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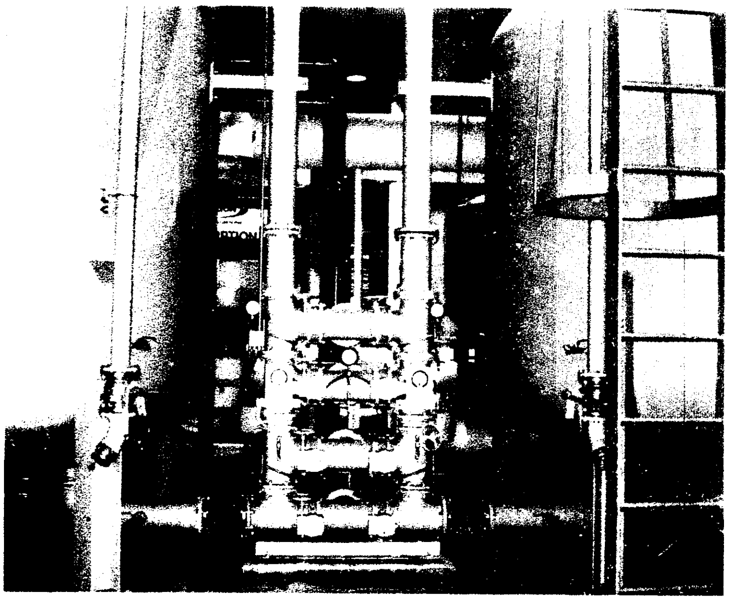
Alternative Feasibility Study
Groundwater Remedial Strategy
Badger Army Ammunition Plant



Prepared for:

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September 2011

SpecPro BTS

SpecPro, Inc. and Badger Technical Services, LLC
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TABLE OF CONTENTS

1.0 CERTIFICATION PAGE 1

2.0 EXECUTIVE SUMMARY 2

3.0 INTRODUCTION 3

4.0 SITE BACKGROUND 4

4.1 Site Description 4

4.2 Site History 5

4.3 Environmental Setting 6

5.0 SOURCE INVESTIGATIONS AND REMEDIAL MEASURES 10

5.1 Propellant Burning Ground 10

5.2 Deterrent Burning Ground 15

5.3 Central Plume Area 16

6.0 GROUNDWATER CHARACTERIZATION 17

6.1 Groundwater Properties 17

6.2 Nature and Extent of Groundwater Contamination 20

6.3 Groundwater Modeling 29

7.0 CONCEPTUAL SITE MODEL 31

7.1 Current and Potential Land Uses 31

7.2 Sources of Contamination 31

7.3 Environmental Medium and Exposure Points 32

7.4 Exposure Pathways and Receptors 32

8.0 REGULATORY REQUIREMENTS 33

8.1 Wisconsin Spill Statute 33

8.2 Groundwater Quality Regulations 33

8.3 Wisconsin Water Quality Standards and Criteria ... 35

9.0 REMEDIAL ALTERNATIVES ... 37

9.1 Groundwater Remedial Action Objective ... 37

9.2 Remedial Alternatives ... 37

9.3 Detailed Analysis of Alternatives ... 37

9.4 Monitored Natural Attenuation Evaluation ... 39

9.5 Technical Impracticability ... 42

9.6 Alternative 1 – IRM/MIRM Treatment and Monitored Natural Attenuation ... 42

9.7 Alternative 2 – In-Situ Biochemical Treatment and Monitored Natural Attenuation ... 44

9.8 Alternative 3 – Public Water System and Monitored Natural Attenuation ... 47

10.0 COMPARISON OF ALTERNATIVES ... 49

11.0 REMEDY SELECTION ... 50

12.0 REFERENCES ... 51

LIST OF FIGURES

Figure 1	Site Location Map
Figure 2	Geology of Sauk County, Wisconsin
Figure 3	Generalized Geologic Cross Section West-East
Figure 4	Generalized Geologic Cross Section North-South
Figure 5	Bedrock Surface Isopach map
Figure 6	Location and Orientation of Geologic Cross Sections
Figure 7	Geologic Cross Section A-A' – Propellant Burning Ground
Figure 8	Geologic Cross Section B-B' – Propellant Burning Ground
Figure 9	Geologic Cross Section C-C' – Propellant Burning Ground
Figure 10	Geologic Cross Section D-D' – Propellant Burning Ground
Figure 11	Geologic Cross Section E-E' – Deterrent Burning Ground
Figure 12	Geologic Cross Section F-F' – Deterrent Burning Ground
Figure 13	Geologic Cross Section G-G' – Central Plume
Figure 14	September 2010 Groundwater Contours
Figure 15	Monitoring Well Locations
Figure 16	Off-Site Plume Area, Southeast Area, and Private Well Locations
Figure 17	Interim Remedial Measures (IRM) and Modified Interim Remedial Measures (MIRM) Extraction Wells
Figure 18	Groundwater Plumes
Figure 19	Propellant Burning Ground Groundwater Plume Conceptual Model
Figure 20	Carbon Tetrachloride Isoconcentration Map (Elevation above 705 feet) – Propellant Burning Ground
Figure 21	Carbon Tetrachloride Isoconcentration Map (Elevation below 705 feet) – Propellant Burning Ground
Figure 22	March 1993 – September 2010 Carbon Tetrachloride Isoconcentration Map, Propellant Burning Ground – Off-Site Area
Figure 23	Carbon Tetrachloride Isoconcentration Section A-A' – Propellant Burning Ground
Figure 24	Carbon Tetrachloride Isoconcentration Section B-B' – Propellant Burning Ground
Figure 25	Carbon Tetrachloride Isoconcentration Section D-D' – Propellant Burning Ground
Figure 26	Total Dinitrotoluene Isoconcentration Map (Elevation above 705 feet) – Propellant Burning Ground
Figure 27	Total Dinitrotoluene Isoconcentration Map (Elevation below 705 feet) – Propellant Burning Ground
Figure 28	Total Dinitrotoluene Isoconcentration Section A-A' – Propellant Burning Ground
Figure 29	Total Dinitrotoluene Isoconcentration Section B-B' – Propellant Burning Ground
Figure 30	Total Dinitrotoluene Isoconcentration Section D-D' – Propellant Burning Ground
Figure 31	Total Dinitrotoluene Isoconcentration Map (Elevation above 752 feet) – Deterrent Burning Ground
Figure 32	Total Dinitrotoluene Isoconcentration Map (Elevation below 752 feet) – Deterrent Burning Ground
Figure 33	Total Dinitrotoluene Isoconcentration Map – Deterrent Burning Ground
Figure 34	Total Dinitrotoluene Isoconcentration Section E-E' – Deterrent Burning Ground
Figure 35	Total Dinitrotoluene Isoconcentration Section F-F' – Deterrent Burning Ground

Figure 36 Total Dinitrotoluene Isoconcentration Map – Central Plume
Figure 37 Total Dinitrotoluene Isoconcentration Section G-G' – Central Plume
Figure 38 Conceptual Site Model
Figure 39 Proposed Remedy Area

LIST OF TABLES

Table 1 Propellant Burning Ground – Volatile Organic Compounds Soil Sample Results (2005)
Table 2 DNT-Impacted Soil Contaminant Mass Estimate – PBG and DBG Source Areas
Table 3 Contaminant Mass Removal in Pounds – IRM and MIRM Systems
Table 4 Groundwater Analytical Results – December 2010
Table 5 Field Hydraulic Conductivity Test Results
Table 6 Horizontal Groundwater Gradient
Table 7 Vertical Groundwater Gradient
Table 8 Groundwater Analytical Results – Northeast Boundary Monitoring Well Installation – August 2010
Table 9 Groundwater Analytical Results – September 2010 Round
Table 10 Groundwater Analytical Results – 2010 Site-wide Monitoring Well installation
Table 11 Groundwater Plume Contaminant Mass Estimate – Propellant Burning Ground
Table 12 Dinitrotoluene Groundwater Plume Contaminant Mass Estimate – Deterrent Burning Ground and Central Plumes
Table 13 Regulatory Requirements: VOCs and SVOCs
Table 14 Comparison of Alternatives

LIST OF APPENDICES

Appendix A Plume Concentrations Over Time Graphs
Appendix B Groundwater Monitoring Well Installation Documentation
Appendix C September and October 2010 Contaminant Concentration Maps
Appendix D Technical Memorandum – Groundwater Flow and Solute Transport Modeling
Appendix E Remedial Alternative Cost Summary

LIST OF ACRONYMS

1,1,1-TCA	1,1,1-Trichloroethane
1,1,2-TCA	1,1,2-Trichloroethane
2,4-DNT	2,4-Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
µg/l	Micrograms per liter
AFS	Alternative Feasibility Study
Army	Department of the Army
bgs	Below ground surface
BAAP	Badger Army Ammunition Plant (WDNR designation)
BAAAP	Badger Army Ammunition Plant (Department of Defense designation)
BEST	Biologically Enhanced Subsurface Treatment
BIA	United States Bureau of Indian Affairs
BNA	Base Neutral Acid
BSD	Bluffview Sanitary District
cm/sec	Centimeters per second
COC	Contaminant of Concern
CSM	Conceptual Site Model
CTET	Carbon Tetrachloride
DBG	Deterrent Burning Ground
DNT	Dinitrotoluene
ES	Enforcement Standard
°F	Degrees Fahrenheit
FS	Feasibility Study
ft/ft	Feet per foot
GAC	Granular Activated Carbon
gpm	Gallons per minute
GSM	Groundwater Modeling System
HCC	Human Cancer Criteria
HDPE	High-Density Polyethylene
HCN	Ho-Chunk Nation
HTC	Human Threshold Criteria
HWTTU	Hazardous Waste Thermal Treatment Unit
IFCR	In-Field Conditions Report
IRM	Interim Remedial Measures
MCL	Maximum Contaminant Level
MEC	Munitions and Explosives of Concern
MIRM	Modified Interim Remedial Measures
mg/l	Milligrams per liter
MNA	Monitored Natural Attenuation
MSL	Mean Sea Level
NC	Nitrocellulose
NG	Nitroglycerin
NPS	National Park Service
NR	Natural Resources

NPWS	Non-Public Water System
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic Aromatic Hydrocarbon
PAL	Preventive Action Limit
PBG	Propellant Burning Ground
ppt	Inches of Precipitation
PSTS	Pilot-Scale Treatability Study
RA	Remedial Action
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
SVE	Soil Vapor Extraction
SVOC	Semi-volatile Organic Compounds
TCE	Trichloroethylene or Trichloroethene
USDA	United States Department of Agriculture
VOC	Volatile Organic Compounds
WDNR	Wisconsin Department of Natural Resources
WDOT	Wisconsin Department of Transportation
Wis. Adm. Code	Wisconsin Administrative Code
WPDES	Wisconsin Pollutant Discharge Elimination System
WP&L	Wisconsin Power and Light
WWTP	Wastewater Treatment Plant

1.0 CERTIFICATION PAGE

In accordance with section NR 712.09, Wisconsin Administrative Code (Wis. Adm. Code), a registered professional engineer, a hydrogeologist, or a scientist from the State of Wisconsin shall certify this report. The required certification statements are presented, and signed and sealed, as follows:

Report prepared by:

"*I,* **Joel L. Janssen,** *hereby certify that I am a scientist as that term is defined in s. NR 712.03(1), Wis. Adm. Code, and that, to the best of my knowledge, all of the information contained in this document is correct and the document was prepared in compliance with all applicable requirements in chs. NR 700 to 726, Wis. Adm. Code.*"

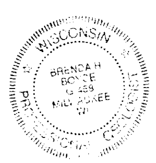
________________________________ ________________

Signature and title **Date**

"*I,* **Brenda H. Boyce, P.G.,** *hereby certify that I am a scientist as that term is defined in s. NR 712.03(1), Wis. Adm. Code, and that, to the best of my knowledge, all of the information contained in this document is correct and the document was prepared in compliance with all applicable requirements in chs. NR 700 to 726, Wis. Adm. Code.*"

________________________________ ________________

Signature and title **Date**



Report reviewed by:

"*I,* **Clair E. Ruenger P.G.,** *hereby certify that I am a hydrogeologist as that term is defined in s. NR 712.03(1), Wis. Adm. Code, and that, to the best of my knowledge, all of the information contained in this document is correct and the document was prepared in compliance with all applicable requirements in chs. NR 700 to 726, Wis. Adm. Code.*"

________________________________ ________________

Signature and title **Date**

2.0 EXECUTIVE SUMMARY

The Badger Army Ammunition Plant (BAAAP BAAP), located in south-central Wisconsin within Sumpter and Merrimac Townships in Sauk County, was constructed in 1942 to produce smokeless gunpowder and solid rocket propellant as munitions components for World War II. The installation is located on the Sauk Prairie, between the Baraboo Range and the Wisconsin River. As a result of production and waste disposal practices that were common at the time, soil and groundwater at the BAAAP were impacted.

Comment [JT1]: One too many A's in the acronym? I've seen BAAP everywhere else

Numerous site investigations and remedial actions have been conducted at the BAAAP. Groundwater investigation activities at BAAAP began in 1980 and continue today. Site-wide groundwater-related assessment activities include the following: monitoring well installation; water level measurements; pump testing; monitoring well and residential drinking water well sampling; and groundwater modeling. Groundwater impact source-related investigations and remedial actions have been conducted for the three source areas: Propellant Burning Ground (PBG), Central Plume area, and Deterrent Burning Ground (DBG). Groundwater in the PBG and DBG areas are impacted by dinitrotoluene (DNT) and chlorinated solvents. Groundwater in the Central Plume area is impacted by DNT.

An *In-Field Conditions Report* (IFCR), issued by the Wisconsin Department of Natural Resources (WDNR) in 1987, required groundwater monitoring, reporting, and performance-based responses at the BAAAP. The current site-wide groundwater monitoring program follows the IFCR dated August 15, 2005. The interim groundwater remedial action at the PBG began in 1990 and continues today. Groundwater monitoring with the current remedies in place could continue indefinitely (30 years or more).

Groundwater modeling of the PBG contaminant plume is included as part of this Alternative Feasibility Study (AFS) to better understand fate and transport mechanisms and anticipate plume dynamics into the future. Model simulations were not prepared for the DBG and Central plumes. The flow model assumes that the groundwater in the PBG plume moves approximately one foot per day. The model predicts that it would take approximately 30 years for groundwater to flow from the PBG source area to the Wisconsin River. This estimate does not include the complicated interactions with contaminants present in the groundwater, which typically result in the contaminant plume moving slower.

The groundwater model predicts that by 2040 the carbon tetrachloride (CTET) in the PBG plume will be significantly reduced in size and contaminant level. The concentrations of CTET in the PBG are expected to continue to decrease after 2040 until they are no longer detectable. These predictions assume that the extraction wells will not be pumping.

A Conceptual Site Model (CSM) is provided in this AFS to explain the relationship of contaminant sources, environmental media, exposure pathways, and potential human and ecological receptors. All applicable and appropriate regulatory requirements are presented and discussed as they relate to the remediation of the groundwater plumes at BAAAP. These regulations help frame the remedial objective, which is to protect human health by preventing exposure of contaminated groundwater from BAAAP, to restore groundwater to the extent practicable, and minimize the impact of the contaminant plumes on the environment.

The purpose of this AFS is to determine the most appropriate and cost-effective final remedy for the groundwater plumes at BAAAP. A discussion of the three source areas of groundwater impact is included in this AFS and three alternatives are evaluated to address the residual groundwater impacts. Remedial action alternatives were assembled and screened resulting in three alternatives. Each alternative is capable of accomplishing the remedial objective. The final three remedial alternatives evaluated include:

Alternative 1: Interim Remedial Measures/Modified Interim Remedial Measures (IRM/MIRM) Treatment and Monitored Natural Attenuation
This alternative continues IRM/MIRM treatment of the PBG Plume, continued groundwater monitoring, and natural attenuation of the DBG and Central Plumes.

Alternative 2: In-Situ Biochemical Treatment and Monitored Natural Attenuation
This alternative would use in-situ groundwater treatment, a modified groundwater monitoring program, and natural attenuation of the PBG, DBG, and Central Plumes.

Alternative 3: Public Water System and Monitored Natural Attenuation
This alternative involves the installation of a public water system, a phased shutdown of the IRM and MIRM systems, a modified groundwater monitoring program, and natural attenuation of the PBG, DBG, and Central Plumes.

Each alternative is evaluated using the following nine criteria: overall protection of human health and the environment; compliance with applicable regulations; long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; cost; state acceptance; and community acceptance. Based on a thorough evaluation, Alternative 3, Public Water System and Monitored Natural Attenuation, is proposed as the final groundwater remedy for the groundwater contaminant plumes at BAAAP.

3.0 INTRODUCTION

This AFS report was prepared to serve as a principal source for decision-making relating to remediation of groundwater impacts from the BAAAP. The AFS provides a summary of historic and current groundwater investigation and remediation efforts by the Department of the Army (Army) and describes the development and re-evaluation of groundwater remedial action alternatives for the BAAAP.

The IFCR, issued by the WDNR in 1987, and subsequent amendments, calls for groundwater monitoring, reporting, and performance-based responses at the BAAAP. The current site-wide groundwater monitoring program follows the IFCR dated August 15, 2005. On November 23, 2009, additional changes to the northeast area (including the DBG) groundwater monitoring requirements were approved by the WDNR. Investigation of groundwater has been ongoing at the BAAAP from 1980 to the present. The interim groundwater remedial action began in 1990 and continues today. Groundwater monitoring with the current remedies in place would continue indefinitely (30 years or more) until the WDNR approved case closure.

The initial site-wide remedial investigation (RI) and feasibility study (FS) was completed in 1993 and 1994 (ABB-ES, 1993 and 1994). Soil and groundwater remedial alternatives were analyzed, selected, and approved by the Army and state and federal regulators for the PBG and DBG areas, and their associated groundwater contaminant plumes. In addition to the PBG and DBG areas and their associated plumes, the Rocket Paste Area/Central Plume has since been identified through further groundwater investigations.

A re-evaluation of the current groundwater remediation alternative at the BAAAP was warranted because: 1) the current remedial alternative in place is an interim action, which addresses only the PBG Plume, 2) the timeframe required for the IRM/MIRM to meet cleanup standards is indefinite, and 3) recent changes in state groundwater standards make meeting those cleanup standards even more difficult. The revised alternatives were developed and evaluated to achieve the remedial objective. The objective of the groundwater remedial action is to protect human health by preventing exposure of contaminated groundwater from BAAAP, to restore groundwater to the extent practicable, and minimize the impact of the contaminant plumes on the environment.

4.0 SITE BACKGROUND

4.1 Site Description

The BAAAP, located in south-central Wisconsin within Sumpter and Merrimac Townships in Sauk County, was constructed in 1942 to produce smokeless gunpowder and solid rocket propellant as munitions components for World War II. The installation is located on the Sauk Prairie, between the Baraboo Range and the Wisconsin River. The impoundment of the Wisconsin River forms Lake Wisconsin, which borders the southeast side of the BAAAP.

Production of nitric acid, sulfuric acid, oleum (also known as fuming sulfuric acid), nitrocellulose (NC), and nitroglycerin (NG) occurred in support of munitions components production. Production periods were as follows: World War II (1942 to 1945), Korean War (1951 to 1958), and Vietnam Conflict (1966 to 1975). Disposal of excess hazardous substances occurred at primarily two locations on-site: the PBG and the DBG. As a result of production and waste disposal practices that were common at the time, soil and groundwater at the BAAAP were impacted with several contaminants of concern (COCs).

The primary land uses in the immediate vicinity of the BAAAP are agricultural, recreational, and residential. The agricultural use of the BAAAP is raising crops and cattle grazing, which continues to be the primary use of lands within and adjacent to the installation. The United States Department of Agriculture (USDA) has used the land in and around the southern portion of the installation for grazing and crop development research for many years. The Dairy Forage Research Center Farm was constructed in the 1980s on land transferred from the Army to the USDA.

The primary land use to the north of the installation is for recreation at Devil's Lake State Park, managed by the WDNR. This area is not impacted by past activities at BAAAP as it is located hydrologically upgradient. Lake Wisconsin and the Wisconsin River, to the south and southeast of the BAAAP, are hydraulically connected to the installation. Lake Wisconsin was formed in 1914 by the Wisconsin Power and Light (WP&L) dam on the Wisconsin River, near Prairie du Sac.

The 2010 United States Census estimated the Township of Sumpter population at 1,191 residents and the Township of Merrimac at 942 residents. Since 1980, 256 private residential wells to the south, east, and west of the installation have been sampled as part of the groundwater monitoring program at BAAAP. Five residential drinking water wells, downgradient of the installation, have been replaced by the Army due to groundwater impacts.

Comment [JT2]: In my opinion, this needs to be a separate section with significantly more detail about well location, construction, new construction details, etc. More on this later.

4.2 Site History

Production and Standby Periods

During World War II, BAAAP employed approximately 7,500 workers and produced approximately 271 million pounds of single- and double-base propellant. Oleum and smokeless powder production began in 1943. Rocket paste powder production began in 1945. The solventless extrusion smokeless propellant process was installed in 1944 and 1945. From 1945 to 1951, the installation was in standby status.

BAAAP was reactivated for the Korean War in 1951. Reactivation activities were completed by 1954. Facilities for the manufacture of Ball Powder® propellant were constructed during 1954 and 1955. A facility to recycle old cannon powder as a source of NC for the new propellant was also constructed in 1954 and 1955. BAAAP remained in production until the Korean War ended and the propellant magazines were full (1958). During the Korean War, approximately 286 million pounds of single- and double-base propellant were manufactured with a peak production employment of 5,022 employees. The installation was in standby status again from 1958 to 1966.

BAAAP was reactivated in 1966 for the Vietnam Conflict. The installation manufactured Ball Powder® propellant, rocket propellant, and smokeless propellant from 1966 to 1975. In 1972, construction included new sewage treatment systems, new acid production, and new NG production facilities. During the Vietnam Conflict approximately 487 million pounds of single- and double-base propellant were manufactured with a peak production employment of 5,400 employees. The installation was placed in standby status in 1975 and was declared excess in 1998, which began the dismantling process.

Waste Disposal Practices

The PBG, DBG, and Rocket Paste Area have been identified as the source areas of groundwater contamination. The PBG Plume source area includes Landfill #1, PBG Waste Pits, 1949 Pit, and the Racetrack Area. The DBG Plume source area includes Landfill #3, Landfill #5, and the DBG

Waste Pit. The Central Plume source area is near the NG and Rocket Paste areas. The locations of these areas are depicted in Figure 1.

During production periods, the PBG and DBG were used as disposal areas for waste and excess production chemicals, primarily solvents, plasticizers, and explosives. Excess chemicals and munitions components were placed in open pits and burned to dispose of them.

Process wastewater from the Rocket Paste Area and the Nitroglycerin Area was conveyed in open ditches from the north-central to the south side of the installation where it subsequently flowed to the Settling Ponds and Spoils Disposal Areas, and eventually to the Wisconsin River.

Demolition and Restoration

Environmental investigation and restoration activities began at the BAAAP in 1977. Groundwater monitoring and characterization activities began in 1980, with groundwater treatment beginning in 1990. These activities are still in progress today.

Ongoing demolition activities include the following: removal of all process chemicals, equipment, piping, process and storage tanks, munitions and explosives of concern (MEC) that may reasonably be expected to cause an environmental or safety hazard, and the majority of the structures on the installation. Many of the concrete slabs that lay underneath these structures have been removed or are planned for removal and recycling. Current environmental restoration activities include the following: soil investigation and remediation; groundwater monitoring and remediation; impacted process and sanitary sewer removal; friable asbestos removal; and MEC screening, clearance, and certification.

4.3 Environmental Setting

Topography

The land surface at the installation is the result of glaciation. The installation is located on the southern edge of the Baraboo Range, also commonly referred to as the Baraboo Hills. The terminal moraine, deposited by the leading edge of the last glacier as it moved from east to west, extends from north to south across the central portion of the installation. The topography in the eastern two-thirds of the installation consists of gently rolling hills with numerous depressions. The western third of the installation is an outwash plain that is nearly level to gently sloping towards the southwest.

Climate

The climate of the installation area is typically continental with some influence from the Great Lakes system. Average annual temperatures in the region vary from 39 degrees Fahrenheit (°F) to 50°F. The freeze-free season is typically 80 to 180 days. From 1971 to 2000, the Southwest Wisconsin Divisional Climate Summary included the following averages: Winter: 19.7°F, 3.44 inches of precipitation (ppt); Spring: 45.8°F, 9.24 ppt; Summer: 69.2°F, 13.14 ppt; Fall: 48.0°F, 8.10 ppt (Wisconsin State Climatology Office Website, 2010). Precipitation for the area averages approximately 30 inches annually. Typically, 70% of this rainfall occurs during the growing season: April through September. The one year and ten year predicted maximum 24-hour rainfall totals for Sauk County are 2.3 and 4.1 inches, respectively.

Surface Water Hydrology

Surface drainage consists of overland flow to the west, south, and east. Much of the run-off collects in isolated depressions on-site and infiltrates or evaporates. The ditches in the northwest portion of the installation drain toward the Ballistics Pond and subsequently to Otter Creek to the west of the installation. The surface water from the NG, Rocket Paste, and Magazine Areas, located in the central and southeast areas of the installation, discharges to the Settling Ponds and Spoils Disposal Areas in the south-central portion of BAAAP. The Settling Ponds are manmade areas that received wastewater from production, but are now almost entirely dry except in severe rain events. The Settling Pond Area drains to the south and east at Gruber's Grove Bay, on Lake Wisconsin. Ponds that contain water throughout most of the year include the Ballistics Pond, Oleum Pond, Wood Duck Pond, Rocket Paste Pond, and NG/Over Flow Ponds.

Comment [JT3]: These settling ponds and spoils disposal areas are not ID'd on any figure, which makes this text difficult to understand

Geology

A thick sequence of unconsolidated sediments was deposited during multiple glaciation events. A glacial terminal moraine transects the installation from north to south, as shown in Figure 2. Figure 2 is a map depicting the geological features at the surface. This map was adapted from the Geology of Sauk County by Attig and Clayton, 1990. Bisecting BAAAP from north to south is the terminal moraine shown in dark green (gj) and classified as thick till of the Johnstown Moraine. Thinner glacial till, shown in light green (gd), is found east of the terminal moraine. On the far eastern side of BAAAP is a unit classified as a collapsed meltwater-stream sediment (se). West of the terminal moraine is stream sediment (sj) of the Johnstown Moraine, shown in pink. There is also a unit of stream sediment (ss) shown cutting through the terminal moraine in the southern portion of BAAAP. This stream sediment unit is younger than the Johnstown sediment, contains ice rafted boulders, and was deposited by floodwater during the drainage of glacial Lake Wisconsin during the Elderon Phase of glaciation.

Based on the borings advanced at BAAAP, the glacial till varies in thickness from 10 to 90 feet. Outwash sand and gravel or fluvial deposits (stream sediment) lie beneath the till. The water table does not intersect the till beneath BAAAP, only the outwash is in contact with the groundwater. West of the terminal moraine, a thick sequence of glacial outwash sand and gravel was deposited (sj). Glacial tills to the east are primarily silty sands with cobbles and boulders. Several feet of clay and silt (loess) overlie the glacial sediments.

Figures 3 and 4 are generalized geologic cross sections that show thickness of the unconsolidated sediment (sand and gravel) overlying bedrock. These two cross sections were adapted from figures in *Hydrogeology and Simulation of Groundwater Flow in Sauk County, Wisconsin* (Gotkowitz et al. 2005). The unconsolidated sediment and bedrock unit thicknesses were derived by reviewing boring logs from wells at and near BAAAP. Bedrock geology at BAAAP is dominated by the Eau Claire Formation (Cambrian age) beneath most of BAAAP, with some Precambrian metamorphosed quartzite, granite, and rhyolite. The Eau Claire Formation consists of sandstone/shale/siltstone/dolomite. The Baraboo Range to the north of the installation contains Precambrian conglomerate and quartzite, which are part of the Baraboo Syncline, rising approximately 500 feet above the installation. The bedrock surface dips steeply toward the south, where soil deposits quickly thicken to a maximum of approximately 250 feet. Along the northern installation boundary, soil deposits are thin or absent and bedrock outcrops are common. Figure 5 illustrates the bedrock surface beneath and surrounding BAAAP. This bedrock surface isopach map was based on available monitoring well, production well, and private well construction logs. The bedrock surface drops 200 feet in the northern third of BAAAP and flattens out in the southern two-thirds of BAAAP.

Comment [JT4]: Fig 5 note also mentions that geophysics were conducted in the NE portion of site to evaluate bedrock topo

Figure 3 shows the BAAAP Well #1 on the far left penetrating the entire Eau Claire Formation and entering the Baraboo quartzite. A layer of shale is shown to underlay the western half of BAAAP. The shale layer acts as an aquitard which retards groundwater in the sand and gravel aquifer and the upper sandstone aquifer from moving downward into the lower sandstone aquifer. The Eau Claire Formation is shown to thin out to the east and acts as both an aquitard and an aquifer based on the thickness of the sandstone. The BAAAP Well #1 draws its water from the Eau Claire Formation.

Figure 4 is a cross section that runs from the Baraboo Range south to the Village of Prairie du Sac. This section also shows the BAAAP Well #1 on the far left and the Prairie du Sac (PDS) Well #3 on the far right. The PDS Well #3 penetrates through the Eau Claire Formation and a layer of shale before entering the Mt. Simon Formation (sandstone). The shale layer is shown to be present from just north of the BAAAP Well #1 down to PDS. This shale layer acts as an aquitard which restricts groundwater from migrating deeper into the Mt. Simon Formation. Based on the well log, the PDS Well #3 has a water depth at the ground surface, whereas the local water table is located 45 feet below ground. This implies that the PDS Well #3 is a flowing or artesian well. The thick sequence of the Eau Claire Formation and the shale layer protect the PDS Well #3 from contaminants on the surface and in the sand and gravel aquifer.

Comment [JT5]: If hydraulic head in the Mt. Simon is higher than the Eau Claire and outwash units (as suggested by this sentence about the PDS Well #3), then it's possible that upward vertical gradients in the unconsolidated materials are linked to the Eau Claire Fm (shale) not fully acting like an aquitard.

Geologic cross sections depicting stratigraphic relationships between the various soil units, bedrock units, and water table are orientated in Figure 6. Figures 7, 8, 9, and 10 are geologic cross sections that are orientated through the PBG area. Figures 11 and 12 are geologic cross sections that are orientated through the DBG area. Figure 13 is a geologic cross section orientated through the Central Plume area. The terminal moraine is shown in many sections, represented as glacial till (SP-SM or SM-SP), and consists mostly of varying grain sizes of sand with fines and some gravel/cobbles/boulders. Based on the cross sections, the glacial till is not present beneath the water table. Beneath the glacial till lies sand of varying grain sizes that was deposited by glacial fluvial processes (glacial outwash). The sand outwash contains many pockets of gravel with some being localized and others interconnecting. The gravel layers have been encountered up to 40 feet thick. A uniform layer of gravel exists near the bedrock surface, south of the PBG. A layer of clay and silt (CL-ML), up to 30 feet thick, is present in the DBG area. As shown in Figure 11, the fine grained layer appears to pinch out approximately 1,300

Comment [JT6]: Any theories about how these semi-continuous gravel and CL-ML layers affect GW flow and contaminant distribution on a smaller scale? Is the gravel layer on top of bedrock a preferential flow path?

feet east of the DBG. Both Figure 11 and 12 show the fine grained unit located beneath the water table. The bedrock shown in each cross section consists of the Eau Claire Formation.

