These wells are in the alluvium west of the WBFZ and serve to bound the plume both horizontally and vertically.

4.2 Groundwater Monitoring Well Construction

Groundwater monitoring well construction varies at WSTF based on the specific geological conditions and groundwater monitoring requirements at each well location. Groundwater monitoring wells are described as conventional or multiport. Currently, active multiport wells utilize Westbay®[2] or Water FLUTe™ sampling systems (see Sections 5.2 and 5.3). NASA may consider the use of other multiport monitoring systems. The details of these designs are discussed below. Additional information related to the construction of WSTF groundwater monitoring wells is provided in Table 5.

4.2.1 Conventional Monitoring Wells

Conventional monitoring wells are designed to monitor specific, discrete intervals within the aquifer. Conventional monitoring wells consist of a single borehole in which the well casing is installed. The targeted zone or zones are monitored using a segment of slotted, or screened, casing which accesses the formation surrounding this screened interval. Screened intervals are typically 10 to 20 ft in length and are isolated from the remainder of the boreholes during installation of the casing to ensure only the targeted zones are sampled. Conventional wells are used to measure groundwater elevations and to collect groundwater samples that are representative of the groundwater in the vicinity of the screened interval.

Conventional well casing size and material varies based on the geological and chemical conditions and groundwater monitoring requirements at each well location. WSTF conventional groundwater monitoring wells vary in size from 1.5 to 5 in. in diameter and are constructed of PVC, stainless steel, or a combination of PVC and stainless steel.

4.2.2 Westbay Monitoring Wells

Westbay multilevel groundwater monitoring systems are designed to monitor multiple water-bearing zones within a single borehole. The systems are currently in use at WSTF to collect groundwater samples, obtain groundwater formation pressures to determine piezometric elevations, and perform hydraulic conductivity determinations. Data obtained from these wells are used to formulate a three-dimensional conceptualization of the groundwater contamination plume.

The Westbay system is a multiple-level groundwater monitoring system which employs a single, closed access, PVC casing with valved ports to perform well monitoring activities. The valved ports are used to provide controlled access to a multiple number of monitoring zones within a single borehole. The Westbay system is installed directly in a stable borehole or in a multi-screened conventionally installed monitoring well casing. Inflatable packers are integrated into the Westbay casing design and are individually inflated against the walls of the borehole or outer casing to isolate specific monitoring zones

[2] Westbay is a registered trademark of Nova Metrix Ground Monitoring (Canada) Ltd.

and secure the Westbay casing within the borehole or outer casing. Westbay wells are designed to provide direct access to formation water. This allows the collection of in situ groundwater samples and hydrogeological data. As a result of this design, the requirement to excessively purge each monitoring zone prior to sample collection is eliminated. Specialized downhole instruments are used to access the valved ports within the well.

Based on direction from NMED, NASA developed a plan to reduce the use of Westbay wells at WSTF and perform monitoring at some present Westbay locations with sampling systems that allow for some purging of groundwater (NMED, 2011). In 2013, NASA removed the Westbay casing from monitoring wells JP-3 and WW-2 and replaced the Westbay sampling systems with two dedicated low-flow sampling systems (NASA, 2013b). In November 2014, NASA removed the Westbay casing from monitoring wells BLM-28 and BLM-32. NASA installed a Water FLUTe sampling system in the open borehole at BLM-32 in August 2015 (NASA, 2016). Groundwater sampling of the well was initiated in the fourth quarter of 2015. NASA plans to install a single zone low-flow sampling system in the open borehole at BLM-28 in 2017. NASA reconfigured Westbay wells WW-4 and WW-5 to purgeable sampling systems in 2015 in accordance with the NMED approved schedule. The Westbay sampling systems were removed from both wells and redevelopment of the sampling zones began in September 2015. NASA installed four-zone Water FLUTe systems in these wells in November 2015 (NASA, 2016) and performed initial groundwater sampling in December 2015 and January 2016, respectively. In 2016 and early 2017, NASA removed the Westbay sampling systems from monitoring wells JER-1, JER-2, ST-6, and ST-7. Following redevelopment of the conventional casings in each well, multi-zone Water FLUTe systems were installed in each well (NASA, 2017a). Westbay monitoring well BLM-37 was also scheduled for reconfiguration in 2016. However, the Westbay casing became lodged in the outer stainless steel casing and broke. Numerous attempts to retrieve the casing failed and the well cannot be used. NASA recommended abandonment and replacement of the well with new groundwater monitoring well BLM-42 (NASA, 2018a), which is scheduled for installation in mid-2019. Additional Westbay reconfigurations are expected to be completed in the future.

4.2.3 Water FLUTe Monitoring Wells

Water FLUTe monitoring well systems are designed to monitor multiple water-bearing zones within a single borehole or conventional well. The systems are currently used at WSTF to collect groundwater samples and obtain groundwater elevation data. Data obtained from these wells are used in combination with data obtained from Westbay monitoring wells to continually refine the three-dimensional conceptualization of the groundwater contamination plume.

Similar to the Westbay monitoring system, the Water FLUTe system may be installed directly in a stable borehole or within a multi-screened conventional monitoring well casing. The Water FLUTe consists of a flexible polyurethane coated nylon fabric liner that contains several monitoring ports. Sealing pressure created by excess water inside the waterproof flexible liner above the static water level in the formation ensures that there is no communication between monitoring zones in the borehole or well. Tubing extends from multiple sample ports in the flexible liner to the top of the borehole or well casing. This allows for the collection of representative groundwater samples from discrete depths. Pressurized gas (typically nitrogen) is used to drive water from the pump tube in the system to the sampling tube and up to the surface during purging and groundwater sampling activities. Purging is required before sampling to ensure representative groundwater samples are being collected. No downhole instruments are required to operate the Water FLUTe monitoring system. The system is operated from ground surface with pressurized gas during purging and sample collection activities.

4.3 Groundwater Monitoring Well Security

WSTF is a secure facility that is regularly patrolled by trained security forces tasked with restricting access to the facility to authorized personnel only. In addition to this institutional security, monitoring wells are equipped with locking caps that are secured at all times, except during monitoring activities conducted in accordance with this Plan or other site-specific project documents. Keys are issued only to personnel directly involved in the collection of groundwater samples, well maintenance, or well inspection activities.

4.4 Groundwater Monitoring Well Evaluation and Maintenance

Groundwater monitoring well sites are inspected during each sampling event and during periodic inspections to ensure safe and secure sampling locations are maintained at all times.

WSTF NASA performs qualitative evaluations of monitoring well performance on an ongoing basis to determine if monitoring wells require additional development, maintenance, reconfiguration, or replacement. Groundwater monitoring wells may also be inspected with a downhole camera system to ensure well and sample integrity is maintained. The downhole camera system is utilized on an as-needed basis to perform inspections at the discretion of WSTF groundwater personnel. NASA has identified several wells that may require attention.

4.4.1 200-D-109

Monitoring well 200-D-109 (Figure 2) is installed in the Gardner Spring Arroyo downgradient of historical 200 Area contaminant discharges. In the mid-1990s, concentrations of groundwater COC in well 200-D-109 were some of the highest in WSTF groundwater. Concentrations have declined significantly in the area due to natural plume migration, but NASA considers this location important to overall plume delineation. Groundwater elevations have declined in this well, and are typically below the screened interval, which prevents the collection of representative groundwater samples from the well. NASA evaluated the potential future use of this well and determined that it is not suitable for continued monitoring. NASA plans to plug and abandon the well in 2019. See also Section 4.4.4.

4.4.2 200-KV-150

During attempted sampling events in 2018 and early 2019, NASA observed that groundwater monitoring well 200-KV-150 fails to recharge adequately for representative groundwater sampling using the dedicated low-flow bladder pump system. NASA was not able to sample the well in December 2018 and March 2019 and is evaluating options for disposition of this well.

4.4.3 200-LV-150

Groundwater monitoring well 200-LV-150 was installed in June 2014 as part of the 200 Area investigation. In the Groundwater Monitoring Plan Update for 2015 (NASA, 2015), NASA indicated that well 200-LV-150 had not been fully developed and required further characterized before a sampling system was selected and installed. In 2017 and early 2018, NASA completed development of this monitoring well, installed a dedicated low-flow bladder pump in the well, and collected the required groundwater samples from the well in February 2018. NASA sampled the well again in November 2018 and established an annual sampling schedule for the well as indicated in Table 15.

4.4.4 200-SG Wells

On September 13, 2018, NMED approved NASA's April 24, 2018 GMP update for 2018 (NMED, 2018c; NASA, 2018e) with modifications, one of which required NASA to provide additional information on wells 200-SG-2 and 200-SG-3 (Figure 2) and provide the rationale for not including them in the sampling schedule. NASA's December 3, 2018 response provided the required information and indicated that NASA would evaluate wells 200-SG-2 and 200-SG-3 for potential future sampling (NASA, 2018e). In April 2019, NASA attempted to evaluate the performance of the two wells, but determined that the groundwater levels in each are inadequate to allow for the collection of representative samples. NASA also evaluated historical groundwater analytical data from the two wells, which were sampled in 2010, 2012, 2013, and 2014. It was determined that the relatively low concentrations of WSTF COC in these wells are not representative of groundwater within the Gardner Spring Arroyo in which monitoring well 200-D-109 (Section 4.4.1) is installed. NASA plans to plug and abandon the groundwater monitoring portions of wells 200-SG-2 and 200-SG-3 and will evaluate the need for additional monitoring wells in this area of the contaminant plume.

4.4.5 BLM-30

On March 29, 2016, NMED approved NASA's January 27, 2016 *NASA WSTF Periodic Monitoring Report – Fourth Quarter 2015* with a comment expressing uncertainty about the source of detections of NDMA in well BLM-30 during 2015 (NMED, 2016a). NMED directed NASA to submit a work plan for the conversion of these Westbay wells to purgeable systems. NASA developed and submitted the *Westbay Well Reconfiguration Work Plan for Well BLM-30* (NASA, 2017b) on March 30, 2017 and received NMED's October 4, 2017 Approval with Modifications (NMED, 2017a) that required NASA to revise the BLM-30 reconfiguration work plan. NASA evaluated NMED's comments and submitted the *Well Reconfiguration Work Plan for Well BLM-30* on December 28, 2017 (NASA, 2017g). NASA attempted to remove the Westbay sampling system from the borehole at well BLM-30 in December 2018. After numerous attempts to retrieve the Westbay casing from the borehole, NASA and the off-site contractors determined that the borehole had sloughed and that there is approximately 40 ft of material on top of the uppermost packer, preventing removal of the system. NASA is investigating alternate methods for removing the Westbay casing from well BLM-30.

4.4.6 BLM-31

The Westbay sampling system in groundwater monitoring well BLM-31 became inaccessible to downhole sampling equipment in 2002. NASA discontinued sampling of the well at that time because it was located beyond the conceptualized groundwater contaminant plume. NASA believes that this well may be useful for future groundwater monitoring associated with ongoing or upcoming environmental investigations. NASA expects to reconfigure this Westbay well with an alternate sampling system. NASA will evaluate the potential reconfiguration of this well following fieldwork and reporting associated with an evaluation of the representativeness of groundwater data from a Water FLUTe well (NASA, 2018e).

4.4.7 BLM-37

As described in Section 4.2.2, the Westbay sampling system became lodged in the stainless steel conventional casing in well BLM-37 while attempting to remove the casing in order to reconfigure the well to a purgeable sampling system. The PVC casing broke and numerous follow-on attempts to remove it failed. NASA proposed to abandon the well and replace it with new groundwater monitoring well BLM-42 (NASA, 2018a). NMED approved the work plan that included abandonment of well BLM-37 (NMED, 2018a) and NASA plans to perform the required plugging and abandonment in mid-2019.

4.4.8 BW-4

Westbay monitoring well BW-4 (Figure 2) was utilized as a monitoring location for the 200/600 Areas and Mid-plume Constriction Area groundwater tracer test (NASA, 2012d). While attempting to remove groundwater dye tracer sampling equipment deployed in the Westbay casing, the equipment became lodged in the casing and could not be retrieved. In February 2018, NASA's subcontracted drilling company removed approximately 185 ft (of 475 ft total) of Westbay casing. The remainder of the Westbay casing was drilled out of the borehole. A camera log revealed that numerous locations in the borehole contain residual PVC fragments from the drilling operation. Additional borehole development is required to determine if the borehole can be reused or if it must be abandoned. NASA plans to perform borehole development work and evaluate the borehole for use as a monitoring well in 2019. Additional information related to the project will be provided in PMR.

4.4.9 PL-5

On March 29, 2016, NMED approved NASA's January 27, 2016 *NASA WSTF Periodic Monitoring Report – Fourth Quarter 2015* with a comment expressing uncertainty about the source of detections of TCE in well PL-5 during 2015 (NMED, 2016a). NMED directed NASA to submit a work plan for the conversion of this Westbay well to a purgeable system. NASA evaluated the current configuration of the well and determined that well PL-5 is not installed in accordance with the current requirements of Permit Attachment 19. Specifically, the annular seals between groundwater monitoring zones are inadequate. PL-5 is located near the PFTS and is important to NASA's understanding and interpretation of contaminant plume movement in that area. As a result, NASA proposed to replace this monitoring well (NASA, 2017b) and submitted the NASA WSTF Drilling Work Plan for Groundwater Monitoring Well PL-12 (NASA, 2017e). NMED approved the work plan (NMED, 2018b) and in December 2018 NASA removed the Westbay casing from the well and prepared it to be plugged and abandoned in mid-2019.

4.5 Groundwater Monitoring Well Abandonment

When groundwater monitoring wells are no longer required to meet the objectives of the groundwater assessment program, or have reached the end of their useful lives, they are abandoned. The goal of well abandonment is to seal the borehole so that it cannot serve as a conduit for the migration of contaminants. Well abandonment at WSTF is performed in accordance with procedures established in the Permit and 19.27.4 NMAC. Typically, the well casing is filled from the bottom upwards with an appropriate sealing material (bentonite, cement slurry, etc.) approved by NMOSE (NM Office of the State Engineer). NASA will submit a well abandonment plan to the NMOSE in accordance with 19.27.4 NMAC. If the well to be plugged and abandoned is an active sampling location in this Plan, the Permit requires that NASA submit a copy of the certification required by 19.27.4 NMAC to NMED no less than fifteen days prior to the well's removal from service. Because the cited NMAC does not include a requirement for certification, NASA will provide a copy of the plugging plan that must be submitted to the NMOSE prior to well abandonment fieldwork. 19.27.4 NMAC also requires that the driller contractor that plugs a well submit a plugging record to the NMOSE within 30 days of well abandonment. NASA receives copies of the plugging records and will provide these records to NMED within 60 days of well abandonment.

5.0 Sample Equipment

Equipment used for the collection of groundwater samples is designed to minimize the impact on sample integrity during the sample collection process. Equipment requirements for WSTF groundwater monitoring wells vary depending upon the type of monitoring well installed at the monitoring location. As previously indicated in this Plan, WSTF utilizes both conventionally installed monitoring wells and multiport monitoring wells for groundwater assessment purposes. This section describes the groundwater sampling equipment utilized in each type of monitoring well currently installed at WSTF. Sampling equipment is also summarized in Table 5.

5.1 Conventional Monitoring Wells

Several types of dedicated and non-dedicated well sampling systems are used at WSTF due to the variability of sampling conditions encountered. Factors that influence the type of system selected for each conventional monitoring well include the depth to water, volume of water to be purged, water recovery rate, frequency of sampling, overall integrity of the well casing, and the cost of system installation.

5.1.1 Dedicated Bladder Pump Systems

Numerous conventional wells are equipped with dedicated positive displacement bladder pump systems. In this design, the wells are purged and sampled using the dedicated bladder pump. The pumps are constructed of PVC, stainless steel, and/or Teflon®[3] depending on the monitoring objectives at that location. Samples are collected directly from Teflon-lined polyethylene or Teflon discharge tubing. These materials are used to minimize the sorptive effects of pump or tubing material on sample quality. The pressure necessary to operate the bladder pumps is supplied by compressed nitrogen cylinders or liquid nitrogen dewars.

5.1.1.1 Bladder Pump Systems for Low-Flow Sampling

Many of the wells equipped with dedicated bladder pumps are designated for low-flow sampling. Wells equipped with low-flow systems are slowly purged until groundwater indicator parameters stabilize. When these parameters are stable, sample collection is initiated as described in later sections of this Plan.

5.1.1.2 Bladder Pump Systems for Higher Volume Purging and Sampling

Certain conventional monitoring wells equipped with dedicated bladder pumps that are used to purge at least three casing volumes of groundwater prior to sampling with the bladder pump. Dedicated bladder pump systems are used in wells with relatively short groundwater columns and small purge volumes.

5.1.2 Dedicated Bladder Pump/Inflatable Packer Systems

Several wells are equipped with dedicated inflatable packer/bladder pump systems. In this type of system, an inflatable packer is used to isolate monitoring zones to facilitate purging. Water is purged and sampled from the monitoring zone(s) using a dedicated stainless steel/Teflon bladder pump. Samples are collected directly from the Teflon-lined polyethylene or Teflon discharge tubing to ensure sample quality.

5.1.2.1 Single Zone Packer Systems

Many conventional monitoring wells have a single screened interval near the bottom of the well. In these wells, an inflatable packer is used to isolate a sampling zone in the well extending from just above the screened interval or targeted monitoring zone to the bottom of the well. This significantly reduces the amount of purge water generated prior to sample collection. This type of sampling system is used in monitoring wells where a relatively large amount of purging would be required if the packer was not used

[3] Teflon is a registered trademark of E.I. du Pont de Nemours & Company Corporation (Dupont).

or where an irregularity in the casing prevents the collection of representative samples using other sampling techniques.

5.1.2.2 Multiple Zone Packer Systems

Conventional monitoring wells may also be equipped with multiple screened intervals within a single casing to allow for the collection of groundwater samples from multiple depths within the aquifer. The screened intervals are separated by inflatable packer(s) to prevent vertical mixing between monitoring zones. This type of sampling system is used to provide for the collection of high quality groundwater samples from multiple screened intervals in one conventional well casing in which other multiport sampling systems are not ideally suited or have proven to be suboptimal.

5.1.3 Non-Dedicated Purge Pumps and Bailers

Although dedicated equipment is preferred for sample collection at WSTF, there are occasions when dedicated equipment is impractical or is incapable of sample collection because of equipment failure or current well and/or hydrogeologic conditions. Under specific circumstances, such as dedicated equipment failure, non-dedicated equipment is used to purge groundwater monitoring wells and to collect groundwater samples. Additionally, new groundwater monitoring wells may also be sampled using non-dedicated purge pumps and bailers until their purge characteristics can be determined and the appropriate dedicated equipment selected, acquired, and installed.

When sampling conditions preclude the use of dedicated sampling equipment, non-dedicated Teflon bailers are used to collect samples after purging with a non-dedicated pump. A non-dedicated pneumatically driven purge pump is used to evacuate the specified volume of water, then a bailer is lowered into the well for sample collection using a non-dedicated stainless steel cable. The pump, if required, can also be used to collect samples for inorganic analytes. Due to possible effects on sample integrity, this pump is not typically used to collect samples with volatilization potential.

To eliminate cross-contamination between wells, the pneumatic pump and Teflon bailer are decontaminated prior to each use. To ensure that the decontamination procedures are effective and to determine the potential occurrence of field contamination, equipment blanks are collected at regular intervals as indicated in later sections of this Plan. Decontamination procedures are briefly described in Section 6.0.

5.1.4 Other Equipment and Supplies

In addition to the specific sampling equipment listed in the previous sections, a variety of general equipment is required for sampling conventional monitoring wells. For instance, certified clean sample containers are used to ensure the collection of quality groundwater samples. Sample containers are provided by the contracted analytical laboratory or a qualified third party vendor and meet strict industry standard cleanliness requirements. NASA requires that sample containers be certified clean by an independent laboratory. Additional required equipment includes, but is not limited to: source of compressed nitrogen (or other suitable compressed gas to operate pneumatic equipment); pneumatic controllers and related hardware; replacement Teflon tubing; portable purge/decon water collection container(s); portable electric generator; water level indicator (depth probe); field logbook; portable water quality instruments; calibration/check standards for instruments; PPE (personal protective equipment); polyethylene baggies; ice chests and ice; and decontamination equipment and supplies (steam cleaner/pressure washer, detergent, brushes, etc.).

5.2 Westbay Monitoring Wells

Westbay sampling systems are designed to monitor multiple water-bearing zones within a single borehole using a single dedicated casing string. The systems are currently in use at WSTF to collect groundwater samples, obtain groundwater formation pressures to estimate piezometric elevations, and perform hydraulic conductivity determinations. NASA uses data obtained from these wells to formulate a three-dimensional conceptualization of the groundwater contamination plume.

5.2.1 MOSDAX Sampler Probe

The MOSDAX®[4] sampler probe is a non-dedicated electronic tool used to measure downhole fluid pressures and obtain in situ groundwater samples from Westbay wells. The system is operated by a handheld controller. The controller displays pressure readings and controls the downhole fluid measurement and sample collection functions of the probe. The probe contains an electronic strain-gauge pressure transducer for measuring fluid pressures within the Westbay standpipe and through the measurement port couplings located in each monitoring zone. The probe is equipped with an electronically controlled sample apparatus that, when appropriately activated, accesses a one-way valve in the Westbay well casing and collects a groundwater sample directly from the aquifer.

5.2.2 Stainless Steel Sample Bottles

Groundwater samples are collected from Westbay wells using the MOSDAX sampler probe and retrieved in a series of stainless steel sample bottles that are attached to the probe. These non-dedicated sample bottles are decontaminated prior to sample collection at each well, and equipment blanks are collected for analysis by the specific volatile analytical method(s) required at each well. Decontamination procedures are briefly described in Section 6.0.

5.2.3 Other Equipment and Supplies

In addition to the specific sampling equipment listed in the previous sections, a variety of general equipment is required for sampling Westbay monitoring wells. For instance, certified clean sample containers are used to ensure the collection of quality groundwater samples. Additional equipment includes, but is not limited to: portable purge/decontamination water collection container(s); portable electric generator; vacuum pump; water level indicator (depth probe); field logbook; portable water quality instruments; calibration/check standards for instruments; PPE; polyethylene baggies; ice chests and ice; and decontamination equipment and supplies (steam cleaner/pressure washer, detergent, brushes, etc.).

5.3 Water FLUTe Monitoring Wells

The Water FLUTe is a purgeable groundwater sampling and water level measurement system designed to monitor multiple zones within a single borehole. The system consists of waterproof polyurethane coated nylon fabric liner with integrated spacers that create sampling intervals for each discrete sampling port. Groundwater flows from the formation into the spacer and through a sealed sample port in the liner. Polyvinylidene fluoride and/or nylon tubing extends from the sample port to the top of the well casing to permit groundwater purging and sample collection from discrete monitoring zones.

---

[4] MOSDAX® is a registered trademark of Nova Metrix Ground Monitoring (Canada) Ltd.

5.3.1 Water FLUTe Flexible Liner

The Water FLUTe flexible liner is constructed of polyurethane coated nylon. The waterproof liner seals the entire borehole by maintaining excess water inside the liner above the static groundwater level in the formation. Spacers are sewn into the liner, which pull the liner away from the borehole wall to create discrete monitoring intervals.

5.3.2 Water FLUTe Sample Port and Internal Tubing

Sample ports are located in the Water FLUTe liner at the top of each monitoring zone to facilitate purging and sample collection. Polyvinylidene fluoride and/or nylon tubing extends from each sample port to the top of the well casing. Two tubes are present at the top of the well casing for each monitoring zone. Pressurized gas (i.e., nitrogen) is applied to the larger pump tube within the system during purging and sampling activities to drive water down to the bottom of the liner and up the second smaller sample tube of the system. A check valve is located at the bottom of the pump tube in order to isolate the sample port and formation from the pump tube during purging and sampling activities. A second check valve is located near the bottom of the sample tube and prevents the backflow of water from the sample tube to the pump tube and formation once the gas pressure is released.

5.3.3 Other Equipment and Supplies

In addition to the specific sampling equipment listed in the previous sections, a variety of general equipment is required for sampling Water FLUTe monitoring wells. For instance, certified clean sample containers are used to ensure the collection of quality groundwater samples. Additional equipment includes, but is not limited to: source of compressed nitrogen (or other suitable compressed gas to operate the Water FLUTe system); pneumatic controllers and related hardware; portable purge/decontamination water collection container(s); water level indicator (depth probe); transducer interface module; field logbook; portable water quality instruments; calibration/check standards for instruments; PPE; polyethylene baggies; and ice chests and ice.

6.0 Pre-Sampling Activities

A variety of tasks are performed at groundwater sampling events prior to the collection of groundwater samples. These pre-sampling activities include: initiation of the field sampling record (logbook); decontamination of non-dedicated sampling equipment; well site inspection; measurement of the groundwater elevation; well purging (if required); and the measurement of groundwater indicator parameters. As previously indicated, WSTF currently utilizes both conventional and multiport monitoring well configurations for the collection of groundwater samples. Monitoring well sampling systems can be further categorized depending on the purge and sample methods utilized at each monitoring well. In general, purging and sampling of conventional monitoring wells is performed either by utilizing low-flow techniques (i.e., a minimal volume of water is purged prior to sampling), or by purging a set volume of groundwater prior to sample collection. Some pre-sampling activities and equipment requirements differ based upon the specific sampling system and techniques in use at each monitoring well. The following sections briefly describe the basic pre-sampling tasks that are performed at each groundwater sampling event.

6.1 Decontamination of Non-Dedicated Equipment

Non-dedicated sampling equipment is thoroughly decontaminated between uses to prevent cross-contamination. Previous demonstrations have shown that WSTF contaminants are efficiently removed through the use of heated water, environmentally safe detergent, and/or triple rinsing with purified water.

Equipment is first transferred to the steam cleaning pad or decontamination sink. Equipment is disassembled if possible, and each piece is pressure washed on the steam pad or washed with heated water and detergent in the decontamination sink. Equipment is then rinsed with purified water before being covered or wrapped with polyethylene sheets or placed in plastic baggies to prevent contamination before use. If the equipment cannot be steam cleaned or exposed to detergent, it is triple rinsed with purified water and stored in polyethylene wrap or plastic baggies. All fluids used or produced during the decontamination activities are managed as investigation-derived waste (IDW) as described later in this Plan.

6.2 Field Sampling Record (Logbook)

The field sampling record, typically a bound, hard copy logbook, is used to record all activities, observations, and measurements that take place in the field during sampling events. Records of the field activities should be sufficient to allow an experienced individual, not associated with the sampling event, to recreate the events by reading the logbook. Following each sampling event, the field sampling record for the event is reviewed and approved by a knowledgeable contractor environmental staff member to ensure completeness and accuracy. The sampling record is maintained on site as a permanent record of the sampling event.

Information that is included in the field sampling record each time sampling is conducted includes:

- Monitoring well identification/designation.
- Date of the sampling event.
- Site-specific procedural documentation to be used.
- Identification of the members of the sampling party.
- Climatic/weather conditions.
- Initial static water level.
- Calculated purge volume (if required – dependent on sampling equipment).
- Purge rate, purge duration, purge time, and volume of water purged (if required).
- Well evacuation method and equipment.
- Sample collection method and equipment.
- Decontamination procedures for non-dedicated equipment in use.
- Indicator parameter measurements, equipment used, calibration or check standards, standard lot number(s), and most recent calibration date(s).
- Identification of field quality control samples and source of blank water.
- Groundwater sample collection sequence.
- Unique sample identification number for each sample.
- Type of sample container used for each sample.
- Method(s) of preservation used for each sample.
- Chemical analysis or analytical method to be performed on each sample.
- Laboratory (or laboratories) performing the analyses.

- Problems encountered during field activities and any corrective actions implemented.
- Any other relevant field observations.
- Signatures of preparer and reviewer.

Individual field sampling records vary depending on the type of well sampled, sampling equipment used, specific samples and quality control samples collected, and other project-specific requirements. Site-specific procedural documents used for groundwater sampling provide the specific requirements of the field sampling record for each type of groundwater sampling operation.

6.3 Equipment Calibration/Verification

Prior to use, field instrumentation and/or equipment used for the measurement of groundwater indicator parameters and/or the collection of other data is calibrated or verified as instructed in site-specific procedural documentation. Field instruments are calibrated as recommended by the manufacturer using certified traceable calibration standards. Records of calibration and/or field verification of calibration and operation are included in the field sampling record.

6.4 Well Site Inspection

Upon arrival at the well location, and prior to implementation of sampling activities, field personnel inspect the well location to ensure that it is safe and easily accessible for the planned work activities. They also inspect the condition of the wellhead, locking well cap, cement pad, and protective bollards. Any anomalies are noted in the field logbook and reported to the appropriate contractor environmental organization personnel for corrective action.

6.5 Groundwater Elevation

6.5.1 Static Water Level in Conventional Monitoring Wells

The static water level, or groundwater elevation, is manually measured in each conventional monitoring well prior to collecting samples at each sampling event. The static water level is also measured in many wells on an established schedule to provide consistent groundwater elevation data for use in groundwater modeling and the development of groundwater elevation maps for reporting. The frequency for determining the groundwater elevation in conventional wells is presented in Section 11.1.

To measure the static water level in a conventional monitoring well, a water level probe is slowly lowered down the well casing until it contacts the water surface as indicated by audible/visual alarms on the probe. The probe is then raised and lowered very slowly until the depth to water is determined to the nearest 0.01 ft. The depth measurement, reference point (top of casing or ground surface), and the corresponding date and time of measurement are recorded in the appropriate field logbook, which is provided to the responsible environmental contractor personnel for review.

On infrequent occasions when a water level cannot be measured due to unforeseen circumstances, such as a depressed water level or equipment failure, the field sampling record will be updated with the pertinent information.

6.5.2 Static Water Level in Westbay Monitoring Wells

In order to determine the groundwater elevation in Westbay wells, the hydraulic pressure at the desired measurement port is measured using the MOSDAX sampler probe. This pressure is used to calculate the piezometric level of the measurement port, which is converted to the groundwater elevation at that location. Prior to sampling a zone in a Westbay well, the hydraulic pressure at the measurement port is measured and recorded in the field logbook. Groundwater elevations are also determined at select Westbay wells on an established schedule to facilitate groundwater modeling and aid in the development of groundwater elevation maps for reporting. The frequency for determining the groundwater elevation in Westbay wells is presented in Section 11.1.

The depth to water inside the Westbay casing is first measured as indicated in the preceding section. A series of surface checks are performed on the MOSDAX sampler probe to ensure it is functioning correctly prior to measurement and sampling activities. To measure the hydraulic pressure, the MOSDAX sampler probe is lowered into the Westbay casing and located in the desired measurement port within the casing. The probe is allowed to equilibrate, after which the hydraulic pressure of the formation is measured using the electronic transducer in the MOSDAX sampler probe. If required, the hydraulic pressure is measured at each measurement port in the Westbay well to complete the pressure profile. These pressure measurements and their corresponding date and time of measurement are recorded in the field sampling record, which is provided to the responsible contractor environmental personnel for review. A relatively simple mathematical equation is applied later to convert field measurements to the piezometric elevation for the desired location.

6.5.3 Static Water Level in Water FLUTe Monitoring Wells

Deep water table depths and small diameter tubing used within the Water FLUTe monitoring well systems prevent direct measurement of the static water level in most Water FLUTe monitoring wells at WSTF. In lieu of direct measurement, dedicated vented pressure transducers are used to determine the static water level at individual Water FLUTe monitoring zones before collecting samples during each sampling event. If there is there is no pressure transducer present at a specific monitoring zone, or the transducer fails to function as designed, the static water level may be determined by the measuring the volume of water expelled during a full purge cycle. The frequency for determining the groundwater elevation in Water FLUTe wells is presented in Section 11.1.

To determine the static water level at a Water FLUTe well, the indicated feet of water above the transducer is recorded and subtracted from the initial transducer reading that was obtained immediately following installation of the Water FLUTe system. The difference between these values is then subtracted from the recorded static water level that was measured before installation of the Water FLUTe system. Groundwater elevation is determined by subtracting the calculated static water level value from the measuring reference point elevation, which is the top of the well casing. The transducer reading and the corresponding date and time of the measurement are recorded in the appropriate field logbook and provided to the responsible environmental contractor personnel for review.

In cases where a Water FLUTe monitoring zone does not contain a dedicated pressure transducer, or the transducer fails to provide a reliable reading, the static water level is calculated from the volume of water expelled from the zone during a full purge cycle. The measured purge volume and system tubing diameter measurement is used with the general cylinder volume equation to determine the height of water above the bottom of the Water FLUTe system. The calculated water height measurement is added to known depth of the system to determine the static water level. Groundwater elevation is determined by subtracting the calculated static water level value from the measuring reference point elevation, which is the top of the well casing. The purge volume and the corresponding date and time of the measurement are recorded in the appropriate field logbook and provided to the responsible environmental contractor personnel for review after the completion of field sampling activities. Groundwater elevations calculated from purge volumes are not used to develop graphical representations of the groundwater surface at WSTF.

6.6 Well Purging/Preparation

This section provides basic purging procedures for the well systems described in previous sections of this Plan.

6.6.1 Bladder Pump Systems for Low-Flow Sampling

Most conventional groundwater monitoring wells are purged and sampled using dedicated low-flow sampling equipment (Table 5). Groundwater is purged from these wells slowly to avoid vertical mixing of the water within the casing. Some non-dedicated low-flow sampling equipment is assembled prior to purging a monitoring well. Using a properly rated pressure regulator and flex hose, a pressure source (typically compressed nitrogen gas) is connected to a pneumatic controller box, which is then attached to the wellhead with a second flex hose. A dedicated virgin Teflon discharge tube is attached to the appropriate port on the wellhead and routed to the flow-through cell (flow cell). A section of non-dedicated tubing is routed from the flow cell to the purge water collection container.

The pressure source and pneumatic controller are set at the starting pressure based on the depth of the bladder pump. The purge cycle is then optimized using the available settings (refill, discharge, and throttle) on the pneumatic controller. The static water level is monitored during purging to ensure minimal drawdown. If the water level begins to drop, the purge rate of the well is reduced such that the water level can be maintained within 25% of the distance between the top of the screened interval and the pump intake. If the drawdown exceeds this limit, an additional volume of water equal to that of the excess drawdown is purged prior to sample collection.

Some wells at WSTF are installed in very low yield formations. If the water level in the well continues to drop with each purge cycle when the refill is set to the maximum time, the well is considered low yield. For these wells, modified purging techniques are used to ensure that stagnant casing water is not sampled. Purging is continued at the low rate until the water level has dropped to three times the maximum allowable drawdown. Purging is discontinued at this point and the water level is allowed to recover to a level adequate to collect groundwater samples without exceeding three times the allowable drawdown. When the water level has recovered sufficiently, the bladder pump is cycled several times to clear stagnant water from the discharge tubing before sample collection.

During purging operations, groundwater indicator parameters are monitored at regular intervals as discussed in Section 6.7.1.

6.6.2 Dedicated Bladder Pump Systems for Higher Volume Purging and Sampling

In wells with dedicated bladder pump systems (Table 5), the depth to water in the well casing is utilized in conjunction with the total well depth to calculate the required volume of groundwater to be purged. Typically, three well volumes are purged prior to sampling. Using a properly rated pressure regulator and flex hose, a pressure source (typically compressed nitrogen gas) is connected to a pneumatic controller box, which is then attached to the wellhead with a second flex hose. If the well is not already equipped with dedicated discharge tubing, a dedicated virgin Teflon discharge tube is attached to the appropriate port on the wellhead and routed to the purge water collection container.

The pressure source and pneumatic controller are set at the starting pressure based on the depth of the bladder pump. The purge cycle is then optimized using the available settings (refill, discharge, and throttle) on the pneumatic controller. Using a container of known volume, the purge rate is determined by monitoring the time required to fill the container. At established intervals during purging, primary and secondary indicator parameters are measured as indicated in Section 6.7.2. When three well casing volumes have been removed, purging is complete and sampling can be initiated.

Low yield wells (those that do not recover sufficiently to produce three well casing volumes) are pumped dry. If the recovery rate is greater than 10 ft per hour, the well is allowed to recover for one hour then purged dry again. The well can be sampled when the water rises to a level that permits the pump to function. In cases where the recovery rate is less than 10 ft per hour, the water level is allowed to rise to a level that permits the pump to function, then sampling is performed. All pertinent information related to purge volumes and times is recorded in the field logbook.

6.6.3 Dedicated Bladder Pump/Inflatable Packer Systems

Several conventional monitoring wells are equipped with dedicated inflatable packers (Table 5) that are positioned to isolate the monitoring zone(s) in the well. Inflation of the packer shortens the water column and effectively reduces the required purge volume. The well casing volume used for purging is equal to that between the bottom of the packer and the bottom of the well sump or the volume required to achieve stable indicator parameters during low-flow sampling. Following packer inflation using compressed nitrogen, purging is performed using a dedicated bladder pump as described in the preceding section.

6.6.4 Non-Dedicated Purge Pumps and Bailers

Recently installed groundwater monitoring wells, those that have not been fully characterized, or wells in which dedicated equipment is not ideal, are purged using the non-dedicated pump (Table 5). Also, in the event that dedicated equipment fails or otherwise becomes unserviceable, it can be removed and non-dedicated equipment can be used to purge and sample a monitoring well. The total required purge volume is calculated based on the monitoring well design. The decontaminated non-dedicated purge pump is lowered into the well and activated using a pressure source. The pumping rate is measured to determine the time required to complete purging. The well is then purged as described in previous sections. When the required volume of groundwater has been purged and groundwater indicator parameters have been measured, the non-dedicated purge pump is removed from the well and sampling can be performed as indicated later in this Plan.

6.6.5 Westbay Monitoring Wells

Westbay wells are designed to allow the collection of groundwater samples directly from the formation with minimal active purging. The Westbay sampling apparatus must be assembled prior to sample collection. Previously decontaminated stainless steel sampling bottles are triple rinsed with purified water and attached to the bottom of the Westbay probe for use in sample collection. WSTF procedures for sampling Westbay wells require that these stainless steel sample bottles be rinsed once with formation water prior to sample collection. The sampling apparatus is lowered into the monitoring well and located in the sampling port at the least contaminated monitoring zone. The sampler probe, which is controlled from the surface, is used to access the formation outside the Westbay casing through a one-way valve in the casing and a corresponding valve in the probe. When the probe is located in the sampling port, it is sealed against the one-way valve in the casing to open it. The valve in the probe is then opened and a small volume of groundwater is drawn through the probe and into the stainless steel sample bottles attached to it. This volume, typically between one and two liters, is purged from the formation and used for the measurement of groundwater indicator parameters prior to sample collection.

6.6.6 Water FLUTe Monitoring Wells

Water FLUTe monitoring systems allow for the purging and sampling of multiple groundwater monitoring zones within a single conventional well or borehole. Monitoring wells or open boreholes equipped with Water FLUTe sampling systems (Table 5) are configured to isolate the monitoring zone(s) in the well or borehole. The pressure provided by excess water inside the FLUTe liner above the formation static water level seals the liner to the borehole or casing wall. This process isolates the monitoring zone and significantly reduces the volume of groundwater that must be purged to obtain representative samples.

The Water FLUTe monitoring system uses pressurized gas (typically nitrogen) to drive water from the system's larger pump tube to the smaller sample tube during purging activities. The gas pressure applied during purging activities is sufficient to expel all water from the system. Once all water is expelled, the gas pressure is released and a check valve opens to allow the system to refill with formation water through the sample port. This process is repeated until a sufficient volume of water is discharged from the system to ensure representative groundwater samples are collected. Two to four gallons are typically purged from each monitoring zone prior to sample collection.

6.7 Groundwater Indicator Parameters

This section describes the field measurements, or groundwater indicator parameters, that are collected during the purging and sampling of groundwater monitoring wells. Generally, the first and last samples of groundwater collected at each sampling event are reserved for the measurement of indicator parameters. The collection of groundwater for the measurement of indicator parameters is an integral part of the groundwater sampling process. As a result, the process of collecting indicator parameters varies slightly depending on the specific monitoring well system in use. The following is a brief discussion of indicator parameters and the equipment and supplies used for the different monitoring well configurations present at WSTF.

6.7.1 Bladder Pump Systems for Low-Flow Sampling

The majority of conventional monitoring wells at WSTF are sampled using dedicated low-flow bladder pumps (Table 5). Indicator parameters are measured during low-flow purging operations in accordance with acceptable low-flow practices and recorded in "sets." Indicator parameters are monitored using an in-line flow-through cell, which is equipped with multiple probes and/or sensors that measure temperature, pH, conductivity, ORP (oxidation/reduction potential), and DO (dissolved oxygen). Turbidity is frequently measured separately using water collected upstream of the flow cell. The depth to water is also closely monitored to ensure minimal drawdown during low-flow sampling. Indicator parameters are monitored throughout purging operations. When three sets of indicator parameters have stabilized to within 10%, purging is considered complete and sampling is initiated.

6.7.2 Dedicated Bladder Pump Systems

A number of conventional monitoring wells at WSTF are equipped with dedicated bladder pumps (Table 5). Some of these monitoring wells also utilize dedicated inflatable packers to isolate the screened intervals and reduce the volume of purge water generated during purging. Indicator parameters are collected from non-low-flow dedicated bladder pumps in a similar manner. Groundwater is collected directly from the dedicated bladder pump discharge tubing and is dispensed into a small clean container for parameter measurement using field instruments. A small volume of groundwater is dispensed directly into the turbidity vial for use in the field turbidity meter. Each set of indicator parameters typically consists of temperature, pH, conductivity, and turbidity. Generally, sampling personnel collect three sets of indicator parameters when sampling a well equipped with a dedicated bladder pump: the initial parameters are collected when approximately two casing volumes of water have been removed from the well; the secondary parameters are collected immediately prior to sampling after three casing volumes of water have been purged; and the third and final set is collected after all the necessary groundwater samples have been collected.

6.7.3 Non-Dedicated Purge Pumps and Bailers

When dedicated sampling systems are not practical, or fail to provide the overall groundwater sample quality required at WSTF, non-dedicated purge pumps and bailers are used (Table 5). When sampling with this equipment, indicator parameters are measured in a manner similar to that employed when sampling with dedicated bladder pumps, in which three sets of indicator parameters are collected. The initial and secondary parameters are measured using groundwater collected directly from the discharge tubing of the non-dedicated purge pump and dispensed into a small clean container or turbidity vial. The final set of indicator parameters is dispensed from the bailer into the appropriate vessel after the required groundwater samples have been collected.

6.7.4 Westbay Monitoring Wells

The collection of indicator parameters at Westbay monitoring wells (Table 5) utilizes much of the same equipment as other sampling methods. Groundwater obtained from the initial sample collection "run" is used for the measurement of indicator parameters. When the Westbay probe and sampling apparatus is brought to the surface, groundwater is dispensed directly from the lowermost sample bottle into a small clean container and turbidity vial for measurement of indicator parameters with field instruments. Excess groundwater is discarded into the purge water collection container and managed appropriately in accordance with specific instructions provided in later sections of this Plan. Two sets of indicator parameters are measured – initial and final. Each set consists of temperature, pH, conductivity, and turbidity. Initial parameters are obtained using water collected before the groundwater samples, while the final parameters are those measured using the water that remains in the stainless steel Westbay sampling bottles after groundwater samples have been collected.

6.7.5 Water FLUTe Monitoring Wells

Indicator parameters are measured at Water FLUTe wells (Table 5) using groundwater collected during the first sample "stroke" of the system. After purging is complete, the gas pressure is lowered to the required sampling pressure defined for the particular system. The sampling pressure for each Water FLUTe is carefully calculated to ensure that a buffer of water remains in the pump tube during sample collection. This ensures that the water being collected during sampling is not aerated by the pressurized gas used to expel water from the system. During the initial sample stroke, an initial volume of water is collected to ensure any residual air is removed from the system prior to sampling. This water is used for the measurement of indicator parameters to help monitor system performance. Any excess groundwater remaining after these indicator parameters are collected is discarded into the purge water collection container and managed appropriately in accordance with specific instructions provided in later sections of this Plan. Two sets of indicator parameters are measured as part of sampling – initial and final. Each set consists of temperature, pH, conductivity, and turbidity. Initial parameters are obtained using water collected before the groundwater samples, while the final parameters are those measured using groundwater that is discharged in the final sample stroke after groundwater samples have been collected.

7.0 Sampling Procedures

This section summarizes the procedures for sampling groundwater monitoring wells at WSTF.

7.1 Conventional Monitoring Wells

7.1.1 Dedicated Bladder Pump Systems

After the monitoring well has been purged as described in Section 6.6, the pumping rate is adjusted to approximately 100 mL per minute to facilitate the collection of samples for analysis of volatiles. A VOC sample vial is positioned under the discharge tube at an angle that allows the water to flow down the inside of the container with a minimum of turbulence. As the vial fills, it is rotated to an upright position and filled until a reverse meniscus is visible. The vial is capped, inverted to check for air bubbles, and placed on ice. When the vials have been filled, they are assigned a sample number as indicated in this Plan and appropriately labeled and sealed. The remaining groundwater samples are collected in descending order of sensitivity to volatilization. Each sample is assigned a sample number and appropriately labeled and sealed. Samples that must be cooled are placed on ice. Pertinent sampling information (sample numbers, relevant activities/conditions, etc.) are recorded in the field logbook.

7.1.2 Non-Dedicated Purge Pumps and Bailers

Following removal of the non-dedicated purge pump from the groundwater monitoring well after purging, the well is sampled using a non-dedicated Teflon bailer. The bailer is first decontaminated as previously described, and then transported to the well site wrapped in polyethylene sheeting to ensure cleanliness. It is attached to a stainless steel wire rope and lowered into the monitoring well. As it approaches the groundwater surface, the rate of descent is slowed and personnel listen for the sound of the bailer entering the water. It is slowly lowered into the water until it fills and is then raised to the surface. A decontaminated Teflon delivery stopcock is placed into the bottom of the bailer and a small amount of groundwater is flowed through the stopcock to serve as a final rinse. Groundwater is also collected at this time to measure the final turbidity. Samples sensitive to volatilization are collected from the stopcock in a manner similar to that previously described. VOC vials are filled, checked for headspace, labeled, sealed, and placed on ice. The bailer is lowered, filled, and retrieved as necessary to fill the remaining sample containers. Groundwater is collected from the last bailer run to measure final indicator parameters other than turbidity. All pertinent information related to sample collection is recorded in the field logbook.

7.2 Westbay Monitoring Wells

Previous sections of this Plan described the processes for measuring the hydraulic pressure in Westbay monitoring zones, assembling the sampling apparatus, and removing a small volume of groundwater from the formation at the sampling location to measure indicator parameters and rinse the sample collection bottles. To collect groundwater samples, the Westbay sampling apparatus is lowered into the well casing and located in the sampling port at the least contaminated monitoring zone, ensuring that equipment is not cross-contaminated between zones if decontamination is ineffective. It is sealed against the one-way valve in the casing and the valve in the probe is opened. Groundwater is collected from the sampling port using the MOSDAX sampler probe and stainless steel sample bottles. When the bottles have been filled with groundwater, the valves are closed and the sampling apparatus is brought to the surface. Groundwater is then dispensed from the lowermost stainless steel sampling bottle directly into the appropriate sample container. Samples are collected in descending order of sensitivity to volatilization as described in previous sections of the Plan. The process is repeated at each required monitoring zone. All pertinent information related to sample collection is recorded in the field logbook.

7.3 Water FLUTe Monitoring Wells

Previous sections of this Plan described the processes for determining the water level in Water FLUTe sampling systems and purging a sufficient volume of groundwater from the formation at the sampling location to measure indicator parameters and ensure the collection of representative groundwater. To collect groundwater samples, the gas pressure is lowered to the predefined sampling pressure for the system. The sampling pressure varies between each well because of different static water levels and tubing lengths within the Water FLUTe systems. The defined sampling pressure for each system maintains a buffer of water in the system's pump tube while samples are being collected. This ensures that the water being collected is not aerated by the pressurized gas. A sample "stroke" is initiated at a zone by opening the control valve for the pressurized gas, which pushes water down the pump tube to the sampling tube within the system. This process is identical to the purging procedure, but the gas is applied at a lower pressure to maintain the buffer of water with the system, as described previously. An initial volume of water is collected to ensure there is no remaining air within the system, which is also used to measure initial indicator parameters.

After confirming no air remains within the system, groundwater samples are collected directly from the Water FLUTe sample tube at the top of the well casing. The discharge from the sample tube slows and eventually stops as water is expelled from the system. When this occurs, the gas pressure is released, which allows the check valve at the bottom of the pump tube to open. This allows groundwater from within the liner spacer to flow through the sample port and refill the pump tube. A second check valve at the bottom of the sample tube also closes to prevent the backflow of water from the sample tube to the pump tube while the system is in a relaxed state. Subsequent sample strokes are used to produce a sufficient volume of water for the required samples. Samples are collected in descending order of sensitivity to volatilization as described in previous sections of the Plan. Following final sample collection and measurement of final indicator parameters, the gas pressure is increased back to the purge pressure to expel all water from the system's sample tube. This water is discarded into the purge water collection container and managed appropriately in accordance with specific instructions provided in later sections of this Plan. All pertinent information related to sample collection is recorded in the field logbook.

8.0 Post-sampling Activities

Following groundwater sampling, a variety of tasks must be performed to complete the sampling event. Post-sampling activities are summarized in this section.

8.1 Sample Management

Environmental samples collected at WSTF are strictly controlled. This section briefly describes the manner in which samples are identified, labeled and sealed, stored, documented, and shipped to off-site laboratories to ensure proper custody is maintained.

8.1.1 Sample Identification

A unique sample number is assigned to each sample at the time of collection that identifies the general sample collection location and sample date (year, month, day, and time. An example of a sample number is: 1905251035. In this example, 19 refers to the year (2019), 0525 refers to the date of collection (May 25), and 1035 refers to the time of collection (1035 hours, or 10:35 AM). In some instances, the sample number may be followed by a letter that identifies a specific field sampling crew or project. Additionally, when collecting samples for certain projects, the sample number may be preceded by an additional letter that identifies the sample collection location (e.g., Plume Front extraction well). This sample identification format is used for all groundwater samples and quality control samples.

8.1.2 Sample Labels and Custody Seals

Sample labels are required to avoid sample misidentification, either in the field, during packaging, or at the analytical laboratory. Sample labels are affixed to each sample container by sampling personnel immediately after sample collection and preservation (if required). Sample labels include, at a minimum, the following information:

- The unique sample number as previously defined.
- Identification of the well/zone being sampled.
- Identification of the sampling personnel.
- The analysis required for the sample.
- The preservation method utilized for the sample.

Sample custody seals are required to ensure that samples are not tampered with prior to laboratory preparation or analysis. Custody seals are completed and affixed to each sample container by sampling personnel immediately after the sample label is affixed to the container. Custody seals are placed over or around the cap of each sample container in a manner that ensures the seal must be broken to access the groundwater in the container. This ensures that access to the sample is controlled and limited to the receiving laboratory. Seals are inspected upon arrival of the sample at the analytical laboratory. Sample seals include, at a minimum, the following information:

- The unique sample number.
- Identification of the well/zone being sampled.
- Identification of the sampling personnel.

Additional custody seals are placed on sample shipping containers to demonstrate that the container is not tampered with during shipment to the analytical laboratory. Ice chest custody seals are affixed to the ice chest in a manner that ensures the seal must be broken to access the samples in the shipping container. Seals are inspected upon arrival of the shipping container at the analytical laboratory. Seals include, at a minimum, the following information:

- The date the container was packaged.
- The initials or signature of the individual responsible for packaging the sample shipping container.

8.1.3 Sample Storage

Most groundwater samples collected at WSTF must be cooled to 4 ± 2 °C following collection. To prevent alteration of these samples during collection, sample containers are cooled on ice prior to sample collection. Immediately following collection, preservation, and labeling, groundwater samples are placed on ice until they are transferred to refrigerated storage. Until shipment or transfer to the analytical laboratory, groundwater samples that require refrigeration are stored in a secure dedicated refrigerator that maintains a constant temperature of 4 ± 2 °C. Additionally, all samples that potentially contain contaminants that are sensitive to volatilization are stored (and later shipped) with the container septa facing down. This procedure minimizes possible volatilization of the target compounds through the septum.

8.1.4 Sample Custody

NASA maintains strict custody of groundwater samples at all times. As part of each sampling event, field chain of custody forms are updated with pertinent sample information, including: the date of the sampling event; location of sampling event; unique sample number(s); number of sample containers for each sample; sample matrix; required analysis for each sample; signature of the individual relinquishing custody; signature of the individual accepting custody; and the date of each. Throughout the sampling event, sampling personnel retain physical custody of groundwater samples. Upon completion of the sampling event, or as dictated by operational requirements, sampling personnel deliver groundwater samples to a secure dedicated refrigerator for storage prior to their shipment to a contracted laboratory. These personnel sign and date the internal chain of custody form(s) and indicate that sample custody was relinquished to secure storage. Access to the sample storage refrigerator is restricted to sampling and sample management personnel.

The designated sample management personnel accept custody of the samples as part of the packaging and shipment process described in the following section, and sign and date the custody form(s) accordingly. Separate lab- or contract-specific external chain of custody forms are prepared by the designated sample management personnel as part of the sample shipping process. The external chain of custody form includes pertinent information, including: date of shipment; laboratory name and purchase order number; return address for analytical results; project personnel contact information; unique sample number(s); number of sample containers for each sample; sample matrix; required analysis for each sample; applicable notes/comments; signature of the individual relinquishing custody; signature of the individual accepting custody; and the date of each. Completed chain of custody forms are retained as part of the sampling event record.

8.1.5 Sample Packaging and Shipment

Groundwater samples are securely packaged prior to shipment to off-site contracted analytical laboratories. Sample management personnel inspect sample containers to confirm sample identity and the accuracy and consistency of labels and related documentation. Sample containers are then wrapped or packaged in appropriately sized packaging material such as bubble wrap or foam inserts in a manner that will prevent breakage during shipment. Samples are then securely packed into an appropriately sized ice chest with sealed drain hole for shipment to the contracted analytical laboratory. The signed and dated external chain of custody form is placed in the ice chest, which is then sealed with a custody seal as previously indicated. The ice chest is further sealed to prevent any potential leakage should a sample container break during shipment.

After being securely packaged, groundwater samples collected at WSTF are typically shipped by commercial carrier (UPS, FedEx, etc.) to an off-site contracted analytical laboratory. Sealed ice chests are provided to the designated representative of the commercial carrier and shipped via next-day delivery service to the analytical laboratory. Sample shipping containers are managed by the commercial carrier as standard parcels to ensure delivery to the analytical laboratory in the specified time. Sealed ice chests are not accessed by shipping company personnel during shipment. Samples are scheduled for delivery to the analytical laboratory within their method-specified holding times with adequate time for the laboratory to initiate sample preparation and analysis. Upon arrival at the analytical laboratory, the shipping container is inspected by laboratory sample management personnel. Laboratory personnel then break the ice chest custody seal, review the chain of custody form, inspect sample containers, determine the temperature of samples using their laboratory-approved method, and accept custody of the samples by signing and dating the custody form. Complete chain of custody forms are included in the final report submitted by the analytical laboratory to NASA and are maintained at WSTF as part of the final analytical report.

8.2 IDW Management

WSTF groundwater contains halogenated and non-halogenated solvents such as TCE and Freon 11 that were used historically for degreasing and other laboratory processes. Due to the presence of these types of contaminants, special management requirements apply to purged groundwater and related media.

Under the Contained-In Policy, EPA requires environmental media to be managed as if they were hazardous waste if they contain listed hazardous waste or exhibit a hazardous characteristic. By application of the Contained-In Policy, groundwater removed from the contaminated portion of the WSTF plume has been characterized as F001 and F002 listed waste. Furthermore, several F001 and F002 regulated hazardous constituents are present at many monitoring locations in WSTF groundwater at concentrations that exceed cleanup levels.

Environmental media is considered to meet the definition of a RCRA solid waste at the time it becomes actively managed. The term “Active Management” is defined by EPA as “physically disturbing the accumulated wastes within a management unit…” (EPA530-K-05-011). Therefore, contaminated groundwater is considered to be a solid waste and is therefore subject to the RCRA hazardous waste identification and management requirements at the time that it is removed from a groundwater monitoring well. Because groundwater removed from the WSTF plume meets one or more of the listed waste definitions, any other material that comes into contact with contaminated groundwater is similarly regulated as “contact waste.” Contact waste includes spent PPE, contaminated sampling supplies, plastic, and other material that has come into contact with contaminated media. More specifically, this material is debris contaminated with environmental media containing hazardous waste.

During groundwater monitoring activities, several types of IDW are generated, including, but not limited to: contaminated groundwater collected during monitoring well purging and sampling operations; fluids generated during decontamination of non-dedicated sampling equipment; and potentially contaminated debris. The management strategy for this IDW is provided in the following sections.

8.2.1 IDW Water

Water generated during purging and/or development of monitoring wells or during decontamination of equipment that has come into contact with contaminated groundwater is collected in containers of various sizes (carboys, drums, trailer-mounted tanks, etc.). Containers are managed on site in accordance with requirements of 40 CFR 262.17 (2017) and 20.4.1.300 NMAC, including markings, accumulation time limits, and container requirements.

Within the permissible accumulation time limits, IDW water is transferred to the MPITS for storage, treatment, and discharge. The MPITS was designed and operates with provisions for the storage and treatment of IDW water as described in the MPITS Interim Measure Work Plan (NASA, 2008).

8.2.2 IDW Contact Waste

IDW contact waste, or potentially contaminated debris, that has come into contact with contaminated water includes, but is not limited to: non-dedicated sampling equipment (tubing, bailers, etc.) that cannot be decontaminated for recycling or reuse; disposable PPE such as gloves; and disposable equipment used for decontamination of equipment. This waste is collected at the end of each working shift and transferred into an appropriate container that is managed on site in accordance with the requirements of 40 CFR 262.17 (2017), including markings, accumulation time limits, and container requirements. Within the permissible accumulation time limits, IDW contact waste is shipped off-site for treatment and disposal at an approved facility, as appropriate.

8.3 Determination of Groundwater Flow Direction and Rate

Groundwater flow directions are estimated using hand-contoured potentiometric surface maps. Groundwater flow direction is assumed to occur perpendicular to equipotential lines, except where contaminant distribution or other data indicate significant anisotropy. Currently, the spatial distribution of groundwater contaminants is consistent with groundwater flow directions approximately perpendicular to equipotential lines; however, this may change as more data are collected.

The groundwater flow rate is calculated for several facility zones based on groundwater flow directions inferred from potentiometric surface maps and physical properties of aquifer materials. For example, the facility is typically subdivided into zones such as “source areas, Mid-plume, and Plume Front” or “bedrock and alluvium”. The average gradient and flow direction for all shallow monitoring intervals inside each of the zones are determined using groundwater gradient calculations. The rate of groundwater flow is calculated using Darcy’s Law according to the equation:

$$\text{Groundwater velocity} = [K(dh/dl)]/n_e$$

In the above equation, K is the average horizontal hydraulic conductivity of the aquifer zone, dh/dl is the average hydraulic gradient, and ne is the average effective porosity of the zone. The negative sign indicates that the direction of groundwater flow is down the hydraulic gradient. Average hydraulic conductivity is calculated using available aquifer test and numerical modeling results. Average effective porosity is estimated based on available lithologic data and numerical modeling results. Groundwater flow direction at WSTF is represented in Figure 12.

9.0 Chemical Analytical Methods

Samples are collected from WSTF groundwater monitoring wells and analyzed by a variety of chemical analytical methods. Chemical analytical methods used to analyze for the hazardous constituents and other analytes discussed in Section 3.1 are specified in this section. For many hazardous constituents or other analytes, NASA requests a chemical analytical method that is best suited for quantitation of that analyte based on past experience with WSTF groundwater. In other cases, NASA expects the analytical laboratory to propose an analytical method for the most effective and efficient analysis of the compound. In all cases, the analytical laboratory will utilize the most recent EPA and/or industry-accepted chemical analytical methods available for the hazardous constituent specified. For each hazardous constituent, preferred MDL (method detection limits), which are equal to 20 percent of the applicable cleanup level in accordance with Permit Section 17.3, are presented. Preferred MDL and accompanying PQL (practical quantitation limits) are incorporated into the competitive bid process for securing contracted analytical services in order to obtain the most sensitive analyses possible. Laboratories are required to achieve the lowest practicable MDL for hazardous constituents as indicated in Permit Section 17.3.3.c. More specific information related to the QA/QC (quality assurance and quality control) practices and procedures associated with the WSTF groundwater monitoring program are provided in Section 10.0.

9.1 Volatile Organic Compounds

Samples for the analysis of VOC are collected at each groundwater monitoring well or zone at each scheduled sampling event. To best quantitate the levels of VOC in WSTF groundwater, NASA uses the most current version of SW-846 Method 8260 (EPA, 2007). Table 6 provides the preferred MDL and PQL for the analysis of volatile organic hazardous constituents and other analytes in WSTF groundwater.

9.2 NDMA

Samples for the analysis of NDMA are collected at each groundwater monitoring well or zone outside of the 100/600 Area at most scheduled sampling events. To most effectively quantitate the levels of NDMA in WSTF groundwater, NASA uses two analytical methods: Modified EPA Method 607 (for groundwater with higher levels of NDMA) and a more sensitive low-level analytical method (for groundwater with lower levels of NDMA). NASA selects the appropriate analytical method for the analysis of NDMA based on well location and expected concentrations. Table 6 provides the preferred MDL and PQL for the low-level analytical method for the analysis of NDMA in WSTF groundwater.

9.3 Metals

Samples for the analysis of metals are collected at each groundwater monitoring well or zone, usually on a less frequent basis than for VOC and nitrosamines. Several different methods are used to analyze for metals in groundwater samples. The contracted analytical laboratory specifies the most appropriate analytical method to best achieve the preferred MDL and PQLs. Table 6 provides the preferred MDLs and PQL for the analysis of metals in WSTF groundwater.

9.4 Inorganic Compounds

Samples for the analysis of inorganic compounds are collected at most groundwater monitoring wells and zones on a less frequent basis than for VOC and nitrosamines. Inorganic compounds are analyzed for in groundwater samples using several different methods. The recommended methods and associated preferred MDLs and PQLs are provided in Table 7. The contracted analytical laboratory may recommend analytical methods other than those requested by NASA to more effectively and efficiently achieve the preferred MDL and PQL. NASA expects to accept these laboratory recommendations if the proposed alternate analytical methods meet or exceed the analytical criteria of the analytical methods specified in Table 7. Specific information related to the analytical method utilized is included in the PMR.

9.5 Semi-Volatile Organic Compounds

Samples for the analysis of SVOC are collected at most groundwater monitoring wells and zones on a less frequent basis than for VOC and nitrosamines because only a limited number of SVOC have been detected in WSTF groundwater. To quantitate concentrations of SVOC in WSTF groundwater, NASA uses the most current version of SW-846 Method 8270 (EPA, 2017). The recommended methods and associated target MDL and PQL for the analysis of SVOC are provided in Table 7. The contracted analytical laboratory may recommend analytical methods other than those requested by NASA to more effectively and efficiently achieve the preferred MDL and PQL. NASA expects to accept these laboratory recommendations if the proposed alternate analytical methods meet or exceed the analytical criteria of the analytical methods specified in Table 7. Specific information related to the analytical method utilized is included in the PMR.

On December 19, 2017, NMED directed NASA to utilize SW-846 Method 8270 with Selective Ion Monitoring for the analysis of 1,4-dioxane at specific groundwater monitoring wells at WSTF (NMED, 2017b). Table 7 also provides the target MDL and PQL for the analysis of 1,4-dioxane.

9.6 Miscellaneous Hazardous Constituents

Samples for the analysis of miscellaneous hazardous constituents are collected only at selected groundwater monitoring wells and zones. Samples are collected on a relatively infrequent basis because only a limited number of these hazardous constituents have been detected in WSTF groundwater. The recommended methods and associated preferred MDL and PQL for the analysis of miscellaneous hazardous constituents are provided in Table 7. The contracted analytical laboratory may recommend analytical methods other than those requested by NASA to more effectively and efficiently achieve the preferred MDLs and PQLs. NASA expects to accept these laboratory recommendations if the proposed alternate analytical methods meet or exceed the analytical criteria of the analytical methods specified in Table 7. Specific information related to the analytical method utilized is included in the PMR.