Hydrogeology

Two major aquifers and one minor aquifer are present beneath the installation: the surficial sand and gravel aquifer, the Eau Claire Formation, and the deeper Mt. Simon Formation (sandstone aquifer), respectively. The sand and gravel aquifer and the Eau Claire are un-confined to semi-confined and possibly hydraulically connected. The Eau Claire Formation varies between 80 to 280 feet below ground surface (bgs). The Mt. Simon Formation is located approximately 400 feet bgs and is mostly present to the east and south of BAAAP. The general direction of groundwater flow is south to southeast. Steep gradients exist along the northern boundary of the installation. The gradient flattens substantially in the central and southern portions of the installation. Recharge to the sand and gravel aquifer is limited by infiltration through a fine-grained loess unit (silt/clay) in some areas.

As previously mentioned, Figures 3 and 4 show that the Eau Claire Formation contains at least one uniform shale layer that acts as an aquitard, which retards groundwater in the sand and gravel aquifer from moving downward into the lower sandstone aquifer (Mt. Simon Formation). The Eau Claire Formation also contains many thinner layers of shale and thick sequences of dolomite that act as an aquitard.

The regional groundwater flow direction in the BAAAP area is south-southeast towards the Wisconsin River as depicted in *Water-Table Elevation Map of Sauk County, Wisconsin* (Gotkowitz and Zeiler, 2003) and *Hydrogeology and Simulation of Groundwater Flow in Sauk County, Wisconsin* (Gotkowitz et al. 2005). This direction of flow correlates well with the groundwater contours generated by collecting water levels in the BAAAP monitoring wells. Figure 14 depicts the groundwater contours at BAAAP during September 2010.

The Wisconsin River acts as a discharge point for groundwater east and south of BAAAP. As depicted in *Water Resources of Wisconsin Lower Wisconsin River Basin* (Hindall and Borman, 1974) groundwater on both the west and east sides of the Wisconsin River discharge discharges into the Wisconsin River. The Lake Wisconsin Reservoir, caused by the hydroelectric dam on the Wisconsin River, influences groundwater flow across the installation. The Reservoir is north of the dam where there is an approximate 40-foot surface water drop. The water level in the Reservoir is elevated above the water table for much of the southeastern portion of the installation. Anywhere the Reservoir elevation is higher than the water table, the water in the Reservoir will discharge to the groundwater. Subsequently, the Reservoir discharges to the groundwater in the Gruber's Grove Bay area and continues to discharge to the groundwater until it reaches the WP&L dam. The net result is groundwater flow parallel to the Reservoir with discharge to the Wisconsin River south of the dam. Groundwater in the northeast portion of the installation is higher in elevation than the Reservoir; therefore, the groundwater discharges to the Reservoir in this area.

Comment [JT7]: Is this a significant effect on a site-wide scale (any more than it would be for a silty loam soil, etc.)?

Comment [JT8]: See comment on previous page. Has contamination from BAAP reached the Eau Claire formation above the shale/aquitard layer, and if so, is that a preferential flow path that might affect private well owners with open boreholes in the same unit?

Comment [JT9]: Suggest labeling this feature on Figure 14

Comment [JT10]: Suggest labeling this feature on Figure 14

Comment [JT11]: Suggest labeling this feature on Figure 14

5.0 SOURCE INVESTIGATIONS AND REMEDIAL MEASURES

Numerous site investigations and remedial actions have been conducted at the BAAAP. Groundwater investigation activities at BAAAP began in 1980 and continue today. Site-wide groundwater related assessment activities, agreed upon by the Army and WDNR, include the following: monitoring well installation; water level measurements; pump testing; monitoring well and residential drinking water well sampling; and groundwater modeling. Groundwater impact source-related investigations and remedial actions, for the PBG, Central Plume Area, and DBG are discussed below. Figure 15 shows the locations of the monitoring wells and Figure 16 shows the locations of the private wells.

Comment [JT12]: As yet, I haven't read anything about SpecPro obtaining and reviewing construction details for the private wells. Has that been done by the WDNR? Just generally knowing what unit(s) those wells are screened in (or open to), approximate age, etc., helps put the rest of this section in context – ie., what is the threat to downgradient water supplies, which private wells have been affected, and why? Assuming this has already been done, the background document should be referenced.

5.1 Propellant Burning Ground

The PBG is located in the southwestern portion of the BAAAP. The PBG is comprised of the following areas: Waste Pits, 1949 Pit, Racetrack/Hazardous Waste Thermal Treatment Unit (HWTTU) area, and Landfill #1. The location and layout of the PBG is shown in Figure 17.

DNT and organic solvent-containing materials are known to have been disposed of at the PBG through open burning and burial during production periods. Subsequently, localized impacts to soil consisted of 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), polycyclic aromatic hydrocarbons (PAHs), benzene, trichloroethylene (TCE), arsenic, chromium, lead, selenium, and zinc above soil cleanup remedial action objectives.

The PBG Waste Pits consisted of three waste pits and an open burning area. A soil vapor extraction (SVE) system operated at the Waste Pits from 1997 to 1999. Approximately 1,600 pounds of solvent-related Volatile Organic Compounds (VOCs) were successfully removed from within the vadose zone. Approximately 2,280 cubic yards of soil were removed from the PBG Waste Pits, from ground surface to approximately 23 feet bgs in 1999. The soil was transported off-site and incinerated by a licensed hazardous waste contractor. The Waste Pits were filled with clean gravel to grade.

A pilot biotreatment system was installed at Waste Pit 1 in 1999. A Pilot-Scale Treatability Study (PSTS) was conducted in 2000 to evaluate the effectiveness of bacterial degradation of DNT by naturally occurring bacteria in the soil (in-situ). The PSTS extracted groundwater beneath Waste Pit 1, treated the water with phosphate, and reinjected it into the soil column above the waste pit. Oxygen was added to the vadose zone by injecting air through the former SVE system wells, which now served as air sparge wells. Carbohydrate (ethanol) injection wells for the control of nitrate byproduct were installed downgradient, but never used. Monitoring results indicated the indigenous bacteria were aerobically biodegrading DNT in the soil column successfully; therefore, the Army decided to go full-scale with the biotreatment system.

The Biologically Enhanced Subsurface Treatment (BEST) system was installed in 2000 and operated from 2001 to 2005. From 2001 through 2003, additional air sparge wells were installed to aid bacterial degradation of DNT in the groundwater. The air sparge wells were in operation until 2006. Evaluation of the BEST system indicated effective DNT reduction in groundwater occurred during the operation of the system.

A geocomposite cap was installed at the 1949 Pit in 1998 to inhibit the movement of contaminants in the soil. The *1949 Pit Phase One Cap, Final Construction Report* (Olin Corporation, 1999) was submitted and approved by the WDNR in 1999.

The Racetrack/HWTTU area consisted of an oval gravel road, three refuse pits, and burning plates, as well as the HWTTU. In 1995, three-fourths of the Racetrack/HWTTU area was closed with a soil cover to prevent contact with lead residual in the soil. The *Final Documentation Report For Soil Cover Construction Racetrack And Thermal Treatment Unit Closure* (Olin Corporation, 1996) was approved by the WDNR. The remaining portion of the Racetrack area had impacted soil removed in 1997 with no cover required.

Landfill #1 contained structural timbers, asphalt shingles, cardboard, and other office refuse. Landfill #1 was covered with a WDNR-approved geocomposite cap in 1997.

In 2005, Shaw Environmental, Inc. (Shaw) conducted an investigation in the PBG area to evaluate the existing soil conditions beneath the PBG waste pits. This investigation included drilling borings through each of the waste pits and collecting soil samples for laboratory analysis. No additional soil sampling has been conducted since 2005. This investigation determined that carbon tetrachloride and other VOCs were no longer present in the soil beneath the PBG Waste Pits. A summary of the VOC soil sample results are provided in Table 1. SpecPro, Inc. (SpecPro) calculated that the amount of remaining DNT-impacted soil is approximately 25,058 pounds. This calculation does not represent pounds of DNT remaining in the soil. Input parameters are provided in Table 2.

Comment [JT13]: Why pounds of soil instead of pounds of contaminant?

In 2006, a draft AFS was completed to re-evaluate the interim remedial actions for soils at the PBG and determine the final remedy. The selected remedy included the previous remedial actions: soil vapor extraction, partial soil excavation and incineration, and full-scale bioremediation. The final remedy chosen included removal of the bioremediation system, installation of an impermeable cap and cover, and continued groundwater monitoring and remediation. On March 17, 2008, the WDNR approved of the final remedy for the PBG subsurface soil.

Removal of the BEST system was completed in 2008. The Waste Pits were then capped with a geosynthetic barrier and compacted clay, according to regulatory requirements. The area was then covered with topsoil, graded, and seeded. The *Construction Documentation Report, PBG Phase 2, Cap and Construction* (SpecPro, Inc., 2009) report was submitted to the WDNR and approved in 2009.

The Waste Pits, 1949 Pit, Racetrack/HWTTU, and Landfill #1 areas are regularly inspected. Signage and fencing are inspected and maintained. Cover areas are inspected annually for erosion, settlement, undesirable vegetation, and other deficiencies. Required repair work to maintain proper grade and drainage is completed. Annual Cap and Cover Reports are submitted to the WDNR.

Interim Remedial Measures/Modified Interim Remedial Measures

Groundwater contamination in monitoring wells at the PBG was first detected in 1982 (Tsai, 1988). Although an exhaustive investigation of groundwater contamination was not completed at the time, proposed interim remedial measures were evaluated in 1989. The goals of the early groundwater remedial action were to: 1) curb the advancement of the plume, 2) reduce contaminants within the plume, and 3) be compliant with local, state, and federal regulations. Options considered included: total plume capture, boundary control extraction, source control extraction, and a combination of boundary and source control extraction. Components of the remedy that were evaluated included: air stripping, activated carbon adsorption, and combined air stripping and carbon adsorption.

The IRM groundwater pump and treat system began operations during June 1990. At that time, the extent of groundwater contamination was believed to be within the installation boundary. The IRM groundwater treatment system originally consisted of one source control well and three boundary control wells. The groundwater was treated with an air stripping tower and liquid phase granular activated carbon (GAC) treatment. In 1996, the IRM pumping system was modified to include two source control wells and discontinued the use of the three PBG area boundary control wells within the PBG area, labeled BCW-1, 2, and 3. Since November 2008, the two source control wells (SCW-1 and SCW-2R) have extracted groundwater from the PBG source area at a combined rate of approximately 350 gallons per minute (gpm). Figure 17 shows the locations of the existing IRM extraction wells.

Comment [JT14]: Given how the next paragraph begins, it's not clear whether the IRM air stripper is still operating, but I suspect so.

Extracted groundwater is pumped through a GAC system that removes VOCs and DNT from the water by adsorption. The GAC system consists of two units that each contains 20,000 pounds of carbon. The treated water then flows through a 30-inch high-density polyethylene (HDPE) pipeline and discharges into the Lake Wisconsin Reservoir near Gruber's Grove Bay, regulated under a Wisconsin Pollutant Discharge Elimination System (WPDES) permit. A 10-inch pipeline to the Lake Wisconsin Reservoir was the original discharge line, and was used until the 30-inch line was constructed in 1995. The ozone treatment and multi-media filter were removed from the system during BEST System removal in 2008 2008.

Comment [JT15]: Why?

An evaluation of the IRM was conducted in 1993 to address new regulatory requirements. This evaluation concluded that the PBG Plume was not being entirely captured by the IRM system. In particular, the plume was extending beneath and east of the three original boundary control wells. A groundwater model was used to evaluate alternative groundwater extraction and treatment options. A groundwater treatment system was designed to augment the existing IRM system.

This augmented groundwater treatment system called the MIRM system was installed in 1995 and 1996 and began operations on June 20, 1996. The MIRM groundwater treatment system originally consisted of six boundary extraction wells (EW-161, EW-162, EW-163, EW-164, EW-165, and EW-166), automatic self-cleaning strainers, air strippers, vapor phase GAC treatment, and liquid phase GAC treatment. Four additional extraction wells (EW-167, EW-168, EW-169, and EW-170) were installed along the axis of the plume in 2005. The pumping of these extraction wells was refined over the years to optimize removal of groundwater contaminants. The currently operating five MIRM extraction wells (EW-163R, EW-167, EW-168, EW-169, and EW-170R) extract groundwater from the PBG Plume at a combined rate of approximately 2,400 gpm. MIRM extraction well EW-164 is currently on standby and not pumping. Figure 17 shows the locations of the existing MIRM extraction wells.

A sulfuric acid tank and pumps are used for descaling the system periodically. A phosphate-based sequestering agent is added to avoid carbonate scaling and fouling of the system.

The water from the MIRM extraction wells flows through three individual air strippers for treatment of VOCs. Each air stripping tower is 27 feet high, eight feet in diameter, and constructed of fiberglass reinforced plastic. A 15.5-foot neoprene packing bed of 3.5-inch media is contained within each tower, which is designed to handle a normal flow of 1,000 gpm and a maximum flow of 1,500 gpm. Each air stripper contains a centrifugal blower capable of supplying 4,600 standard cubic feet per minute of air. The VOCs are thus transferred from water to air.

The air then flows through three GAC vapor phase units, to remove the VOCs through carbon adsorption before being released to the atmosphere. Each GAC unit contains 5,000 pounds of carbon. The MIRM air emissions have been monitored and found to be well below any applicable regulatory limits. The GAC treatment of the air emissions has been discontinued recently following WDNR approval in 2010.

The water then collects in the air stripper basin after the vapor phase units have removed approximately 98% of the VOCs. The water then flows from the air stripper basin into the liquid phase GAC units. The liquid phase GAC treatment system as originally designed consists of five GAC units arranged in parallel. Each unit has a self-cleaning strainer and two separate beds of GAC adsorbers. The ten liquid phase adsorbers contain 20,000 pounds of carbon each which captures the remaining VOCs and DNTs. The treated water is collected in the treated effluent storage basin. Approximately 500 gpm of treated water is used for the BAAAP fire suppression water supply system. The remaining treated water is discharged under a modified WPDES permit to the Lake Wisconsin Reservoir through the 30-inch HDPE pipeline.

In 2002, extraction well EW-163 was replaced with EW-163R due to equipment getting stuck in the borehole during maintenance operations. Additional modifications were made to the system in 2004 and 2005 by placing more extraction wells within the body of the plume. This allowed the system to treat water with the highest level of contaminants. MIRM well re-alignment activities in 2006 included the installation of four high-capacity wells, pumps, piping, and control systems. In 2008, one of the original source control wells (SCW-2) was abandoned and replaced with SCW-2R to allow the construction of the PBG cap. The MIRM system was modified in 2008 to include two more GAC units to increase the total capacity of the

IRM/MIRM system to 4,500 gpm. In 2010, extraction well EW-170 was replaced with EW-170R due to well bio-fouling and poor well performance.

Bio-fouling is caused by iron-oxidizing bacteria, commonly referred to as "iron bacteria". The primary form of iron bacteria present at the IRM/MIRM is *Gallionella sp.*. Iron bacteria are generally aerobic and oxidize iron and manganese to a lesser extent. Dissolved ferrous iron (II) is oxidized to ferric iron (III) or ferric oxide. The result is a mucilaginous slime that contains precipitated ferric oxide. The slime and ferric oxide protect the bacteria, but cause clogging of well screens, pipes, and pumps. Repeated well rehabilitation has been conducted consisting of the following: pre-rehabilitation video logging, wire brushing, bailing debris, adding hydrochloric acid, adding dispersant polymer, surging, acid removal and neutralization, and well sterilization with sodium hypochlorite. The iron bacteria are most likely from an indigenous source.

Total suspended solids cause clogging of the liquid phase GAC units, which subsequently require frequent backwashing. Backwashing currently occurs five to 10 times per month. Backwashing and clogging reduces the treatment capacity at the MIRM.

Currently, the IRM/MIRM and the wastewater treatment plant (WWTP) have a combined WPDES permit. Bluffview Sanitary District (BSD) is scheduled to take over ownership of the WWTP in 2011. It is anticipated this changeover in the WWTP ownership along with the renewal of the WPDES permit by December 2011 will result in the submittal of separate permits by the Army for the IRM/MIRM and the BSD for the WWTP.

Comment [JT16]: On site or municipal? If on site, add location to Figure 1, or reference another figure that shows the location.

SpecPro calculated the annual total mass of DNT and VOCs removed by the IRM and MIRM systems over the past four years. The monthly influent concentrations of total DNT, 1,1,1-Trichloroethane (1,1,1-TCA), CTET, chloroform, and TCE were multiplied by the estimated volume of groundwater treated each month. The total estimated mass of DNT removed in 2007, 2008, 2009, and 2010 was less than 44.34, 6.52, 12.62, and 14.40 pounds, respectively. The total estimated mass of VOCs removed in 2007, 2008, 2009, and 2010 was less than 53.00, 78.52, 81.93, and 65.62 pounds, respectively. Input parameters are provided in Table 3. Considering an average mass of 19.47 pounds of DNT removed per year and an annual IRM/MIRM operation and maintenance cost of $1.7 million, the cost to remove one pound of DNT is $87,314.

Comment [JT17]: If these are the primary VOCs of concern for the PBG, it should be noted here

Comment [JT18]: Seems more appropriate to cite this calculation in Section 9 rather than here, when comparing Alternative 1 to Alternative 3

Table 4 summarizes the analytical results for the IRM/MIRM system from samples collected in December 2010. The table provides total DNT, 1,1,1-TCA, CTET, chloroform, and TCE concentrations for each MIRM extraction well, IRM influent, MIRM influent, and the combined IRM/MIRM effluent. Two concentration over time graphs for the MIRM influent are presented in Appendix A. The first graph displays the MIRM influent concentrations for VOCs (CTET, chloroform, and TCE) in relation to the MIRM pumping rate for the time period from 2001 to 2011. It appears that regardless of the flow rate, the VOC contaminant concentrations in the MIRM influent have been decreasing since 2005. Since June 2009, concentrations for all three VOCs have been below their respective groundwater ES. The second graph displays the MIRM influent concentrations for 2,3-DNT, 2,4-DNT, 2,5-DNT, 2,6-DNT, 3,4-DNT, and 3,5-DNT in relation to the MIRM pumping rate for the time period from 2001 to 2011. Since the flow rate

Comment [JT19]: Why is TCA now excluded from the analysis?

was increased in January 2008, the 2,3-DNT and 3,4-DNT concentrations increased for two years. Since February 2010, the 2,3-DNT and 3,4-DNT concentrations have been decreasing. Total DNT concentrations in the MIRM influent are consistently above the groundwater ES (0.05 µg/l).

5.2 Deterrent Burning Ground

The DBG area consists of seven acres and is located in the northeastern portion of BAAAP. The DBG area was used as a sand borrow pit from the 1940s until the early 1960s, and a waste disposal site from the 1940s to the 1970s. The DBG consisted of three burn areas within a man-made depression, approximately three acres in size and 20 feet deep.

Coal ash from the power plant, construction rubble, trash, and burned garbage were deposited inside the DBG sand borrow pit. The remaining portion of the DBG was used for open burning of deterrent, a liquid organic extract from surplus propellant, composed mostly of DNT and di-n-butyl phthalate, as well as minor amounts of diphenylamine, benzene, and NC. Structural timbers, asphalt shingles, cardboard, paper, and office waste were also burned in the pits. Subsurface soils at the DBG were found to be impacted with DNT, n-nitrosodiphenylamine, arsenic, and chromium. The majority of the impacts were found in the shallowest portion of the pit, with arsenic and chromium in limited areas of the site. Investigations also showed DNT spread laterally in the subsurface soils and reached groundwater.

Landfill #5 is located to the northeast of the DBG. During operations, the landfill reportedly received solid waste, including office waste, demolition debris, laboratory waste, and coal ash from the power plant. No hazardous materials were reported to have been disposed in Landfill #5. The landfill was opened in the early 1940s when operations began and was closed in 1989 with a clay cap.

An interim corrective action consisting of the removal and off-site incineration of DBG waste pit soil occurred in 1999 and 2000. Impacted soil from the three pits was excavated to a depth of approximately 15 feet. The total volume of the excavated and incinerated soil was approximately 4,260 cubic yards. Each pit was backfilled with clean fill to pre-excavation grades. This removed the surface soil contaminated with the highest DNT levels and metals.

In 2001, the backfilled area was temporarily capped and additional soil and groundwater studies were started to better understand the groundwater flow in the area. On May 6, 2002, following submittal of the Draft Alternative Feasibility Study - Deterrent Burning Ground Waste Pits Subsurface Soil (Stone & Webster, Inc., 2002), the Army requested a permit modification to perform the remedial action (RA), including partial excavation and incineration (completed in 2000), resource conservation and recovery act (RCRA) cap/cover, institutional controls, and groundwater monitoring. The final remedy, approved by the WDNR, was installed in 2003.

Comment [JT20]: Clarify why no GW treatment included in the DBG final remedy

SpecPro calculated that the amount of remaining DNT-impacted soil is approximately 40,200 pounds. This calculation does not represent pounds of DNT remaining in the soil. Input parameters are provided in Table 2. This calculation was based on investigation data presented

Comment [JT21]: Again, not sure why this calculation not done, yet explicitly called out in the *Alternative Feasibility Study* (Stone & Webster, Inc., April 24, 2002). Concentrations and volume data were used to derive a mass volume in pounds. It should be noted that the data used in the calculation was collected from 1991 to 1998. No additional soil sampling has been conducted since 1998.

5.3 Central Plume Area

Based on the knowledge of groundwater flow and monitoring results, the detection of DNT in groundwater at the Water's Edge Subdivision, south of the central portion of the installation near Gruber's Grove Bay, indicated another source of DNT in groundwater besides the PBG or DBG was likely. In 2004, DNT was first detected within private wells located in the subdivision near Lake Wisconsin. The 2,6-DNT concentration in two private wells exceeded the Chapter NR 140, Wisconsin Administrative Code (Wis. Adm. Code), Enforcement Standard (ES). In 2005, the Army replaced these two private wells.

In 2006, the USDA installed a well (USDA 6) in the southeast portion of BAAAP to water cattle. The USDA 6 well is located approximately 4,300 feet north of the Water's Edge Subdivision. Sampling results indicated 2,6-DNT exceeded the Chapter NR 140, Wis. Adm. Code, ES. Based on the groundwater flow direction and the groundwater contaminant detections, the source of DNT contaminated groundwater is believed to be from the north-central portion of BAAAP where rocket paste and rocket propellant were produced. However, several investigations to date have not determined a specific source of DNT contamination. It is believed that the broad production area may have caused the groundwater impacts. The following is a summary of the DNT source investigations that were conducted in the Central Plume area.

Comment [JT22]: In my opinion, it's significant that the Central Plume source area was not identified or investigated until a (routine?) private well sampling event showed a DNT detection that could not have come from the PBG or DBG source areas. Given the long history of investigation and source characterization at the BAAP, the fairly recent discovery of a third source area seems to be in conflict with later portions of this document that portray a clear boundary for private wells that might be affected (and should therefore be replaced with municipal water), without a solid hydrogeologic premise for (a) plume stability or (b) groundwater contamination limited to the unconsolidated materials. In other words, is there any reasonable scenario under which private wells outside the proposed remedy area in Figure 39 might be impacted in the future? This becomes more difficult to answer if you're not confident that all significant source areas have been investigated and that the private well supplies beyond the boundary of Figure 39 are hydraulically separated from the outwash and/or bedrock units with contamination. These data may exist, but I'm not convinced from what's in this AFS.

Comment [JT23]: Reference Figure 16B?

DNT Source Investigation

In 2006, monitoring well sample results north and south of the USDA 6 well indicated the source of the Central Plume groundwater contamination was most likely located north of the Rocket Production Area. A DNT sources investigation followed.

Groundwater data and historical standard operating procedures were reviewed. Based on these reviews, the investigation of the source of DNT contamination focused on the Pre-Mix Houses, located near the Rocket Paste area. The Pre-Mix Houses supported the production of rocket paste. Barrels of production chemicals, which contained DNT, were transported by rail to each Pre-Mix House from the Bag Loading House. NC and NG were added to the chemical mixture in each Pre-Mix House. The resulting slurry was then pumped to the Final Mix Houses.

In 2007, soil borings to a depth of 20 feet bgs were completed and continuously sampled at locations where releases of DNT may have occurred. Soil samples were analyzed for DNT, base neutral acids (BNAs), and total lead. DNT was not detected in soil samples collected adjacent to the Pre-Mix Houses. In 2008, soil samples were collected to a depth of nine feet bgs in ditches and potential drainage pathways leading from the Rocket Paste and NG Production areas. Only very low concentrations of DNT were detected in several soil samples. In 2010, soil samples were collected to a depth of eight feet bgs near over 20 production buildings located in the NG Production area. Only very low concentrations of DNT were detected in several soil samples. Seven groundwater monitoring wells were installed in 2007. Three of the wells were constructed so that the screen intersected the water table. The four remaining monitoring wells were constructed so that the screen was submerged below the water table (approximately two-thirds the depth of the sand and gravel aquifer). The wells ranged in depth from 115 to 207 feet bgs. Groundwater samples from each well were analyzed for VOCs, DNT, and BNAs. 2,4-DNT was detected in several monitoring wells and also the laboratory method blanks. The laboratory equipment may have contaminated the well samples, rendering these results invalid. Subsequent groundwater sampling conducted during June 2008 confirmed that 2,4-DNT and 2,6-DNT were present in one of the deeper wells (RIN-0702C) and 2,6-DNT was present in another deeper well (RIN-0703C). These detections of DNT confirmed that the source of DNT contamination was located northwest of the USDA 6 well.

6.0 GROUNDWATER CHARACTERIZATION

Monitoring well locations are shown on Figure 15. Since 1979, the Army has installed over 400 monitoring wells at BAAAP. Groundwater quality data is collected from monitoring wells to assess contaminant concentrations. The groundwater results are reported to the WDNR.

Between April and July of 2010, the Army installed 40 monitoring wells inside and outside BAAAP to supplement the existing groundwater monitoring network. Eleven of those monitoring wells were installed downgradient from the DBG. The installation and sampling of those eleven wells were documented in the *Northeast Boundary Monitoring Well Installation Report* (SpecPro, Inc., 2010). The other 29 monitoring wells were installed within the DBG, PBG, and Central Plumes. Appendix B contains documentation of the installation of these 29 monitoring wells and a well location map.

6.1 Groundwater Properties

Water Level Elevations and Flow Direction

Water level data collected from monitoring wells across BAAAP indicate groundwater depths ranging from 40 to 130 feet bgs or 765 to 855 feet above mean sea level (MSL). Figure 14 is a representation of the groundwater elevation surface in September 2010. The groundwater flow direction is generally to the south-southeast. In the southeast corner of BAAAP, groundwater flow is deflected slightly to the south, presumably due to influences from the Lake Wisconsin Reservoir. In the southwest corner of BAAAP, groundwater flow is influenced by the IRM/MIRM extraction wells. Due to the large number of monitoring wells, the elevation measurements for a sampling round are taken within a 30-day period.

The general groundwater flow direction at the installation is from north to south, but is locally influenced by the Lake Wisconsin Reservoir and the IRM/MIRM pumping wells. The Lake Wisconsin Reservoir, located to the east and southeast of BAAAP, is formed by the WP&L dam, which results in a constant lake elevation of approximately 774 feet MSL. Below the dam, the

Comment [JT24]: Suggest labeling this feature on Figure 14

Comment [JT25]: Consider elaborating – "Therefore, variations in the water table elevations during the 30-day measurement period (e.g., responses to large rainfall events) may be over- or under-represented in the data, but are still appropriate for larger-scale contour maps such as Figure 14." If precip and snowmelt do not affect water levels much, then the point may be moot.

Comment [JT26]: Suggest labeling this feature on Figure 14 water elevation drops abruptly to 736 feet MSL as the lake reverts to the flowing Wisconsin River. The rapid change in water elevations at the dam results in a dramatic hydraulic drop in groundwater elevations around the dam. The pumping of the IRM/MIRM extraction wells located on the western half of the BAAAP southern boundary results in an abrupt elongated groundwater depression zone. Groundwater captured by the depression zone flows toward the IRM/MIRM extraction wells where it is eventually pumped from the sand and gravel aquifer.

Comment [JT27]: Suggest adding a smaller-scale figure for the PBG extraction well area that shows this localized drawdown effect more clearly. Fig 14 is at too large a scale to really see it.

Comparison of groundwater and Reservoir level elevations indicates water from the Reservoir recharges groundwater or, depending on relation to the WP&L dam, groundwater discharges to the Wisconsin River. Groundwater discharges to the Reservoir when adjacent groundwater levels are higher than the Reservoir level. Groundwater discharges to the Reservoir in the northeastern portion of BAAAP. The Reservoir discharges to the sand and gravel aquifer when adjacent groundwater levels are lower than the Reservoir level. About three miles north of the WP&L dam, the Reservoir transitions from recharging to discharging to the underlying sand and gravel aquifer. Directly south of the WP&L dam, the Wisconsin River resumes with groundwater discharging to the river.

Hydraulic Conductivity

Hydraulic conductivity values were calculated based on aquifer testing at two MIRM extraction wells located near the PBG in 2005. The aquifer tests, which were comprised of a pump test followed by a step test, were conducted at extraction well EW-169 in February 2005 and at EW-167 in March 2005. The tests were conducted by continuously pumping the extraction wells over a period of time and measuring the drawdown in nearby observation wells. Observation wells (PBN-8504A, PBM-8505, and PBM-8904C) were monitored for the test at EW-169, which lasted two and one half days. The aquifer test at EW-169 yielded a hydraulic conductivity value between 1.39E-02 to 6.27E-02 centimeters per second (cm/sec). The aquifer test at extraction well EW-167 lasted seven days and drawdown was measured in four nearby observation wells (PBM-8503, PBN-8502A, PBN-8901C, and PBN-8902C). The results of this testing yielded a hydraulic conductivity value between 4.85E-02 and 9.60E-02 cm/sec. Testing methodology is presented in further detail in the *Draft Corrective Measures Implementation Report, MIRM Extraction Well Realignment Project* (Shaw Environmental, Inc., 2006).

During the RI (ABB-ES, 1993), slug tests were performed on monitoring wells across the BAAAP. The RI report included hydraulic conductivity values for 54 monitoring wells. Table 5 summarizes the hydraulic conductivity data collected during the RI. The average hydraulic conductivity of these 54 wells was 4.0E-02 cm/sec. The hydraulic conductivity values obtained during the MIRM pump tests correlated well with the average value obtained from the RI slug tests.

Hydraulic Gradients

Wells are screened at various depths and assigned an alphabetical designation after the number of the well ID. A is the shallow water table interval, and B, C, D, and E are piezometric intervals that increase in depth from B to E. The piezometers ending in E were constructed so that the screen was located in the bedrock. It should be noted that the unconsolidated sand and gravel aquifer is unconfined vertically.

As evident from the groundwater elevation map showing the September 2010 data (Figure 14), the northern half of BAAAP has a much steeper horizontal hydraulic gradient than the southern half. The magnitude and direction of flow for the three plume areas are represented by the groundwater contours presented in Figure 14. Data sets from each groundwater plume were used to calculate horizontal hydraulic gradient. Groundwater elevations from the sampling periods of March 2010, September 2010, and March 2011 were used to calculate an average hydraulic gradient for each plume area (Table 6). The average hydraulic gradient calculated for the PBG area wells was 0.00165 feet per foot (ft/ft). The average hydraulic gradient calculated for the DBG area wells was 0.00127 ft/ft. The hydraulic gradient calculated for the Central Plume area wells was 0.001063 ft/ft.

Vertical groundwater movement is evaluated by comparing groundwater levels from the different aquifer layers to determine vertical gradient. Monitoring well clusters, where two or more wells have screens positioned at different depths within the aquifer, are used to examine differences in the potentiometric groundwater surface between different layers of the aquifer. Vertical hydraulic gradients were evaluated for nested well pairs in the three plume areas. Table 7 summarizes the vertical groundwater gradients for the chosen well nests. Gradients were evaluated from the groundwater elevation data collected during the March 2010, September 2010, and March 2011 monitoring events. Positive vertical gradients indicate groundwater is flowing upward and negative vertical gradients indicated groundwater is flowing downward.

The majority of the well pairs in the PBG exhibited an upward vertical groundwater gradient between shallow to deep wells. The majority of the well pairs in the DBG exhibited a downward vertical groundwater gradient between shallow to deep wells. The four well pairs in the Central Plume were split between a downward or upward vertical groundwater gradient between shallow to deep wells.

Groundwater Flow Velocities

The advective groundwater flow velocity is derived from the hydraulic conductivity value, horizontal gradient, and effective porosity. Advective groundwater movement does not take into account dispersion, diffusion, or chemical retardation of groundwater contaminants which can increase or decrease the rate of groundwater flow. It is a calculated value that provides an estimate of the rate of groundwater flow over time. The mathematical formula for determining advective groundwater flow velocity (v) is:

$v = Ki/n_e$ Where:

K = hydraulic conductivity (feet/day)

i = hydraulic gradient (feet/feet)

n_e = effective porosity

Comment [JT28]: Aren't there some D piezometers in bedrock?

Comment [JT29]: Are there areas where CL-ML layers within the outwash create a localized upward vertical gradient (i.e., semi-confining layers)?

Comment [JT30]: For the conceptual site model, does SpecPro have any opinions about what hydrogeologic conditions are causing upward vertical gradients if "the aquifer" is truly unconfined? Where is that higher head coming from – the Baraboo Hills/bedrock, WI River, etc.? In other words, is it reasonable to assume continuity within the outwash aquifer (probably a required assumption for modeling and hydraulic calculations) if horizontal layering is creating zones of much greater/lesser permeability?

Comment [JT31]: Add ?- In general, vertical hydraulic gradients at BAAP are __ orders of magnitude greater than horizontal hydraulic gradients, which means that ____

The average hydraulic conductivity value from the RI, 0.04 cm/sec or 113.4 ft/day, was used in all the groundwater flow velocity calculations. An effective porosity value of 0.26 was obtained during the recent groundwater modeling effort. Average horizontal gradients of 0.00165 ft/ft for the PBG, 0.00127 ft/ft for the DBG, and 0.00103 ft/ft for the Central Plume were used to calculate the groundwater flow velocities. The calculated average groundwater flow velocities as shown in Table 6 equal 0.72 ft/day for the PBG, 0.55 ft/day for the DBG, and 0.45 ft/day for the Central Plume. These groundwater flow velocity values equate to 263 ft/year for the PBG, 201 ft/year for the DBG, and 164 ft/year for the Central Plume.

Comment [JT32]: Cite section?

Comment [JT33]: As noted above, since vertical gradients are so much greater than horizontal, shouldn't this be accounted for in the velocity calculations (and the conceptual site model)?

6.2 Nature and Extent of Groundwater Contamination

Groundwater investigation activities at BAAAP began in 1980 and continue today. Site-wide groundwater-related assessment activities, agreed upon by the Army and WDNR, include the following: soil vapor surveys; monitoring well drilling, installation, and surveying; water level measurements; pump testing; monitoring well and residential drinking water well sampling; and groundwater modeling. Each year, the Army completes an *Annual Groundwater Narrative Summary Report* that summarizes the groundwater data collected during the previous year.

Historical Groundwater Plume Characterization

Groundwater contamination in monitoring wells at the PBG was first detected in 1982 (Tsai, 1988). During the 1980s, monitoring wells were installed across BAAAP during various investigations. The draft final (Phase 1) RI report (January 1990) indicated that two plumes of contamination had migrated beyond BAAAP boundaries. From the DBG/Landfill #5 area, a sulfate plume had been detected past the eastern boundary. Concentrations of sulfate at the eastern boundary were reported at 640 milligrams per liter (mg/l), but concentrations in private wells outside the boundary were below the Chapter NR 140, Wis. Adm. Code, PAL of 150 mg/l. From the PBG area, a plume of VOCs with CTET as the primary contaminant had moved past the southern boundary.

An off-site groundwater monitoring program was initiated in January 1990. In late April 1990, results of monitoring residential supply wells south of BAAAP showed that three private potable water wells had been contaminated with CTET and chloroform at levels of 80 µg/l and 9.9 µg/l, respectively. A VOC plume moved south from the PBG waste pits, past the installation's southern boundary, then easterly to the Wisconsin River below the WP&L dam. Two replacement residential wells were installed in December 1990 as a remedial measure. The third resident finalized their agreement with the Army in 1995, and the well replacement was completed in 1996. Prior to well replacement, bottled water had been provided to the affected residences. At the southern boundary of the PBG waste pits, the IRM system was constructed and began operating in June 1990.

The 1993 RI and 1994 FS identified the types, concentrations, and locations of contamination at the installation. This RI/FS looked at the possible ways to treat the contamination and recommended remedies for each site. The regulators agreed with the Army's recommendations for remedies. These were incorporated into the IFCR modifications of June 1995 and the RCRA permit modification of January 6, 1996.

The recent groundwater data reported to the WDNR included results for 175 monitoring wells and 48 private wells that were sampled during the August, September, and October 2010 rounds. The August, September, and October 2010 groundwater monitoring data is summarized in Tables 8, 9, and 10, respectively. See Appendix C for maps displaying groundwater concentrations from the August, September, and October 2010 groundwater data for CTET, chloroform, total DNT, ethyl ether, 1,1,1-TCA, 1,1,2-trichloroethane (1,1,2-TCA), and TCE. Appendix C also contains maps of the August, September, and October 2010 groundwater exceedances.

Wisconsin Groundwater Rule Revisions

Effective January 1, 2011, Chapter NR 140, Wis. Adm. Code, groundwater standards were revised. The revision included new standards for DNT (total residues). The ES for DNT (total residues) is 0.05 micrograms per liter (µg/l) and the PAL is 0.005 µg/l. All six DNT isomers (2,3-DNT; 2,4-DNT; 2,5-DNT; 2,6-DNT; 3,4-DNT; and 3,5-DNT) must be added together to determine the DNT (total residues) value, or total DNT. There is no existing federal standard for total DNT. The laboratory's current level of detection (LOD) for all DNT isomers is 0.015 µg/l.

Propellant Burning Ground Plume

The PBG Plume originates at the PBG and extends southeast beyond the installation boundary. ~~South of BAAAP, the~~ The plume then turns southeast towards the Wisconsin River ~~due to the influence of the WP&L dam, just north of Prairie du Sac~~. The PBG groundwater plume shown in Figures 18 and 19 represents the area where groundwater concentrations exceed a Chapter NR 140, Wis. Adm. Code, PAL for one or more of the following compounds: CTET, total DNT, ethyl ether, or TCE. All six DNT isomers (2,3-DNT, 2,4-DNT, 2,5-DNT, 2,6-DNT, 3,4-DNT, and 3,5-DNT) have been detected in the PBG Plume, mostly in the PBG Waste Pits. The plume boundary is an interpretation of the September and October 2010 groundwater data collected from both monitoring wells and private wells. Tables 9 and 10 summarize the groundwater analytical results from the September and October 2010 monitoring well sampling events.

Figure 19 is a conceptual model of the groundwater contamination plume originating from the PBG. The conceptual model shows the plume in relation to the water table and the underlying bedrock. Concentrations of DNT and CTET, above the PAL, have been detected in several monitoring wells that are screened in the bedrock. As shown in Figure 19, there is a shale layer beneath the contamination plume that retards groundwater contamination from migrating into the lower Mt. Simon Formation (sandstone

The horizontal distribution of CTET is illustrated in Figures 20 and 21. These isoconcentration maps were prepared using groundwater data collected during September and October 2010. Figure 20 displays the horizontal extent of CTET that is located above an elevation of 705 feet. Figure 21 displays the horizontal extent of CTET that is located below an elevation of 705 feet.

Comment [JT34]: Which laboratory? Is there any laboratory in the US capable of reaching the PAL for individual isomers?

Comment [JT35]: Should this be Limit, not Level? Add LOD to Acronym list?

Comment [JT36]: Does one isomer predominate once the plume leaves the site? What are the degradation products, and have they been detected?

Comment [JT37]: Since I haven't compared boring logs to x-sections, I have to ask – how many wells intercepted the shale? Just the BAP and PDS production wells, but no exploratory wells on site? Is it reasonable to assume lateral continuity of the shale unit over the horizontal distance shown in Figure 19? Did Gotkowicz et al. make this assumption? If you have upward vertical gradients from the D/E wells to the C/B wells, that may be a more convincing line of evidence.

An elevation of 705 feet was chosen to help visualize the difference between the shallow and deeper zones of CTET contamination in the sand and gravel aquifer.

Figure 22 illustrates how the CTET concentrations in the PBG plume have changed between 1993 and 2010. Figure 21 displays only the area south of the BAAAP boundary where the PBG plume has not been influenced by pumping from the IRM and MIRM extraction wells. The isoconcentration map is broken up into three separate vertical well screen intervals. B series (shallow aquifer zone), C series (intermediate aquifer zone), and D-E series (deep aquifer zone). This area located downgradient of BAAAP does not contain any monitoring wells that are screened at the water table surface (A level). The CTET in the PBG plume exhibits typical chlorinated solvent characteristics of migrating in the direction of groundwater flow and sinking to deeper zones within the sand and gravel aquifer.

Figure 6 shows the orientation of the contaminant plume isoconcentration cross sections for CTET, which are illustrated in Figures 23, 24, and 25. CTET was chosen for visual representation because it best represents the horizontal and vertical extents of the VOC plume.

Comment [JT38]: General comment – these figures are nicely done, and reflect substantial effort. Kudos to your team.

Figure 23 (A-A') illustrates the estimated vertical extent of CTET from the PBG in the north to the Wisconsin River in the south (centerline of PBG plume). The CTET concentrations are highest south of the BAAAP boundary and in wells screened approximately 70 to 100 feet below the water table. The CTET plume extends north to south from the PBG to the Wisconsin River with an average thickness of 90 feet beneath BAAAP and 140 feet south of BAAAP. The maximum depth of CTET is 145 feet below the water table at monitoring well PBN-9903D, which is screened in sandstone at the top of the Eau Claire Formation. CTET concentrations beneath the PBG (source area) are much lower than what is found downgradient of the PBG. Figure 23 supports the interpretation that the VOC plume is moving deeper into the sand and gravel aquifer as it moves southeast. The estimated boundary of the CTET plume is shown to approach the Wisconsin River, but first encounters the groundwater/surface water interface. The groundwater/surface water interface is an area beneath a river where the groundwater mixes with the surface water. The fate of groundwater contaminant plumes as they discharge through river beds and the groundwater/surface water interface is not well understood (Conant, 2000). Dilution of the CTET plume is expected to occur within the groundwater/surface water interface.

Comment [JT39]: Does the predicted CTET biodegradation pathway also change substantially as GW mixes with more oxygenated SW?

Figure 24 (B-B') illustrates the width and depth of the CTET plume approximately 2,000 feet south of the PBG. Figure 25 (D-D') illustrates the width and depth of the CTET plume, but off-site and approximately 12,000 feet south of the PBG. An isoconcentration section for CTET was not prepared for section C-C'. The CTET plume is estimated to be approximately 3,100 feet wide and a maximum depth of 135 feet below the water table in Figure 24, which is close to the source area. The CTET plume is estimated to be approximately 2,200 feet wide and a maximum depth of 135 feet below the water table in Figure 25, which is 12,000 feet downgradient of the source area.

The horizontal distribution of total DNT is illustrated in Figures 26 and 27. These isoconcentration maps were prepared using groundwater data collected during September and October 2010. Figure 26 displays the horizontal extent of total DNT that is located above an elevation of 705 feet. Figure 27 displays the horizontal extent of total DNT that is located below an elevation of 705 feet. An elevation of 705 feet was chosen to help visualize the difference between the shallow and deeper zones of total DNT contamination in the sand and gravel aquifer. Below an elevation of 705 feet, groundwater beneath the PBG does not contain DNT (see Figure 27).

Figure 6 shows the orientation of the contaminant plume isoconcentration cross sections for total DNT, which are illustrated in Figures 28, 29, and 30. Total DNT was chosen for visual representation because it best represents the horizontal and vertical extents of the DNT plume.

Figure 28 (A-A') illustrates the estimated vertical extent of total DNT from the PBG in the north to the Wisconsin River in the south (centerline of PBG plume). Total DNT concentrations beneath the PBG (source area) are higher than what is found downgradient. The total DNT concentrations are much lower south of the BAAAP boundary than what is found on BAAAP. The total DNT plume extends north to south from the PBG to the Wisconsin River with a thickness between 50 and 120 feet. The influence of the IRM can be seen on the far left side (north) of the cross section by the separation of the DNT plume. The influence of the MIRM can be seen in the middle of the cross section (BAAAP boundary) by the higher DNT concentrations on the left (north) and the lower DNT concentrations of the right (south). The estimated boundary of the DNT plume is shown to approach the Wisconsin River but first encounters the groundwater/surface water interface. Dilution of the DNT plume is expected to occur within the groundwater/surface water interface.

Comment [JT40]: Some of the cross sections show no detects in the upper portion of the aquifer. Any theories about what is causing this?

Comment [JT41]: Same question as before for estimated degradation pathway changes in the mixing zone

Figure 29 (B-B') illustrates the width and depth of the total DNT plume approximately 2,000 feet south of the PBG. Figure 30 (D-D') illustrates the width and depth of the total DNT plume, but off-site and approximately 12,000 feet south of the PBG. An isoconcentration section for DNT was not prepared for section C-C'. The total DNT plume is estimated to be approximately 3,100 feet wide and a maximum depth of 135 feet below the water table in Figure 29, which is close to the source area. The total DNT plume is estimated to be approximately 2,200 feet wide and a maximum depth of 135 feet below the water table in Figure 30, which is 12,000 feet downgradient of the source area.

Comment [JT42]: What's the justification for assuming that higher DNT concentrations, when detected in an extraction well with a long screen, are coming from the upper section rather than the middle or lower section of the screened interval?

DNT is routinely detected in monitoring wells located both inside and outside of BAAAP. DNT has been detected at varying depths in the sand and gravel aquifer. The highest DNT concentrations are found at the PBG Waste Pits (source area). The IRM extraction wells, SCW-1 and SCW-2R, capture any contaminated groundwater migration from the PBG Waste Pits. The highest total DNT concentration detected during September 2010 was 1,166.1 µg/l in PBM-0002. PBM-0002 is located at the PBG Waste Pits. DNT is occasionally detected in private wells located south of BAAAP, but always at concentrations below the ES.

Comment [JT43]: Overstatement?

Comment [JT44]: Is this true historically, and does it also account for the ES for all isomers combined, especially if the LOD can't be reached reliably?

Elevated levels of CTET (above the ES) are routinely detected in monitoring wells located both inside and outside of BAAAP. CTET has been detected at varying depths in the sand and gravel aquifer. The highest of the CTET detections are found south of the PBG Waste Pits. Elevated concentrations of CTET are found near the MIRM extraction wells, near the BAAAP boundary, and in several wells located off-site towards the Wisconsin River. The highest CTET concentration detected during September 2010 was 75.9 µg/l in SWN-9103C. SWN-9103C is located south of BAAAP along County Road Z. The highest CTET concentration, 23 µg/l, located on BAAAP was detected in PBN-8502A. CTET (below the PAL) is rarely detected in private wells located south of BAAAP.

Elevated levels of TCE (above the ES) are routinely detected in monitoring wells located both inside and outside of BAAAP. TCE has been detected at varying depths in the sand and gravel aquifer. The highest of the TCE detections are found south of the PBG Waste Pits. Elevated concentrations of TCE are found near the MIRM extraction wells, near the BAAAP boundary, and in several wells located off-site towards the Wisconsin River. The highest TCE concentration detected during September 2010 was 13.1 µg/l in SPN-8904C. SPN-8904C is located near the BAAAP boundary. The highest TCE concentration, 6.82 µg/l, located off-site was detected in PBN-9903C. TCE (below the PAL) is rarely detected in private wells located south of BAAAP.

Elevated concentrations of ethyl ether have only been detected near the BAAAP boundary. Only low concentrations of ethyl ether have been detected off-site. The highest ethyl ether concentration detected during October 2010 was 4,610 µg/l (above the ES) in PBN-1001C, located near an extraction well.

SpecPro calculated a contaminant mass estimate for the CTET and total DNT groundwater contamination in the PBG Plume. Assuming a porosity of 20 percent, the pore space volume was derived based on the dimensions of the plume. The plume dimensions were approximated by using the isoconcentration cross sections and maps contained in this report. This volume was multiplied by the average concentration within the plume and converted from cubic feet of liquid to pounds. The mass of the CTET within the plume is estimated to be 3,576 pounds. The mass of the total DNT within the plume is estimated to be 487 pounds. A summary of the input parameters is provided in Table 11.

In order to evaluate plume dynamics, analytical data from select off-site wells were graphed over time. Concentrations over time graphs are presented in Appendix A. Four contaminants of concern (carbon tetrachloride, chloroform, TCE and total DNT) were used for trend analysis. Generally, the VOC compounds showed similar characteristics in the PBG Plume. As the plume extends off-site, the VOC compounds show a decreasing trend in the shallow wells and an increasing trend in the deeper wells, which is likely due to the fact that these compounds are more dense than water (DNAPL) and tend to sink in groundwater. One of the wells at the leading edge of the plume, screened within the D interval, shows a gradual increase up until 2009 followed by a steep increase over the past two years; however, other leading edge wells showed decreasing trends in recent years to below the PAL. Further details on trend analyses are provided below for each compound evaluated.

For carbon tetrachloride at the off-site plume center, wells PBN-9903A, B, C, and D show stable to decreasing trends, but an increasing trend in the deep well since 2008. At the off-site west plume edge, both SWN-9102C and D show decreasing trends. The downgradient, off-site plume center nested wells, SWN-9103B, C, D and E showed a decreasing trend in the shallow interval

Comment [JT45]: Incorrect. Are the VOC and DNT concentrations high enough, even in the source areas, to indicate non-aqueous phase liquids? There's been no mention of DNAPLs originating in the source areas, and that's not how the GW data is portrayed on the cross sections. If you have dissolved-phase VOCs showing increases at depth, but decreases at shallow, there's something happening with the hydrogeology, not the contaminants (e.g., the strong downward vertical gradients discussed elsewhere, dilution from recharge at the top of the aquifer, preferential flow paths, etc).

Comment [JT46]: Without digging too deep into the data, here's a general question – is there any evidence to suggest that the contaminants of concern have reached bedrock (or a more permeable layer at the top of bedrock), and are now moving faster (horizontally) than contaminants in the upper unconsolidated units?

since 2004, an increasing trend in the C well since 2008, a stable trend in both the D and E wells. The downgradient, off-site plume center wells, SWN-9104C and D show stable trends, and the plume leading edge well, PBM-9001D shows a gradual increase up until 2009 followed by a steep increase over the past two years. Three other nested leading edge wells (PBN-9102B, C and PBM-9002D) showed decreasing carbon tetrachloride trends to below the PAL over the past year.

For chloroform at the off-site plume center, wells PBN-9903A, B, C, and D show stable to decreasing trends, but an increasing trend in the deep well since 2008. At the off-site west plume edge, both SWN-9102C and D show stable to decreasing trends with concentrations around the PAL. The downgradient, off-site plume center nested wells, SWN-9104C and D show increasing trends, but the concentrations remain below the PAL. Another well nest in this location (SWN-9103B, C, D, and E) showed a decreasing trend in the B well, an increasing trend in the C well, a decreasing trend in the D well depth since 2006 and a stable trend in the deep E well. The plume leading edge well, PBM-9001D shows a gradual increase up until 2009 followed by a steep increase over the past two years. Three other nested leading edge wells (PBN-9102B, C and PBM-9002D) showed decreasing chloroform trends since 2006 to below the PAL.

For TCE at the off-site plume center, nested wells PBN-9903A, B, C and D show stable to decreasing trends in the upper zones, but an unstable to increasing trend in the deeper wells. The downgradient, off-site plume center nested wells, SWN-9103B, C, D and E showed a decreasing trend in the shallow interval since 2000, an increasing trend in the C well since 2009, a decreasing trend in the D well depth since 2007, and a stable trend in the deep E well. The plume leading edge well, PBM-9001D shows a gradual increase up until 2009 followed by a steep increase over the past two years.

Trend analysis for total DNT concentrations was difficult as concentrations showed variability from one sampling event to the next with no consistent trend. It should be noted that the DNT isomer concentrations were extremely low if detected at all.

Deterrent Burning Ground Plume

The DBG groundwater plume shown in Figure 18 represents the area where groundwater concentrations exceed a Chapter NR 140, Wis. Adm. Code, PAL for either total DNT or 1,1,2-TCA. Only five DNT isomers (2,3-DNT, 2,4-DNT, 2,6-DNT, 3,4-DNT, and 3,5-DNT) have been detected in the DBG Plume, mostly in the DBG source area. The plume boundary is an interpretation of the August, September, and October 2010 groundwater data collected from both monitoring wells and private wells. Tables 8, 9, and 10 summarize the groundwater analytical results from the August, September, and October 2010 monitoring well sampling events.

The horizontal distribution of total DNT is illustrated in Figures 31, 32, and 33. Isoconcentration boundaries in Figures 31 and 32 were prepared using groundwater data collected during September and October 2010. Figure 31 displays the horizontal extent of total DNT that is located above an elevation of 752 feet. Figure 32 displays the horizontal extent of total DNT that is located below an elevation of 752 feet. An elevation of 752 feet was chosen to help visualize the difference between the shallow and deeper zones of total DNT contamination in the sand and gravel aquifer. Total DNT concentrations are shown to be lower below an elevation of 752. Isoconcentration boundaries in Figure 33 were prepared using groundwater data collected during March 2007. Figure 33 displays the horizontal extent of total DNT in all monitoring wells and private wells.

Figure 6 shows the orientation of the contaminant plume isoconcentration cross sections for total DNT, which are illustrated in Figures 34 and 35. Total DNT was chosen for visual representation because it best represents the horizontal and vertical extents of the DNT plume.

Figure 34 (E-E') illustrates the estimated vertical extent of total DNT, along the centerline of the DBG plume, from the DBG (northwest) towards the Wisconsin River or Weigand's Bay (southeast). The total DNT concentrations are highest south of the DBG and in wells screened approximately 0 to 40 feet below the water table. The total DNT plume extends northwest to southeast from the DBG with an average thickness of 90 feet. Total DNT concentrations beneath the DBG (source area) are lower than what is found downgradient. Figure 34 supports the interpretation that the DNT plume is vertically distributed across the sand and gravel aquifer as it moves southward.

Figure 35 (F-F') illustrates the width and depth of the total DNT plume between 200 to 1,200 feet south of the DBG. The total DNT plume is estimated to be approximately 1,300 feet wide and a maximum depth of 55 feet below the water table in Figure 35 (F-F'), which is close to the source area.

DNT is routinely detected in monitoring wells located near the DBG. DNT has been detected at varying depths in the sand and gravel aquifer. The highest DNT concentrations are found near the DBG (source area). The highest total DNT concentration detected during September 2010 was 5.982 μg/l in ELM-8901. ELM-8901 is located just east of the DBG. DNT has migrated downgradient from the DBG, east and southeast, and has been detected in several monitoring wells located on the BAAAP boundary. Since 2003, DNT is routinely detected in the ELM-9501 well nest, consisting of ELM-9501, ELN-0801B, ELN-0801C, and ELN-0801E.

Detections of DNT have been sporadic in private wells located southeast of BAAAP (Weigand's Bay area). Results from the August 2010 sampling of 21 private wells located in the Weigand's Bay area found that DNT was not detected.

Elevated levels of 1,1,2-TCA, between the PAL and ES, are routinely detected in one monitoring well (ELN-8203B) located east of the DBG. The concentration of 1,1,2-TCA in ELN-8203B was 1.12 μg/l in September 2010. 1,1,2-TCA is detected in several other monitoring wells but below the PAL. Since August 2009, 1,1,2-TCA has been routinely detected (below the PAL) in a private well located east of BAAAP.

In 2009, additional investigation work was conducted southeast of the DBG to delineate the downgradient extent of the DBG Plume. Groundwater samples were collected from 12 temporary soil borings. The investigation defined the extent of the DNT and VOC plume. The data indicated that DNT had migrated outside the BAAAP boundary. The results from this investigation were used to determine the best placement of permanent monitoring wells in the area. Further information on this investigation is presented in the *Northeast Boundary Groundwater Investigation Report* (SpecPro, Inc., December 2009).

During 2010, 11 monitoring wells were installed downgradient of the ELM-9501 well nest. These wells were intended to monitor any off-site migration of DNT and VOCs. DNT was not detected in these 11 monitoring wells. The low 1,1,1-TCA concentrations found in ELN-1003B and ELN-1003C are well below the PAL. Because 1,1,1-TCA has also been consistently detected in upgradient wells near the DBG, the DBG is a likely source of these off-site 1,1,1-TCA detections. Table 8 summarizes the groundwater analytical results from the August 2010 well sampling event. Further information on the monitoring well installation is presented in the *Northeast Boundary Monitoring Well Installation Report* (SpecPro, Inc., September 2010).

SpecPro calculated a contaminant mass estimate for the total DNT contamination in the DBG Plume. Assuming a porosity of 20 percent, the pore space volume was derived based on the dimensions of the plume. This volume was multiplied by the average concentration within the plume and converted from cubic feet of liquid to pounds. The total mass of the total DNT within the plume is 5.1 pounds. A summary of the input parameters is provided in Table 12.

In order to evaluate contaminant trend data for the DBG Plume, SpecPro selected wells within the plume and graphed the concentrations over time. Graphs showing DBG Plume contaminant concentrations over time are presented in Appendix A. The primary contaminant of concern in the DBG Plume is DNT; therefore, concentrations of total DNT were evaluated. In the source area, data from wells DBM-8201 and 8202 were graphed. Well DBM-8201 shows a generally stable trend with some periods of elevated concentrations. Well DBM-8202 shows a spike in 2003 followed by a stable to decreasing trend. At the center of the DBG Plume, data from wells ELM-8907 and 8908 were graphed. ELM-8907 showed a generally stable trend followed by increasing trend since 2008. ELM-8908 showed variability up to 2007 followed by a steadily decreasing trend. Data from four wells (ELM-9501, ELN-0801B, ELN-0801C, and ELN-0801E) were used to evaluate the downgradient portion of the plume. ELM-9501 and ELN-0801E demonstrated stable trends since 2009. Wells ELN-0801B and C show a steady decrease in total DNT concentrations since 2009.

Central Plume

The Central groundwater plume shown in Figure 18 represents the area where groundwater concentrations exceed a Chapter NR 140, Wis. Adm. Code, PAL for total DNT. Only 2,4-DNT and 2,6-DNT have been detected in either monitoring wells or private wells in the Central Plume. The plume boundary is an interpretation of the September and October 2010 groundwater data collected from both monitoring wells and private wells. DNT has been detected at shallow depths in the sand and gravel aquifer. The highest total DNT concentration detected during October 2010 was 0.061 µg/l in RIN-1004B. RIN-1004B is located between the

USDA 6 well and the Water's Edge Subdivision. Tables 9 and 10 summarize the groundwater analytical results from the September and October 2010 monitoring well sampling events. The horizontal distribution of total DNT is illustrated in Figure 36. This isoconcentration map was prepared using groundwater data collected during September and October 2010. The isoconcentration map could not be broken into two vertical zones because fewer wells have been installed in the Central Plume. The elevated concentrations of DNT (above 0.05 µg/l) are located approximately 7,500 feet downgradient of the potential source area. Because the total DNT in the northern section of the plume (source area) is depleted, it appears there was not a continuous source of contamination.

Comment [JT47]: Reference Figure 16B?

Figure 6 shows the orientation of the contaminant plume isoconcentration cross section (Figure 37) for total DNT. Total DNT was chosen for visual representation because it best represents the horizontal and vertical extents of the DNT plume.

Comment [JT48]: 37?

Comment [JT49]: Delete?

Figure 37 (G-G') illustrates the estimated vertical extent of total DNT, along the centerline of the Central Plume, as it migrates towards the Wisconsin River Reservoir. The total DNT concentrations are highest near the BAAAP boundary and in wells screened approximately 0 to 40 feet below the water table. The total DNT plume extends from the north to the south with an average thickness of 90 feet. Figure 37 indicates that the highest concentrations of DNT are located in the upper portions of the sand and gravel aquifer and downgradient of the potential source area.

In 2004, DNT was first detected within private wells located in the Water's Edge Subdivision, along the north shore of Gruber's Grove Bay. The 2,6-DNT concentration in two private wells exceeded the Chapter NR 140, Wis. Adm. Code, ES. In 2005, the Army replaced these private wells. Also in 2005, the Army installed eight monitoring wells in the Water's Edge Subdivision to monitor the groundwater quality. Sampling results indicate that 2,6-DNT is routinely found above the Chapter NR 140, Wis. Adm. Code, ES in two of these monitoring wells.
In 2006, the USDA installed a well (USDA 6) at BAAAP. The well is located approximately 4,300 feet upgradient of the Water's Edge Subdivision. 2,6-DNT is routinely found above the Chapter NR 140, Wis. Adm. Code, ES in the USDA 6 well. The Army has sampled existing monitoring wells at BAAAP and installed additional monitoring wells to define the DNT groundwater plume. Results from these additional wells indicate the source of DNT groundwater contamination is located north of the Rocket Production Area in BAAAP. The source of the Central Plume is not clearly defined.