NASA submitted the *Response to Disapproval of First Tracking and Data Relay Satellite System (TDRSS) Diesel Release (SMWU 50) Investigation Work Plan* on July 27, 2017 (NASA, 2017d). In the revised work plan, NASA recommended the collection of groundwater samples for the analysis of TPH (total petroleum hydrocarbons; GRO [gasoline range organics] and DRO [diesel range organics]) by SW-846 Method 8015 from groundwater monitoring wells that may have been impacted by the release of diesel fuel at SWMU 50. Though GRO and DRO are not considered hazardous constituents, preferred MDL and PQL are provided in Table 7.

10.0 Quality Assurance/Quality Control Program

This section outlines QA/QC requirements to ensure that WSTF groundwater monitoring data are valid and of known quality. Collecting and maintaining valid data of known quality supports the groundwater monitoring program goal of providing consistent and accurate representation of actual groundwater contaminant concentrations and movement over time. To achieve this goal, this Plan as a whole provides a consistent framework for the generation of valid physical and chemical analytical data. This section addresses the following specific data quality elements:

- Field and laboratory quality control procedures and measurement evaluation criteria to ensure that collection and analytical systems generate data of sufficient quality to meet the program goals.
- Laboratory reporting requirements sufficient to support the program goals.
- Quality assurance review procedures designed to indicate the extent to which groundwater monitoring data generated is appropriate for its intended use.
- Early detection of deficiencies and prompt corrective action to minimize effects on data quality.

All data generating steps, including sample collection, shipment, analysis, custody control, document control, data review, and data storage are performed using established procedures to ensure data quality. This Plan, coupled with adherence to procedures outlined in site-specific procedural documents, equipment operation and maintenance manuals, analytical statements of work, NELAC (National Environmental Laboratory Accreditation Conference) accreditation standards, laboratory SOP (standard operating procedures), and laboratory quality manuals ensures that data meet the objectives of the WSTF groundwater monitoring program.

This section provides specific information related to the following QA/QC issues associated with the groundwater monitoring program at WSTF:

- Contracted chemical analytical laboratories.
- Quality control samples and related procedures.
- Data quality indicators.
- Analytical data quality exceptions and qualified data.
- Analytical data management, including verification and validation.

- Internal reporting.

10.1 Contracted Analytical Laboratories

The contractor environmental organization contracts accredited analytical laboratories to analyze groundwater samples in support of the WSTF groundwater monitoring program. Prior to awarding any analytical support contracts, each analytical laboratory must respond to all requirements in the Statement of Work prepared by qualified contractor environmental organization personnel, submit proof of accreditation by an industry-recognized accreditation body, and submit the laboratory quality manual and applicable SOP to the contractor environmental organization for review and approval. These documents ensure that laboratories meet the performance criteria for WSTF groundwater monitoring activities.

Contracted analytical laboratories will perform all analyses using procedures detailed in the submitted laboratory SOP that are based on the most recent EPA and industry-accepted preparation and analytical methods for an aqueous matrix (groundwater) as discussed in the previous section.

10.1.1 Laboratory Quality Manual

Documentation of the analytical effort is outlined in the Quality Manuals submitted by the analytical laboratories as part of the competitive bid process. The contractor environmental organization reviews and approves the laboratory Quality Manual prior to a contracted laboratory commencing analyses. The laboratory’s Quality Manual must include, at a minimum, the following:

- Personnel qualifications and training plans.
- Documentation and records management procedures.
- Quality control procedures.
- Work processes, operating procedures and methods.
- Quality assessment, standardization and response action plans.

10.1.2 Laboratory Deliverables

The laboratory analytical data package shall be prepared with sufficient information to meet the requirements of the WSTF groundwater monitoring program. The data packages shall be delivered to responsible contractor environmental organization personnel for review and incorporation into the data management module. At a minimum, the laboratory analytical data packages will include the following information:

- Laboratory company name.
- Client provided project number or client company name.
- Laboratory work order, report number or sample delivery group identifier.
- Laboratory report date.
- Client provided sample number.
- Laboratory assigned sample identification.
- Sample matrix.

- Sample type identifier, i.e., SA (sample), MB (method blank), LCS (laboratory control samples), LCSD (laboratory control sample duplicates), MS (matrix spikes), or MSD (matrix spike duplicates).
- Date sample received in laboratory.
- Instrument calibration.
- Calibration range for all analytes.
- Preparation method identifier.
- Date of sample preparation and/or extraction.
- Analytical method identifier.
- Date sample analyzed.
- Time sample analyzed.
- Extraction batch number (if applicable).
- Quality control lot number.
- Dilution factor.
- Quantitation limits.
- Method detection limits.
- Instrument-specific detection limits.
- Instrument number or identification.
- Sample preparation logs.
- Analyst name.
- Analyst bench notes.
- CAS (Chemical Abstract Service) numbers.
- Analyte names.
- Analytical results.
- Result units.
- Extraction efficiency (if appropriate).
- Surrogate recovery information (if appropriate), including %R (percent recovery), control limits, and spiking levels.
- Quality control sample results including, but not limited to, LCS and LCSD, MB, MS and MSD, and AD (analyst duplicates).
- Spiking levels, calculations, and control limits for %R and RPD (relative percent difference) of LCS/LCSD and MS/MSD pairs as well as RPD for analyst duplicates.
- Quality control data qualifiers and associated narratives including corrective action narratives and narratives that indicate no quality issues were encountered for each method (as applicable).
- Definitions for all laboratory data qualifiers used.

- Relevant comments concerning sample or analytical conditions.
- Confirmation of conformance with required analytical protocol(s).
- Pertinent sample receipt information and documentation including holding times and condition of sample upon receipt.
- Final signed copy of the chain(s) of custody for samples in the report.
- Laboratory approval signatures.

10.1.3 Retention of Documents

The analytical laboratory is required to maintain demonstrations of capability, raw data, chromatograms, logbooks, and all other relevant analytical information for at least five years after sample analysis and must make this information available to the responsible contractor environmental organization personnel upon request. This information is required to ensure the validity of reported data and to rectify any discrepancies that may arise.

10.2 Quality Control Samples

The WSTF groundwater monitoring program utilizes both field and laboratory QC samples to ensure that program quality objectives are met.

10.2.1 Field Quality Control Samples

Field QC samples include equipment blanks, field blanks, trip blanks, and field duplicate samples. The descriptions and purposes of field QC samples are provided in Table 8. Field QC samples are collected at the frequencies specified in Table 9. The evaluation criteria and potential corrective actions for issues related to field QC samples are described in Table 10.

10.2.2 Laboratory Quality Control Samples

Laboratory QC samples include method blanks, laboratory control samples, matrix spikes, matrix spike duplicates, and surrogate spikes. The descriptions and purposes of laboratory QC samples are provided in Table 11. Laboratory QC sample analysis is performed at the frequencies specified in Table 12. The evaluation criteria and potential corrective actions for issues related to laboratory QC samples are described in Table 13.

10.3 DQI (Data Quality Indicators)

This section describes the DQIs that are applicable to the WSTF groundwater monitoring program.

10.3.1 Precision

Precision is the degree to which a set of measurements of the same property, obtained under similar conditions conform to themselves. Precision is expressed as RPD between field duplicate samples, duplicate matrix spikes, duplicate laboratory control samples or analyst duplicate samples. RPD is calculated as follows:

$$RPD = [\,|x_1 - x_2| \,/\, ((x_1 + x_2) / 2)]\,(100)$$

In the above equation, x_1 and x_2 are the reported concentrations for each duplicate sample.

For values approaching the limit of quantitation (less than three times the PQL), a qualitative evaluation of precision may be applied.

10.3.2 Bias

Bias is the systematic or persistent distortion of a measurement process, which causes errors in one direction (i.e., the expected sample measurement is different from the sample's true value). Bias is expressed as percent recovery. Percent recovery (%R) is calculated as follows:

$$\%R = (R / S)(100)$$

In the above equation, R is the reported concentration and S is the spiked concentration.

10.3.3 Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a population characteristic. Representativeness is a qualitative term that should be evaluated to determine whether measurements are made and physical samples collected in such a manner that the resulting data appropriately reflect the media and phenomenon measured or studied. The representativeness criteria is satisfied by ensuring that samples are collected and analyzed using standardized procedures throughout the sampling and analytical process. These standardized procedures include: this Plan; all applicable WSTF site-specific procedural documentation associated with groundwater sample collection, sample management, and data review and management; standardized laboratory accreditation requirements for quality systems; and current laboratory-specific SOP for all chemical analytical methods.

10.3.4 Comparability

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. Sample data should be comparable with other measurement data for similar samples and sampling conditions. This goal is achieved using standard collection and analytical techniques and reporting analytical data in appropriate units.

10.3.5 Sensitivity

Sensitivity refers to the capability of a method or instrument to discriminate between measurement responses representing different levels (e.g., concentrations) of a variable of interest. The sensitivity indicator of primary interest is the limit of detection. In determining the detection limit, the focus is on the concentration that can be distinguished from the noise of the method. The preferred limits of detection are a maximum of 20% of the cleanup levels. These preferred limits will be incorporated into the analytical statements of work for the groundwater monitoring program. Detection limits that exceed the cleanup levels for analytical results reported as "not detected" are considered data quality exceptions and an explanation for the exceedance and its acceptability for use shall be provided.

10.4 Analytical Data Quality Exceptions (Qualifications)

The analytical laboratory is required to assign data qualifiers (flags) to analytical results that are outside the laboratory acceptance criteria and constitute data quality exceptions. Designated contractor environmental organization personnel review laboratory deliverables and convert laboratory-assigned data qualifiers to the equivalent WSTF-designated qualifiers provided in Table 14. Laboratory-assigned qualifiers are converted in order to maintain data comparability and integrity and to ensure consistency of data qualification across the WSTF groundwater monitoring program regardless of contracted analytical laboratories.

A significant data quality exception is the result of an anomaly in the analytical process that will negatively impact the usability of the chemical analytical data. During groundwater monitoring activities, significant data quality exceptions may infrequently arise at the laboratory that negatively impact the implementation of this Plan or interfere with the ability to meet the objectives of the groundwater monitoring program. In the event of a significant data quality exception at a contracted analytical laboratory, the laboratory must notify the responsible WSTF contractor environmental organization personnel within one business day of the discovery in order to allow for the consideration and implementation of corrective actions. If corrective actions that meet the objectives of this Plan cannot be implemented, the responsible contractor environmental organization personnel will relate the issue to the facility project manager or designee, who will contact NMED within one business day of receipt of laboratory notification of the exception. The facility project manager or designee will discuss the implications of the data quality exception with the NMED project leader and determine whether the data will still be considered acceptable or if sample re-analysis or resampling is necessary. The facility project manager or designee will summarize the results of the discussion with the NMED project leader in a memorandum, which will be submitted to NMED by email within three business days of the verbal discussion.

10.5 Analytical Data Management

The amount of chemical analytical data produced by WSTF groundwater monitoring activities requires that standard procedures are used to manage, store, and process all groundwater chemical analytical data. This section discusses the procedures used to ensure that groundwater chemical analytical data are effectively processed.

The environmental database used by the site contractor environmental organization is a modular database system. Modules included in this system are the data management module and the environmental database module. The contractor environmental organization also retains all documentation related to chemical analytical data in the database modules. All documentation is managed pursuant to federal records management protocol, Permit-required records retention criteria, and site-specific record management procedures.

10.5.1 Data Management Module

The data management module is utilized to gather and organize analytical data for the various evaluation and reporting requirements associated with WSTF groundwater monitoring activities. Responsible contractor environmental organization personnel perform verification and validation procedures, organize the laboratory data and the corresponding QA discussion, set data qualifiers, and prepare the data for final reporting. The evaluation criteria in Table 10 and Table 13 as well as all associated documentation mentioned in this groundwater monitoring plan provide the basis for the data quality review. The data are reviewed, qualified, and approved by the responsible contractor environmental organization personnel.

10.5.2 Environmental Database Module

The WSTF environmental database module is managed by the contractor environmental organization as directed by NASA. Groundwater chemical analytical data are verified and validated by the contractor environmental organization prior to incorporation into the archival environmental database module. This module is the final repository for all verified and validated analytical data and allows data end-users the ability to use stored data for generating reports, tables, graphs, and other visual presentations.

10.5.2.1 Database Management

Management of the environmental database is performed pursuant to specific procedures outlined in site-specific procedural documentation applicable to groundwater database operations and quality assurance. The site contractor environmental organization is the only organization which can input or edit data in the environmental database module. All other individuals are granted "read only" access. This precludes data modification by personnel other than specific qualified personnel within the contractor environmental organization.

10.5.2.2 Analytical Data End-Users

The primary end-users of groundwater chemical analytical data are the contractor environmental organization, NASA Environmental Office personnel, and NMED. The contractor environmental organization uses the chemical analytical data, in conjunction with collected geophysical data, to interpret and present technical assessments of the hydrogeological system. In addition, the contractor environmental organization uses the data to prepare regulatory and technical reports. NASA Environmental Office personnel and NMED use data presentations as guidance for making decisions concerning the groundwater monitoring program.

10.6 Internal Reporting

In order to facilitate the transfer of information within the contractor environmental organization and to other interested on-site stakeholders, various internal assessment and reporting mechanisms have been developed. These include: internal quality systems evaluation and related report; internal quality assurance report; and consideration and evaluation of corrective actions applicable to organizational operations. These tools are described in more detail below.

10.6.1 Technical Systems Evaluation

Technical system evaluations are an essential element in the overall management of groundwater chemical analytical data. These evaluations are designed to verify compliance with this Plan and other applicable documentation and to assess the overall quality of the data collection and generation system. Evaluated systems include sample collection, sample analysis procedures, and data management and reporting techniques.

A technical systems evaluation is a qualitative evaluation of the entire data collection and generation system used in the WSTF groundwater monitoring program. This evaluation examines all phases of the sampling and analysis system: collection of samples; preservation and handling of samples; transport of samples; documentation of field and analytical steps; quality control procedures; data reporting; and data processing and management.

This evaluation is performed on at least an annual basis by an independent individual with the training and expertise to perform the evaluation. The evaluator submits an evaluation report to the responsible contractor environmental organization management personnel. The report presents the results of the evaluation and provides recommendations for corrective actions.

10.6.2 Internal Quality Assurance Report

Responsible contractor environmental organization data management personnel develop QAR (Quality Assurance Reports) periodically during the year to facilitate the review and evaluation of overall groundwater analytical data quality by stakeholders in the groundwater monitoring program. At a minimum, QAR include the quantity and type of field QC samples analyzed, the quantity and type of individual field data qualifiers applied, the quantity and type of individual laboratory data qualifiers applied, a list of all QA narratives associated with the included sampling events, a summary by analytical method of notable data quality issues, a summary of all notable anomalies associated with the report, and a follow-up, if necessary, on previous notable anomalies. QAR are prepared periodically during the PMR reporting period (see Section 11.4) using chemical analytical data for the reporting period. They are compiled on a quarterly basis for inclusion in the PMRs for submittal to NMED.

10.6.3 Internal Corrective Actions

Responsible contractor environmental organization personnel initiate corrective actions when data evaluation, preparation of environmental reports, or technical systems evaluations indicate discrepancies. The corrective actions can include procedural changes, resampling, collection of additional quality control samples, additional field evaluations, review of analytical laboratory procedures, addition of data qualifiers and narratives to analytical data, or any other procedure that will mitigate issues or identify further discrepancies. Discrepancies deemed to meet the definition of a data quality exception will be reported as described in Section 10.4. Corrective actions, recommendations, and specific steps taken to resolve data quality discrepancies are reported to the responsible contractor environmental organization management representative for further action.

11.0 Schedule

This section provides the schedules for activities specified in this Plan.

11.1 Groundwater Elevations

Groundwater elevations are determined as described in Section 6.5. At a minimum, groundwater elevations are measured each time a groundwater monitoring well is sampled, assuming the water level is adequate and groundwater sampling equipment allows access. The groundwater elevation may be determined more frequently at some groundwater monitoring wells to provide consistent groundwater elevation data for use in groundwater modeling and the development of groundwater elevation maps for reporting.

11.2 Groundwater Monitoring Schedule

Each groundwater monitoring location is sampled for specific hazardous constituents and other analytes based on its location in the conceptualized contaminant plume as illustrated in Section 4.1. Groundwater sampling is performed at these monitoring wells and/or zones as described in Section 7.0 for some or all of the chemical analyses discussed in Section 9.0. Table 15 provides the monitoring requirements and sampling frequencies for each active groundwater monitoring well or zone in the WSTF groundwater monitoring network.

Table 15 includes several frequencies for sampling groundwater monitoring wells. Monitoring wells/zones scheduled for quarterly sampling will be sampled for the specified analyses four times per calendar year, with sampling events approximately three months apart. Monitoring wells/zones scheduled for semi-annual sampling will be sampled for the specified analysis twice per calendar year, with sampling events approximately six months apart. Monitoring wells/zones scheduled for annual sampling will be sampled for the specified analysis once per calendar year, with sampling events occurring approximately twelve months apart. Monitoring wells/zones scheduled for biennial sampling will be sampled for the specified analysis every two calendar years, with sampling events occurring approximately 24 months apart. Monitoring wells/zones scheduled for triennial sampling will be sampled for the specified analysis every three calendar years, with sampling events occurring approximately the 36 months apart. The completion of individual scheduled sampling events may vary by several weeks as a result of well site accessibility, personnel/equipment availability, and other project-specific limitations.

Groundwater sampling schedules are developed on a monthly basis and used to schedule sampling activities for the coming month. Monthly schedules can also be approximated for subsequent months upon NMED request. NASA's ability to complete groundwater sampling as scheduled may be impacted by lack of access to well locations, equipment malfunction, or other unforeseen events. If a groundwater monitoring well/zone cannot be sampled within 30 days of its scheduled sampling date for reasonably foreseen reasons, NASA will request a variance from the established sampling schedule 30 days prior to the scheduled sampling event. Reasonably foreseen reasons for not completing sampling within 30 days of a scheduled sampling event include, but are not limited to planned access limitations for security reasons, chronic equipment restrictions that affect multiple sampling events over the longer term, and site infrastructure limitations that prevent access. If a monitoring well/zone is not sampled within 30 days of its scheduled sampling event because of unforeseen reasons, NASA will notify NMED of the delay in the subsequent Monthly EAR (Environmental Activity Report) and indicate when sampling is expected to be completed. Unforeseen reasons for not completing planned sampling include such problems as failure of sampling equipment or short-term unplanned resource limitations with lingering impact.

11.3 Schedule for Sampling New Monitoring Wells

Following installation, groundwater monitoring wells are developed in accordance with industry accepted practices and established site-specific procedures. Hydrogeological personnel oversee drilling, installation, and development activities. When development is complete, groundwater monitoring wells are allowed to equilibrate for up to 30 days prior to initial sampling, which is typically performed between ten and 30 days after completion of development. New or reconfigured groundwater monitoring wells and zones are sampled quarterly for at least one year for VOC, nitrosamines, metals, SVOC, and inorganic compounds. After at least one year of sampling, the monitoring well will be assigned to the appropriate well group as described in Section 4.1 and the results of the initial sampling will be utilized to determine the most appropriate sampling requirements and schedule. Results of initial sampling will be reported in the PMR with other chemical analytical data. The sampling schedule assigned to the monitoring well will be included in the first annual revision of this Plan following establishment of the schedule and sampling requirements.

11.4 Schedule for Periodic Reporting

The environmental program at WSTF is diverse and comprehensive, requiring the submittal of several routine reports to keep NMED updated on environmental activities, including groundwater monitoring. Three periodic reports are applicable to groundwater monitoring:

- Monthly EAR, which includes a brief description of compliance, monitoring, and corrective action activities during the month. The EAR is submitted to NMED no later than the 15th of each month for activities in the preceding calendar month.
- "Routine" PMR, which include chemical analytical data that were processed through the WSTF data management system during the reporting period (calendar quarter). These PMR also include brief discussions of groundwater monitoring and remediation activities, and summarize the results of groundwater and remediation system monitoring. These PMR are submitted to NMED no later than April 30 (for January through March), July 31 (for April through June), and October 31 (for July through September) of each year.

- Comprehensive PMR, which includes additional data and a more comprehensive evaluation of corrective measures. This PMR includes a complete evaluation of contaminant plume capture and detailed results of remediation system monitoring. This PMR is submitted to NMED no later than January 31 of each year and includes information applicable to the preceding year (January through December).

PMR will provide the results of groundwater monitoring conducted in accordance with this Plan for the calendar quarter that coincides with chemical analytical data processed in the three months prior to the month in which the report is submitted. This three-month period is referred to as the reporting period, and is offset from the calendar quarter by two months. For instance, the PMR submitted in April will include the results of groundwater monitoring (including monitoring well sampling) performed in November, December, and January and represent data processed and evaluated during the reporting period (January, February, and March).

11.5 Schedule for Review and Revision of Plan

In accordance with Section VI.B.3 of the Permit, this Plan will be reviewed and revised on an annual basis to include such changes as: the addition of new monitoring wells/zones; deletion of abandoned monitoring wells/zones; deletion of or reduction in sampling requirements at monitoring wells/zones whose production of groundwater has been significantly reduced; sampling of wells beyond the Outer Boundary; or to change monitoring parameters or frequencies. The Permit requires that a revised Plan be submitted no later than April 1 of the second and each subsequent year after the effective date of the Permit. However, communication with NMED subsequent to issuance of the Permit indicated that April 30 would be a more acceptable date. Therefore, annual revisions of the Plan are scheduled for submittal to NMED on or before April 30 of each year. Submittal of the revised Plan does not constitute a Permit modification.

12.0 References

Conditions for exemption for a large quantity generator that accumulates hazardous waste, 40 C.F.R. 262.17 (2017).

EPA. (1989, December 18). *U.S. EPA Docket No. VI-002(h)-88-H.* Dallas, TX.

EPA. Office of Solid Waste and Emergency Response. (2007, February). *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846), Third Edition, Final Update IV*. Washington, D.C.

EPA. (2017, November). *Regional Screening Level Tables; Residential Tapwaters*. Retrieved from http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm

Ground and Surface Water Protection, Water Quality Control Commission, 20.6.2 NMAC (12-21-18).

Hazardous Waste Management, Environmental Improvement Board, 20.4.1 NMAC, (12-1-18).

Identification and Listing of Hazardous Waste, 40 C.F.R. § 261 (2011).

NASA Johnson Space Center White Sands Test Facility. (1996a, March 1). *Submittal of Draft RCRA Facility Investigation (RFI) and Corrective Measures Study (CMS) Reports*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (1996b, July 3). *NASA White Sands Test Facility (WSTF) Solid Waste Management Facility – Closure and Post-Closure Care Plan*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (1999, September) *Phase II Mid-plume Constriction Area (MPCA) Investigation Report*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2008, July 15). *Mid-plume Interception and Treatment System Interim Measures Work Plan*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2010, December 21). *Investigation Report for NASA WSTF Required Interim Measures Work Plan for Sampling Off-site Water Supply Wells*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2011, June 27). *NASA WSTF 400 Area Closure Investigation Work Plan, 400 Area Historical Information Summary (HIS), 400 Aspirator Discharge Pipes HIS, and 500 Fuel Storage Area HIS*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2012a, June 20). *Response to NMED Disapproval – NASA White Sands Test Facility (WSTF) 200 Area Investigation Work Plan and 200 Area Historical Information Summary*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2012b, May 17). *NASA WSTF Groundwater Monitoring Plan Update for 2012*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2012c, September 13,). *Response to NMED Disapproval – NASA White Sands Test Facility (WSTF) 600 Area Soil Vapor Extraction Pilot Test Investigation Report*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility, (2012d, May 10). *Work Plan for Tracer Testing in the 200/600 Areas and Mid-Plume Constriction Area*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2013a, May 15). Update of the NASA-JSC White Sands Test Facility Groundwater Flow and Contaminant Transport Model. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2013b, December 16). *Well Completion Reports for the Conversion of Westbay Wells WW-2 and JP-3*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2015, April 29). *NASA WSTF Groundwater Monitoring Plan Update for 2015*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2016, March 30). *Well Configuration Reports for Wells BLM-32, WW-4 and WW-5*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017a, March 22). *Westbay Reconfiguration Report (Wells JER-1, JER-2, ST-6, and ST-7)*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017b, March 30). *Work Plan for Westbay wells conversion WW-3, PL-5, PL-6, PL-7, PL-8, PL-10, ST-5, and WW-3*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017c, July 27). *NOD Response to First TDRSS Diesel Release (SWMU 50) Revised IWP*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017d, December 27). *NASA WSTF Drilling Work Plan for Groundwater Monitoring Well PL-12*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017e, December 28). NASA White Sands Test Facility (WSTF) SWMU 49 (700 Area Landfill) Phase I Investigation Work Plan (IWP) and Historical Information Summary (HIS). Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017f, December 28). *Well Reconfiguration Work Plan for Well BLM-30*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018a, January 30). *Work Plan for Abandonment of NASA WSTF Monitoring Well BLM-37 and Replacement with Monitoring Well BLM-42*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018b, May 3). 600 Area Perched Groundwater Extraction Pilot Test Interim Status Report – Project Year 5. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018c, August 14c). NASA WSTF Remediation System Monitoring Plan Annual Update for 2018. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018d, September 26). 500 Area Fuel Storage (SWMU 47) Investigation Work Plan. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018e, December 3). Response to NMED Approval with Modifications WSTF 2018 Groundwater Monitoring Plan Correction. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018f, December 21). Abbreviated Investigation Work Plan for Groundwater Data Representativeness, Phase 1: FLUTe Well Evaluation. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2019, February 19). NASA WSTF Periodic Monitoring Report – Fourth Quarter 2018. Las Cruces, NM.

National Primary Drinking Water Regulations, 40 C.F.R. § 141 (2013). Retrieved from http://www.ecfr.gov

NELAC. (2003, June). *NELAC Standard, EPA/600/R-04/003*. Retrieved from http://www.nelac-institute.org/docs/2003nelacstandard.pdf

NMED. Hazardous Waste Bureau. (2001, October). *Position Paper. Use of Low-Flow and Other Non-Traditional Sampling Techniques for RCRA Compliant Groundwater Monitoring*. Santa Fe, New Mexico.

NMED. Hazardous Waste Bureau. (2009, November). *Hazardous Waste Permit. NM8800019434, to United States National Aeronautics and Space Administration for the White Sands Test Facility Located in Doña Ana County, New Mexico*. Santa Fe, NM.

NMED. Hazardous Waste Bureau. (2011, December 16). *Notice of Approval with Modifications Investigation Report for Evaluating the Representativeness of Groundwater Samples Collected from Westbay Wells*. Santa Fe, NM.

NMED. Hazardous Waste Bureau. (2012, August 8). *Approval 2012 Update Groundwater Monitoring Plan*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2016a, March 29). *Approval NASA WSTF Periodic Monitoring Report Fourth Quarter 2015*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2016b, November 10). Administrative Completeness and Fee Assessment Transmittal of Class 1 Permit Modification Without Prior Approval. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2017a, October 4). *Approval with Modifications Detections of NDMA (N-Nitrosodimethylamine) and TCE (Trichloroethylene) In WSTF Groundwater Monitoring Wells BLM-30, PL-5, PL-6, PL-7, PL-8, PL-10, ST-5, and WW-3*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2017b, December 19). *Approval with Modifications Groundwater Monitoring Plan*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2018a, September 10). Approval Work Plan for Abandonment of NASA WSTF Monitoring Well BLM-37 and Replacement with Monitoring Well BLM-42. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2018b, September 10). Approval Work Plan for Abandonment of NASA WSTF Well PL-5 and Replacement with Monitoring Well PL-12. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2018c, September 13). Approval with Modifications White Sands Test Facility Groundwater Monitoring Plan. Santa Fe, NM.

Seager, W. (1981, May). *Geology of Organ Mountains and Southern San Andres Mountains, New Mexico. Memoir 36, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico*.

Solid Waste Facility Ground Water Monitoring System Plan and Ground Water Monitoring Plan; Corrective Action, New Mexico Environmental Improvement Board, 20.9.9 NMAC (8-2-07).

Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, 40 C.F.R. § 264 (2014).

Wilson, C., White, R., Orr, B., & Roybal, R. (1981). *Water Resources of the Rincon and Mesilla Valleys and Adjacent Areas, New Mexico. New Mexico State Engineer's Technical Report,* Santa Fe, New Mexico.

Well Driller Licensing; Construction, Repair and Plugging of Wells, Office of the State Engineer, 19.27.4 NMAC (6-30-17).

Tables

Table 1 Summary of COC/Waste Utilization and Potential Sources at WSTF

COC	100 Area	200 Area	300 Area	400 Area	500 Area	600 Area	700 Area
NDMA		*	X	X	*		
TCE		X	X			X	*
PCE	X	X					
Freon 11		X	X	X		X	*
Freon 113		X	X	X		X	*

X – Indicates that the COC was utilized in this area or that there is a known source/release of the COC.
* – Indicates a potential source/release of the COC in this area.

Table 2 Zones of Hydraulic Conductivity (K) at WSTF

Geologic Unit	Distribution	Calculated Horizontal K (m/day)	Calculated Vertical K (m/day)	Geometric Mean Horizontal K (min/max) (m/day)
Low permeability rhyolite and andesite	Areas defined by dry holes and low well yields north and south of contaminant plume (includes flow-banded rhyolite [FBR])	2.0E-006	6.33E-009	N/A[1] (dry/29)
Fractured rhyolite	Mid-plume area	0.119	0.199	0.06 (1.7e-003/0.27)
Fractured andesite	Zone extending south to north across the east central model domain	0.00454	0.00016	0.012 (1.2e-004/1.92)
Limestone	Zone along eastern boundary of the model domain	0.04009	0.00058	1.39 (3.4e-003/224)
Basin-fill sediments	PFTS area	12[2]	1.2	1.62 (2.6e-003/116)
Basin-fill sediments	PFTS area, layers 1-14 and as a sediment veneer overlying most of the fractured rock zones	12[2]	1.2	1.62 (2.6e-003/116)
Distal basin-fill sediments	Western portion of the model domain in the JDMB	4.6[2]	0.1	1.62 (2.6e-003/116)
Fractured rhyolite	South of flow-banded rhyolite	0.081	0.2	0.198 (1.2e-003/3.42)
Fractured andesite	Zone encompassing the 300 and 400 Areas	0.391	0.0047	0.51 (4.1e-003/20.8)
Fractured rhyolite	Zone east of the FBR	0.0046	0.0199	0.69[3] (0.14/2.82)

[1] – Not applicable – hydraulic conductivity of dry and low yield wells not estimated.

[2] – Alluvium horizontal hydraulic conductivity was calibrated to distance-drawdown observations during pumping tests of Well J and PFE-3.

3 – Only three slug test measured hydraulic conductivity measurements available. Reasonable hydraulic conductivity range assumed equal to Zone 2.

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source
				Volatile Organics				
100-41-4	Ethylbenzene	Yes	700	700	15	**15**	µg/L	EPA RSL
100-42-5	Styrene	Yes	100	100	1,200	**100**	µg/L	40 CFR Part 141
107-06-2	1,2-Dichloroethane (EDC)	Yes	5	5	1.7	**1.7**	µg/L	EPA RSL
107-12-0	Propionitrile (Ethyl Cyanide)[1]	No	NA	NA	NA	**NA**	NA	NA
107-13-1	Acrylonitrile	Yes	NA	NA	0.52	**0.52**	µg/L	EPA RSL
108-88-3	Toluene	Yes	1,000	1,000	1,100	**1,000**	µg/L	40 CFR Part 141
108-90-7	Chlorobenzene	Yes	100	NA	78	**78**	µg/L	EPA RSL
127-18-4	Tetrachloroethene (PCE)[2]	Yes	5	5	110	**5**	µg/L	40 CFR Part 141
1330-20-7	m,p-Xylenes	Yes	10,000	620	190	**190**	µg/L	EPA RSL
156-60-5	trans-1,2-Dichloroethene	Yes	100	100	360	**100**	µg/L	40 CFR Part 141
56-23-5	Carbon tetrachloride	Yes	5	5	4.6	**4.6**	µg/L	EPA RSL
67-64-1	Acetone	No	NA	NA	14,000	**14,000**	µg/L	EPA RSL
67-66-3	Chloroform[2]	Yes	NA	100	2.2	**2.2**	µg/L	EPA RSL
71-43-2	Benzene	Yes	5	5	4.6	**4.6**	µg/L	EPA RSL
71-55-6	1,1,1-Trichloroethane (TCA)	Yes	200	200	8,000	**200**	µg/L	40 CFR Part 141
74-83-9	Bromomethane	Yes	NA	NA	7.5	**7.5**	µg/L	EPA RSL
74-87-3	Chloromethane	Yes	NA	NA	190	**190**	µg/L	EPA RSL
75-00-3	Chloroethane (Ethyl Chloride)	No	NA	NA	21,000	**21,000**	µg/L	EPA RSL
75-01-4	Vinyl chloride	Yes	2	2	0.19	**0.19**	µg/L	EPA RSL
75-09-2	Methylene chloride (dichloromethane)	Yes	5	5	110	**5**	µg/L	40 CFR Part 141
75-15-0	Carbon disulfide	No	NA	NA	810	**810**	µg/L	EPA RSL
75-25-2	Bromoform	Yes	NA	NA	33	**33**	µg/L	EPA RSL

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source
75-27-4	Bromodichloromethane	Yes	NA	NA	1.3	**1.3**	µg/L	EPA RSL
75-34-3	1,1-Dichloroethane	Yes	NA	25	28	**25**	µg/L	20.6.2.3103 NMAC
75-35-4	1,1-Dichloroethene	Yes	7	7	280	**7**	µg/L	40 CFR Part 141
75-69-4	Trichlorofluoromethane (CFC 11)	Yes	NA	NA	5,200	**5,200**	µg/L	EPA RSL
75-71-8	Dichlorodifluoromethane (CFC 12)	Yes	NA	NA	200	**200**	µg/L	EPA RSL
78-87-5	1,2-Dichloropropane (DCPA)	Yes	5	5	8.5	**5**	µg/L	40 CFR Part 141
78-93-3	2-Butanone (MEK)	No	NA	NA	5,600	**5,600**	µg/L	EPA RSL
79-00-5	1,1,2-Trichloroethane	Yes	5	5	2.8	**2.8**	µg/L	EPA RSL
79-01-6	Trichloroethene (TCE)[2]	Yes	5	5	4.9	**4.9**	µg/L	EPA RSL
				Nitrosamines				
62-75-9	N-Nitrosodimethylamine[2]	Yes	NA	NA	0.0011	**0.0011**	µg/L	EPA RSL
				Metals				
7439-92-1	Lead	No	NA	0.015	0.015	**0.015**	mg/L	20.6.2.3103 NMAC
7439-97-6	Mercury (elemental)	No	0.002	0.002	0.00063	**0.002**	mg/L	40 CFR Part 141
7440-02-0	Nickel (soluble salts)	No	NA	0.2	0.39	**0.2**	mg/L	20.6.2.3103 NMAC
7440-22-4	Silver	No	NA	0.05	0.094	**0.05**	mg/L	20.6.2.3103 NMAC
7440-28-0	Thallium (soluble salts)	No	0.002	0.002	0.0002	**0.0002**	mg/L	EPA RSL
7440-31-5	Tin	No	NA	NA	12	**12**	mg/L	EPA RSL
7440-36-0	Antimony (metallic)	No	0.006	0.006	0.0078	**0.006**	mg/L	40 CFR Part 141
7440-38-2	Arsenic	No	0.01	0.01	0.00052	**0.01**	mg/L	40 CFR Part 141
7440-39-3	Barium	No	2	2	3.8	**2**	mg/L	40 CFR Part 141
7440-41-7	Beryllium	No	0.004	0.004	0.025	**0.004**	mg/L	40 CFR Part 141
7440-43-9	Cadmium	No	0.005	0.005	0.0092	**0.005**	mg/L	40 CFR Part 141

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source
7440-47-3	Chromium (Total)	No	0.1	0.05	NA	**0.05**	mg/L	20.6.2.3103 NMAC
7440-48-4	Cobalt	No	NA	0.05	0.006	**0.006**	mg/L	EPA RSL
7440-50-8	Copper	No	1.3[3]	1.0	0.8	**1.0**	mg/L	20.6.2.3103 NMAC
7440-62-2	Vanadium	No	NA	NA	0.086	**0.086**	mg/L	EPA RSL
7440-66-6	Zinc	No	NA	10.0	6.0	**10.0**	mg/L	20.6.2.3103 NMAC
7782-49-2	Selenium	No	0.05	0.05	0.1	**0.05**	mg/L	40 CFR Part 141
	Inorganics							
14797-73-0	Perchlorate[4]	Yes	NA	NA	14	**14**	µg/L	EPA RSL
	Semi-volatile Organics							
84-74-2	Di-n-butylphthalate (Dibutyl Phthalate)	Yes	NA	NA	900	**900**	µg/L	EPA RSL
108-39-4	m-Cresol	No	NA	NA	930	**930**	µg/L	EPA RSL
117-81-7	Bis(2-Ethylhexyl)phthalate	Yes	6	NA	56	**6**	µg/L	40 CFR Part 141
	Miscellaneous Hazardous Constituents							
108-95-2	Phenol	Yes	NA	5	5,800	**5**	µg/L	20.6.2.3103 NMAC
3268-87-9	Octachlorodibenzo-p-dioxin (OCDD)[5]	No	NA	NA	NA	**NA**	NA	NA
39001-02-0	Octachlorodibenzofuran (OCDF)[5]	No	NA	NA	NA	**NA**	NA	NA
57-12-5	Cyanide	No	0.2	0.2	0.0015	**0.2**	mg/L	40 CFR Part 141
93-72-1	2,4,5-Trichlorophenoxypropionic (TP) acid (Silvex)	No	50	NA	110	**50**	µg/L	40 CFR Part 141
18496-25-8	Sulfide[1]	No	NA	NA	NA	**NA**	NA	NA

MCL – Maximum Contaminant Level

WQCC – New Mexico Water Quality Control Commission Numerical Standard

RSL – EPA Regional Screening Level for Residential Tapwaters; equivalent to H=1 or modified to = 1.0E-05 risk.

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source

NA – Not Available/Applicable

[1] The constituent is listed in 40 CFR 264, Appendix IX. No further information is available.

[2] NMED Discharge Permit (DP)-1255 Treatment Standard for this contaminant may be lower than the Cleanup Level derived through the process established in the Permit.

[3] Drinking water action level. If this concentration is detected in more than 10% of customer taps sampled, the drinking water utility must take action to reduce the concentration at customer taps.

[4] Perchlorate is not listed in 40 CFR 261, Appendix VIII or 40 CFR 264, Appendix IX. However, it is listed as a toxic pollutant in 20.6.2.7 NMAC.

[5] The constituent is listed in 40 CFR 261, Appendix VIII. No further information is available.

Table 4 Other Analytes of Interest in WSTF Groundwater

CAS Number	Analyte Name	Analysis Type	CAS Number	Analyte Name	Analysis Type
109-99-9	Tetrahydrofuran (THF)	VOC	14808-79-8	Sulfate	Inorganics
306-83-2	2,2-Dichloro-1,1,1-trifluoroethane (CFC 123)	VOC	16887-00-6	Chloride	Inorganics
354-23-4	1,2-Dichloro-1,1,2-trifluoroethane (CFC 123a)	VOC	16984-48-8	Fluoride	Inorganics
67-63-0	2-Propanol	VOC	14797-55-8	Nitrate/Nitrite as N	Inorganics
75-43-4	Dichlorofluoromethane (CFC 21)	VOC	NA	Alkalinity	Inorganics
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC 113)	VOC	NA	Total Dissolved Solids (TDS)	Inorganics
4164-28-7	N-Nitrodimethylamine	Nitrosamines	314-40-9	Bromacil	SVOC
7440-70-2	Calcium	Metals	123-91-1	1,4-dioxane	SVOC SIM
7440-23-5	Sodium	Metals	30402-15-4	Total Penta CDF	Miscellaneous
7440-24-6	Strontium	Metals	41903-57-5	Total Tetra CDD	Miscellaneous
7440-42-8	Boron	Metals	55684-94-1	Hexachlorodibenzofurans (HxCDF), Total	Miscellaneous
8006-61-9	GRO	TPH			
68334-30-5	DRO	TPH			

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
		Upgradient Monitoring Wells	
100-F-358	Conventional PVC	358-368	Dedicated low-flow bladder pump
100-G-223	Conventional PVC	223-233	Dedicated low-flow bladder pump
300-F-175	Conventional PVC	175-185	Dedicated low-flow bladder pump
NASA 3	Conventional PVC/SS	119-139	Dedicated bladder pump
		100/600 Area Monitoring Wells	
100-A-182	Conventional PVC/SS	182-192	Dedicated low-flow bladder pump
100-D-176	Conventional PVC/SS	176-196	Dedicated low-flow bladder pump
100-HG-139	Conventional PVC w/MSVM	139-159	Dedicated low-flow bladder pump
600-C-173	Conventional PVC/SS	173-193	Dedicated low-flow bladder pump
600-E	Open borehole	280	Westbay MP-38
600-G-138	Conventional PVC	138-148	Non-dedicated purge pump and bailer
BLM-3-182[1]	Conventional PVC/SS	182-203	Dedicated low-flow bladder pump
BW-3-180	Conventional PVC/SS	179-200	Dedicated low-flow bladder pump
NASA 4	Conventional PVC/SS	146-166	Dedicated bladder pump
WB-1	Open borehole	200, 225, 330	Westbay MP-38
		200 Area Monitoring Wells	
200-B-240[1]	Conventional PVC/SS	240-250	Dedicated low-flow bladder pump
200-C	Open borehole	170, 225, 270	Westbay MP-38
200-D-109[2]	Conventional PVC/SS	109-129	Non-dedicated purge pump and bailer
200-D-240	Conventional PVC/SS	240-250	Dedicated low-flow bladder pump
200-F	Open borehole	225, 370, 420	Westbay MP-38
200-G	Open borehole	175, 220, 340, 420, 495	Westbay MP-38
200-H	Open borehole	225, 331, 433	Westbay MP-38
200-I	Open borehole	185, 300, 375, 490, 675, 795	Westbay MP-38

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
200-JG-110	Conventional PVC w/MSVM	110-130	Dedicated low-flow bladder pump
200-SG-1[1]	Conventional PVC w/MSVM	123-138	Dedicated bladder pump
200-KV-150[2]	Conventional PVC w/MSVM	150-170	Dedicated bladder pump
200-LV-150	Conventional PVC w/MSVM	150-170	Dedicated bladder pump
BW-4[3]	Open borehole	TBD	TBD
300/400 Area Monitoring Wells			
300-A-120[1]	Conventional PVC/SS	121-146	Dedicated low-flow bladder pump
300-A-170	Conventional PVC/SS	170-175	Dedicated low-flow bladder pump
300-B-166	Conventional SS	166-176	Dedicated low-flow bladder pump
300-C-128	Conventional SS	128-154	Dedicated low-flow bladder pump
300-D-153	Conventional PVC/SS	153-174	Dedicated bladder pump
300-E	Open borehole	138, 183	Westbay MP-38
400-A-151	Conventional SS	151-176	Dedicated low-flow bladder pump
400-C-118[1]	Conventional SS	118-143	Dedicated low-flow bladder pump
400-C-143	Conventional SS	143-153	Dedicated low-flow bladder pump
400-D	Open borehole	195, 275, 355	Westbay MP-38
400-EV-131	Conventional SS w/MSVM	131-146	Dedicated low-flow bladder pump
400-FV-131	Conventional SS w/MSVM	131-146	Dedicated low-flow bladder pump
400-GV-125	Conventional SS w/MSVM	125-140	Dedicated low-flow bladder pump
400-HV-147	Conventional SS w/MSVM	147-162	Dedicated low-flow bladder pump
400-IV-123	Conventional SS w/MSVM	123-138	Dedicated low-flow bladder pump
400-JV-150	Conventional PVC w/MSVM	150-165	Dedicated low-flow bladder pump
400-KV-142	Conventional PVC w/MSVM	142-157	Not currently equipped[4]
400-LV-125	Conventional PVC w/MSVM	125-140	Not currently equipped[5]
BW-1-268	Conventional PVC/SS	268-289	Dedicated low-flow bladder pump
BW-5-295	Conventional PVC/SS	295-305	Dedicated low-flow bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
BW-7-211	Conventional PVC/SS	211-222	Dedicated low-flow bladder pump
NASA 5	Conventional PVC/SS	110-130	Dedicated bladder pump
NASA 6	Conventional PVC/SS	128-148	Dedicated bladder pump
NASA 8[2]	Conventional PVC/SS	172-192	Dedicated bladder pump
NASA 9[2]	Conventional PVC/SS	129-149	Dedicated bladder pump
NASA 10	Conventional PVC/SS	110-130	Dedicated bladder pump
Northern Boundary Monitoring Wells			
700-A-253	Conventional SS	253-263	Dedicated low-flow bladder pump
700-B-510	Conventional SS	510-530	Dedicated low-flow bladder pump
700-D-186	Conventional PVC/SS	186-196	Dedicated low-flow bladder pump
700-E-458	Conventional SS	458-479	Dedicated low-flow bladder pump
700-F-455[6]	Conventional SS	455-475	None
700-H	Open borehole	350, 535, 670	Westbay MP-38
700-J-200	Conventional SS	200-220	Dedicated low-flow bladder pump
BLM-24-565	Conventional SS	565-585	Dedicated low-flow bladder pump
BLM-32	Open borehole	543-563, 571-591, 632-647	Water FLUTe
BLM-41-420	Conventional PVC	420-430	Dedicated low-flow bladder pump
BLM-41-670	Conventional PVC	670-680	Dedicated low-flow bladder pump
BW-6-355	Conventional SS	355-375	Dedicated low-flow bladder pump
JER-1	Conventional PVC	483-493, 563-573, 683-693	Water FLUTe
JER-2	Conventional PVC	504-514, 584-894, 683-693	Water FLUTe
Southern Boundary Monitoring Wells			
100-C-365	Conventional SS	365-386	Dedicated low-flow bladder pump
100-E-261	Conventional PVC/SS	261-271	Dedicated low-flow bladder pump
BLM-6-488	Conventional SS	488-498	Dedicated low-flow bladder pump
BLM-13-300	Conventional PVC/SS	300-310	Dedicated low-flow bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
BLM-25-455	Conventional SS	455-465	Dedicated low-flow bladder pump
BLM-28	Open borehole	TBD	TBD
BLM-31[7]	Open borehole	350, 485, 770	Westbay MP-38
BLM-40-517	Conventional PVC	517-527	Dedicated low-flow bladder pump
BLM-40-595	Conventional PVC	595-605	Dedicated low-flow bladder pump
BLM-40-688	Conventional PVC	688-698	Dedicated low-flow bladder pump
WB-5	Open borehole	250, 280, 345	Westbay MP-38
WB-14	Open borehole	520	Westbay MP-38
MPCA Monitoring Wells			
BLM-5-527	Conventional SS	527-537	Dedicated low-flow bladder pump
BLM-8-418	Conventional SS	418-428	Dedicated low-flow bladder pump
BLM-9-419	Conventional SS	419-440	Dedicated low-flow bladder pump
BLM-14-327	Conventional SS	327-337	Dedicated low-flow bladder pump
BLM-15-305	Conventional PVC/SS	305-315	Dedicated low-flow bladder pump
BLM-18-430	Conventional SS	430-451	Dedicated low-flow bladder pump
BLM-21-400	Conventional SS	400-410	Dedicated low-flow bladder pump
BLM-22-570	Conventional SS	570-592	Dedicated low-flow bladder pump
BLM-23-431	Conventional SS	431-441	Dedicated low-flow bladder pump
BLM-26-404	Conventional SS	404-414	Dedicated low-flow bladder pump
BLM-27-270	Conventional SS	270-280	Dedicated low-flow bladder pump
BLM-30	Open borehole	NA	Not currently equipped[8]
BLM-36	Conventional SS	350, 610, 800, 860	Westbay MP-38
BLM-38	Conventional SS	480, 620	Westbay MP-38
BLM-39	Conventional SS	385, 560	Westbay MP-38
Main Plume Monitoring Wells			
BLM-1-435	Conventional SS	435-446	Dedicated inflatable packer and bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
BLM-2-482[2]	Conventional SS	482-493	Dedicated low-flow bladder pump
BLM-2-630	Conventional SS	630-640	Dedicated low-flow bladder pump
BLM-17-493	Conventional SS	493-513	Dedicated low-flow bladder pump
BLM-17-550	Conventional SS	550-561	Dedicated low-flow bladder pump
PL-1-486	Conventional SS	486-496	Dedicated low-flow bladder pump
PL-2-504	Conventional SS	405-514	Dedicated low-flow bladder pump
PL-5	Conventional SS		Not currently equipped[9]
ST-1-473	Conventional SS	473-483	Dedicated low-flow bladder pump
ST-1-541	Conventional SS	541-551	Dedicated low-flow bladder pump
ST-1-630	Conventional SS	630-640	Dedicated low-flow bladder pump
ST-3-486	Conventional SS	486-496	Dedicated low-flow bladder pump
ST-3-586	Conventional SS	586-596	Dedicated low-flow bladder pump
ST-3-666	Conventional SS	666-676	Dedicated low-flow bladder pump
ST-3-735	Conventional SS	735-755	Dedicated low-flow bladder pump
Plume Front Monitoring Wells			
BLM-7-509	Conventional SS	509-520	Dedicated low-flow bladder pump
BLM-10-517	Conventional SS	517-527	Dedicated low-flow bladder pump
PL-3-453	Conventional SS	453-646	Dedicated low-flow bladder pump
PL-4-464	Conventional SS	464-474	Dedicated low-flow bladder pump
PL-6	Conventional SS	545, 725, 915, 1195, 1335	Westbay MP-38
PL-7	Conventional SS	480, 560, 630	Westbay MP-38
ST-2-466	Conventional SS	466-476	Dedicated low-flow bladder pump
ST-4-481	Conventional SS	481-491	Dedicated low-flow bladder pump
ST-4-589	Conventional SS	589-599	Dedicated low-flow bladder pump
ST-4-690	Conventional SS	690-710	Dedicated low-flow bladder pump
ST-5-481	Conventional SS	481-491	Dedicated low-flow bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
ST-5	Conventional SS	485, 655, 815, 985, 1175	Westbay MP-38
ST-6	Conventional SS	528-538, 568-578, 678-688, 824-834, 970-980	Water FLUTe
ST-7	Conventional SS	453-463, 543-553, 779-789, 970-980	Water FLUTe
WW-1-452	Conventional SS	452-462	Dedicated low-flow bladder pump
		Sentinel Monitoring Wells	
BLM-37	Conventional SS	NA	Not currently equipped[10]
JP-1-424	Conventional SS	424-434	Dedicated low-flow bladder pump
JP-2-447	Conventional SS	447-457	Dedicated low-flow bladder pump
JP-3	Conventional SS	509-519, 689-699	Dedicated low-flow bladder pumps separated by dedicated inflatable packer
PL-8	Conventional SS	455, 605, 780, 965	Westbay MP-38
PL-10	Conventional SS	592, 484, 813, 962	Westbay MP-55
PL-11	Conventional PVC	470-480, 530-540, 710-720, 820-830, 980-990	Water FLUTe
WW-2	Conventional SS	489-499, 664-674	Dedicated low-flow bladder pumps separated by dedicated inflatable packer
WW-3	Conventional PVC	469, 569, 710, 978	Westbay MP-55
WW-4	Conventional PVC	419-429, 589-599, 848-858, 948-958	Water FLUTe
WW-5	Conventional PVC	459-469, 579-589, 809-819, 909-919	Water FLUTe

[1] – Indicates that the well has been designated for detection monitoring in accordance with Section 3.3.1.

[2] – Indicates that the water level in this well has declined or well production is insufficient, preventing the collection of groundwater samples at this time. The water level or well performance is periodically evaluated and the well will be sampled when adequate groundwater is present. Disposition of wells with repeated inadequate water level measurements will be addressed in the text of this annual update.

[3] – Indicates that the Westbay sampling system was removed from this well. The current open borehole cannot be sampled. NASA is evaluating potential sampling systems for installation in the borehole.

[4] – Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available.

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System

[5] – Indicates that the well is installed in a currently unproductive fracture zone. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is observed. Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available.

[6] – Indicates that the well is located on the USDA Jornada Experimental Range and no longer accessible to NASA for sampling. NASA is consulting with USDA personnel to determine the well's final disposition.

[7] – Indicates that a deflection in the Westbay casing prevents access to the Westbay sampling zones. The well cannot be sampled.

[8] – Indicates that the attempt to remove the Westbay casing from this borehole was unsuccessful and the Westbay system is partially removed. NASA is evaluating options for restoration of this borehole.

[9] – Indicates that the Westbay system has been removed from this well and the well is not sampled and has been scheduled for abandonment and replacement.

[10] – Indicates that a portion of the Westbay sampling system and a length of drill pipe are irretrievably lodged in the conventional casing following an attempt to remove the Westbay casing from the conventional casing. The well cannot be sampled and has been scheduled for abandonment and replacement.

MP-38 – Westbay multiport casing with 38 mm (1.5 in.) ID

MP-55 – Westbay multiport casing with 55 mm (2.25 in.) ID

MSVM – Multiport soil vapor monitoring

PVC – Polyvinyl chloride

SS – Stainless steel

TBD – To be determined. Indicates that the Westbay multiport casing has been removed from this borehole and the replacement sampling system has not been installed.

Table 6 Preferred Analytical Requirements for VOCs, Nitrosamines, and Metals in WSTF Groundwater

CAS Number	Analyte	Preferred MDL – 20% of cleanup level[1]	Preferred PQL [1]	Unit
VOCs by SW-846 Method 8260 (current version)				
100-41-4	Ethylbenzene	3.0	15	µg/L
100-42-5	Styrene	20	100	µg/L
107-06-2	1,2-Dichloroethane (EDC)	0.34	1.7	µg/L
107-12-0	Propionitrile	NA[2]	NA[2]	µg/L
107-13-1	Acrylonitrile	0.104	0.52	µg/L
108-88-3	Toluene	150	750	µg/L
108-90-7	Chlorobenzene	15.6	78	µg/L
109-99-9	Tetrahydrofuran (THF)	NA[2]	NA[2]	µg/L
127-18-4	Tetrachloroethene (PCE)	1.0	5.0	µg/L
1330-20-7	m,p-Xylenes	38	190	µg/L
156-60-5	trans-1,2-Dichloroethene	20	100	µg/L
306-83-2	2,2-Dichloro-1,1,1-trifluoroethane (Freon123)	NA[2]	NA[2]	µg/L
354-23-4	1,2-Dichloro-1,1,2-trifluoroethane (Freon123a)	NA[2]	NA[2]	µg/L
56-23-5	Carbon tetrachloride	0.92	4.6	µg/L
67-63-0	2-Propanol	NA[2]	NA[2]	µg/L
67-64-1	Acetone	2,800	14,000	µg/L
67-66-3	Chloroform	0.44	2.2	µg/L
71-43-2	Benzene	0.92	4.6	µg/L
71-55-6	1,1,1-Trichloroethane (TCA)	12	60	µg/L
74-83-9	Bromomethane	1.5	7.5	µg/L
74-87-3	Chloromethane	38	190	µg/L
75-00-3	Chloroethane	4,200	21,000	µg/L
75-01-4	Vinyl chloride	0.038	0.19	µg/L
75-09-2	Methylene chloride	1.0	5.0	µg/L
75-15-0	Carbon disulfide	162	810	µg/L
75-25-2	Bromoform	6.6	33	µg/L
75-27-4	Bromodichloromethane	0.26	1.3	µg/L
75-34-3	1,1-Dichloroethane	5.0	25	µg/L
75-35-4	1,1-Dichloroethene	1.0	5.0	µg/L
75-43-4	Dichlorofluoromethane (Freon 21)	NA[2]	NA[2]	µg/L
75-69-4	Trichlorofluoromethane (Freon11)	1,040	5,200	µg/L
75-71-8	Dichlorodifluoromethane (Freon12)	40	200	µg/L
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	NA[2]	NA[2]	µg/L

Table 6 Preferred Analytical Requirements for VOCs, Nitrosamines, and Metals in WSTF Groundwater

CAS Number	Analyte	Preferred MDL – 20% of cleanup level[1]	Preferred PQL [1]	Unit
78-87-5	1,2-Dichloropropane (DCPA)	1	5	µg/L
78-93-3	2-Butanone (MEK)	1,120	5,600	µg/L
79-00-5	1,1,2-Trichloroethane	0.56	2.8	µg/L
79-01-6	Trichloroethene (TCE)	0.98	4.9	µg/L
Nitrosamines by Low Level Analytical Method				
4164-28-7	N-Nitrodimethylamine	NA[2]	NA[2]	µg/L
62-75-9	N-Nitrosodimethylamine	0.00022	0.0011	µg/L
Metals by Laboratory-Specified Best Method				
7439-92-1	Lead	0.01	0.05	mg/L
7439-97-6	Mercury	0.0004	0.002	mg/L
7440-02-0	Nickel	0.04	0.20	mg/L
7440-22-4	Silver	0.01	0.050	mg/L
7440-23-5	Sodium	NA[2]	NA[2]	mg/L
7440-24-6	Strontium	1.86	9.3	mg/L
7440-28-0	Thallium	0.00004	0.0002	mg/L
7440-31-5	Tin	2.4	12	mg/L
7440-36-0	Antimony	0.0012	0.0060	mg/L
7440-38-2	Arsenic	0.002	0.01	mg/L
7440-39-3	Barium	0.2	1.0	mg/L
7440-41-7	Beryllium	0.0008	0.004	mg/L
7440-42-8	Boron	0.15	0.75	mg/L
7440-43-9	Cadmium	0.001	0.005	mg/L
7440-70-2	Calcium	NA[2]	NA[2]	mg/L
7440-47-3	Chromium	0.01	0.05	mg/L
7440-48-4	Cobalt	0.0012	0.006	mg/L
7440-50-8	Copper	0.20	1.0	mg/L
7440-62-2	Vanadium	0.0172	0.086	mg/L
7440-66-6	Zinc	2	10	mg/L
7782-49-2	Selenium	0.01	0.05	mg/L

NA – Not Available/Applicable

[1] – These are the maximum preferred analytical requirements allowed by Permit Section 17.3.

[2] – Indicates that the analytical laboratory will be required to provide the best achievable level for review prior to performing analytical work related to the WSTF groundwater monitoring program.

Table 7 Preferred Analytical Requirements for Inorganics, SVOCs, and Miscellaneous COCs in WSTF Groundwater

CAS Number	Analyte	Recommended Analytical Method	Preferred MDL[1] – 20% of cleanup level	Preferred PQL[1]
Inorganic Compounds by Various Methods				
14797-55-8	Nitrate/Nitrite as N	300.0	2.0 mg/L	10 mg/L
14797-73-0	Perchlorate	331.0	2.2 µg/L	11 µg/L
14808-79-8	Sulfate	300.0	NA[2]	NA[2]
16887-00-6	Chloride	300.0	NA[2]	NA[2]
16984-48-8	Fluoride	300.0	NA[2]	NA[2]
NA	Alkalinity	SM2320	NA[2]	NA[2]
NA	Total Dissolved Solids (TDS)	SM2540	100 mg/L	500 mg/L
SVOCs by Various Methods				
84-74-2	Di-n-butylphthalate	SW-846 Method 8270	180 µg/L	900 µg/L
108-39-4	m-Cresol	SW-846 Method 8270	186 µg/L	930 µg/L
117-81-7	Bis(2-Ethylhexyl)phthalate	SW-846 Method 8270	1.2 µg/L	6.0 µg/L
314-40-9	Bromacil	Modified EPA Method 607	NA[2]	NA[2]
Miscellaneous Constituents by Various Methods				
123-91-1	1,4-Dioxane	SW-846 Method 8270 SIM	0.92 µg/L	4.59 µg/L
108-95-2	Phenol	SW-846 Method 9066	1.0 µg/L	5.0 µg/L
30402-15-4	Total Penta CDF	SW-846 Method 8290	NA[2]	NA[2]
3268-87-9	Octachlorodibenzo-p-dioxin (OCDD)	SW-846 Method 8290	NA[2]	NA[2]
39001-02-0	Octachlorodibenzofuran (OCDF)	SW-846 Method 8290	NA[2]	NA[2]
41903-57-5	Total Tetra CDD	SW-846 Method 8290	NA[2]	NA[2]
55684-94-1	Hexachlorodibenzofurans (HxCDF), Total	SW-846 Method 8290	NA[2]	NA[2]
57-12-5	Total Cyanide	SW-846 Method 9012	0.04 mg/L	0.2 mg/L
93-72-1	2,4,5-TP (Silvex)	SW-846 Method 8151	10 µg/L	50 µg/L

Table 7 Preferred Analytical Requirements for Inorganics, SVOCs, and Miscellaneous COCs in WSTF Groundwater

CAS Number	Analyte	Recommended Analytical Method	Preferred MDL[1] – 20% of cleanup level	Preferred PQL[1]
8006-61-9	GRO	SW-846 Method 8015	50 µg/L[3]	100 µg/L[3]
68334-30-5	DRO	SW-846 Method 8015	50 µg/L[3]	100 µg/L[3]
NA	Sulfide	SW-846 Method 9030	NA[2]	NA[2]

NA – Not Available/Applicable

[1] – These are the maximum preferred analytical requirements allowed by Permit Section 17.3.

[2] – Indicates that the analytical laboratory will be required to provide the best achievable level for review prior to performing analytical work related to the WSTF groundwater monitoring program.

[3] – Indicates that the constituent is not a hazardous constituent with a WSTF groundwater cleanup level and that the MDL and PQL are recommended to meet project objectives in the SMWU 50 Investigation Work Plan (NASA, 2017c)

Table 8 Field Quality Control Samples

QC Sample	QC Sample Description and Purpose
Equipment Blank	A sample of analyte-free purified water which has been used to rinse common sampling equipment to check effectiveness of decontamination procedures. This type of blank also indicates contamination in the field and during handling, transport, shipping, laboratory, and analytical processes which may affect analytical results.
Field Blank	A blank prepared in the field by filling a clean sample container with analyte-free purified water and appropriate preservative, if any, for the specific sampling activity being undertaken. This type of sample provides a check for contamination derived in the field and during handling, transport, shipping, laboratory, and analytical processes.
Trip Blank	A sample of analyte-free purified water prepared in a contaminant free environment that is carried to the sampling site and transported to the laboratory for analysis without having been exposed to sampling procedures. This type of sample serves as a check on sample contamination originating from sample handling, transport, shipping, site conditions, laboratory, and analytical processes.
Field Duplicate Sample	A second sample is taken immediately after an original sample at the same sampling location. This sample provides an estimate of the overall system precision.

Table 9 Frequencies for the Collection of Field Quality Control Samples

QC Sample	Frequency for VOCs	Frequency for High Level Nitrosamines Method	Frequency for Low Level Nitrosamines Method	Frequency for Metals
Equipment Blank	100% of all VOC sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.	2% of all high-level nitrosamines sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.	100% of all low-level nitrosamines sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.	5% of all metals sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.
Field Blank	100% of all VOC sampling events where dedicated sampling equipment is used. Not required if non-dedicated sampling equipment is used and a VOC equipment blank is collected in the field.	Not required if a high-level equipment blank is collected in the field, otherwise 2% of all high level nitrosamines sampling events.	100% of all low-level nitrosamines sampling events where dedicated sampling equipment is used. Not required if non-dedicated sampling equipment is used and a low-level nitrosamines equipment blank is collected in the field.	Not required if a metals equipment blank is collected in the field, otherwise 5% of all metals sampling events.
Trip Blank	Collected for VOC sampling event at a frequency sufficient to fulfill minimum requirement of one trip blank per VOC sample shipment.	Not required.	Collected for low-level nitrosamines sampling event at a frequency sufficient to fulfill minimum requirement of one trip blank per low level nitrosamines sample shipment.	Not required.
Field Duplicate Sample	10% of all VOC sampling events.	10% of all high-level nitrosamines sampling events.	10% of all low-level nitrosamines sampling events.	10% of all metals sampling events

Table 10 Evaluation Criteria and Corrective Action for Field QC Samples

QC Sample	Evaluation Criteria and Corrective Action
Equipment Blank	In the event of equipment blank contamination, analytical data shall be qualified if the concentration of an analyte in the blank is greater than 1/10 of the amount measured in the sample. The primary reason to collect an equipment blank is to check effectiveness of equipment decontamination procedures. However, an equipment blank is also subject to the same field, handling, transport, shipping, laboratory, and analytical conditions as the sample. To determine whether equipment blank contamination results from ineffective equipment decontamination procedures, all blank and sample contamination must be evaluated. When significant and consistent equipment blank contamination is present, the cause must be investigated and corrective action taken to minimize or eliminate the problem.
Field Blank	In the event of field blank contamination, analytical data shall be qualified if the concentration of an analyte in the blank is greater than 1/10 of the amount measured in the sample. The primary reason to collect a field blank is to check for contamination derived in the field. However, a field blank is also subject to the same handling, transport, shipping, laboratory, and analytical conditions as the sample. To determine whether field blank contamination results from field conditions, all blank and sample contamination must be evaluated. When significant and consistent field blank contamination is present, the cause must be investigated and corrective action taken to minimize or eliminate the problem.
Trip Blank	In the event of trip blank contamination, analytical data shall be qualified if the concentration of an analyte in the blank is greater than 1/10 of the amount measured in the sample. The primary reason to collect a trip blank is to check for contamination derived from sample handling, transport, shipping, and site conditions. However, a trip blank is also subject to the same laboratory and analytical conditions as the sample. To determine whether trip blank contamination results from sample handling, transport, shipping, or site conditions, all blank and sample contamination must be evaluated. When significant and consistent trip blank contamination is present, the cause must be investigated and corrective action taken to minimize or eliminate the problem.
Field Duplicate Sample	The results from field duplicate samples are primarily designed to estimate overall system precision. Precision is expressed as RPD (relative percent difference). Results are compared to the evaluation criteria for field duplicate samples in the test method. Where there are no established criteria for field duplicate samples, the WSTF contractor environmental organization shall determine internal criteria, such as adopting analyst duplicate or laboratory control sample duplicate criteria, and document the method used to establish the limits. For field duplicate results outside established criteria, the data shall be reported with appropriate data qualifying codes. When field duplicate precision is significantly and consistently outside evaluation criteria, corrective action shall be taken to minimize or eliminate the problem.

Table 11 Descriptions of Laboratory Quality Control Samples

QC Sample	QC Sample Description
Method Blank	Analyte-free deionized water processed simultaneously with and under the same conditions as samples through all steps of the analytical procedures, and in which no analytes or interferences are present at concentrations that impact the analytical results for sample analyses. The method blank is used to assess the preparation or analytical batch for possible contamination during the preparation and processing steps.
Laboratory Control Sample	Analyte-free deionized water spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes. The laboratory control sample is used to evaluate the performance of the total analytical system (i.e., for systematic error or bias) including all preparation and analysis steps.
Matrix Spike	A sample prepared by adding a known mass of analyte to a specified amount of matrix sample for which an independent estimate of analyte concentration is available. Matrix spike samples are used to indicate the effect of the sample matrix on the accuracy of the results generated using the selected method. The information from these controls is sample/matrix specific and would not normally be used to determine the validity of the entire batch.
Matrix Spike Duplicate	A second replicate matrix spike prepared in the laboratory and analyzed to obtain a measure of the precision of the recovery for each analyte.
Surrogate Spike	Introduction of a compound into the samples, blanks, and laboratory control samples similar to the analytes of interest, but not normally found in environmental samples, blanks and laboratory control samples. The surrogate spike provides a continuous monitor of the performance of the analytical system and the effectiveness of the method in dealing with sample matrices.

Table 12 Frequency of Analysis for Laboratory Quality Control Samples

QC Sample	Frequency for VOCs	Frequency for High Level Nitrosamines Method	Frequency for Low Level Nitrosamines Method	Frequency for Metals
Method Blank	One for each preparation or analytical batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.
Laboratory Control Sample	One for each preparation or analytical batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.
Matrix Spike/Matrix Spike Duplicate[1]	2% of groundwater samples analyzed.	2% of groundwater samples analyzed.	2% of groundwater samples analyzed.	2% of groundwater samples analyzed.
Surrogate Spike	100% of all blanks, groundwater samples and standards.	100% of all blanks, groundwater samples and standards.	100% of all blanks, groundwater samples and standards.	Not applicable.

[1] – WSTF matrix spike samples are collected in the field specifically as matrix spikes and delivered to the analytical laboratory to be appropriately spiked and analyzed. The analytical laboratory is required to spike these samples as specified in the method regardless of the requirements for other project samples in the same analytical batch. In this way, matrix specific recovery for WSTF groundwater is monitored without placing onerous requirements on the analytical laboratory. Historically, matrix effects on volatiles, semi-volatiles, and metals analysis of WSTF groundwater are not significant. Therefore, the frequencies of these samples have been decreased from historical levels to levels sufficient to monitor potential changes in the matrix.

Table 13 Evaluation Criteria and Corrective Action for Laboratory QC Samples

QC Sample	Evaluation Criteria and Corrective Action
Method Blank	While the goal is to have no detectable contaminants, each method blank must be critically evaluated as to the nature of the interference and the effect on the analysis of each sample with the batch. The source of contamination shall be investigated and measures taken to minimize or eliminate the problem and affected samples reprocessed or data shall be appropriately qualified if: 1. The concentration of an analyte in the blank is at or above the quantitation limit, and is greater than 1/10 of the amount measured in any sample. 2. The blank contamination otherwise affects the sample results as per the method requirements. 3. When a blank is determined to be contaminated, the cause must be investigated and measures taken to minimize or eliminate the problem. Samples associated with a contaminated blank shall be evaluated as to the best corrective action for the samples (e.g. reprocessing or data qualifying codes). In all cases the corrective action must be documented by the laboratory.
Laboratory Control Sample	The results of the individual batch laboratory control sample are calculated in percent recovery (bias) allowing comparison to method or laboratory established evaluation criteria. The individual laboratory control sample is compared to the evaluation criteria as published in the test method. Where there are no established criteria, the laboratory shall determine internal criteria and document the method used to establish the limits. A laboratory control sample that is determined to be within the criteria effectively establishes that the analytical system is in control and validates system performance for the samples in the associated batch. Samples analyzed along with a laboratory control sample determined to be "out of control" shall be considered suspect and the samples reprocessed and re-analyzed or the data reported with appropriate data qualifying codes. If a large number of analytes are in the laboratory control sample, it becomes statistically likely that a few well be outside control limits. Contracted laboratories shall refer to the NELAC accreditation standards for handling marginal laboratory control sample exceedances for laboratory control samples with a large number of analytes.
Matrix Spike/Matrix Spike Duplicate	The results from the matrix spike/matrix spike duplicate are primarily designed to assess the accuracy of analytical results in a given matrix and are expressed as bias, or percent recovery, and precision, or relative percent difference. The laboratory shall document the calculation for percent recovery and relative percent difference. The results are compared to the evaluation criteria as published in the test method. Where there are no established criteria, the laboratory shall determine internal criteria and document the method used to establish the limits. For matrix spike results outside established criteria corrective action shall be documented or the data reported with appropriate data qualifying codes.
Surrogate Spike	Surrogate spike results are compared to the evaluation criteria as published in the test method. Where there are no established criteria, the laboratory shall determine internal criteria and document the method used to establish the limits. Surrogates outside the evaluation criteria must be evaluated for the

Table 13 Evaluation Criteria and Corrective Action for Laboratory QC Samples

QC Sample	Evaluation Criteria and Corrective Action
	effect on individual sample results. Results reported from analyses with “out of control” surrogate recoveries should include appropriate data qualifiers.

Table 14 Description of WSTF Data Qualifiers

Data Qualifier	Description
*	User defined qualifier. See specific quality assurance narrative.
A	The result of an analyte for a LCS (laboratory control sample), ICV (initial calibration verification) or CCV (continuing calibration verification) was outside standard limits.
AD	Relative percent difference for analyst (laboratory) duplicates was outside standard limits.
D	The reported result is from a dilution.
EB	The analyte was detected in the equipment blank.
FB	The analyte was detected in the field blank.
G	The result is an estimated value greater than the upper calibration limit.
i	The result, quantitation limit, and/or detection limit may have been affected by matrix interference.
J	The result is an estimated value less than the quantitation limit, but greater than or equal to the detection limit.
NA	The value/result was either not analyzed for or not applicable.
ND	The analyte was not detected above the detection limit.
Q	The result for a blind control sample was outside standard limits.
QD	The relative percent difference for a field duplicate was outside standard limits.
R	The result is rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
RB	The analyte was detected in the method blank.
S	The result was determined by the method of standard addition.
SP	The matrix spike recovery and/or the relative percent difference for matrix spike duplicates was outside standard limits.
T	The sample was analyzed outside the specified holding time or temperature.
TB	The analyte was detected in the trip blank.
TIC	The analyte was tentatively identified by a GC/MS library search and the amount reported is an estimated value.

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
Upgradient Monitoring Wells/Zones							
100-F-358	SA	SA	A	A	A	SA[2]	Annual Appendix IX, 1,4-Dioxane
100-G-223	SA	SA	A	A	A[3]	SA[2, 3]	Annual Appendix IX, Annual SWMU 50, 1,4-Dioxane
300-F-175	SA	SA	A	A	A	SA[2]	Annual Appendix IX, 1,4-Dioxane
NASA 3	SA	SA	A	A	A	A	Annual Appendix IX
100/600 Area Monitoring Wells/Zones							
100-A-182	A		A	TA	A[3,4]	A[3]	Annual SWMU 50
100-D-176	A		A	TA	A[3,4]	A[3]	Annual SWMU 50
100-HG-139	A		A	TA	A[4]		
600-C-173	A		A	TA	A[4]		
600-E-280	A		A	TA	A[4]		
600-G-138	A		A	TA	A[4]		
BLM-3-182[5]	A		A	TA	A[4]		Annual Appendix IX
BW-3-180	SA		SA	BA	SA[4]		
NASA 4	A		A	TA	A[4]		
WB-1-200	A		A	TA	A[4]		
WB-1-255	A		A	TA	A[4]		
WB-1-330	A		A	TA	A[4]		
200 Area Monitoring Wells/Zones							
200-B-240[5]	A	A	A	TA	A[4]		Annual Appendix IX
200-C-170	A	A	A	TA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
200-C-225	A	A	A	TA	A[4]		
200-C-270	A	A	A	TA	A[4]		
200-D-109[6]	A	A	A	TA	A[4]		
200-D-240	A	A	A	TA	A[4]		
200-F-225	A	A	A	TA	A[4]		
200-F-370	A	A	A	TA	A[4]		
200-F-420	A	A	A	TA	A[4]		
200-G-175	A	A	A	TA	A[4]		
200-G-220	A	A	A	TA	A[4]		
200-G-340	A	A	A	TA	A[4]		
200-G-420	A	A	A	TA	A[4]		
200-G-495	A	A	A	TA	A[4]		
200-H-225	A	A	A	TA	A[4]		
200-H-331	A	A	A	TA	A[4]		
200-H-433	A	A	A	TA	A[4]		
200-I-185	A	A	A	TA	A[4]		
200-I-300	A	A	A	TA	A[4]		
200-I-375	A	A	A	TA	A[4]		
200-I-490	A	A	A	TA	A[4]		
200-I-675	A	A	A	TA	A[4]		
200-I-795	A	A	A	TA	A[4]		
200-JG-110	A	A	A	TA	A[4]		
200-SG-1[5]	A	A	A	TA	A[4]	A	Annual Appendix IX
200-KV-150[6]	Q	Q	Q	Q	Q		
200-LV-150	A	A	A	TA	A[4]		
BW-4-270[7]	A	A	A	TA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
BW-4-355[7]	A	A	A	TA	A[4]		
BW-4-455[7]	A	A	A	TA	A[4]		
300/400 Area Monitoring Wells/Zones							
300-A-120[5]	A	A	A	TA	A[4]	A	Annual Appendix IX
300-A-170	A	A	A	TA	A[4]		
300-B-166	A	A	A	TA	A[4]		
300-C-128	A	A	A	TA	A[4]		
300-D-153	A	A	A	TA	A[4]		
300-E-138	A	A	A	TA	A[4]		
300-E-183	A	A	A	TA	A[4]		
400-A-151	A	A	A	TA	A[4]		
400-C-118[5]	A	A	A	TA	A[4]	A	Annual Appendix IX
400-C-143	A	A	A	TA	A[4]		
400-D-195	A	A	A	TA	A[4]		
400-D-275	A	A	A	TA	A[4]		
400-D-355	A	A	A	TA	A[4]		
400-EV-131	Q	A	A	TA	A[4]		
400-FV-131	Q	A	A	TA	A[4]		
400-GV-125	Q	A	A	TA	A[4]		
400-HV-147	Q	A	A	TA	A[4]		
400-IV-123	Q	A	A	TA	A[4]		
400-JV-150	Q	A	A	TA	A[4]		
400-KV-142[8]							
400-LV-125[9]							
BW-1-268	SA	SA	SA	BA	SA[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
BW-5-295	SA	SA	SA	BA	SA[4]		
BW-7-211	SA	SA	SA	BA	SA[4]		
NASA 5	A	A	A	TA	A[4]		
NASA 6	A	A	A	TA	A[4]		
NASA 8[6]	A	A	A	TA	A[4]		
NASA 9[6]	A	A	A	TA	A[4]		
NASA 10	A	A	A	TA	A[4]		
Northern Boundary Monitoring Wells/Zones							
700-A-253	SA	SA	A	BA	A[4]		SA Landfill
700-B-510	A	A	A	BA	A[4]		
700-D-186	SA	SA	A	BA	A[4]		SA Landfill
700-E-458	A	A	A	BA	A[4]		
700-F-455[10]							
700-H-350	SA	SA	A	BA	A[4]		SA Landfill
700-H-535	SA	SA	A	BA	A[4]		SA Landfill
700-H-670	SA	SA	A	BA	A[4]		SA Landfill
700-J-200	SA	SA	A	BA	A[4]		SA Landfill
BLM-24-565	SA	SA	A	BA	A[4]		
BLM-32-543	Q	Q	A	Q	Q		
BLM-32-571	Q	Q	A	BA	A[4]		
BLM-32-632	Q	Q	A	BA	A[4]		
BLM-41-420	SA	SA	A	BA	A[4]		
BLM-41-670	SA	SA	A	BA	A[4]		
BW-6-355	SA	SA	A	BA	A[4]		
JER-1-483	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-1-563	Q	Q	A	BA	A	Q[3]	1,4-Dioxane

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
JER-1-683	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-2-504	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-2-584	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-2-684	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
Southern Boundary Monitoring Wells/Zones							
100-C-365	A		A	BA	A[2,4]	A[2]	Annual SWMU 50
100-E-261	A		A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-6-488	Q	Q	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-13-300	A	A	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-25-455	A	A	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-28[11]				TBD			
BLM-31[12]							
BLM-40-517	SA	SA	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-40-595	SA	SA	A	BA	A[4]		
BLM-40-688	SA	SA	A	BA	A[4]		
WB-5-250	A		A	BA	A[4]		
WB-5-280	A		A	BA	A[4]		
WB-5-345	A		A	BA	A[4]		
WB-14-520	A		A	BA	A[4]		
MPCA Monitoring Wells/Zones							
BLM-5-527	SA	SA	A	BA	A[4]		
BLM-8-418	SA	SA	A	BA	A[4]		
BLM-9-419	SA	SA	A	BA	A[4]		
BLM-14-327	SA	SA	A	BA	A[4]		
BLM-15-305	SA	SA	A	BA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
BLM-18-430	SA	SA	A	BA	A[4]		
BLM-21-400	SA	SA	A	BA	A[4]		
BLM-22-570	SA	SA	A	BA	A[4]		
BLM-23-431	SA	SA	A	BA	A[4]		
BLM-26-404	SA	SA	A	BA	A[4]		
BLM-27-270	SA	SA	A	BA	A[4]		
BLM-30-585	SA	SA	A	BA	A[4]		
BLM-36-350	SA	SA	A	BA	A[4]		
BLM-36-610	SA	SA	A	BA	A[4]		
BLM-36-800	SA	SA	A	BA	A[4]		
BLM-36-860	SA	SA	A	BA	A[4]		
BLM-38-480	SA	SA	A	BA	A[4]		
BLM-38-620	SA	SA	A	BA	A[4]		
BLM-39-385	SA	SA	A	BA	A[4]		
BLM-39-560	SA	SA	A	BA	A[4]		
Main Plume Monitoring Wells/Zones							
BLM-1-435	SA	SA	A	BA	A[4]		
BLM-2-482[6]	SA	SA	A	BA	A[4]		
BLM-2-630	SA	SA	A	BA	A[4]		
BLM-17-493	SA	SA	A	BA	A[4]		
BLM-17-550	SA	SA	A	BA	A[4]		
PL-1-486	Q	Q	A	BA	A[4]		
PL-2-504	Q	Q	A	BA	A[4]		
PL-5-495[13]							
PL-5-595[13]							
PL-5-715[13]							

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
PL-5-795[13]							
PL-5-895[13]							
PL-5-985[13]							
ST-1-473	SA	SA	A	BA	A[4]		
ST-1-541	SA	SA	A	BA	A[4]		
ST-1-630	SA	SA	A	BA	A[4]		
ST-3-486	SA	SA	A	BA	A[4]		
ST-3-586	SA	SA	A	BA	A[4]		
ST-3-666	SA	SA	A	BA	A[4]		
ST-3-735	SA	SA	A	BA	A[4]		
Plume Front Monitoring Wells/Zones							
BLM-7-509	Q	Q	A	BA	A[4]		
BLM-10-517	Q	Q	A	BA	A[4]		
PL-3-453	Q	Q	A	BA	A[4]		
PL-4-464	Q	Q	A	BA	A[4]		
PL-6-545	Q	Q	A	BA	A[4]		
PL-6-725	Q	Q	A	BA	A[4]		
PL-6-915	A	A	A	BA	A[4]		
PL-6-1195	A	A	A	BA	A[4]		
PL-6-1335	A	A	A	BA	A[4]		
PL-7-480	Q	Q	A	BA	A[4]		
PL-7-560	Q	Q	A	BA	A[4]		
PL-7-630	A	A	A	BA	A[4]		
ST-2-466	A	A	A	BA	A[4]		
ST-4-481	Q	Q	A	BA	A[4]		
ST-4-589	Q	Q	A	BA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
ST-4-690	Q	Q	A	BA	A[4]		
ST-5-481	A	A	A	BA	A[4]		
ST-5-485	Q	Q	A	BA	A[4]		
ST-5-655	Q	Q	A	BA	A[4]		
ST-5-815	A	A	A	BA	A[4]		
ST-5-985	A	A	A	BA	A[4]		
ST-5-1175	A	A	A	BA	A[4]		
ST-6-528	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
ST-6-568	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
ST-6-678	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
ST-6-824	Q	Q	A	BA	A		
ST-6-970	Q	Q	A	BA	A		
ST-7-453	Q	Q	A	BA	A		
ST-7-544	Q	Q	A	BA	A		
ST-7-779	Q	Q	A	BA	A		
ST-7-970	Q	Q	A	BA	A		
WW-1-452	Q	Q	A	BA	A[4]		
Sentinel Monitoring Wells/Zones							
BLM-37-490[13]							
BLM-37-640[13]							
BLM-37-750[13]							
BLM-37-885[13]							
JP-1-424	Q	Q	A	BA	BA[4]		
JP-2-447	Q	Q	A	BA	BA[4]		
JP-3-509	Q	Q	A	BA	BA[4]		
JP-3-689	Q	Q	A	BA	BA[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
PL-8-455	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-8-605	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-8-780	A	A	A	BA	BA[4]		
PL-8-965	A	A	A	BA	BA[4]		
PL-10-484	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-10-592	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-10-813	A	A	A	BA	BA[4]		
PL-10-962	A	A	A	BA	BA[4]		
PL-11-470	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
PL-11-530	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
PL-11-710	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
PL-11-820	Q	Q	A	BA	A		
PL-11-980	Q	Q	A	BA	A		
WW-2-489	Q	Q	A	BA	BA[4]		
WW-2-664	Q	Q	A	BA	BA[4]		
WW-3-469	Q	Q	A	BA	BA[4]		
WW-3-569	Q	Q	A	BA	BA[4]		
WW-3-710	A	A	A	BA	BA[4]		
WW-3-978	A	A	A	BA	BA[4]		
WW-4-419	Q	Q	A	BA	Q		
WW-4-589	Q	Q	A	BA	Q		
WW-4-848	Q	Q	A	BA	Q		
WW-4-948	Q	Q	A	BA	Q		
WW-5-459	Q	Q	A	BA	A		
WW-5-579	Q	Q	A	BA	A		
WW-5-809	Q	Q	A	BA	A		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
WW-5-909	Q	Q	A	BA	A		

[1] – The selection of the appropriate analytical method for the analysis of NDMA (Modified EPA Method 607 or the approved low-level method) is based on location and expected concentration at the designated well/zone.

[2] – Indicates that the well has been designated for sampling of 1,4-dioxane in accordance with NMED requirements (NMED, 2017b).

[3] – Indicates that the well is sampled annually for PAH and TPH (DRO and GRO) in accordance with the NMED-approved SWMU 50 Investigation Work Plan.

[4] – Indicates that the well/zone will be sampled for bromacil only.

[5] – Indicates that the well/zone has been designated for detection monitoring in accordance with Section 3.3.1.

[6] – Indicates that the water level in this well has declined, preventing the collection of groundwater samples at this time. The water level is regularly monitored and the well will be sampled when adequate groundwater is present. Disposition of wells with repeated inadequate water level measurements will be addressed in the text of this annual update.

[7] – Indicates that the Westbay sampling system was removed from this well. The current open borehole cannot be sampled. NASA is evaluating potential sampling systems for installation in the borehole.

[8] – Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available. Samples will be collected for the same analyses as those in well 400-JV-150.

[9] – Indicates that the well is installed in a currently unproductive fracture zone. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is observed. Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available. Samples will be collected for the same analyses as those in well 400-JV-150.

[10] – Indicates that the well is located on the USDA Jornada Experimental Range and no longer accessible to NASA for sampling. NASA is consulting with USDA personnel to determine the well's final disposition.

[11] – Indicates that the Westbay sampling system was removed from this well as part of the NMED-approved Westbay conversion project at WSTF. An alternate sampling system will be installed within this open borehole, after which sampling will be performed as required for new wells.

[12] – Indicates that a deflection in the Westbay casing prevents access to the Westbay sampling zones. The well cannot be sampled.

[13] – Indicates that that Westbay system in this well has been partially or fully removed. The well cannot be sampled and has been scheduled for abandonment and replacement.

Q – Indicates that sampling is performed for this analysis quarterly.

SA – Indicates that sampling is performed for this analysis semi-annually.

SA Landfill – Indicates that the well is sampled semi-annually in accordance with 20.9.9 NMAC and the NASA WSTF 700 Area Landfill Closure and Post-Closure Care (CPCC) Plan (NASA, 1996b).

A – Indicates that sampling is performed for this analysis annually.

BA – Indicates that sampling is performed for this analysis biennially.

TA – Indicates that sampling is performed for this analysis triennially.

TBD – To be determined.

Figures

Figure 1 **WSTF and Surrounding Areas**

(SEE NEXT PAGE)

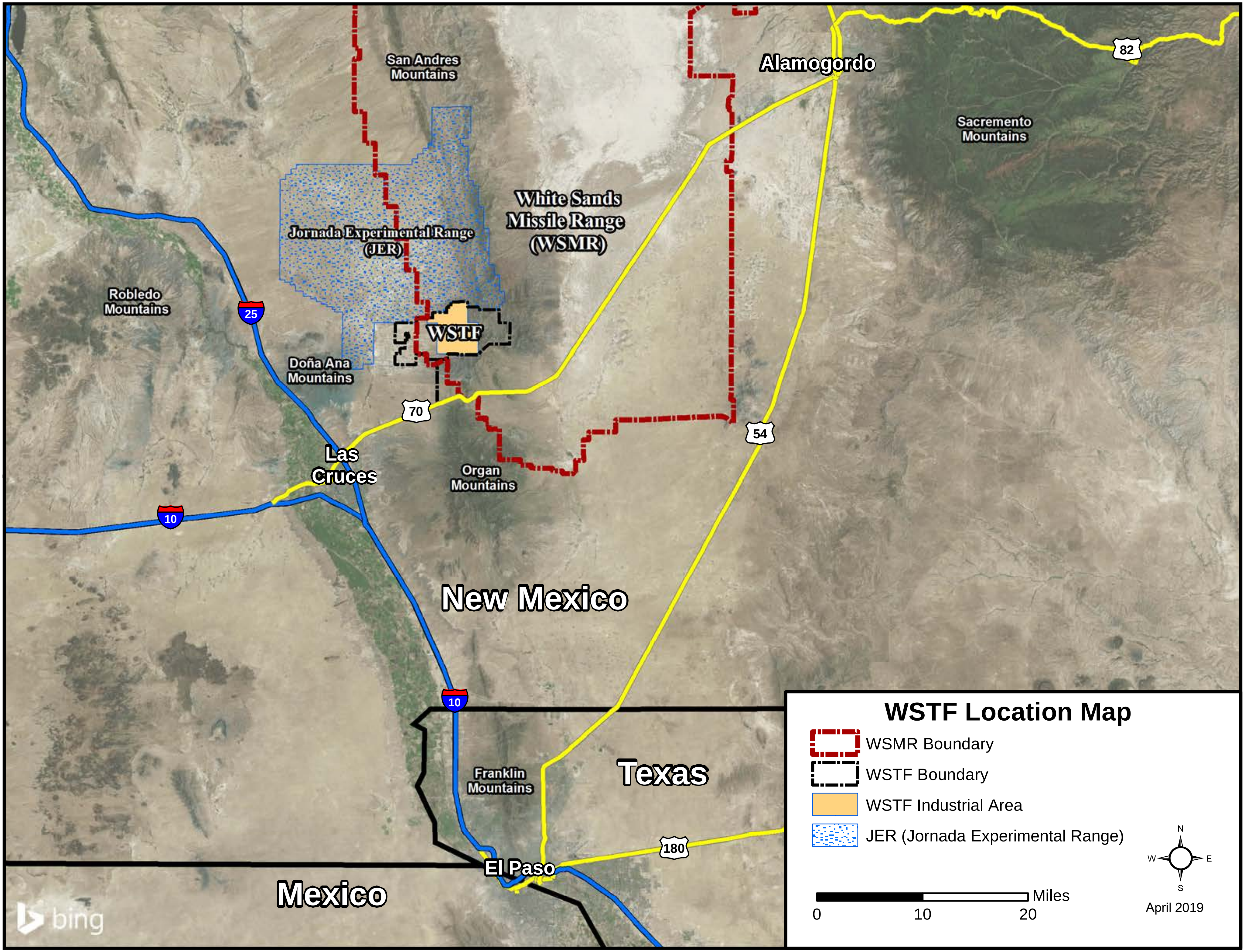
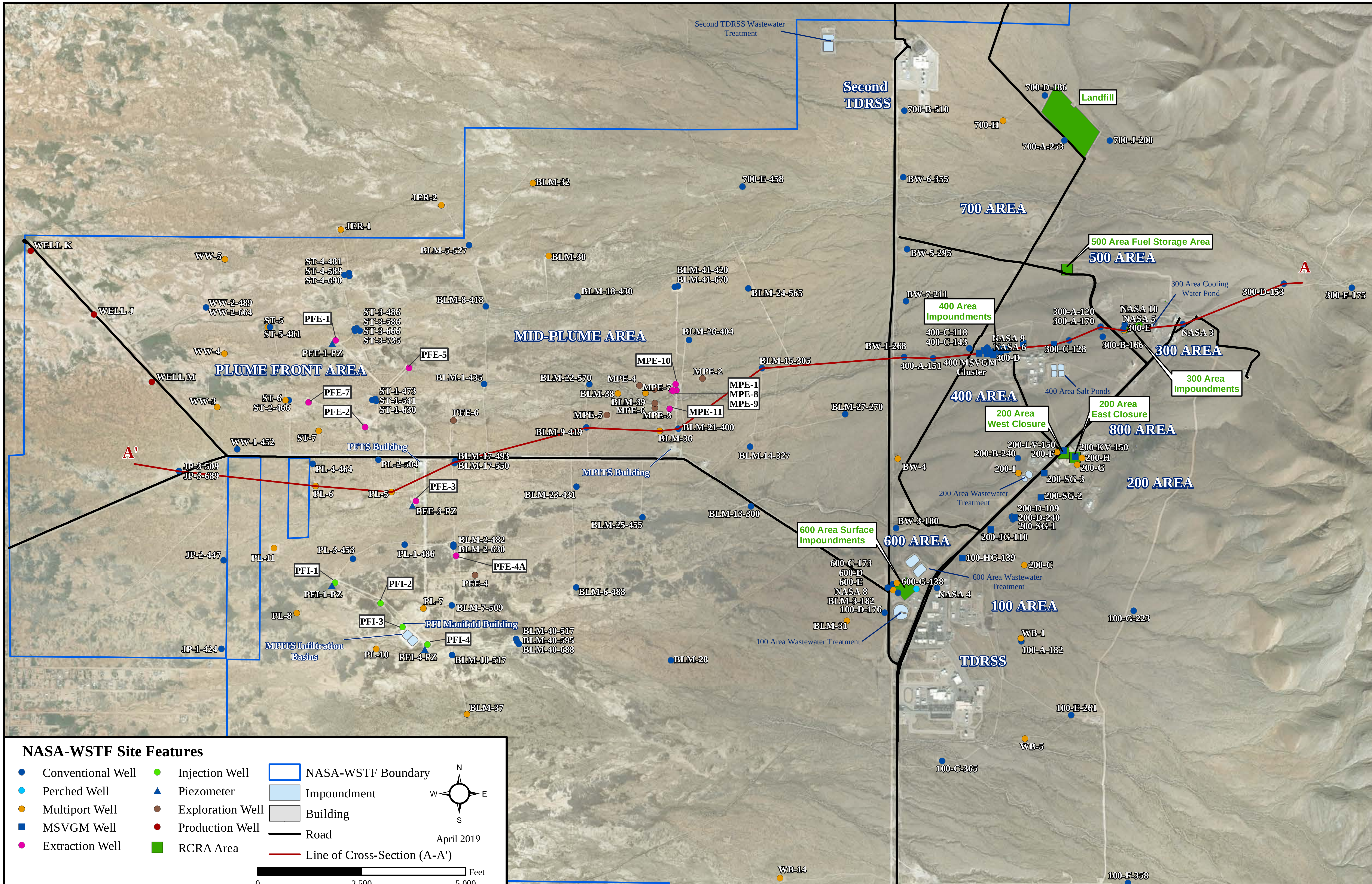

WSTF Location Map
WSMR Boundary
WSTF Boundary
WSTF Industrial Area
JER (Jornada Experimental Range)
Miles
0
10
20
N
S
E
W
April 2019
San Andres Mountains
Alamogordo
82
Sacremento Mountains
White Sands Missile Range (WSMR)
Jornada Experimental Range (JER)
Robledo Mountains
25
WSTF
Doña Ana Mountains
70
54
Las Cruces
Organ Mountains
10
New Mexico
10
Franklin Mountains
Texas
180
El Paso
Mexico
bing

Figure 2 **Pertinent WSTF Site Features**

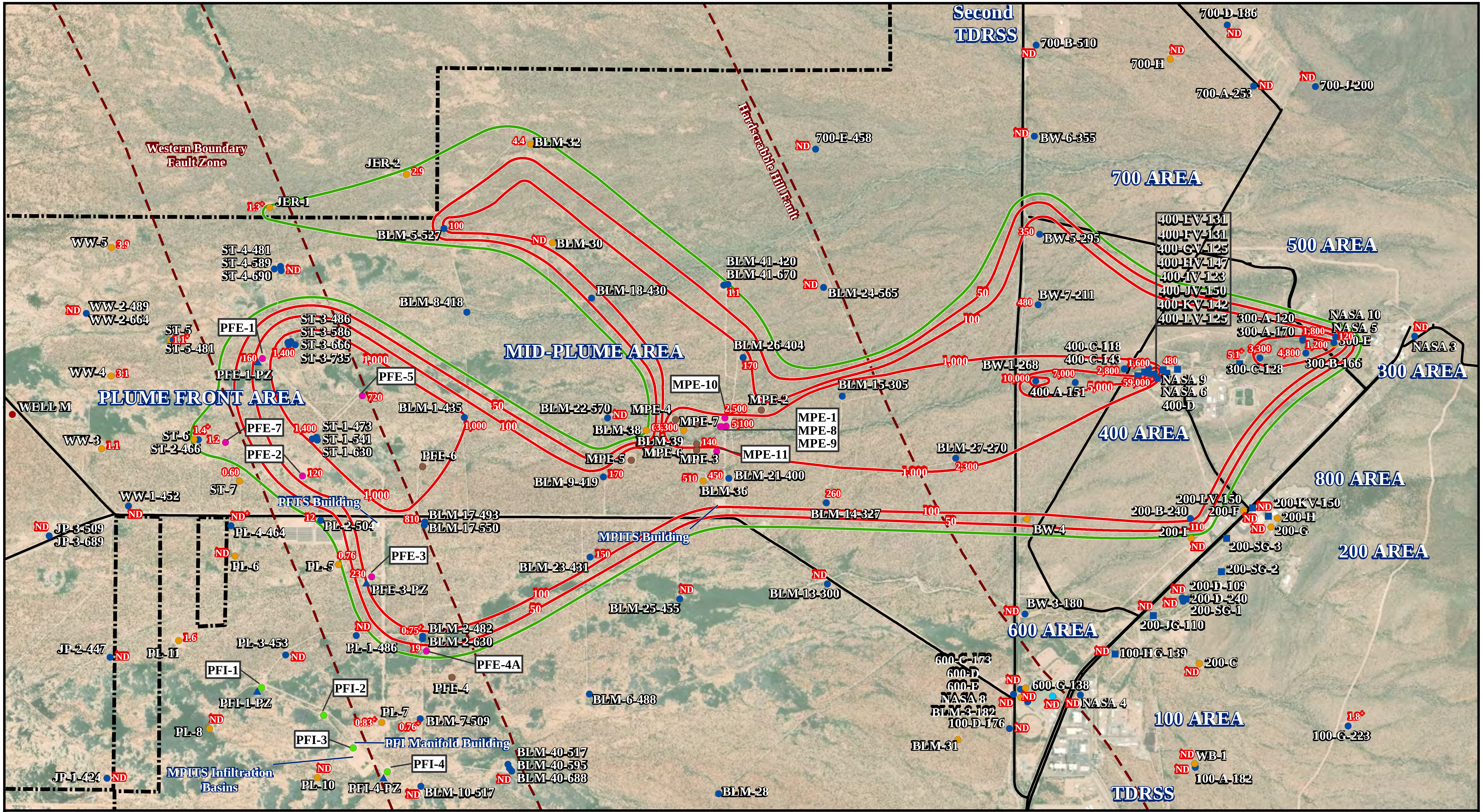
(SEE NEXT PAGE)



NASA-WSTF Site Features
Conventional Well
Perched Well
Multiport Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
RCRA Area
NASA-WSTF Boundary
Impoundment
Building
Road
Line of Cross-Section (A-A')
N
W
E
S
April 2019
Feet
0
2,500
5,000
Second TDRSS Wastewater Treatment
Second TDRSS
700 AREA
Landfill
500 Area Fuel Storage Area
500 AREA
400 Area Impoundments
300 Area Cooling Water Pond
300 AREA
300 Area Impoundments
400 AREA
400 Area Salt Ponds
400 MSVGM Cluster
200 Area West Closure
200 Area East Closure
800 AREA
200 AREA
200 Area Wastewater Treatment
600 Area Surface Impoundments
600 AREA
600 Area Wastewater Treatment
100 AREA
100 Area Wastewater Treatment
TDRSS
MID-PLUME AREA
PLUME FRONT AREA
PFTS Building
MPITS Building
PFI Manifold Building
MPITS Infiltration Basins
A
A'
WELL K
WELL J
WELL M
WW-5
WW-2-489
WW-2-664
WW-4
WW-3
WW-1-452
ST-4-481
ST-4-589
ST-4-690
ST-5
ST-5-481
ST-3-486
ST-3-586
ST-3-666
ST-3-735
ST-1-473
ST-1-541
ST-1-630
ST-6
ST-2-466
ST-7
PFE-1
PFE-1-PZ
PFE-2
PFE-3
PFE-3-PZ
PFE-4
PFE-4A
PFE-5
PFE-6
PFE-7
PFI-1
PFI-1-PZ
PFI-2
PFI-3
PFI-4
PFI-4-PZ
MPE-1
MPE-2
MPE-3
MPE-4
MPE-5
MPE-6
MPE-7
MPE-8
MPE-9
MPE-10
MPE-11
JER-1
JER-2
JP-1-424
JP-2-447
JP-3-509
JP-3-689
PL-1-486
PL-2-504
PL-3-453
PL-4-464
PL-5
PL-6
PL-7
PL-8
PL-10
PL-11
BLM-1-435
BLM-2-482
BLM-2-630
BLM-3-182
BLM-5-527
BLM-6-488
BLM-7-509
BLM-8-418
BLM-9-419
BLM-10-517
BLM-13-300
BLM-14-327
BLM-15-305
BLM-17-493
BLM-17-550
BLM-18-430
BLM-21-400
BLM-22-570
BLM-23-431
BLM-24-565
BLM-25-455
BLM-26-404
BLM-27-270
BLM-28
BLM-30
BLM-31
BLM-32
BLM-36
BLM-37
BLM-38
BLM-39
BLM-40-517
BLM-40-595
BLM-40-688
BLM-41-420
BLM-41-670
700-B-510
700-D-186
700-H
700-A-253
700-J-200
700-E-458
BW-6-355
BW-5-295
BW-7-211
BW-1-268
BW-4
BW-3-180
400-C-118
400-C-143
400-A-151
400-D
NASA 9
NASA 6
NASA 10
NASA 5
NASA 3
NASA 8
NASA 4
300-A-120
300-A-170
300-E
300-C-128
300-B-166
300-D-153
300-F-175
200-B-240
200-LV-150
200-F
200-KV-150
200-H
200-G
200-I
200-SG-3
200-SG-2
200-D-109
200-D-240
200-SG-1
200-JG-110
200-C
100-HG-139
600-C-173
600-D
600-E
600-G-138
100-D-176
100-G-223
WB-1
100-A-182
100-E-261
WB-5
100-C-365
WB-14
100-F-358

Figure 3 **Distribution of NDMA in WSTF Groundwater**

(SEE NEXT PAGE)



NDMA Maximum Concentrations in Groundwater for Fourth Quarter 2018

- Equiconcentration Line (ng/L)
- NDMA Cleanup Level (1.1 ng/L)
- Multiport
- Conventional Well
- Perched Well
- MSVGM Well
- Extraction Well
- Injection Well
- Piezometer
- Exploration Well
- Production Well
- Main Road
- Fault
- WSTF Boundary

Feet: 0 — 4,000 — 8,000

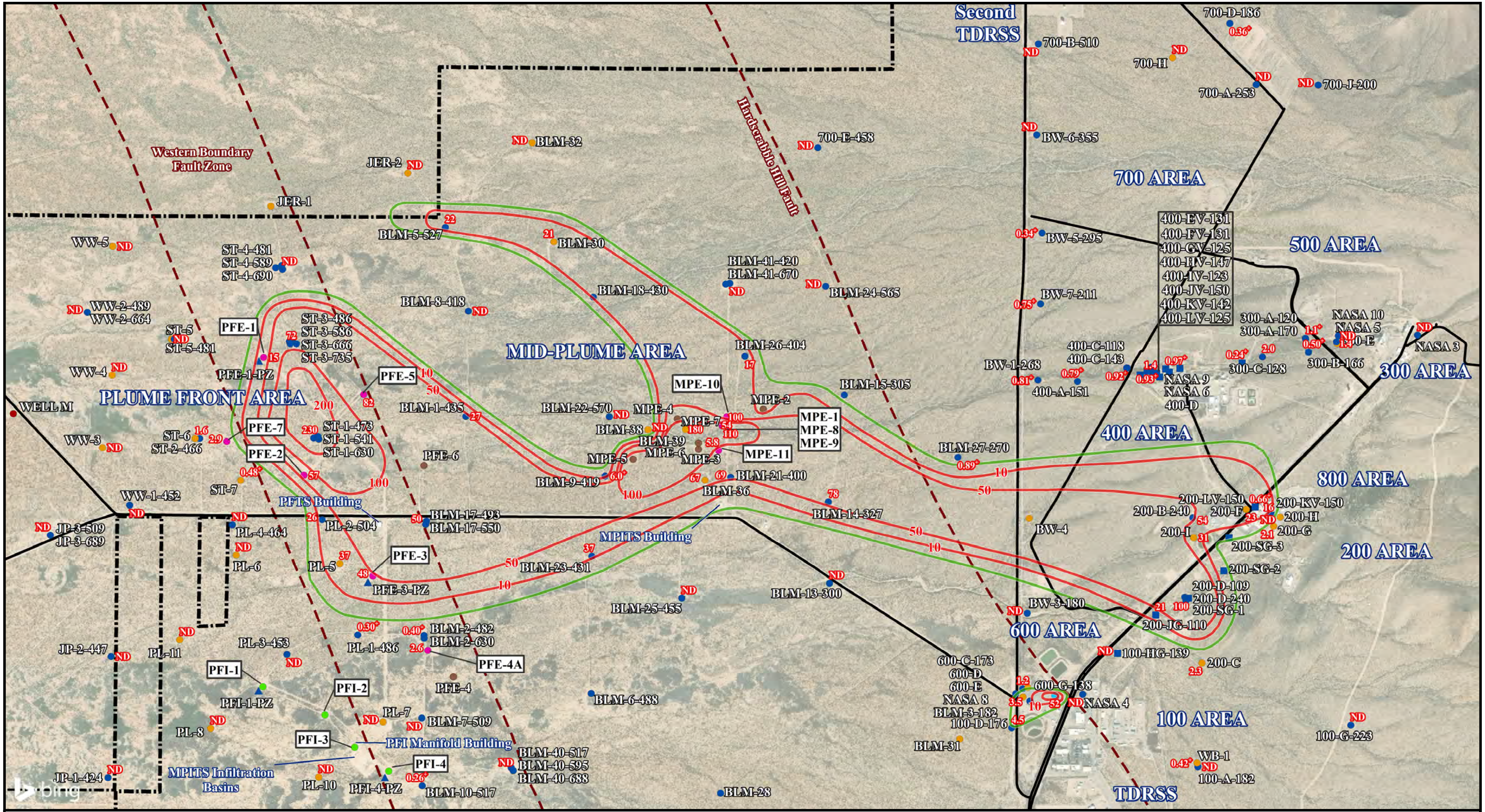
N S E W

Note:
Method 607 NDMA results corrected for extraction efficiency.
\+ - Data value has a QA flag. See Appendix A.2 for specific flags.
ND - Non-detect values <0.15 ng/L (NDMA-LL) or <4.7 ng/L (607)
- No value indicates the well has not been sampled in the last year.

Original: January 2019
Update: February 2020

Figure 4 **Distribution of TCE in WSTF Groundwater**

(SEE NEXT PAGE)



TCE Maximum Concentrations in Groundwater for Fourth Quarter 2018

Equiconcentration Line (ug/L)
TCE Cleanup Level (4.9 ug/L)
Multiport
Conventional Well
Perched Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Main Road
Fault
WSTF Boundary

0 4,000 8,000 Feet

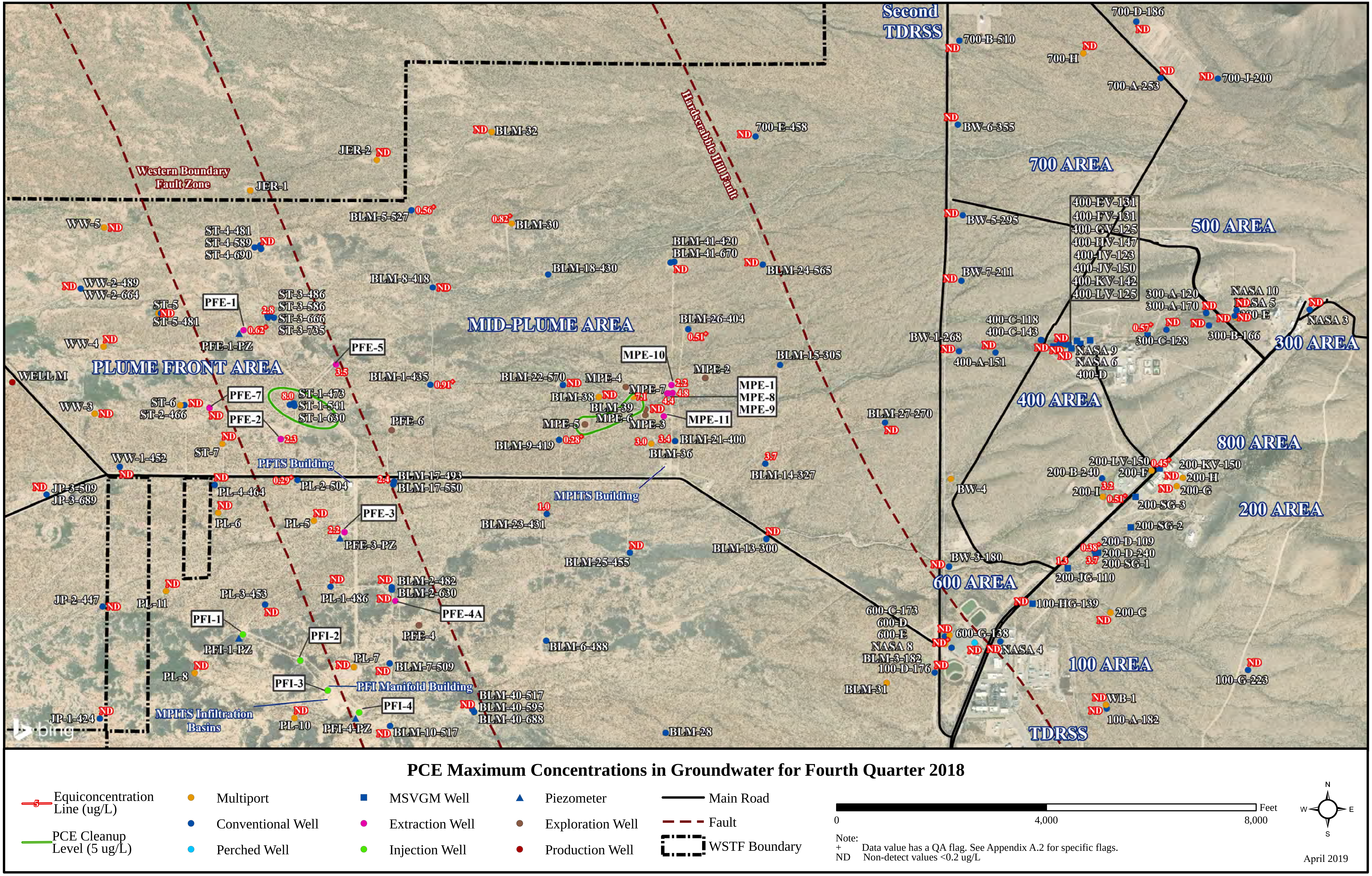
N W E S

Note:
+ - Data value has a QA flag. See Appendix A.2 for specific flags.
ND - Non-detect values <0.1116 ug/L
- No value indicates the well has not been sampled in the last year.

April 2019

Figure 5 **Distribution of PCE in WSTF Groundwater**

(SEE NEXT PAGE)



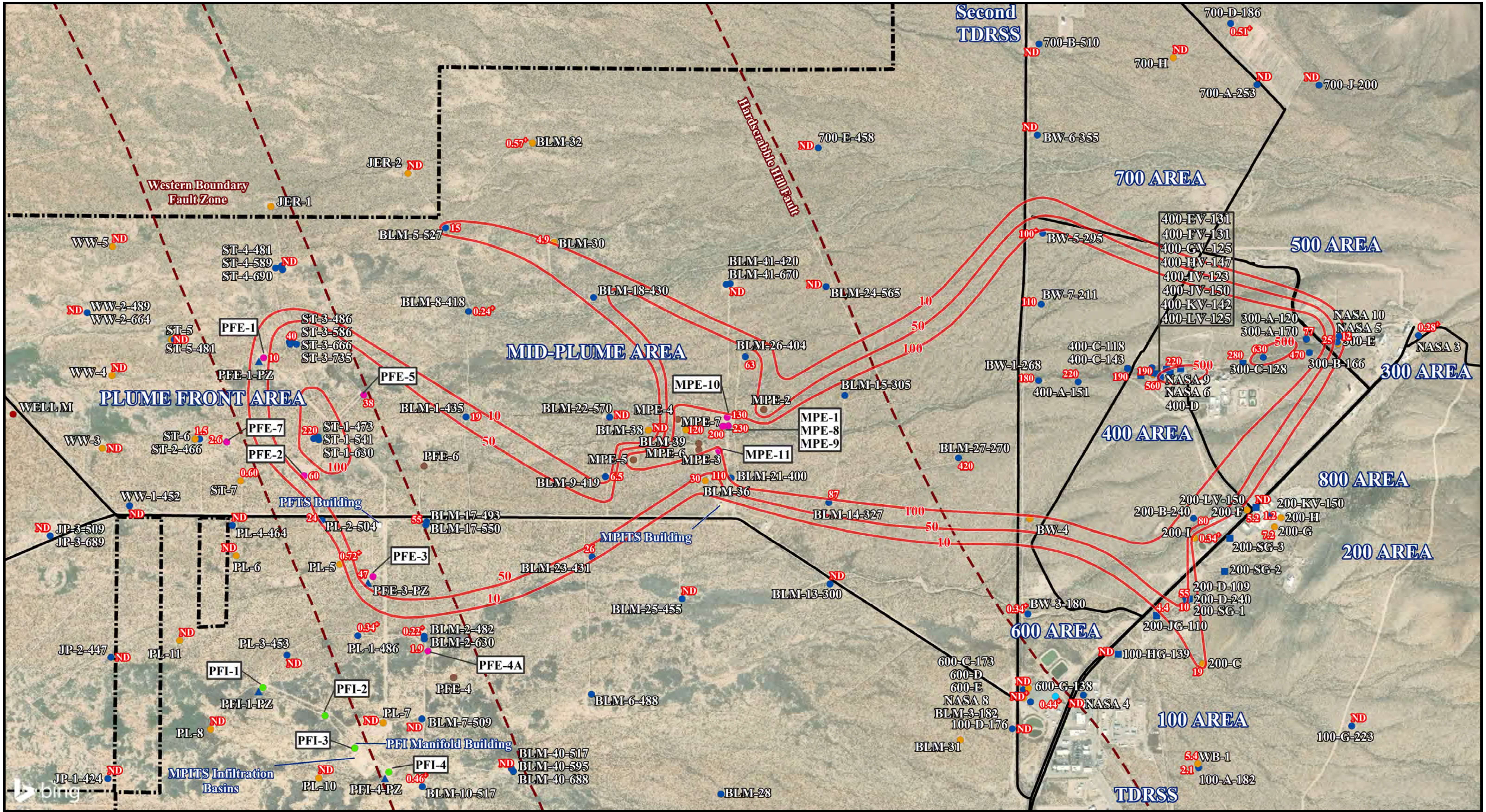
PCE Maximum Concentrations in Groundwater for Fourth Quarter 2018

Note:
\+ Data value has a QA flag. See Appendix A.2 for specific flags.
ND Non-detect values <0.2 ug/L

April 2019

Figure 6 **Distribution of Freon 11 in WSTF Groundwater**

(SEE NEXT PAGE)



Freon 11 Maximum Concentrations in Groundwater for Fourth Quarter 2018

- Multiport
- Conventional Well
- Perched Well
- MSVGM Well
- Extraction Well
- Injection Well
- Piezometer
- Exploration Well
- Production Well
- Main Road
- Fault
- WSTF Boundary
- Equiconcentration Line (ug/L)

0 — 4,000 — 8,000 Feet

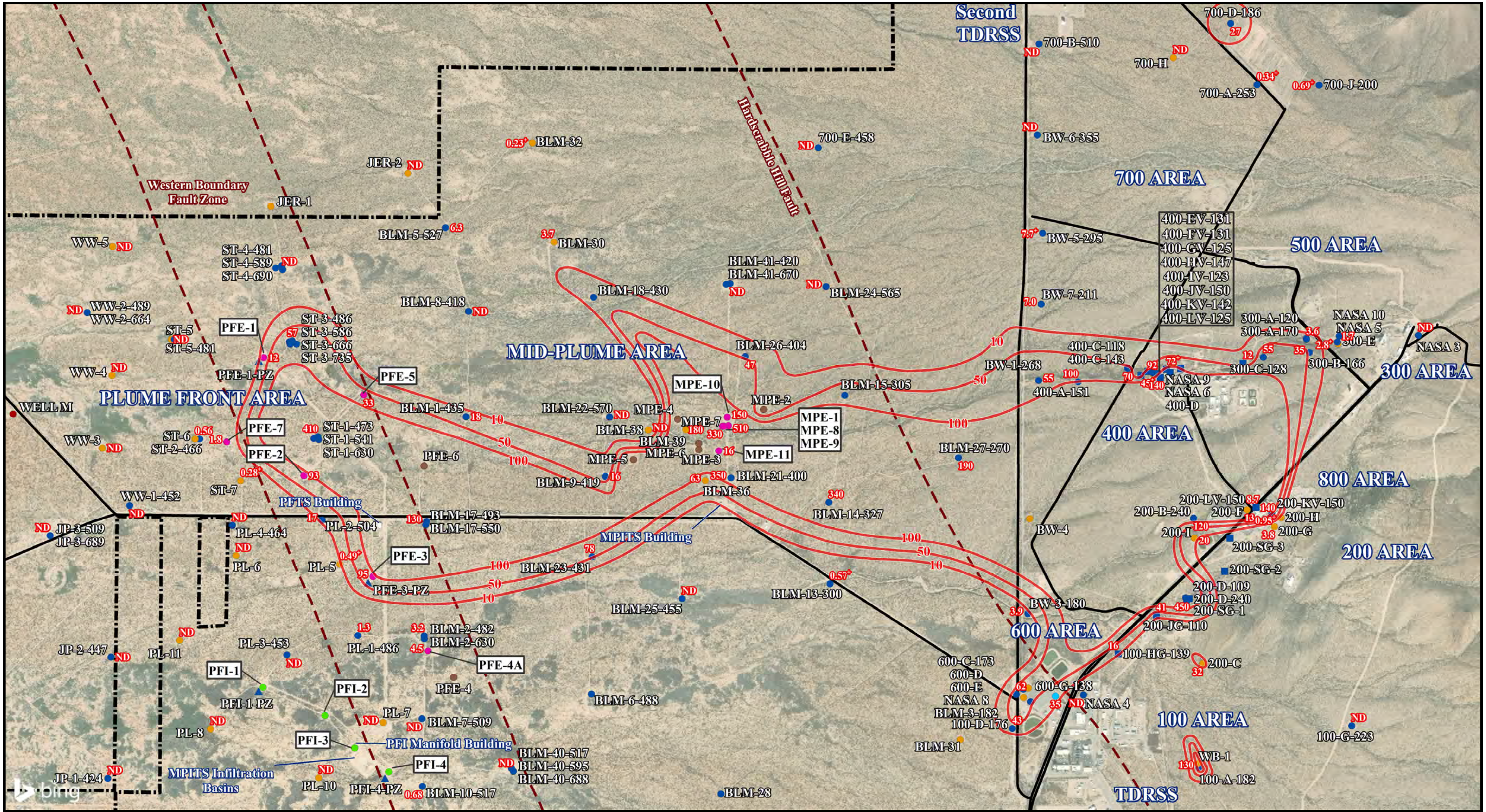
N / E / S / W

Note:
Freon 11 concentations are below the EPA RSL (5,200 ug/L).
\+ Data value has a QA flag. See Appendix A.2 for specific flags.
ND Non-detect values <0.20 ug/L

April 2019

Figure 7 **Distribution of Freon 113 in WSTF Groundwater**

(SEE NEXT PAGE)



Freon 113 Maximum Concentrations in Groundwater for Fourth Quarter 2018

Multiport	MSVGM Well	Piezometer	Main Road	Equiconcentration Line (ug/L)
Conventional Well	Extraction Well	Exploration Well	Fault	
Perched Well	Injection Well	Production Well	WSTF Boundary	

0 4,000 8,000 Feet

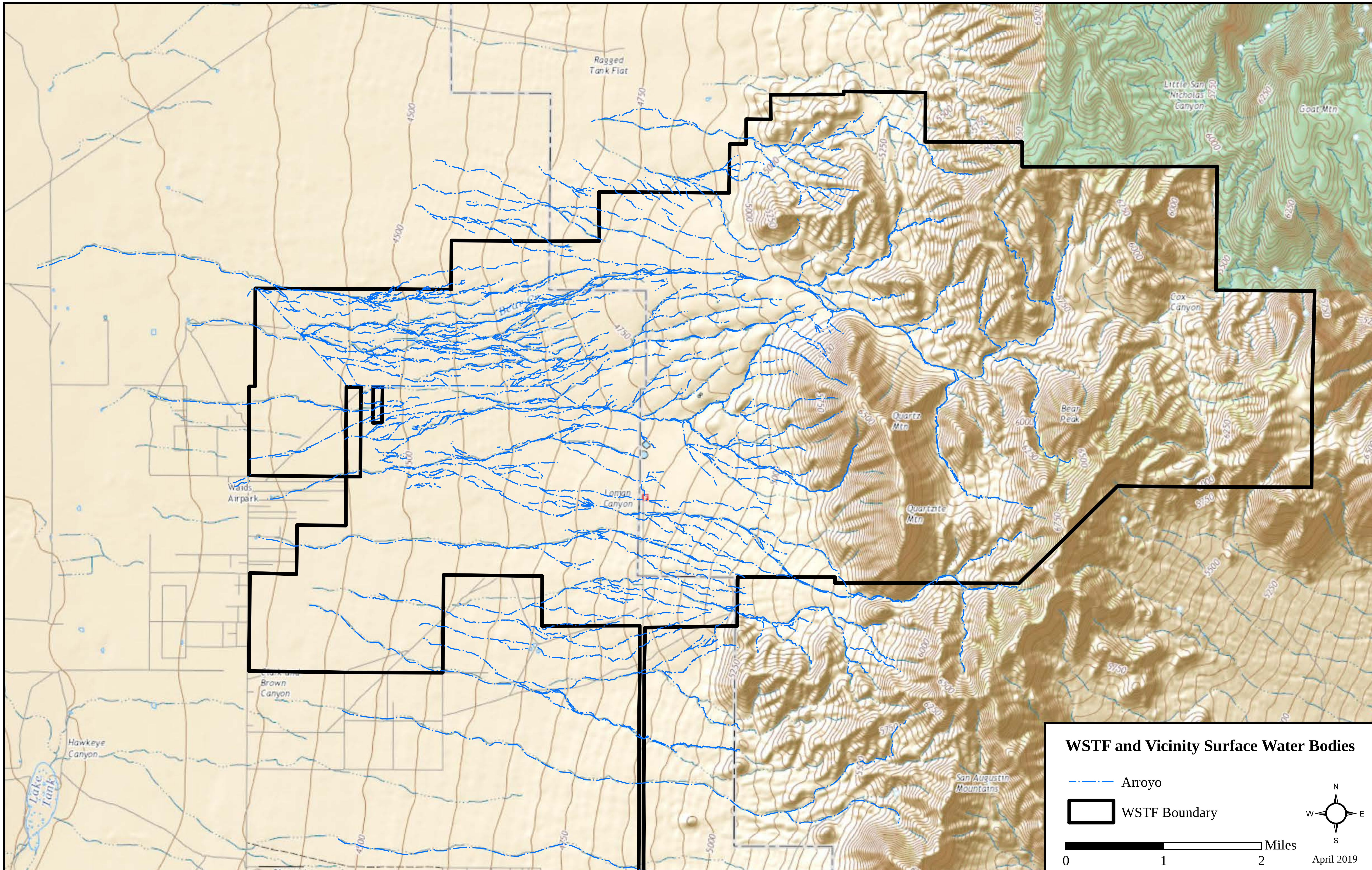
N E S W

Note:
Freon 113 concentations are below the EPA RSL (10,000 ug/L).
\+ Data value has a QA flag. See Appendix A.2 for specific flags.
ND Non-detect values <0.31 ug/L

April 2019

Figure 8 **WSTF and Vicinity Surface Water Bodies**

(SEE NEXT PAGE)



WSTF and Vicinity Surface Water Bodies
Arroyo
WSTF Boundary
N
S
E
W
0
1
2
Miles
April 2019
Ragged Tank Flat
Little San Nicholas Canyon
Goat Mtn
Cox Canyon
Bear Peak
Quartz Mtn
Quartzite Mtn
Lohman Canyon
Wards Airpark
Clark and Brown Canyon
Hawkeye Canyon
Lake Tank
San Augustin Mountains
Shoestring

Figure 9 Geological Features of Eastern WSTF (modified from Seager, 1981)

(SEE NEXT PAGE)

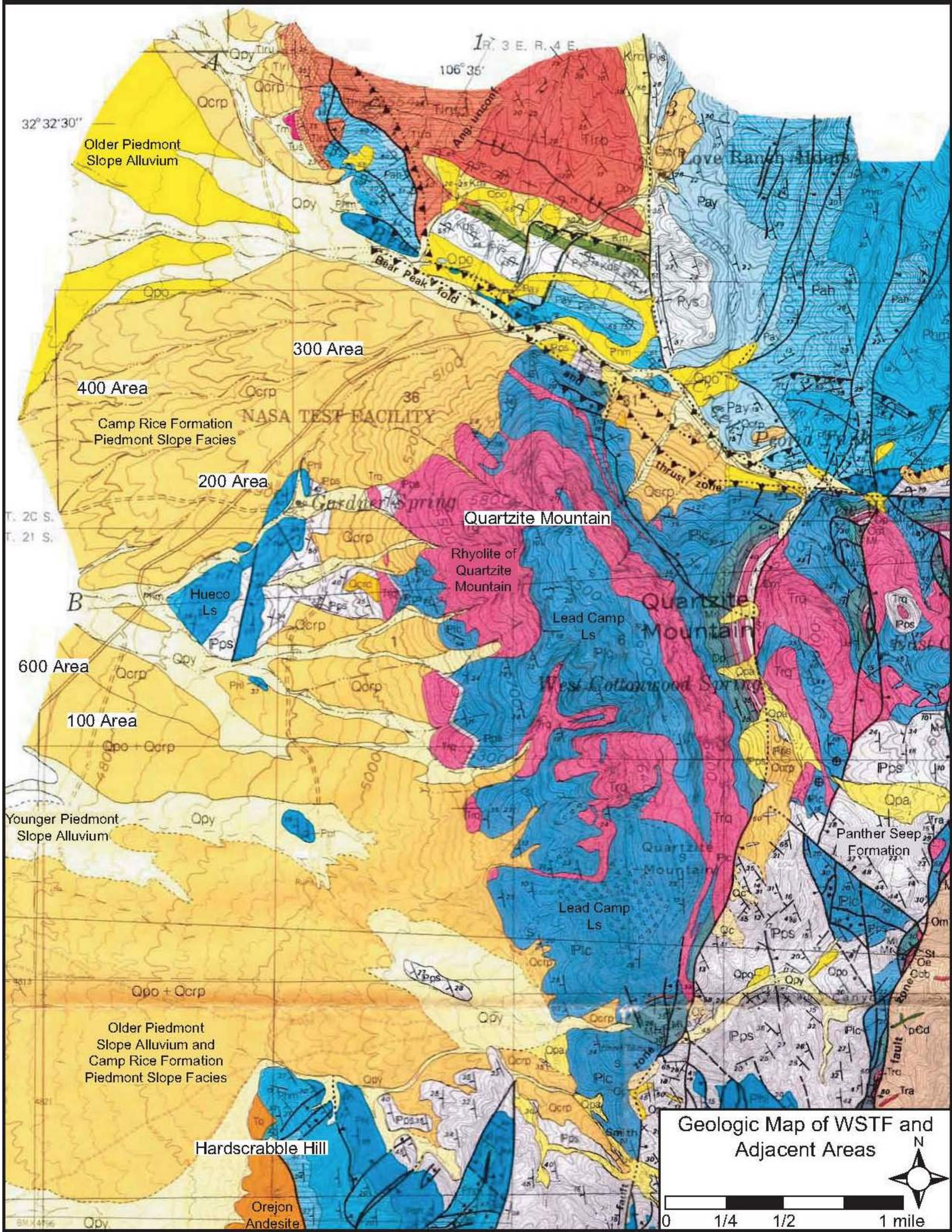

Older Piedmont Slope Alluvium
300 Area
400 Area
Camp Rice Formation Piedmont Slope Facies
200 Area
NASA TEST FACILITY
Quartzite Mountain
Rhyolite of Quartzite Mountain
Hueco Ls
Lead Camp Ls
600 Area
100 Area
Younger Piedmont Slope Alluvium
Lead Camp Ls
Panther Seep Formation
Older Piedmont Slope Alluvium and Camp Rice Formation Piedmont Slope Facies
Hardscrabble Hill
Orejon Andesite
Love Ranch Hills
Bear Peak fold
Quartzite Mountain
West Cottonwood Spring
Gardner Spring
32° 32' 30"
106° 35'
T. 20 S.
T. 21 S.
R. 3 E. R. 4 E.
Geologic Map of WSTF and Adjacent Areas
N
0
1/4
1/2
1 mile