Comment [JT50]: Where? Label separately on Fig 1?

SpecPro calculated a contaminant mass estimate for the total DNT contamination in the Central Plume. Assuming a porosity of 20 percent, the pore space volume was derived based on the dimensions of the plume. This volume was multiplied by the average concentration within the plume and converted from cubic feet of liquid to pounds. The total mass of the total DNT within the plume is estimated to be less than two pounds. A summary of the input parameters is provided in Table 12.

In order to evaluate contaminant trend data for the Central Plume, SpecPro selected wells within the plume and graphed the concentrations over time. Concentration over time graphs are provided in Appendix A. The primary contaminant of concern in the Central Plume is DNT; therefore, concentrations of total DNT were evaluated. There was not enough data to establish any trends from the upgradient portion of the plume; however, the downgradient portion contained several wells with sufficient data to support trend analyses. All the wells selected (USDA 6, SEN-0501A, B, D, SEN-0502B, and SEN-0503A, B, D) showed stable to decreasing trends at the downgradient, leading edge of the plume. This indicates that the Central Plume is receding or decreasing in concentration.

6.3 Groundwater Modeling

A groundwater model was developed to help understand how the groundwater flows beneath BAAAP and help predict the movement of groundwater contamination. A groundwater model is not an exact description of the subsurface but uses mathematical equations to estimate the subsurface conditions. A groundwater model is just a tool to help understand the complicated interaction between soil, bedrock, groundwater, and contaminants.

Comment [EO51]: It is not very clear how the model helps support the argument in favor of the proposed alternative, since the model was inconclusive with respect to DNT, and the statements about the extent of the CTET plume are very general.

Groundwater modeling conducted in conjunction with this AFS consisted of reviewing and updating the existing groundwater flow and solute transport models developed previously for the BAAAP. These previous studies included, but were not limited to, the groundwater flow and solute transport models developed by Woodward-Clyde in 1995, T N & Associates and Stone & Webster in 2001 for the PBG, and the subsequent refinement of that effort completed by Shaw Environmental, Inc. (Shaw) in 2006. The current effort entailed: 1) adjusting the site-wide groundwater flow model developed by Shaw to a regional flow model; 2) updating the groundwater flow and solute transport models completed by Shaw for the PBG; 3) developing a regional transient flow model; and 4) performing model simulations to approximate the migration of the PBG groundwater contaminant plume over time. Model simulations were not prepared for the DBG and Central plumes. Appendix D contains the groundwater modeling technical memorandum prepared by Mr. David Voight (subcontractor to SpecPro).

Comment [EO52]: A brief explanation of why the other plumes were not modeled would be helpful.

The Department of Defense Groundwater Modeling System (GMS) (2010) is a computer graphical system used to construct the models, which includes modeling tools to facilitate site characterization, model conceptualization, mesh and grid generation, geostatistical computations, and post processing. GMS is linked with groundwater transport and water quality models to predict the fate and transport of contaminants at a site. Several geostatistical (interpolation/extrapolation) numerical tools are integrated into GMS to help visualize and model the distribution of contaminants in the groundwater.

The latest update of the modular finite-difference groundwater flow model (MODFLOW) was used to calculate the groundwater flow field at BAAAP. MODFLOW is a common groundwater flow model used to solve groundwater flow equations in three dimensions. Solute contaminant transport was evaluated by using MT3DMS, a modular three-dimensional multispecies transport model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater.

The original site-wide groundwater flow model, generated by MODFLOW, consisted of six stratigraphic layers. The updated regional flow model refined the layering to reference elevation and utilized four layers in the glacial outwash. Model boundary conditions were reassessed from a hydrologic basin perspective that considered groundwater divide locations and resulted in the establishment of boundary conditions that provided relatively definitive head control for model input. This approach was considered an improvement over previous models since head data from surface water features helped remove some of the ambiguity associated with defining model boundary conditions noted during prior modeling efforts.

Comment [EO53]: How many layers overall in the new model?

Comment [EO54]: How do the boundaries and size of the new model compare to the previous models?

Development of the regional transient model included the input of hydrogeological parameter data, including precipitation and recharge data from a period from 1988 to 2010. The regional transient model is based on the original site-wide model. The original site-wide model utilized steady-state flow which implies the magnitude and direction of flow is constant with time. The steady-state flow model also included the continuous pumping from the IRM/MIRM extraction wells. Conversely, transient flow occurs when the magnitude and direction of the flow changes with time. Transient flow allows for changes in precipitation and recharge from upgradient sources. The regional transient flow model does not include pumping from the IRM/MIRM extraction wells. The regional transient flow model assumes that the groundwater in the PBG plume moves approximately one foot per day. The model predicts that it would take approximately 30 years for groundwater to flow from the PBG source area to the Wisconsin River. This estimate does not include the complicated interactions with contaminants present in the groundwater, which typically result in retardation of contaminant plume movement.

Comment [EO55]: Clarify reason why? Because pumping will cease in the proposed remedy?

Comment [EO56]: What is the basis for this assumption? If advective flow is known to be 1 foot per day, what value is the model adding as a predictive tool? If it is the model that is calculating the average flow velocity based on observed heads and aquifer parameters then this should be stated more clearly.

Solute Transport Modeling

Contaminant plume occurrence as predicted by the groundwater model is based on reasonable assumptions made during model set-up and execution. The modeling results are not to be considered a representation of the actual site conditions. All simulations assumed the IRM/MIRM extraction wells were not pumping

Historical 2,4-DNT concentrations measured in soil and groundwater at the PBG area were used to develop a SESOIL model. SESOIL is a seasonal soil compartment model which simulates long-term pollutant fate and migration in the unsaturated soil zone (from the ground surface to the groundwater table). Contaminant source loading of 2,4-DNT into SESOIL was based on the 1995 soil investigation study completed by Shaw at the PBG Waste Pits. SESOIL modeling indicated that the excavation of the shallow contaminated soil, operation of the BEST system, and the installation of the soil cap over the PBG Waste Pits have significantly reduced the amount of 2,4-DNT that would leach to groundwater. SESOIL modeling also showed that the cleanup timeframe will also be greatly reduced from the aforementioned remedial actions conducted to date. The SESOIL data was used in the MODFLOW/MT3DMS contaminant transport model to simulate loading the 2,4-DNT into the groundwater. The 2,4-DNT transport model could not be calibrated to historic data collected from monitoring wells. Future predictive runs for 2,4-DNT also could not accurately predict the 2,4-DNT concentration or distribution;

therefore, contaminant transport model simulations for 2,4-DNT were not provided in the groundwater modeling technical memorandum.

Solute transport modeling using MT3DMS was performed to provide a preliminary evaluation of transport characteristics of the CTET groundwater contaminant plume at the PBG. The PBG plume was modeled for CTET because it best represents the horizontal and vertical extent of groundwater contamination. Site-specific testing data and literature values obtained from prior investigations conducted at the PBG were used to develop likely CTET loading rates from soil to groundwater at the former PBG Waste Pits (SESOIL modeling was not employed for CTET). An initial run (baseline) was completed for 2010. Then simulations were completed for historical CTET concentrations between 1988 to 2010 (IRM/MIRM pumping active). These results compared favorably with historical data collected from monitoring wells. CTET transport in groundwater was simulated from 2012 to 2050 with the IRM/MIRM extraction wells shut off. The model simulations show that by 2040 the majority of the PBG plume will contain CTET at concentrations below the NR 140 ES (5.0 μg/l). Comparison of the 2050 model simulation with earlier predictive runs shows a decrease in CTET concentrations across all model layers, suggesting that the PBG plume will stabilize and shrink.

Comment [EO57]: A brief explanation of why SESOIL was used in one case but not another would be helpful.

Comment [EO58]: Is this strictly a transport simulation with dilution, or are processes of degradation/interaction with aquifer materials also included?

Comment [EO59]: Is there a drawing that shows this?

7.0 CONCEPTUAL SITE MODEL

In order to more fully understand the relationships between contaminants, affected environmental media, exposure pathways, and human and ecological receptors, a CSM was developed. A CSM is a conceptual understanding of a site that identifies suspected sources of hazardous substances, types, and concentrations of hazardous substances, potentially contaminated media, and actual and potential exposure pathways and receptors. Figure 38 shows a CSM based on the known presence and transport of COCs.

7.1 Current and Potential Land Uses

The BAAAP is a former munitions components production facility undergoing demolition, investigation, and remediation activities. The property under Department of Defense ownership has an active security, administration, environmental, maintenance, and demolition workforce. Army staff manage all aspects of ongoing work. Currently, a portion of the installation is off limits to the public and is secured by a security fence.

Future use of the former BAAAP will be divided between the USDA, Wisconsin Department of Transportation (WDOT), United States Bureau of Indian Affairs (BIA) on behalf of the Ho-Chunk Nation (HCN), United States Department of Health Services on behalf of the BSD, Town of Sumpter, and the National Park Service (NPS) on behalf of the WDNR. The installation will serve as agricultural and grazing land (USDA and BIA/HCN), recreational land (NPS/WDNR), cemeteries (Town of Sumpter), and as a wastewater treatment plant (BSD).

Comment [JT60]: Qualify as "Anticipated future use.." ? Is there a document you can reference for this?

Comment [JT61]: Still true? October press release by BIA to the contrary

7.2 Sources of Contamination

On-Site Sources

Sources of groundwater contamination include the PBG, DBG, and the Central Plume source areas. Figure 1 shows the locations of these source areas and Figure 6 shows groundwater contaminant plumes. DNT and chlorinated solvents are known to have been disposed in the PBG and DBG source areas. WDNR-approved remedial actions relating to soil contamination at the PBG and DBG source areas have been implemented. The source of the Central Plume contamination is generally located based on groundwater flow direction and the groundwater contaminant detections. DNT contaminated groundwater is believed to be from the north-central portion of BAAAP where rocket paste and rocket propellant were produced. It is believed general production operations in this area caused the groundwater impacts.

Off-Site Sources

Nitrates from non-point sources that are outside of Army control are known to affect groundwater in and around BAAAP. The WDNR has a best management practice program it administers for these agricultural and grazing-related sources.

Comment [JT62]: Background sources? This report has not focused on metals in GW, but you might consider some mention of background water quality for arsenic, lead, manganese, etc., since those are often significant for these bedrock units & outwash.

An unknown source of TCE has been detected in monitoring well BGM-9103, on the west-central boundary of BAAAP. Based on the groundwater flow direction, the source of TCE appears to be located off-site (northwest of BGM-9103).

7.3 Environmental Medium and Exposure Points

Groundwater is the environmental medium of concern at the BAAAP. Both the shallow unconsolidated and deeper bedrock groundwater aquifers are sources of potable water in residential communities downgradient (south and east) of the installation boundaries. In addition, groundwater discharges into the Lake Wisconsin/Lower Wisconsin River area.

7.4 Exposure Pathways and Receptors

Workers involved with groundwater remediation, investigation, actions, and monitoring are subject to some level of risk when working at the BAAAP. Worker safety is currently managed through a health and safety program that complies with all Occupational Safety and Health Administration (OSHA), Department of Defense, and other state and federal health and safety requirements; therefore, this exposure route is not currently a risk or regulatory concern.

The potential exists for VOCs present in the groundwater plumes to migrate vertically in the unsaturated soil column. According to the WDNR's vapor intrusion guidance (2010), light end petroleum compounds and chlorinated VOCs are most likely to create a vapor intrusion problem. DNT is not a risk for vapor intrusion because it is a semi-volatile organic compound (SVOC). A vapor intrusion pathway screening will be conducted by the Army for the groundwater contamination originating from BAAAP. The vapor migration pathway will be addressed separately from the determination of a final groundwater remedy.

The general public is subject to some level of risk through recreational use of the Lake Wisconsin/Lower Wisconsin River. VOCs and SVOCs do not bioaccumulate in organisms. For this reason, consumption of fish from Lake Wisconsin or the Lower Wisconsin River way is identified as a pathway of no regulatory concern. In addition, a comparison of National Recommended Water Quality Criteria, developed to protect aquatic life from acute and chronic health effects, shows all surface water criteria are much higher than the groundwater concentrations off-site. Therefore, exposure through surface water is currently not a risk or regulatory concern. For more information on National Recommended Aquatic Life Values, refer to United States Environmental Protection Agency publication *2009 National Recommended Water Quality Criteria* available at http://www.epa.gov/ost/criteria/wqctable/.

Comment [JT63]: Passive voice. Who made this determination, and is there a report to cite?

Groundwater used for private drinking water has been a concern of residents nearby BAAAP. The Army currently has an environmental monitoring and health protection program in place that is protective of the private water well users. If a Chapter NR 140, Wis. Adm. Code, ES is exceeded in a private well in two consecutive sampling rounds, bottled water is made available to the occupant. If the exceedances continue, well replacement is offered to the owner. To date, the Army has replaced five shallow private wells with deeper aquifer private wells. However, this exposure route continues to be a potential risk and regulatory concern.

Comment [JT64]: As mentioned previously, there's a significant data omission in how the private wells are discussed in the AFS, which seems odd given the regulatory attention BAAP has received to date (perhaps there's a related document that has not been cited?). Although private wells are the primary receptor/exposure point, (Fig 38), there's been no analysis or mention of (a) the specific areas/neighborhoods where private wells exist, relative to the known and predicted plume pathways; (b) private well construction logs and open-interval information for each neighborhood; or (c) how private well open intervals relate to the hydrogeologic units and plume geometries shown in the cross sections.

It should be noted, per consultation with the WDNR, irrigation wells downgradient of BAAAP are not being monitored and are not considered to be a potential risk or regulatory concern.

8.0 REGULATORY REQUIREMENTS

Under Section NR 722.09(2), Wis. Adm. Code, *Standard for Selecting Remedial Actions*, responsible parties shall select a remedial action...(that shall) comply with all applicable state and federal public health and environmental laws and standards. The following subsections outline the regulations applicable and relevant to the groundwater plumes at BAAAP.

8.1 Wisconsin Spill Statute

Wisconsin Spill Statute 292.11 (3) states, "A person who possesses or controls a hazardous substance which is discharged or who causes the discharge of a hazardous substance shall take the actions necessary to restore the environment to the extent practicable and minimize the harmful effects from the discharge to the air, lands, or waters of this state." The Army has met the requirement of restoring the environment to the extent practicable and minimizing the harmful effects by the remediation of the soil in the source areas and the installation and operation of the IRM/MIRM groundwater treatment system for the past 20 years.

8.2 Groundwater Quality Regulations

Chapter NR 140, Wis. Adm. Code, establishes ESs and PALs for groundwater beneath the State of Wisconsin. The Wisconsin groundwater ES is consistent with federal and Wisconsin drinking water Maximum Contaminant Levels (MCLs), which applies to public water systems.

Enforcement Standards

The groundwater ESs are protective of public health and welfare on the premise that the groundwater may be ingested through use as drinking water. ESs exist for all the groundwater VOC and SVOC COCs listed in Table 13. All ESs are Public Health Groundwater Quality Standards listed in Table 1 at Section NR 140.10, Wis. Adm. Code, except sulfate, which is a Public Welfare Groundwater Quality Standard listed in Table 2 at Section NR 140.12, Wis. Adm. Code.

Preventive Action Limits

The PALs serve "to inform the WDNR of potential groundwater contamination problems (and to) establish the level of groundwater contamination at which the WDNR is required to commence efforts to control the contamination". PALs exist for all the groundwater COCs listed in Table 13. All PALs are Public Health Groundwater Quality Standards listed in Table 1 of Section NR 140.10, Wis. Adm. Code, except sulfate, which is a Public Welfare Groundwater Quality Standard listed in Table 2 in Section NR 140.12, Wis. Adm. Code.

Action Required for Exceedance of an ES or a PAL

Actions required by a groundwater ES exceedance are codified in Section NR 140.26, Wis. Adm. Code (Table 6). The regulation lists eight responses appropriate to the detection of an ES exceedance. They are as follows:

1. Require a revision of the operational procedures at a facility, practice or activity.
2. Require a change in the design or construction of the facility, practice or activity.
3. Require an alternate method of waste treatment or disposal.
4. Require prohibition or closure and abandonment of a facility, practice or activity.
5. Require remedial action to renovate or restore groundwater quality.
6. Require remedial action to prevent or minimize the further release of the substance to groundwater.
7. Revise rules or criteria on facility design, location or management practices.
8. Require the collection and evaluation of data to determine whether natural attenuation can be effective to restore groundwater quality within a reasonable period of time, considering applicable criteria specified in ss. NR 140.24, 722.07 and 722.09 or 722.11, and require monitoring to determine whether or not natural attenuation is occurring in compliance with the requirements of s. NR 140.26(2)(a).

The Army has completed or has in place action specific steps 1 through 7 and will evaluate action step 8 more thoroughly during this AFS.

Section NR 140.24, Wis. Adm. Code, (Table 5) lists 12 responses appropriate to the detection of a PAL exceedance. They are as follows:

1. No action pursuant to s. NR 140.24(5) and consistent with s. 160.23, Stats.
2. Require the installation and sampling of groundwater monitoring wells.
3. Require a change in the monitoring program, including increased monitoring.
4. Require an investigation of the extent of groundwater contamination.
5. Require a revision of the operational procedures at the facility, practice or activity.
6. Require a change in the design or construction of the facility, practice or activity.
7. Require an alternate method of waste treatment or disposal.
8. Require prohibition or closure and abandonment of a facility, practice or activity in accordance with sub. (6).
9. Require remedial action to renovate or restore groundwater.
10. Require remedial action to prevent or minimize the further discharge or release of the substance to groundwater.
11. Revise rules or criteria on facility design, location or management practices.
12. Require the collection and evaluation of data to determine whether natural attenuation can be effective to restore groundwater quality within a reasonable period of time, considering applicable criteria specified in ss. NR 140.24, 722.07 and 722.09 or 722.11, and require monitoring to determine whether or not natural attenuation is occurring in compliance with the requirements of s. NR 140.26(2)(a).

The Army has completed or has in place action specific steps 1 through 11 and will evaluate action step 12 more thoroughly during this AFS.

8.3 Wisconsin Water Quality Standards and Criteria

The Wisconsin Water Quality Standards and Criteria requirements are applicable to existing and proposed point source discharges to surface waters of the state that may be associated with the final groundwater remedy. Two downgradient surface water bodies are in the area: the Lake Wisconsin Reservoir (above the WP&L dam) and the Lower Wisconsin River (below the WP&L dam).

The designated use for the Lake Wisconsin Reservoir is defined as "warm water sport fish community" in Section NR 102.13, Wis. Adm. Code. The use classification for the Lower Wisconsin River, below the WP&L dam to Prairie du Chien, is "Exceptional Resource Water" in Section NR 102.11, Wis. Adm. Code.

Water Surface Quality Criteria have been developed in Wisconsin as "Human Threshold Criteria" for 2,4-DNT and 1,1,1-TCA. Wisconsin "Human Cancer Criteria" have been developed for the following: CTET, chloroform, 2,4-DNT, 1,1,2–TCA, and TCE.

Wisconsin Human Threshold Criteria

The human threshold criterion (HTC) is the maximum concentration of a substance established to protect humans from adverse effects resulting from contact with or ingestion of surface waters of the state and from ingestion of aquatic organisms taken from surface waters of the state. Human threshold criteria are derived for those toxic substances for which a threshold dosage or concentration can be estimated below which no adverse effect or response is likely to occur. (Section NR 105.08, Wis. Adm. Code). Currently, HTC-Non-Public Water System (NPWS) have been developed in Wisconsin for two relevant COCs: 2,4-DNT and 1,1,1-TCA.

Chronic exposure to 2,4-DNT at 13 µg/l has been shown to have no adverse effect due to human ingestion of surface water and organisms. The maximum value of 2,4-DNT found in off-site wells (monitoring or residential well) in 2010 was 0.02 µg/l, or less than 1% of the permissible HTC-NPWS criteria.

Chronic exposure to 1,1,1-TCA at 270,000 µg/l has been shown to have no adverse effect due to ingestion of surface water and organisms. 1,1,1-TCA was not found above detectible levels in any off-site wells in 2009.

Wisconsin Human Cancer Criteria

The human cancer criterion (HCC) is the maximum concentration of a substance or mixture of substances established to protect humans from an unreasonable incremental risk of cancer resulting from contact with or ingestion of surface waters of the state and from ingestion of aquatic organisms taken from surface waters of the state over a lifetime of 70 years (Section NR 105.09, Wis. Adm. Code). Currently, HCC- NPWS have been developed in Wisconsin for five relevant COCs: CTET, chloroform, 2,4-DNT, 1,1,2–TCA, and TCE.

Chronic exposure to chloroform at 1,960 µg/l, 2,4-DNT at 13 µg/l, 1,1,2-TCA at 195 µg/l, and TCE at 539 µg/l has been shown to have no unreasonable incremental risk of cancer due to ingestion of surface water and organisms. The maximum value of any of these chemicals found in off-site monitoring wells in 2010 is less than 4% of the permissible HCC-NPWS criteria.

Chronic exposure to CTET at 29 µg/l has been shown to have no unreasonable incremental risk of cancer due to ingestion of surface water and organisms. The maximum value of CTET found in off-site monitoring wells in 2010 is 248% of the permissible HCC-NPWS criteria. This monitoring well (SWN-9103C) in the PBG Plume is located approximately 3,200 feet from the Wisconsin River. Monitoring well PBN-9101C is located further downgradient and only 1,400 feet from the Wisconsin River. The last time PBN-9101C was sampled in 1998, the CTET value was less than 30% of the permissible HCC-NPWS criteria.

Numerous studies or tests have been conducted throughout the years in which surface water samples have been collected and analyzed. Data collected includes Gruber's Grove Bay investigations conducted by Shaw Environmental, Inc. and an April 2007 Weigand's Bay water sample, the December 2007 shallow temporary well water samples (adjacent to Weigand's Bay), and the annual WPDES Whole Effluent Toxicity Monitoring (background samples collected near Inspiration Point and Weigand's Bay) conducted by SpecPro, Inc. Based on the data from these investigations and applicable scientific and regulatory information, the residual contaminant plumes do not adversely affect receptors in the environment.

9.0 REMEDIAL ALTERNATIVES

9.1 Groundwater Remedial Action Objective

The objective of the groundwater remedial action is to protect human health by preventing exposure to contaminated groundwater from BAAAP, to restore groundwater to the extent practicable, and minimize the impact of the contaminant plumes on the environment.

9.2 Remedial Alternatives

Based on site conditions and the screening of cleanup action options, three remedial alternatives were developed to address the presence of contaminants in groundwater at the BAAAP. Each alternative is capable of accomplishing the remedial objective.

Alternative 1: IRM/MIRM Treatment and Monitored Natural Attenuation

This alternative continues IRM/MIRM treatment of the PBG Plume, residential and groundwater monitoring, and monitored natural attenuation of the DBG and Central Plumes.

Alternative 2: In-Situ Biochemical Treatment and Monitored Natural Attenuation

This alternative would use in-situ groundwater treatment instead of the current IRM/MIRM treatment, a modified residential and groundwater monitoring program, and monitored natural attenuation of the PBG, DBG, and Central Plumes.

Alternative 3: Public Water System and Monitored Natural Attenuation

This alternative involves the installation of a public water system and subsequent elimination of residential wells and IRM/MIRM treatment, a modified groundwater monitoring program, and monitored natural attenuation of the PBG, DBG, and Central Plumes.

9.3 Detailed Analysis of Alternatives

The following describes the conceptual design and criteria for detailed analysis of each alternative. This section provides a description of the criteria for detailed analysis and the detailed analysis of the groundwater alternatives. Each alternative is evaluated against the same criteria established by the WDNR in accordance with Chapter NR 722, Wis. Adm. Code, Standards for Selecting Remedial Actions.

The development of remedial alternatives is evaluated for each contaminated medium or migration or exposure pathway. This evaluation process is to be used to determine which remedial alternative constitutes the most appropriate technology or combination of technologies to restore the environment, to the extent practicable, within a reasonable period of time, and to minimize the harmful effects of the contamination to the air, land, or waters.

Criteria for Detailed Analysis

Relative performance of each alternative is evaluated using the following nine criteria:

1. Overall protection of human health and the environment
   The remedy should be protective of human health and minimize the harmful effects to the environment.

2. Compliance with applicable regulations
   This shall include federal and state regulations.

3. Long-term effectiveness and permanence
   This shall consider the risks remaining after completion of the remedial action and the adequacy and suitability of controls, if any, that are used to manage untreated contaminants remaining at the site.

4. Reduction of toxicity, mobility, and volume through treatment
   This shall include the expected reduction in toxicity, mobility, and volume measured as a percentage or order of magnitude, and the type and quantity of treatment residuals that will remain following treatment.

5. Short-term effectiveness
   This shall include protection of the community during the remedial action, protection of workers during remedial action, environmental impacts to natural resources, and time until remedial response objectives are achieved.

6. Implementability
   This shall consider the feasibility of the remedy including: construction and operation; reliability of technology; ease of undertaking additional remediation, if necessary; and monitoring considerations, addressing the ability to adequately monitor the effectiveness of the remedy and the risks should monitoring be insufficient to detect a system failure.

7. Cost
   This shall consider capital costs, both direct and indirect; annual operations and maintenance (O&M) costs; and present worth analysis (or net present value) of costs.

8. State Acceptance
   This shall consider the issues and concerns that the state may have regarding each alternative. This criterion will be evaluated throughout the development, screening, and evaluation of alternatives based on comments and input received from the WDNR.

9. Community Acceptance

This involves an evaluation of issues and concerns the public may have regarding each alternative. This criterion will be evaluated throughout the development, screening, and evaluation of alternatives based on comments and input received from the public.

9.4 Monitored Natural Attenuation Evaluation

Because monitored natural attenuation (MNA) is proposed as an element of all suggested remedial options at BAAAP, an evaluation is necessary to illustrate that MNA has a reasonable probability of restoring the groundwater to the extent practicable.

MNA relies on natural attenuation processes to achieve remediation objectives within a time frame that is reasonable compared to that offered by other more active methods. These natural attenuation processes include a variety of physical, chemical, or biological processes that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants.

Natural attenuation processes typically occur at all sites, but to varying degrees of effectiveness depending on the types and concentrations of contaminants present and the physical, chemical, and biological characteristics of the soil and groundwater. Natural attenuation processes may reduce the potential risk posed by site contaminants in three ways: (1) Transformation of contaminant(s) to a less toxic form through destructive processes such as biodegradation or abiotic transformations; (2) Reduction of contaminant concentrations whereby potential exposure levels may be reduced; and (3) Reduction of contaminant mobility and bioavailability through sorption onto the soil or rock matrix.

According to the USEPA (OSWER Directive 9200.4-17P), MNA can be considered to be an alternative means of achieving remediation objectives that may be appropriate for specific site circumstances where its use meets the applicable statutory and regulatory requirements. As there is often a variety of methods available for achieving remediation objectives at any given site, MNA may be evaluated and compared to other viable remediation methods. As proposed in this AFS, MNA is one component of the total remedy. It is used in conjunction with active remediation as a follow-up measure that will be monitored and compared with expectations.

MNA has several potential advantages and disadvantages, and these factors should be carefully considered during site characterization and evaluation of remediation alternatives before selecting MNA as the remedial alternative. Potential advantages of MNA include:

- Some natural attenuation processes may result in in-situ destruction of contaminants;

- Less intrusion as few surface structures are required;

- Potential for application to all or part of a given site, depending on site conditions and remediation objectives;

- Use in conjunction with, or as a follow-up to, other (active) remedial measures; and

- Potentially lower overall remediation costs than those associated with active remediation.

The potential disadvantages of MNA include:

- Longer time frames may be required to achieve remediation objectives, compared to active remediation measures at a given site;

- Site characterization is expected to be more complex and costly;

- Long-term performance monitoring will be required;

- Institutional controls may be necessary to ensure long term protectiveness;

- Potential exists for continued contamination migration, and/or cross-media transfer of contaminants;

The regulatory and policy frameworks for corrective actions under the RCRA program have been established to implement their respective statutory mandates and to promote the selection of technically defensible, consistent, and cost effective solutions for the cleanup of contaminated media. The WDNR and EPA recognize MNA may be an appropriate remediation option for contaminated soil and groundwater under certain circumstances (i.e., National Presto/Town of Lake Hallie).

Key principles considered during selection of the BAAAP groundwater remedial measures, include:

- Source control measures should use treatment to address "principal threat" wastes where practicable; and engineering controls for waste that pose a relatively low long-term threat, or where treatment is impracticable.

- Contaminated groundwater should be returned to beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site. When restoration of groundwater is not practicable, prevention of further migration of the plume and exposure to the contaminated groundwater is important.

The determination of whether MNA is an appropriate remedy for groundwater is based on the following:

- *Are the contaminants present in the groundwater being effectively remediated by natural attenuation processes?* Studies investigating natural attenuation in the PBG Plume at BAAAP have provided evidence that DNT and VOCs are naturally attenuating in the subsurface. The *Draft Technical Report Natural Attenuation Screening Study for the Propellant Burning Ground* (Stone & Webster, August 1999) states that biological degradation of DNT was clearly demonstrated under the oxidative conditions that exist in the subsurface, but other processes are reducing the VOC contaminant mass based on the concentrations of chlorinated solvents in the groundwater, which decrease over both distance from the source area and over time at each location sampled.

Comment [JT65]: This statement does not seem consistent with the CTET data/figures

- *Are the contaminant plumes stable and does the potential exist for the environmental conditions that influence plume stability to change over time?* Overall, the three contaminant plumes are stable, and there are no potential conditions that would change this.

Comment [JT66]: This statement also not supported by the data for CTET and DNT. In my opinion, a strong case for plume stability has not been made, though I concur that providing reliable water supply to known potentially affected users is a reasonable approach to close the exposure pathway.

- *Could human health, drinking water supplies, other groundwater, surface waters, ecosystems, sediments, air, or other environmental resources be adversely impacted as a consequence of selecting MNA as the remediation option?* No other receptors could be adversely affected by continuing to allow MNA to occur. (See conceptual site model.)

Comment [JT67]: Not clear what's meant here

- *Could the current and projected demand for the affected resource over the time period that the remedy will remain in effect change?* Transfer of BAAAP to other owners is not expected to increase groundwater usage within the installation boundary. Additional residential development is not expected to significantly increase groundwater use via private wells. Abandonment of private wells for inclusion in a municipal water system would decrease demand on the groundwater in the area of the remedy. The resulting reduced drawdown after private well abandonment is not anticipated to significantly affect plume dynamics or conditions.

Comment [JT68]: Has the WDNR already designated special construction requirements for new private wells in the area? Does the financial cost projection for the selected remedy address how future (new) connections to the public water supply would be handled?