Figure 10 **Geological Features of Western WSTF**

(SEE NEXT PAGE)

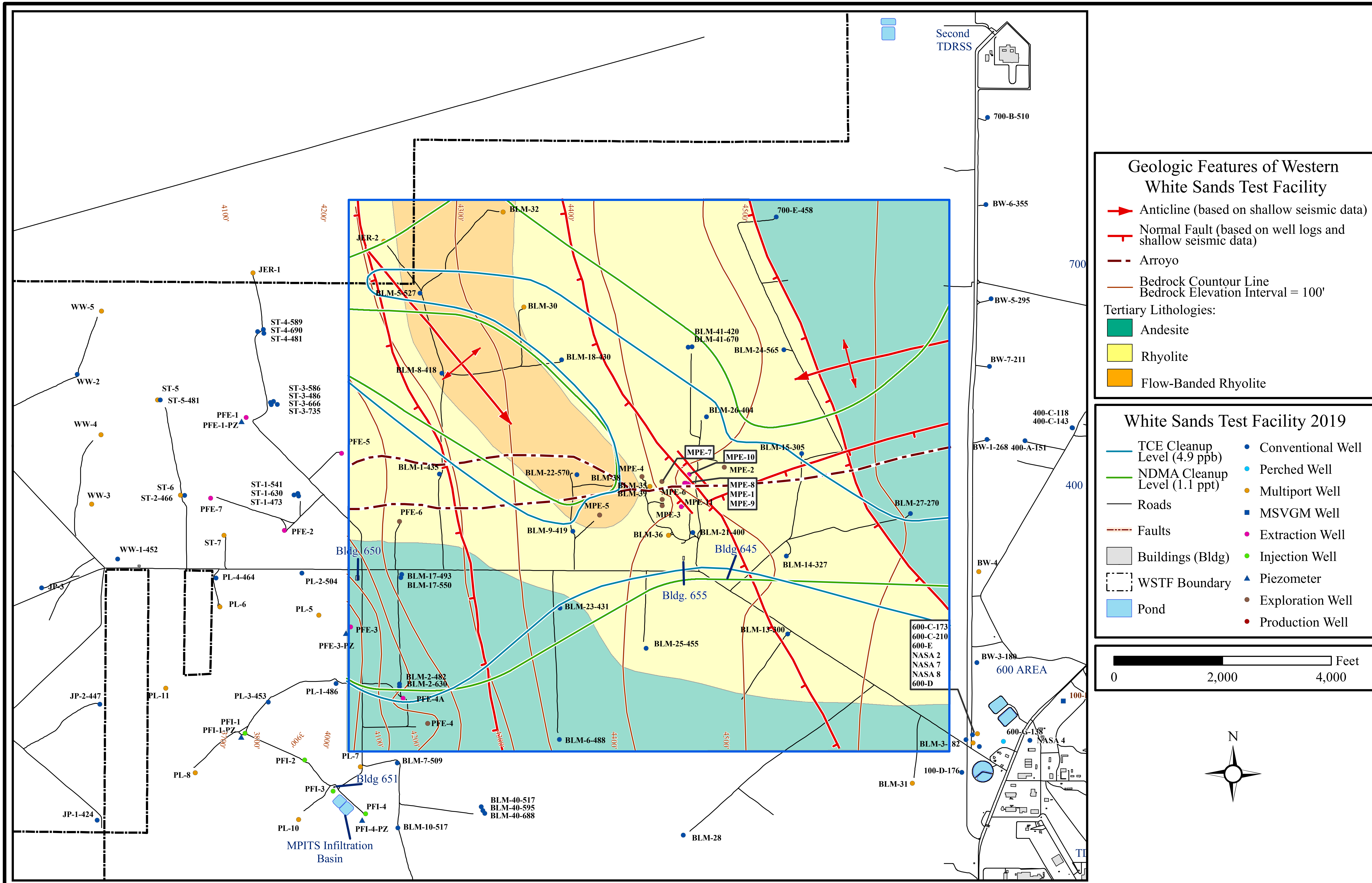
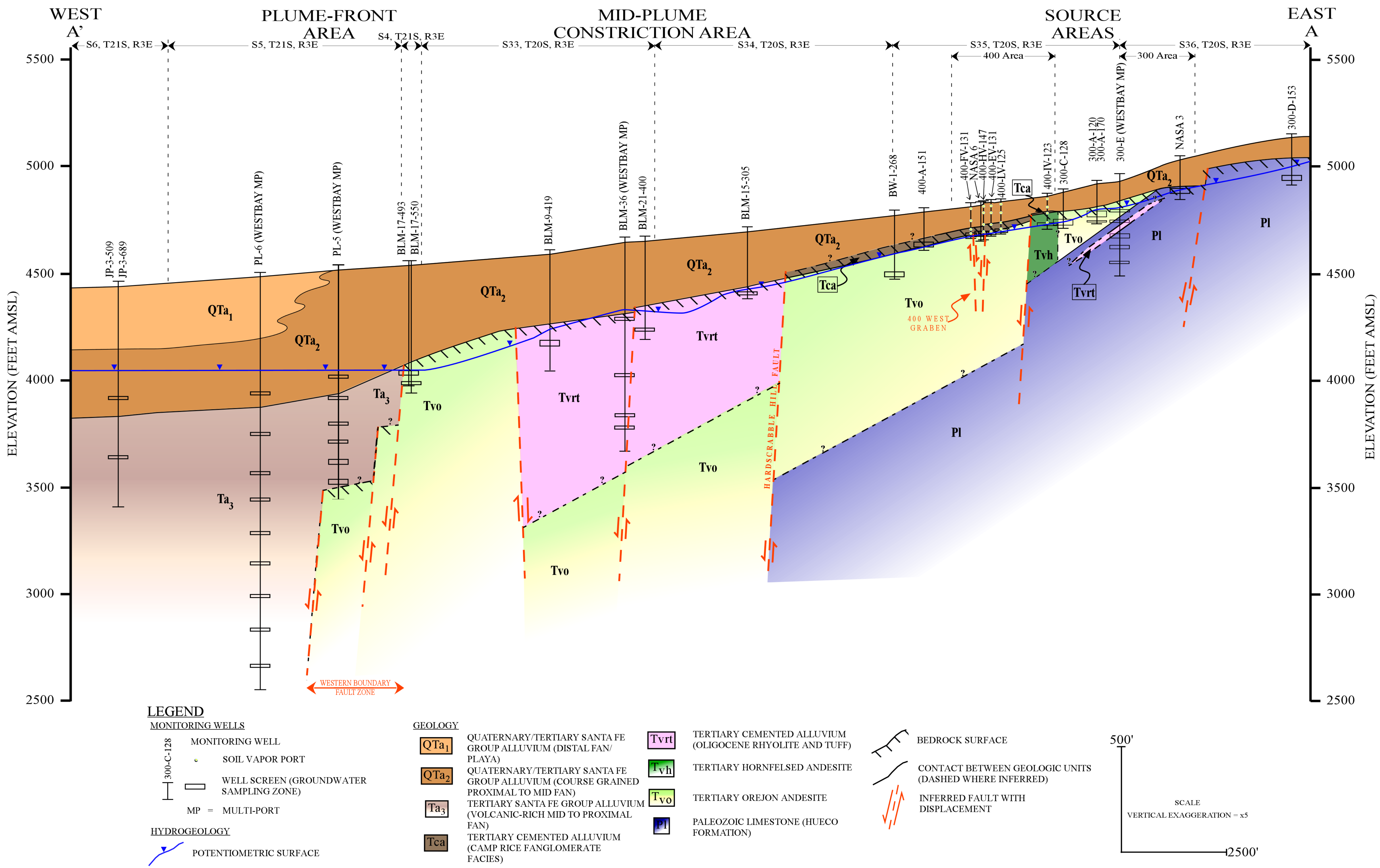

Geologic Features of Western White Sands Test Facility
Anticline (based on shallow seismic data)
Normal Fault (based on well logs and shallow seismic data)
Arroyo
Bedrock Countour Line
Bedrock Elevation Interval = 100'
Tertiary Lithologies:
Andesite
Rhyolite
Flow-Banded Rhyolite
White Sands Test Facility 2019
TCE Cleanup Level (4.9 ppb)
NDMA Cleanup Level (1.1 ppt)
Roads
Faults
Buildings (Bldg)
WSTF Boundary
Pond
Conventional Well
Perched Well
Multiport Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Feet
0
2,000
4,000
N
Second TDRSS
700
400
600 AREA
Bldg. 650
Bldg. 645
Bldg. 655
Bldg 651
MPITS Infiltration Basin
600-C-173
600-C-210
600-E
NASA 2
NASA 7
NASA 8
600-D
MPE-7
MPE-10
MPE-8
MPE-1
MPE-9

Figure 11 **WSTF Hydrostratigraphy (Geologic Cross-section)**

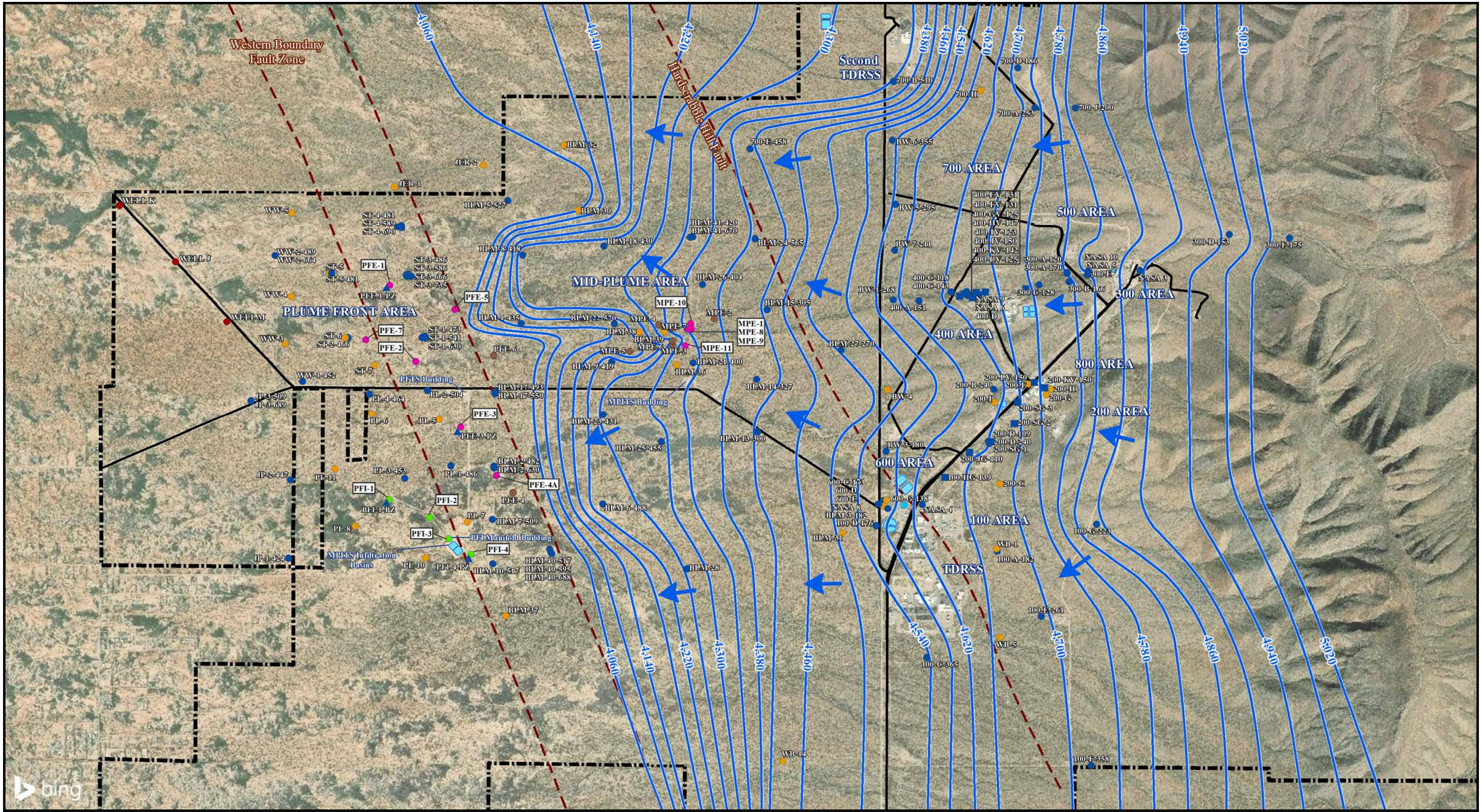
(SEE NEXT PAGE)



WEST A'
PLUME-FRONT AREA
MID-PLUME CONSTRICTION AREA
SOURCE AREAS
EAST A
S6, T21S, R3E
S5, T21S, R3E
S4, T21S, R3E
S33, T20S, R3E
S34, T20S, R3E
S35, T20S, R3E
400 Area
300 Area
S36, T20S, R3E
ELEVATION (FEET AMSL)
5500
5000
4500
4000
3500
3000
2500
JP-3-509
JP-3-689
PL-6 (WESTBAY MP)
PL-5 (WESTBAY MP)
BLM-17-493
BLM-17-550
BLM-9-419
BLM-36 (WESTBAY MP)
BLM-21-400
BLM-15-305
BW-1-268
400-A-151
400-FV-131
NASA 6
400-HV-147
400-EV-131
400-LV-125
400-IV-123
300-C-128
300-A-120
300-A-170
300-E (WESTBAY MP)
NASA 3
300-D-153
QTa1
QTa2
Ta3
Tvo
Tvrt
Tca
Tvh
Pl
400 WEST GRABEN
HARDSCRABBLE HILL FAULT
WESTERN BOUNDARY FAULT ZONE
LEGEND
MONITORING WELLS
MONITORING WELL
SOIL VAPOR PORT
WELL SCREEN (GROUNDWATER SAMPLING ZONE)
MP = MULTI-PORT
HYDROGEOLOGY
POTENTIOMETRIC SURFACE
GEOLOGY
QTa1 QUATERNARY/TERTIARY SANTA FE GROUP ALLUVIUM (DISTAL FAN/ PLAYA)
QTa2 QUATERNARY/TERTIARY SANTA FE GROUP ALLUVIUM (COURSE GRAINED PROXIMAL TO MID FAN)
Ta3 TERTIARY SANTA FE GROUP ALLUVIUM (VOLCANIC-RICH MID TO PROXIMAL FAN)
Tca TERTIARY CEMENTED ALLUVIUM (CAMP RICE FANGLOMERATE FACIES)
Tvrt TERTIARY CEMENTED ALLUVIUM (OLIGOCENE RHYOLITE AND TUFF)
Tvh TERTIARY HORNFELSED ANDESITE
Tvo TERTIARY OREJON ANDESITE
Pl PALEOZOIC LIMESTONE (HUECO FORMATION)
BEDROCK SURFACE
CONTACT BETWEEN GEOLOGIC UNITS (DASHED WHERE INFERRED)
INFERRED FAULT WITH DISPLACEMENT
500'
2500'
SCALE
VERTICAL EXAGGERATION = x5

Figure 12 **WSTF Groundwater Elevation Map**

(SEE NEXT PAGE)



Site-Wide Groundwater Elevations for Fourth Quarter 2018

4064 Groundwater Elevation Contour (Feet)
Groundwater Flow Direction
Multiport
Conventional Well
Perched Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Main Road
WSTF Boundary
Impoundment
Faults

0 4,000 8,000 Feet

Contour Interval = 40 Feet

N W E S

April 2019

Figure 13 Numerical Flow Model Calibrated K, Estimated Using PEST

(SEE NEXT PAGE)

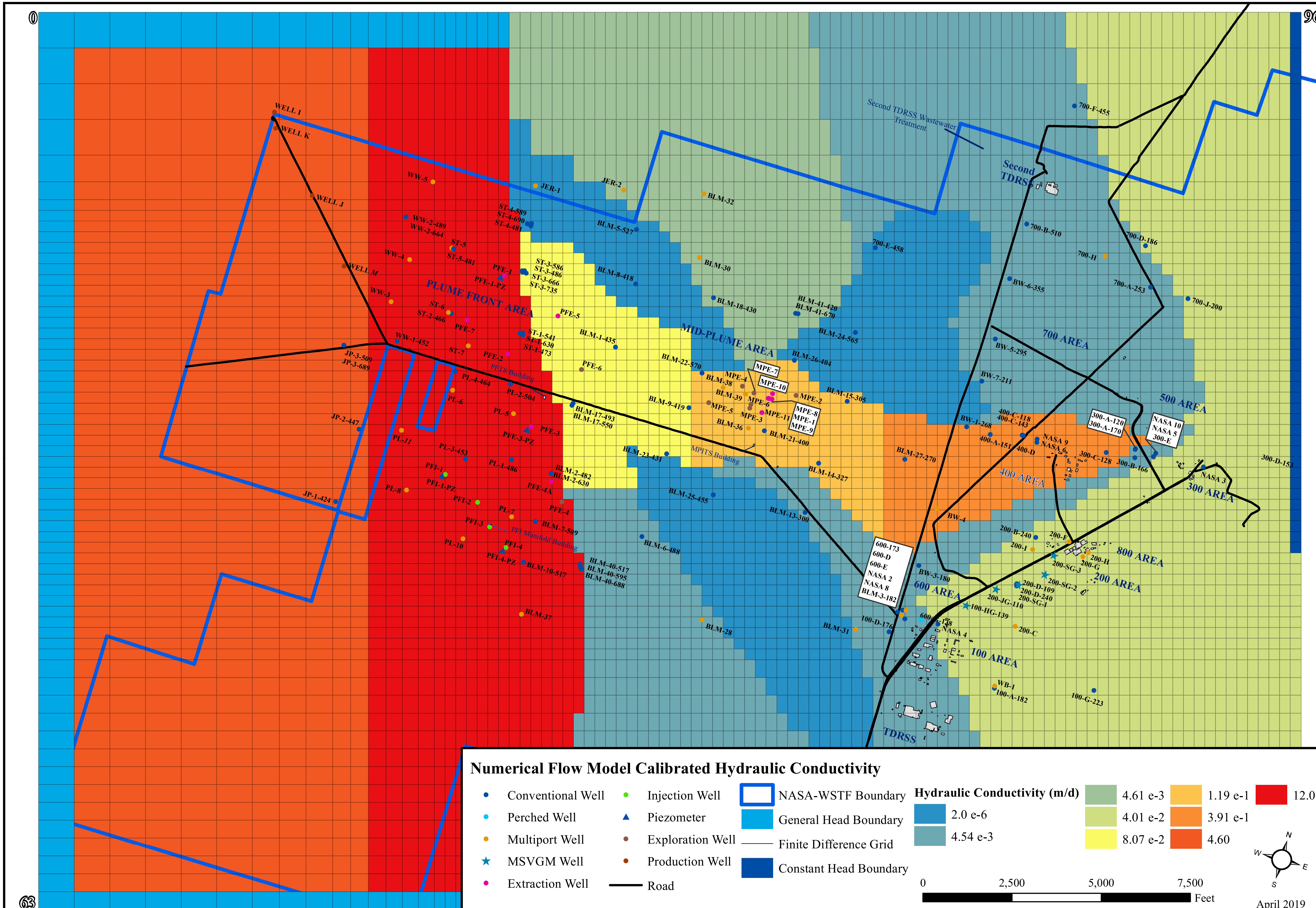
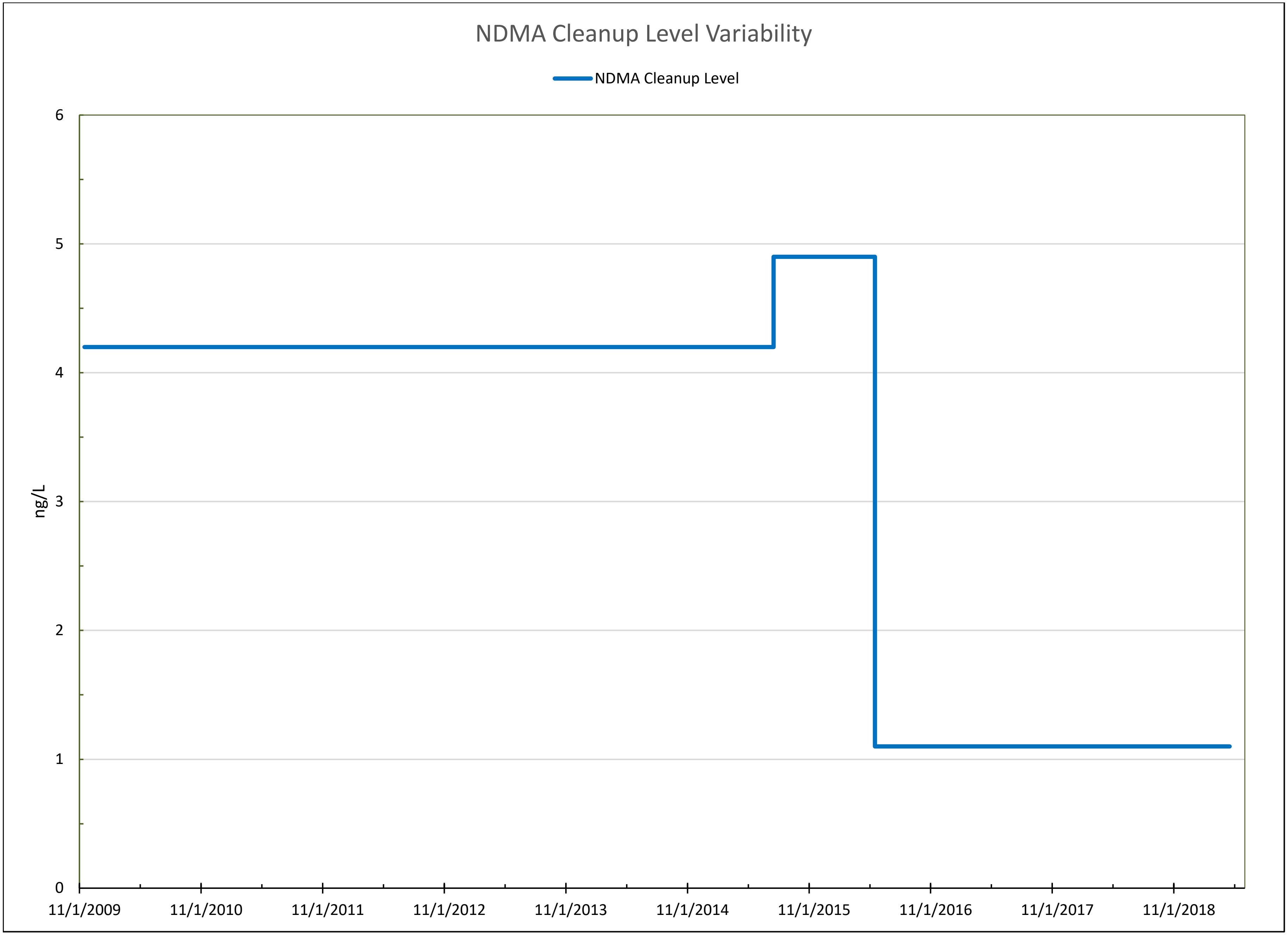
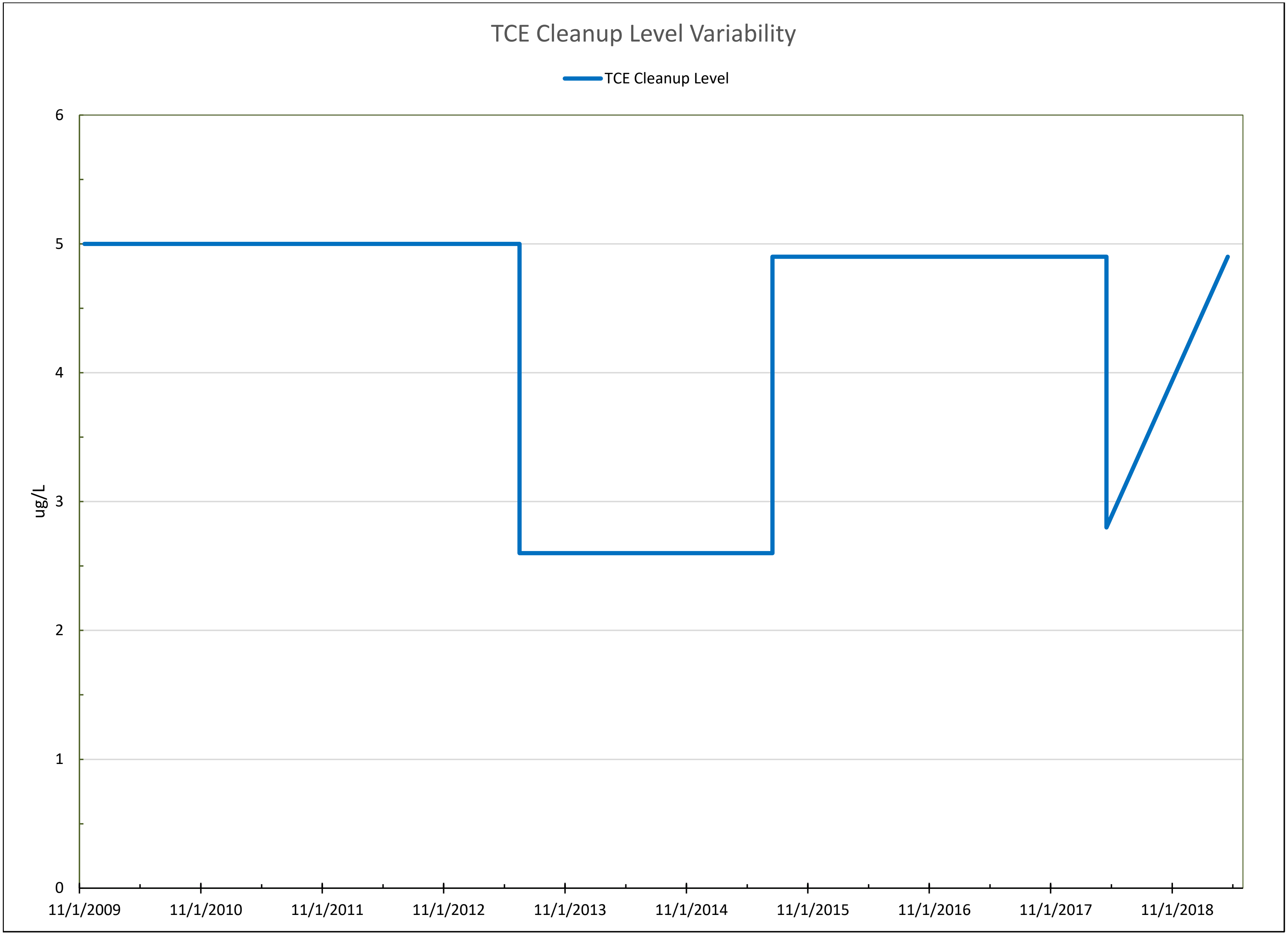
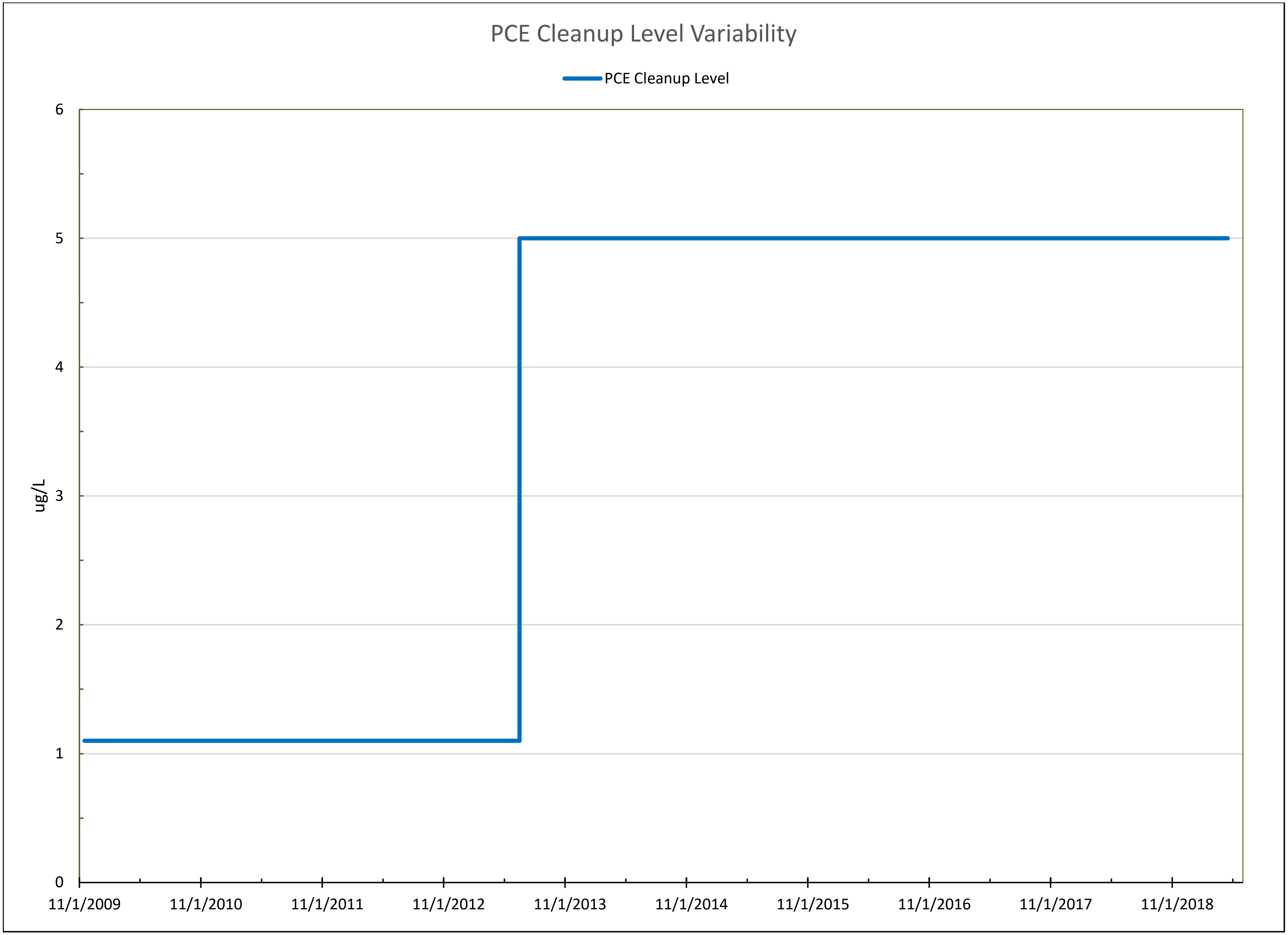

Numerical Flow Model Calibrated Hydraulic Conductivity
Conventional Well
Perched Well
Multiport Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Road
NASA-WSTF Boundary
General Head Boundary
Finite Difference Grid
Constant Head Boundary
Hydraulic Conductivity (m/d)
2.0 e-6
4.54 e-3
4.61 e-3
4.01 e-2
8.07 e-2
1.19 e-1
3.91 e-1
4.60
12.0
0
2,500
5,000
7,500
Feet
N
E
S
W
April 2019
0
96
63
PLUME FRONT AREA
MID-PLUME AREA
700 AREA
500 AREA
400 AREA
300 AREA
800 AREA
200 AREA
600 AREA
100 AREA
TDRSS
Second TDRSS
Second TDRSS Wastewater Treatment
PFTS Building
MPITS Building
PFI Manifold Building
WELL I
WELL J
WELL K
WELL M

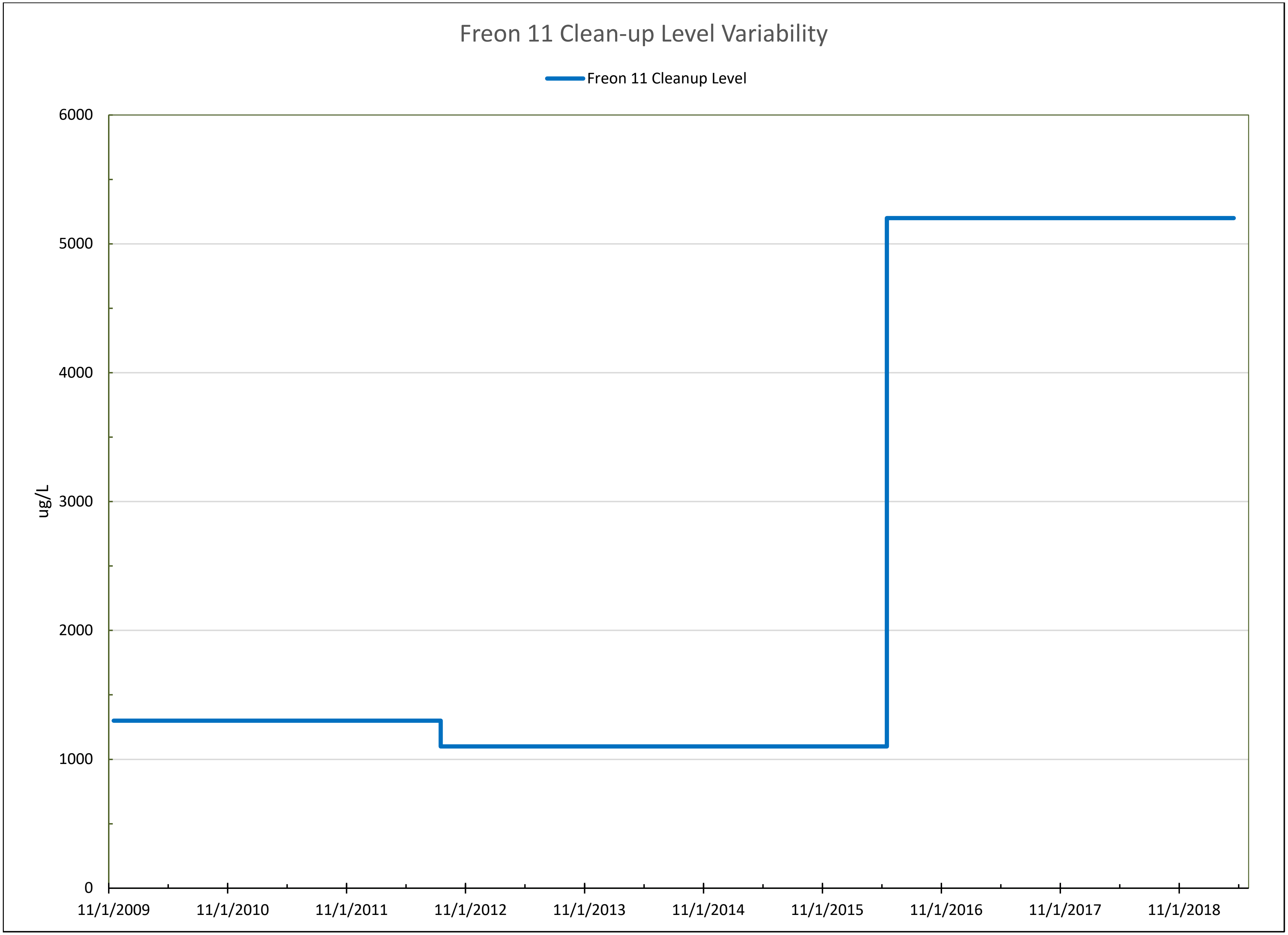
Figure 14 **Groundwater Cleanup Level Variability**

(SEE NEXT PAGE)


NDMA Cleanup Level Variability
NDMA Cleanup Level
ng/L
0
1
2
3
4
5
6
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018


TCE Cleanup Level Variability
TCE Cleanup Level
ug/L
0
1
2
3
4
5
6
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018


PCE Cleanup Level Variability
PCE Cleanup Level
ug/L
0
1
2
3
4
5
6
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018



Freon 11 Clean-up Level Variability
Freon 11 Cleanup Level
ug/L
6000
5000
4000
3000
2000
1000
0
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018

National Aeronautics and Space Administration

White Sands Test Facility

Groundwater Monitoring Plan

April 2019

Revised February 2020

NM8800019434

NASA Johnson Space Center White Sands Test Facility

Groundwater Monitoring Plan

April 2019

Revised February 2020

NM8800019434

Certification Statement

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

______________________________ ______________

Timothy J. Davis Date
Chief, NASA Environmental Office

National Aeronautics and Space Administration

Johnson Space Center
White Sands Test Facility
12600 NASA Road
Las Cruces, NM 88012
www.nasa.gov/centers/wstf

www.nasa.gov

Executive Summary

This Groundwater Monitoring Plan (Plan) provides information related to routine groundwater monitoring performed at the NASA (National Aeronautics and Space Administration) WSTF (White Sands Test Facility). Groundwater monitoring is conducted in accordance with NASA WSTF's Hazardous Waste Permit (Permit), issued by the NMED (New Mexico Environment Department) in November 2009 and modified in November 2016. Permit Section VII.B requires that NASA develop a facility-wide Groundwater Monitoring Plan to set forth detailed methods, procedures, and schedules. This plan meets the requirements of the Permit and satisfies the regulatory requirements of 40 CFR 264.90(f) as directed by NMED.

This plan provides specific information related to groundwater monitoring at WSTF, including:

- Background information on the facility, operations performed, hazardous constituents and hazardous wastes managed and released, the nature and extent of groundwater contamination resulting from those operations and releases, potential receptors of contaminated groundwater, pertinent previous investigations related to groundwater, and surface and subsurface conditions.
- Applicable regulatory criteria.
- A detailed description of the existing WSTF groundwater monitoring system.
- Descriptions of the sampling equipment utilized for groundwater monitoring.
- Descriptions of pre-sampling activities such as equipment decontamination, sampling records, determination of groundwater elevations and indicator parameters, and purging of groundwater monitoring wells.
- Discussion of sampling procedures for WSTF groundwater monitoring wells.
- Descriptions of post-sampling activities such as sample management (identification, storage, custody, and shipment), IDW (investigation-derived waste) management, and the determination of groundwater flow direction and rate.
- A summary of the chemical analytical methods utilized by contracted analytical laboratories to analyze for hazardous constituents and other analytes in WSTF groundwater.
- An introduction to the WSTF QA/QC (quality assurance/quality control) program, including a discussion of requirements for contracted analytical laboratories, QC samples, data quality indicators, analytical data quality exceptions, and analytical data management processes.
- The schedules for various activities presented in the Plan.

Table of Contents

History of Revisions

Data of Revision	Summary of Revision
June 2010	Original Groundwater Monitoring Plan
April 2012	Annual revision/update. Significant revisions in the annual update include: an evaluation of hazardous constituents and subsequent revision of text and tables in affected sections; reference to off-site sampling performed in accordance with Permit Section VII.G.2; inclusion of the results of an evaluation of groundwater background concentrations are required by Permit Section 17.5; and the addition of new groundwater monitoring wells to affected sections and tables.
April 2013	Annual revision/update. Significant revisions in the annual update include: removal of text and tables discussing groundwater background sampling and statistical evaluations; addition of new groundwater monitoring wells to the affected sections and tables; update of cleanup levels; and update of sampling frequencies.
April 2014	Annual revision/update. Significant revisions in the annual update include: modification of groundwater monitoring parameters and frequencies; revision of tables and text to reflect well changes since last GMP update; and review/update of cleanup levels.
April 2015	Annual revision/update. Significant revisions in the annual update include: modification of groundwater monitoring parameters and frequencies; revision or addition of tables and text to reflect well changes since the last GMP update; and review and update of cleanup levels.
May 2016	Annual revision/update. Significant revisions in the annual update include: modification of groundwater monitoring parameters and frequencies; revision of tables and text to reflect changes in monitoring wells and sampling equipment since last GMP update; and review and update of groundwater cleanup levels, including a discussion and figure showing historical cleanup levels to support periodic reporting.
April 2017	Annual revision/update. Significant revisions in the annual update include: addition of new groundwater monitoring wells to text and tables; revision of tables and text to reflect changes in monitoring wells and sampling equipment since last GMP update; addition of monitoring well inspection requirements and monitoring wells that require attention in 2017; and review and update of groundwater cleanup levels. Certain sections of the text and tables were also updated to address NMED comments provided in the October 6, 2016 Approval with Modifications Groundwater Monitoring Plan May 2016 (resolved in NASA's December 22, 2016 response to that Approval) and NMED's April 12, 2017 NMED Response to Permittee Comments on the Approval with Modifications of 2016 GMP Update.
April 2018	Annual revision/update. Significant revisions in the annual update include: inclusion of monitoring for 1,4-dioxane as directed by NMED on December 19, 2017; inclusion of analysis of groundwater samples from certain wells by SW-846 Methods 8015 and 8270 as indicated in NASA's IWP for the TDRSS diesel release (SWMU 50), approved by NMED on January 17, 2018; revision of tables and text to reflect changes in monitoring wells and sampling equipment since last GMP update; update on monitoring wells that required attention in

Data of Revision	Summary of Revision
	2017 and additional work for 2018. Certain sections of the text and tables were also updated to address NMED comments provided in the December 19, 2017 Approval with Modifications of the 2017 Groundwater Monitoring Plan.
April 2019	Annual revision/update. Significant revisions in the annual update include: updated text in Section 4.4 to reflect current status of groundwater well evaluation and maintenance activities; revision of tables and text to reflect changes in monitoring wells, sampling equipment, and sampling frequencies since last GMP update; and, updates to certain sections of the text and tables to address NMED comments provided in the September 13, 2018 Approval with Modifications Groundwater Monitoring Plan.

List of Acronyms and Abbreviations

%R	Percent recovery
µg/L	Micrograms per liter
AD	Analyst Duplicates
bgs	Below ground surface
BLM	Bureau of Land Management
CAS	Chemical Abstract Service
CFR	Code of Federal Regulations
COC	Contaminant of Concern
DMN	N-Nitrodimethylamine
DO	Dissolved oxygen
DP	Discharge Plan
DQI	Data quality indicator
DRO	Diesel range organics
EAR	Environmental Activities Report
EPA	U.S. Environmental Protection Agency
FBR	Flow-banded rhyolite
ft	Feet
GRO	Gasoline range organics
HWMU	Hazardous waste management unit
IDW	Investigation -derived waste
in.	Inch(es)
JDMB	Jornada del Muerto Basin
JER	Jornada Experimental Range (U.S. Department of Agriculture)
JP	Jet Propellant Test Area (used in alphanumeric well identification)
K	Hydraulic conductivity
L	Liter
LCS	Laboratory control sample
LCSD	Laboratory control sample duplicate
MB	Method blank
MCL	Maximum Contaminant Level
MDL	Method detection limit
mi	Mile(s)
mL	Milliliters
mm	Millimeter
MPCA	Mid-plume Constriction Area
MPITS	Mid-plume Interception and Treatment System
MS	Matrix spike
MSD	Matrix spike duplicate
NASA	National Aeronautics and Space Administration
NDMA	N-Nitrosodimethylamine

NELAC	National Environmental Laboratory Accreditation Conference
ng/L	Nanograms per liter
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMOSE	New Mexico Office of the State Engineer
ORP	Oxidation reduction potential
PCB	Polychlorinated Biphenyl
PCC	Post-Closure Care
PCE	Tetrachloroethene
PEST	Automated parameter estimation software
PFTS	Plume Front Treatment System
PL	Private land (used in alphanumeric well identification)
PMR	Periodic Monitoring Report
PPE	Personal protective equipment
PQL	Practical quantitation limit
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
QAR	Quality Assurance Report
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RPD	Relative percent difference
RSL	EPA Regional Screening Level
SA	Sample
SAM	San Andres Mountains
SOP	Standard operating procedure
ST	State (used in alphanumeric well identification)
SVOC	Semi-volatile organic compounds
SWMU	Solid waste management unit
T	Transmissivity
TCE	Trichloroethene
TDRSS	Tracking and Data Relay Satellite System
TP	Toxic pollutant
TPH	Total petroleum hydrocarbons
UDMH	1,1-Dimethylhydrazine
VOC	Volatile organic compounds
WB	Westbay (used in alphanumeric well identification)
WBFZ	Western Boundary Fault Zone
WQCC	NM Water Quality Control Commission
WSTF	White Sands Test Facility

1.0 Introduction

WSTF (White Sands Test Facility) currently operates as a field test installation under the NASA (National Aeronautics and Space Administration) Lyndon B. Johnson Space Center in Houston, Texas. WSTF is a restricted access site and all activities are industrial in nature. Although the primary purpose of the facility is to provide test services and support to NASA for the United States space program, services are also provided for the Department of Defense, Department of Energy, private industry, and foreign government agencies. WSTF operates several laboratory facilities that conduct simulated use tests for space vehicles and space station materials and compatibility testing.

WSTF is located approximately 18 mi (miles) northeast of Las Cruces, New Mexico. Figure 1 provides a vicinity map that shows the general location of WSTF relative to other dominant features and major properties in southern Dona Ana County. Historical operations at WSTF have resulted in a groundwater plume requiring extensive investigation activities and associated corrective actions. The nature and extent of groundwater contamination at WSTF is discussed in further detail in Section 2.0.

The groundwater assessment program at WSTF was established to determine the nature and extent of groundwater contamination present at WSTF as a result of historical releases of hazardous waste and/or hazardous constituents. Prior to issuance of the current Hazardous Waste Permit (Permit; NMED, 2016b), groundwater sampling was performed as required by NASA's former Hazardous Waste Operating Permit, PCC (Post-Closure Care) Permit, 3008(h) Consent Order (EPA, 1989), the requirements of RCRA (Resource Conservation Recovery Act), and site-specific project plans. Routine groundwater monitoring has enabled NASA to delineate WSTF's groundwater contaminant plume and has provided a thorough understanding of the nature and extent of groundwater contamination. This has allowed NASA to design, construct, and operate state of the art pump and treat systems for corrective actions at the Plume Front and Mid-plume areas. The primary objective of the PFTS (Plume Front Treatment System) is to prevent further migration of the WSTF groundwater contaminant plume. The MPITS (Mid-plume Interception and Treatment System), another voluntary interim measures presumptive remedy, is intended to significantly reduce groundwater contamination through removal and treatment of groundwater in the MPCA (Mid-plume Constriction Area). NASA monitors the effectiveness of the PFTS and MPITS in accordance with the Remediation System Monitoring Plan (NASA, 2018c) and operates and maintains the systems as specified in project-specific plans and other documentation submitted to and approved by NMED (New Mexico Environment Department).

1.1 Purpose

This Plan satisfies the requirements of the Permit to develop a comprehensive facility-wide groundwater monitoring plan. It serves as a procedural outline for personnel engaged in routine groundwater sampling and analysis activities at WSTF. It is used in conjunction with site-specific procedural documentation and specific equipment operations and maintenance manuals. Procedures outlined are consistent with those specified for use at sites subject to the requirements of RCRA, and have been adapted to meet WSTF groundwater monitoring program and Permit requirements. This Plan introduces the methods, procedures, and schedules for conducting routine groundwater monitoring at WSTF. Adherence to the protocols presented in this document assures that samples are collected in a consistent manner, representative of actual groundwater conditions, managed efficiently and effectively, and analyzed by appropriate analytical methods. This Plan outlines the process for reviewing chemical analytical data to ensure that only the highest quality data are generated and available for use in other WSTF projects (corrective action, reporting, etc.).

1.2 Scope

This Plan directs activities related to routine groundwater monitoring throughout WSTF in accordance with Section VI.B of the Permit. It is intended for use as an aid for training technical staff and as an informational guide for trained personnel involved in the collection and processing of WSTF groundwater samples and in the management of chemical analytical data generated from the analyses of those samples. It is also used by NMED to ensure that NASA is performing groundwater monitoring in accordance with applicable federal and state regulations and the Permit. The requirements of this Plan are applicable to all groundwater sampling events performed to accomplish the objectives of this Plan. A WSTF groundwater sampling event consists of specific activities and relevant documentation associated with the collection, management, and analysis of groundwater samples from a distinct groundwater source. A sampling event is performed at a specific groundwater source, typically an individual monitoring well or zone of a multiport well that has been completed in accordance with the Permit and applicable site-specific documentation. Specific requirements and procedures for performing sampling are provided in later sections of this Plan.

1.3 Objectives

The current objective of the groundwater monitoring program is to collect and manage groundwater chemical analytical data to:

- Provide a consistent, accurate representation of actual concentrations of hazardous constituents in the groundwater.
- Monitor the distribution, extent, and movement of hazardous constituents in the groundwater.
- Determine potential threats to human health and the environment from hazardous constituents in the groundwater.
- Monitor the effectiveness of corrective measures used to remediate hazardous constituents released from hazardous waste management units to the groundwater as a result of historical operations.
- Detect the presence of hazardous constituents not previously detected in the groundwater.
- Determine when the corrective measures have reduced the concentrations of hazardous constituents in the groundwater to less than the cleanup levels established according to Permit guidance.

The on-site contractor environmental organization is tasked with the management and implementation of groundwater monitoring activities. This organization is staffed with groundwater, hydrogeological, engineering, and environmental compliance personnel. Groundwater personnel are primarily involved in the collection and analysis of groundwater samples for assessment and remediation activities. Hydrogeological personnel are primarily involved in the installation, development, and maintenance of groundwater monitoring and remediation wells and the hydrogeologic interpretation of contaminant distribution and migration. Engineering personnel are responsible for the design, construction, and implementation of corrective actions and successful operation of environmental remediation systems. Compliance personnel are responsible for overseeing the numerous facets of compliance with multiple permits, plans, and other regulatory requirements applicable to WSTF.

2.0 Background

WSTF was established in the early 1960s to support the NASA Apollo Space Program. Primary site activities serve to: develop, qualify, refurbish, and test spacecraft propulsion systems, subsystems, and ground support equipment; investigate flight hardware anomalies; test materials and components; and perform hazard and failure analyses.

Hazardous wastes generated at WSTF during testing and evaluation procedures were historically managed in surface impoundments and underground storage tanks that leaked, subsequently contaminating groundwater. From the early 1960s through the mid-1980s, tanks or waste impoundments in the 200, 300, 400, and 600 industrial areas contributed to groundwater contamination. To minimize further releases of contaminants, these impoundments and tanks were closed under RCRA, and approved by NMED in 1989. The closures were permitted under a PCC Permit in the early 1990s and continue to be monitored in accordance with the Permit and related plans. The locations of these closures, as well as other pertinent WSTF features, are provided in Figure 2.

2.1 Wastes Managed and Released

This section provides a brief description of the primary wastes managed and released at the facility during historical operations, and discusses the releases as sources of contamination in the groundwater.

The primary hazardous constituents in groundwater originated from historical waste management operations within the WSTF industrial area (NASA, 1996a). Sources within these industrial areas are shown on Figure 2. NDMA (N-Nitrosodimethylamine) contamination primarily originated from operations in the 300 and 400 Areas. Most of the halogenated volatile contaminants (TCE [trichloroethene], PCE [tetrachloroethene], Freon®[1] 11 [trichlorofluoromethane], and chloroform) originated from the 200 Area with lesser contributions from the 100, 300, 400, and 600 Areas. Four of these hazardous constituents – NDMA, PCE, TCE, and Freon 11 – are considered the primary COC (contaminants of concern) in WSTF groundwater.

Additional hazardous constituents, discussed in later sections of this Plan, were also managed and released from activities in the WSTF industrial area. Several other chemicals, which do not meet the criteria to be designated as hazardous constituents, were also managed and released to the groundwater at WSTF. While not of primary concern to the groundwater monitoring program, these constituents are routinely sampled for and are discussed in many NASA documents, both current and historical. These chemicals include DMN (N-Nitrodimethylamine), Freon 21 (dichlorofluoromethane), and Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane). Freon 113 had historically been considered a hazardous constituent, but was reassessed in 2012 in accordance with the process described in Section 3.1, which resulted in it being removed as a hazardous constituent. However, because it was used in large quantities at WSTF, and is prevalent throughout the groundwater contaminant plume, it is frequently considered a COC within the groundwater assessment program and is included in specific sections of this document.

Little historical data are available describing the exact nature and amounts of chemical wastes that were contained or released at WSTF. COC release estimates were derived from numerical models. Table 1 provides a list of potential COC released from individual WSTF areas. Subsequent sections describe sources at the industrial areas at which contaminants were introduced to the surface and subsurface.

2.1.1 Wastes Managed and Released in the 100 Area

The 100 Area Burn Pit (Figure 2) is a potential minor source of contamination to the subsurface. This pit, in operation from 1969 to 1983, was used for fire-suppression training. Flammable liquid wastes were poured onto the water surface in the pit and ignited. An estimated 1,000 gallons of flammable liquids was

---

[1] The trade name Freon is a registered trademark of E.I. du Pont de Nemours & Company Corporation (DuPont).

burned each year during operation. This pit was excavated and residual fluids and soils were removed in 1984. Five other SWMU (solid waste management units), the Container Storage Area, Container Storage Unit, wastewater lagoon, Drum Storage Facility, and Temporary PCB (Polychlorinated Biphenyl) Storage Area, are located in the 100 Area. These SWMU are not considered to be significant sources of COC to groundwater at WSTF.

2.1.2 Wastes Managed and Released in the 200 Area

Several contaminant sources were identified in the 200 Area (Figure 2). The two major sources of contamination in the 200 Area, the Chemistry Lab Tank and the Clean Room Tank, are considered the primary source of TCE in WSTF groundwater. The Chemistry Lab Tank had a storage capacity of 1,500 gallons. This tank was installed in 1964 and received wastes from metallurgical and etching laboratory operations. These wastes were periodically transferred to the 600 Area impoundments. Wastes discharged to the Chemistry Lab Tank included aerospace propellants, organic solvents, oils, spent cutting fluids, spent x-ray developer solutions, cooling water, and other liquids. Closure activity was completed in June 1989.

The Clean Room Tank was a 4,000-gallon tank used from 1964 to 1979 to accumulate wastes generated by precision cleaning of flight hardware. Chemicals disposed to this tank included Freon 113, Freon 11, TCE, chromic acid, isopropyl alcohol, and other solvents. These accumulated wastes were periodically transferred to the 600 Area impoundments. In 1979, the severely corroded tank was removed and was replaced by a new tank installed approximately 50 ft (feet) to the west. The replacement tank was removed from service in 1986 and was found to be extensively corroded upon its removal.

Other potential sources for minor groundwater contamination at the 200 Area included the Clean Room Discharge Pipe, Scape Room Discharge Pipe, Building 203 Discharge Pipe, South Highbay Discharge Pipe, and several other areas of concern identified during historical information research performed prior to the 200 Area investigation (NASA, 2012a). The exact quantities or types of waste discharged to grade at these locations are not known.

2.1.3 Wastes Managed and Released in the 300 Area

The 300 Area surface impoundments (Figure 2) are a primary source for release of NDMA to the subsurface. Operation of these impoundments, located in the 300 propulsion testing area of WSTF, began in 1965. The impoundments provided emergency spill containment and fuel treatment systems for discharges of hypergolic rocket fuels, including hydrazine, monomethylhydrazine, unsymmetrical dimethylhydrazine, Aerozine 50, and nitrogen tetroxide. Treatment of rocket fuels consisted of oxidation with calcium hypochlorite followed by discharge to grade to adjacent arroyos. Freon 113 and isopropyl alcohol also were used as referee propellants until 1972. TCE was also used as a cleaning solvent in 1964. Freon 113, isopropyl alcohol, and TCE were discharged to the surface impoundments and, in some instances, to grade.

Additionally, TCE was used to clean pipelines during facility construction of the 300 Propulsion Area during the early 1960s. TCE waste derived from this cleaning activity is suspected to be a source for TCE contamination in groundwater.

2.1.4 Wastes Managed and Released in the 400 Area

The 400 Area Surface Impoundments (Figure 2) in the propulsion testing area are a primary source for release of NDMA to the subsurface. These impoundments became operational in 1964. The impoundments provided emergency spill containment and fuel treatment systems for discharges of hypergolic rocket fuels, including hydrazine, monomethylhydrazine, unsymmetrical dimethylhydrazine, Aerozine 50, and nitrogen tetroxide. Treatment of rocket fuels consisted of oxidation with calcium hypochlorite followed by discharge to grade in adjacent arroyos. Freon 113 and isopropyl alcohol also were used as referee propellants until 1972. Freon 11 and Freon 21 were also used as cleaning solvents. Freon 11, Freon 113, and isopropyl alcohol were discharged to the surface impoundments and, in some instances, to grade.

Additionally, TCE was used to clean pipelines during facility construction at the 400 propulsion area during the early 1960s. TCE waste from this cleaning activity is suspected to be a source for TCE contamination in groundwater.

2.1.5 Wastes Managed and Released in the 500 Area

The 500 Area Fuel Storage Area (Figure 2) is a potential minor source of NDMA in the subsurface. This area consisted of a 20,000-gallon storage tank with secondary containment that was used to store hydrazine fuel. Treatment of fuel and release to grade may have taken place at this potential source. NASA performed a preliminary investigation at the 500 Area Fuel Storage Area in 2000 and 2001 and submitted a summary of the results in the 500 Fuel Storage Area Historical Information Summary (NASA, 2011). NASA recently recommended additional investigation at this area (NASA, 2018d).

2.1.6 Wastes Managed and Released in the 600 Area

NASA operated the 600 Area Surface Impoundments (Figure 2) from 1968 to 1986. These impoundments were designed to contain saltwater backwash from the facility's water softening plant. They also received an undetermined amount of hazardous waste from the 200 Area Chemistry Lab Tank and Clean Room Tank. The impoundments were lined with an 8-mm PVC (polyvinyl chloride) liner and had a combined capacity of 2 million gallons. NASA closed this unit in 1989, performed an investigation at the 600 Area Closure in 2009 and 2010, and subsequently performed a soil vapor extraction pilot test in 2012. After completing the pilot test, NASA concluded that the vadose zone beneath the Closure is not a source of continuing contamination to the groundwater (NASA, 2012c). Contaminated perched groundwater is being extracted from beneath the 600 Area Closure and transported to and treated by the MPITS (NASA, 2018b).

2.1.7 Wastes Managed and Released in the 700 Area

The 700 Area Landfill (Figure 2) is a potential minor source of groundwater contamination. NASA used this 24-acre landfill for the disposal of solid waste between 1964 and 1997. Hazardous wastes may have been disposed to this landfill prior to 1987, when weekly inspections were implemented. Hazardous wastes may have included spent solvents, waste paints, and soft goods contaminated with hydrazine and oxidizer. The landfill was closed in 1998 and is monitored under a PCC Plan (NASA, 1996b) approved by the NMED Solid Waste Bureau. Routine groundwater monitoring is performed in accordance with that plan, and additional investigation has been proposed (NASA, 2017f).

2.2 Extent of Contamination

This section briefly describes the spatial distribution of the five primary COC in groundwater at WSTF. The approximate extent and thickness of COC plumes are derived primarily from maps constructed using 2018 concentration data, cross sections constructed in the draft RCRA Facility Investigation (NASA, 1996a), and concentration data from wells with multiple completion depths. The distribution of other hazardous constituents present in WSTF groundwater does not exceed that of the COC presented in this section. Those hazardous constituents are discussed in more detail in later sections of this Plan.

2.2.1 N-Nitrosodimethylamine

NDMA is believed to have been released to the environment due to its creation during chemical oxidation of UDMH (1,1-dimethylhydrazine) by calcium hypochlorite. An estimated 34 kg of contaminant mass was released to the environment (NASA, 1996a). Figure 3 shows a manual interpretation of the NDMA conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. The NDMA plume extends westward approximately 20,400 ft from sources at the 300 and 400 Areas; is located entirely within WSTF boundaries; and, is as much as 6,100 ft wide in the area upgradient from the MPCA. The highest concentration in this area occurs within well 400-HV-147 installed through the 400 Area Closure at 59,000 ng/L. Downgradient of the 400 Area, concentrations reach 10,000 ng/L within the main mass of NDMA along the plume axis. The width of the NDMA plume narrows to less than 2,800 ft within the MPCA where observed concentrations are between 260 and 13,000 ng/L. A northwest trending plume arm extends approximately 7,000 ft from the MPCA with NDMA concentrations between 1.1 and 170 ng/L. Within the Plume Front area downgradient from the MPCA, the plume widens to approximately 6,700 ft with maximum observed concentrations between 720 and 1,400 ng/L. The vertical extent of NDMA, inferred from measured NDMA concentrations in water from wells with multiple-depth sampling points, is estimated to range from less than 325 ft bgs (below ground surface) to approximately 750 ft bgs.

2.2.2 Trichloroethene

An estimated 4,663 kg of TCE contaminant mass was released to the environment (NASA, 1996a). Figure 4 shows a manual interpretation of the TCE conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. The TCE plume extends westward approximately 18,500 ft from primary sources at the 200 Area and is located within WSTF boundaries. The maximum width of the TCE plume is approximately 4,400 ft upgradient from the MPCA in the industrial 200 Area. Downgradient, the width of the TCE plume decreases to approximately 1,600 ft in the vicinity of the MPCA. Observed maximum TCE concentrations in MPCA groundwater are between 100 and 180 µg/L. A northwest trending plume arm extends approximately 7,000 ft from the MPCA with TCE concentrations between 17 and 22 µg/L. Within the Plume Front, west of the MPCA, the TCE plume is approximately 7,000 ft wide. Concentrations in the Plume Front range from the detection limit to approximately 230 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of TCE in WSTF groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.2.3 Tetrachloroethene

An estimated 80 kg of PCE contaminant mass was released to the environment (NASA, 1996a). Figure 5 shows a manual interpretation of the PCE conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2087. The PCE plume originating from sources at the 100, 200, and 600 Areas, contains two separate portions, extends westward approximately 20,000 ft from the original release location in the WSTF test areas, and is located entirely within WSTF boundaries. In the MPCA, the PCE plume occurs as a small lobe approximately 1,500 ft in length by 400 ft in width before pinching out. Observed concentrations are between 2.2 and 7.1 µg/L within the Mid-plume area, although the plume is defined by the PCE cleanup level of 5 µg/L and centered on well BLM-39. Within the Plume Front, downgradient from the MPCA, a second plume lobe is centered on the ST-1 well cluster with an observed concentration of 8.0 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of PCE in groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.2.4 Freon 11

An estimated 2,766 kg of Freon 11 contaminant mass was released to the environment (NASA, 1996a). Figure 6 shows a manual interpretation of the Freon 11 conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. The Freon 11 plume extends westward approximately 23,000 ft from sources at the 200, 300, 400, and 700 Areas and is entirely located within WSTF boundaries. The plume is as much as 7,000 ft wide upgradient from the MPCA in the WSTF industrial area. The highest concentrations range from 470 to 630 µg/L in the 300 Area, with concentrations from 180 to 560 µg/L existing throughout much of the area upgradient from the MPCA. The width of the Freon 11 plume narrows to approximately 1,200 ft within the MPCA where observed concentrations are between 30 and 230 µg/L. A northwest trending plume arm extends approximately 7,000 ft from the MPCA with maximum Freon 11 concentrations between 4.9 and 63 µg/L. Within the Plume Front, downgradient from the MPCA, the plume widens to approximately 5,500 ft with maximum observed concentrations between 24 and 220 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of Freon 11 in groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.2.5 Freon 113

Though not designated as a hazardous constituent, Freon 113 remains of interest to NASA for groundwater monitoring purposes. An estimated 4,621 kg of Freon 113 contaminant mass was released to the environment (NASA, 1996a). Figure 7 shows a manual interpretation of the Freon 113 conceptualized groundwater plume at WSTF utilizing analytical data obtained from groundwater sampling in 2018. Coalescing Freon 113 plumes originating from sources at the 100, 200, 300, and 400 Areas extend westward approximately 19,000 ft. The coalesced plume is entirely located within WSTF boundaries. The plume is as much as 7,000 ft wide in the area upgradient from the MPCA. The highest concentrations are 140, 510, and 410 µg/L in the 200 Area, MPCA, and Plume Front areas, respectively. The width of the Freon 113 plume narrows to approximately 1,600 ft within the MPCA where observed concentrations are between 16 and 510 µg/L. A northwest trending plume arm extends approximately 4,000 ft from the MPCA with a maximum Freon 113 concentration of 47 µg/L. Within the Plume Front downgradient from the MPCA, the plume widens to approximately 8,500 ft with observed concentrations between 12 and 410 µg/L. A confined secondary plume centered on well 700-D-186 is present near the 700 Area with a Freon113 concentration of 27 µg/L. Based on multiple-depth sampling data, the inferred vertical extent of Freon 113 in groundwater likely ranges from less than 325 ft bgs to approximately 750 ft bgs.

2.3 Potential Receptors

Under current and future conditions, NASA maintains administrative control of lands below which groundwater has been contaminated by historical activities at WSTF. No expansion of water use will occur on lands within NASA’s administrative control. Thus, conservatively, the nearest location where a water use well may be installed by an outside entity is at the property boundary directly downgradient of the plume.

Currently, there are no complete exposure pathways or human or ecological receptors of contaminated groundwater. Downgradient public and WSTF water supply wells comprise potential future pathways for exposure to groundwater contamination. Under current conditions, the nearest downgradient water wells are NASA WSTF water supply wells. The distance between the edge of the conceptualized groundwater contaminant plume and the property boundary is approximately 7,300 ft. The locations of the WSTF water supply wells relative to other pertinent site features are shown in Figure 2. Routine sampling of drinking water from the NASA supply wells indicates that the WSTF water supply has not been impacted by WSTF groundwater contaminants. NASA also performed groundwater sampling at six off-site water supply wells in 2010. There was no evidence that these wells had been impacted by NASA’s groundwater contaminant plume (NASA, 2010).

2.4 Previous Investigations

NASA has performed numerous environmental investigations at WSTF, including soil sampling, soil gas sampling, air monitoring, and groundwater monitoring. Historical and ongoing groundwater monitoring are most applicable to this Plan. A detailed discussion of the results of routine groundwater monitoring at WSTF is provided in the PMR (Periodic Monitoring Reports) submitted regularly to NMED. PMR include a comprehensive database of historical chemical analytical data from groundwater monitoring.

2.5 Surface Conditions

This section provides a brief description of the surface conditions as they relate to routine groundwater monitoring. Specific information on site conditions was provided in the WSTF RFI (RCRA Facility Investigation; NASA, 1996a).

2.5.1 Climate

The climate at WSTF is characterized by abundant sunshine, wide diurnal variation in temperature, low relative humidity, and variable precipitation. WSTF typically receives an average of 10 in. (inches) of rain per year, with the majority of rainfall events occurring in intense, brief, and localized thunderstorms during the late summer.

2.5.2 Surface Water Bodies

The major perennial surface water body in the region is the Rio Grande River, located approximately 15 mi west of WSTF within the Mesilla Valley. There are no natural surface water bodies at WSTF. The natural surface water body closest to the facility is Isaacks Lake, an ephemeral playa lake located approximately 8 mi southwest of the site at the lowest elevation in the JDMB (Jornada del Muerto Basin), a hydrologically closed basin (Figure 8) that is separated from the Mesilla Valley to the west by an uplifted horst block represented by the Doña Ana Mountains. Water is typically present in the playa only in years with above-average precipitation.

In certain areas, man-made channels or structures have been constructed to facilitate drainage and prevent erosion during high flow events. The only permanent surface water bodies at WSTF are the Test Stand 302 Cooling Water Discharge Pond and the 400 Area discharge ponds.

2.5.3 Surface Drainage

WSTF is characterized by high evaporation and infiltration rates, which are typical of a desert climate. Precipitation from the brief intense thunderstorms that falls upon the mountain range and alluvial fans cannot evaporate or infiltrate immediately and is transported downstream via arroyos. Arroyo surface flow generally terminates within minutes to hours after the end of a precipitation event. Topographic maps of the area indicate that numerous well-developed arroyos from WSTF terminate northeast of Isaacks Lake, and sheet flow drainage patterns characterize the western half of WSTF.

2.6 Subsurface Conditions

This section provides a brief description of the surface conditions as they relate to routine groundwater monitoring. Specific information on site conditions was provided in the WSTF RFI (NASA, 1996a).

2.6.1 Site-Wide Stratigraphy

Outcrops of Pennsylvanian limestone, sandstone, and siltstone bedrock that dip at approximately 22 degrees to the west occur adjacent and east of the WSTF 200 and 300 Areas. Exposed bedrock, or shallow bedrock covered by a thin (0 ft to 100 ft) veneer of alluvial sediments characterizes the fractured bedrock aquifer in the source areas. Figure 9 shows the geologic features of the eastern areas of WSTF. Bedrock west of the source areas is comprised of more gently westward dipping Tertiary volcanics overlain by a thicker alluvial sequence. Pennsylvanian and Tertiary bedrock lithologies are juxtaposed in the subsurface along the regional northwest- trending Hardscrabble Hill Fault that is exposed 2 mi south of WSTF on Hardscrabble Hill. West of the WSTF source areas, the alluvium thickness increases from approximately 100 ft to 350 ft within the MPCA. Immediately west of the MPCA, a structural feature known as the WBFZ (Western Boundary Fault Zone) displaces bedrock and the thickness of the alluvial unit increases significantly to over 2,500 ft within the JDMB. Alluvium consists of unconsolidated Quaternary alluvial fan deposits of the Santa Fe Group derived from the SAM (San Andres Mountains), located to the east of WSTF. Figure 10 shows additional geological features of the western areas of WSTF, with emphasis on the MPCA where the predominant WSTF geological features coexist. A detailed description of site geology is available in the Draft RFI Report, Volume Two, Chapter Four (NASA, 1996a).

2.6.2 Site-Wide Structural Geology

Two types of geologic deformation of the alluvium/bedrock stratigraphic section are recognized near WSTF. The oldest and least prevalent deformation consists of west-trending folds and faults associated with the Late Cretaceous to Early Tertiary Laramide Orogeny (Seager, 1981). This deformation is confined to the western SAM, and is exposed within the Bear Peak Fold and Thrust Zone located 1 mi northeast of the eastern limit of the groundwater plume in the 300 Area.

Younger and more widespread deformation is attributable to regional Late Tertiary Basin and Range normal faulting and directly affects the stratigraphy within the contaminated portion of the aquifer. East-west extensional forces across the southwestern United States resulted in the formation of northwest-trending structural depressions and adjacent fault-bound mountains. WSTF is located partially on the pediment slope of the SAM (bounding the JDMB on the east) and partially in the downfaulted JDMB, which is bounded on the west by the Doña Ana Mountains. Numerous subsurface half-graben normal faults within the western pediment slope of the SAM below WSTF have been identified from shallow seismic reflection and well log data. Regional structural features displaying the predominant northwest trend include the WBFZ and the Tertiary Hardscrabble Hill fault. The Hardscrabble Hill fault which lies to the east of the Mid-plume and passes through the WSTF 100 Area has an inferred displacement of several thousand feet. The WBFZ is a northwest-trending, regional-scale series of normal half-graben faults that offset the top of the bedrock from a depth of 400 ft in the MPCA pediment to >2,500 ft within the JDMB to the west over a horizontal distance of 2,000 ft.

2.6.3 Groundwater Hydrostratigraphy

Groundwater below the WSTF industrial areas is hosted within a fractured bedrock aquifer comprised of Pennsylvanian sedimentary rocks and Tertiary volcanic rocks at depths between approximately 100 ft and 200 ft bgs. The water table is relatively coincident with, and just below the contact between bedrock and the overlying alluvium. In the MPCA, groundwater occurs at a depth of approximately 300 to 450 ft bgs in an unconfined to semi-confined fractured bedrock aquifer. In the Plume Front area west of the WBFZ, groundwater occurs in an alluvial aquifer as a result of bedrock being displaced to inferred depths of up to 2,500 ft bgs toward the center of the JDMB. This aquifer yields relatively large quantities of potable water. At the Plume Front, the elevation of the water table within the upper aquifer of the JDMB ranges from 390 to 475 ft bgs and has been relatively consistent (within 3 to 6 ft) over a historical monitoring period of 40 years. Aquifer conditions in the vicinity of the Plume Front vary from unconfined to leaky confined due to the presence of discontinuous confining layers of clay or cemented alluvial horizons. Leaky confined conditions are generally prevalent within and to the west of the WBFZ. Figure 11 shows a cross-sectional view of WSTF's geology. The location of the cross-section is shown in Figure 2.

2.6.4 Groundwater Flow System

Groundwater beneath WSTF generally originates as recharge through precipitation in the southern SAM immediately east of the facility. As shown in Figure 11, groundwater flows generally to the west through fractured bedrock and the lower portion of the overlying alluvium down the pediment slope on the western flank of the SAM, and merges with the groundwater flow system of the JDMB alluvial aquifer west of the WBFZ.

Groundwater recharge to the bedrock and alluvial aquifers occur primarily through precipitation infiltrating into exposed bedrock fractures and faults. Annual mountain-front recharge is estimated to be 50 to 200 acre-ft per mi of mountain front (Wilson et al., 1981; NASA, 1996a, 1999). Recharge from the SAM catchment areas infiltrates the aquifer within the source areas and moves across the MPCA into the Plume Front area. West of the WSTF site boundary in the vicinity of the axis of the JDMB, recharge is more limited. This is a result of reduced precipitation, higher evaporation rates, an increased depth to groundwater, and the presence of shallow and relatively thick lacustrine clay deposits within the alluvial section.

Minor artificial recharge areas are present on the pediment slope adjacent to the 300 and 400 Areas where WSTF has discharged excess test water relatively continuously over the last 30 years. Spent test water, discharged to grade, infiltrates in the adjacent arroyo and recharges the groundwater system. Annually, approximately 90 acre-ft are estimated to recharge the aquifer over a distance of 7,000 ft downgradient of the 300 Area in the 300/400 Area arroyo (NASA, 1996a, 1999, 2013a). Water used in testing activities at WSTF is supplied by production wells completed in the JDMB aquifer in the western portion of WSTF. Hence, this artificial recharge simply recycles groundwater from one part of the flow system to another and does not represent a net increase in aquifer recharge.

Groundwater flow from east to west in the fractured bedrock aquifer below WSTF is a result of a hydraulic gradient between the higher topographic elevations in the SAM-front recharge area and the lower elevations of the WSTF Plume Front in the JDMB. Horizontal hydraulic gradients at WSTF are steep in the source area and MPCA bedrock pediment aquifer (0.05 ft/ft or 250 ft/mi), where small-scale, interconnected fractures promote localized irregular downgradient groundwater movement. The rates of movement through the fractured bedrock are highly variable, but are inferred to reach velocities of up to 750 ft per year. West of the WBFZ, horizontal hydraulic gradients are significantly lower within the alluvial aquifer of the JDMB (0.0002 ft/ft or 1 ft/mi).

Figure 12 provides a basic groundwater elevation map of WSTF.

2.6.5 Hydraulic Properties

Hydraulic conductivity (K) and transmissivity (T) values are typically several orders of magnitude greater in the alluvial aquifer than in the fractured bedrock aquifer. Recent groundwater flow modeling was accomplished by adjusting hydraulic conductivity to best match observed hydraulic heads. Figure 13 presents the calibrated horizontal hydraulic conductivity values used in the model, which match the range of hydraulic conductivities measured during aquifer pumping and slug tests.

Hydraulic conductivity zones were delineated across the WSTF model domain based on distribution of geologic units. Those units included fractured rocks (limestone, rhyolite, and andesite) and alluvial fan deposits. Figure 13 shows the distribution of these zones. Table 2 identifies these zones, geologic units they represent, distribution, K values derived from model calibration, and the range and geometric mean values for K derived from aquifer tests. The large number of significant digits indicated for hydraulic conductivities in Figure 13 and Table 2 were calculated by automated PEST (parameter estimation software). While measuring hydraulic conductivity to this level of accuracy is impossible, the software resolves hydraulic conductivity within the range of acceptable values specified by the user so that model calibration errors are minimized. These hydraulic conductivities are not field measured; however, they lie within the range of conductivities observed during field testing and result in a best fit match to observed hydraulic heads when paired with the other model hydraulic parameters.

The low permeability rhyolite and andesite unit, representing areas of dry holes and extremely small well yields, was assigned a very low K to represent these low permeability rocks. No test data are available to verify the calibrated value.

With one exception, calibrated horizontal K of zones representing other fractured rock units fell within the range of measured K derived from aquifer pumping and slug tests. These tests represented point values in an extremely heterogeneous system and the range was correspondingly large. Calibrated K of the representing fractured rhyolite east of the flow-banded rhyolite was lower than the observed range. That range was obtained from only three slug tests and may not be representative of the bulk hydraulic properties of this fractured rhyolite. In the case of several of the fractured rock units, the calibrated vertical K exceeds the horizontal K. This is a reasonable result given that fracture permeability dominates and near-vertical normal faults are known to exist in the fractured bedrock units.

The K of the alluvium was calibrated to observed distance-drawdown relationships observed during pumping tests at Well J (for the distal basin-fill deposits) and NASA-PT (alluvium in zone). The actual rates of groundwater flow at the Plume Front and similar areas of the JDMB alluvium are inferred to vary between 17 and 50 ft per year.

3.0 Regulatory Criteria

3.1 Hazardous Constituents and Cleanup Levels

The Permit requires that NASA establish cleanup levels for hazardous waste and hazardous waste constituents (Permit Attachment 15), as well as several site-specific contaminants identified in the Permit Section I.J (perchlorate, methyl tert-butyl ether, and munitions constituents). In accordance with the definition provided in Permit Section I.J, NASA identified hazardous constituents as those compounds specified in 40 CFR Part 261 Appendix VIII and 40 CFR Part 264 (2014) Appendix IX which have been consistently detected at the facility and “are reasonably expected to be in or derived from waste contained in a regulated unit” as indicated in 40 CFR 264.93 (2014). Cleanup levels were assigned to groundwater contaminants listed in Appendix VIII in 40 CFR Part 261 (2011) and/or Appendix IX in 40 CFR Part 264 (2014). The following steps were followed to develop cleanup levels:

1. Each hazardous constituent was evaluated individually to determine if an EPA (United States Environmental Protection Agency) Drinking Water MCL (Maximum Contaminant Level; 40 CFR Part 141 [2013]) exists.
2. Each hazardous constituent was evaluated to determine if a New Mexico WQCC (Water Quality Control Commission) numeric standard existed in Paragraphs (1-33) of Subsection A; Paragraphs (1-10) of Subsection B; and, Paragraphs (1-5) of Subsection C 20.6.2.3103 NMAC (New Mexico Administrative Code).

3. Each hazardous constituent was evaluated to determine if it is listed as a TP (toxic pollutant) in Paragraphs (1-54) of Subsection WW 20.6.2.7 NMAC.
4. If the hazardous constituent is NOT listed as a TP and has:
    a. Either an MCL or a WQCC standard, that value was assigned.
    b. Both an MCL and a WQCC standard, the lower of the two values was assigned.
    c. Neither an MCL nor a WQCC standard, an RSL (Regional Screening Level) was determined in accordance with Permit Attachment 15.1.1.c (Step 7) and assigned as the cleanup level.
5. If the contaminant is listed as a TP in paragraphs (1-54) of Subsection WW 20.6.2.7 NMAC, the RSL was determined according to Step 7.
6. Then, for each hazardous constituent listed as a TP, the lowest value of the existing drinking water MCL, the WQCC numeric standard, or the EPA RSL was assigned as the cleanup level.
7. For each hazardous constituent falling into the category of Step 4c or Step 5, above, the EPA RSL for tap water was determined as follows:
    a. For carcinogenic hazardous constituents, the RSL corresponding to a cancer risk level of 1.0E-05 was assigned. Note that the EPA RSLs for carcinogens are equivalent to a 1.0E-06 excess cancer risk. Therefore, for carcinogens, the RSL must be increased by an order of magnitude to meet Permit Attachment 15 requirements (NMED, 2016b).
    b. For each non-carcinogenic hazardous constituent, the RSL for tap water corresponding to a hazard index of 1.0 was determined (EPA, 2017).

Hazardous constituents are classified into the following categories to facilitate their analysis: VOC (volatile organic compounds); nitrosamines; metals; inorganics; SVOC (semi-volatile organic compounds); and miscellaneous hazardous constituents. Table 3 provides the current cleanup levels for hazardous wastes and hazardous constituents detected in groundwater at WSTF. In each PMR submitted to NMED, NASA compares the results of groundwater monitoring to the current established cleanup levels. Groundwater cleanup levels tend to fluctuate over time as the understanding of health risk evolves. To illustrate this variability, Figure 14 summarizes the cleanup levels for the four primary hazardous constituents in WSTF groundwater (NDMA, TCE, PCE, and Freon 11) between November 2009, when the current RCRA permit was issued by NMED, and the present. Table 4 identifies several other constituents that have been detected in WSTF groundwater that are of interest to NASA. These analytes are not hazardous constituents and thus do not have cleanup levels. However, NASA believes these analytes may be associated with historical or other activities at WSTF and has determined that they should be included in routine groundwater monitoring at WSTF.

3.2 Background Concentrations

NASA performed groundwater sampling at four upgradient monitoring wells and provided a statistical evaluation of background concentrations in Appendix A of the 2012 GMP Update (NASA, 2012b). However, the data set was not sufficient to perform all required statistical evaluations (NMED, 2012), so additional sampling is required. NASA anticipates the collection of additional groundwater samples from locations appropriate for the determination of background concentrations and expects a subsequent statistical evaluation will be performed when an adequate data set can be compiled.

3.3 Detection Monitoring

Detection monitoring will be performed at WSTF as required by Permit Section VI.D.2, which requires NASA to report new detections and refers to the requirements of this Plan and incorporates the requirements of 40 CFR 264.101 (2014). This section discusses these requirements and provides procedures for conducting detection monitoring at WSTF.

3.3.1 Detection Monitoring at HWMU (Hazardous Waste Management Units)

40 CFR 264.101 (2014) does not specifically address requirements related to detection monitoring at HWMU the (hazardous waste management units). In order to determine potential requirements for detection monitoring, NASA consulted 40 CFR 264.98 (2014), which requires the collection of samples for analyses of Appendix IX constituents at the compliance point. Because NASA has entered corrective action and is not specifically subject to these requirements, specific compliance points have not been identified for the facility or closed HWMU. However, in order to ensure that additional hazardous constituents are not released to the groundwater from the closed HWMU or current activities in the operational areas of the facility, groundwater samples from several locations will be analyzed for Appendix IX constituents. Appendix IX constituents that have been detected at WSTF are included in Table 4. Wells that are utilized for detection monitoring near HWMU are identified in Section 4.1 and Table 5. Detections of new Appendix IX constituents are managed as indicated in Section 3.3.3.

3.3.2 Facility-wide Detection Monitoring

As indicated in the Permit, a "new detection is any incidence of a constituent being detected in a groundwater sample collected from a monitoring well that has never been detected in prior samples obtained from that monitoring well." NASA samples groundwater monitoring wells at WSTF for a variety of hazardous constituents in accordance with this Plan. Chemical analytical data are reviewed to determine if new hazardous constituents have been detected. New detections are managed as indicated in the following section.

3.3.3 Management and Reporting of New Detections

If detection monitoring at WSTF results in the detection of previously undetected hazardous constituents, NASA will determine the reporting and monitoring requirements for that constituent as follows:

- The chemical analytical data and related laboratory reports will be evaluated by project chemists in accordance with the quality requirements specified in Section 10.0 to determine if the detection is reliable.
- If the detection is not validated, or is an estimated value, no further action is required.
- If the detection is validated, resampling will be performed for the constituent during the next scheduled sampling event at that monitoring well or zone. NASA will report the detection and scheduled confirmatory resampling in the subsequent PMR.
- If the constituent is not detected in the resample, NASA will report the resampling results to NMED in the subsequent PMR. No additional further action is required.
- If the detection is confirmed in the resample, NASA will report the detection to NMED in the subsequent PMR and propose a course of action related to the detection.

New or reconfigured groundwater monitoring wells will not be subject to facility-wide detection monitoring and related reporting until they have been sampled for at least one year as specified in Section 11.3.

4.0 Groundwater Monitoring System

This section describes the groundwater monitoring system in use at WSTF. It provides general information related to the groundwater monitoring wells in use, including: a list of the monitoring wells and their designations; a discussion of well drilling activities and basic procedures; a summary of well construction information; a description of well security practices; a summary of well maintenance activities; and a brief description of the procedures for well abandonment.

4.1 Groundwater Monitoring Well Identification and Designation

In general, groundwater monitoring wells are identified by a three-part alphanumeric code stenciled on the protective outer casing or on one of the well's protective barrier posts. The exception to this are those monitoring wells that were installed as part of the original RCRA groundwater detection program, which are designated as NASA 3 through NASA 10. The designations of wells installed after March 1987 are determined by location of the well site or other unique descriptor, an alphanumeric identification digit, and the depth (in feet below ground surface) to the top of the screened interval or to the discreet location of a multiport monitoring well. Multiport wells, in their entirety, are designated only by the location of the well site or other unique descriptor and the alphanumeric identification digit. The designation of a specific sampling zone in a multiport well incorporates the depth to that zone for three-part well zone designation and unique identification.

Groundwater monitoring wells at WSTF have been installed to monitor various areas of the groundwater plume or to serve specific functions in the groundwater monitoring program. The functional groups into which WSTF groundwater monitoring wells have been assigned are described below. A summary of WSTF's active groundwater monitoring wells is provided in Table 5. The location of groundwater monitoring well are provided in Figure 2.

4.1.1 Background Wells

Background monitoring wells are installed in the aquifer upgradient of the facility and HWMU at which hazardous waste was released to the groundwater. These wells are reasonably expected to be free of contamination resulting from activities at WSTF. In general, groundwater samples collected from these well can be considered representative of the background conditions at eastern WSTF. Due to the size and geological complexity of the facility, upgradient wells may not be fully representative of background conditions at some locations to the west of the WSTF industrial area.

4.1.2 Source/Industrial Area Wells

Numerous groundwater monitoring wells have been installed in the vicinity of or adjacent to closed HWMU at WSTF and in nearby sections of the industrial area. These wells were originally intended to monitor groundwater downgradient of the closures, determine if the HWMU were continuing sources of contamination to the groundwater, and/or determine the nature and extent of groundwater contamination in the industrial area. Several of these wells or zones were previously designated as PCC monitoring wells (Points of Compliance or Supplemental) and were subject to semi-annual replicate sampling for a variety of hazardous constituents (NASA, 1996a). Historical and current chemical analytical data indicate that groundwater in these areas remains contaminated, but show no evidence of additional releases of hazardous constituents to the groundwater (NASA, 2019). Typical PCC monitoring is not required by the

Permit. Source/industrial area groundwater monitoring wells are now primarily used on a less frequent basis to continue monitoring groundwater contaminant behavior in the vicinity of the HWMUs in order to support characterization of the contaminant plume, assist with source are investigations, and, if required, provide data for the development, implementation, and monitoring of corrective actions in these areas. Source/industrial area monitoring wells are installed in the thin veneer of alluvial sediments or the fractured bedrock underlying the thin alluvium in the WSTF industrial area.

Source/industrial area wells are divided into three subcategories: 100/600 Area wells; 200 Area wells; and 300/400 Area wells. Among these are five wells designated for detection monitoring as indicated in Section 3.3.1: 200-B-240; 200-SG-1; 300-A-120; 400-C-118; and BLM-3-182.

4.1.3 Northern Boundary Wells

Groundwater monitoring wells installed to the north and west of the WSTF industrial area serve primarily to bound the conceptualized groundwater contaminant plume in that region. Chemical analytical data collected from these wells provide information related to the migration of hazardous constituents along the northern limit of the plume. Included in this group of monitoring wells are those designated for groundwater monitoring in the vicinity of the closed 700 Area Landfill. Sampling of these monitoring wells is performed in accordance with a Closure and Post-closure Care Plan (NASA, 1996b) approved by the NMED Solid Waste Bureau.

4.1.4 Southern Boundary Wells

Groundwater monitoring wells installed to the south and west of the WSTF industrial area are also utilized to bound the conceptualized groundwater contaminant plume in that region. Chemical analytical data collected from these wells provide information related to the migration of hazardous constituents along the southern limit of the plume. Historical analytical data indicate very little plume activity in this area, thus monitoring of wells to the south of the industrial boundary is typically performed less frequently than at other more critical locations in and around the plume.

4.1.5 Mid-plume Constriction Area Wells

The MPCA is of great interest to NASA because of the potential for intercepting significant concentrations of groundwater contaminants in the area. As a result, numerous groundwater monitoring wells have been installed both upgradient and downgradient of the MPCA to characterize groundwater and contaminant movement in that region of the plume. These wells are installed at varying depths in both alluvium and fractured bedrock.

4.1.6 Plume Front Wells

Groundwater monitoring wells installed in the Plume Front area are used to characterize the conceptualized groundwater contaminant plume, identify and monitor the leading edge of the plume, and monitor the effects of the PFTS, NASA’s voluntary interim measures to prevent further westward migration of the plume. These wells are installed at varying depths in the alluvium west of the WBFZ and provide horizontal and vertical delineation of the plume.

Plume Front groundwater monitoring wells are further divided into two subcategories: wells within the main portion of the contaminant plume that are used to determine the impacts of the PFTS on groundwater contamination and those installed near the leading edge of the plume that are used to effectively monitor the horizontal and vertical extent of the contaminant plume and ensure the overall effectiveness of the PFTS.

4.1.7 Sentinel Wells

Sentinel wells are those groundwater monitoring wells installed beyond the leading edge of the conceptualized contaminant plume that have not been impacted by historical or current operations at WSTF. Sentinel wells provide monitoring points at depths within the aquifer where contaminant migration is a concern. Evidence of WSTF COC at these wells or zones indicate uncontrolled migration of contaminants beyond a defined spatial limit (such as a capture zone) and may initiate changes in remediation system operation or other actions to prevent further contaminant migration. These wells are in the alluvium west of the WBFZ and serve to bound the plume both horizontally and vertically.

4.2 Groundwater Monitoring Well Construction

Groundwater monitoring well construction varies at WSTF based on the specific geological conditions and groundwater monitoring requirements at each well location. Groundwater monitoring wells are described as conventional or multiport. Currently, active multiport wells utilize Westbay®[2] or Water FLUTe™ sampling systems (see Sections 5.2 and 5.3). NASA may consider the use of other multiport monitoring systems. The details of these designs are discussed below. Additional information related to the construction of WSTF groundwater monitoring wells is provided in Table 5.

4.2.1 Conventional Monitoring Wells

Conventional monitoring wells are designed to monitor specific, discrete intervals within the aquifer. Conventional monitoring wells consist of a single borehole in which the well casing is installed. The targeted zone or zones are monitored using a segment of slotted, or screened, casing which accesses the formation surrounding this screened interval. Screened intervals are typically 10 to 20 ft in length and are isolated from the remainder of the boreholes during installation of the casing to ensure only the targeted zones are sampled. Conventional wells are used to measure groundwater elevations and to collect groundwater samples that are representative of the groundwater in the vicinity of the screened interval.

Conventional well casing size and material varies based on the geological and chemical conditions and groundwater monitoring requirements at each well location. WSTF conventional groundwater monitoring wells vary in size from 1.5 to 5 in. in diameter and are constructed of PVC, stainless steel, or a combination of PVC and stainless steel.

4.2.2 Westbay Monitoring Wells

Westbay multilevel groundwater monitoring systems are designed to monitor multiple water-bearing zones within a single borehole. The systems are currently in use at WSTF to collect groundwater samples, obtain groundwater formation pressures to determine piezometric elevations, and perform hydraulic conductivity determinations. Data obtained from these wells are used to formulate a three-dimensional conceptualization of the groundwater contamination plume.

The Westbay system is a multiple-level groundwater monitoring system which employs a single, closed access, PVC casing with valved ports to perform well monitoring activities. The valved ports are used to provide controlled access to a multiple number of monitoring zones within a single borehole. The Westbay system is installed directly in a stable borehole or in a multi-screened conventionally installed monitoring well casing. Inflatable packers are integrated into the Westbay casing design and are individually inflated against the walls of the borehole or outer casing to isolate specific monitoring zones

[2] Westbay is a registered trademark of Nova Metrix Ground Monitoring (Canada) Ltd.

and secure the Westbay casing within the borehole or outer casing. Westbay wells are designed to provide direct access to formation water. This allows the collection of in situ groundwater samples and hydrogeological data. As a result of this design, the requirement to excessively purge each monitoring zone prior to sample collection is eliminated. Specialized downhole instruments are used to access the valved ports within the well.

Based on direction from NMED, NASA developed a plan to reduce the use of Westbay wells at WSTF and perform monitoring at some present Westbay locations with sampling systems that allow for some purging of groundwater (NMED, 2011). In 2013, NASA removed the Westbay casing from monitoring wells JP-3 and WW-2 and replaced the Westbay sampling systems with two dedicated low-flow sampling systems (NASA, 2013b). In November 2014, NASA removed the Westbay casing from monitoring wells BLM-28 and BLM-32. NASA installed a Water FLUTe sampling system in the open borehole at BLM-32 in August 2015 (NASA, 2016). Groundwater sampling of the well was initiated in the fourth quarter of 2015. NASA plans to install a single zone low-flow sampling system in the open borehole at BLM-28 in 2017. NASA reconfigured Westbay wells WW-4 and WW-5 to purgeable sampling systems in 2015 in accordance with the NMED approved schedule. The Westbay sampling systems were removed from both wells and redevelopment of the sampling zones began in September 2015. NASA installed four-zone Water FLUTe systems in these wells in November 2015 (NASA, 2016) and performed initial groundwater sampling in December 2015 and January 2016, respectively. In 2016 and early 2017, NASA removed the Westbay sampling systems from monitoring wells JER-1, JER-2, ST-6, and ST-7. Following redevelopment of the conventional casings in each well, multi-zone Water FLUTe systems were installed in each well (NASA, 2017a). Westbay monitoring well BLM-37 was also scheduled for reconfiguration in 2016. However, the Westbay casing became lodged in the outer stainless steel casing and broke. Numerous attempts to retrieve the casing failed and the well cannot be used. NASA recommended abandonment and replacement of the well with new groundwater monitoring well BLM-42 (NASA, 2018a), which is scheduled for installation in mid-2019. Additional Westbay reconfigurations are expected to be completed in the future.

4.2.3 Water FLUTe Monitoring Wells

Water FLUTe monitoring well systems are designed to monitor multiple water-bearing zones within a single borehole or conventional well. The systems are currently used at WSTF to collect groundwater samples and obtain groundwater elevation data. Data obtained from these wells are used in combination with data obtained from Westbay monitoring wells to continually refine the three-dimensional conceptualization of the groundwater contamination plume.

Similar to the Westbay monitoring system, the Water FLUTe system may be installed directly in a stable borehole or within a multi-screened conventional monitoring well casing. The Water FLUTe consists of a flexible polyurethane coated nylon fabric liner that contains several monitoring ports. Sealing pressure created by excess water inside the waterproof flexible liner above the static water level in the formation ensures that there is no communication between monitoring zones in the borehole or well. Tubing extends from multiple sample ports in the flexible liner to the top of the borehole or well casing. This allows for the collection of representative groundwater samples from discrete depths. Pressurized gas (typically nitrogen) is used to drive water from the pump tube in the system to the sampling tube and up to the surface during purging and groundwater sampling activities. Purging is required before sampling to ensure representative groundwater samples are being collected. No downhole instruments are required to operate the Water FLUTe monitoring system. The system is operated from ground surface with pressurized gas during purging and sample collection activities.

4.3 Groundwater Monitoring Well Security

WSTF is a secure facility that is regularly patrolled by trained security forces tasked with restricting access to the facility to authorized personnel only. In addition to this institutional security, monitoring wells are equipped with locking caps that are secured at all times, except during monitoring activities conducted in accordance with this Plan or other site-specific project documents. Keys are issued only to personnel directly involved in the collection of groundwater samples, well maintenance, or well inspection activities.

4.4 Groundwater Monitoring Well Evaluation and Maintenance

Groundwater monitoring well sites are inspected during each sampling event and during periodic inspections to ensure safe and secure sampling locations are maintained at all times.

WSTF NASA performs qualitative evaluations of monitoring well performance on an ongoing basis to determine if monitoring wells require additional development, maintenance, reconfiguration, or replacement. Groundwater monitoring wells may also be inspected with a downhole camera system to ensure well and sample integrity is maintained. The downhole camera system is utilized on an as-needed basis to perform inspections at the discretion of WSTF groundwater personnel. NASA has identified several wells that may require attention.

4.4.1 200-D-109

Monitoring well 200-D-109 (Figure 2) is installed in the Gardner Spring Arroyo downgradient of historical 200 Area contaminant discharges. In the mid-1990s, concentrations of groundwater COC in well 200-D-109 were some of the highest in WSTF groundwater. Concentrations have declined significantly in the area due to natural plume migration, but NASA considers this location important to overall plume delineation. Groundwater elevations have declined in this well, and are typically below the screened interval, which prevents the collection of representative groundwater samples from the well. NASA evaluated the potential future use of this well and determined that it is not suitable for continued monitoring. NASA plans to plug and abandon the well in 2019. See also Section 4.4.4.

4.4.2 200-KV-150

During attempted sampling events in 2018 and early 2019, NASA observed that groundwater monitoring well 200-KV-150 fails to recharge adequately for representative groundwater sampling using the dedicated low-flow bladder pump system. NASA was not able to sample the well in December 2018 and March 2019 and is evaluating options for disposition of this well.

4.4.3 200-LV-150

Groundwater monitoring well 200-LV-150 was installed in June 2014 as part of the 200 Area investigation. In the Groundwater Monitoring Plan Update for 2015 (NASA, 2015), NASA indicated that well 200-LV-150 had not been fully developed and required further characterized before a sampling system was selected and installed. In 2017 and early 2018, NASA completed development of this monitoring well, installed a dedicated low-flow bladder pump in the well, and collected the required groundwater samples from the well in February 2018. NASA sampled the well again in November 2018 and established an annual sampling schedule for the well as indicated in Table 15.

4.4.4 200-SG Wells

On September 13, 2018, NMED approved NASA's April 24, 2018 GMP update for 2018 (NMED, 2018c; NASA, 2018e) with modifications, one of which required NASA to provide additional information on wells 200-SG-2 and 200-SG-3 (Figure 2) and provide the rationale for not including them in the sampling schedule. NASA's December 3, 2018 response provided the required information and indicated that NASA would evaluate wells 200-SG-2 and 200-SG-3 for potential future sampling (NASA, 2018e). In April 2019, NASA attempted to evaluate the performance of the two wells, but determined that the groundwater levels in each are inadequate to allow for the collection of representative samples. NASA also evaluated historical groundwater analytical data from the two wells, which were sampled in 2010, 2012, 2013, and 2014. It was determined that the relatively low concentrations of WSTF COC in these wells are not representative of groundwater within the Gardner Spring Arroyo in which monitoring well 200-D-109 (Section 4.4.1) is installed. NASA plans to plug and abandon the groundwater monitoring portions of wells 200-SG-2 and 200-SG-3 and will evaluate the need for additional monitoring wells in this area of the contaminant plume.

4.4.5 BLM-30

On March 29, 2016, NMED approved NASA's January 27, 2016 *NASA WSTF Periodic Monitoring Report – Fourth Quarter 2015* with a comment expressing uncertainty about the source of detections of NDMA in well BLM-30 during 2015 (NMED, 2016a). NMED directed NASA to submit a work plan for the conversion of these Westbay wells to purgeable systems. NASA developed and submitted the *Westbay Well Reconfiguration Work Plan for Well BLM-30* (NASA, 2017b) on March 30, 2017 and received NMED's October 4, 2017 Approval with Modifications (NMED, 2017a) that required NASA to revise the BLM-30 reconfiguration work plan. NASA evaluated NMED's comments and submitted the *Well Reconfiguration Work Plan for Well BLM-30* on December 28, 2017 (NASA, 2017g). NASA attempted to remove the Westbay sampling system from the borehole at well BLM-30 in December 2018. After numerous attempts to retrieve the Westbay casing from the borehole, NASA and the off-site contractors determined that the borehole had sloughed and that there is approximately 40 ft of material on top of the uppermost packer, preventing removal of the system. NASA is investigating alternate methods for removing the Westbay casing from well BLM-30.

4.4.6 BLM-31

The Westbay sampling system in groundwater monitoring well BLM-31 became inaccessible to downhole sampling equipment in 2002. NASA discontinued sampling of the well at that time because it was located beyond the conceptualized groundwater contaminant plume. NASA believes that this well may be useful for future groundwater monitoring associated with ongoing or upcoming environmental investigations. NASA expects to reconfigure this Westbay well with an alternate sampling system. NASA will evaluate the potential reconfiguration of this well following fieldwork and reporting associated with an evaluation of the representativeness of groundwater data from a Water FLUTe well (NASA, 2018e).

4.4.7 BLM-37

As described in Section 4.2.2, the Westbay sampling system became lodged in the stainless steel conventional casing in well BLM-37 while attempting to remove the casing in order to reconfigure the well to a purgeable sampling system. The PVC casing broke and numerous follow-on attempts to remove it failed. NASA proposed to abandon the well and replace it with new groundwater monitoring well BLM-42 (NASA, 2018a). NMED approved the work plan that included abandonment of well BLM-37 (NMED, 2018a) and NASA plans to perform the required plugging and abandonment in mid-2019.

4.4.8 BW-4

Westbay monitoring well BW-4 (Figure 2) was utilized as a monitoring location for the 200/600 Areas and Mid-plume Constriction Area groundwater tracer test (NASA, 2012d). While attempting to remove groundwater dye tracer sampling equipment deployed in the Westbay casing, the equipment became lodged in the casing and could not be retrieved. In February 2018, NASA's subcontracted drilling company removed approximately 185 ft (of 475 ft total) of Westbay casing. The remainder of the Westbay casing was drilled out of the borehole. A camera log revealed that numerous locations in the borehole contain residual PVC fragments from the drilling operation. Additional borehole development is required to determine if the borehole can be reused or if it must be abandoned. NASA plans to perform borehole development work and evaluate the borehole for use as a monitoring well in 2019. Additional information related to the project will be provided in PMR.

4.4.9 PL-5

On March 29, 2016, NMED approved NASA's January 27, 2016 *NASA WSTF Periodic Monitoring Report – Fourth Quarter 2015* with a comment expressing uncertainty about the source of detections of TCE in well PL-5 during 2015 (NMED, 2016a). NMED directed NASA to submit a work plan for the conversion of this Westbay well to a purgeable system. NASA evaluated the current configuration of the well and determined that well PL-5 is not installed in accordance with the current requirements of Permit Attachment 19. Specifically, the annular seals between groundwater monitoring zones are inadequate. PL-5 is located near the PFTS and is important to NASA's understanding and interpretation of contaminant plume movement in that area. As a result, NASA proposed to replace this monitoring well (NASA, 2017b) and submitted the NASA WSTF Drilling Work Plan for Groundwater Monitoring Well PL-12 (NASA, 2017e). NMED approved the work plan (NMED, 2018b) and in December 2018 NASA removed the Westbay casing from the well and prepared it to be plugged and abandoned in mid-2019.

4.5 Groundwater Monitoring Well Abandonment

When groundwater monitoring wells are no longer required to meet the objectives of the groundwater assessment program, or have reached the end of their useful lives, they are abandoned. The goal of well abandonment is to seal the borehole so that it cannot serve as a conduit for the migration of contaminants. Well abandonment at WSTF is performed in accordance with procedures established in the Permit and 19.27.4 NMAC. Typically, the well casing is filled from the bottom upwards with an appropriate sealing material (bentonite, cement slurry, etc.) approved by NMOSE (NM Office of the State Engineer). NASA will submit a well abandonment plan to the NMOSE in accordance with 19.27.4 NMAC. If the well to be plugged and abandoned is an active sampling location in this Plan, the Permit requires that NASA submit a copy of the certification required by 19.27.4 NMAC to NMED no less than fifteen days prior to the well's removal from service. Because the cited NMAC does not include a requirement for certification, NASA will provide a copy of the plugging plan that must be submitted to the NMOSE prior to well abandonment fieldwork. 19.27.4 NMAC also requires that the driller contractor that plugs a well submit a plugging record to the NMOSE within 30 days of well abandonment. NASA receives copies of the plugging records and will provide these records to NMED within 60 days of well abandonment.

5.0 Sample Equipment

Equipment used for the collection of groundwater samples is designed to minimize the impact on sample integrity during the sample collection process. Equipment requirements for WSTF groundwater monitoring wells vary depending upon the type of monitoring well installed at the monitoring location. As previously indicated in this Plan, WSTF utilizes both conventionally installed monitoring wells and multiport monitoring wells for groundwater assessment purposes. This section describes the groundwater sampling equipment utilized in each type of monitoring well currently installed at WSTF. Sampling equipment is also summarized in Table 5.

5.1 Conventional Monitoring Wells

Several types of dedicated and non-dedicated well sampling systems are used at WSTF due to the variability of sampling conditions encountered. Factors that influence the type of system selected for each conventional monitoring well include the depth to water, volume of water to be purged, water recovery rate, frequency of sampling, overall integrity of the well casing, and the cost of system installation.

5.1.1 Dedicated Bladder Pump Systems

Numerous conventional wells are equipped with dedicated positive displacement bladder pump systems. In this design, the wells are purged and sampled using the dedicated bladder pump. The pumps are constructed of PVC, stainless steel, and/or Teflon®[3] depending on the monitoring objectives at that location. Samples are collected directly from Teflon-lined polyethylene or Teflon discharge tubing. These materials are used to minimize the sorptive effects of pump or tubing material on sample quality. The pressure necessary to operate the bladder pumps is supplied by compressed nitrogen cylinders or liquid nitrogen dewars.

5.1.1.1 Bladder Pump Systems for Low-Flow Sampling

Many of the wells equipped with dedicated bladder pumps are designated for low-flow sampling. Wells equipped with low-flow systems are slowly purged until groundwater indicator parameters stabilize. When these parameters are stable, sample collection is initiated as described in later sections of this Plan.

5.1.1.2 Bladder Pump Systems for Higher Volume Purging and Sampling

Certain conventional monitoring wells equipped with dedicated bladder pumps that are used to purge at least three casing volumes of groundwater prior to sampling with the bladder pump. Dedicated bladder pump systems are used in wells with relatively short groundwater columns and small purge volumes.

5.1.2 Dedicated Bladder Pump/Inflatable Packer Systems

Several wells are equipped with dedicated inflatable packer/bladder pump systems. In this type of system, an inflatable packer is used to isolate monitoring zones to facilitate purging. Water is purged and sampled from the monitoring zone(s) using a dedicated stainless steel/Teflon bladder pump. Samples are collected directly from the Teflon-lined polyethylene or Teflon discharge tubing to ensure sample quality.

5.1.2.1 Single Zone Packer Systems

Many conventional monitoring wells have a single screened interval near the bottom of the well. In these wells, an inflatable packer is used to isolate a sampling zone in the well extending from just above the screened interval or targeted monitoring zone to the bottom of the well. This significantly reduces the amount of purge water generated prior to sample collection. This type of sampling system is used in monitoring wells where a relatively large amount of purging would be required if the packer was not used

[3] Teflon is a registered trademark of E.I. du Pont de Nemours & Company Corporation (Dupont).

or where an irregularity in the casing prevents the collection of representative samples using other sampling techniques.

5.1.2.2 Multiple Zone Packer Systems

Conventional monitoring wells may also be equipped with multiple screened intervals within a single casing to allow for the collection of groundwater samples from multiple depths within the aquifer. The screened intervals are separated by inflatable packer(s) to prevent vertical mixing between monitoring zones. This type of sampling system is used to provide for the collection of high quality groundwater samples from multiple screened intervals in one conventional well casing in which other multiport sampling systems are not ideally suited or have proven to be suboptimal.

5.1.3 Non-Dedicated Purge Pumps and Bailers

Although dedicated equipment is preferred for sample collection at WSTF, there are occasions when dedicated equipment is impractical or is incapable of sample collection because of equipment failure or current well and/or hydrogeologic conditions. Under specific circumstances, such as dedicated equipment failure, non-dedicated equipment is used to purge groundwater monitoring wells and to collect groundwater samples. Additionally, new groundwater monitoring wells may also be sampled using non-dedicated purge pumps and bailers until their purge characteristics can be determined and the appropriate dedicated equipment selected, acquired, and installed.

When sampling conditions preclude the use of dedicated sampling equipment, non-dedicated Teflon bailers are used to collect samples after purging with a non-dedicated pump. A non-dedicated pneumatically driven purge pump is used to evacuate the specified volume of water, then a bailer is lowered into the well for sample collection using a non-dedicated stainless steel cable. The pump, if required, can also be used to collect samples for inorganic analytes. Due to possible effects on sample integrity, this pump is not typically used to collect samples with volatilization potential.

To eliminate cross-contamination between wells, the pneumatic pump and Teflon bailer are decontaminated prior to each use. To ensure that the decontamination procedures are effective and to determine the potential occurrence of field contamination, equipment blanks are collected at regular intervals as indicated in later sections of this Plan. Decontamination procedures are briefly described in Section 6.0.

5.1.4 Other Equipment and Supplies

In addition to the specific sampling equipment listed in the previous sections, a variety of general equipment is required for sampling conventional monitoring wells. For instance, certified clean sample containers are used to ensure the collection of quality groundwater samples. Sample containers are provided by the contracted analytical laboratory or a qualified third party vendor and meet strict industry standard cleanliness requirements. NASA requires that sample containers be certified clean by an independent laboratory. Additional required equipment includes, but is not limited to: source of compressed nitrogen (or other suitable compressed gas to operate pneumatic equipment); pneumatic controllers and related hardware; replacement Teflon tubing; portable purge/decon water collection container(s); portable electric generator; water level indicator (depth probe); field logbook; portable water quality instruments; calibration/check standards for instruments; PPE (personal protective equipment); polyethylene baggies; ice chests and ice; and decontamination equipment and supplies (steam cleaner/pressure washer, detergent, brushes, etc.).

5.2 Westbay Monitoring Wells

Westbay sampling systems are designed to monitor multiple water-bearing zones within a single borehole using a single dedicated casing string. The systems are currently in use at WSTF to collect groundwater samples, obtain groundwater formation pressures to estimate piezometric elevations, and perform hydraulic conductivity determinations. NASA uses data obtained from these wells to formulate a three-dimensional conceptualization of the groundwater contamination plume.

5.2.1 MOSDAX Sampler Probe

The MOSDAX®[4] sampler probe is a non-dedicated electronic tool used to measure downhole fluid pressures and obtain in situ groundwater samples from Westbay wells. The system is operated by a handheld controller. The controller displays pressure readings and controls the downhole fluid measurement and sample collection functions of the probe. The probe contains an electronic strain-gauge pressure transducer for measuring fluid pressures within the Westbay standpipe and through the measurement port couplings located in each monitoring zone. The probe is equipped with an electronically controlled sample apparatus that, when appropriately activated, accesses a one-way valve in the Westbay well casing and collects a groundwater sample directly from the aquifer.

5.2.2 Stainless Steel Sample Bottles

Groundwater samples are collected from Westbay wells using the MOSDAX sampler probe and retrieved in a series of stainless steel sample bottles that are attached to the probe. These non-dedicated sample bottles are decontaminated prior to sample collection at each well, and equipment blanks are collected for analysis by the specific volatile analytical method(s) required at each well. Decontamination procedures are briefly described in Section 6.0.

5.2.3 Other Equipment and Supplies

In addition to the specific sampling equipment listed in the previous sections, a variety of general equipment is required for sampling Westbay monitoring wells. For instance, certified clean sample containers are used to ensure the collection of quality groundwater samples. Additional equipment includes, but is not limited to: portable purge/decontamination water collection container(s); portable electric generator; vacuum pump; water level indicator (depth probe); field logbook; portable water quality instruments; calibration/check standards for instruments; PPE; polyethylene baggies; ice chests and ice; and decontamination equipment and supplies (steam cleaner/pressure washer, detergent, brushes, etc.).

5.3 Water FLUTe Monitoring Wells

The Water FLUTe is a purgeable groundwater sampling and water level measurement system designed to monitor multiple zones within a single borehole. The system consists of waterproof polyurethane coated nylon fabric liner with integrated spacers that create sampling intervals for each discrete sampling port. Groundwater flows from the formation into the spacer and through a sealed sample port in the liner. Polyvinylidene fluoride and/or nylon tubing extends from the sample port to the top of the well casing to permit groundwater purging and sample collection from discrete monitoring zones.

[4] MOSDAX® is a registered trademark of Nova Metrix Ground Monitoring (Canada) Ltd.

5.3.1 Water FLUTe Flexible Liner

The Water FLUTe flexible liner is constructed of polyurethane coated nylon. The waterproof liner seals the entire borehole by maintaining excess water inside the liner above the static groundwater level in the formation. Spacers are sewn into the liner, which pull the liner away from the borehole wall to create discrete monitoring intervals.

5.3.2 Water FLUTe Sample Port and Internal Tubing

Sample ports are located in the Water FLUTe liner at the top of each monitoring zone to facilitate purging and sample collection. Polyvinylidene fluoride and/or nylon tubing extends from each sample port to the top of the well casing. Two tubes are present at the top of the well casing for each monitoring zone. Pressurized gas (i.e., nitrogen) is applied to the larger pump tube within the system during purging and sampling activities to drive water down to the bottom of the liner and up the second smaller sample tube of the system. A check valve is located at the bottom of the pump tube in order to isolate the sample port and formation from the pump tube during purging and sampling activities. A second check valve is located near the bottom of the sample tube and prevents the backflow of water from the sample tube to the pump tube and formation once the gas pressure is released.

5.3.3 Other Equipment and Supplies

In addition to the specific sampling equipment listed in the previous sections, a variety of general equipment is required for sampling Water FLUTe monitoring wells. For instance, certified clean sample containers are used to ensure the collection of quality groundwater samples. Additional equipment includes, but is not limited to: source of compressed nitrogen (or other suitable compressed gas to operate the Water FLUTe system); pneumatic controllers and related hardware; portable purge/decontamination water collection container(s); water level indicator (depth probe); transducer interface module; field logbook; portable water quality instruments; calibration/check standards for instruments; PPE; polyethylene baggies; and ice chests and ice.

6.0 Pre-Sampling Activities

A variety of tasks are performed at groundwater sampling events prior to the collection of groundwater samples. These pre-sampling activities include: initiation of the field sampling record (logbook); decontamination of non-dedicated sampling equipment; well site inspection; measurement of the groundwater elevation; well purging (if required); and the measurement of groundwater indicator parameters. As previously indicated, WSTF currently utilizes both conventional and multiport monitoring well configurations for the collection of groundwater samples. Monitoring well sampling systems can be further categorized depending on the purge and sample methods utilized at each monitoring well. In general, purging and sampling of conventional monitoring wells is performed either by utilizing low-flow techniques (i.e., a minimal volume of water is purged prior to sampling), or by purging a set volume of groundwater prior to sample collection. Some pre-sampling activities and equipment requirements differ based upon the specific sampling system and techniques in use at each monitoring well. The following sections briefly describe the basic pre-sampling tasks that are performed at each groundwater sampling event.

6.1 Decontamination of Non-Dedicated Equipment

Non-dedicated sampling equipment is thoroughly decontaminated between uses to prevent cross-contamination. Previous demonstrations have shown that WSTF contaminants are efficiently removed through the use of heated water, environmentally safe detergent, and/or triple rinsing with purified water.

Equipment is first transferred to the steam cleaning pad or decontamination sink. Equipment is disassembled if possible, and each piece is pressure washed on the steam pad or washed with heated water and detergent in the decontamination sink. Equipment is then rinsed with purified water before being covered or wrapped with polyethylene sheets or placed in plastic baggies to prevent contamination before use. If the equipment cannot be steam cleaned or exposed to detergent, it is triple rinsed with purified water and stored in polyethylene wrap or plastic baggies. All fluids used or produced during the decontamination activities are managed as investigation-derived waste (IDW) as described later in this Plan.

6.2 Field Sampling Record (Logbook)

The field sampling record, typically a bound, hard copy logbook, is used to record all activities, observations, and measurements that take place in the field during sampling events. Records of the field activities should be sufficient to allow an experienced individual, not associated with the sampling event, to recreate the events by reading the logbook. Following each sampling event, the field sampling record for the event is reviewed and approved by a knowledgeable contractor environmental staff member to ensure completeness and accuracy. The sampling record is maintained on site as a permanent record of the sampling event.

Information that is included in the field sampling record each time sampling is conducted includes:

- Monitoring well identification/designation.
- Date of the sampling event.
- Site-specific procedural documentation to be used.
- Identification of the members of the sampling party.
- Climatic/weather conditions.
- Initial static water level.
- Calculated purge volume (if required – dependent on sampling equipment).
- Purge rate, purge duration, purge time, and volume of water purged (if required).
- Well evacuation method and equipment.
- Sample collection method and equipment.
- Decontamination procedures for non-dedicated equipment in use.
- Indicator parameter measurements, equipment used, calibration or check standards, standard lot number(s), and most recent calibration date(s).
- Identification of field quality control samples and source of blank water.
- Groundwater sample collection sequence.
- Unique sample identification number for each sample.
- Type of sample container used for each sample.
- Method(s) of preservation used for each sample.
- Chemical analysis or analytical method to be performed on each sample.
- Laboratory (or laboratories) performing the analyses.

- Problems encountered during field activities and any corrective actions implemented.
- Any other relevant field observations.
- Signatures of preparer and reviewer.

Individual field sampling records vary depending on the type of well sampled, sampling equipment used, specific samples and quality control samples collected, and other project-specific requirements. Site-specific procedural documents used for groundwater sampling provide the specific requirements of the field sampling record for each type of groundwater sampling operation.

6.3 Equipment Calibration/Verification

Prior to use, field instrumentation and/or equipment used for the measurement of groundwater indicator parameters and/or the collection of other data is calibrated or verified as instructed in site-specific procedural documentation. Field instruments are calibrated as recommended by the manufacturer using certified traceable calibration standards. Records of calibration and/or field verification of calibration and operation are included in the field sampling record.

6.4 Well Site Inspection

Upon arrival at the well location, and prior to implementation of sampling activities, field personnel inspect the well location to ensure that it is safe and easily accessible for the planned work activities. They also inspect the condition of the wellhead, locking well cap, cement pad, and protective bollards. Any anomalies are noted in the field logbook and reported to the appropriate contractor environmental organization personnel for corrective action.

6.5 Groundwater Elevation

6.5.1 Static Water Level in Conventional Monitoring Wells

The static water level, or groundwater elevation, is manually measured in each conventional monitoring well prior to collecting samples at each sampling event. The static water level is also measured in many wells on an established schedule to provide consistent groundwater elevation data for use in groundwater modeling and the development of groundwater elevation maps for reporting. The frequency for determining the groundwater elevation in conventional wells is presented in Section 11.1.

To measure the static water level in a conventional monitoring well, a water level probe is slowly lowered down the well casing until it contacts the water surface as indicated by audible/visual alarms on the probe. The probe is then raised and lowered very slowly until the depth to water is determined to the nearest 0.01 ft. The depth measurement, reference point (top of casing or ground surface), and the corresponding date and time of measurement are recorded in the appropriate field logbook, which is provided to the responsible environmental contractor personnel for review.

On infrequent occasions when a water level cannot be measured due to unforeseen circumstances, such as a depressed water level or equipment failure, the field sampling record will be updated with the pertinent information.

6.5.2 Static Water Level in Westbay Monitoring Wells

In order to determine the groundwater elevation in Westbay wells, the hydraulic pressure at the desired measurement port is measured using the MOSDAX sampler probe. This pressure is used to calculate the piezometric level of the measurement port, which is converted to the groundwater elevation at that location. Prior to sampling a zone in a Westbay well, the hydraulic pressure at the measurement port is measured and recorded in the field logbook. Groundwater elevations are also determined at select Westbay wells on an established schedule to facilitate groundwater modeling and aid in the development of groundwater elevation maps for reporting. The frequency for determining the groundwater elevation in Westbay wells is presented in Section 11.1.

The depth to water inside the Westbay casing is first measured as indicated in the preceding section. A series of surface checks are performed on the MOSDAX sampler probe to ensure it is functioning correctly prior to measurement and sampling activities. To measure the hydraulic pressure, the MOSDAX sampler probe is lowered into the Westbay casing and located in the desired measurement port within the casing. The probe is allowed to equilibrate, after which the hydraulic pressure of the formation is measured using the electronic transducer in the MOSDAX sampler probe. If required, the hydraulic pressure is measured at each measurement port in the Westbay well to complete the pressure profile. These pressure measurements and their corresponding date and time of measurement are recorded in the field sampling record, which is provided to the responsible contractor environmental personnel for review. A relatively simple mathematical equation is applied later to convert field measurements to the piezometric elevation for the desired location.

6.5.3 Static Water Level in Water FLUTe Monitoring Wells

Deep water table depths and small diameter tubing used within the Water FLUTe monitoring well systems prevent direct measurement of the static water level in most Water FLUTe monitoring wells at WSTF. In lieu of direct measurement, dedicated vented pressure transducers are used to determine the static water level at individual Water FLUTe monitoring zones before collecting samples during each sampling event. If there is there is no pressure transducer present at a specific monitoring zone, or the transducer fails to function as designed, the static water level may be determined by the measuring the volume of water expelled during a full purge cycle. The frequency for determining the groundwater elevation in Water FLUTe wells is presented in Section 11.1.

To determine the static water level at a Water FLUTe well, the indicated feet of water above the transducer is recorded and subtracted from the initial transducer reading that was obtained immediately following installation of the Water FLUTe system. The difference between these values is then subtracted from the recorded static water level that was measured before installation of the Water FLUTe system. Groundwater elevation is determined by subtracting the calculated static water level value from the measuring reference point elevation, which is the top of the well casing. The transducer reading and the corresponding date and time of the measurement are recorded in the appropriate field logbook and provided to the responsible environmental contractor personnel for review.

In cases where a Water FLUTe monitoring zone does not contain a dedicated pressure transducer, or the transducer fails to provide a reliable reading, the static water level is calculated from the volume of water expelled from the zone during a full purge cycle. The measured purge volume and system tubing diameter measurement is used with the general cylinder volume equation to determine the height of water above the bottom of the Water FLUTe system. The calculated water height measurement is added to known depth of the system to determine the static water level. Groundwater elevation is determined by subtracting the calculated static water level value from the measuring reference point elevation, which is the top of the well casing. The purge volume and the corresponding date and time of the measurement are recorded in the appropriate field logbook and provided to the responsible environmental contractor personnel for review after the completion of field sampling activities. Groundwater elevations calculated from purge volumes are not used to develop graphical representations of the groundwater surface at WSTF.

6.6 Well Purging/Preparation

This section provides basic purging procedures for the well systems described in previous sections of this Plan.

6.6.1 Bladder Pump Systems for Low-Flow Sampling

Most conventional groundwater monitoring wells are purged and sampled using dedicated low-flow sampling equipment (Table 5). Groundwater is purged from these wells slowly to avoid vertical mixing of the water within the casing. Some non-dedicated low-flow sampling equipment is assembled prior to purging a monitoring well. Using a properly rated pressure regulator and flex hose, a pressure source (typically compressed nitrogen gas) is connected to a pneumatic controller box, which is then attached to the wellhead with a second flex hose. A dedicated virgin Teflon discharge tube is attached to the appropriate port on the wellhead and routed to the flow-through cell (flow cell). A section of non-dedicated tubing is routed from the flow cell to the purge water collection container.

The pressure source and pneumatic controller are set at the starting pressure based on the depth of the bladder pump. The purge cycle is then optimized using the available settings (refill, discharge, and throttle) on the pneumatic controller. The static water level is monitored during purging to ensure minimal drawdown. If the water level begins to drop, the purge rate of the well is reduced such that the water level can be maintained within 25% of the distance between the top of the screened interval and the pump intake. If the drawdown exceeds this limit, an additional volume of water equal to that of the excess drawdown is purged prior to sample collection.

Some wells at WSTF are installed in very low yield formations. If the water level in the well continues to drop with each purge cycle when the refill is set to the maximum time, the well is considered low yield. For these wells, modified purging techniques are used to ensure that stagnant casing water is not sampled. Purging is continued at the low rate until the water level has dropped to three times the maximum allowable drawdown. Purging is discontinued at this point and the water level is allowed to recover to a level adequate to collect groundwater samples without exceeding three times the allowable drawdown. When the water level has recovered sufficiently, the bladder pump is cycled several times to clear stagnant water from the discharge tubing before sample collection.

During purging operations, groundwater indicator parameters are monitored at regular intervals as discussed in Section 6.7.1.

6.6.2 Dedicated Bladder Pump Systems for Higher Volume Purging and Sampling

In wells with dedicated bladder pump systems (Table 5), the depth to water in the well casing is utilized in conjunction with the total well depth to calculate the required volume of groundwater to be purged. Typically, three well volumes are purged prior to sampling. Using a properly rated pressure regulator and flex hose, a pressure source (typically compressed nitrogen gas) is connected to a pneumatic controller box, which is then attached to the wellhead with a second flex hose. If the well is not already equipped with dedicated discharge tubing, a dedicated virgin Teflon discharge tube is attached to the appropriate port on the wellhead and routed to the purge water collection container.

The pressure source and pneumatic controller are set at the starting pressure based on the depth of the bladder pump. The purge cycle is then optimized using the available settings (refill, discharge, and throttle) on the pneumatic controller. Using a container of known volume, the purge rate is determined by monitoring the time required to fill the container. At established intervals during purging, primary and secondary indicator parameters are measured as indicated in Section 6.7.2. When three well casing volumes have been removed, purging is complete and sampling can be initiated.

Low yield wells (those that do not recover sufficiently to produce three well casing volumes) are pumped dry. If the recovery rate is greater than 10 ft per hour, the well is allowed to recover for one hour then purged dry again. The well can be sampled when the water rises to a level that permits the pump to function. In cases where the recovery rate is less than 10 ft per hour, the water level is allowed to rise to a level that permits the pump to function, then sampling is performed. All pertinent information related to purge volumes and times is recorded in the field logbook.

6.6.3 Dedicated Bladder Pump/Inflatable Packer Systems

Several conventional monitoring wells are equipped with dedicated inflatable packers (Table 5) that are positioned to isolate the monitoring zone(s) in the well. Inflation of the packer shortens the water column and effectively reduces the required purge volume. The well casing volume used for purging is equal to that between the bottom of the packer and the bottom of the well sump or the volume required to achieve stable indicator parameters during low-flow sampling. Following packer inflation using compressed nitrogen, purging is performed using a dedicated bladder pump as described in the preceding section.

6.6.4 Non-Dedicated Purge Pumps and Bailers

Recently installed groundwater monitoring wells, those that have not been fully characterized, or wells in which dedicated equipment is not ideal, are purged using the non-dedicated pump (Table 5). Also, in the event that dedicated equipment fails or otherwise becomes unserviceable, it can be removed and non-dedicated equipment can be used to purge and sample a monitoring well. The total required purge volume is calculated based on the monitoring well design. The decontaminated non-dedicated purge pump is lowered into the well and activated using a pressure source. The pumping rate is measured to determine the time required to complete purging. The well is then purged as described in previous sections. When the required volume of groundwater has been purged and groundwater indicator parameters have been measured, the non-dedicated purge pump is removed from the well and sampling can be performed as indicated later in this Plan.