- *Will the contamination exert a long-term detrimental impact on available water supplies or other environmental resources?* No, not as long as the public water supply is available with the water resources located away from the plume areas. The groundwater can still be used for agricultural purposes. No other environmental resources would be affected.

- *Is the estimated timeframe of MNA remediation reasonable compared to timeframes required for the other active methods?* Yes, the other remedial options considered are timeframe comparable as they all include MNA.

- *What is the nature and distribution of sources of contamination and have these sources been, or can be, adequately controlled?* All three of the sources of the contaminant plumes have been adequately investigated and remediated.

- *Do the resulting transformation products present a greater risk, due to increased toxicity and/or mobility, than do the parent contaminants?* No, the breakdown products present no greater risk than the parent compounds. Vinyl chloride, a possible result of TCE reductive dechlorination has not been detected in any monitoring wells. Based on the health advisory levels developed by the Wisconsin Department of Health Services (2008 and 2011), the DNT breakdown products are less toxic than the parent DNT isomers. Outside of the area surrounding the DBG and PBG waste pits, elevated concentrations of DNT breakdown products have not been detected in either monitoring wells or private wells.

- *Are there reliable site-specific mechanisms available for implementing institutional controls (e.g., zoning ordinances), and is an institution responsible for their monitoring and enforcement identifiable?* Yes, there will be municipal ordinances and deed restrictions limiting groundwater use in the affected areas.

Comment [JT69]: I was surprised that the earlier portions of this document did not specify the typical degradation pathway and breakdown products for the primary contaminants of concern. This paragraph helps, but lacks specifics.

It should be noted, the Army will retain responsibility for the groundwater contamination during MNA. Due to uncertainty associated with the potential effectiveness of MNA to meet remediation objectives protective of human health and the environment, long-term performance monitoring will be a fundamental component of the MNA remedy. Once the remedy is implemented and the efficacy of MNA is demonstrated, the Army will pursue case closure.

9.5 Technical Impracticability

The objective of the groundwater remedial action is to protect human health by preventing exposure of contaminated groundwater from BAAAP, to restore groundwater to the extent practicable, and minimize the impact of the contaminant plumes on the environment. To meet these goals, remedial actions at BAAAP have addressed source areas and the associated contaminant plumes, and replaced affected private drinking water wells. At the PBG plume, the IRM/MIRM pump-and treat-technology has been successful at capturing contaminants in groundwater; however, this technology is not able to remove the necessary amount of contaminant mass from groundwater to achieve the expectation of aquifer restoration to beneficial uses (safe drinking water source) within reasonable time frames. Even with a pumping/treatment rate of 3 million gallons per day, the IRM/MIRM only addresses about a third of the entire PBG plume.

Limitations of pump-and-treat technology for many groundwater contaminant scenarios have been well recognized since the late 1980s (AEC, 2004). Despite advances in technologies applicable to groundwater remediation, aquifer restoration for sites with complex geologic and contaminant characteristics is rarely achieved. Technical and regulatory communities generally agree that restoration of groundwater at complex sites like BAAAP is technically impracticable. Therefore, alternative cleanup strategies must be considered and implemented. Information contained in this AFS demonstrates achieving the remediation goal for the contaminated aquifer at BAAAP through groundwater treatment alone is technically impracticable from an engineering perspective.

9.6 Alternative 1 – IRM/MIRM Treatment and Monitored Natural Attenuation

Comment [JT70]: FYI, the bulk of our comments on are Alternative 3, with few or none on Alts 1 and 2 (in the interest of time). Did SpecPro consider barrier systems for the three plumes, to just keep the lower concentration, downgradient contaminants from reaching private wells, or is that ineffective for these contaminants?

Under this alternative, groundwater extraction and treatment of the PBG plume inside the BAAAP boundaries would continue as currently operating.

The current practice of monitored natural attenuation would continue for the other areas of groundwater concern, including the DBG and Central Plumes. Long-term monitoring of the groundwater and residential wells to ensure that remediation and natural attenuation are progressing toward regulatory standards would continue.

Periodic analysis of groundwater (monitoring wells and private wells) would measure the status of the contaminated groundwater plumes, determining when concentrations have decreased below Chapter NR 140, Wis. Adm. Code, standards. After WDNR standards are met in the portion of the PBG plume located inside the BAAAP boundary, the IRM/MIRM would be shut down. Groundwater monitoring would continue for several years, monitoring the PBG plume to ensure stable or receding conditions.

Overall Protection of Human Health and the Environment

This alternative would control and limit the migration of the on-site PBG plume only. There is no capture/treatment planned for the off-site portion of the PBG plume. There is also no capture/treatment planned for the DBG plume or the Central Plume. Monitoring of private wells would continue, and private wells would be replaced if a persistent exceedance of a Chapter NR 140, Wis. Adm. Code, ES is confirmed. Contaminant concentrations are predicted to decrease through natural attenuation processes. Based on the applicable scientific and regulatory information, the residual contaminant plumes do not adversely affect receptors in the environment (see Section 6.4).

Compliance with Applicable Regulations

This alternative currently complies with applicable regulations.

Long-Term Effectiveness and Permanence

In this alternative, contaminant concentrations would continue to decrease below regulatory standards through recovery and treatment of the portion of the PBG plume on the installation, and natural processes (dilution, dispersion, and sorption). Monitoring of the plumes would continue for several years after the plumes attenuate to ensure that all areas remain below regulatory standards. Monitoring of residential wells would continue until the WDNR agrees that residential well monitoring is no longer required.

Reduction of Toxicity, Mobility, and Volume through Treatment

Limited reductions in toxicity, mobility, and volume would occur through treatment of the PBG plume on the installation. The groundwater contamination would continue to decrease due to natural attenuation processes.

Short-Term Effectiveness

The short-term impacts of alternatives shall be assessed considering the following: short-term risks that might be posed to the community during implementation of an alternative; potential impacts on workers during remedial action and the effectiveness and reliability of protective measures; potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and time until protection is achieved.

For this alternative, short-term risks to the community and workers could include those due to potential human or ecological exposure to contaminants. However, there would be no additional short-term risk as this WDNR-approved alternative is already in place and operating on-site.

Implementability

This alternative has already been implemented.

Cost

The estimated present worth costs for Alternative 1 are shown below. See Appendix E for a summary of the costs for Alternative 1.

Engineering design:	$ 0
Capital cost:	$ 0
Annual O&M:	$ 76,911,000
Monitoring and closeout plan/report:	$ 55,000
Total present worth:	**$ 76,966,000**

* Present worth costs use current rates and do not include inflation

State Acceptance

This alternative is a continuation of the current interim groundwater remedy accepted by the WDNR; therefore, it is likely that the WDNR would continue to accept this remedy. However, this criterion would be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from the WDNR.

Community Acceptance

This alternative is a continuation of the current interim groundwater remedy; therefore, it is likely that the community would continue to accept it. However, this criterion would be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from the public.

9.7 Alternative 2 – In-Situ Biochemical Treatment and Monitored Natural Attenuation

This alternative would involve the in-situ biochemical treatment of each of the three plumes (PBG, DBG, and Central), with groundwater monitoring. Only the portions of the plumes that are located on BAAAP would be treated. Natural attenuation would continue for other areas outside the installation boundaries.

The treatment of chlorinated solvent contaminated groundwater has been well studied, but DNT has not. The one known effective in-situ treatment for both types of contamination would consist of injecting a consortium of naturally-occurring microbes selected for their ability to degrade specific chemicals into harmless by-products through aerobic co-metabolism. This bioremediation product, known as CL-Out®, is marketed by CL Solutions, LLC of Cincinnati, Ohio.

This bio-augmentation treatment by CL-Out® introduces a high population of effective degrading organisms, called pseudomonas, into the treatment zone. The population delivered into the treatment zone is 100 to 1,000 times higher than the native bacterial population. While there may be indigenous organisms capable of degrading the contaminants, the benefit of bio-augmentation is that the added population more effectively degrades the contaminants over a shorter amount of time. CL-Out® has been proven at sites across the United States to be capable of remediating chlorinated VOC compounds in the groundwater.

A treatability study was conducted at BAAAP using CL-Out® in 2008. The study consisted of treating two identical groundwater samples as microcosms and a third identical untreated sample maintained under the same conditions as a standard for comparison. One of the microcosms received just a dosage of CL-Out® and the other microcosm was treated with CL-Out® and dextrose. The dextrose was added to determine whether a carbon source was necessary to support microbial growth because the concentration of DNT and other organics in the groundwater were very low. Samples were collected from each microcosm at intervals following treatment. The results of the treatability study showed that the CL-Out® was very effective in degrading the DNT isomers with most of the contaminant reduction complete within seven days of treatment. For further information, see *Sustainable Remediation Alternative Evaluation – Treatability Study of DNT Bio-augmentation at the Badger Army Ammunition Plant* presentation poster found at [illegible].

The groundwater conditions at BAAAP appear to be favorable to allow bio-augmentation to succeed. Pilot tests in the field would be required to prove this is effective on a larger scale.

The CL-Out® mixture would be pumped into a combination of approximately 1,950 temporary wells and existing monitoring wells in the three plumes.

The injection points would need to be spaced approximately 50 feet by 500 feet apart throughout each plume. The existing wells would have their monitoring apparatus removed for the injection. A truck carrying a water/CL-Out® mixture and a pump would be used to bring the treatment to the wells. Approximately 16 pounds of CL-Out® mixture would be pumped into each injection point. The treatment would spread out through the groundwater and take approximately nine months at each plume to show effectiveness. It is assumed that a single round of injections of the CL-Out® mixture would be sufficient to treat each plume. Upon completion of active treatment, each plume would be monitored for contaminant reduction or stabilization.

This alternative would include monitoring of the plume for several years following treatment to ensure the effectiveness of the bioremediation and confirm that concentrations have decreased below regulatory standards. This alternative also involves shutting down the IRM/MIRM upon concurrence from the WDNR that the in-situ biochemical treatment has been effective.

Overall Protection of Human Health and the Environment

This alternative meets the requirements of the remedial action objective because it would effectively degrade the contaminants in groundwater on the installation, thereby minimizing the risk of future contaminant migration to human receptors and the environment. Groundwater monitoring at private wells would continue to provide assurance to the residents that their water is safe to drink. Based on the applicable scientific and regulatory information, the residual contaminant plumes do not adversely affect receptors in the environment (see Section 6.4).

Compliance with Applicable Regulations

This alternative would be designed to comply with applicable regulations.

Long-Term Effectiveness and Permanence

Both active treatment and natural attenuation components of the alternative would be permanent. If effective, groundwater treatment would permanently remove the majority of DNT and the chlorinated solvents from the groundwater. The remaining contamination would continue to decrease due to natural attenuation processes. However, this alternative may require supplemental post-treatment applications, at considerable cost, and would require a groundwater monitoring program to verify the efficacy of the remedial action. This alternative is expected to be effective over the long-term.

Reduction of Toxicity, Mobility, and Volume through Treatment

In-situ bioremediation of groundwater would reduce the toxicity, mobility, and volume of DNT and chlorinated solvents in the treated area more quickly than natural processes alone. The groundwater contamination would also continue to decrease due to natural attenuation processes and no receptors would be at a significant risk.

Short-Term Effectiveness

The short-term impacts of alternatives shall be assessed considering the following: short-term risks that might be posed to the community during implementation of an alternative; potential impacts on workers during remedial action and the effectiveness and reliability of protective measures; potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and time until protection is achieved.

For this alternative, short-term risks to the community and workers could include those due to potential human or ecological exposure to contaminants. Because monitoring well and private well sampling would continue, no significant increase in risk is anticipated for potential receptors with the implementation of this alternative. In addition, there would be little effect on the community as most of the field activity associated with the injection would be conducted by qualified personnel on-site. As observed in the treatability study, the bioremediation occurs very quickly upon introduction of the CL-Out® and no worker safety issues have been identified.

Implementability

CL-Out® has been demonstrated in a drum test to be effective in treating DNT and chlorinated solvents without the production of lasting intermediates or daughter products.

Cost

The estimated present worth costs for Alternative 2 are shown below. See Appendix E for a summary of the costs for Alternative 2.

Engineering design:	$ 45,000
Capital cost:	$ 41,200,000
Post-treatment monitoring:	$ 20,047,000
Monitoring and closeout plan/report:	$ 55,000
Total present worth:	**$ 61,347,000**

* Present worth costs use current rates and do not include inflation

State Acceptance

This criterion would be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from the WDNR.

Community Acceptance

This criterion would be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from the public.

9.8 Alternative 3 – Public Water System and Monitored Natural Attenuation

This alternative consists of the installation of a public water system that would provide a safe, clean, reliable water source for all the potentially affected well owners downgradient of BAAAP. Two public wells would be installed in an area outside the limits of the BAAAP groundwater plumes and draw water from a deep sandstone aquifer. This alternative would eliminate the need to monitor private wells once homes are changed over to public water. The Army proposes that all potable (drinking water) wells be abandoned preventing exposure by ingestion so that receptor would be eliminated. The Army has drafted a proposed remedy area for the public water system (see Figure 39). Cooperation of the affected municipalities in the formation of a

Comment [JT71]: It would be helpful to summarize the basic components of the new water system - is there is more to it than just 2 wells? Appendix E shows some of the breakdown of costs but could provide more detail – ie linear footage of watermain pipe, type of equipment needed to maintain the water system, etc. Would the system have or need to have any special features that would protect it from any contaminants, reduce or minimize migration of contaminants along the pipe, etc out of the ordinary construction of watermain that are not included in the costs?) What is the expected life of the system and would there be any proposed components to increase the life of the system, etc.

Comment [JT72]: Not defined

Comment [JT73]: Technical rationale for this boundary should be included

Comment [JT74]: Water rates for a limited number of households for such a large system may be a financial issue for future management and maintenance. What is the anticipated timeline when the residents/Districts would be solely responsible for the system costs once installed or would there be cost sharing for the life of the system to make rates comparable? Replacement costs of a proposed system would be very costly years down the road once it starts to deteriorate. Exhibit 3, Alternative 3 shows only 5 years of system operation costs and 20 years of sampling. The water system will be around much longer than that. How does a cost comparison for a well compare to payments for a water system over the life of the systems?)

water district is envisioned for the development and long-term management of the system. Details on the Army's proposal are being developed and are available at www.cleanwaterwelldone.com.

This alternative also involves preparing a phased shutdown plan for the IRM and MIRM systems and a groundwater monitoring and closure plan to verify natural attenuation continues to progress toward regulatory case closure standards. Monitoring and closure plans would also be submitted to the WDNR for review and concurrence prior to implementation. These plans would include a systematic procedure to provide the WDNR the necessary information required to make a closure decision. This procedure would also include continued monitoring for steady-state conditions in the three contaminant plumes.

Overall Protection of Human Health and the Environment

This alternative would be the most protective of human health because it completely eliminates the exposure pathway to humans by providing an alternative source of water. Based on the applicable scientific and regulatory information, the residual contaminant plumes do not adversely affect receptors in the environment (see Section 6.4).

Compliance with Applicable Regulations

This alternative would comply with applicable regulations.

Long-Term Effectiveness and Permanence

This alternative provides a permanent, long-term solution to the groundwater threat from BAAAP. The groundwater contamination would continue to decrease due to natural attenuation processes and no receptors would be at a significant risk.

Reduction of Toxicity, Mobility, and Volume through Treatment

This alternative reduces the toxicity, mobility, and volume of the contamination in the groundwater through natural attenuation and eliminates the human exposure pathway by closing the private water wells.

Short-Term Effectiveness

The short-term impacts of this alternative considers the following: short-term risks that might be posed to the community during implementation of an alternative; potential impacts on workers during remedial action and the effectiveness and reliability of protective measures; potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and time until protection is achieved.

For this alternative, short-term risks to the community and workers would not include those due to potential human or ecological exposure to contaminants, as all of the proposed work does not

Comment [JT75]: The northeast part of the map shown in Figure 39 shows a proposed remedy area that splits the Wiggins Bay neighborhood in the Town of Merrimac. Might there be more public opposition to the new water system if some people remained on wells and the others across the bay had water brought to them by the new water system? What is the comfort level of those residents outside but adjacent to the proposed remedy area that years down the road they will not be affected ?

Comment [JT76]: You might want to reference specific aspects of this website. For example, Prairie du Sac submitted a letter to Ackerman at the WDNR stating that the Town has the ability to provide water service to the Extraterritorial Zoning District (ETZ). Was there any consideration to connecting to other existing municipal water supplies to help serve the area? What might the cost / benefit comparison be to utilize other municipal systems vs an entire new system. Is it even feasible because of the elevation differences?

Comment [JT77]: This statement assumes that the plumes are in fact stable and that no additional areas of contamination will be encountered off site (i.e.,, SpecPro is making the significant assumption that private water wells outside the proposed remedy area in Figure 39 will not be impacted in the future, based on data collected to date). Given that the central plume area was discovered fairly recently, that assumption seems weak.

Comment [JT78]: Would the system be able to handle future development needs in the area? Has there been any discussion of future development on the west side of the river if the Ferry was replaced by a bridge? Land costs seem to be less on the west side of the river verses the east side because of the time to commute to Madison. Having a bridge to cross Lake Wisconsin makes Wiggin's Bay approximately only 30 miles from Dane County Regional Airport.

come in contact with impacted groundwater. There would be some effect (road/lane closures, increased worker traffic, equipment noise, etc.) on the community due to construction of the wells, water tower, and underground piping. The construction of the public water system is estimated to take approximately three years.

Implementability

This alternative would be feasible, with the consent and approval of the community and community leaders. The ~~towns~~ Towns of Sumpter, Merrimac, and Prairie du Sac must all work effectively together and coordinate efforts for the public water supply alternative to move forward.

Comment [JT79]: How likely is this to happen? Has there been any opposition to working together expressed by the residents or municipalities?

Cost

The estimated present worth costs for Alternative 3 are shown below. See Appendix E for a summary of the costs for Alternative 3.

Comment [JT80]: We are unable to evaluate these costs because quantities assumed are not provided

Engineering design:	$ 2,900,000
Capital cost:	$ 24,746,000
Annual O&M:	$ 12,218,000
Monitoring and closeout plan/report:	$ 55,000
Total present worth:	**$ 39,919,000**

* Present worth costs use current rates and do not include inflation

State Acceptance

This criterion will be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from the WDNR.

Community Acceptance

This criterion will be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from local governments and the public.

10.0 COMPARISON OF ALTERNATIVES

Through the analysis and evaluation of alternatives using the specified criteria, all three of the presented alternatives are capable of remediating the groundwater contaminant plumes in accordance with WDNR requirements. In addition, all the alternatives provide a reduction in risk to drinking water receptors downgradient of the BAAAP. Alternative 3 provides this reduction of risk in a shorter period of time. All three alternatives carry a measure of uncertainty; Alternative 1 relates to the timeframe necessary to complete the pump and treat phase; Alternative 2 relates to the effectiveness and implementation of the biochemical phase; and Alternative 3 relates to the natural attenuation phase (timeframe).

Comment [JT81]: Plus assumed plume stability within known hydrogeologic boundaries

Alternative 1 – IRM/MIRM Treatment and Monitored Natural Attenuation involves the continued implementation of the existing IRM/MIRM groundwater pump and treat system and groundwater monitoring program. The PBG Plume would continue to be recovered and treated along with groundwater monitoring. This alternative has the advantage of already being in place. In addition, this alternative is effective in actively treating only the PBG Plume. Total cost for Alternative 1 is approximately $77 million present worth.

Alternative 2 – In-situ Biochemical Treatment and Monitored Natural Attenuation involves in-situ biochemical treatment of the three groundwater contaminant plumes and the implementation of a modified groundwater monitoring program. This alternative is effective in actively treating all three groundwater contaminant plumes located on BAAAP. Total cost for Alternative 2 is approximately $61 million present worth.

Alternative 3 – Public Water System and Monitored Natural Attenuation involves installation of a public water system for potentially affected private well owners downgradient of the BAAAP, a phased shutdown of the IRM and MIRM systems, and the implementation of a modified groundwater monitoring program. Overall, Alternative 3 ultimately relies on natural attenuation to address residual contamination in all three groundwater contaminant plumes. This alternative completely eliminates the potential human exposure pathway, which is the primary remedial action objective. Total cost for Alternative 3 is approximately $40 million present worth.

Comment [JT82]: With significant assumptions

11.0 REMEDY SELECTION

Considering all the evaluation criteria and comparative aspects associated with the three proposed alternatives, Alternative 3 – Public Water System has been identified as the preferred final remedy for the BAAAP groundwater plumes. Alternative 3 meets the remedial action objective and regulatory requirements because it is protective of human health and the environment; involves a reasonable implementation and restoration time frame; is feasible; and eliminates down-gradient drinking water receptors.

Comment [JT83]: Same comment as above, plus suggest re-wording – the goal is to eliminate the pathway, not the receptors (which was still illegal the last time I checked!)

Adequate source control measures have been taken, natural attenuation will bring the groundwater into compliance with ch. NR 140 groundwater quality standards within a reasonable period of time, and the groundwater plume margins are stable or receding, and after case closure, groundwater contamination exceeding ch. NR 140 preventive action limits will not migrate beyond the boundaries of any property identified as having existing groundwater contamination. Alternative 3, in conjunction with all the interim actions completed to date (soil excavation, soil vapor extraction, enhanced bioremediation, capping, and groundwater pump and treat) provides a path for case closure and meets the statutory requirement for restoring the environment to the extent practicable [see Statute 292.11 (3)]. Therefore, the Army requests WDNR approval of the selected remedial option in accordance with NR 722.

12.0 REFERENCES

ABB Environmental Services, Inc., 1993. *Final Remedial Investigation Report, Badger Army Ammunition Plant.* Prepared for United States Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland. April.

ABB Environmental Services, Inc., 1994. *Final Feasibility Study, Badger Army Ammunition Plant.* Prepared for United States Army Environmental Center, Aberdeen Proving Ground, Maryland. August.

AEC, 2004. *Technical Impracticability Assessments: Guidelines for Site Applicability and Implementation, Phase II Report.* Prepared for the U.S. Army Environmental Center (AEC) by an expert panel convened by AEC and revised and edited by Malcolm Pirnie, Inc. March.

Attig, J.W., 1990. *Geology of the Badger Army Ammunition Plant Area.* Wisconsin Geological and Natural History Survey.

Clayton, L. and Attig, J.W., 1990. *Geology of Sauk County, Wisconsin.* Wisconsin Geological and Natural History Survey, Information Circular 67.

Conant, B., 2000. *Ground-water Plume Behavior Near The Ground-Water/Surface Water Interface of a River.* Proceedings of the Ground-Water/Surface-Water Interactions Workshop, EPA/600/R-04/027, pp. 23-30.

Department of the Army, 2008. *Letter, Subject: SCW-2R Well Replacement, Propellant Burning Ground.* December 22.

Gotkowitz, M.B. and Zeiler, K.K., 2005. *Water-Table Elevation Map of Sauk County, Wisconsin.* Wisconsin Geological and Natural History Survey, Miscellaneous Map 54-DI.

Gotkowitz, M.B., Zeiler, K.K., Dunning, C.P., Thomas, J.C., and Lin, Y.F., 2005. *Hydrogeology and Simulation of Groundwater Flow in Sauk County, Wisconsin.* Wisconsin Geological and Natural History Survey, Bulletin 102.

Hindall, S.M. and Borman, R.G., 1974. *Water Resources of Wisconsin Lower Wisconsin River Basin.* Wisconsin Geological and Natural History Survey, Atlas HA-479.

Hanson, G.F., 1970. *Geology of the Baraboo District, Wisconsin.* Wisconsin Geological and Natural History Survey, Informational Circular Number 14. Madison, Wisconsin.

Olin Corporation, 1996. *Final Documentation Report For Soil Cover Construction, Racetrack And Thermal Treatment Unit Closure, Badger Army Ammunition Plant. October.*

Olin Corporation, 1999. *1949 Pit Phase One Cap, Final Construction Report, Badger Army Ammunition Plant. January.*

Olin Corporation, 2000 to 2004. *Groundwater Narrative Summary Reports, Badger Army Ammunition Plant.*

Saul, M.T. and Janssen, J.L., 2008. *Sustainable Remedial Alternative Evaluation – Treatability Study of DNT Bioaugmentation at the Badger Army Ammunition Plant.* CL Solutions, LLC, and SpecPro, Inc.

Shaw Environmental, Inc., 2004. *Draft Preliminary Groundwater Investigation Report, Southern Boundary Groundwater, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. April 26.

Shaw Environmental, Inc., 2005. *January 2005 Field Activities Technical Memorandum – Propellant Burning Ground, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. June 6.

Shaw Environmental, Inc., 2005. *Draft Groundwater and Soil Investigation Report, Water's Edge Development, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. August 5.

Shaw Environmental, Inc., 2005. *Draft Southern Boundary Groundwater Phase II Investigation Report, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. March 28.

Shaw Environmental, Inc., 2005. *Draft Technical Memorandum Performance Assessment and Recommended Disposition of the Biologically Enhanced Subsurface Treatment System, Propellant Burning Ground, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. November 14.

Shaw Environmental, Inc., 2006. *Draft Alternative Feasibility Study, Propellant Burning Ground Waste Pits Subsurface Soil, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. April 6.

Shaw Environmental, Inc., 2006. *Draft Corrective Measures Implementation Report, MIRM Extraction Well Realignment Project, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. April 10.

SpecPro, Inc., 2004 to 2010. *Groundwater Narrative Summary Reports, Badger Army Ammunition Plant.*

SpecPro, Inc., 2004 to 2010. *Annual Cap and Cover Reports.*

SpecPro, Inc., 2008. *Dinitrotoluene Sources Remedial Investigation Report, Badger Army Ammunition Plant.* March.

SpecPro, Inc., 2009. *Construction Documentation Report, Propellant Burning Ground Phase 2 Cap Construction, Badger Army Ammunition Plant.* February.

SpecPro, Inc., 2009. *Northeast Boundary Groundwater Investigation Report, Badger Army Ammunition Plant.* December.

SpecPro, Inc., 2010. *Letter Report, Subject: EW-170R Well Replacement, Modified Interim Remedial Measures (MIRM).* July 29.

Stone and Webster, Inc., 2000. *Estimated Mass of Compounds of Concern in Groundwater, Badger Army Ammunition Plant.* March 13.

Stone and Webster, Inc. 2002. *Draft Alternative Feasibility Study – Deterrent Burning Ground Waste Pits Subsurface Soil, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. April 24.

Stone and Webster, Inc., 2003. *Draft Groundwater Investigation Report, Deterrent Burning Ground, Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. January 3.

Stone and Webster, Inc., 1999. *Draft Technical Report, Natural Attenuation Screening Study, Propellant Burning Ground, Badger Army Ammunition Plant.* August 25.

Sverdrup Environmental, Inc., 1997. *Final Documentation of Construction and Completion for Modified Interim Remedial Measures System at the Badger Army Ammunition Plant.* Prepared for United States Army Corps of Engineers. May.

T N and Associates, Inc., 2000. *Technical Memorandum: Groundwater Flow Model for the Propellant Burning Ground, Badger Army Ammunition Plant.* March.

T N and Associates, Inc., 2001. *Technical Memorandum: Solute Transport Modeling for the Badger Army Ammunition Plant Propellant Burning Ground.* April.

Tsai, S.Y., Benioff, P.A., Chiu, S.Y., and Quinn, J.J., 1988. *Master Environmental Plan for the Badger Army Ammunition Plant.* Prepared for the U.S. Army Toxic and Hazardous Materials Agency. Argonne National Laboratory.

United States Army Corps of Engineers, Omaha District, 2009. *Five-Year Review Report Deterrent Burning Ground, Badger Army Ammunition Plant.* Prepared for Base Realignment and Closure Division, United States Army Environmental Command. January.

United States Army Toxic and Hazardous Materials Agency, 1989. *Decision Memorandum for an Interim Remedial Measures Plan at Badger Army Ammunition Plant Propellant Burning Grounds.* February.

United States Environmental Protection Agency, 1999. *Directive Number: 9200.4-17P, Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.* Office of Solid Waste and Emergency Response. April 21.

Wisconsin Department of Health and Family Services, 2008. *Letter, Subject: Interim Drinking Water Health Advisories for meta-, ortho- and para- nitrotoluene, nitrobenzene, and 2-amino-4,6-dinitrotoluene.* January 16.

Wisconsin Department of Health Services, 2011. *Health Advisory for Amino Nitrotoluenes in Groundwater.* July.

Wisconsin Department of Natural Resources, 1987. *Letter, Subject: Final Review of In-Field Conditions Report at the Badger Army Ammunition Plant (BAAP), Sauk County.* September 14.

Wisconsin Department of Natural Resources, 1995. *Letter, Subject: Plan Modification of the September 14, 1987, In-Field Conditions Report Approval: Approval of Corrective Measures Selected in the Final Feasibility Study Report/Corrective Measures Study Report for the Badger Army Ammunition Plant.* June 1.

Wisconsin Department of Natural Resources, 2002. *Letter, Subject: Final Determination of Remedy for the Deterrent Burning Ground.* October 14.

Wisconsin Department of Natural Resources, 2007. *WPDES Permit No. WI-0043975-05-0, Badger Army Ammunition Plant. (Effective July 1, 2007, through June 30, 2012).* June 29.

Wisconsin Department of Natural Resources, 2008. *Letter, Subject: Final Determination of Remedy for Propellant Burning Ground Waste Pits Subsurface Soil.* March 17.

Wisconsin Department of Natural Resources. 2010. *Drinking Water System Public Water Supply Systems Website.* [illegible]

Wisconsin Department of Natural Resources, 2010. *Letter, Subject: Request to Terminate Operation of MIRM Vapor Phase Final Treatment Carbon Adsorption Units and Heaters (approval).* April 8.

Wisconsin Department of Natural Resources, 2010. *Addressing Vapor Intrusion at Remediation & Redevelopment Sites in Wisconsin, PUB-RR-800.* December 16.

Woodward-Clyde, 1995. *Groundwater Modeling Technical Memorandum.* January.

Technical Memorandum – Progress Update

Groundwater Flow and Solute Transport Modeling

Badger Army Ammunition Plant, Baraboo, Wisconsin

September, 2011

Introduction

Discussed in this memo are the findings from additional groundwater flow and contaminant transport modeling performed in support of the Alternative Feasibility Study (AFS) Report completed for the Badger Army Ammunition Plant (BAAAP) site. BAAAP is a former industrial installation located in south-central Wisconsin, approximately 9 miles south of Baraboo and 30 miles northwest of Madison **(Figure 1)**.