6.6.5 Westbay Monitoring Wells

Westbay wells are designed to allow the collection of groundwater samples directly from the formation with minimal active purging. The Westbay sampling apparatus must be assembled prior to sample collection. Previously decontaminated stainless steel sampling bottles are triple rinsed with purified water and attached to the bottom of the Westbay probe for use in sample collection. WSTF procedures for sampling Westbay wells require that these stainless steel sample bottles be rinsed once with formation water prior to sample collection. The sampling apparatus is lowered into the monitoring well and located in the sampling port at the least contaminated monitoring zone. The sampler probe, which is controlled from the surface, is used to access the formation outside the Westbay casing through a one-way valve in the casing and a corresponding valve in the probe. When the probe is located in the sampling port, it is sealed against the one-way valve in the casing to open it. The valve in the probe is then opened and a small volume of groundwater is drawn through the probe and into the stainless steel sample bottles attached to it. This volume, typically between one and two liters, is purged from the formation and used for the measurement of groundwater indicator parameters prior to sample collection.

6.6.6 Water FLUTe Monitoring Wells

Water FLUTe monitoring systems allow for the purging and sampling of multiple groundwater monitoring zones within a single conventional well or borehole. Monitoring wells or open boreholes equipped with Water FLUTe sampling systems (Table 5) are configured to isolate the monitoring zone(s) in the well or borehole. The pressure provided by excess water inside the FLUTe liner above the formation static water level seals the liner to the borehole or casing wall. This process isolates the monitoring zone and significantly reduces the volume of groundwater that must be purged to obtain representative samples.

The Water FLUTe monitoring system uses pressurized gas (typically nitrogen) to drive water from the system's larger pump tube to the smaller sample tube during purging activities. The gas pressure applied during purging activities is sufficient to expel all water from the system. Once all water is expelled, the gas pressure is released and a check valve opens to allow the system to refill with formation water through the sample port. This process is repeated until a sufficient volume of water is discharged from the system to ensure representative groundwater samples are collected. Two to four gallons are typically purged from each monitoring zone prior to sample collection.

6.7 Groundwater Indicator Parameters

This section describes the field measurements, or groundwater indicator parameters, that are collected during the purging and sampling of groundwater monitoring wells. Generally, the first and last samples of groundwater collected at each sampling event are reserved for the measurement of indicator parameters. The collection of groundwater for the measurement of indicator parameters is an integral part of the groundwater sampling process. As a result, the process of collecting indicator parameters varies slightly depending on the specific monitoring well system in use. The following is a brief discussion of indicator parameters and the equipment and supplies used for the different monitoring well configurations present at WSTF.

6.7.1 Bladder Pump Systems for Low-Flow Sampling

The majority of conventional monitoring wells at WSTF are sampled using dedicated low-flow bladder pumps (Table 5). Indicator parameters are measured during low-flow purging operations in accordance with acceptable low-flow practices and recorded in "sets." Indicator parameters are monitored using an in-line flow-through cell, which is equipped with multiple probes and/or sensors that measure temperature, pH, conductivity, ORP (oxidation/reduction potential), and DO (dissolved oxygen). Turbidity is frequently measured separately using water collected upstream of the flow cell. The depth to water is also closely monitored to ensure minimal drawdown during low-flow sampling. Indicator parameters are monitored throughout purging operations. When three sets of indicator parameters have stabilized to within 10%, purging is considered complete and sampling is initiated.

6.7.2 Dedicated Bladder Pump Systems

A number of conventional monitoring wells at WSTF are equipped with dedicated bladder pumps (Table 5). Some of these monitoring wells also utilize dedicated inflatable packers to isolate the screened intervals and reduce the volume of purge water generated during purging. Indicator parameters are collected from non-low-flow dedicated bladder pumps in a similar manner. Groundwater is collected directly from the dedicated bladder pump discharge tubing and is dispensed into a small clean container for parameter measurement using field instruments. A small volume of groundwater is dispensed directly into the turbidity vial for use in the field turbidity meter. Each set of indicator parameters typically consists of temperature, pH, conductivity, and turbidity. Generally, sampling personnel collect three sets of indicator parameters when sampling a well equipped with a dedicated bladder pump: the initial parameters are collected when approximately two casing volumes of water have been removed from the well; the secondary parameters are collected immediately prior to sampling after three casing volumes of water have been purged; and the third and final set is collected after all the necessary groundwater samples have been collected.

6.7.3 Non-Dedicated Purge Pumps and Bailers

When dedicated sampling systems are not practical, or fail to provide the overall groundwater sample quality required at WSTF, non-dedicated purge pumps and bailers are used (Table 5). When sampling with this equipment, indicator parameters are measured in a manner similar to that employed when sampling with dedicated bladder pumps, in which three sets of indicator parameters are collected. The initial and secondary parameters are measured using groundwater collected directly from the discharge tubing of the non-dedicated purge pump and dispensed into a small clean container or turbidity vial. The final set of indicator parameters is dispensed from the bailer into the appropriate vessel after the required groundwater samples have been collected.

6.7.4 Westbay Monitoring Wells

The collection of indicator parameters at Westbay monitoring wells (Table 5) utilizes much of the same equipment as other sampling methods. Groundwater obtained from the initial sample collection "run" is used for the measurement of indicator parameters. When the Westbay probe and sampling apparatus is brought to the surface, groundwater is dispensed directly from the lowermost sample bottle into a small clean container and turbidity vial for measurement of indicator parameters with field instruments. Excess groundwater is discarded into the purge water collection container and managed appropriately in accordance with specific instructions provided in later sections of this Plan. Two sets of indicator parameters are measured – initial and final. Each set consists of temperature, pH, conductivity, and turbidity. Initial parameters are obtained using water collected before the groundwater samples, while the final parameters are those measured using the water that remains in the stainless steel Westbay sampling bottles after groundwater samples have been collected.

6.7.5 Water FLUTe Monitoring Wells

Indicator parameters are measured at Water FLUTe wells (Table 5) using groundwater collected during the first sample "stroke" of the system. After purging is complete, the gas pressure is lowered to the required sampling pressure defined for the particular system. The sampling pressure for each Water FLUTe is carefully calculated to ensure that a buffer of water remains in the pump tube during sample collection. This ensures that the water being collected during sampling is not aerated by the pressurized gas used to expel water from the system. During the initial sample stroke, an initial volume of water is collected to ensure any residual air is removed from the system prior to sampling. This water is used for the measurement of indicator parameters to help monitor system performance. Any excess groundwater remaining after these indicator parameters are collected is discarded into the purge water collection container and managed appropriately in accordance with specific instructions provided in later sections of this Plan. Two sets of indicator parameters are measured as part of sampling – initial and final. Each set consists of temperature, pH, conductivity, and turbidity. Initial parameters are obtained using water collected before the groundwater samples, while the final parameters are those measured using groundwater that is discharged in the final sample stroke after groundwater samples have been collected.

7.0 Sampling Procedures

This section summarizes the procedures for sampling groundwater monitoring wells at WSTF.

7.1 Conventional Monitoring Wells

7.1.1 Dedicated Bladder Pump Systems

After the monitoring well has been purged as described in Section 6.6, the pumping rate is adjusted to approximately 100 mL per minute to facilitate the collection of samples for analysis of volatiles. A VOC sample vial is positioned under the discharge tube at an angle that allows the water to flow down the inside of the container with a minimum of turbulence. As the vial fills, it is rotated to an upright position and filled until a reverse meniscus is visible. The vial is capped, inverted to check for air bubbles, and placed on ice. When the vials have been filled, they are assigned a sample number as indicated in this Plan and appropriately labeled and sealed. The remaining groundwater samples are collected in descending order of sensitivity to volatilization. Each sample is assigned a sample number and appropriately labeled and sealed. Samples that must be cooled are placed on ice. Pertinent sampling information (sample numbers, relevant activities/conditions, etc.) are recorded in the field logbook.

7.1.2 Non-Dedicated Purge Pumps and Bailers

Following removal of the non-dedicated purge pump from the groundwater monitoring well after purging, the well is sampled using a non-dedicated Teflon bailer. The bailer is first decontaminated as previously described, and then transported to the well site wrapped in polyethylene sheeting to ensure cleanliness. It is attached to a stainless steel wire rope and lowered into the monitoring well. As it approaches the groundwater surface, the rate of descent is slowed and personnel listen for the sound of the bailer entering the water. It is slowly lowered into the water until it fills and is then raised to the surface. A decontaminated Teflon delivery stopcock is placed into the bottom of the bailer and a small amount of groundwater is flowed through the stopcock to serve as a final rinse. Groundwater is also collected at this time to measure the final turbidity. Samples sensitive to volatilization are collected from the stopcock in a manner similar to that previously described. VOC vials are filled, checked for headspace, labeled, sealed, and placed on ice. The bailer is lowered, filled, and retrieved as necessary to fill the remaining sample containers. Groundwater is collected from the last bailer run to measure final indicator parameters other than turbidity. All pertinent information related to sample collection is recorded in the field logbook.

7.2 Westbay Monitoring Wells

Previous sections of this Plan described the processes for measuring the hydraulic pressure in Westbay monitoring zones, assembling the sampling apparatus, and removing a small volume of groundwater from the formation at the sampling location to measure indicator parameters and rinse the sample collection bottles. To collect groundwater samples, the Westbay sampling apparatus is lowered into the well casing and located in the sampling port at the least contaminated monitoring zone, ensuring that equipment is not cross-contaminated between zones if decontamination is ineffective. It is sealed against the one-way valve in the casing and the valve in the probe is opened. Groundwater is collected from the sampling port using the MOSDAX sampler probe and stainless steel sample bottles. When the bottles have been filled with groundwater, the valves are closed and the sampling apparatus is brought to the surface. Groundwater is then dispensed from the lowermost stainless steel sampling bottle directly into the appropriate sample container. Samples are collected in descending order of sensitivity to volatilization as described in previous sections of the Plan. The process is repeated at each required monitoring zone. All pertinent information related to sample collection is recorded in the field logbook.

7.3 Water FLUTe Monitoring Wells

Previous sections of this Plan described the processes for determining the water level in Water FLUTe sampling systems and purging a sufficient volume of groundwater from the formation at the sampling location to measure indicator parameters and ensure the collection of representative groundwater. To collect groundwater samples, the gas pressure is lowered to the predefined sampling pressure for the system. The sampling pressure varies between each well because of different static water levels and tubing lengths within the Water FLUTe systems. The defined sampling pressure for each system maintains a buffer of water in the system's pump tube while samples are being collected. This ensures that the water being collected is not aerated by the pressurized gas. A sample "stroke" is initiated at a zone by opening the control valve for the pressurized gas, which pushes water down the pump tube to the sampling tube within the system. This process is identical to the purging procedure, but the gas is applied at a lower pressure to maintain the buffer of water with the system, as described previously. An initial volume of water is collected to ensure there is no remaining air within the system, which is also used to measure initial indicator parameters.

After confirming no air remains within the system, groundwater samples are collected directly from the Water FLUTe sample tube at the top of the well casing. The discharge from the sample tube slows and eventually stops as water is expelled from the system. When this occurs, the gas pressure is released, which allows the check valve at the bottom of the pump tube to open. This allows groundwater from within the liner spacer to flow through the sample port and refill the pump tube. A second check valve at the bottom of the sample tube also closes to prevent the backflow of water from the sample tube to the pump tube while the system is in a relaxed state. Subsequent sample strokes are used to produce a sufficient volume of water for the required samples. Samples are collected in descending order of sensitivity to volatilization as described in previous sections of the Plan. Following final sample collection and measurement of final indicator parameters, the gas pressure is increased back to the purge pressure to expel all water from the system's sample tube. This water is discarded into the purge water collection container and managed appropriately in accordance with specific instructions provided in later sections of this Plan. All pertinent information related to sample collection is recorded in the field logbook.

8.0 Post-sampling Activities

Following groundwater sampling, a variety of tasks must be performed to complete the sampling event. Post-sampling activities are summarized in this section.

8.1 Sample Management

Environmental samples collected at WSTF are strictly controlled. This section briefly describes the manner in which samples are identified, labeled and sealed, stored, documented, and shipped to off-site laboratories to ensure proper custody is maintained.

8.1.1 Sample Identification

A unique sample number is assigned to each sample at the time of collection that identifies the general sample collection location and sample date (year, month, day, and time. An example of a sample number is: 1905251035. In this example, 19 refers to the year (2019), 0525 refers to the date of collection (May 25), and 1035 refers to the time of collection (1035 hours, or 10:35 AM). In some instances, the sample number may be followed by a letter that identifies a specific field sampling crew or project. Additionally, when collecting samples for certain projects, the sample number may be preceded by an additional letter that identifies the sample collection location (e.g., Plume Front extraction well). This sample identification format is used for all groundwater samples and quality control samples.

8.1.2 Sample Labels and Custody Seals

Sample labels are required to avoid sample misidentification, either in the field, during packaging, or at the analytical laboratory. Sample labels are affixed to each sample container by sampling personnel immediately after sample collection and preservation (if required). Sample labels include, at a minimum, the following information:

- The unique sample number as previously defined.
- Identification of the well/zone being sampled.
- Identification of the sampling personnel.
- The analysis required for the sample.
- The preservation method utilized for the sample.

Sample custody seals are required to ensure that samples are not tampered with prior to laboratory preparation or analysis. Custody seals are completed and affixed to each sample container by sampling personnel immediately after the sample label is affixed to the container. Custody seals are placed over or around the cap of each sample container in a manner that ensures the seal must be broken to access the groundwater in the container. This ensures that access to the sample is controlled and limited to the receiving laboratory. Seals are inspected upon arrival of the sample at the analytical laboratory. Sample seals include, at a minimum, the following information:

- The unique sample number.
- Identification of the well/zone being sampled.
- Identification of the sampling personnel.

Additional custody seals are placed on sample shipping containers to demonstrate that the container is not tampered with during shipment to the analytical laboratory. Ice chest custody seals are affixed to the ice chest in a manner that ensures the seal must be broken to access the samples in the shipping container. Seals are inspected upon arrival of the shipping container at the analytical laboratory. Seals include, at a minimum, the following information:

- The date the container was packaged.
- The initials or signature of the individual responsible for packaging the sample shipping container.

8.1.3 Sample Storage

Most groundwater samples collected at WSTF must be cooled to 4 ± 2 °C following collection. To prevent alteration of these samples during collection, sample containers are cooled on ice prior to sample collection. Immediately following collection, preservation, and labeling, groundwater samples are placed on ice until they are transferred to refrigerated storage. Until shipment or transfer to the analytical laboratory, groundwater samples that require refrigeration are stored in a secure dedicated refrigerator that maintains a constant temperature of 4 ± 2 °C. Additionally, all samples that potentially contain contaminants that are sensitive to volatilization are stored (and later shipped) with the container septa facing down. This procedure minimizes possible volatilization of the target compounds through the septum.

8.1.4 Sample Custody

NASA maintains strict custody of groundwater samples at all times. As part of each sampling event, field chain of custody forms are updated with pertinent sample information, including: the date of the sampling event; location of sampling event; unique sample number(s); number of sample containers for each sample; sample matrix; required analysis for each sample; signature of the individual relinquishing custody; signature of the individual accepting custody; and the date of each. Throughout the sampling event, sampling personnel retain physical custody of groundwater samples. Upon completion of the sampling event, or as dictated by operational requirements, sampling personnel deliver groundwater samples to a secure dedicated refrigerator for storage prior to their shipment to a contracted laboratory. These personnel sign and date the internal chain of custody form(s) and indicate that sample custody was relinquished to secure storage. Access to the sample storage refrigerator is restricted to sampling and sample management personnel.

The designated sample management personnel accept custody of the samples as part of the packaging and shipment process described in the following section, and sign and date the custody form(s) accordingly. Separate lab- or contract-specific external chain of custody forms are prepared by the designated sample management personnel as part of the sample shipping process. The external chain of custody form includes pertinent information, including: date of shipment; laboratory name and purchase order number; return address for analytical results; project personnel contact information; unique sample number(s); number of sample containers for each sample; sample matrix; required analysis for each sample; applicable notes/comments; signature of the individual relinquishing custody; signature of the individual accepting custody; and the date of each. Completed chain of custody forms are retained as part of the sampling event record.

8.1.5 Sample Packaging and Shipment

Groundwater samples are securely packaged prior to shipment to off-site contracted analytical laboratories. Sample management personnel inspect sample containers to confirm sample identity and the accuracy and consistency of labels and related documentation. Sample containers are then wrapped or packaged in appropriately sized packaging material such as bubble wrap or foam inserts in a manner that will prevent breakage during shipment. Samples are then securely packed into an appropriately sized ice chest with sealed drain hole for shipment to the contracted analytical laboratory. The signed and dated external chain of custody form is placed in the ice chest, which is then sealed with a custody seal as previously indicated. The ice chest is further sealed to prevent any potential leakage should a sample container break during shipment.

After being securely packaged, groundwater samples collected at WSTF are typically shipped by commercial carrier (UPS, FedEx, etc.) to an off-site contracted analytical laboratory. Sealed ice chests are provided to the designated representative of the commercial carrier and shipped via next-day delivery service to the analytical laboratory. Sample shipping containers are managed by the commercial carrier as standard parcels to ensure delivery to the analytical laboratory in the specified time. Sealed ice chests are not accessed by shipping company personnel during shipment. Samples are scheduled for delivery to the analytical laboratory within their method-specified holding times with adequate time for the laboratory to initiate sample preparation and analysis. Upon arrival at the analytical laboratory, the shipping container is inspected by laboratory sample management personnel. Laboratory personnel then break the ice chest custody seal, review the chain of custody form, inspect sample containers, determine the temperature of samples using their laboratory-approved method, and accept custody of the samples by signing and dating the custody form. Complete chain of custody forms are included in the final report submitted by the analytical laboratory to NASA and are maintained at WSTF as part of the final analytical report.

8.2 IDW Management

WSTF groundwater contains halogenated and non-halogenated solvents such as TCE and Freon 11 that were used historically for degreasing and other laboratory processes. Due to the presence of these types of contaminants, special management requirements apply to purged groundwater and related media.

Under the Contained-In Policy, EPA requires environmental media to be managed as if they were hazardous waste if they contain listed hazardous waste or exhibit a hazardous characteristic. By application of the Contained-In Policy, groundwater removed from the contaminated portion of the WSTF plume has been characterized as F001 and F002 listed waste. Furthermore, several F001 and F002 regulated hazardous constituents are present at many monitoring locations in WSTF groundwater at concentrations that exceed cleanup levels.

Environmental media is considered to meet the definition of a RCRA solid waste at the time it becomes actively managed. The term "Active Management" is defined by EPA as "physically disturbing the accumulated wastes within a management unit…" (EPA530-K-05-011). Therefore, contaminated groundwater is considered to be a solid waste and is therefore subject to the RCRA hazardous waste identification and management requirements at the time that it is removed from a groundwater monitoring well. Because groundwater removed from the WSTF plume meets one or more of the listed waste definitions, any other material that comes into contact with contaminated groundwater is similarly regulated as "contact waste." Contact waste includes spent PPE, contaminated sampling supplies, plastic, and other material that has come into contact with contaminated media. More specifically, this material is debris contaminated with environmental media containing hazardous waste.

During groundwater monitoring activities, several types of IDW are generated, including, but not limited to: contaminated groundwater collected during monitoring well purging and sampling operations; fluids generated during decontamination of non-dedicated sampling equipment; and potentially contaminated debris. The management strategy for this IDW is provided in the following sections.

8.2.1 IDW Water

Water generated during purging and/or development of monitoring wells or during decontamination of equipment that has come into contact with contaminated groundwater is collected in containers of various sizes (carboys, drums, trailer-mounted tanks, etc.). Containers are managed on site in accordance with requirements of 40 CFR 262.17 (2017) and 20.4.1.300 NMAC, including markings, accumulation time limits, and container requirements.

Within the permissible accumulation time limits, IDW water is transferred to the MPITS for storage, treatment, and discharge. The MPITS was designed and operates with provisions for the storage and treatment of IDW water as described in the MPITS Interim Measure Work Plan (NASA, 2008).

8.2.2 IDW Contact Waste

IDW contact waste, or potentially contaminated debris, that has come into contact with contaminated water includes, but is not limited to: non-dedicated sampling equipment (tubing, bailers, etc.) that cannot be decontaminated for recycling or reuse; disposable PPE such as gloves; and disposable equipment used for decontamination of equipment. This waste is collected at the end of each working shift and transferred into an appropriate container that is managed on site in accordance with the requirements of 40 CFR 262.17 (2017), including markings, accumulation time limits, and container requirements. Within the permissible accumulation time limits, IDW contact waste is shipped off-site for treatment and disposal at an approved facility, as appropriate.

8.3 Determination of Groundwater Flow Direction and Rate

Groundwater flow directions are estimated using hand-contoured potentiometric surface maps. Groundwater flow direction is assumed to occur perpendicular to equipotential lines, except where contaminant distribution or other data indicate significant anisotropy. Currently, the spatial distribution of groundwater contaminants is consistent with groundwater flow directions approximately perpendicular to equipotential lines; however, this may change as more data are collected.

The groundwater flow rate is calculated for several facility zones based on groundwater flow directions inferred from potentiometric surface maps and physical properties of aquifer materials. For example, the facility is typically subdivided into zones such as "source areas, Mid-plume, and Plume Front" or "bedrock and alluvium". The average gradient and flow direction for all shallow monitoring intervals inside each of the zones are determined using groundwater gradient calculations. The rate of groundwater flow is calculated using Darcy's Law according to the equation:

$$\text{Groundwater velocity} = [K(dh/dl)]/n_e$$

In the above equation, K is the average horizontal hydraulic conductivity of the aquifer zone, dh/dl is the average hydraulic gradient, and ne is the average effective porosity of the zone. The negative sign indicates that the direction of groundwater flow is down the hydraulic gradient. Average hydraulic conductivity is calculated using available aquifer test and numerical modeling results. Average effective porosity is estimated based on available lithologic data and numerical modeling results. Groundwater flow direction at WSTF is represented in Figure 12.

9.0 Chemical Analytical Methods

Samples are collected from WSTF groundwater monitoring wells and analyzed by a variety of chemical analytical methods. Chemical analytical methods used to analyze for the hazardous constituents and other analytes discussed in Section 3.1 are specified in this section. For many hazardous constituents or other analytes, NASA requests a chemical analytical method that is best suited for quantitation of that analyte based on past experience with WSTF groundwater. In other cases, NASA expects the analytical laboratory to propose an analytical method for the most effective and efficient analysis of the compound. In all cases, the analytical laboratory will utilize the most recent EPA and/or industry-accepted chemical analytical methods available for the hazardous constituent specified. For each hazardous constituent, preferred MDL (method detection limits), which are equal to 20 percent of the applicable cleanup level in accordance with Permit Section 17.3, are presented. Preferred MDL and accompanying PQL (practical quantitation limits) are incorporated into the competitive bid process for securing contracted analytical services in order to obtain the most sensitive analyses possible. Laboratories are required to achieve the lowest practicable MDL for hazardous constituents as indicated in Permit Section 17.3.3.c. More specific information related to the QA/QC (quality assurance and quality control) practices and procedures associated with the WSTF groundwater monitoring program are provided in Section 10.0.

9.1 Volatile Organic Compounds

Samples for the analysis of VOC are collected at each groundwater monitoring well or zone at each scheduled sampling event. To best quantitate the levels of VOC in WSTF groundwater, NASA uses the most current version of SW-846 Method 8260 (EPA, 2007). Table 6 provides the preferred MDL and PQL for the analysis of volatile organic hazardous constituents and other analytes in WSTF groundwater.

9.2 NDMA

Samples for the analysis of NDMA are collected at each groundwater monitoring well or zone outside of the 100/600 Area at most scheduled sampling events. To most effectively quantitate the levels of NDMA in WSTF groundwater, NASA uses two analytical methods: Modified EPA Method 607 (for groundwater with higher levels of NDMA) and a more sensitive low-level analytical method (for groundwater with lower levels of NDMA). NASA selects the appropriate analytical method for the analysis of NDMA based on well location and expected concentrations. Table 6 provides the preferred MDL and PQL for the low-level analytical method for the analysis of NDMA in WSTF groundwater.

9.3 Metals

Samples for the analysis of metals are collected at each groundwater monitoring well or zone, usually on a less frequent basis than for VOC and nitrosamines. Several different methods are used to analyze for metals in groundwater samples. The contracted analytical laboratory specifies the most appropriate analytical method to best achieve the preferred MDL and PQLs. Table 6 provides the preferred MDLs and PQL for the analysis of metals in WSTF groundwater.

9.4 Inorganic Compounds

Samples for the analysis of inorganic compounds are collected at most groundwater monitoring wells and zones on a less frequent basis than for VOC and nitrosamines. Inorganic compounds are analyzed for in groundwater samples using several different methods. The recommended methods and associated preferred MDLs and PQLs are provided in Table 7. The contracted analytical laboratory may recommend analytical methods other than those requested by NASA to more effectively and efficiently achieve the preferred MDL and PQL. NASA expects to accept these laboratory recommendations if the proposed alternate analytical methods meet or exceed the analytical criteria of the analytical methods specified in Table 7. Specific information related to the analytical method utilized is included in the PMR.

9.5 Semi-Volatile Organic Compounds

Samples for the analysis of SVOC are collected at most groundwater monitoring wells and zones on a less frequent basis than for VOC and nitrosamines because only a limited number of SVOC have been detected in WSTF groundwater. To quantitate concentrations of SVOC in WSTF groundwater, NASA uses the most current version of SW-846 Method 8270 (EPA, 2017). The recommended methods and associated target MDL and PQL for the analysis of SVOC are provided in Table 7. The contracted analytical laboratory may recommend analytical methods other than those requested by NASA to more effectively and efficiently achieve the preferred MDL and PQL. NASA expects to accept these laboratory recommendations if the proposed alternate analytical methods meet or exceed the analytical criteria of the analytical methods specified in Table 7. Specific information related to the analytical method utilized is included in the PMR.

On December 19, 2017, NMED directed NASA to utilize SW-846 Method 8270 with Selective Ion Monitoring for the analysis of 1,4-dioxane at specific groundwater monitoring wells at WSTF (NMED, 2017b). Table 7 also provides the target MDL and PQL for the analysis of 1,4-dioxane.

9.6 Miscellaneous Hazardous Constituents

Samples for the analysis of miscellaneous hazardous constituents are collected only at selected groundwater monitoring wells and zones. Samples are collected on a relatively infrequent basis because only a limited number of these hazardous constituents have been detected in WSTF groundwater. The recommended methods and associated preferred MDL and PQL for the analysis of miscellaneous hazardous constituents are provided in Table 7. The contracted analytical laboratory may recommend analytical methods other than those requested by NASA to more effectively and efficiently achieve the preferred MDLs and PQLs. NASA expects to accept these laboratory recommendations if the proposed alternate analytical methods meet or exceed the analytical criteria of the analytical methods specified in Table 7. Specific information related to the analytical method utilized is included in the PMR.

NASA submitted the *Response to Disapproval of First Tracking and Data Relay Satellite System (TDRSS) Diesel Release (SMWU 50) Investigation Work Plan* on July 27, 2017 (NASA, 2017d). In the revised work plan, NASA recommended the collection of groundwater samples for the analysis of TPH (total petroleum hydrocarbons; GRO [gasoline range organics] and DRO [diesel range organics]) by SW-846 Method 8015 from groundwater monitoring wells that may have been impacted by the release of diesel fuel at SWMU 50. Though GRO and DRO are not considered hazardous constituents, preferred MDL and PQL are provided in Table 7.

10.0 Quality Assurance/Quality Control Program

This section outlines QA/QC requirements to ensure that WSTF groundwater monitoring data are valid and of known quality. Collecting and maintaining valid data of known quality supports the groundwater monitoring program goal of providing consistent and accurate representation of actual groundwater contaminant concentrations and movement over time. To achieve this goal, this Plan as a whole provides a consistent framework for the generation of valid physical and chemical analytical data. This section addresses the following specific data quality elements:

- Field and laboratory quality control procedures and measurement evaluation criteria to ensure that collection and analytical systems generate data of sufficient quality to meet the program goals.
- Laboratory reporting requirements sufficient to support the program goals.
- Quality assurance review procedures designed to indicate the extent to which groundwater monitoring data generated is appropriate for its intended use.
- Early detection of deficiencies and prompt corrective action to minimize effects on data quality.

All data generating steps, including sample collection, shipment, analysis, custody control, document control, data review, and data storage are performed using established procedures to ensure data quality. This Plan, coupled with adherence to procedures outlined in site-specific procedural documents, equipment operation and maintenance manuals, analytical statements of work, NELAC (National Environmental Laboratory Accreditation Conference) accreditation standards, laboratory SOP (standard operating procedures), and laboratory quality manuals ensures that data meet the objectives of the WSTF groundwater monitoring program.

This section provides specific information related to the following QA/QC issues associated with the groundwater monitoring program at WSTF:

- Contracted chemical analytical laboratories.
- Quality control samples and related procedures.
- Data quality indicators.
- Analytical data quality exceptions and qualified data.
- Analytical data management, including verification and validation.

- Internal reporting.

10.1 Contracted Analytical Laboratories

The contractor environmental organization contracts accredited analytical laboratories to analyze groundwater samples in support of the WSTF groundwater monitoring program. Prior to awarding any analytical support contracts, each analytical laboratory must respond to all requirements in the Statement of Work prepared by qualified contractor environmental organization personnel, submit proof of accreditation by an industry-recognized accreditation body, and submit the laboratory quality manual and applicable SOP to the contractor environmental organization for review and approval. These documents ensure that laboratories meet the performance criteria for WSTF groundwater monitoring activities.

Contracted analytical laboratories will perform all analyses using procedures detailed in the submitted laboratory SOP that are based on the most recent EPA and industry-accepted preparation and analytical methods for an aqueous matrix (groundwater) as discussed in the previous section.

10.1.1 Laboratory Quality Manual

Documentation of the analytical effort is outlined in the Quality Manuals submitted by the analytical laboratories as part of the competitive bid process. The contractor environmental organization reviews and approves the laboratory Quality Manual prior to a contracted laboratory commencing analyses. The laboratory's Quality Manual must include, at a minimum, the following:

- Personnel qualifications and training plans.
- Documentation and records management procedures.
- Quality control procedures.
- Work processes, operating procedures and methods.
- Quality assessment, standardization and response action plans.

10.1.2 Laboratory Deliverables

The laboratory analytical data package shall be prepared with sufficient information to meet the requirements of the WSTF groundwater monitoring program. The data packages shall be delivered to responsible contractor environmental organization personnel for review and incorporation into the data management module. At a minimum, the laboratory analytical data packages will include the following information:

- Laboratory company name.
- Client provided project number or client company name.
- Laboratory work order, report number or sample delivery group identifier.
- Laboratory report date.
- Client provided sample number.
- Laboratory assigned sample identification.
- Sample matrix.

- Sample type identifier, i.e., SA (sample), MB (method blank), LCS (laboratory control samples), LCSD (laboratory control sample duplicates), MS (matrix spikes), or MSD (matrix spike duplicates).
- Date sample received in laboratory.
- Instrument calibration.
- Calibration range for all analytes.
- Preparation method identifier.
- Date of sample preparation and/or extraction.
- Analytical method identifier.
- Date sample analyzed.
- Time sample analyzed.
- Extraction batch number (if applicable).
- Quality control lot number.
- Dilution factor.
- Quantitation limits.
- Method detection limits.
- Instrument-specific detection limits.
- Instrument number or identification.
- Sample preparation logs.
- Analyst name.
- Analyst bench notes.
- CAS (Chemical Abstract Service) numbers.
- Analyte names.
- Analytical results.
- Result units.
- Extraction efficiency (if appropriate).
- Surrogate recovery information (if appropriate), including %R (percent recovery), control limits, and spiking levels.
- Quality control sample results including, but not limited to, LCS and LCSD, MB, MS and MSD, and AD (analyst duplicates).
- Spiking levels, calculations, and control limits for %R and RPD (relative percent difference) of LCS/LCSD and MS/MSD pairs as well as RPD for analyst duplicates.
- Quality control data qualifiers and associated narratives including corrective action narratives and narratives that indicate no quality issues were encountered for each method (as applicable).
- Definitions for all laboratory data qualifiers used.

- Relevant comments concerning sample or analytical conditions.
- Confirmation of conformance with required analytical protocol(s).
- Pertinent sample receipt information and documentation including holding times and condition of sample upon receipt.
- Final signed copy of the chain(s) of custody for samples in the report.
- Laboratory approval signatures.

10.1.3 Retention of Documents

The analytical laboratory is required to maintain demonstrations of capability, raw data, chromatograms, logbooks, and all other relevant analytical information for at least five years after sample analysis and must make this information available to the responsible contractor environmental organization personnel upon request. This information is required to ensure the validity of reported data and to rectify any discrepancies that may arise.

10.2 Quality Control Samples

The WSTF groundwater monitoring program utilizes both field and laboratory QC samples to ensure that program quality objectives are met.

10.2.1 Field Quality Control Samples

Field QC samples include equipment blanks, field blanks, trip blanks, and field duplicate samples. The descriptions and purposes of field QC samples are provided in Table 8. Field QC samples are collected at the frequencies specified in Table 9. The evaluation criteria and potential corrective actions for issues related to field QC samples are described in Table 10.

10.2.2 Laboratory Quality Control Samples

Laboratory QC samples include method blanks, laboratory control samples, matrix spikes, matrix spike duplicates, and surrogate spikes. The descriptions and purposes of laboratory QC samples are provided in Table 11. Laboratory QC sample analysis is performed at the frequencies specified in Table 12. The evaluation criteria and potential corrective actions for issues related to laboratory QC samples are described in Table 13.

10.3 DQI (Data Quality Indicators)

This section describes the DQIs that are applicable to the WSTF groundwater monitoring program.

10.3.1 Precision

Precision is the degree to which a set of measurements of the same property, obtained under similar conditions conform to themselves. Precision is expressed as RPD between field duplicate samples, duplicate matrix spikes, duplicate laboratory control samples or analyst duplicate samples. RPD is calculated as follows:

$$RPD = [\,|x_1 - x_2| \,/\, ((x_1 + x_2) / 2)]\,(100)$$

In the above equation, x_1 and x_2 are the reported concentrations for each duplicate sample.

For values approaching the limit of quantitation (less than three times the PQL), a qualitative evaluation of precision may be applied.

10.3.2 Bias

Bias is the systematic or persistent distortion of a measurement process, which causes errors in one direction (i.e., the expected sample measurement is different from the sample's true value). Bias is expressed as percent recovery. Percent recovery (%R) is calculated as follows:

$$\%R = (R / S)(100)$$

In the above equation, R is the reported concentration and S is the spiked concentration.

10.3.3 Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a population characteristic. Representativeness is a qualitative term that should be evaluated to determine whether measurements are made and physical samples collected in such a manner that the resulting data appropriately reflect the media and phenomenon measured or studied. The representativeness criteria is satisfied by ensuring that samples are collected and analyzed using standardized procedures throughout the sampling and analytical process. These standardized procedures include: this Plan; all applicable WSTF site-specific procedural documentation associated with groundwater sample collection, sample management, and data review and management; standardized laboratory accreditation requirements for quality systems; and current laboratory-specific SOP for all chemical analytical methods.

10.3.4 Comparability

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. Sample data should be comparable with other measurement data for similar samples and sampling conditions. This goal is achieved using standard collection and analytical techniques and reporting analytical data in appropriate units.

10.3.5 Sensitivity

Sensitivity refers to the capability of a method or instrument to discriminate between measurement responses representing different levels (e.g., concentrations) of a variable of interest. The sensitivity indicator of primary interest is the limit of detection. In determining the detection limit, the focus is on the concentration that can be distinguished from the noise of the method. The preferred limits of detection are a maximum of 20% of the cleanup levels. These preferred limits will be incorporated into the analytical statements of work for the groundwater monitoring program. Detection limits that exceed the cleanup levels for analytical results reported as "not detected" are considered data quality exceptions and an explanation for the exceedance and its acceptability for use shall be provided.

10.4 Analytical Data Quality Exceptions (Qualifications)

The analytical laboratory is required to assign data qualifiers (flags) to analytical results that are outside the laboratory acceptance criteria and constitute data quality exceptions. Designated contractor environmental organization personnel review laboratory deliverables and convert laboratory-assigned data qualifiers to the equivalent WSTF-designated qualifiers provided in Table 14. Laboratory-assigned qualifiers are converted in order to maintain data comparability and integrity and to ensure consistency of data qualification across the WSTF groundwater monitoring program regardless of contracted analytical laboratories.

A significant data quality exception is the result of an anomaly in the analytical process that will negatively impact the usability of the chemical analytical data. During groundwater monitoring activities, significant data quality exceptions may infrequently arise at the laboratory that negatively impact the implementation of this Plan or interfere with the ability to meet the objectives of the groundwater monitoring program. In the event of a significant data quality exception at a contracted analytical laboratory, the laboratory must notify the responsible WSTF contractor environmental organization personnel within one business day of the discovery in order to allow for the consideration and implementation of corrective actions. If corrective actions that meet the objectives of this Plan cannot be implemented, the responsible contractor environmental organization personnel will relate the issue to the facility project manager or designee, who will contact NMED within one business day of receipt of laboratory notification of the exception. The facility project manager or designee will discuss the implications of the data quality exception with the NMED project leader and determine whether the data will still be considered acceptable or if sample re-analysis or resampling is necessary. The facility project manager or designee will summarize the results of the discussion with the NMED project leader in a memorandum, which will be submitted to NMED by email within three business days of the verbal discussion.

10.5 Analytical Data Management

The amount of chemical analytical data produced by WSTF groundwater monitoring activities requires that standard procedures are used to manage, store, and process all groundwater chemical analytical data. This section discusses the procedures used to ensure that groundwater chemical analytical data are effectively processed.

The environmental database used by the site contractor environmental organization is a modular database system. Modules included in this system are the data management module and the environmental database module. The contractor environmental organization also retains all documentation related to chemical analytical data in the database modules. All documentation is managed pursuant to federal records management protocol, Permit-required records retention criteria, and site-specific record management procedures.

10.5.1 Data Management Module

The data management module is utilized to gather and organize analytical data for the various evaluation and reporting requirements associated with WSTF groundwater monitoring activities. Responsible contractor environmental organization personnel perform verification and validation procedures, organize the laboratory data and the corresponding QA discussion, set data qualifiers, and prepare the data for final reporting. The evaluation criteria in Table 10 and Table 13 as well as all associated documentation mentioned in this groundwater monitoring plan provide the basis for the data quality review. The data are reviewed, qualified, and approved by the responsible contractor environmental organization personnel.

10.5.2 Environmental Database Module

The WSTF environmental database module is managed by the contractor environmental organization as directed by NASA. Groundwater chemical analytical data are verified and validated by the contractor environmental organization prior to incorporation into the archival environmental database module. This module is the final repository for all verified and validated analytical data and allows data end-users the ability to use stored data for generating reports, tables, graphs, and other visual presentations.

10.5.2.1 Database Management

Management of the environmental database is performed pursuant to specific procedures outlined in site-specific procedural documentation applicable to groundwater database operations and quality assurance. The site contractor environmental organization is the only organization which can input or edit data in the environmental database module. All other individuals are granted "read only" access. This precludes data modification by personnel other than specific qualified personnel within the contractor environmental organization.

10.5.2.2 Analytical Data End-Users

The primary end-users of groundwater chemical analytical data are the contractor environmental organization, NASA Environmental Office personnel, and NMED. The contractor environmental organization uses the chemical analytical data, in conjunction with collected geophysical data, to interpret and present technical assessments of the hydrogeological system. In addition, the contractor environmental organization uses the data to prepare regulatory and technical reports. NASA Environmental Office personnel and NMED use data presentations as guidance for making decisions concerning the groundwater monitoring program.

10.6 Internal Reporting

In order to facilitate the transfer of information within the contractor environmental organization and to other interested on-site stakeholders, various internal assessment and reporting mechanisms have been developed. These include: internal quality systems evaluation and related report; internal quality assurance report; and consideration and evaluation of corrective actions applicable to organizational operations. These tools are described in more detail below.

10.6.1 Technical Systems Evaluation

Technical system evaluations are an essential element in the overall management of groundwater chemical analytical data. These evaluations are designed to verify compliance with this Plan and other applicable documentation and to assess the overall quality of the data collection and generation system. Evaluated systems include sample collection, sample analysis procedures, and data management and reporting techniques.

A technical systems evaluation is a qualitative evaluation of the entire data collection and generation system used in the WSTF groundwater monitoring program. This evaluation examines all phases of the sampling and analysis system: collection of samples; preservation and handling of samples; transport of samples; documentation of field and analytical steps; quality control procedures; data reporting; and data processing and management.

This evaluation is performed on at least an annual basis by an independent individual with the training and expertise to perform the evaluation. The evaluator submits an evaluation report to the responsible contractor environmental organization management personnel. The report presents the results of the evaluation and provides recommendations for corrective actions.

10.6.2 Internal Quality Assurance Report

Responsible contractor environmental organization data management personnel develop QAR (Quality Assurance Reports) periodically during the year to facilitate the review and evaluation of overall groundwater analytical data quality by stakeholders in the groundwater monitoring program. At a minimum, QAR include the quantity and type of field QC samples analyzed, the quantity and type of individual field data qualifiers applied, the quantity and type of individual laboratory data qualifiers applied, a list of all QA narratives associated with the included sampling events, a summary by analytical method of notable data quality issues, a summary of all notable anomalies associated with the report, and a follow-up, if necessary, on previous notable anomalies. QAR are prepared periodically during the PMR reporting period (see Section 11.4) using chemical analytical data for the reporting period. They are compiled on a quarterly basis for inclusion in the PMRs for submittal to NMED.

10.6.3 Internal Corrective Actions

Responsible contractor environmental organization personnel initiate corrective actions when data evaluation, preparation of environmental reports, or technical systems evaluations indicate discrepancies. The corrective actions can include procedural changes, resampling, collection of additional quality control samples, additional field evaluations, review of analytical laboratory procedures, addition of data qualifiers and narratives to analytical data, or any other procedure that will mitigate issues or identify further discrepancies. Discrepancies deemed to meet the definition of a data quality exception will be reported as described in Section 10.4. Corrective actions, recommendations, and specific steps taken to resolve data quality discrepancies are reported to the responsible contractor environmental organization management representative for further action.

11.0 Schedule

This section provides the schedules for activities specified in this Plan.

11.1 Groundwater Elevations

Groundwater elevations are determined as described in Section 6.5. At a minimum, groundwater elevations are measured each time a groundwater monitoring well is sampled, assuming the water level is adequate and groundwater sampling equipment allows access. The groundwater elevation may be determined more frequently at some groundwater monitoring wells to provide consistent groundwater elevation data for use in groundwater modeling and the development of groundwater elevation maps for reporting.

11.2 Groundwater Monitoring Schedule

Each groundwater monitoring location is sampled for specific hazardous constituents and other analytes based on its location in the conceptualized contaminant plume as illustrated in Section 4.1. Groundwater sampling is performed at these monitoring wells and/or zones as described in Section 7.0 for some or all of the chemical analyses discussed in Section 9.0. Table 15 provides the monitoring requirements and sampling frequencies for each active groundwater monitoring well or zone in the WSTF groundwater monitoring network.

Table 15 includes several frequencies for sampling groundwater monitoring wells. Monitoring wells/zones scheduled for quarterly sampling will be sampled for the specified analyses four times per calendar year, with sampling events approximately three months apart. Monitoring wells/zones scheduled for semi-annual sampling will be sampled for the specified analysis twice per calendar year, with sampling events approximately six months apart. Monitoring wells/zones scheduled for annual sampling will be sampled for the specified analysis once per calendar year, with sampling events occurring approximately twelve months apart. Monitoring wells/zones scheduled for biennial sampling will be sampled for the specified analysis every two calendar years, with sampling events occurring approximately 24 months apart. Monitoring wells/zones scheduled for triennial sampling will be sampled for the specified analysis every three calendar years, with sampling events occurring approximately the 36 months apart. The completion of individual scheduled sampling events may vary by several weeks as a result of well site accessibility, personnel/equipment availability, and other project-specific limitations.

Groundwater sampling schedules are developed on a monthly basis and used to schedule sampling activities for the coming month. Monthly schedules can also be approximated for subsequent months upon NMED request. NASA’s ability to complete groundwater sampling as scheduled may be impacted by lack of access to well locations, equipment malfunction, or other unforeseen events. If a groundwater monitoring well/zone cannot be sampled within 30 days of its scheduled sampling date for reasonably foreseen reasons, NASA will request a variance from the established sampling schedule 30 days prior to the scheduled sampling event. Reasonably foreseen reasons for not completing sampling within 30 days of a scheduled sampling event include, but are not limited to planned access limitations for security reasons, chronic equipment restrictions that affect multiple sampling events over the longer term, and site infrastructure limitations that prevent access. If a monitoring well/zone is not sampled within 30 days of its scheduled sampling event because of unforeseen reasons, NASA will notify NMED of the delay in the subsequent Monthly EAR (Environmental Activity Report) and indicate when sampling is expected to be completed. Unforeseen reasons for not completing planned sampling include such problems as failure of sampling equipment or short-term unplanned resource limitations with lingering impact.

11.3 Schedule for Sampling New Monitoring Wells

Following installation, groundwater monitoring wells are developed in accordance with industry accepted practices and established site-specific procedures. Hydrogeological personnel oversee drilling, installation, and development activities. When development is complete, groundwater monitoring wells are allowed to equilibrate for up to 30 days prior to initial sampling, which is typically performed between ten and 30 days after completion of development. New or reconfigured groundwater monitoring wells and zones are sampled quarterly for at least one year for VOC, nitrosamines, metals, SVOC, and inorganic compounds. After at least one year of sampling, the monitoring well will be assigned to the appropriate well group as described in Section 4.1 and the results of the initial sampling will be utilized to determine the most appropriate sampling requirements and schedule. Results of initial sampling will be reported in the PMR with other chemical analytical data. The sampling schedule assigned to the monitoring well will be included in the first annual revision of this Plan following establishment of the schedule and sampling requirements.

11.4 Schedule for Periodic Reporting

The environmental program at WSTF is diverse and comprehensive, requiring the submittal of several routine reports to keep NMED updated on environmental activities, including groundwater monitoring. Three periodic reports are applicable to groundwater monitoring:

- Monthly EAR, which includes a brief description of compliance, monitoring, and corrective action activities during the month. The EAR is submitted to NMED no later than the 15th of each month for activities in the preceding calendar month.
- “Routine” PMR, which include chemical analytical data that were processed through the WSTF data management system during the reporting period (calendar quarter). These PMR also include brief discussions of groundwater monitoring and remediation activities, and summarize the results of groundwater and remediation system monitoring. These PMR are submitted to NMED no later than April 30 (for January through March), July 31 (for April through June), and October 31 (for July through September) of each year.

- Comprehensive PMR, which includes additional data and a more comprehensive evaluation of corrective measures. This PMR includes a complete evaluation of contaminant plume capture and detailed results of remediation system monitoring. This PMR is submitted to NMED no later than January 31 of each year and includes information applicable to the preceding year (January through December).

PMR will provide the results of groundwater monitoring conducted in accordance with this Plan for the calendar quarter that coincides with chemical analytical data processed in the three months prior to the month in which the report is submitted. This three-month period is referred to as the reporting period, and is offset from the calendar quarter by two months. For instance, the PMR submitted in April will include the results of groundwater monitoring (including monitoring well sampling) performed in November, December, and January and represent data processed and evaluated during the reporting period (January, February, and March).

11.5 Schedule for Review and Revision of Plan

In accordance with Section VI.B.3 of the Permit, this Plan will be reviewed and revised on an annual basis to include such changes as: the addition of new monitoring wells/zones; deletion of abandoned monitoring wells/zones; deletion of or reduction in sampling requirements at monitoring wells/zones whose production of groundwater has been significantly reduced; sampling of wells beyond the Outer Boundary; or to change monitoring parameters or frequencies. The Permit requires that a revised Plan be submitted no later than April 1 of the second and each subsequent year after the effective date of the Permit. However, communication with NMED subsequent to issuance of the Permit indicated that April 30 would be a more acceptable date. Therefore, annual revisions of the Plan are scheduled for submittal to NMED on or before April 30 of each year. Submittal of the revised Plan does not constitute a Permit modification.

12.0 References

Conditions for exemption for a large quantity generator that accumulates hazardous waste, 40 C.F.R. 262.17 (2017).

EPA. (1989, December 18). *U.S. EPA Docket No. VI-002(h)-88-H.* Dallas, TX.

EPA. Office of Solid Waste and Emergency Response. (2007, February). *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846), Third Edition, Final Update IV*. Washington, D.C.

EPA. (2017, November). *Regional Screening Level Tables; Residential Tapwaters*. Retrieved from http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm

Ground and Surface Water Protection, Water Quality Control Commission, 20.6.2 NMAC (12-21-18).

Hazardous Waste Management, Environmental Improvement Board, 20.4.1 NMAC, (12-1-18).

Identification and Listing of Hazardous Waste, 40 C.F.R. § 261 (2011).

NASA Johnson Space Center White Sands Test Facility. (1996a, March 1). *Submittal of Draft RCRA Facility Investigation (RFI) and Corrective Measures Study (CMS) Reports*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (1996b, July 3). *NASA White Sands Test Facility (WSTF) Solid Waste Management Facility – Closure and Post-Closure Care Plan*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (1999, September) *Phase II Mid-plume Constriction Area (MPCA) Investigation Report*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2008, July 15). *Mid-plume Interception and Treatment System Interim Measures Work Plan*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2010, December 21). *Investigation Report for NASA WSTF Required Interim Measures Work Plan for Sampling Off-site Water Supply Wells*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2011, June 27). *NASA WSTF 400 Area Closure Investigation Work Plan, 400 Area Historical Information Summary (HIS), 400 Aspirator Discharge Pipes HIS, and 500 Fuel Storage Area HIS*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2012a, June 20). *Response to NMED Disapproval – NASA White Sands Test Facility (WSTF) 200 Area Investigation Work Plan and 200 Area Historical Information Summary*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2012b, May 17). *NASA WSTF Groundwater Monitoring Plan Update for 2012*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2012c, September 13,). *Response to NMED Disapproval – NASA White Sands Test Facility (WSTF) 600 Area Soil Vapor Extraction Pilot Test Investigation Report*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility, (2012d, May 10). *Work Plan for Tracer Testing in the 200/600 Areas and Mid-Plume Constriction Area*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2013a, May 15). Update of the NASA-JSC White Sands Test Facility Groundwater Flow and Contaminant Transport Model. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2013b, December 16). *Well Completion Reports for the Conversion of Westbay Wells WW-2 and JP-3*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2015, April 29). *NASA WSTF Groundwater Monitoring Plan Update for 2015*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2016, March 30). *Well Configuration Reports for Wells BLM-32, WW-4 and WW-5*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017a, March 22). *Westbay Reconfiguration Report (Wells JER-1, JER-2, ST-6, and ST-7)*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017b, March 30). *Work Plan for Westbay wells conversion WW-3, PL-5, PL-6, PL-7, PL-8, PL-10, ST-5, and WW-3*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017c, July 27). *NOD Response to First TDRSS Diesel Release (SWMU 50) Revised IWP*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017d, December 27). *NASA WSTF Drilling Work Plan for Groundwater Monitoring Well PL-12*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017e, December 28). NASA White Sands Test Facility (WSTF) SWMU 49 (700 Area Landfill) Phase I Investigation Work Plan (IWP) and Historical Information Summary (HIS). Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2017f, December 28). *Well Reconfiguration Work Plan for Well BLM-30*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018a, January 30). *Work Plan for Abandonment of NASA WSTF Monitoring Well BLM-37 and Replacement with Monitoring Well BLM-42*. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018b, May 3). 600 Area Perched Groundwater Extraction Pilot Test Interim Status Report – Project Year 5. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018c, August 14c). NASA WSTF Remediation System Monitoring Plan Annual Update for 2018. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018d, September 26). 500 Area Fuel Storage (SWMU 47) Investigation Work Plan. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018e, December 3). Response to NMED Approval with Modifications WSTF 2018 Groundwater Monitoring Plan Correction. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2018f, December 21). Abbreviated Investigation Work Plan for Groundwater Data Representativeness, Phase 1: FLUTe Well Evaluation. Las Cruces, NM.

NASA Johnson Space Center White Sands Test Facility. (2019, February 19). NASA WSTF Periodic Monitoring Report – Fourth Quarter 2018. Las Cruces, NM.

National Primary Drinking Water Regulations, 40 C.F.R. § 141 (2013). Retrieved from http://www.ecfr.gov

NELAC. (2003, June). *NELAC Standard, EPA/600/R-04/003*. Retrieved from http://www.nelac-institute.org/docs/2003nelacstandard.pdf

NMED. Hazardous Waste Bureau. (2001, October). *Position Paper. Use of Low-Flow and Other Non-Traditional Sampling Techniques for RCRA Compliant Groundwater Monitoring*. Santa Fe, New Mexico.

NMED. Hazardous Waste Bureau. (2009, November). *Hazardous Waste Permit. NM8800019434, to United States National Aeronautics and Space Administration for the White Sands Test Facility Located in Doña Ana County, New Mexico*. Santa Fe, NM.

NMED. Hazardous Waste Bureau. (2011, December 16). *Notice of Approval with Modifications Investigation Report for Evaluating the Representativeness of Groundwater Samples Collected from Westbay Wells*. Santa Fe, NM.

NMED. Hazardous Waste Bureau. (2012, August 8). *Approval 2012 Update Groundwater Monitoring Plan*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2016a, March 29). *Approval NASA WSTF Periodic Monitoring Report Fourth Quarter 2015*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2016b, November 10). Administrative Completeness and Fee Assessment Transmittal of Class 1 Permit Modification Without Prior Approval. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2017a, October 4). *Approval with Modifications Detections of NDMA (N-Nitrosodimethylamine) and TCE (Trichloroethylene) In WSTF Groundwater Monitoring Wells BLM-30, PL-5, PL-6, PL-7, PL-8, PL-10, ST-5, and WW-3*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2017b, December 19). *Approval with Modifications Groundwater Monitoring Plan*. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2018a, September 10). Approval Work Plan for Abandonment of NASA WSTF Monitoring Well BLM-37 and Replacement with Monitoring Well BLM-42. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2018b, September 10). Approval Work Plan for Abandonment of NASA WSTF Well PL-5 and Replacement with Monitoring Well PL-12. Santa Fe, NM.

NMED Hazardous Waste Bureau. (2018c, September 13). Approval with Modifications White Sands Test Facility Groundwater Monitoring Plan. Santa Fe, NM.

Seager, W. (1981, May). *Geology of Organ Mountains and Southern San Andres Mountains, New Mexico. Memoir 36, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico*.

Solid Waste Facility Ground Water Monitoring System Plan and Ground Water Monitoring Plan; Corrective Action, New Mexico Environmental Improvement Board, 20.9.9 NMAC (8-2-07).

Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, 40 C.F.R. § 264 (2014).

Wilson, C., White, R., Orr, B., & Roybal, R. (1981). *Water Resources of the Rincon and Mesilla Valleys and Adjacent Areas, New Mexico. New Mexico State Engineer's Technical Report,* Santa Fe, New Mexico.

Well Driller Licensing; Construction, Repair and Plugging of Wells, Office of the State Engineer, 19.27.4 NMAC (6-30-17).

Tables

Table 1 Summary of COC/Waste Utilization and Potential Sources at WSTF

COC	100 Area	200 Area	300 Area	400 Area	500 Area	600 Area	700 Area
NDMA		*	X	X	*		
TCE		X	X			X	*
PCE	X	X					
Freon 11		X	X	X		X	*
Freon 113		X	X	X		X	*

X – Indicates that the COC was utilized in this area or that there is a known source/release of the COC.

* – Indicates a potential source/release of the COC in this area.

Table 2 Zones of Hydraulic Conductivity (K) at WSTF

Geologic Unit	Distribution	Calculated Horizontal K (m/day)	Calculated Vertical K (m/day)	Geometric Mean Horizontal K (min/max) (m/day)
Low permeability rhyolite and andesite	Areas defined by dry holes and low well yields north and south of contaminant plume (includes flow-banded rhyolite [FBR])	2.0E-006	6.33E-009	N/A[1] (dry/29)
Fractured rhyolite	Mid-plume area	0.119	0.199	0.06 (1.7e-003/0.27)
Fractured andesite	Zone extending south to north across the east central model domain	0.00454	0.00016	0.012 (1.2e-004/1.92)
Limestone	Zone along eastern boundary of the model domain	0.04009	0.00058	1.39 (3.4e-003/224)
Basin-fill sediments	PFTS area	12[2]	1.2	1.62 (2.6e-003/116)
Basin-fill sediments	PFTS area, layers 1-14 and as a sediment veneer overlying most of the fractured rock zones	12[2]	1.2	1.62 (2.6e-003/116)
Distal basin-fill sediments	Western portion of the model domain in the JDMB	4.6[2]	0.1	1.62 (2.6e-003/116)
Fractured rhyolite	South of flow-banded rhyolite	0.081	0.2	0.198 (1.2e-003/3.42)
Fractured andesite	Zone encompassing the 300 and 400 Areas	0.391	0.0047	0.51 (4.1e-003/20.8)
Fractured rhyolite	Zone east of the FBR	0.0046	0.0199	0.69[3] (0.14/2.82)

[1] – Not applicable – hydraulic conductivity of dry and low yield wells not estimated.

[2] – Alluvium horizontal hydraulic conductivity was calibrated to distance-drawdown observations during pumping tests of Well J and PFE-3.

3 – Only three slug test measured hydraulic conductivity measurements available. Reasonable hydraulic conductivity range assumed equal to Zone 2.

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source
			Volatile Organics					
100-41-4	Ethylbenzene	Yes	700	700	15	**15**	µg/L	EPA RSL
100-42-5	Styrene	Yes	100	100	1,200	**100**	µg/L	40 CFR Part 141
107-06-2	1,2-Dichloroethane (EDC)	Yes	5	5	1.7	**1.7**	µg/L	EPA RSL
107-12-0	Propionitrile (Ethyl Cyanide)[1]	No	NA	NA	NA	**NA**	NA	NA
107-13-1	Acrylonitrile	Yes	NA	NA	0.52	**0.52**	µg/L	EPA RSL
108-88-3	Toluene	Yes	1,000	1,000	1,100	**1,000**	µg/L	40 CFR Part 141
108-90-7	Chlorobenzene	Yes	100	NA	78	**78**	µg/L	EPA RSL
127-18-4	Tetrachloroethene (PCE)[2]	Yes	5	5	110	**5**	µg/L	40 CFR Part 141
1330-20-7	m,p-Xylenes	Yes	10,000	620	190	**190**	µg/L	EPA RSL
156-60-5	trans-1,2-Dichloroethene	Yes	100	100	360	**100**	µg/L	40 CFR Part 141
56-23-5	Carbon tetrachloride	Yes	5	5	4.6	**4.6**	µg/L	EPA RSL
67-64-1	Acetone	No	NA	NA	14,000	**14,000**	µg/L	EPA RSL
67-66-3	Chloroform[2]	Yes	NA	100	2.2	**2.2**	µg/L	EPA RSL
71-43-2	Benzene	Yes	5	5	4.6	**4.6**	µg/L	EPA RSL
71-55-6	1,1,1-Trichloroethane (TCA)	Yes	200	200	8,000	**200**	µg/L	40 CFR Part 141
74-83-9	Bromomethane	Yes	NA	NA	7.5	**7.5**	µg/L	EPA RSL
74-87-3	Chloromethane	Yes	NA	NA	190	**190**	µg/L	EPA RSL
75-00-3	Chloroethane (Ethyl Chloride)	No	NA	NA	21,000	**21,000**	µg/L	EPA RSL
75-01-4	Vinyl chloride	Yes	2	2	0.19	**0.19**	µg/L	EPA RSL
75-09-2	Methylene chloride (dichloromethane)	Yes	5	5	110	**5**	µg/L	40 CFR Part 141
75-15-0	Carbon disulfide	No	NA	NA	810	**810**	µg/L	EPA RSL
75-25-2	Bromoform	Yes	NA	NA	33	**33**	µg/L	EPA RSL

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source
75-27-4	Bromodichloromethane	Yes	NA	NA	1.3	**1.3**	µg/L	EPA RSL
75-34-3	1,1-Dichloroethane	Yes	NA	25	28	**25**	µg/L	20.6.2.3103 NMAC
75-35-4	1,1-Dichloroethene	Yes	7	7	280	**7**	µg/L	40 CFR Part 141
75-69-4	Trichlorofluoromethane (CFC 11)	Yes	NA	NA	5,200	**5,200**	µg/L	EPA RSL
75-71-8	Dichlorodifluoromethane (CFC 12)	Yes	NA	NA	200	**200**	µg/L	EPA RSL
78-87-5	1,2-Dichloropropane (DCPA)	Yes	5	5	8.5	**5**	µg/L	40 CFR Part 141
78-93-3	2-Butanone (MEK)	No	NA	NA	5,600	**5,600**	µg/L	EPA RSL
79-00-5	1,1,2-Trichloroethane	Yes	5	5	2.8	**2.8**	µg/L	EPA RSL
79-01-6	Trichloroethene (TCE)[2]	Yes	5	5	4.9	**4.9**	µg/L	EPA RSL
	Nitrosamines							
62-75-9	N-Nitrosodimethylamine[2]	Yes	NA	NA	0.0011	**0.0011**	µg/L	EPA RSL
	Metals							
7439-92-1	Lead	No	NA	0.015	0.015	**0.015**	mg/L	20.6.2.3103 NMAC
7439-97-6	Mercury (elemental)	No	0.002	0.002	0.00063	**0.002**	mg/L	40 CFR Part 141
7440-02-0	Nickel (soluble salts)	No	NA	0.2	0.39	**0.2**	mg/L	20.6.2.3103 NMAC
7440-22-4	Silver	No	NA	0.05	0.094	**0.05**	mg/L	20.6.2.3103 NMAC
7440-28-0	Thallium (soluble salts)	No	0.002	0.002	0.0002	**0.0002**	mg/L	EPA RSL
7440-31-5	Tin	No	NA	NA	12	**12**	mg/L	EPA RSL
7440-36-0	Antimony (metallic)	No	0.006	0.006	0.0078	**0.006**	mg/L	40 CFR Part 141
7440-38-2	Arsenic	No	0.01	0.01	0.00052	**0.01**	mg/L	40 CFR Part 141
7440-39-3	Barium	No	2	2	3.8	**2**	mg/L	40 CFR Part 141
7440-41-7	Beryllium	No	0.004	0.004	0.025	**0.004**	mg/L	40 CFR Part 141
7440-43-9	Cadmium	No	0.005	0.005	0.0092	**0.005**	mg/L	40 CFR Part 141

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source
7440-47-3	Chromium (Total)	No	0.1	0.05	NA	**0.05**	mg/L	20.6.2.3103 NMAC
7440-48-4	Cobalt	No	NA	0.05	0.006	**0.006**	mg/L	EPA RSL
7440-50-8	Copper	No	1.3[3]	1.0	0.8	**1.0**	mg/L	20.6.2.3103 NMAC
7440-62-2	Vanadium	No	NA	NA	0.086	**0.086**	mg/L	EPA RSL
7440-66-6	Zinc	No	NA	10.0	6.0	**10.0**	mg/L	20.6.2.3103 NMAC
7782-49-2	Selenium	No	0.05	0.05	0.1	**0.05**	mg/L	40 CFR Part 141
Inorganics								
14797-73-0	Perchlorate[4]	Yes	NA	NA	14	**14**	µg/L	EPA RSL
Semi-volatile Organics								
84-74-2	Di-n-butylphthalate (Dibutyl Phthalate)	Yes	NA	NA	900	**900**	µg/L	EPA RSL
108-39-4	m-Cresol	No	NA	NA	930	**930**	µg/L	EPA RSL
117-81-7	Bis(2-Ethylhexyl)phthalate	Yes	6	NA	56	**6**	µg/L	40 CFR Part 141
Miscellaneous Hazardous Constituents								
108-95-2	Phenol	Yes	NA	5	5,800	**5**	µg/L	20.6.2.3103 NMAC
3268-87-9	Octachlorodibenzo-p-dioxin (OCDD)[5]	No	NA	NA	NA	**NA**	NA	NA
39001-02-0	Octachlorodibenzofuran (OCDF)[5]	No	NA	NA	NA	**NA**	NA	NA
57-12-5	Cyanide	No	0.2	0.2	0.0015	**0.2**	mg/L	40 CFR Part 141
93-72-1	2,4,5-Trichlorophenoxypropionic (TP) acid (Silvex)	No	50	NA	110	**50**	µg/L	40 CFR Part 141
18496-25-8	Sulfide[1]	No	NA	NA	NA	**NA**	NA	NA

MCL – Maximum Contaminant Level

WQCC – New Mexico Water Quality Control Commission Numerical Standard

RSL – EPA Regional Screening Level for Residential Tapwaters; equivalent to H=1 or modified to = 1.0E-05 risk.

Table 3 Hazardous Constituents in WSTF Groundwater

CAS Number	Analyte Name	Toxic Pollutant	MCL	WQCC	RSL	Cleanup Level	Unit	Source

NA – Not Available/Applicable

[1] The constituent is listed in 40 CFR 264, Appendix IX. No further information is available.

[2] NMED Discharge Permit (DP)-1255 Treatment Standard for this contaminant may be lower than the Cleanup Level derived through the process established in the Permit.

[3] Drinking water action level. If this concentration is detected in more than 10% of customer taps sampled, the drinking water utility must take action to reduce the concentration at customer taps.

[4] Perchlorate is not listed in 40 CFR 261, Appendix VIII or 40 CFR 264, Appendix IX. However, it is listed as a toxic pollutant in 20.6.2.7 NMAC.

[5] The constituent is listed in 40 CFR 261, Appendix VIII. No further information is available.

Table 4 Other Analytes of Interest in WSTF Groundwater

CAS Number	Analyte Name	Analysis Type	CAS Number	Analyte Name	Analysis Type
109-99-9	Tetrahydrofuran (THF)	VOC	14808-79-8	Sulfate	Inorganics
306-83-2	2,2-Dichloro-1,1,1-trifluoroethane (CFC 123)	VOC	16887-00-6	Chloride	Inorganics
354-23-4	1,2-Dichloro-1,1,2-trifluoroethane (CFC 123a)	VOC	16984-48-8	Fluoride	Inorganics
67-63-0	2-Propanol	VOC	14797-55-8	Nitrate/Nitrite as N	Inorganics
75-43-4	Dichlorofluoromethane (CFC 21)	VOC	NA	Alkalinity	Inorganics
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (CFC 113)	VOC	NA	Total Dissolved Solids (TDS)	Inorganics
4164-28-7	N-Nitrodimethylamine	Nitrosamines	314-40-9	Bromacil	SVOC
7440-70-2	Calcium	Metals	123-91-1	1,4-dioxane	SVOC SIM
7440-23-5	Sodium	Metals	30402-15-4	Total Penta CDF	Miscellaneous
7440-24-6	Strontium	Metals	41903-57-5	Total Tetra CDD	Miscellaneous
7440-42-8	Boron	Metals	55684-94-1	Hexachlorodibenzofurans (HxCDF), Total	Miscellaneous
8006-61-9	GRO	TPH			
68334-30-5	DRO	TPH			

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
		Upgradient Monitoring Wells	
100-F-358	Conventional PVC	358-368	Dedicated low-flow bladder pump
100-G-223	Conventional PVC	223-233	Dedicated low-flow bladder pump
300-F-175	Conventional PVC	175-185	Dedicated low-flow bladder pump
NASA 3	Conventional PVC/SS	119-139	Dedicated bladder pump
		100/600 Area Monitoring Wells	
100-A-182	Conventional PVC/SS	182-192	Dedicated low-flow bladder pump
100-D-176	Conventional PVC/SS	176-196	Dedicated low-flow bladder pump
100-HG-139	Conventional PVC w/MSVM	139-159	Dedicated low-flow bladder pump
600-C-173	Conventional PVC/SS	173-193	Dedicated low-flow bladder pump
600-E	Open borehole	280	Westbay MP-38
600-G-138	Conventional PVC	138-148	Non-dedicated purge pump and bailer
BLM-3-182[1]	Conventional PVC/SS	182-203	Dedicated low-flow bladder pump
BW-3-180	Conventional PVC/SS	179-200	Dedicated low-flow bladder pump
NASA 4	Conventional PVC/SS	146-166	Dedicated bladder pump
WB-1	Open borehole	200, 225, 330	Westbay MP-38
		200 Area Monitoring Wells	
200-B-240[1]	Conventional PVC/SS	240-250	Dedicated low-flow bladder pump
200-C	Open borehole	170, 225, 270	Westbay MP-38
200-D-109[2]	Conventional PVC/SS	109-129	Non-dedicated purge pump and bailer
200-D-240	Conventional PVC/SS	240-250	Dedicated low-flow bladder pump
200-F	Open borehole	225, 370, 420	Westbay MP-38
200-G	Open borehole	175, 220, 340, 420, 495	Westbay MP-38
200-H	Open borehole	225, 331, 433	Westbay MP-38
200-I	Open borehole	185, 300, 375, 490, 675, 795	Westbay MP-38

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
200-JG-110	Conventional PVC w/MSVM	110-130	Dedicated low-flow bladder pump
200-SG-1[1]	Conventional PVC w/MSVM	123-138	Dedicated bladder pump
200-KV-150[2]	Conventional PVC w/MSVM	150-170	Dedicated bladder pump
200-LV-150	Conventional PVC w/MSVM	150-170	Dedicated bladder pump
BW-4[3]	Open borehole	TBD	TBD
300/400 Area Monitoring Wells			
300-A-120[1]	Conventional PVC/SS	121-146	Dedicated low-flow bladder pump
300-A-170	Conventional PVC/SS	170-175	Dedicated low-flow bladder pump
300-B-166	Conventional SS	166-176	Dedicated low-flow bladder pump
300-C-128	Conventional SS	128-154	Dedicated low-flow bladder pump
300-D-153	Conventional PVC/SS	153-174	Dedicated bladder pump
300-E	Open borehole	138, 183	Westbay MP-38
400-A-151	Conventional SS	151-176	Dedicated low-flow bladder pump
400-C-118[1]	Conventional SS	118-143	Dedicated low-flow bladder pump
400-C-143	Conventional SS	143-153	Dedicated low-flow bladder pump
400-D	Open borehole	195, 275, 355	Westbay MP-38
400-EV-131	Conventional SS w/MSVM	131-146	Dedicated low-flow bladder pump
400-FV-131	Conventional SS w/MSVM	131-146	Dedicated low-flow bladder pump
400-GV-125	Conventional SS w/MSVM	125-140	Dedicated low-flow bladder pump
400-HV-147	Conventional SS w/MSVM	147-162	Dedicated low-flow bladder pump
400-IV-123	Conventional SS w/MSVM	123-138	Dedicated low-flow bladder pump
400-JV-150	Conventional PVC w/MSVM	150-165	Dedicated low-flow bladder pump
400-KV-142	Conventional PVC w/MSVM	142-157	Not currently equipped[4]
400-LV-125	Conventional PVC w/MSVM	125-140	Not currently equipped[5]
BW-1-268	Conventional PVC/SS	268-289	Dedicated low-flow bladder pump
BW-5-295	Conventional PVC/SS	295-305	Dedicated low-flow bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
BW-7-211	Conventional PVC/SS	211-222	Dedicated low-flow bladder pump
NASA 5	Conventional PVC/SS	110-130	Dedicated bladder pump
NASA 6	Conventional PVC/SS	128-148	Dedicated bladder pump
NASA 8[2]	Conventional PVC/SS	172-192	Dedicated bladder pump
NASA 9[2]	Conventional PVC/SS	129-149	Dedicated bladder pump
NASA 10	Conventional PVC/SS	110-130	Dedicated bladder pump
Northern Boundary Monitoring Wells			
700-A-253	Conventional SS	253-263	Dedicated low-flow bladder pump
700-B-510	Conventional SS	510-530	Dedicated low-flow bladder pump
700-D-186	Conventional PVC/SS	186-196	Dedicated low-flow bladder pump
700-E-458	Conventional SS	458-479	Dedicated low-flow bladder pump
700-F-455[6]	Conventional SS	455-475	None
700-H	Open borehole	350, 535, 670	Westbay MP-38
700-J-200	Conventional SS	200-220	Dedicated low-flow bladder pump
BLM-24-565	Conventional SS	565-585	Dedicated low-flow bladder pump
BLM-32	Open borehole	543-563, 571-591, 632-647	Water FLUTe
BLM-41-420	Conventional PVC	420-430	Dedicated low-flow bladder pump
BLM-41-670	Conventional PVC	670-680	Dedicated low-flow bladder pump
BW-6-355	Conventional SS	355-375	Dedicated low-flow bladder pump
JER-1	Conventional PVC	483-493, 563-573, 683-693	Water FLUTe
JER-2	Conventional PVC	504-514, 584-894, 683-693	Water FLUTe
Southern Boundary Monitoring Wells			
100-C-365	Conventional SS	365-386	Dedicated low-flow bladder pump
100-E-261	Conventional PVC/SS	261-271	Dedicated low-flow bladder pump
BLM-6-488	Conventional SS	488-498	Dedicated low-flow bladder pump
BLM-13-300	Conventional PVC/SS	300-310	Dedicated low-flow bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
BLM-25-455	Conventional SS	455-465	Dedicated low-flow bladder pump
BLM-28	Open borehole	TBD	TBD
BLM-31[7]	Open borehole	350, 485, 770	Westbay MP-38
BLM-40-517	Conventional PVC	517-527	Dedicated low-flow bladder pump
BLM-40-595	Conventional PVC	595-605	Dedicated low-flow bladder pump
BLM-40-688	Conventional PVC	688-698	Dedicated low-flow bladder pump
WB-5	Open borehole	250, 280, 345	Westbay MP-38
WB-14	Open borehole	520	Westbay MP-38
MPCA Monitoring Wells			
BLM-5-527	Conventional SS	527-537	Dedicated low-flow bladder pump
BLM-8-418	Conventional SS	418-428	Dedicated low-flow bladder pump
BLM-9-419	Conventional SS	419-440	Dedicated low-flow bladder pump
BLM-14-327	Conventional SS	327-337	Dedicated low-flow bladder pump
BLM-15-305	Conventional PVC/SS	305-315	Dedicated low-flow bladder pump
BLM-18-430	Conventional SS	430-451	Dedicated low-flow bladder pump
BLM-21-400	Conventional SS	400-410	Dedicated low-flow bladder pump
BLM-22-570	Conventional SS	570-592	Dedicated low-flow bladder pump
BLM-23-431	Conventional SS	431-441	Dedicated low-flow bladder pump
BLM-26-404	Conventional SS	404-414	Dedicated low-flow bladder pump
BLM-27-270	Conventional SS	270-280	Dedicated low-flow bladder pump
BLM-30	Open borehole	NA	Not currently equipped[8]
BLM-36	Conventional SS	350, 610, 800, 860	Westbay MP-38
BLM-38	Conventional SS	480, 620	Westbay MP-38
BLM-39	Conventional SS	385, 560	Westbay MP-38
Main Plume Monitoring Wells			
BLM-1-435	Conventional SS	435-446	Dedicated inflatable packer and bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
BLM-2-482[2]	Conventional SS	482-493	Dedicated low-flow bladder pump
BLM-2-630	Conventional SS	630-640	Dedicated low-flow bladder pump
BLM-17-493	Conventional SS	493-513	Dedicated low-flow bladder pump
BLM-17-550	Conventional SS	550-561	Dedicated low-flow bladder pump
PL-1-486	Conventional SS	486-496	Dedicated low-flow bladder pump
PL-2-504	Conventional SS	405-514	Dedicated low-flow bladder pump
PL-5	Conventional SS		Not currently equipped[9]
ST-1-473	Conventional SS	473-483	Dedicated low-flow bladder pump
ST-1-541	Conventional SS	541-551	Dedicated low-flow bladder pump
ST-1-630	Conventional SS	630-640	Dedicated low-flow bladder pump
ST-3-486	Conventional SS	486-496	Dedicated low-flow bladder pump
ST-3-586	Conventional SS	586-596	Dedicated low-flow bladder pump
ST-3-666	Conventional SS	666-676	Dedicated low-flow bladder pump
ST-3-735	Conventional SS	735-755	Dedicated low-flow bladder pump
Plume Front Monitoring Wells			
BLM-7-509	Conventional SS	509-520	Dedicated low-flow bladder pump
BLM-10-517	Conventional SS	517-527	Dedicated low-flow bladder pump
PL-3-453	Conventional SS	453-646	Dedicated low-flow bladder pump
PL-4-464	Conventional SS	464-474	Dedicated low-flow bladder pump
PL-6	Conventional SS	545, 725, 915, 1195, 1335	Westbay MP-38
PL-7	Conventional SS	480, 560, 630	Westbay MP-38
ST-2-466	Conventional SS	466-476	Dedicated low-flow bladder pump
ST-4-481	Conventional SS	481-491	Dedicated low-flow bladder pump
ST-4-589	Conventional SS	589-599	Dedicated low-flow bladder pump
ST-4-690	Conventional SS	690-710	Dedicated low-flow bladder pump
ST-5-481	Conventional SS	481-491	Dedicated low-flow bladder pump

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System
ST-5	Conventional SS	485, 655, 815, 985, 1175	Westbay MP-38
ST-6	Conventional SS	528-538, 568-578, 678-688, 824-834, 970-980	Water FLUTe
ST-7	Conventional SS	453-463, 543-553, 779-789, 970-980	Water FLUTe
WW-1-452	Conventional SS	452-462	Dedicated low-flow bladder pump
		Sentinel Monitoring Wells	
BLM-37	Conventional SS	NA	Not currently equipped[10]
JP-1-424	Conventional SS	424-434	Dedicated low-flow bladder pump
JP-2-447	Conventional SS	447-457	Dedicated low-flow bladder pump
JP-3	Conventional SS	509-519, 689-699	Dedicated low-flow bladder pumps separated by dedicated inflatable packer
PL-8	Conventional SS	455, 605, 780, 965	Westbay MP-38
PL-10	Conventional SS	592, 484, 813, 962	Westbay MP-55
PL-11	Conventional PVC	470-480, 530-540, 710-720, 820-830, 980-990	Water FLUTe
WW-2	Conventional SS	489-499, 664-674	Dedicated low-flow bladder pumps separated by dedicated inflatable packer
WW-3	Conventional PVC	469, 569, 710, 978	Westbay MP-55
WW-4	Conventional PVC	419-429, 589-599, 848-858, 948-958	Water FLUTe
WW-5	Conventional PVC	459-469, 579-589, 809-819, 909-919	Water FLUTe

[1] – Indicates that the well has been designated for detection monitoring in accordance with Section 3.3.1.

[2] – Indicates that the water level in this well has declined or well production is insufficient, preventing the collection of groundwater samples at this time. The water level or well performance is periodically evaluated and the well will be sampled when adequate groundwater is present. Disposition of wells with repeated inadequate water level measurements will be addressed in the text of this annual update.

[3] – Indicates that the Westbay sampling system was removed from this well. The current open borehole cannot be sampled. NASA is evaluating potential sampling systems for installation in the borehole.

[4] – Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available.

Table 5 WSTF Groundwater Monitoring Wells

Well Name	Well Construction	Monitoring Zone(s) (ft bgs)	Sampling System

[5] – Indicates that the well is installed in a currently unproductive fracture zone. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is observed. Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available.

[6] – Indicates that the well is located on the USDA Jornada Experimental Range and no longer accessible to NASA for sampling. NASA is consulting with USDA personnel to determine the well's final disposition.

[7] – Indicates that a deflection in the Westbay casing prevents access to the Westbay sampling zones. The well cannot be sampled.

[8] – Indicates that the attempt to remove the Westbay casing from this borehole was unsuccessful and the Westbay system is partially removed. NASA is evaluating options for restoration of this borehole.

[9] – Indicates that the Westbay system has been removed from this well and the well is not sampled and has been scheduled for abandonment and replacement.

[10] – Indicates that a portion of the Westbay sampling system and a length of drill pipe are irretrievably lodged in the conventional casing following an attempt to remove the Westbay casing from the conventional casing. The well cannot be sampled and has been scheduled for abandonment and replacement.

MP-38 – Westbay multiport casing with 38 mm (1.5 in.) ID

MP-55 – Westbay multiport casing with 55 mm (2.25 in.) ID

MSVM – Multiport soil vapor monitoring

PVC – Polyvinyl chloride

SS – Stainless steel

TBD – To be determined. Indicates that the Westbay multiport casing has been removed from this borehole and the replacement sampling system has not been installed.

Table 6 Preferred Analytical Requirements for VOCs, Nitrosamines, and Metals in WSTF Groundwater

CAS Number	Analyte	Preferred MDL – 20% of cleanup level[1]	Preferred PQL [1]	Unit
VOCs by SW-846 Method 8260 (current version)				
100-41-4	Ethylbenzene	3.0	15	µg/L
100-42-5	Styrene	20	100	µg/L
107-06-2	1,2-Dichloroethane (EDC)	0.34	1.7	µg/L
107-12-0	Propionitrile	NA[2]	NA[2]	µg/L
107-13-1	Acrylonitrile	0.104	0.52	µg/L
108-88-3	Toluene	150	750	µg/L
108-90-7	Chlorobenzene	15.6	78	µg/L
109-99-9	Tetrahydrofuran (THF)	NA[2]	NA[2]	µg/L
127-18-4	Tetrachloroethene (PCE)	1.0	5.0	µg/L
1330-20-7	m,p-Xylenes	38	190	µg/L
156-60-5	trans-1,2-Dichloroethene	20	100	µg/L
306-83-2	2,2-Dichloro-1,1,1-trifluoroethane (Freon123)	NA[2]	NA[2]	µg/L
354-23-4	1,2-Dichloro-1,1,2-trifluoroethane (Freon123a)	NA[2]	NA[2]	µg/L
56-23-5	Carbon tetrachloride	0.92	4.6	µg/L
67-63-0	2-Propanol	NA[2]	NA[2]	µg/L
67-64-1	Acetone	2,800	14,000	µg/L
67-66-3	Chloroform	0.44	2.2	µg/L
71-43-2	Benzene	0.92	4.6	µg/L
71-55-6	1,1,1-Trichloroethane (TCA)	12	60	µg/L
74-83-9	Bromomethane	1.5	7.5	µg/L
74-87-3	Chloromethane	38	190	µg/L
75-00-3	Chloroethane	4,200	21,000	µg/L
75-01-4	Vinyl chloride	0.038	0.19	µg/L
75-09-2	Methylene chloride	1.0	5.0	µg/L
75-15-0	Carbon disulfide	162	810	µg/L
75-25-2	Bromoform	6.6	33	µg/L
75-27-4	Bromodichloromethane	0.26	1.3	µg/L
75-34-3	1,1-Dichloroethane	5.0	25	µg/L
75-35-4	1,1-Dichloroethene	1.0	5.0	µg/L
75-43-4	Dichlorofluoromethane (Freon 21)	NA[2]	NA[2]	µg/L
75-69-4	Trichlorofluoromethane (Freon11)	1,040	5,200	µg/L
75-71-8	Dichlorodifluoromethane (Freon12)	40	200	µg/L
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	NA[2]	NA[2]	µg/L

Table 6 Preferred Analytical Requirements for VOCs, Nitrosamines, and Metals in WSTF Groundwater

CAS Number	Analyte	Preferred MDL – 20% of cleanup level[1]	Preferred PQL [1]	Unit
78-87-5	1,2-Dichloropropane (DCPA)	1	5	µg/L
78-93-3	2-Butanone (MEK)	1,120	5,600	µg/L
79-00-5	1,1,2-Trichloroethane	0.56	2.8	µg/L
79-01-6	Trichloroethene (TCE)	0.98	4.9	µg/L
Nitrosamines by Low Level Analytical Method				
4164-28-7	N-Nitrodimethylamine	NA[2]	NA[2]	µg/L
62-75-9	N-Nitrosodimethylamine	0.00022	0.0011	µg/L
Metals by Laboratory-Specified Best Method				
7439-92-1	Lead	0.01	0.05	mg/L
7439-97-6	Mercury	0.0004	0.002	mg/L
7440-02-0	Nickel	0.04	0.20	mg/L
7440-22-4	Silver	0.01	0.050	mg/L
7440-23-5	Sodium	NA[2]	NA[2]	mg/L
7440-24-6	Strontium	1.86	9.3	mg/L
7440-28-0	Thallium	0.00004	0.0002	mg/L
7440-31-5	Tin	2.4	12	mg/L
7440-36-0	Antimony	0.0012	0.0060	mg/L
7440-38-2	Arsenic	0.002	0.01	mg/L
7440-39-3	Barium	0.2	1.0	mg/L
7440-41-7	Beryllium	0.0008	0.004	mg/L
7440-42-8	Boron	0.15	0.75	mg/L
7440-43-9	Cadmium	0.001	0.005	mg/L
7440-70-2	Calcium	NA[2]	NA[2]	mg/L
7440-47-3	Chromium	0.01	0.05	mg/L
7440-48-4	Cobalt	0.0012	0.006	mg/L
7440-50-8	Copper	0.20	1.0	mg/L
7440-62-2	Vanadium	0.0172	0.086	mg/L
7440-66-6	Zinc	2	10	mg/L
7782-49-2	Selenium	0.01	0.05	mg/L

NA – Not Available/Applicable

[1] – These are the maximum preferred analytical requirements allowed by Permit Section 17.3.

[2] – Indicates that the analytical laboratory will be required to provide the best achievable level for review prior to performing analytical work related to the WSTF groundwater monitoring program.

Table 7 Preferred Analytical Requirements for Inorganics, SVOCs, and Miscellaneous COCs in WSTF Groundwater

CAS Number	Analyte	Recommended Analytical Method	Preferred MDL[1] – 20% of cleanup level	Preferred PQL[1]
Inorganic Compounds by Various Methods				
14797-55-8	Nitrate/Nitrite as N	300.0	2.0 mg/L	10 mg/L
14797-73-0	Perchlorate	331.0	2.2 µg/L	11 µg/L
14808-79-8	Sulfate	300.0	NA[2]	NA[2]
16887-00-6	Chloride	300.0	NA[2]	NA[2]
16984-48-8	Fluoride	300.0	NA[2]	NA[2]
NA	Alkalinity	SM2320	NA[2]	NA[2]
NA	Total Dissolved Solids (TDS)	SM2540	100 mg/L	500 mg/L
SVOCs by Various Methods				
84-74-2	Di-n-butylphthalate	SW-846 Method 8270	180 µg/L	900 µg/L
108-39-4	m-Cresol	SW-846 Method 8270	186 µg/L	930 µg/L
117-81-7	Bis(2-Ethylhexyl)phthalate	SW-846 Method 8270	1.2 µg/L	6.0 µg/L
314-40-9	Bromacil	Modified EPA Method 607	NA[2]	NA[2]
Miscellaneous Constituents by Various Methods				
123-91-1	1,4-Dioxane	SW-846 Method 8270 SIM	0.92 µg/L	4.59 µg/L
108-95-2	Phenol	SW-846 Method 9066	1.0 µg/L	5.0 µg/L
30402-15-4	Total Penta CDF	SW-846 Method 8290	NA[2]	NA[2]
3268-87-9	Octachlorodibenzo-p-dioxin (OCDD)	SW-846 Method 8290	NA[2]	NA[2]
39001-02-0	Octachlorodibenzofuran (OCDF)	SW-846 Method 8290	NA[2]	NA[2]
41903-57-5	Total Tetra CDD	SW-846 Method 8290	NA[2]	NA[2]
55684-94-1	Hexachlorodibenzofurans (HxCDF), Total	SW-846 Method 8290	NA[2]	NA[2]
57-12-5	Total Cyanide	SW-846 Method 9012	0.04 mg/L	0.2 mg/L
93-72-1	2,4,5-TP (Silvex)	SW-846 Method 8151	10 µg/L	50 µg/L

Table 7 Preferred Analytical Requirements for Inorganics, SVOCs, and Miscellaneous COCs in WSTF Groundwater

CAS Number	Analyte	Recommended Analytical Method	Preferred MDL[1] – 20% of cleanup level	Preferred PQL[1]
8006-61-9	GRO	SW-846 Method 8015	50 µg/L[3]	100 µg/L[3]
68334-30-5	DRO	SW-846 Method 8015	50 µg/L[3]	100 µg/L[3]
NA	Sulfide	SW-846 Method 9030	NA[2]	NA[2]

NA – Not Available/Applicable

[1] – These are the maximum preferred analytical requirements allowed by Permit Section 17.3.

[2] – Indicates that the analytical laboratory will be required to provide the best achievable level for review prior to performing analytical work related to the WSTF groundwater monitoring program.

[3] – Indicates that the constituent is not a hazardous constituent with a WSTF groundwater cleanup level and that the MDL and PQL are recommended to meet project objectives in the SMWU 50 Investigation Work Plan (NASA, 2017c)

Table 8 Field Quality Control Samples

QC Sample	QC Sample Description and Purpose
Equipment Blank	A sample of analyte-free purified water which has been used to rinse common sampling equipment to check effectiveness of decontamination procedures. This type of blank also indicates contamination in the field and during handling, transport, shipping, laboratory, and analytical processes which may affect analytical results.
Field Blank	A blank prepared in the field by filling a clean sample container with analyte-free purified water and appropriate preservative, if any, for the specific sampling activity being undertaken. This type of sample provides a check for contamination derived in the field and during handling, transport, shipping, laboratory, and analytical processes.
Trip Blank	A sample of analyte-free purified water prepared in a contaminant free environment that is carried to the sampling site and transported to the laboratory for analysis without having been exposed to sampling procedures. This type of sample serves as a check on sample contamination originating from sample handling, transport, shipping, site conditions, laboratory, and analytical processes.
Field Duplicate Sample	A second sample is taken immediately after an original sample at the same sampling location. This sample provides an estimate of the overall system precision.

Table 9 Frequencies for the Collection of Field Quality Control Samples

QC Sample	Frequency for VOCs	Frequency for High Level Nitrosamines Method	Frequency for Low Level Nitrosamines Method	Frequency for Metals
Equipment Blank	100% of all VOC sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.	2% of all high-level nitrosamines sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.	100% of all low-level nitrosamines sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.	5% of all metals sampling events where non-dedicated sampling equipment is used. Not applicable if dedicated sampling equipment is used.
Field Blank	100% of all VOC sampling events where dedicated sampling equipment is used. Not required if non-dedicated sampling equipment is used and a VOC equipment blank is collected in the field.	Not required if a high-level equipment blank is collected in the field, otherwise 2% of all high level nitrosamines sampling events.	100% of all low-level nitrosamines sampling events where dedicated sampling equipment is used. Not required if non-dedicated sampling equipment is used and a low-level nitrosamines equipment blank is collected in the field.	Not required if a metals equipment blank is collected in the field, otherwise 5% of all metals sampling events.
Trip Blank	Collected for VOC sampling event at a frequency sufficient to fulfill minimum requirement of one trip blank per VOC sample shipment.	Not required.	Collected for low-level nitrosamines sampling event at a frequency sufficient to fulfill minimum requirement of one trip blank per low level nitrosamines sample shipment.	Not required.
Field Duplicate Sample	10% of all VOC sampling events.	10% of all high-level nitrosamines sampling events.	10% of all low-level nitrosamines sampling events.	10% of all metals sampling events

Table 10 Evaluation Criteria and Corrective Action for Field QC Samples

QC Sample	Evaluation Criteria and Corrective Action
Equipment Blank	In the event of equipment blank contamination, analytical data shall be qualified if the concentration of an analyte in the blank is greater than 1/10 of the amount measured in the sample. The primary reason to collect an equipment blank is to check effectiveness of equipment decontamination procedures. However, an equipment blank is also subject to the same field, handling, transport, shipping, laboratory, and analytical conditions as the sample. To determine whether equipment blank contamination results from ineffective equipment decontamination procedures, all blank and sample contamination must be evaluated. When significant and consistent equipment blank contamination is present, the cause must be investigated and corrective action taken to minimize or eliminate the problem.
Field Blank	In the event of field blank contamination, analytical data shall be qualified if the concentration of an analyte in the blank is greater than 1/10 of the amount measured in the sample. The primary reason to collect a field blank is to check for contamination derived in the field. However, a field blank is also subject to the same handling, transport, shipping, laboratory, and analytical conditions as the sample. To determine whether field blank contamination results from field conditions, all blank and sample contamination must be evaluated. When significant and consistent field blank contamination is present, the cause must be investigated and corrective action taken to minimize or eliminate the problem.
Trip Blank	In the event of trip blank contamination, analytical data shall be qualified if the concentration of an analyte in the blank is greater than 1/10 of the amount measured in the sample. The primary reason to collect a trip blank is to check for contamination derived from sample handling, transport, shipping, and site conditions. However, a trip blank is also subject to the same laboratory and analytical conditions as the sample. To determine whether trip blank contamination results from sample handling, transport, shipping, or site conditions, all blank and sample contamination must be evaluated. When significant and consistent trip blank contamination is present, the cause must be investigated and corrective action taken to minimize or eliminate the problem.
Field Duplicate Sample	The results from field duplicate samples are primarily designed to estimate overall system precision. Precision is expressed as RPD (relative percent difference). Results are compared to the evaluation criteria for field duplicate samples in the test method. Where there are no established criteria for field duplicate samples, the WSTF contractor environmental organization shall determine internal criteria, such as adopting analyst duplicate or laboratory control sample duplicate criteria, and document the method used to establish the limits. For field duplicate results outside established criteria, the data shall be reported with appropriate data qualifying codes. When field duplicate precision is significantly and consistently outside evaluation criteria, corrective action shall be taken to minimize or eliminate the problem.

Table 11 Descriptions of Laboratory Quality Control Samples

QC Sample	QC Sample Description
Method Blank	Analyte-free deionized water processed simultaneously with and under the same conditions as samples through all steps of the analytical procedures, and in which no analytes or interferences are present at concentrations that impact the analytical results for sample analyses. The method blank is used to assess the preparation or analytical batch for possible contamination during the preparation and processing steps.
Laboratory Control Sample	Analyte-free deionized water spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes. The laboratory control sample is used to evaluate the performance of the total analytical system (i.e., for systematic error or bias) including all preparation and analysis steps.
Matrix Spike	A sample prepared by adding a known mass of analyte to a specified amount of matrix sample for which an independent estimate of analyte concentration is available. Matrix spike samples are used to indicate the effect of the sample matrix on the accuracy of the results generated using the selected method. The information from these controls is sample/matrix specific and would not normally be used to determine the validity of the entire batch.
Matrix Spike Duplicate	A second replicate matrix spike prepared in the laboratory and analyzed to obtain a measure of the precision of the recovery for each analyte.
Surrogate Spike	Introduction of a compound into the samples, blanks, and laboratory control samples similar to the analytes of interest, but not normally found in environmental samples, blanks and laboratory control samples. The surrogate spike provides a continuous monitor of the performance of the analytical system and the effectiveness of the method in dealing with sample matrices.

Table 12 Frequency of Analysis for Laboratory Quality Control Samples

QC Sample	Frequency for VOCs	Frequency for High Level Nitrosamines Method	Frequency for Low Level Nitrosamines Method	Frequency for Metals
Method Blank	One for each preparation or analytical batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.
Laboratory Control Sample	One for each preparation or analytical batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.	One for each preparation batch of 20 groundwater samples or less.
Matrix Spike/Matrix Spike Duplicate[1]	2% of groundwater samples analyzed.	2% of groundwater samples analyzed.	2% of groundwater samples analyzed.	2% of groundwater samples analyzed.
Surrogate Spike	100% of all blanks, groundwater samples and standards.	100% of all blanks, groundwater samples and standards.	100% of all blanks, groundwater samples and standards.	Not applicable.

[1] – WSTF matrix spike samples are collected in the field specifically as matrix spikes and delivered to the analytical laboratory to be appropriately spiked and analyzed. The analytical laboratory is required to spike these samples as specified in the method regardless of the requirements for other project samples in the same analytical batch. In this way, matrix specific recovery for WSTF groundwater is monitored without placing onerous requirements on the analytical laboratory. Historically, matrix effects on volatiles, semi-volatiles, and metals analysis of WSTF groundwater are not significant. Therefore, the frequencies of these samples have been decreased from historical levels to levels sufficient to monitor potential changes in the matrix.

Table 13 Evaluation Criteria and Corrective Action for Laboratory QC Samples

QC Sample	Evaluation Criteria and Corrective Action
Method Blank	While the goal is to have no detectable contaminants, each method blank must be critically evaluated as to the nature of the interference and the effect on the analysis of each sample with the batch. The source of contamination shall be investigated and measures taken to minimize or eliminate the problem and affected samples reprocessed or data shall be appropriately qualified if: 1. The concentration of an analyte in the blank is at or above the quantitation limit, and is greater than 1/10 of the amount measured in any sample. 2. The blank contamination otherwise affects the sample results as per the method requirements. 3. When a blank is determined to be contaminated, the cause must be investigated and measures taken to minimize or eliminate the problem. Samples associated with a contaminated blank shall be evaluated as to the best corrective action for the samples (e.g. reprocessing or data qualifying codes). In all cases the corrective action must be documented by the laboratory.
Laboratory Control Sample	The results of the individual batch laboratory control sample are calculated in percent recovery (bias) allowing comparison to method or laboratory established evaluation criteria. The individual laboratory control sample is compared to the evaluation criteria as published in the test method. Where there are no established criteria, the laboratory shall determine internal criteria and document the method used to establish the limits. A laboratory control sample that is determined to be within the criteria effectively establishes that the analytical system is in control and validates system performance for the samples in the associated batch. Samples analyzed along with a laboratory control sample determined to be “out of control” shall be considered suspect and the samples reprocessed and re-analyzed or the data reported with appropriate data qualifying codes. If a large number of analytes are in the laboratory control sample, it becomes statistically likely that a few well be outside control limits. Contracted laboratories shall refer to the NELAC accreditation standards for handling marginal laboratory control sample exceedances for laboratory control samples with a large number of analytes.
Matrix Spike/Matrix Spike Duplicate	The results from the matrix spike/matrix spike duplicate are primarily designed to assess the accuracy of analytical results in a given matrix and are expressed as bias, or percent recovery, and precision, or relative percent difference. The laboratory shall document the calculation for percent recovery and relative percent difference. The results are compared to the evaluation criteria as published in the test method. Where there are no established criteria, the laboratory shall determine internal criteria and document the method used to establish the limits. For matrix spike results outside established criteria corrective action shall be documented or the data reported with appropriate data qualifying codes.
Surrogate Spike	Surrogate spike results are compared to the evaluation criteria as published in the test method. Where there are no established criteria, the laboratory shall determine internal criteria and document the method used to establish the limits. Surrogates outside the evaluation criteria must be evaluated for the

Table 13 Evaluation Criteria and Corrective Action for Laboratory QC Samples

QC Sample	Evaluation Criteria and Corrective Action
	effect on individual sample results. Results reported from analyses with "out of control" surrogate recoveries should include appropriate data qualifiers.

Table 14 Description of WSTF Data Qualifiers

Data Qualifier	Description
*	User defined qualifier. See specific quality assurance narrative.
A	The result of an analyte for a LCS (laboratory control sample), ICV (initial calibration verification) or CCV (continuing calibration verification) was outside standard limits.
AD	Relative percent difference for analyst (laboratory) duplicates was outside standard limits.
D	The reported result is from a dilution.
EB	The analyte was detected in the equipment blank.
FB	The analyte was detected in the field blank.
G	The result is an estimated value greater than the upper calibration limit.
i	The result, quantitation limit, and/or detection limit may have been affected by matrix interference.
J	The result is an estimated value less than the quantitation limit, but greater than or equal to the detection limit.
NA	The value/result was either not analyzed for or not applicable.
ND	The analyte was not detected above the detection limit.
Q	The result for a blind control sample was outside standard limits.
QD	The relative percent difference for a field duplicate was outside standard limits.
R	The result is rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
RB	The analyte was detected in the method blank.
S	The result was determined by the method of standard addition.
SP	The matrix spike recovery and/or the relative percent difference for matrix spike duplicates was outside standard limits.
T	The sample was analyzed outside the specified holding time or temperature.
TB	The analyte was detected in the trip blank.
TIC	The analyte was tentatively identified by a GC/MS library search and the amount reported is an estimated value.

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
Upgradient Monitoring Wells/Zones							
100-F-358	SA	SA	A	A	A	SA[2]	Annual Appendix IX, 1,4-Dioxane
100-G-223	SA	SA	A	A	A[3]	SA[2, 3]	Annual Appendix IX, Annual SWMU 50, 1,4-Dioxane
300-F-175	SA	SA	A	A	A	SA[2]	Annual Appendix IX, 1,4-Dioxane
NASA 3	SA	SA	A	A	A	A	Annual Appendix IX
100/600 Area Monitoring Wells/Zones							
100-A-182	A		A	TA	A[3,4]	A[3]	Annual SWMU 50
100-D-176	A		A	TA	A[3,4]	A[3]	Annual SWMU 50
100-HG-139	A		A	TA	A[4]		
600-C-173	A		A	TA	A[4]		
600-E-280	A		A	TA	A[4]		
600-G-138	A		A	TA	A[4]		
BLM-3-182[5]	A		A	TA	A[4]		Annual Appendix IX
BW-3-180	SA		SA	BA	SA[4]		
NASA 4	A		A	TA	A[4]		
WB-1-200	A		A	TA	A[4]		
WB-1-255	A		A	TA	A[4]		
WB-1-330	A		A	TA	A[4]		
200 Area Monitoring Wells/Zones							
200-B-240[5]	A	A	A	TA	A[4]		Annual Appendix IX
200-C-170	A	A	A	TA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
200-C-225	A	A	A	TA	A[4]		
200-C-270	A	A	A	TA	A[4]		
200-D-109[6]	A	A	A	TA	A[4]		
200-D-240	A	A	A	TA	A[4]		
200-F-225	A	A	A	TA	A[4]		
200-F-370	A	A	A	TA	A[4]		
200-F-420	A	A	A	TA	A[4]		
200-G-175	A	A	A	TA	A[4]		
200-G-220	A	A	A	TA	A[4]		
200-G-340	A	A	A	TA	A[4]		
200-G-420	A	A	A	TA	A[4]		
200-G-495	A	A	A	TA	A[4]		
200-H-225	A	A	A	TA	A[4]		
200-H-331	A	A	A	TA	A[4]		
200-H-433	A	A	A	TA	A[4]		
200-I-185	A	A	A	TA	A[4]		
200-I-300	A	A	A	TA	A[4]		
200-I-375	A	A	A	TA	A[4]		
200-I-490	A	A	A	TA	A[4]		
200-I-675	A	A	A	TA	A[4]		
200-I-795	A	A	A	TA	A[4]		
200-JG-110	A	A	A	TA	A[4]		
200-SG-1[5]	A	A	A	TA	A[4]	A	Annual Appendix IX
200-KV-150[6]	Q	Q	Q	Q	Q		
200-LV-150	A	A	A	TA	A[4]		
BW-4-270[7]	A	A	A	TA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
BW-4-355[7]	A	A	A	TA	A[4]		
BW-4-455[7]	A	A	A	TA	A[4]		
300/400 Area Monitoring Wells/Zones							
300-A-120[5]	A	A	A	TA	A[4]	A	Annual Appendix IX
300-A-170	A	A	A	TA	A[4]		
300-B-166	A	A	A	TA	A[4]		
300-C-128	A	A	A	TA	A[4]		
300-D-153	A	A	A	TA	A[4]		
300-E-138	A	A	A	TA	A[4]		
300-E-183	A	A	A	TA	A[4]		
400-A-151	A	A	A	TA	A[4]		
400-C-118[5]	A	A	A	TA	A[4]	A	Annual Appendix IX
400-C-143	A	A	A	TA	A[4]		
400-D-195	A	A	A	TA	A[4]		
400-D-275	A	A	A	TA	A[4]		
400-D-355	A	A	A	TA	A[4]		
400-EV-131	Q	A	A	TA	A[4]		
400-FV-131	Q	A	A	TA	A[4]		
400-GV-125	Q	A	A	TA	A[4]		
400-HV-147	Q	A	A	TA	A[4]		
400-IV-123	Q	A	A	TA	A[4]		
400-JV-150	Q	A	A	TA	A[4]		
400-KV-142[8]							
400-LV-125[9]							
BW-1-268	SA	SA	SA	BA	SA[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
BW-5-295	SA	SA	SA	BA	SA[4]		
BW-7-211	SA	SA	SA	BA	SA[4]		
NASA 5	A	A	A	TA	A[4]		
NASA 6	A	A	A	TA	A[4]		
NASA 8[6]	A	A	A	TA	A[4]		
NASA 9[6]	A	A	A	TA	A[4]		
NASA 10	A	A	A	TA	A[4]		
Northern Boundary Monitoring Wells/Zones							
700-A-253	SA	SA	A	BA	A[4]		SA Landfill
700-B-510	A	A	A	BA	A[4]		
700-D-186	SA	SA	A	BA	A[4]		SA Landfill
700-E-458	A	A	A	BA	A[4]		
700-F-455[10]							
700-H-350	SA	SA	A	BA	A[4]		SA Landfill
700-H-535	SA	SA	A	BA	A[4]		SA Landfill
700-H-670	SA	SA	A	BA	A[4]		SA Landfill
700-J-200	SA	SA	A	BA	A[4]		SA Landfill
BLM-24-565	SA	SA	A	BA	A[4]		
BLM-32-543	Q	Q	A	Q	Q		
BLM-32-571	Q	Q	A	BA	A[4]		
BLM-32-632	Q	Q	A	BA	A[4]		
BLM-41-420	SA	SA	A	BA	A[4]		
BLM-41-670	SA	SA	A	BA	A[4]		
BW-6-355	SA	SA	A	BA	A[4]		
JER-1-483	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-1-563	Q	Q	A	BA	A	Q[3]	1,4-Dioxane

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
JER-1-683	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-2-504	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-2-584	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
JER-2-684	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
Southern Boundary Monitoring Wells/Zones							
100-C-365	A		A	BA	A[2,4]	A[2]	Annual SWMU 50
100-E-261	A		A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-6-488	Q	Q	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-13-300	A	A	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-25-455	A	A	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-28[11]				TBD			
BLM-31[12]							
BLM-40-517	SA	SA	A	BA	A[2,4]	A[2]	Annual SWMU 50
BLM-40-595	SA	SA	A	BA	A[4]		
BLM-40-688	SA	SA	A	BA	A[4]		
WB-5-250	A		A	BA	A[4]		
WB-5-280	A		A	BA	A[4]		
WB-5-345	A		A	BA	A[4]		
WB-14-520	A		A	BA	A[4]		
MPCA Monitoring Wells/Zones							
BLM-5-527	SA	SA	A	BA	A[4]		
BLM-8-418	SA	SA	A	BA	A[4]		
BLM-9-419	SA	SA	A	BA	A[4]		
BLM-14-327	SA	SA	A	BA	A[4]		
BLM-15-305	SA	SA	A	BA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
BLM-18-430	SA	SA	A	BA	A[4]		
BLM-21-400	SA	SA	A	BA	A[4]		
BLM-22-570	SA	SA	A	BA	A[4]		
BLM-23-431	SA	SA	A	BA	A[4]		
BLM-26-404	SA	SA	A	BA	A[4]		
BLM-27-270	SA	SA	A	BA	A[4]		
BLM-30-585	SA	SA	A	BA	A[4]		
BLM-36-350	SA	SA	A	BA	A[4]		
BLM-36-610	SA	SA	A	BA	A[4]		
BLM-36-800	SA	SA	A	BA	A[4]		
BLM-36-860	SA	SA	A	BA	A[4]		
BLM-38-480	SA	SA	A	BA	A[4]		
BLM-38-620	SA	SA	A	BA	A[4]		
BLM-39-385	SA	SA	A	BA	A[4]		
BLM-39-560	SA	SA	A	BA	A[4]		
Main Plume Monitoring Wells/Zones							
BLM-1-435	SA	SA	A	BA	A[4]		
BLM-2-482[6]	SA	SA	A	BA	A[4]		
BLM-2-630	SA	SA	A	BA	A[4]		
BLM-17-493	SA	SA	A	BA	A[4]		
BLM-17-550	SA	SA	A	BA	A[4]		
PL-1-486	Q	Q	A	BA	A[4]		
PL-2-504	Q	Q	A	BA	A[4]		
PL-5-495[13]							
PL-5-595[13]							
PL-5-715[13]							

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
PL-5-795[13]							
PL-5-895[13]							
PL-5-985[13]							
ST-1-473	SA	SA	A	BA	A[4]		
ST-1-541	SA	SA	A	BA	A[4]		
ST-1-630	SA	SA	A	BA	A[4]		
ST-3-486	SA	SA	A	BA	A[4]		
ST-3-586	SA	SA	A	BA	A[4]		
ST-3-666	SA	SA	A	BA	A[4]		
ST-3-735	SA	SA	A	BA	A[4]		
Plume Front Monitoring Wells/Zones							
BLM-7-509	Q	Q	A	BA	A[4]		
BLM-10-517	Q	Q	A	BA	A[4]		
PL-3-453	Q	Q	A	BA	A[4]		
PL-4-464	Q	Q	A	BA	A[4]		
PL-6-545	Q	Q	A	BA	A[4]		
PL-6-725	Q	Q	A	BA	A[4]		
PL-6-915	A	A	A	BA	A[4]		
PL-6-1195	A	A	A	BA	A[4]		
PL-6-1335	A	A	A	BA	A[4]		
PL-7-480	Q	Q	A	BA	A[4]		
PL-7-560	Q	Q	A	BA	A[4]		
PL-7-630	A	A	A	BA	A[4]		
ST-2-466	A	A	A	BA	A[4]		
ST-4-481	Q	Q	A	BA	A[4]		
ST-4-589	Q	Q	A	BA	A[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
ST-4-690	Q	Q	A	BA	A[4]		
ST-5-481	A	A	A	BA	A[4]		
ST-5-485	Q	Q	A	BA	A[4]		
ST-5-655	Q	Q	A	BA	A[4]		
ST-5-815	A	A	A	BA	A[4]		
ST-5-985	A	A	A	BA	A[4]		
ST-5-1175	A	A	A	BA	A[4]		
ST-6-528	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
ST-6-568	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
ST-6-678	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
ST-6-824	Q	Q	A	BA	A		
ST-6-970	Q	Q	A	BA	A		
ST-7-453	Q	Q	A	BA	A		
ST-7-544	Q	Q	A	BA	A		
ST-7-779	Q	Q	A	BA	A		
ST-7-970	Q	Q	A	BA	A		
WW-1-452	Q	Q	A	BA	A[4]		
Sentinel Monitoring Wells/Zones							
BLM-37-490[13]							
BLM-37-640[13]							
BLM-37-750[13]							
BLM-37-885[13]							
JP-1-424	Q	Q	A	BA	BA[4]		
JP-2-447	Q	Q	A	BA	BA[4]		
JP-3-509	Q	Q	A	BA	BA[4]		
JP-3-689	Q	Q	A	BA	BA[4]		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
PL-8-455	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-8-605	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-8-780	A	A	A	BA	BA[4]		
PL-8-965	A	A	A	BA	BA[4]		
PL-10-484	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-10-592	Q	Q	A	BA	BA[4]	Q[3]	1,4-Dioxane
PL-10-813	A	A	A	BA	BA[4]		
PL-10-962	A	A	A	BA	BA[4]		
PL-11-470	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
PL-11-530	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
PL-11-710	Q	Q	A	BA	A	Q[3]	1,4-Dioxane
PL-11-820	Q	Q	A	BA	A		
PL-11-980	Q	Q	A	BA	A		
WW-2-489	Q	Q	A	BA	BA[4]		
WW-2-664	Q	Q	A	BA	BA[4]		
WW-3-469	Q	Q	A	BA	BA[4]		
WW-3-569	Q	Q	A	BA	BA[4]		
WW-3-710	A	A	A	BA	BA[4]		
WW-3-978	A	A	A	BA	BA[4]		
WW-4-419	Q	Q	A	BA	Q		
WW-4-589	Q	Q	A	BA	Q		
WW-4-848	Q	Q	A	BA	Q		
WW-4-948	Q	Q	A	BA	Q		
WW-5-459	Q	Q	A	BA	A		
WW-5-579	Q	Q	A	BA	A		
WW-5-809	Q	Q	A	BA	A		

Table 15 Sampling Frequencies of WSTF Groundwater Monitoring Wells/Zones

Well/Zone	VOC	NDMA[1]	Metals	Inorganics	SVOC	Misc.	Comments
WW-5-909	Q	Q	A	BA	A		

[1] – The selection of the appropriate analytical method for the analysis of NDMA (Modified EPA Method 607 or the approved low-level method) is based on location and expected concentration at the designated well/zone.

[2] – Indicates that the well has been designated for sampling of 1,4-dioxane in accordance with NMED requirements (NMED, 2017b).

[3] – Indicates that the well is sampled annually for PAH and TPH (DRO and GRO) in accordance with the NMED-approved SWMU 50 Investigation Work Plan.

[4] – Indicates that the well/zone will be sampled for bromacil only.

[5] – Indicates that the well/zone has been designated for detection monitoring in accordance with Section 3.3.1.

[6] – Indicates that the water level in this well has declined, preventing the collection of groundwater samples at this time. The water level is regularly monitored and the well will be sampled when adequate groundwater is present. Disposition of wells with repeated inadequate water level measurements will be addressed in the text of this annual update.

[7] – Indicates that the Westbay sampling system was removed from this well. The current open borehole cannot be sampled. NASA is evaluating potential sampling systems for installation in the borehole.

[8] – Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available. Samples will be collected for the same analyses as those in well 400-JV-150.

[9] – Indicates that the well is installed in a currently unproductive fracture zone. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is observed. Initial development at this well indicated that groundwater recovery following well evacuation is less than 1/10 ft per day. The water level in this well will be monitored following recharge events and the well will be sampled with decontaminated non-dedicated sampling equipment if adequate groundwater is available. Samples will be collected for the same analyses as those in well 400-JV-150.

[10] – Indicates that the well is located on the USDA Jornada Experimental Range and no longer accessible to NASA for sampling. NASA is consulting with USDA personnel to determine the well's final disposition.

[11] – Indicates that the Westbay sampling system was removed from this well as part of the NMED-approved Westbay conversion project at WSTF. An alternate sampling system will be installed within this open borehole, after which sampling will be performed as required for new wells.

[12] – Indicates that a deflection in the Westbay casing prevents access to the Westbay sampling zones. The well cannot be sampled.

[13] – Indicates that that Westbay system in this well has been partially or fully removed. The well cannot be sampled and has been scheduled for abandonment and replacement.

Q – Indicates that sampling is performed for this analysis quarterly.

SA – Indicates that sampling is performed for this analysis semi-annually.

SA Landfill – Indicates that the well is sampled semi-annually in accordance with 20.9.9 NMAC and the NASA WSTF 700 Area Landfill Closure and Post-Closure Care (CPCC) Plan (NASA, 1996b).

A – Indicates that sampling is performed for this analysis annually.

BA – Indicates that sampling is performed for this analysis biennially.

TA – Indicates that sampling is performed for this analysis triennially.

TBD – To be determined.

Figures

Figure 1 **WSTF and Surrounding Areas**

(SEE NEXT PAGE)

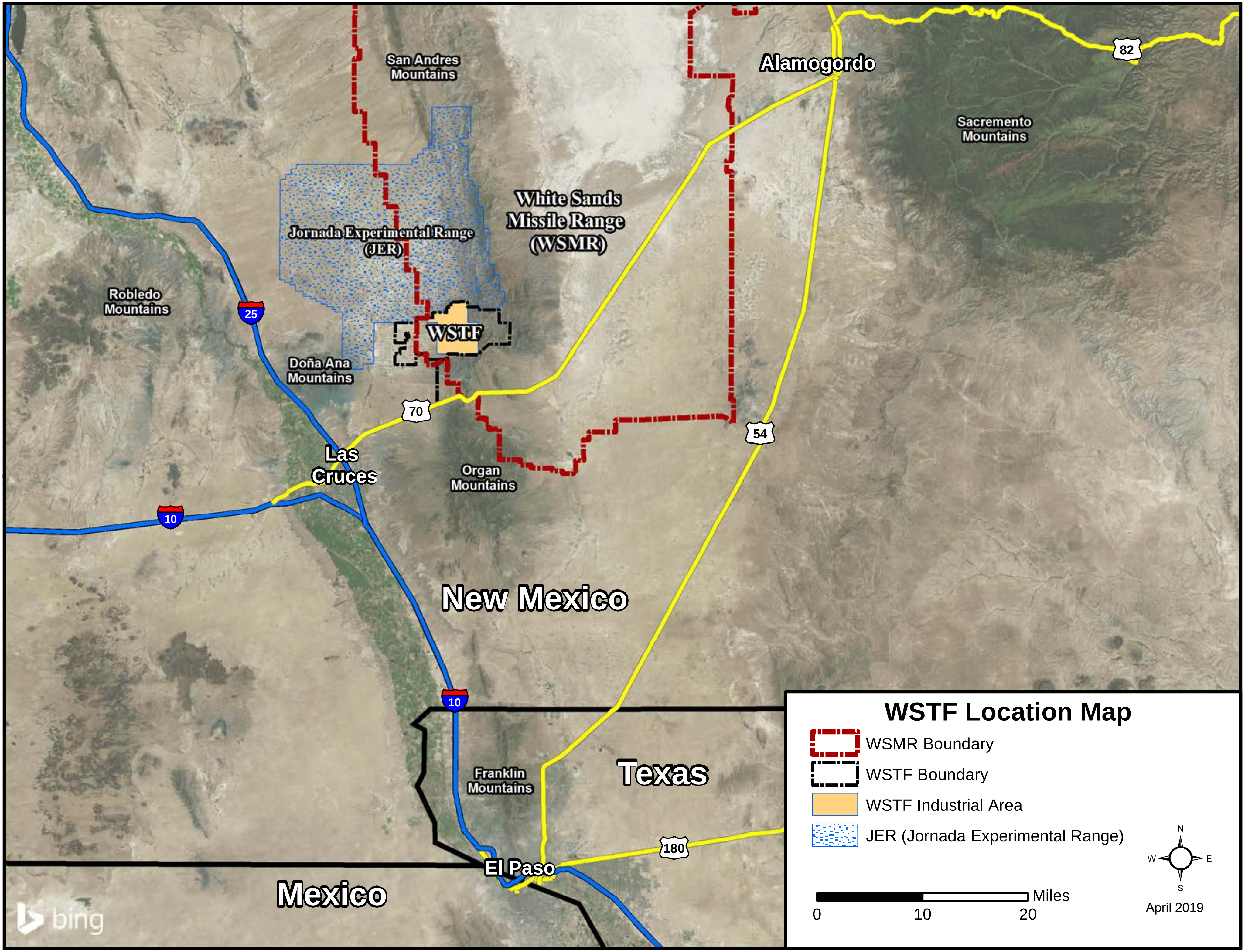
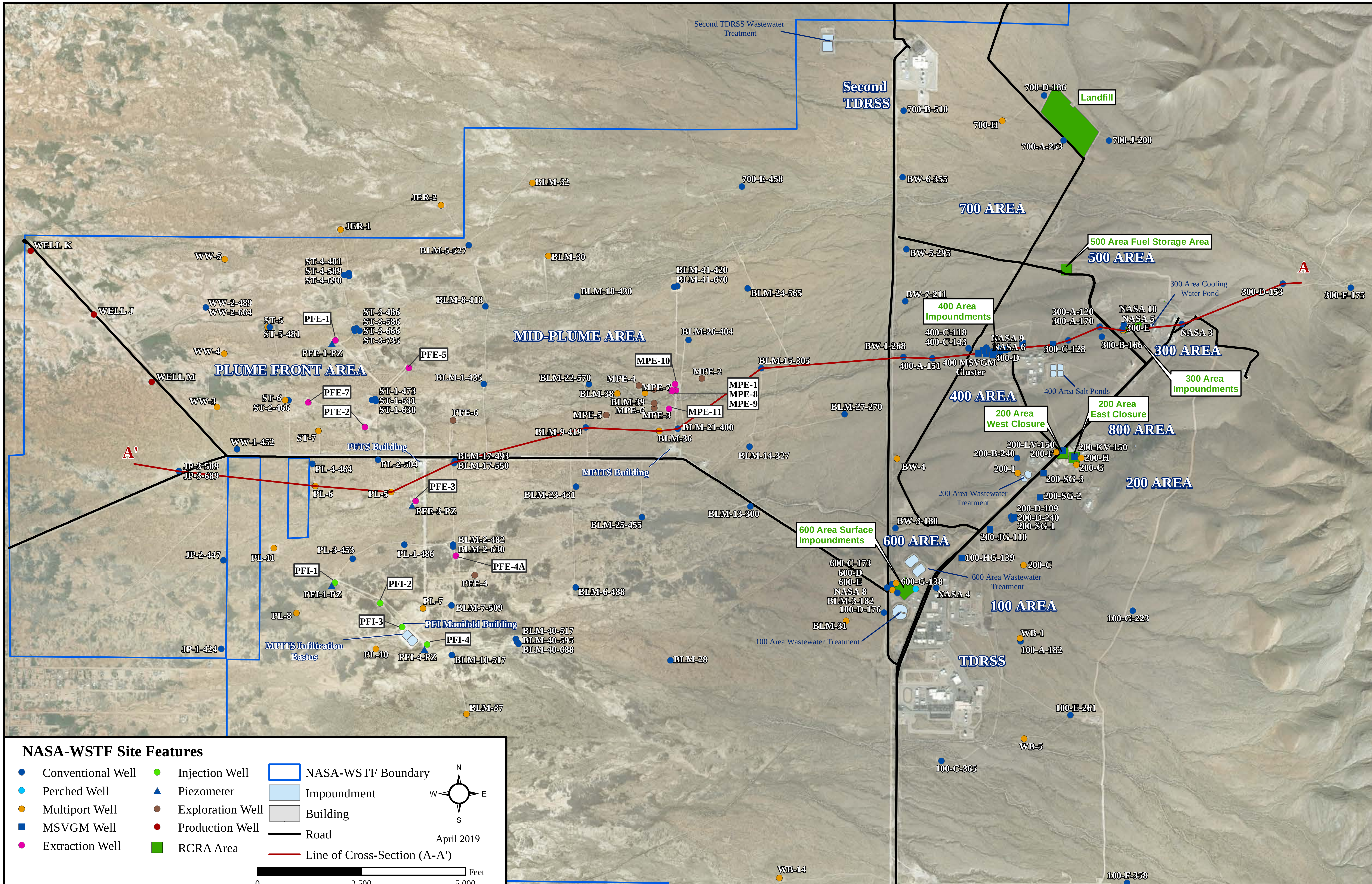

WSTF Location Map
WSMR Boundary
WSTF Boundary
WSTF Industrial Area
JER (Jornada Experimental Range)
San Andres Mountains
Alamogordo
Sacremento Mountains
White Sands Missile Range (WSMR)
Jornada Experimental Range (JER)
Robledo Mountains
WSTF
Doña Ana Mountains
Las Cruces
Organ Mountains
New Mexico
Texas
Franklin Mountains
El Paso
Mexico
25
10
70
54
82
180
N
W
E
S
Miles
0
10
20
April 2019
bing

Figure 2 **Pertinent WSTF Site Features**

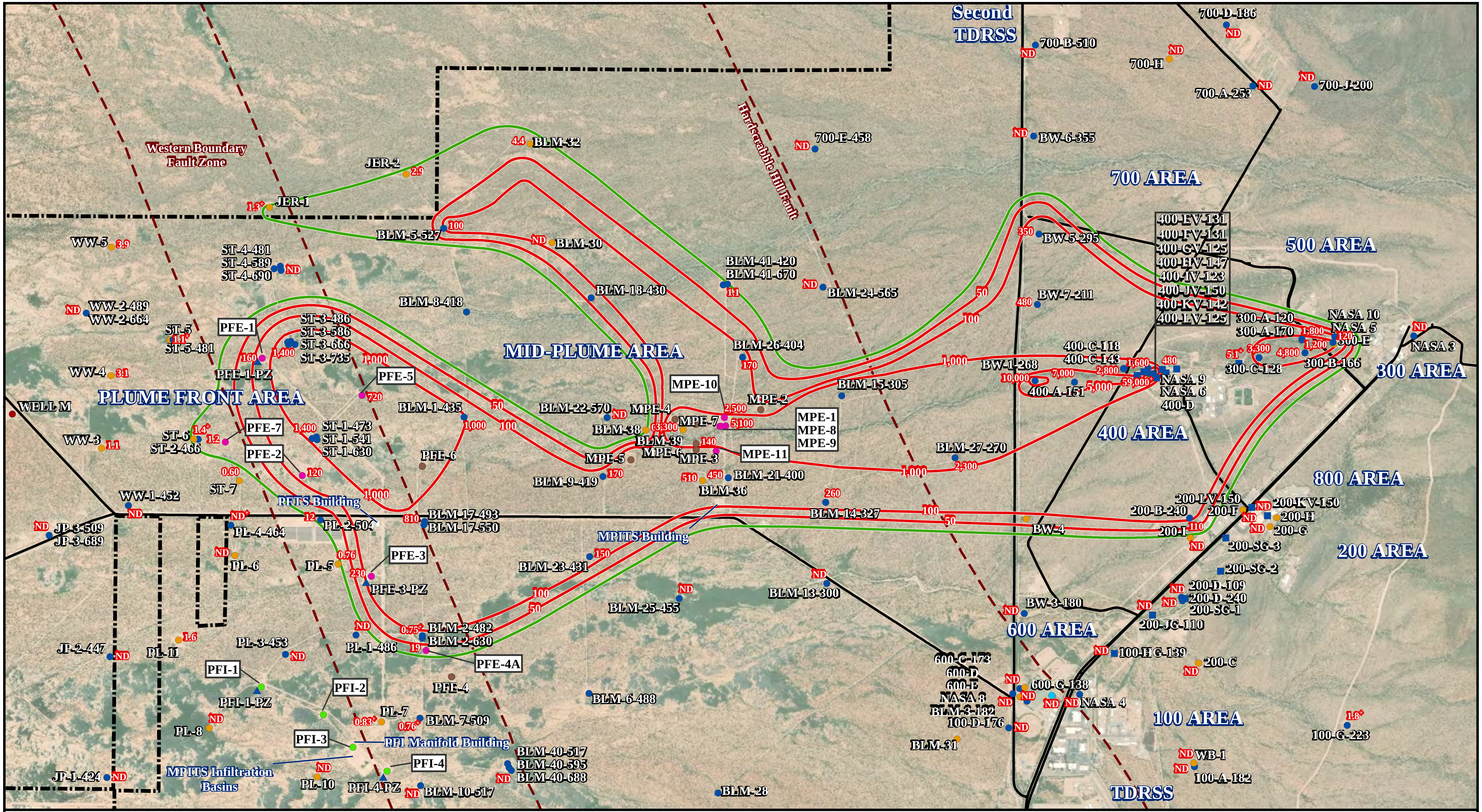
(SEE NEXT PAGE)



NASA-WSTF Site Features
Conventional Well
Perched Well
Multiport Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
RCRA Area
NASA-WSTF Boundary
Impoundment
Building
Road
Line of Cross-Section (A-A')
April 2019
0
2,500
5,000
Feet
N
E
S
W
PLUME FRONT AREA
MID-PLUME AREA
Second TDRSS
700 AREA
500 AREA
400 AREA
300 AREA
800 AREA
200 AREA
600 AREA
100 AREA
TDRSS
Landfill
500 Area Fuel Storage Area
400 Area Impoundments
300 Area Impoundments
200 Area West Closure
200 Area East Closure
600 Area Surface Impoundments
Second TDRSS Wastewater Treatment
300 Area Cooling Water Pond
400 Area Salt Ponds
200 Area Wastewater Treatment
600 Area Wastewater Treatment
100 Area Wastewater Treatment
PFTS Building
MPITS Building
PFI Manifold Building
MPITS Infiltration Basins
A
A'

Figure 3 **Distribution of NDMA in WSTF Groundwater**

(SEE NEXT PAGE)



NDMA Maximum Concentrations in Groundwater for Fourth Quarter 2018

Equiconcentration Line (ng/L)	Multiport	MSVGM Well	Piezometer	Main Road
NDMA Cleanup Level (1.1 ng/L)	Conventional Well	Extraction Well	Exploration Well	Fault
	Perched Well	Injection Well	Production Well	WSTF Boundary

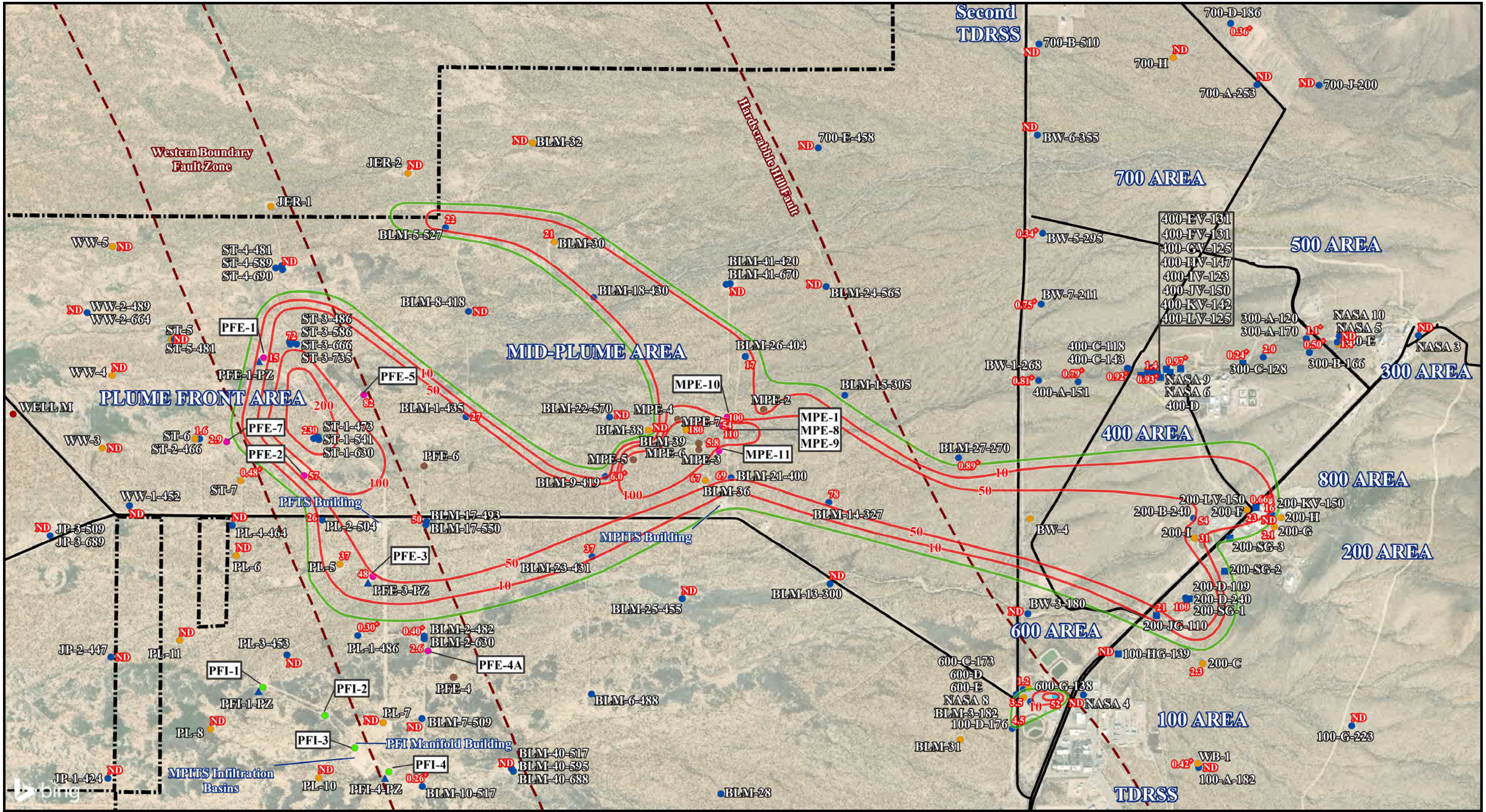
0 4,000 8,000 Feet

Note:
Method 607 NDMA results corrected for extraction efficiency.
\+ - Data value has a QA flag. See Appendix A.2 for specific flags.
ND - Non-detect values <0.15 ng/L (NDMA-LL) or <4.7 ng/L (607)
- No value indicates the well has not been sampled in the last year.