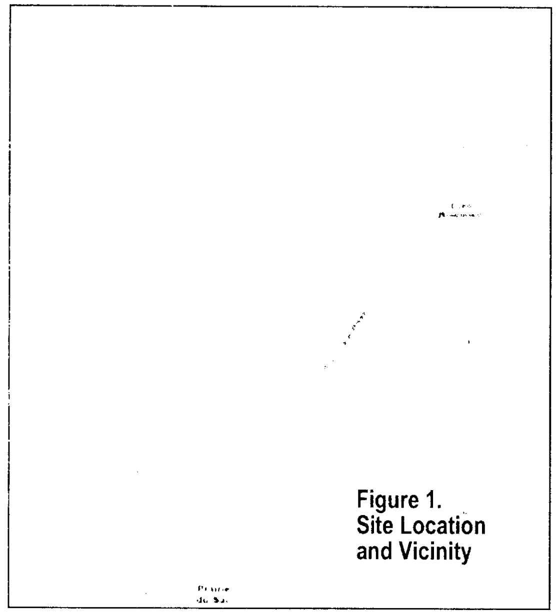


Figure 1. Site Location and Vicinity

Several modeling projects have been completed in support of the AFS Report prepared for BAAAP (April, 2011). This includes recent modeling analyses completed in April 2011 for three areas known to have been affected by prior site operations – the Propellant Burning Ground (PBG), the Central Plume Area and the Deterrent Burning Ground (DBG)[1]. The contaminants of concern identified are carbon tetrachloride (CTET) at the PBG, and dinitrotoluene (DNT) at the PBG, Central Plume Area and the DBG.

The current modeling was performed to supplement hydrogeochemical evaluations as well as other models developed for BAAAP. The information contained herein is supplemental to the AFS Report and should be reviewed in this context.

Site Conceptual Model

The site conceptual model describes the physical geologic and hydrologic conditions understood to exist in the area of the BAAAP site and forms the basis for the numerical models developed to predict groundwater flow and contaminant transport conditions at the site. This includes: (1) the site-wide (regional) steady-state model update, (2) steady-state sub-models created for the PBG, Central Plume Area and DBG; (3) local and regional historical transient models; and (4) local and regional predictive transient models. The site conceptual model included throughout this modeling effort is based on numerous studies conducted at BAAAP (and the surrounding area) over the past decades, including extensive field investigations and on-going long-term water level monitoring. Described in the following sections is the conceptual understanding of the surface and groundwater system in the project area as it relates to historical and predictive groundwater flow and contaminant transport model development and analyses.

Outwash Gravel Aquifer

The BAAAP site lies within a thick glacial outwash sequence, comprised predominantly of intermixed sequences of well-graded to poorly-graded sands (SW-SP) that are locally more silty (SM). Locally, coarser-grained, well-graded to poorly-graded gravel (GW-GP) layers are present within the outwash sequence. At the DBG, discontinuous fine-layers of fine-grained glaciofluvial sediment consisting predominantly of silt (ML) and clay (CL) occur above the water table.

[1]Prior modeling efforts completed by others (ABB-Environmental Services, Inc., 1993; Woodward-Clyde, 1995; T N & Associates, Inc. (2000); and the Shaw Group, Inc. (2006). The most recent version of the groundwater flow model (April, 2011) included further refinements to the Shaw model and the use of more recent groundwater monitoring data. Separate groundwater flow and contaminant transport models were subsequently developed for the PBG, DBG and Central Plume areas.

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The water table ranges from about 740 feet above mean sea level (amsl) in the southern part of the BAAAP site to around 825 feet amsl in the northwest. The soil materials at and below the water table are similar to those reported above, consisting predominantly of separate or intermixed layers of sand and gravel. Gravel lenses appear to occur more frequently just above bedrock.

Bedrock geology at BAAAP is dominated by Cambrian-age sandstones, with some metamorphosed Precambrian granites and rhyolites. The Baraboo Range to the north and west of BAAAP contain Precambrian quartzite conglomerates and sandstones that are part of the Baraboo syncline, which rises some 500 feet above the BAAAP site at its north end. The bedrock surface dips steeply towards the south, where soil deposits quickly thicken to a maximum of 250 feet. Along the north boundary of the BAAAP site, soil deposits are thin or absent, and quartz and sandstone outcrops are common. A Precambrian quartzite occurs at the base of the hills, along the north boundary of BAAAP. South of the Baraboo Range the quartzite surface dips steeply towards the south, and is underlain unconformably by Cambrian fine to medium sandstones with minor amounts of limestone and shale. A steep hydraulic gradient (0.11 ft/ft) has been reported to occur in this area.

Further review of geologic cross-sections, maps depicting the top of the water table, hydraulic conductivity data, aquifer test results, and other data was performed to assess whether distinct hydrostratigraphic units were present at the site. Prior models used as many as six layers to represent site stratigraphy. The basis for such subdivision was not clear however, since no obvious characteristics to separate the outwash sequence was noted (other than a general coarsening of grain-size with depth).

The upper model layer(s) used in prior models dewatered and/or did not extend across the site. Based on these findings, it was determined that a model depicting four glacial outwash units (layers) at the site was sufficient to represent site geology. The relative relationship and characteristics of each model layer are presented in **Table 1**.

Table 1. Model Layers, Bottom Elevations and Soil Types for the BAAAP Model

Layer	Depth Interval	Soil Type and Other Related Information	Ave. Kh* (cm/sec)
1	>740 feet amsl	Dominated by glacial outwash comprised of well to poorly-graded (SP) and well-graded sand (SW). Some loess occurs locally in upper part of soil profile as discontinuous fine-grained silt and clay (ML, CL). Fine (ML, CL) glaciofluvial material was reported from 763.6 to 775.3 feet amsl at the DBG. The water table ranges from around 740 feet amsl (south) to 825 feet amsl (northwest).	4.34E-02
2	700-740 feet amsl	Glacial outwash. Predominantly SW, SP. Some well-sorted (GW) to poorly-sorted (GP) gravel units are also present locally	5.21E-02
3	660-700 feet amsl	Glacial outwash. Predominantly SW, SP. Some gravel units are also present (GW, GP).	1.90E-02
4	Top of Bedrock to 660 feet amsl	Glacial outwash. Predominantly SW, SP. Some gravel units are also present (GW, GP). Overall, the amount of gravel appears to increase with depth.	4.33E-02
	Bedrock	Late-Cambrian age bedrock of the Eau Claire formation underlies the glacial outwash at BAAAP and serves as a regional aquitard in the area. In general, the bedrock consists of fine- to medium-grained fossiliferous and dolomitic sandstone that is locally interbedded with argillaceous siltstone and silty mudstone.	

*Kh – average saturated hydraulic conductivity as determined through field testing (ABB ES, 1993)

During this model update, all hydrogeological and geochemical information has been referenced to depth rather than Layer as used in prior models. Hydraulic head data were referenced to the bottom of screen depth for site groundwater monitoring wells, and auto-assigned to the appropriate model layers. This reference system was employed to overcome inaccuracies resulting from well designations not corresponding to the proper model layer.

During the Remedial Investigation (RI) conducted by ABB-ES in 1993, slug tests were performed on monitoring wells across the BAAAP site. The RI report included saturated horizontal hydraulic conductivity (K_h) values obtained at 54 monitoring well locations. Based on this data, little difference in K_h is noted within the soils at BAAAP, except for a discontinuous, fine-grained layer encountered at the DBG. The K_h across all layers ranges from 1.90E-02 cm/sec (Layer 3) to 4.33E-02 cm/sec (Layer 4), with an average value (all layers) of approximately 4E-02 cm/sec. Aquifer pump tests were also performed at two extraction wells (EW-167, EW-169) in Spring, 2005. The results of this testing yielded a hydraulic conductivity value between 4.85E-02 and 9.60E-02 cm/sec. The K_h values obtained are consistent with the soil types encountered (well-sorted sand or sand/gravel, grading to poorly-graded sand).

Hydraulic conductivity data, along with other site and aquifer characterization was input into MODFLOW, a commonly used groundwater flow model developed by the U.S. Geological Survey (USGS) which uses the finite difference methods to solve flow equations in three dimensions. The computer code within MODFLOW consists of a structured package of independent modules that address features associated with a hydrologic system, including rivers, drains, wells, recharge and evapotranspiration, as well as constant-head, general head and no-flow boundaries. Layers may be simulated as unconfined, confined, or a combination of both. In addition, groundwater flow patterns were evaluated using MODPATH, a particle tracking computer code that uses MODFLOW output to generate a set of pathlines from particles placed within the model domain.

The model interpolated distribution of Kh across the model domain is shown by Layer on **Figures 2a-d.** To achieve better results and sufficient heterogeneity for hydraulic conductivity distribution, numerous control ("pilot") points were inserted at locations within the model domain. Pilot points were placed: (1) between observation points adding greater density in those areas where more observations points were located; (2) in areas where the observed head gradient was steep; (3) between observation wells and head-dependent boundaries; and (4) at other locations as considered necessary to fill in gaps. Inverse modeling employed PEST, the automated parameter estimation code within MODFLOW. Regularization was applied as a homogeneity constraint during each PEST simulation to improve pilot point matching and add extra stability to the inversion process.

Surface Water Features and Groundwater Interaction

The BAAAP model domain lies within the Wisconsin River drainage basin, in southeastern Sauk County. The principal surface water drainage features within the basin include Otter Creek (west), Manley Creek (northeast) and the Wisconsin River (east, southeast and south). The north and northwest sides of the basin are defined by coexisting surface and groundwater divides that extend along the south side of the Baraboo Hills. A groundwater high in the water table elevation and steep groundwater gradients occurs just northwest of the BAAAP model domain.

The direction of regional shallow groundwater flow in the northern part of the basin is generally towards the south and southeast across the model domain. Hydraulic gradients within the water table aquifer flatten further south and southeast towards the Wisconsin River. A component of groundwater within the northeastern portion of the BAAAP site is directed towards the east, with groundwater flow elsewhere flowing towards the Wisconsin River (south and southeast).

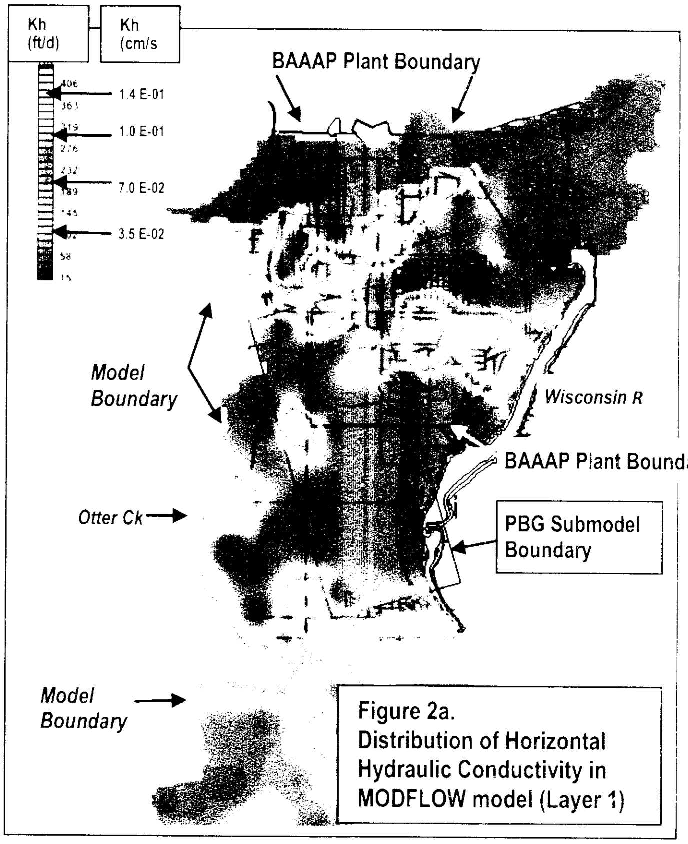

Figure 2a.
Distribution of Horizontal Hydraulic Conductivity in MODFLOW model (Layer 1)

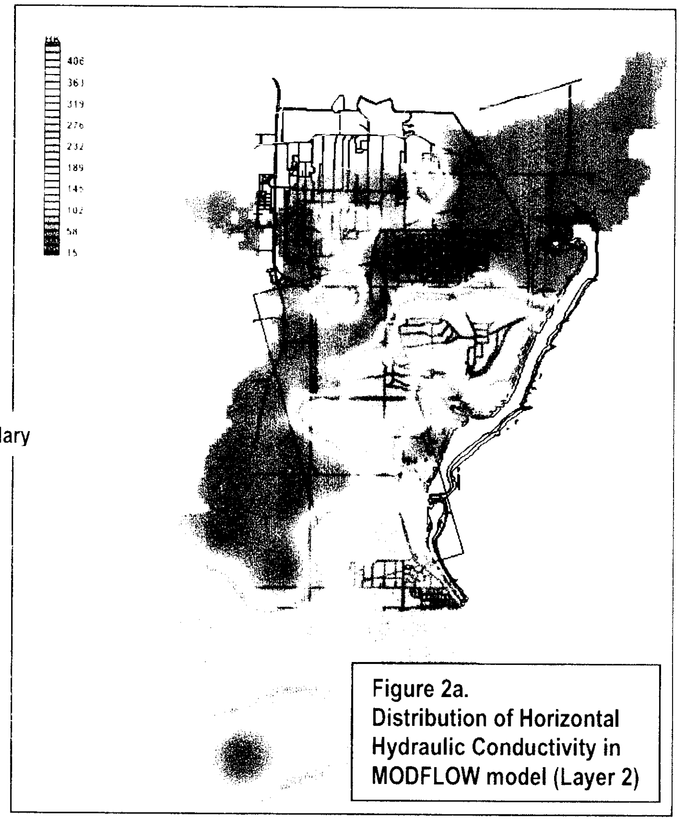

Figure 2a.
Distribution of Horizontal Hydraulic Conductivity in MODFLOW model (Layer 2)

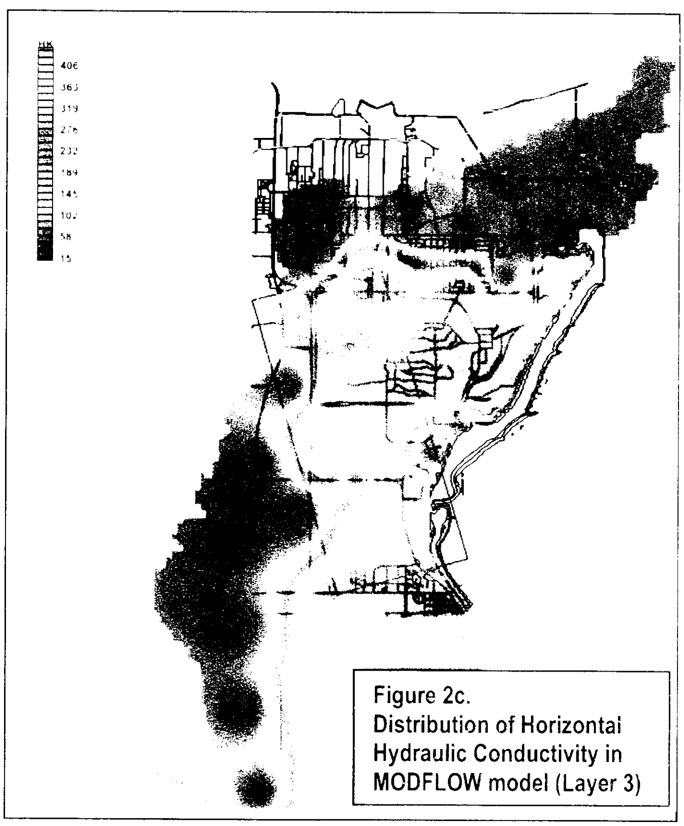

Figure 2c.
Distribution of Horizontal Hydraulic Conductivity in MODFLOW model (Layer 3)

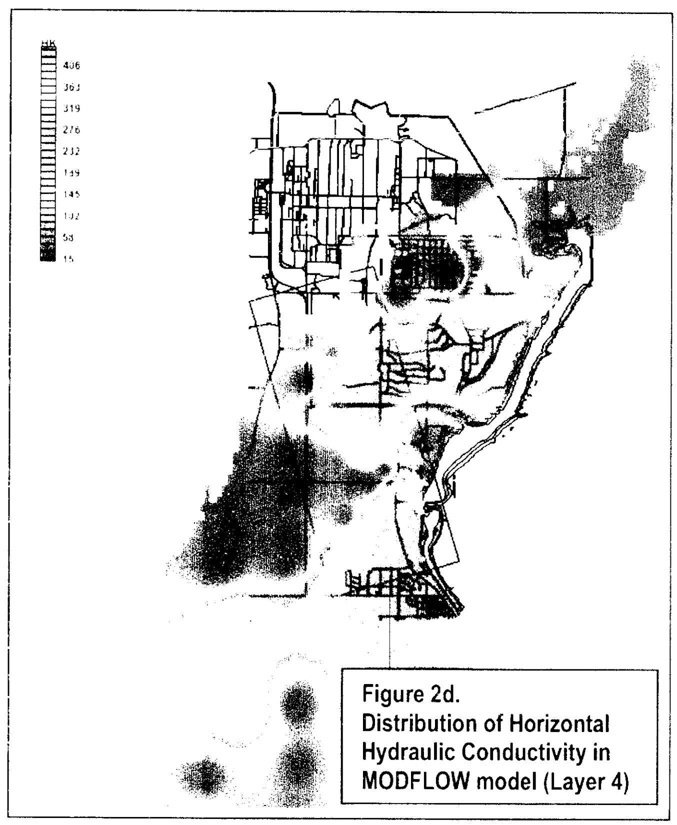

Figure 2d.
Distribution of Horizontal Hydraulic Conductivity in MODFLOW model (Layer 4)

Completed in 1924, the Wisconsin Power and Light (P&L) dam impounds the Wisconsin River north of Prairie du Sac, forming the Lake Wisconsin Reservoir. Records available from Alliant Energy (owner of Wisconsin P&L) indicate that the head water level above the hydroelectric power dam (north) is 774.3 feet NGVD, with a tail water level of 734.9 feet NGVD. While total flow rates exceeding 12,000 CFS have been reported for this impoundment, the total flow on July 18, 2011 measured 4,620 CFS. The Wisconsin River is believed to be hydraulically connected to groundwater in the outwash. Relatively flat gradients in the vicinity of the Wisconsin River are interpreted to represent the hydraulic connection between the groundwater and surface water systems.

The water sources to the groundwater system include a combination of direct precipitation, infiltrating surface water, and groundwater inflow. Local wetlands act as sources of recharge to groundwater when surface water elevations are higher than groundwater elevations, and groundwater discharges to the surface water occur when groundwater elevations are higher than surface water. Groundwater also enters the project area as regional groundwater inflow derived from upgradient recharge. Precipitation, flow between groundwater and surface water, and upgradient inflow are all included in the model.

Development of Transient Groundwater Flow Models for BAAAP

Model boundary conditions were reassessed from a hydrologic basin perspective that considered groundwater divide locations and resulted in the establishment of boundary conditions that provided relatively definitive head control for input into the model. As shown in **Figure 3**, model

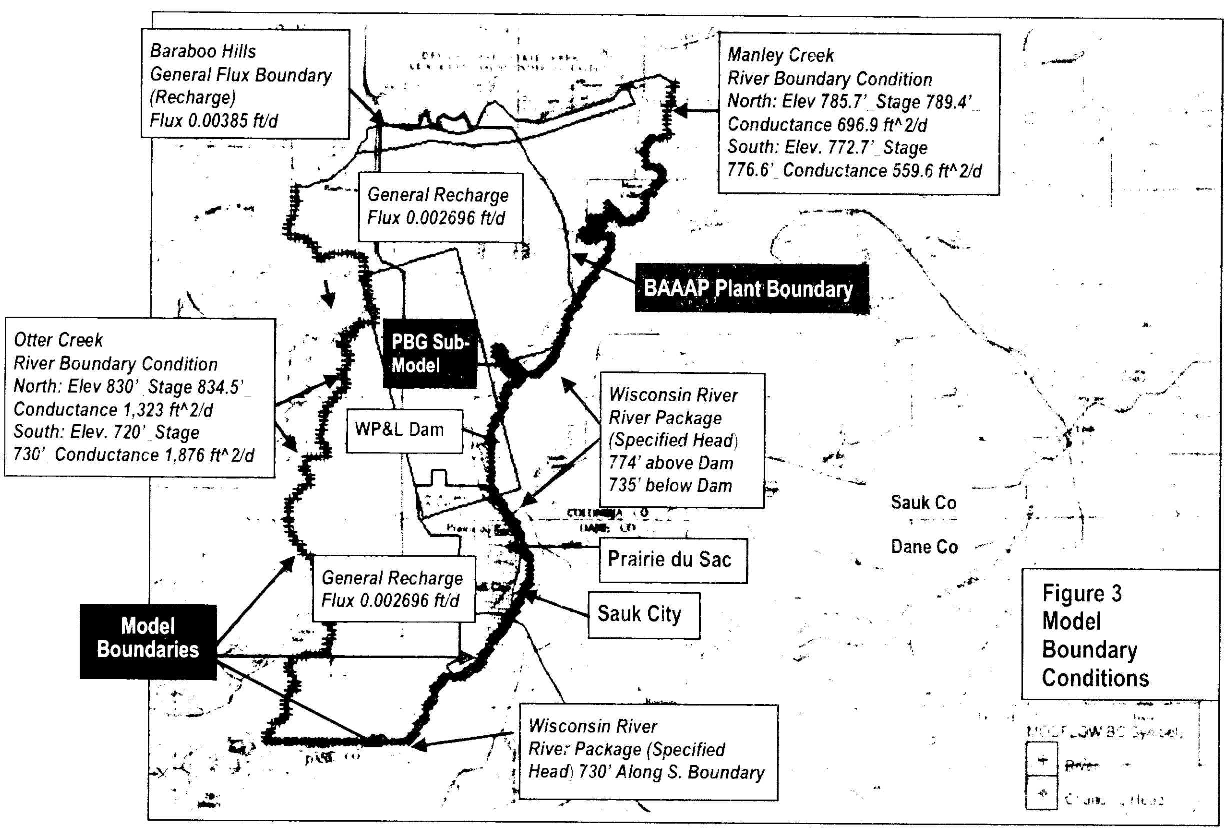

Figure 3
Model
Boundary
Conditions

boundaries are defined by Otter Creek (west), the Baraboo Hills (north) and the Wisconsin River (east, south). This approach was considered an improvement over previous models since head data from surface water features helped remove some of the ambiguity associated with defining model boundary conditions noted during prior modeling efforts.

The current modeling effort included reassessing model boundary conditions, available precipitation and recharge rates, hydraulic conductivity and a number of other factors. Substantial increases in the average precipitation rate recorded over four of the past five years have locally affected the magnitude and direction of groundwater flow at BAAAP. Such conditions necessitated the development of a transient numerical model capable of depicting such conditions. The transient model also provided BAAAP with a tool to assess the likely affect that shutting down the existing Interim Remedial Measures/Modified Interim Remedial Measures (IRM/MIRM) groundwater pump and treat system would exert on local groundwater flow and contaminant transport at the PBG.

The transient MODFLOW models developed for this project were derived from a calibrated regional steady-state model, prepared as an update to prior models. The regional steady-state MODFLOW model is not discussed in further detail in this memo since the focus of the current effort was to develop transient models that could be used to assess how variations in the local hydrologic flow regime would affect groundwater flow pathways and contaminant transport.

Transient model development began with the input of hydrogeological parameter data, including precipitation and recharge data from 1988, 1989, 1993, 1995, 2007 and 2010 into the regional steady-state model. This task was followed by calibration of the transient flow model. The calibration procedure consisted of conducting backward model simulations using PEST, followed by an evaluation of precipitation, recharge and specified flow rates over the historical data period (1988-2010) to assess reasonableness. To assist with model interpolation, pseudo-wells were added to the model domain at a few locations in this area (and other locations) where data gaps in head information existed. Forward MODFLOW simulations were then performed to record the sensitivity of the model to changes in input parameters and assess the residual mean square (RMS) error associated with model calibration. The RMS error values obtained verified model calibration.

The reassessment of the initial MODFLOW model boundary conditions included an evaluation of precipitation and recharge. On average, 30-32 in/year of precipitation falls on the ground surface in Sauk County, with only 25-30 percent (9.6 inches) remaining as surface water. Of this amount, some infiltrates to the groundwater while some flows as runoff to streams or drainages. During this modeling effort, it was assumed that 25% of the available water (2.4 inches) infiltrates to the groundwater system.

Specified flow boundaries were assigned to represent water pushing into the model from the north and west sides of the model. The amount of water entering the model was estimated by dividing the contributed area for each arc, with each contributing area being defined by surface water divides located in the basin[2].

Thirty-five (35) percent of the available precipitation (3.4 inches) was applied to each contributing area as an initial estimate of potential recharge amounts entering the model area. Comparison of precipitation, recharge and specified flow data were adjusted to the appropriate rates for each year. Presented in **Table 2** are the precipitation and recharge rates associated with each year included in transient model development. The RMS associated with each data set is also included, along with generalizing bounding assumptions associated with model inflows.

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[2] Each surface water divide was generally noted to coincide with the groundwater divides in this area (Gotkowitz and Zeiler, 2002)

Table 2. Precipitation Amounts and Estimated Recharge for the BAAAP Model Domain

Year	Precipitation (in/yr)	Recharge (in/yr)	RMS	Assumptions
1988	28.85	2.63	4.09	No flow in Otter Creek until it joins the Wisconsin River (south)
1989	26.06	2.38	3.13	No flow in Otter Creek until it joins the Wisconsin River (south)
1993	36.83	3.74	2.28	Not much flow in river, head stage only 0.5 ft above bottom elevation
1995	29.64	2.70	4.16	No flow in Otter Creek until it joins the Wisconsin River (south)
2007	44.02	7.54	1.37	Used 92% of assigned recharge (3.644 inches/yr)
2010	40.45	6.87	0.856	Used 50% of available recharge for the North area; 35% for the Main area; and 10% for developed (paved) areas

The RMS values obtained indicate fairly good agreement between the transient MODFLOW model predicted heads and field observed water level elevations indicating model calibration. Such a conclusion appears reasonable when considering that more than a couple feet variation in head elevation occurs seasonally at many well locations across the model domain.

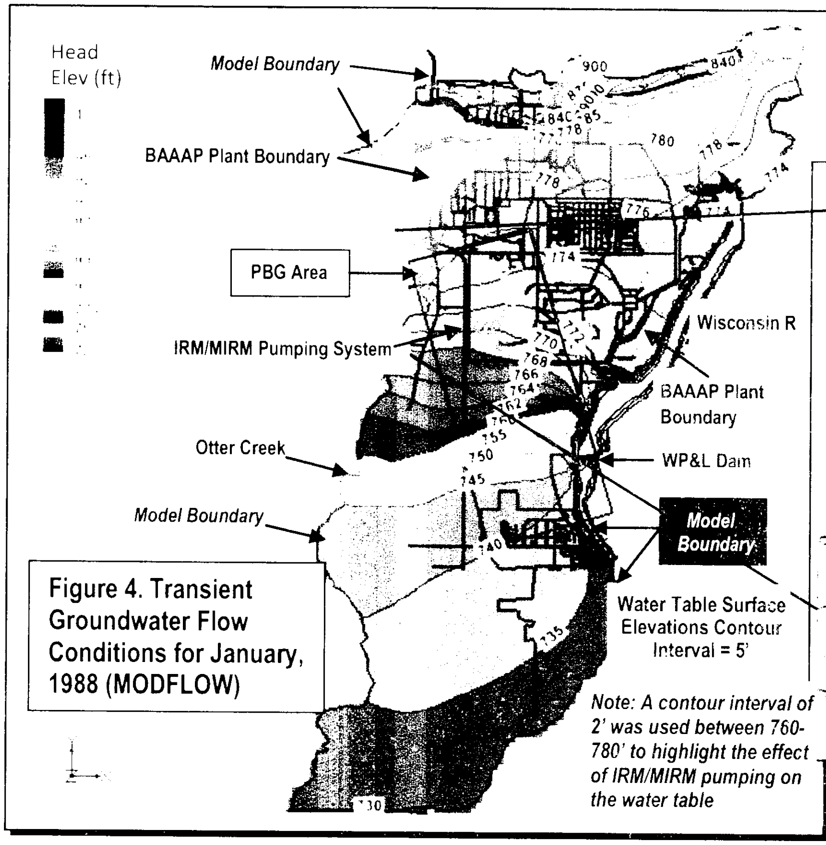
Presented on the following pages are depictions[3] of the historical groundwater elevation data as generated by the regional transient MODFLOW model **(Figures 4-9).** This information is followed by a presentation of transient MODFLOW model predicted results for the period from 2012-2050 **(Figures 10-15).** The same input parameters used for the historical predictive runs were used during the future predictive simulations.

In this modeling assessment, specific focus has been placed on illustrating the influence that the IRM/MIRM pumping system has historically exerted on groundwater flow patterns within the PBG. Through the model calibration process, this information has been used to help assess the potential effects that discontinuation of the IRM/MIRM pumping system at the PBG would exert on the local flow regime over the next forty years.

Provided later in this memo are transient model generated plots showing the possible distribution of DNT and CTET at the BAAAP site. The results obtained are based on the predictive calibrated transient groundwater flow models, and include source loading to reflect contaminant leaching from source areas at the PBG. Solute transport was evaluated by using MT3DMS, a modular 3D transport model within the Groundwater Modeling System (GMS) MODFLOW package. With MT3D, the effect of advection, dispersion and chemical reactions on dissolved constituents in groundwater can be simulated (Zheng, 1990).

[3] Note: Because no model solution is unique, all of the illustrations provided in this memo should be viewed as one possible example of how groundwater flow pathways and contaminant distribution may look over time.