Original: January 2019
Update: February 2020

Figure 4 **Distribution of TCE in WSTF Groundwater**

(SEE NEXT PAGE)



TCE Maximum Concentrations in Groundwater for Fourth Quarter 2018

Equiconcentration Line (ug/L)	Multiport	MSVGM Well	Piezometer	Main Road
TCE Cleanup Level (4.9 ug/L)	Conventional Well	Extraction Well	Exploration Well	Fault
	Perched Well	Injection Well	Production Well	WSTF Boundary

Feet: 0, 4,000, 8,000

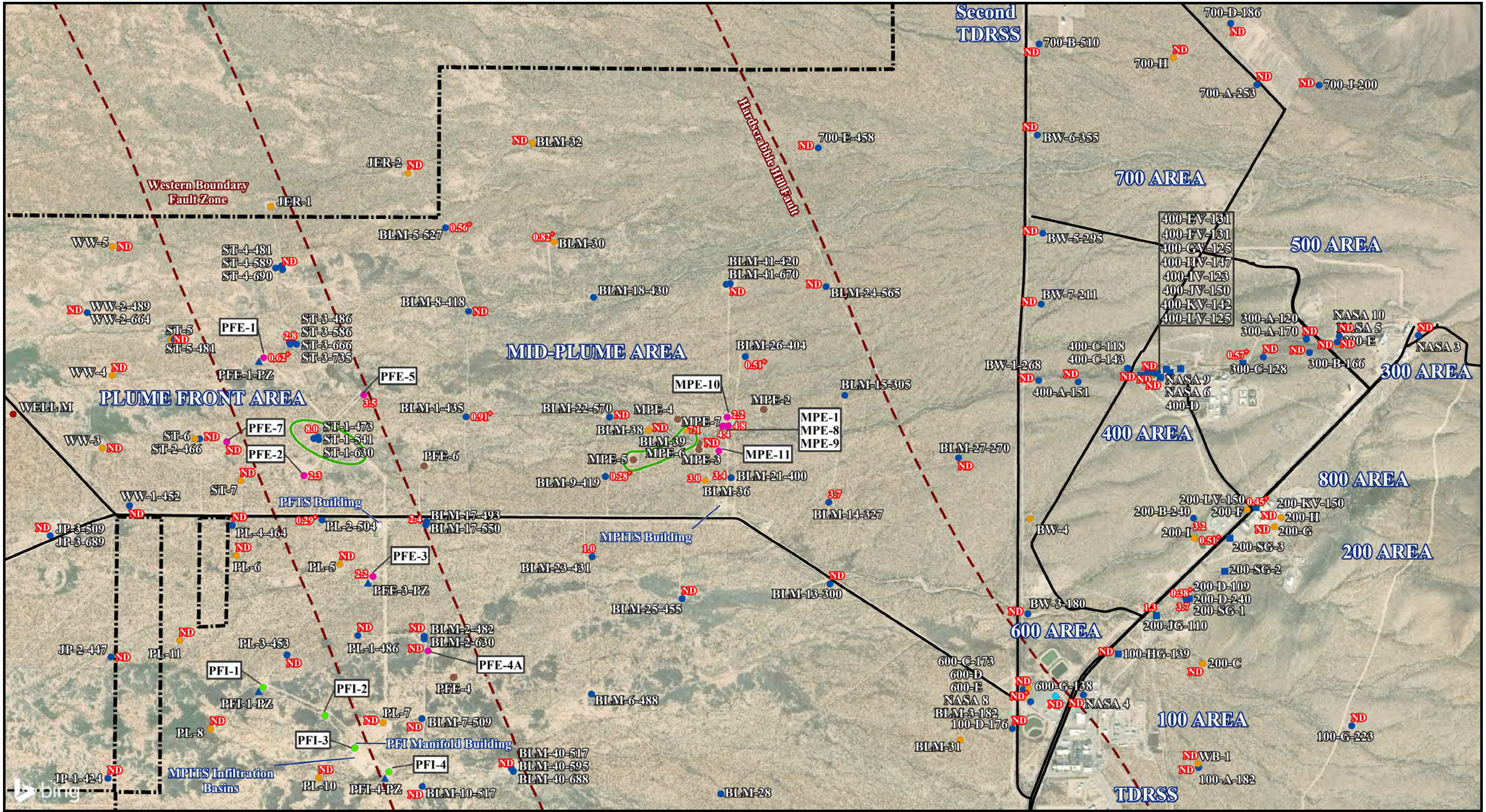
N, E, S, W

Note:
\+ - Data value has a QA flag. See Appendix A.2 for specific flags.
ND - Non-detect values <0.1116 ug/L
- No value indicates the well has not been sampled in the last year.

April 2019

Figure 5 **Distribution of PCE in WSTF Groundwater**

(SEE NEXT PAGE)



PCE Maximum Concentrations in Groundwater for Fourth Quarter 2018

Equiconcentration Line (ug/L)
PCE Cleanup Level (5 ug/L)

Multiport
Conventional Well
Perched Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Main Road
Fault
WSTF Boundary

0 4,000 8,000 Feet

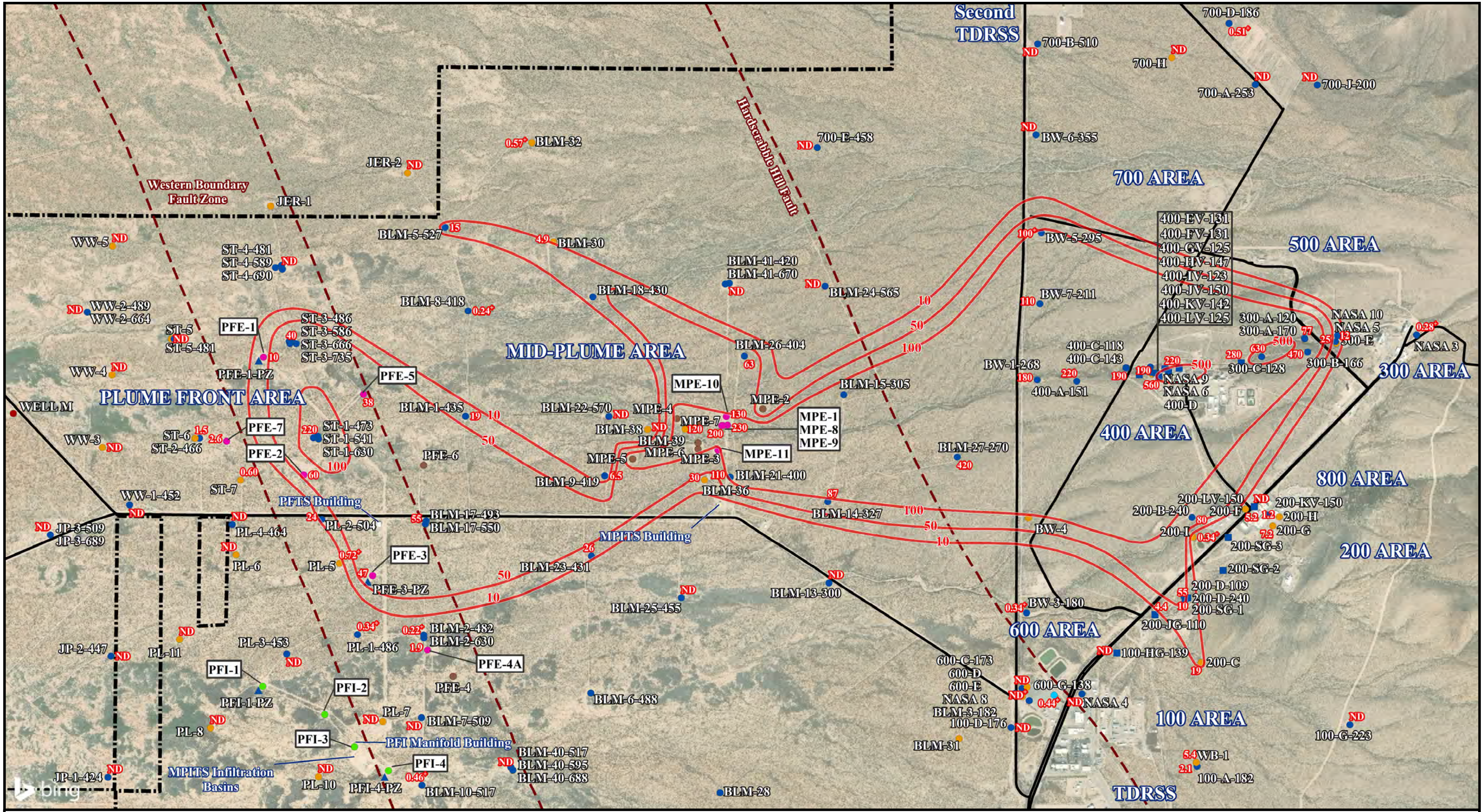
N W E S

Note:
+ Data value has a QA flag. See Appendix A.2 for specific flags.
ND Non-detect values <0.2 ug/L

April 2019

Figure 6 Distribution of Freon 11 in WSTF Groundwater

(SEE NEXT PAGE)



Freon 11 Maximum Concentrations in Groundwater for Fourth Quarter 2018

Multiport	MSVGM Well	Piezometer	Main Road	Equiconcentration Line (ug/L)
Conventional Well	Extraction Well	Exploration Well	Fault	
Perched Well	Injection Well	Production Well	WSTF Boundary	

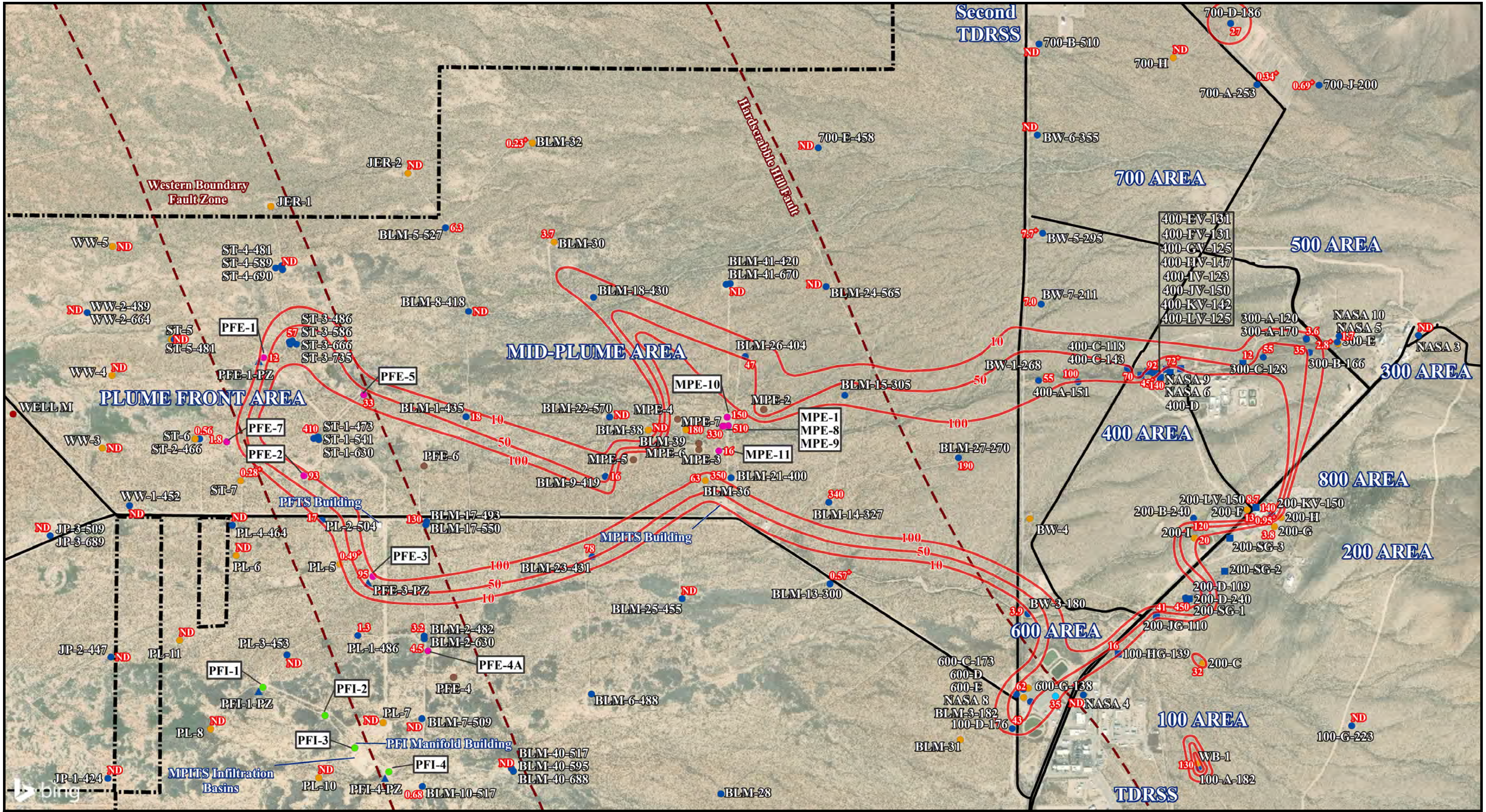
Feet: 0 — 4,000 — 8,000

Note:
Freon 11 concentations are below the EPA RSL (5,200 ug/L).
\+ Data value has a QA flag. See Appendix A.2 for specific flags.
ND Non-detect values <0.20 ug/L

April 2019

Figure 7 **Distribution of Freon 113 in WSTF Groundwater**

(SEE NEXT PAGE)



Freon 113 Maximum Concentrations in Groundwater for Fourth Quarter 2018

Multiport	MSVGM Well	Piezometer	Main Road	Equiconcentration Line (ug/L)
Conventional Well	Extraction Well	Exploration Well	Fault	
Perched Well	Injection Well	Production Well	WSTF Boundary	

0 4,000 8,000 Feet

N S E W

Note:
Freon 113 concentations are below the EPA RSL (10,000 ug/L).
\+ Data value has a QA flag. See Appendix A.2 for specific flags.
ND Non-detect values <0.31 ug/L

April 2019

Figure 8 **WSTF and Vicinity Surface Water Bodies**

(SEE NEXT PAGE)

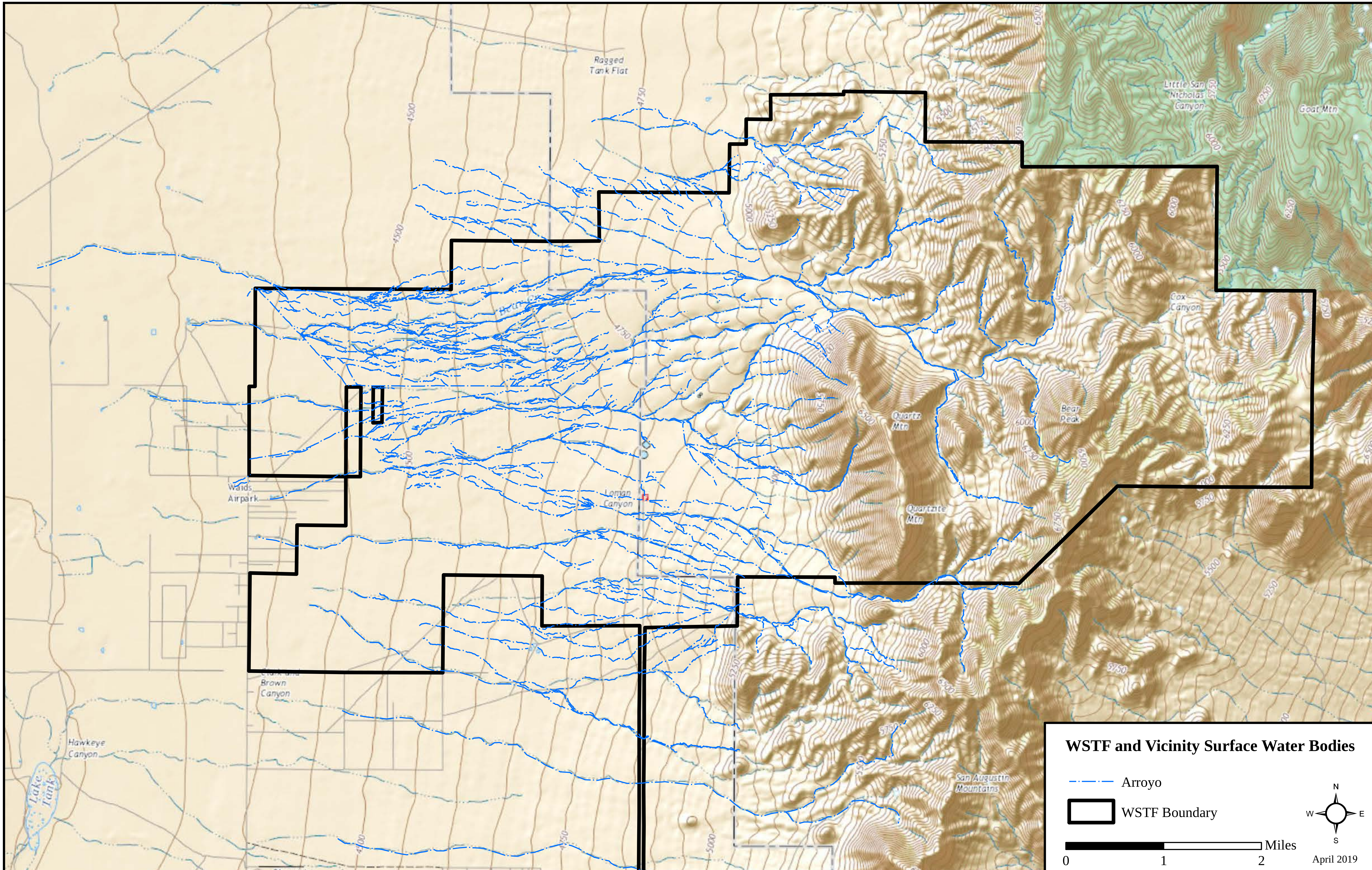

WSTF and Vicinity Surface Water Bodies
Arroyo
WSTF Boundary
Miles
0
1
2
N
S
E
W
April 2019
Ragged Tank Flat
Little San Nicholas Canyon
Goat Mtn
Cox Canyon
Quartz Mtn
Bear Peak
Quartzite Mtn
Logan Canyon
Wilds Airpark
Clark and Brown Canyon
Hawkeye Canyon
Lake Tank
San Augustin Mountains
Shoestring

Figure 9 Geological Features of Eastern WSTF (modified from Seager, 1981)

(SEE NEXT PAGE)

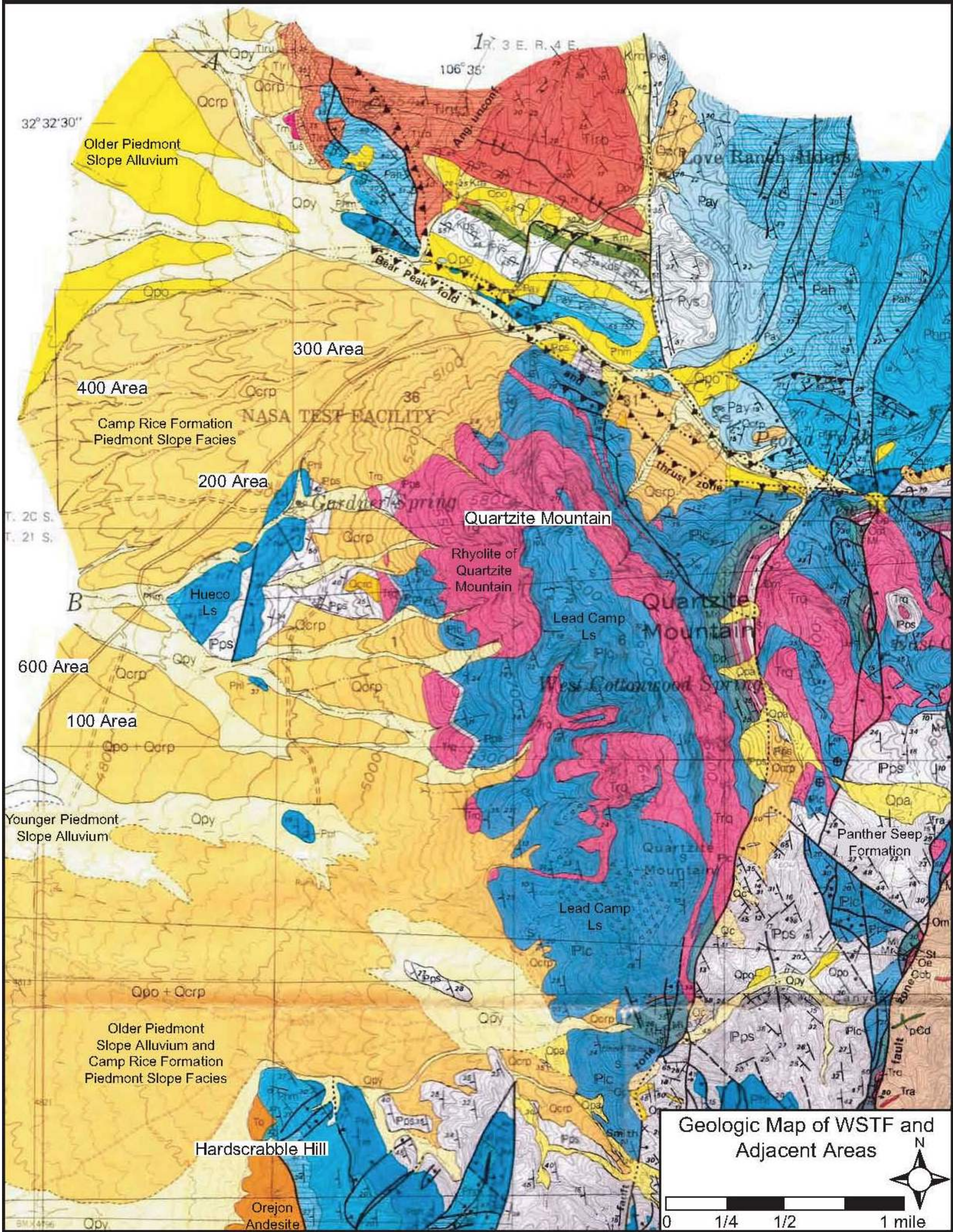

Geologic Map of WSTF and Adjacent Areas
N
0
1/4
1/2
1 mile
Older Piedmont Slope Alluvium
300 Area
400 Area
NASA TEST FACILITY
Camp Rice Formation Piedmont Slope Facies
200 Area
Gardner Spring
Quartzite Mountain
Rhyolite of Quartzite Mountain
Hueco Ls
Lead Camp Ls
600 Area
100 Area
West Cottonwood Spring
Younger Piedmont Slope Alluvium
Panther Seep Formation
Lead Camp Ls
Older Piedmont Slope Alluvium and Camp Rice Formation Piedmont Slope Facies
Hardscrabble Hill
Orejon Andesite
Bear Peak fold
Love Ranch Hills
thrust zone
106° 35'
32° 32' 30''
T. 20 S.
T. 21 S.
R. 3 E. R. 4 E.

Figure 10 **Geological Features of Western WSTF**

(SEE NEXT PAGE)

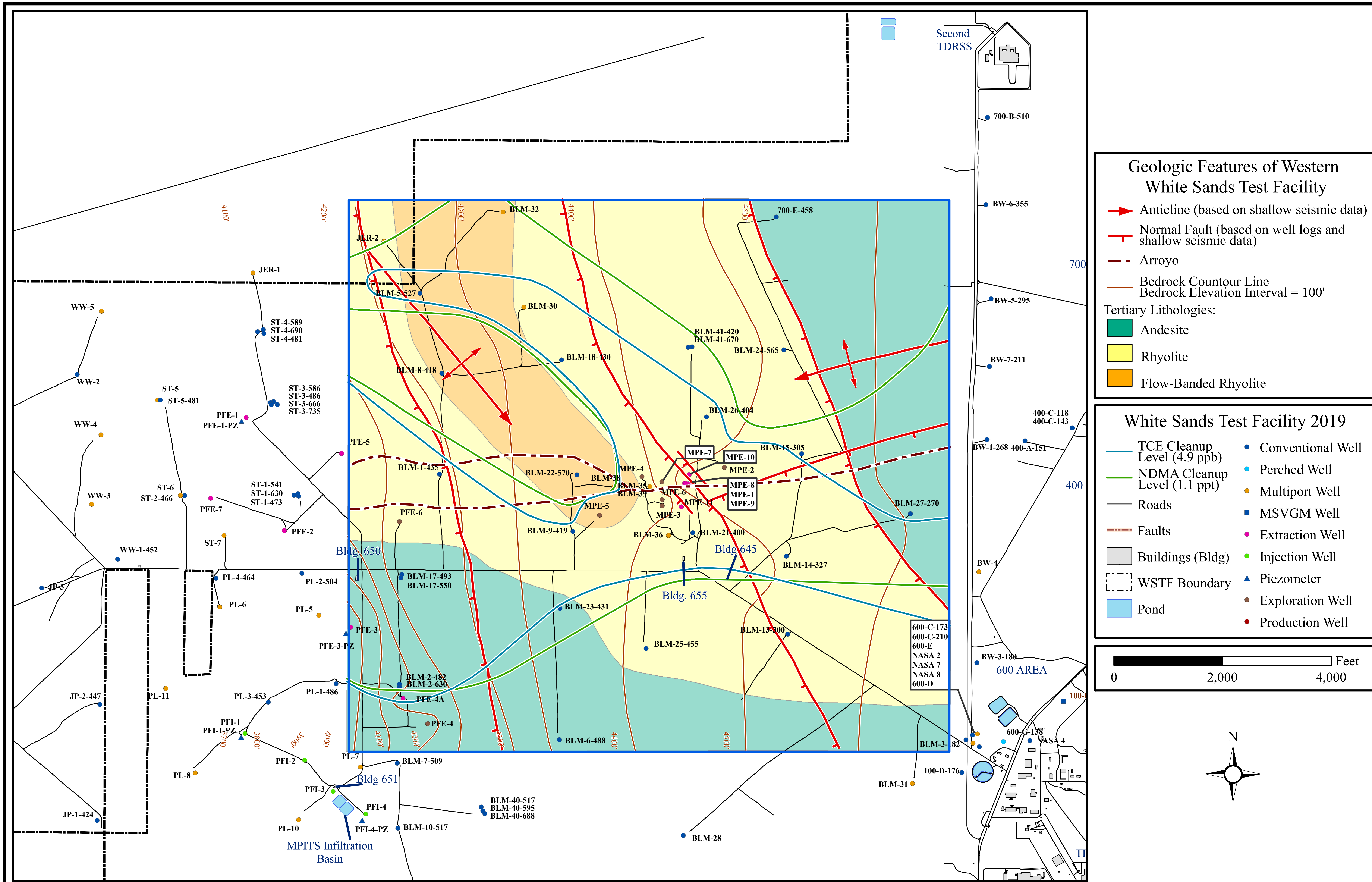
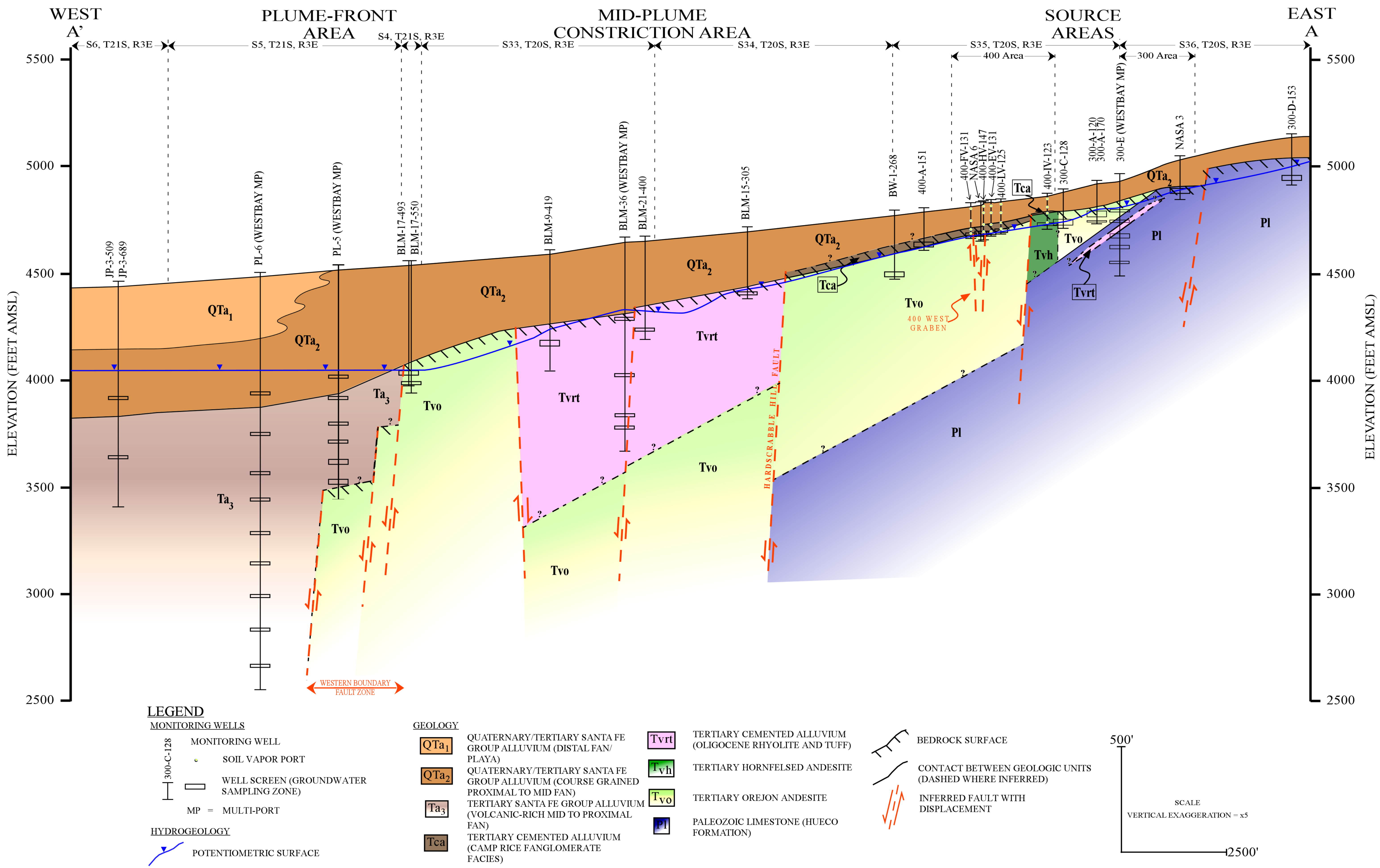

Geologic Features of Western White Sands Test Facility
Anticline (based on shallow seismic data)
Normal Fault (based on well logs and shallow seismic data)
Arroyo
Bedrock Countour Line
Bedrock Elevation Interval = 100'
Tertiary Lithologies:
Andesite
Rhyolite
Flow-Banded Rhyolite
White Sands Test Facility 2019
TCE Cleanup Level (4.9 ppb)
NDMA Cleanup Level (1.1 ppt)
Roads
Faults
Buildings (Bldg)
WSTF Boundary
Pond
Conventional Well
Perched Well
Multiport Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Feet
0
2,000
4,000
N
Second TDRSS
700
400
600 AREA
Bldg. 650
Bldg. 645
Bldg. 655
Bldg 651
MPITS Infiltration Basin
700-B-510
BW-6-355
BW-5-295
BW-7-211
400-C-118
400-C-143
BW-1-268
400-A-151
BW-4
BW-3-180
600-G-138
NASA 4
100-D-176
BLM-31
BLM-3-182
BLM-28
700-E-458
BLM-32
JER-2
JER-1
BLM-5-527
BLM-30
BLM-41-420
BLM-41-670
BLM-24-565
BLM-18-430
BLM-8-418
BLM-26-404
BLM-15-305
MPE-7
MPE-10
MPE-2
MPE-4
MPE-8
MPE-1
MPE-9
MPE-6
MPE-11
MPE-3
MPE-5
BLM-1-435
BLM-22-570
BLM-38
BLM-35
BLM-39
BLM-27-270
PFE-5
PFE-6
BLM-9-419
BLM-36
BLM-21-400
BLM-14-327
BLM-17-493
BLM-17-550
BLM-23-431
BLM-25-455
BLM-13-300
600-C-173
600-C-210
600-E
NASA 2
NASA 7
NASA 8
600-D
BLM-2-482
BLM-2-630
PFE-4A
PFE-4
BLM-6-488
PFE-3
PFE-3-PZ
WW-5
WW-2
WW-4
WW-3
WW-1-452
ST-4-589
ST-4-690
ST-4-481
ST-5
ST-5-481
ST-3-586
ST-3-486
ST-3-666
ST-3-735
PFE-1
PFE-1-PZ
ST-6
ST-2-466
ST-1-541
ST-1-630
ST-1-473
PFE-7
PFE-2
ST-7
JP-3
PL-4-464
PL-2-504
PL-6
PL-5
PL-11
JP-2-447
PL-3-453
PL-1-486
PFI-1
PFI-1-PZ
PFI-2
PL-8
PL-7
BLM-7-509
PFI-3
PFI-4
PFI-4-PZ
PL-10
BLM-10-517
BLM-40-517
BLM-40-595
BLM-40-688
JP-1-424
3700'
3800'
3900'
4000'
4100'
4200'
4300'
4400'
4500'

Figure 11 WSTF Hydrostratigraphy (Geologic Cross-section)

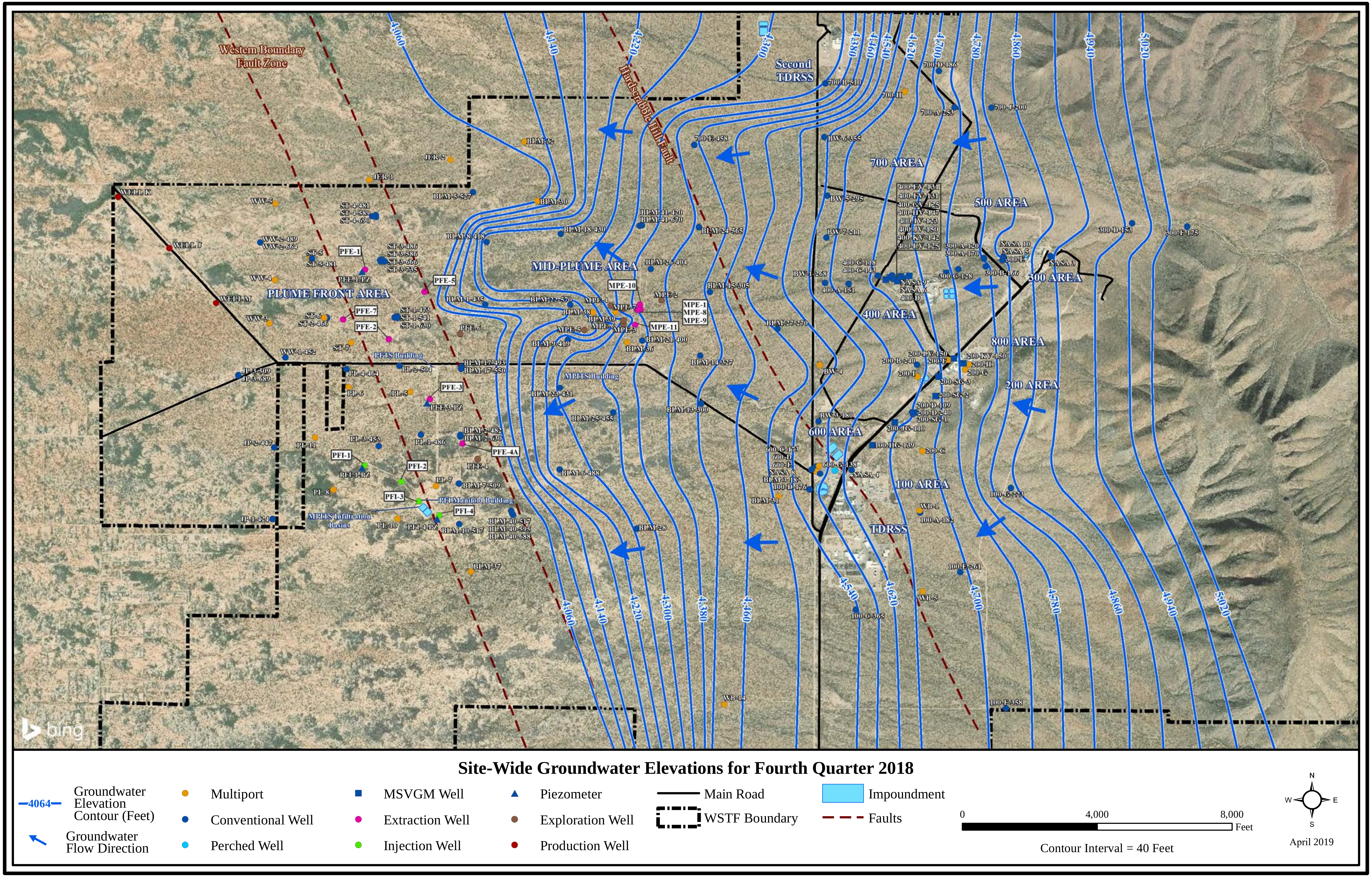
(SEE NEXT PAGE)



WEST
A'
PLUME-FRONT AREA
MID-PLUME CONSTRICTION AREA
SOURCE AREAS
EAST
A
S6, T21S, R3E
S5, T21S, R3E
S4, T21S, R3E
S33, T20S, R3E
S34, T20S, R3E
S35, T20S, R3E
S36, T20S, R3E
400 Area
300 Area
ELEVATION (FEET AMSL)
5500
5000
4500
4000
3500
3000
2500
JP-3-509
JP-3-689
PL-6 (WESTBAY MP)
PL-5 (WESTBAY MP)
BLM-17-493
BLM-17-550
BLM-9-419
BLM-36 (WESTBAY MP)
BLM-21-400
BLM-15-305
BW-1-268
400-A-151
400-FV-131
NASA 6
400-HV-147
400-EV-131
400-LV-125
400-IV-123
300-C-128
300-A-120
300-A-170
300-E (WESTBAY MP)
NASA 3
300-D-153
QTa1
QTa2
Ta3
Tvo
Tvrt
Tca
Tvh
Pl
400 WEST GRABEN
HARDSCRABBLE HILL FAULT
WESTERN BOUNDARY FAULT ZONE
LEGEND
MONITORING WELLS
MONITORING WELL
SOIL VAPOR PORT
WELL SCREEN (GROUNDWATER SAMPLING ZONE)
MP = MULTI-PORT
HYDROGEOLOGY
POTENTIOMETRIC SURFACE
GEOLOGY
QUATERNARY/TERTIARY SANTA FE GROUP ALLUVIUM (DISTAL FAN/ PLAYA)
QUATERNARY/TERTIARY SANTA FE GROUP ALLUVIUM (COURSE GRAINED PROXIMAL TO MID FAN)
TERTIARY SANTA FE GROUP ALLUVIUM (VOLCANIC-RICH MID TO PROXIMAL FAN)
TERTIARY CEMENTED ALLUVIUM (CAMP RICE FANGLOMERATE FACIES)
TERTIARY CEMENTED ALLUVIUM (OLIGOCENE RHYOLITE AND TUFF)
TERTIARY HORNFELSED ANDESITE
TERTIARY OREJON ANDESITE
PALEOZOIC LIMESTONE (HUECO FORMATION)
BEDROCK SURFACE
CONTACT BETWEEN GEOLOGIC UNITS (DASHED WHERE INFERRED)
INFERRED FAULT WITH DISPLACEMENT
500'
2500'
SCALE
VERTICAL EXAGGERATION = x5

Figure 12 **WSTF Groundwater Elevation Map**

(SEE NEXT PAGE)



Site-Wide Groundwater Elevations for Fourth Quarter 2018

Figure 13 Numerical Flow Model Calibrated K, Estimated Using PEST

(SEE NEXT PAGE)

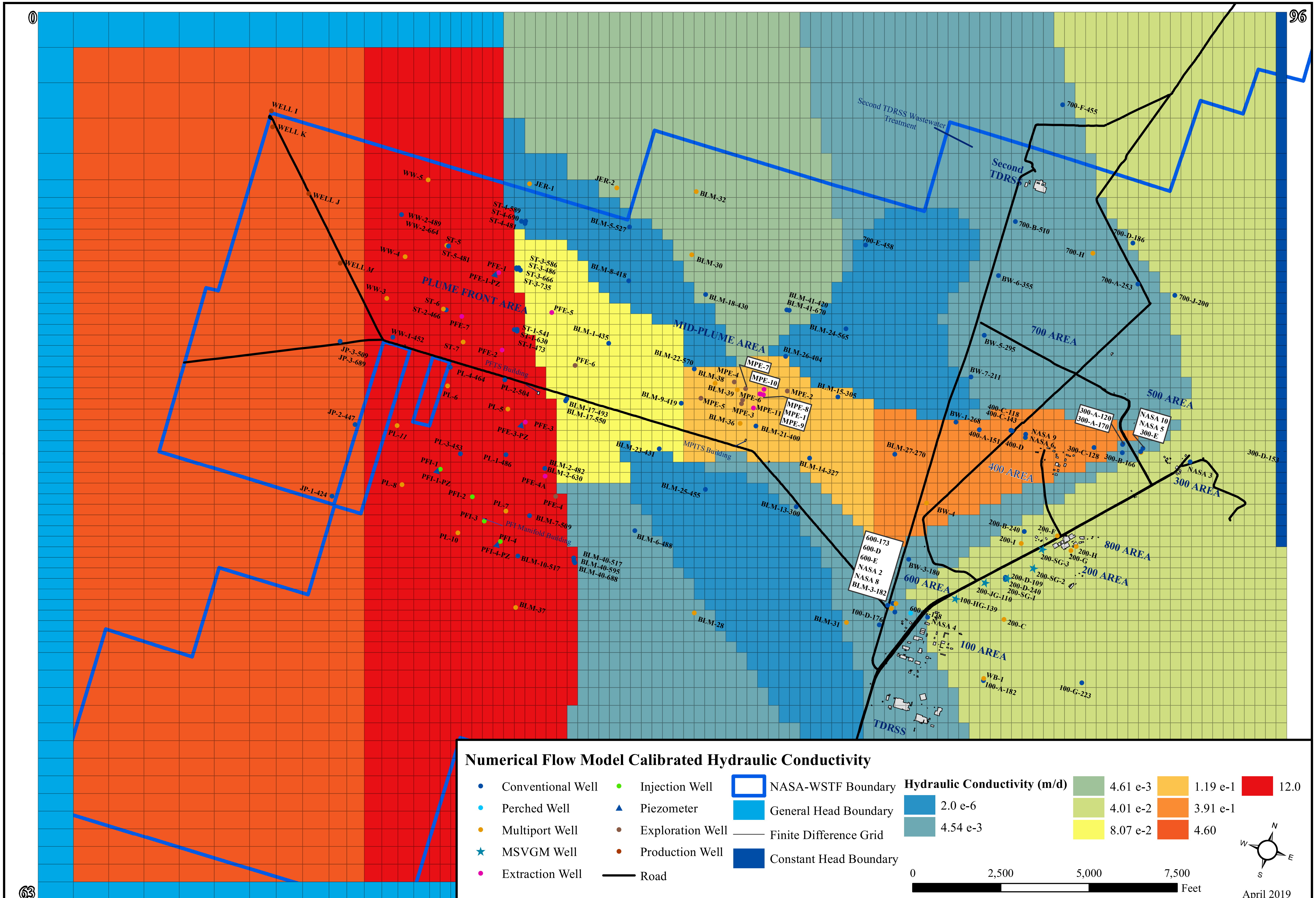
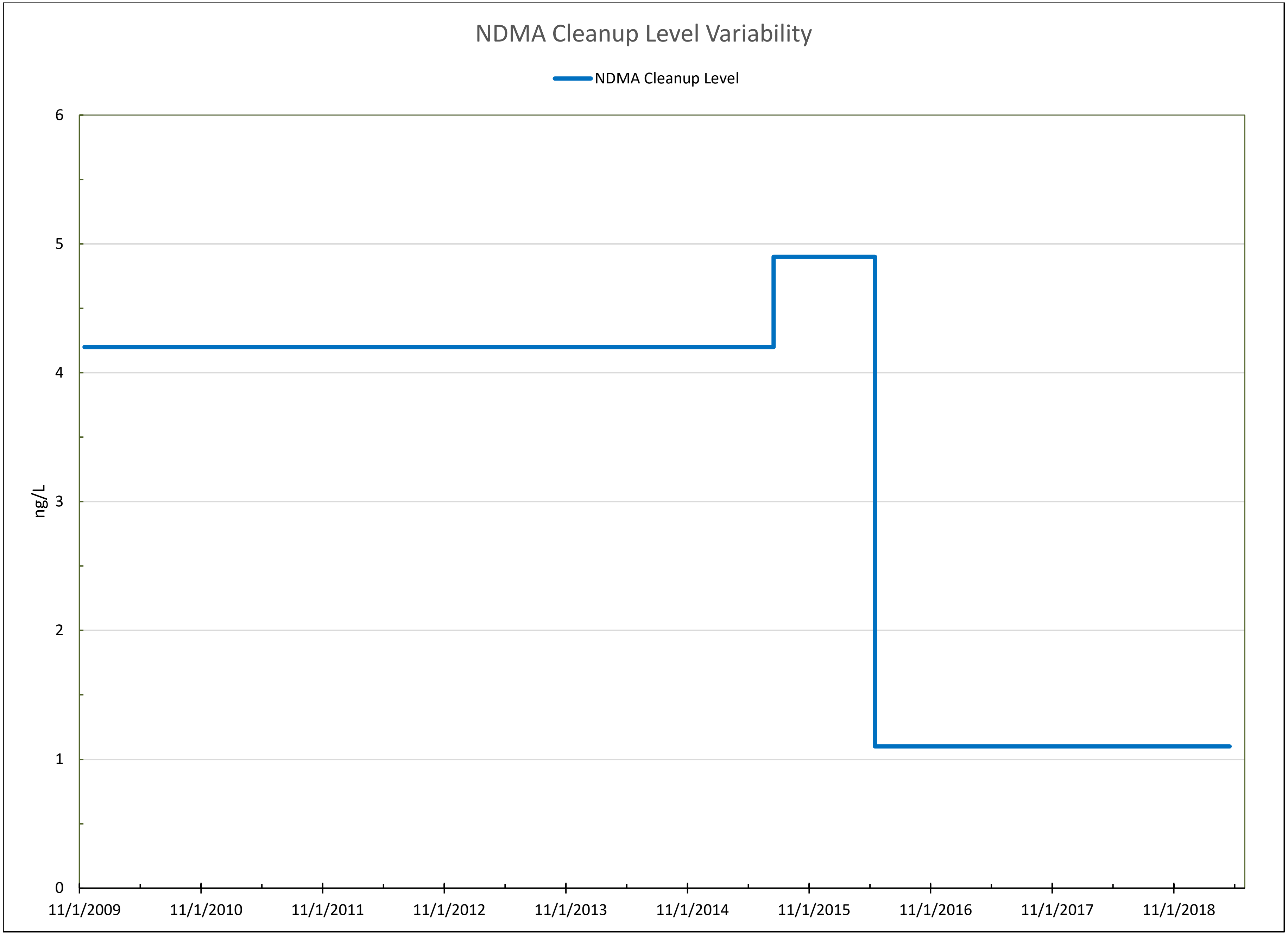
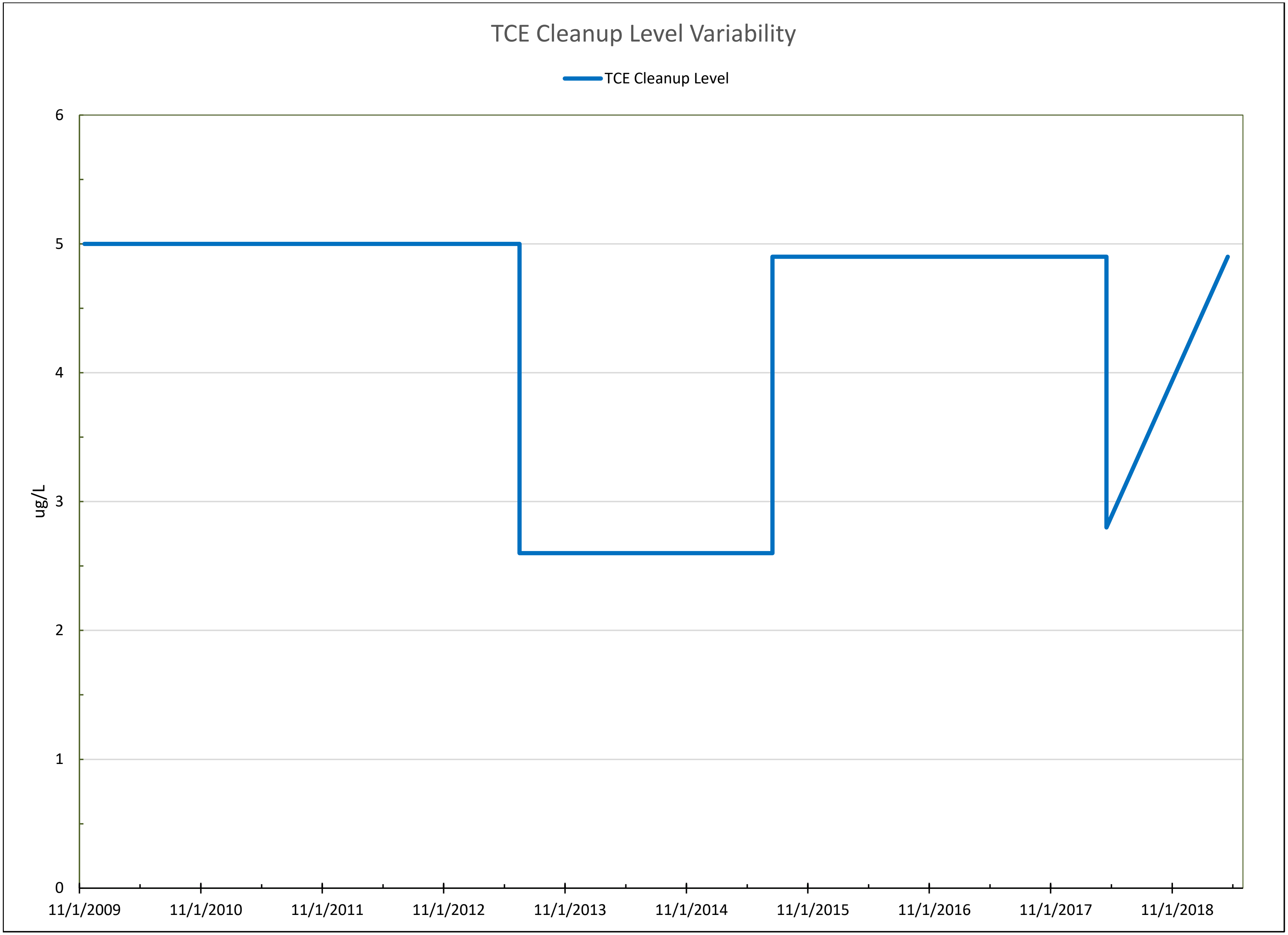

Numerical Flow Model Calibrated Hydraulic Conductivity
Conventional Well
Perched Well
Multiport Well
MSVGM Well
Extraction Well
Injection Well
Piezometer
Exploration Well
Production Well
Road
NASA-WSTF Boundary
General Head Boundary
Finite Difference Grid
Constant Head Boundary
Hydraulic Conductivity (m/d)
2.0 e-6
4.54 e-3
4.61 e-3
4.01 e-2
8.07 e-2
1.19 e-1
3.91 e-1
4.60
12.0
0
2,500
5,000
7,500
Feet
N
E
S
W
April 2019
0
96
63
PLUME FRONT AREA
MID-PLUME AREA
700 AREA
500 AREA
400 AREA
300 AREA
800 AREA
200 AREA
600 AREA
100 AREA
TDRSS
Second TDRSS
Second TDRSS Wastewater Treatment
PFTS Building
MPITS Building
PFI Manifold Building

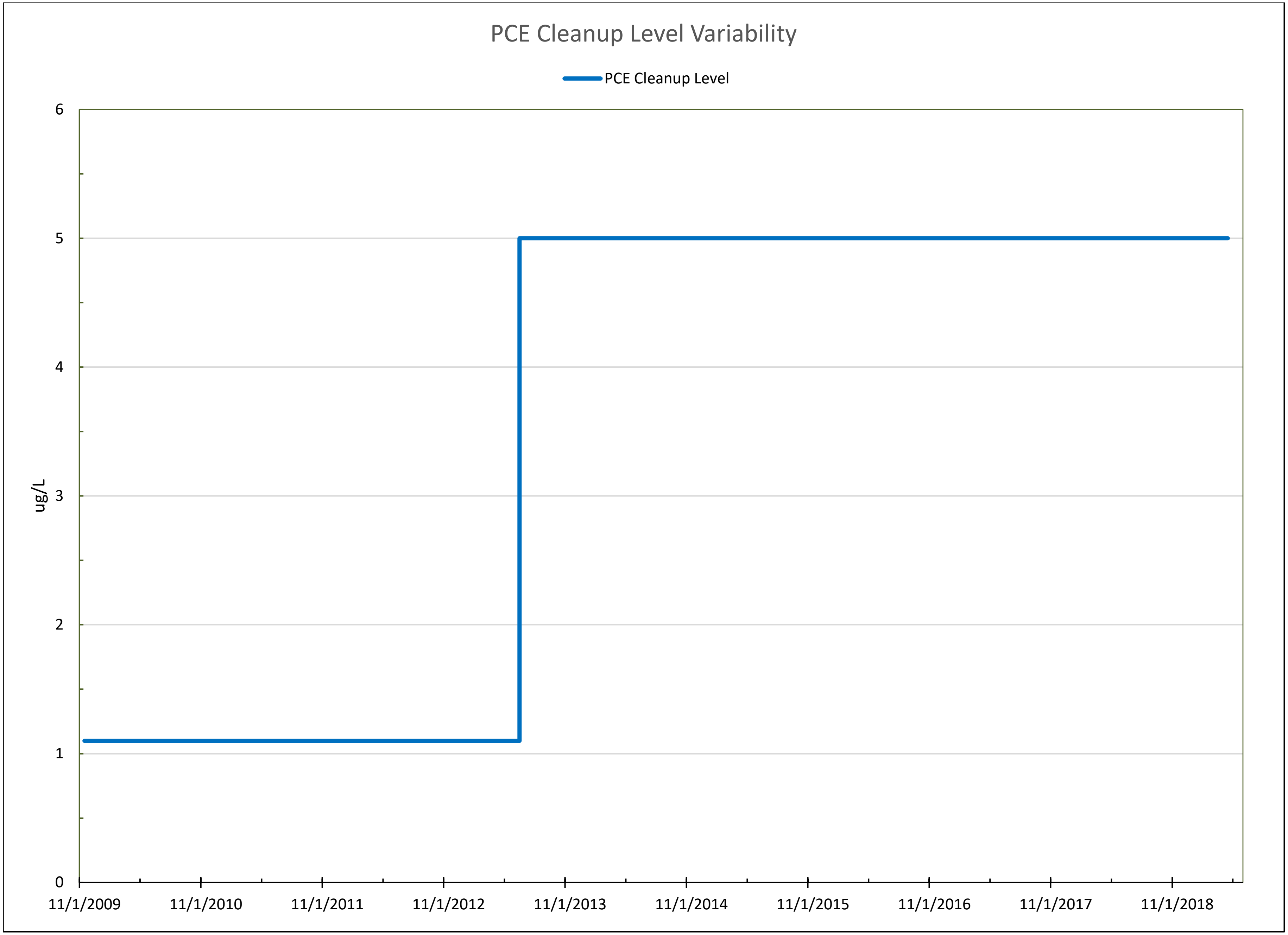
Figure 14 **Groundwater Cleanup Level Variability**

(SEE NEXT PAGE)

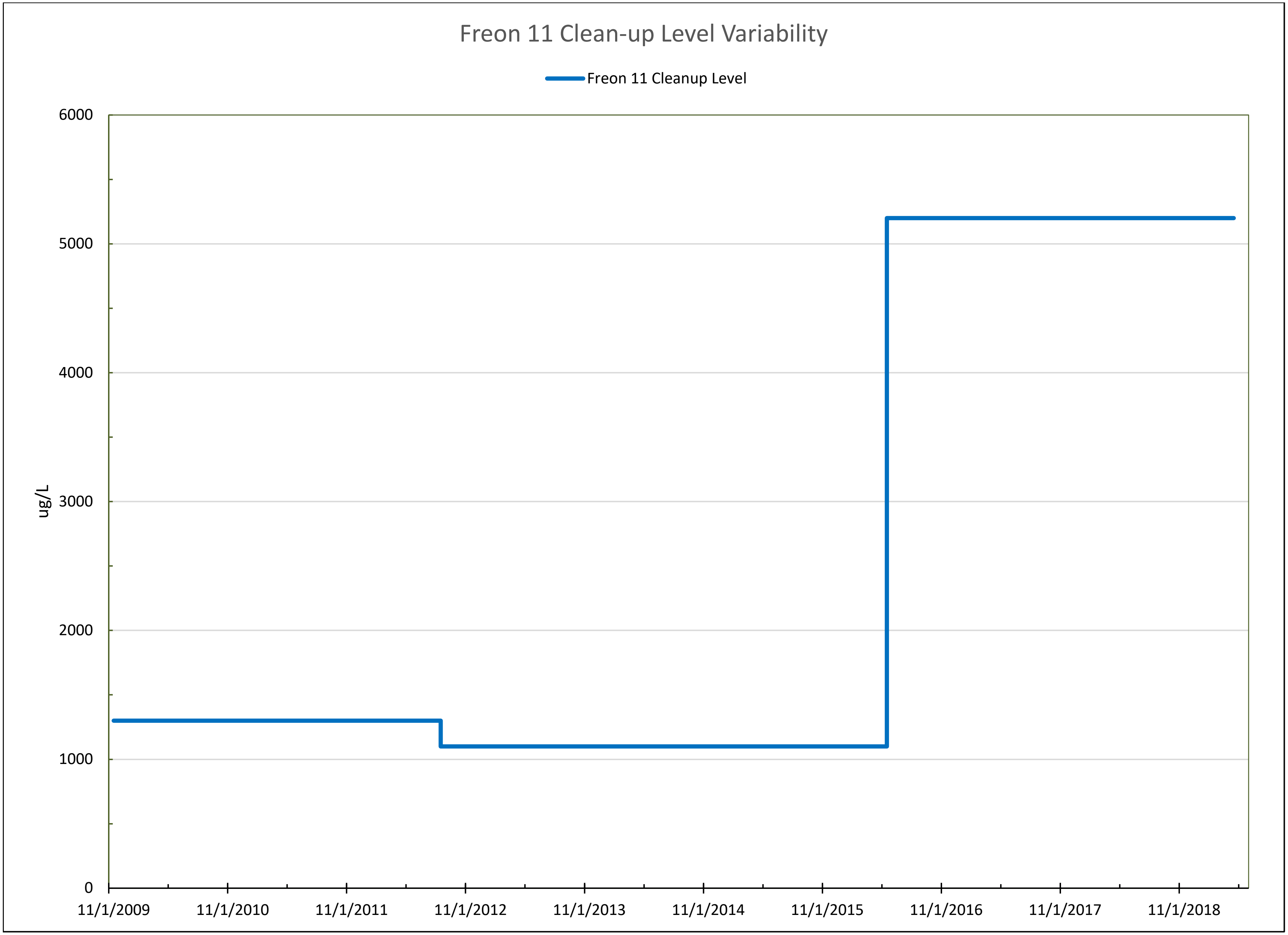

NDMA Cleanup Level Variability
NDMA Cleanup Level
ng/L
6
5
4
3
2
1
0
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018



TCE Cleanup Level Variability
TCE Cleanup Level
ug/L
0
1
2
3
4
5
6
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018



PCE Cleanup Level Variability
PCE Cleanup Level
ug/L
0
1
2
3
4
5
6
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018



Freon 11 Clean-up Level Variability
Freon 11 Cleanup Level
ug/L
6000
5000
4000
3000
2000
1000
0
11/1/2009
11/1/2010
11/1/2011
11/1/2012
11/1/2013
11/1/2014
11/1/2015
11/1/2016
11/1/2017
11/1/2018