Historical Transient Flow Simulations ; 1988-2010 (IRM/MIRM PUMPING ON)



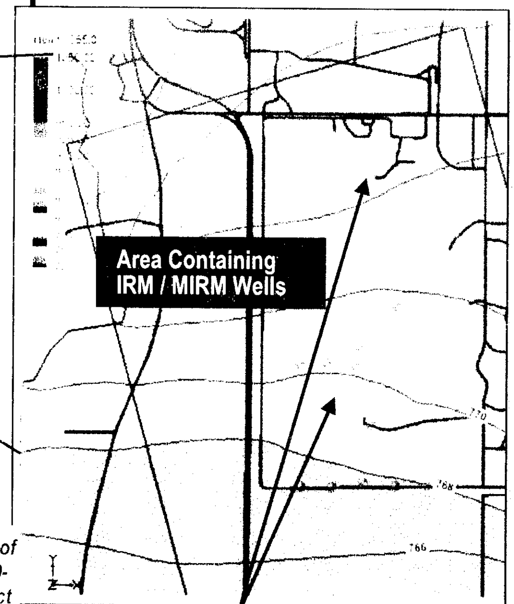
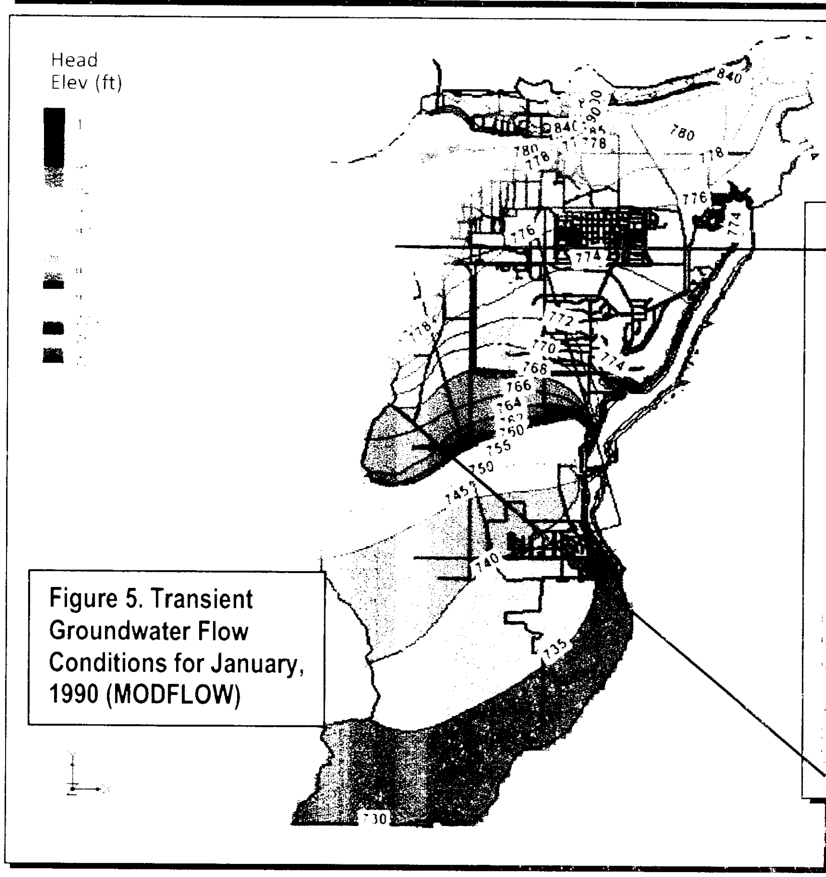


Figure 4. Transient Groundwater Flow Conditions for January, 1988 (MODFLOW)

Remarks: The IRM pumping system started up in June, 1990. It consisted of three boundary control wells and one source control well (a second source control well was installed in 1997). Little or no observable effect on the water table surface is shown in 1990.



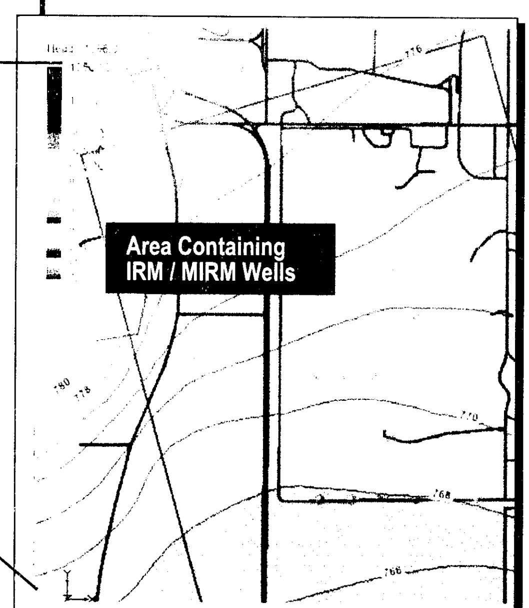
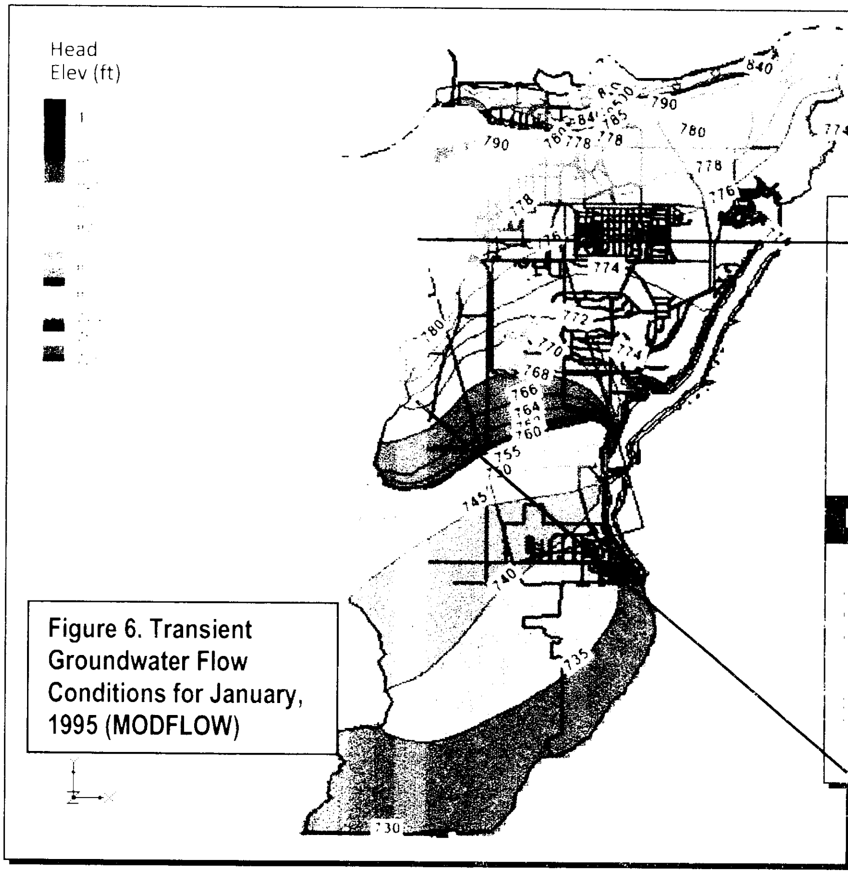


Figure 5. Transient Groundwater Flow Conditions for January, 1990 (MODFLOW)

Historical Transient Flow Simulations ; 1988-2010 (IRM/MIRM PUMPING ON)



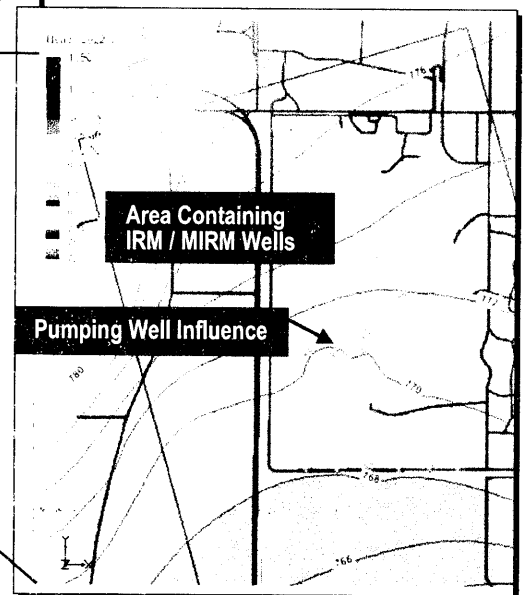
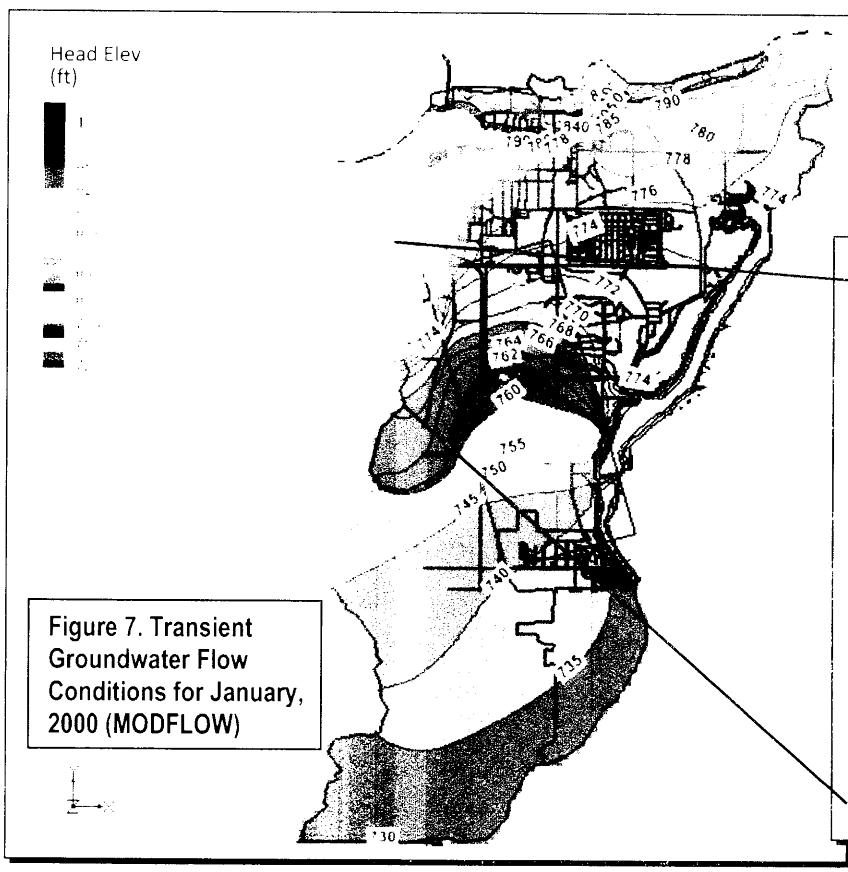


Figure 6. Transient Groundwater Flow Conditions for January, 1995 (MODFLOW)

Remarks: The MIRM was installed in 1995 w/pumping starting in June 1996. The MIRM realignment occurred in Sept 2004, with the system coming online in May 2005. Influence of pumping on the water table surface locally observed at the source control wells and at MIRM well locations.



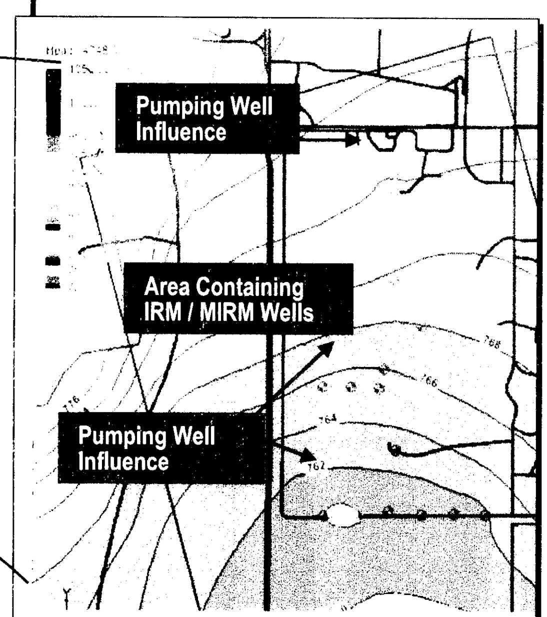


Figure 7. Transient Groundwater Flow Conditions for January, 2000 (MODFLOW)

Historical Transient Flow Simulations ; 1988-2010 (IRM/MIRM PUMPING ON)

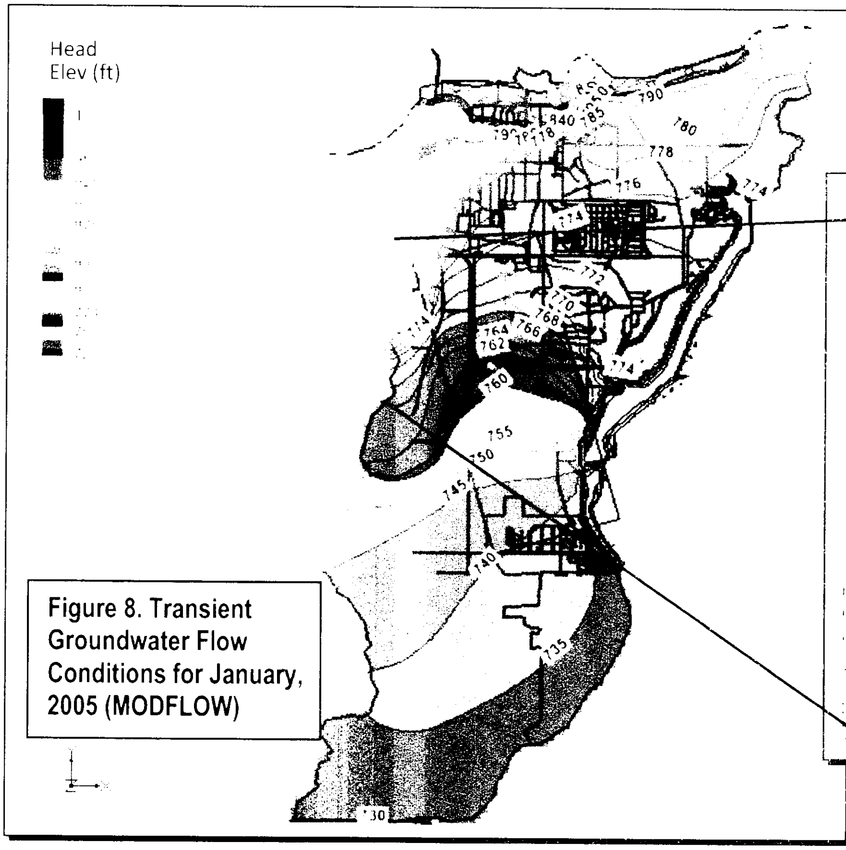
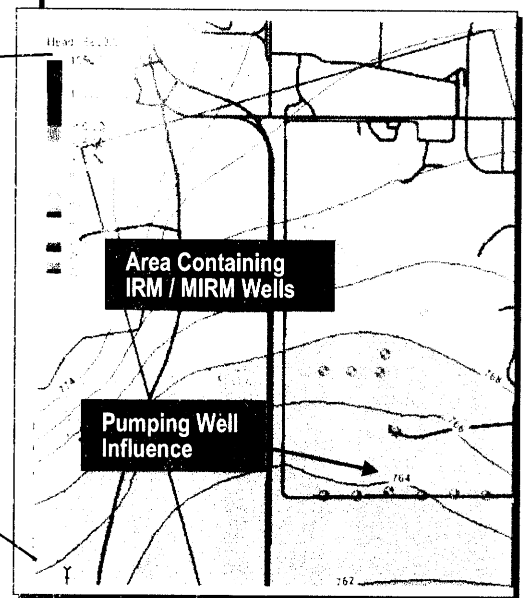


Figure 8. Transient Groundwater Flow Conditions for January, 2005 (MODFLOW)



Remarks: Increased water level elevations within the PBG in 2005. Little or no observable effect on water table elevations due to pumping. Below. Pumping influence is affecting water table elevations, especially near the center of the pumping field.

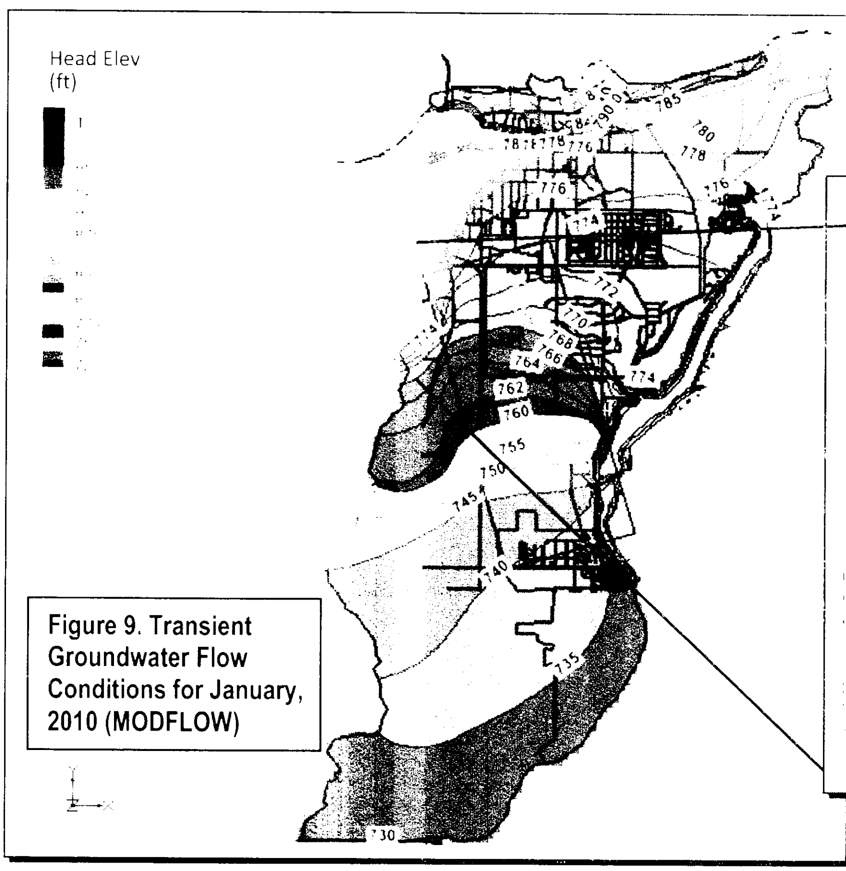
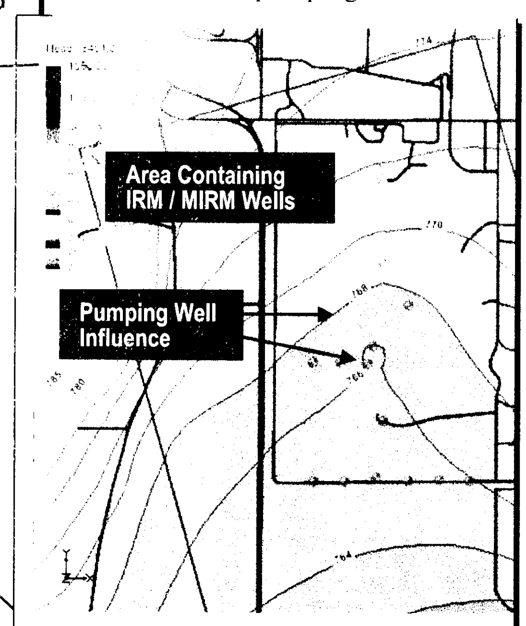


Figure 9. Transient Groundwater Flow Conditions for January, 2010 (MODFLOW)



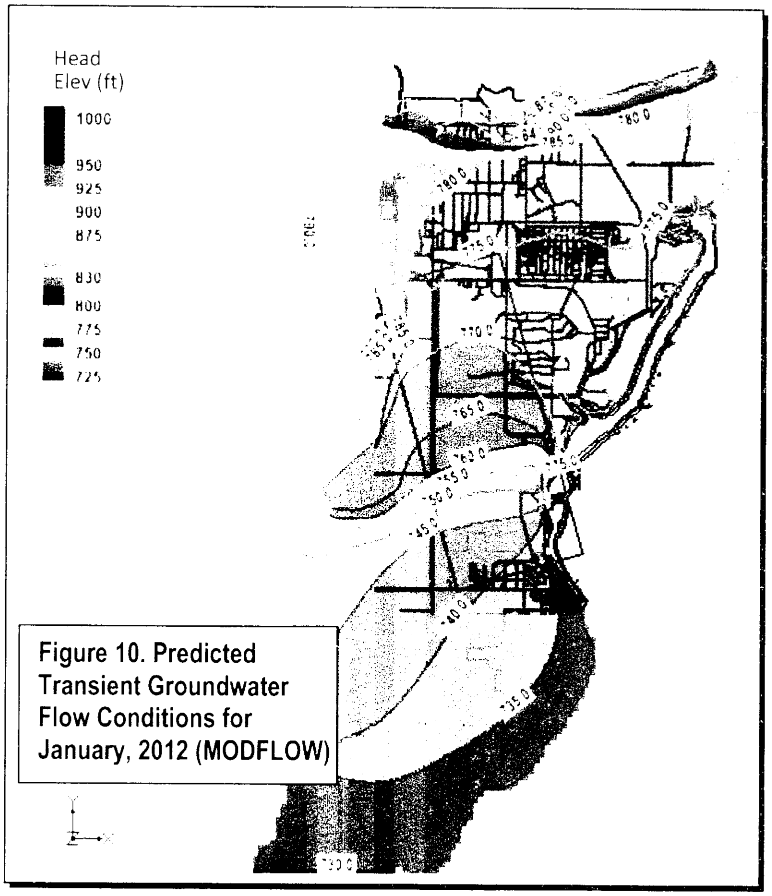


Figure 10. Predicted Transient Groundwater Flow Conditions for January, 2012 (MODFLOW)

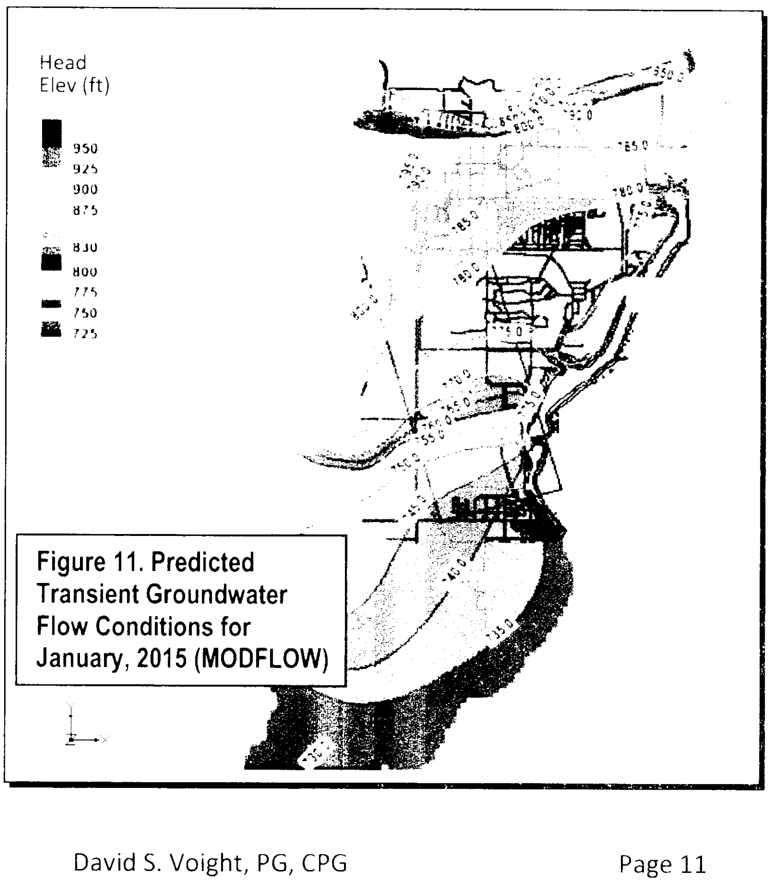


Figure 11. Predicted Transient Groundwater Flow Conditions for January, 2015 (MODFLOW)

Predictive Transient Simulations; 2012-2050 (NO PUMPING)

Depicted in **Figures 10-15** are the groundwater flow conditions as predicted by the transient model over a 40-year period (2012-2050).

The same input parameters used for the historical predictive runs were used during the future predictive simulations. The one notable difference is that the IRM/MIRM pumping system has been discontinued in all simulations.

Because no model solution is unique, the enclosed illustrations should be viewed as one possible example of how the flow field across the PBG area could change as the aquifer system recovers.

<u>Remarks</u>. Based on the transient model, increased water table elevations (on the order of 2-5 ft) can be expected to occur across the northern part of the PBG area between 2012 and 2015. This is not unexpected as the pumping system is discontinued and the aquifer recovers. The model also predicts higher water table elevations further south, although less change is noted (on the order of 2-3 ft).

Other observations:

- A steeping of the hydraulic gradient is noted in the vicinity of the WP&L dam between 2012-2015.
- Groundwater flow pathways within the MIRM pumping area has changed. The area of capture within the MIRM have given way to south and southeasterly flow within the shallow aquifer system.

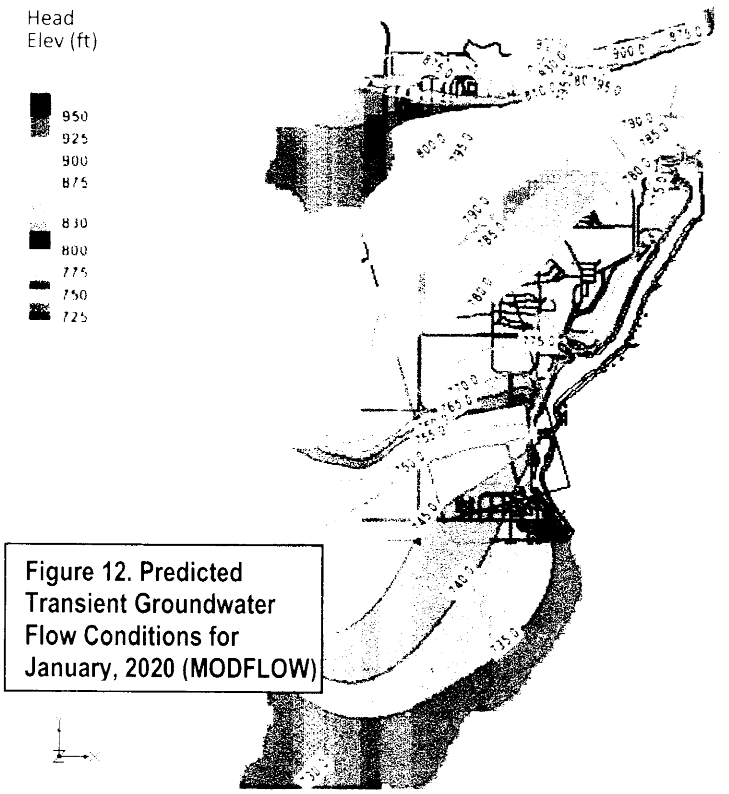


Figure 12. Predicted Transient Groundwater Flow Conditions for January, 2020 (MODFLOW)

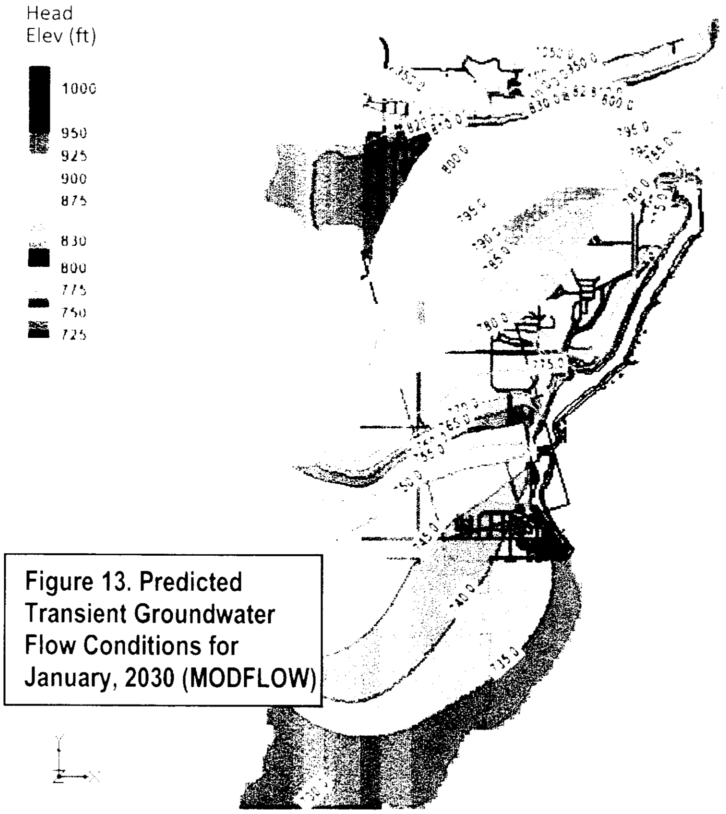


Figure 13. Predicted Transient Groundwater Flow Conditions for January, 2030 (MODFLOW)

Predictive Transient Simulations, 2012-2050 (NO PUMPING)

Remarks. The model predicts continued increases in the elevation of the water table surface over much of the northern half of the PBG area.

The direction of groundwater flow within the shallow aquifer system in 2020 is similar to that noted in 2015 – although there appears to be a trend towards more consistent southeasterly flow across the model domain. This pattern may even be more clearly exhibited by the model predicted simulation for 2030.

The 2030 model also continues to show the considerable effect that recharge along the northern boundary of the model is exerting on groundwater table elevations and groundwater flow pathways.

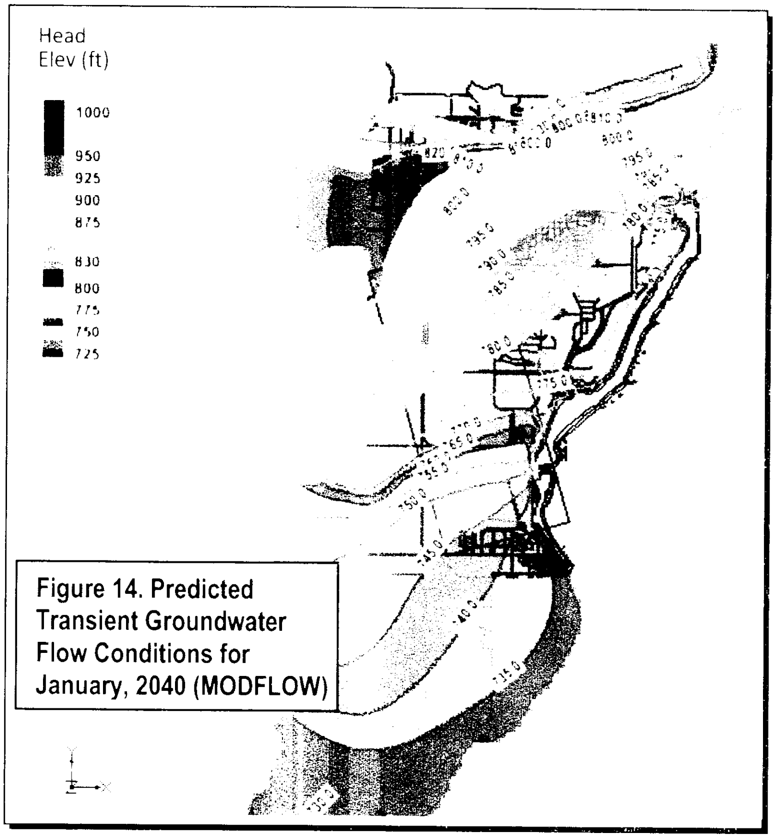


Figure 14. Predicted Transient Groundwater Flow Conditions for January, 2040 (MODFLOW)

Predictive Transient Simulations, 2012-2050 (NO PUMPING)

Remarks. The model predicts relatively little change in the elevation of the water table surface over the model domain between 2030 and 2040. Based on this depiction, little if any change can be expected in water table elevations or groundwater flow pathways between 2040 and 2050.

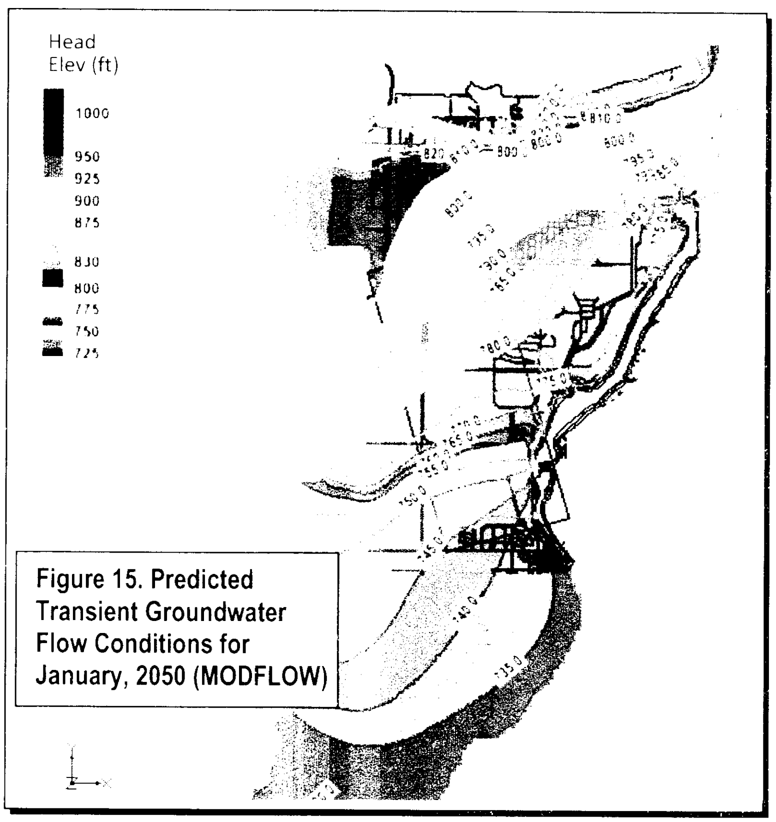


Figure 15. Predicted Transient Groundwater Flow Conditions for January, 2050 (MODFLOW)

Modeling of 2,4-DNT Occurrence at the BAAAP PBG

Historical 2,4-DNT concentrations measured in soil and groundwater at the PBG area were used to calibrate the following models:

1. Soil-water partition equation
2. SESOIL
3. MODFLOW-MT3D

The primary objectives associated with this effort were to: (1) use site-specific testing, literature data and SESOIL modeling methods to assess likely 2,4-DNT loading rates from soil to groundwater at the former PBG Waste Pit (WP) areas; (2) develop a transient groundwater flow and contaminant transport model capable of assessing historical 2,4-DNT fate and transport in groundwater; and (3) evaluate the likely effect that discontinuation of the IRM/MIRM pumping system would exert on 2,4-DNT concentrations and distribution.

SESOIL is a seasonal compartment model which simulates long-term pollutant fate and migration in the unsaturated soil zone (from the ground surface to the groundwater table). User provided inputs into SESOIL consider the hydrologic cycle of the unsaturated soil zone; pollutant concentrations and masses in water, soil, and air phases; pollutant migration to ground water; pollutant volatilization at the ground surface; and pollutant transport in washload due to surface runoff and erosion at the ground surface. SESOIL creates an output file which contains monthly results for hydrologic cycle components, pollutant mass distribution, and pollutant concentration distribution for each layer or sublayer. SESOIL also generates a file which contains pollutant mass-to-ground-water leachate quantities entering the aquifer from the unsaturated zone. This file can be input into the MODFLOW/MT3D groundwater flow and contaminant transport model for further analysis of aquifer and contaminant characteristics.

A key factor in assessing contaminant occurrence in the environment is the soil-water partitioning coefficient (Kd), which relates the amount of a specific chemical (contaminant) bonded to soil vs. the concentration of the same substance dissolved in water. The Kd for 2,4-DNT at the BAAAP site was estimated by:

$\mathbf{K_d\ (L/kg) \sim C_{gw}\ (mg/L)\ /\ C_{so}\ (mg/kg)}$, where

C_{gw} is the concentration of 2,4-DNT dissolved in water
C_{so} is the amount of 2,4-DNT sorbed to the soil

Field measured 2,4-DNT concentrations in soil and groundwater, along with laboratory analyzed total organic carbon (TOC) and literature values for the organic carbon absorption coefficient (Koc) were used to estimate Kd. Based on this approach, it was estimated that the Kd for DNT at the PBG area ranged from 0.0006 L/kg to 0.062 L/kg.

Three modeling scenarios were completed for assessing 2,4-DNT fate and transport at the PBG. An initial run (Baseline) was completed to assess contaminant characteristics prior to remediation being performed at the waste pit source areas. This was followed by a post-remediation scenario (Scenario 1) that considered the benefit associated with partial soil excavation (removal and off-site disposal of the upper 30 feet of soil within the source areas). The second post-remediation scenario (Scenario 2) considered soil excavation and the biologically-enhanced subsurface treatment (BEST) system that targeted the remediation of impacted soils to a depth of 60 feet. Under Scenarios 1 and 2, leachate concentrations at the water table were expected to decrease with time.

MODFLOW-MT3D was calibrated with IRM/MIRM and other historically measured groundwater data to determine future contaminant distribution if the existing IRM/MIRM pumping system was discontinued. The regional steady-state MODFLOW model, with a cell size of 400 ft x 400 ft was refined using the GW Vista Telescope Mesh Refinement (TMR) tool to a smaller cell size of 100 ft x 100 ft in order to better locate the waste pits and the engineered cover that was placed over this area of the BAAAP site. The steady-state model was then transformed into a transient model so the variable leachate concentrations from SESOIL runs performed at the waste pit locations could be input into MODFLOW-MT3D. The flux was estimated by comparing the simulated vs. measured 2,4-DNT concentrations in groundwater for the period from 2000 to 2005. The soil remediation activity completed between 1999-2007 and the capping that took place in 2008 were simulated in the MODFLOW-MT3D model by further decreasing the mass input into the system (biological treatment decreased 2,4-DNT concentrations, while the aforementioned capping decreased the flux).

Calibration of the SESOIL model was accomplished by assessing the concentration of 2,4-DNT predicted by the model at the bottom of the soil column vs. those actually observed.

SESOIL runs relying on measured soil distribution data (Kd ~ 0 L/kg) indicated that the amount of leaching to groundwater for 2,4-DNT was around 200,000 ug/L. A conservative dilution attenuation factor (DAF) of 10 would indicate that historical 2,4-DNT concentrations are approximately 20,000 ug/L. This value is consistent with the historical measured groundwater concentrations noted within the PBG waste pit source areas.

As shown below, the MODFLOW/MT3D runs (combined with SESOIL output) included a calibration run as well as forward model runs with and without the IRM/MIRM pumping:

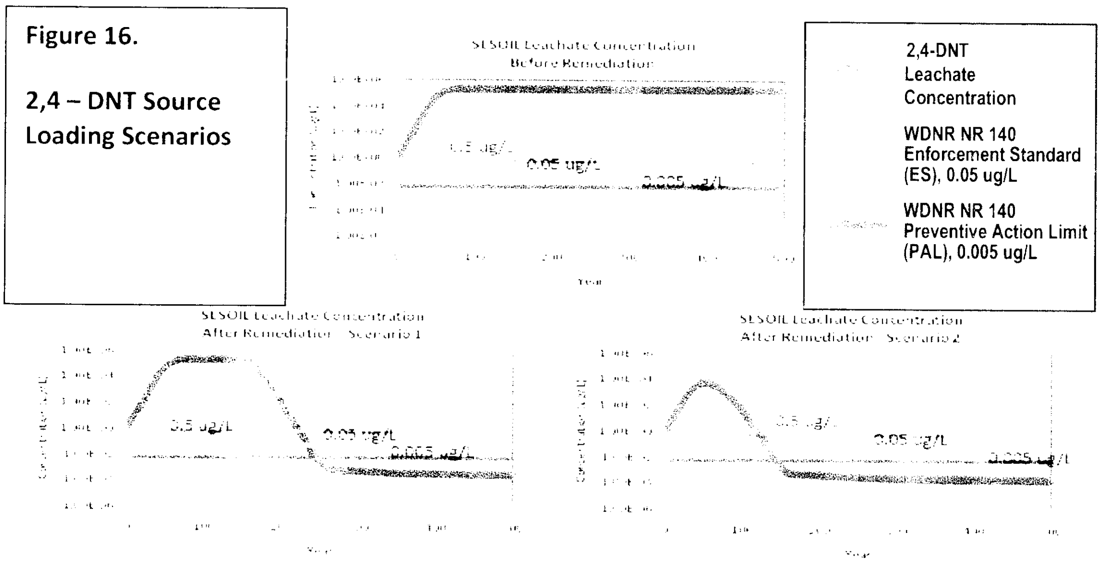
Timeframe	Model Setup
Baseline 1988 to 2007 Calibrated to 2000-2005 Concentrations	Variable Mass Loading from SESOIL–before remediation run (Baseline): IRM/MIRM pumping active
2008 to 2012–Forward run: w IRM/MIRM pumping	Variable Mass Loading from SESOIL–after remediation run (Scenario 1): IRM/MIRM pumping active; Capping–Infiltration in the Waste Pit (WP) Area–recharge 0 ft/day
2008 to 2012 Forward run: w/o IRM/MIRM Pumping	Variable Mass Loading from SESOIL–after remediation run (Scenario 2): IRM/MIRM pumping active; Capping–Infiltration in the WP Area–recharge 0 ft/day
2012 to 2052–Forward run: w/o IRM/MIRM Pumping	Variable Mass Loading from SESOIL after remediation run (Scenario 2): IRM/MIRM pumping discontinued; Capping–Infiltration in the WP Area–recharge 0 ft/day
Notes: Longitudinal dispersivity = 25'; Ratio of horizontal transverse dispersivity to longitudinal dispersivity=1; Ratio of vertical transverse dispersivity to longitudinal dispersivity= 0.5; Kd ~ 0 L/kg; Does not include the effects of chemical or biological degradation	

The developed transient model used for the MODFLOW/MT3D runs included no recharge (infiltration) within the Waste Pit area and evaluated 2,4-DNT occurrence under pre-remediation and post-remediation conditions. The predictive transient model (2012 –2050) was used to evaluate the effect that discontinuation of the IRM/MIRM system would have on 2,4-DNT distribution.

Comparison of SESOIL leachate concentrations for 2,4-DNT under pre-remediation and remediation scenarios are shown in **Figure 16.** For future reference, the concentrations obtained are compared to Wisconsin Department of Natural Resources (WDNR) groundwater quality standards given in Chap NR140, Wis. Adm. Code. SESOIL runs performed under the no remediation scenario indicate that the concentration of 2,4-DNT will likely remain fairly constant at the Waste Pit source areas for a long period of time (>500 years). Partial excavation and removal of the most impacted soil in combination with operation of the BEST system (Scenario 2) has reduced the time for the 2,4-DNT concentrations at the source area to reach acceptable groundwater quality standards[1] (< 150 years). These estimates should be considered conservative however, since no soil degradation was considered. Bench-scale treatability studies performed on DNT-containing soils obtained from other locations at BAAAP indicate that the potential for the degradation of 2,4-DNT (and other DNT isomers) exists (Nishino, et. al., 2005).

Figure 16.

2,4 – DNT Source Loading Scenarios



MODFLOW/MT3D runs using the loading concentrations from SESOIL were performed on the transient model over the period from 2000 to 2005. The purpose of these simulations was to assess how the model predicted 2,4-DNT concentrations in groundwater compared to field observations obtained over the same time period. Contaminant source loading of 2,4-DNT into SESOIL has been based on the 2005 soil investigation study completed by Shaw for the PBG Waste Pit areas. Time series plots showing the model predicted distribution of 2,4-DNT in groundwater over time were then developed. Calibration of the SESOIL model consisted of comparing the loading concentrations for 2,4-DNT, relative to those observed in groundwater. Historical model runs showed a relatively poor comparison between the calibration results and real data. Future predictive runs were made but they were not accurate. This appears to be due to the present model inputs being overly conservative. Further assessment of contaminant dispersion and the use of the MT3D chemical reaction package to simulate degradation processes in the natural environment is anticipated to result in a transient model for DNT that better calibrates to historical conditions and more likely represents future conditions.

Modeling of CTET Occurrence at the BAAAP PBG

Historical CTET concentrations measured in soil and groundwater at the PBG area were used to calibrate the transient (non-pumping) MODFLOW/MT3D model developed for this contaminant of concern. Site-specific testing data and literature values obtained from prior investigation conducted at the PBG were used to develop likely CTET loading rates from soil to groundwater at the former PBG Waste Pit areas (SESOIL modeling was not employed for CTET). As was the case with 2,4-DNT, the transient model was developed to further evaluate the likely effect that discontinuation of the IRM/MIRM pumping system would exert on CTET concentrations and distribution.

CTET concentrations in soil and groundwater, along with laboratory analyzed total TOC and literature values for Koc were used to estimate Kd. Values entered into the chemical reaction package of MT3DMS consisted of bulk density and the first order sorption coefficient (linear isotherm). No other chemical or biological degradation processes were used.

Three modeling scenarios were completed for assessing CTET fate and transport at the PBG. An initial run (Baseline) was completed for 2010. This modeling was followed by the completion of MODFLOW/MT3D simulations that considered historical CTET concentrations over the period from 1988-2010 (IRM/MIRM pumping active). The final model scenario consisted of performing forward (predictive) runs from 2012-2050 (IRM/MIRM pumping discontinued).

Timeframe	Model Setup
1998 to 2012–Forward run; w/ IRM/MIRM pumping	Variable Mass Loading from Site Investigation Results; IRM/MIRM pumping active (as appropriate)
2012 to 2050–Forward run; w/o IRM/MIRM Pumping	Variable Mass Loading from Site Investigation Results; IRM/MIRM pumping discontinued.
Notes: Longitudinal dispersivity = 25; Ratio of horizontal transverse dispersivity to longitudinal dispersivity=0.2; Ratio of vertical transverse dispersivity to longitudinal dispersivity= 0.01; Kd ~ 0 L/kg; include the effects of some chemical degradation, but no biological degradation	

The transient MODFLOW/MT3D model developed to assess CTET fate and transport at the PBG was calibrated against historically measured groundwater data from 2000, 2002, 2007 and 2010. The regional steady-state MODFLOW model, with a cell size of 400' x 400' was refined to a smaller cell size of 150' x 150' in order to better locate the waste pits and engineered cover placed over this area of the BAAAP site. Initial model runs showed that the CTET contaminant plume extended beyond the boundary of the refined grid however, and therefore use of this refined model was abandoned.

The transient model simulations for CTET are based on the representativeness of the historical predictive model. With that said however, uncertainty remains regarding the actual source(s) of the CTET and the concentration that will be leached to groundwater over time. Groundwater CTET concentrations of 500 ug/L (Layer 1) and 100 ug/L (Layer 2) were used for the initial stress period (2012), with concentrations decreasing further over time. The values used for source loading are largely empirical and based on professional judgment. As with all numerical groundwater flow and solute transport models, assumptions made to address inherent uncertainties associated with the model may result in different findings than noted during this model assessment.

CTET groundwater concentrations and distribution as predicted by the developed transient model for the period from 2012-2050 are shown on **Figures 17-22**. These results compare favorably with field observed concentrations reported for 2010. Remarks are provided below.

Model simulations for 2012-2040 show continued lengthening and widening of the CTET plume over time. In the absence of pumping, groundwater flow patterns have changed within the PBG area. Under such conditions, predictive model simulations show that the CTET will tend to migrate more eastward, and further south towards Prairie du Sac. Over time, the model predicts that CTET

Predictive Transient Flow Simulations for CTET; 2012-2050 (NO PUMPING)

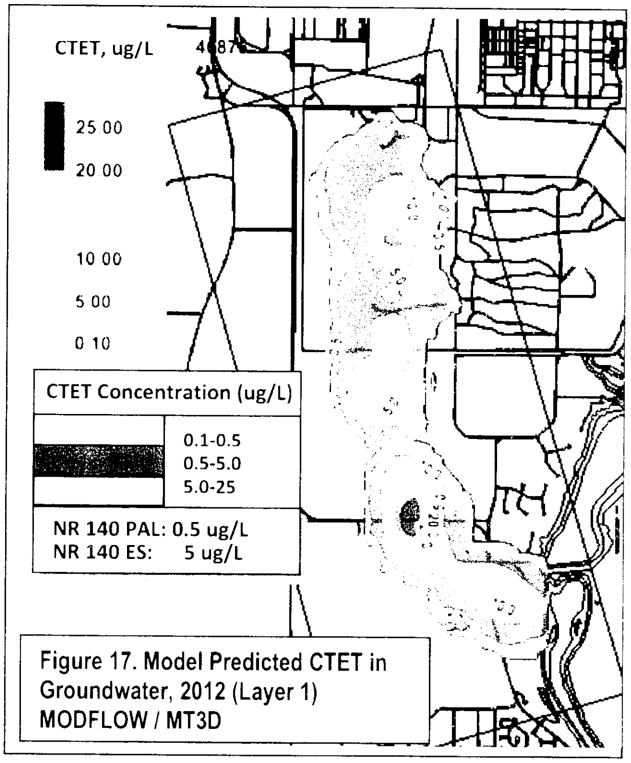


Figure 17. Model Predicted CTET in Groundwater, 2012 (Layer 1) MODFLOW / MT3D

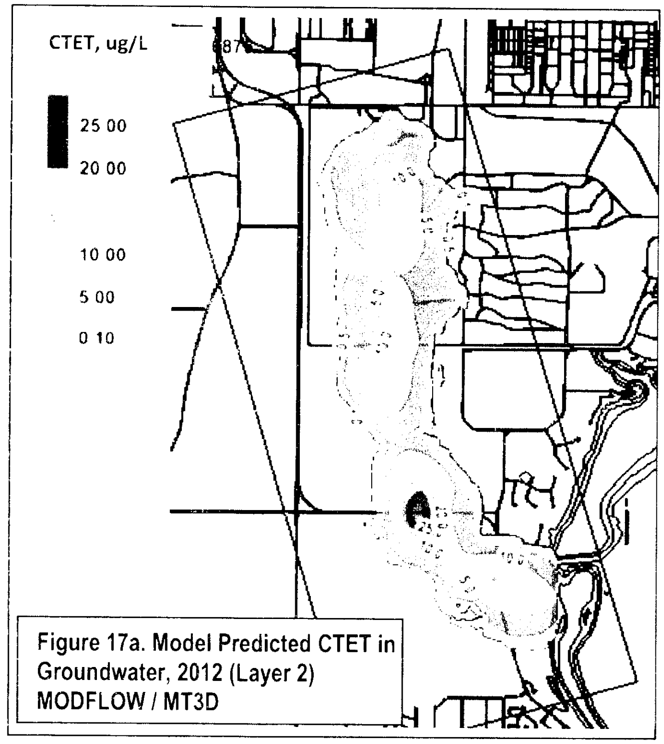


Figure 17a. Model Predicted CTET in Groundwater, 2012 (Layer 2) MODFLOW / MT3D

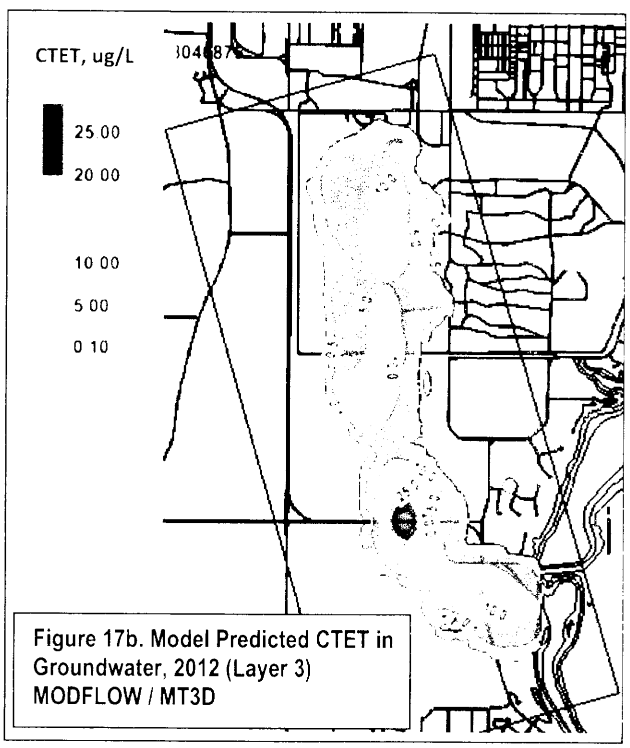


Figure 17b. Model Predicted CTET in Groundwater, 2012 (Layer 3) MODFLOW / MT3D

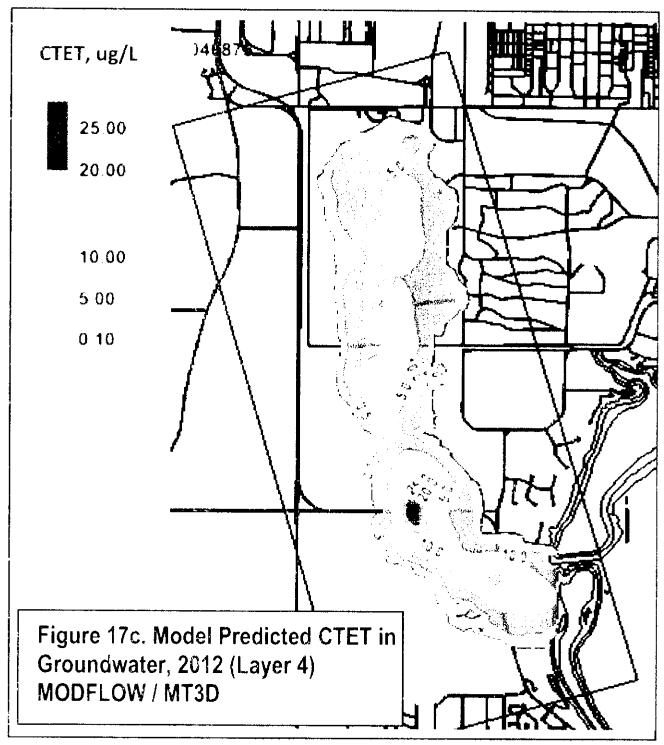


Figure 17c. Model Predicted CTET in Groundwater, 2012 (Layer 4) MODFLOW / MT3D

Predictive Transient Flow Simulations for CTET; 2012-2050 (NO PUMPING)

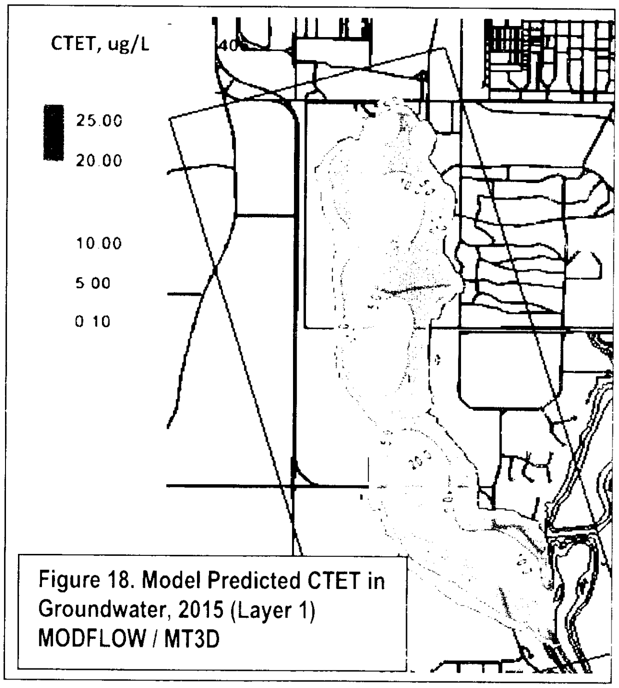


Figure 18. Model Predicted CTET in Groundwater, 2015 (Layer 1) MODFLOW / MT3D

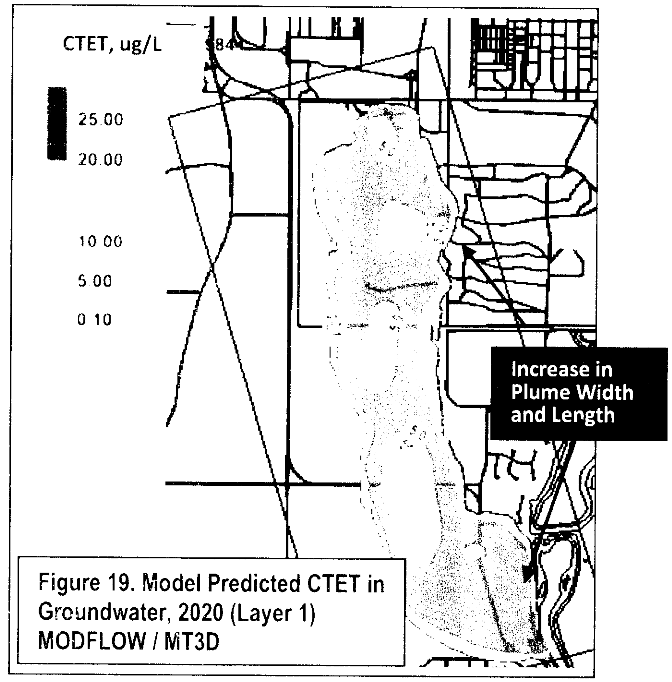


Figure 19. Model Predicted CTET in Groundwater, 2020 (Layer 1) MODFLOW / MT3D

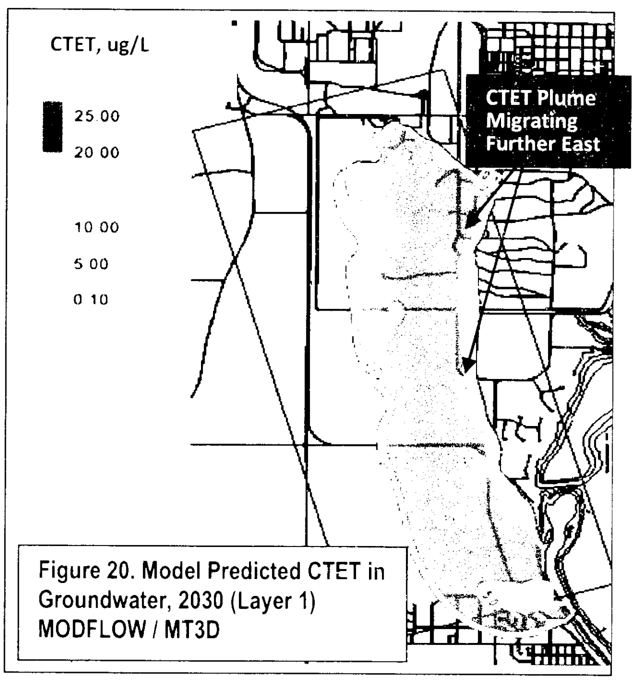


Figure 20. Model Predicted CTET in Groundwater, 2030 (Layer 1) MODFLOW / MT3D

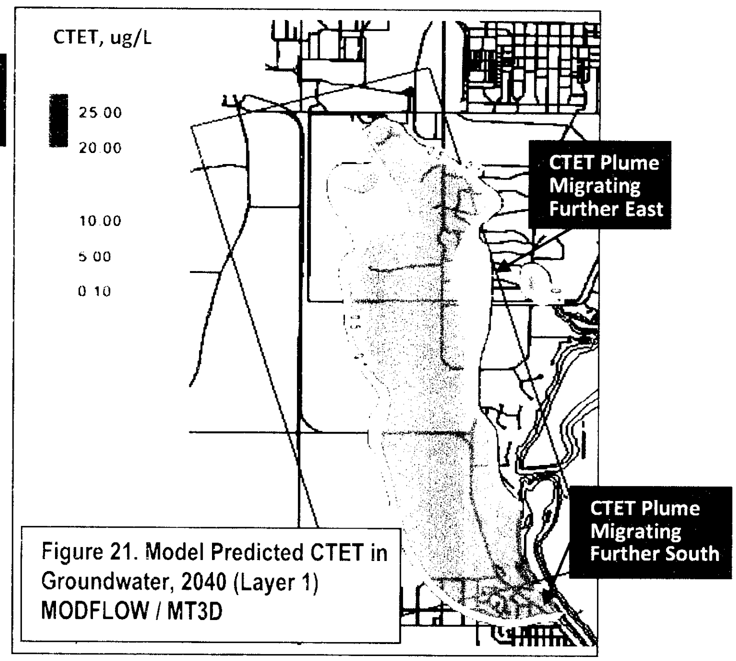


Figure 21. Model Predicted CTET in Groundwater, 2040 (Layer 1) MODFLOW / MT3D

concentrations in groundwater will decrease, with only small areas of the contaminant plume containing CTET at levels above 5 ug/L, the WDNR NR140 ES. An ES exceedance for CTET is not predicted by the 2040 model simulation. At that time, it is anticipated that the majority of the plume will contain CTET at concentrations between the NR140 ES and PAL (0.5 ug/L).

As shown on Figures 22-22c, the model predicted CTET concentrations for 2050 decrease with depth and the deeper model layers are not as affected by the CTET contaminant plume. Comparison

Predictive Transient Flow Simulations for CTET; 2012-2050 (NO PUMPING)

of the 2050 model simulation with earlier predictive runs shows a decrease in CTET concentrations across all model layers, suggesting that the plume will stabilize and shrink. It is expected that longer predictive runs (beyond 2050) may help determine when the concentrations within the CTET plume decrease below the NR140 PAL.

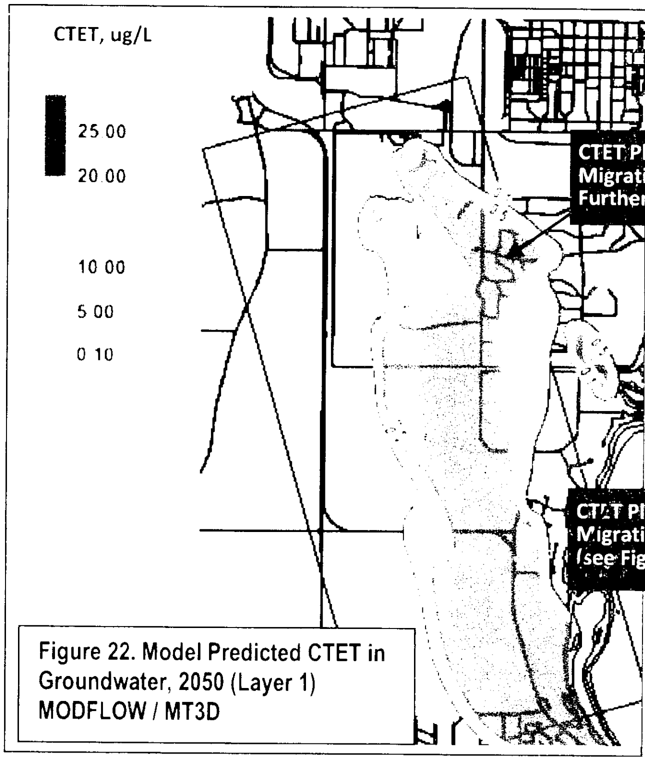


Figure 22. Model Predicted CTET in Groundwater, 2050 (Layer 1) MODFLOW / MT3D

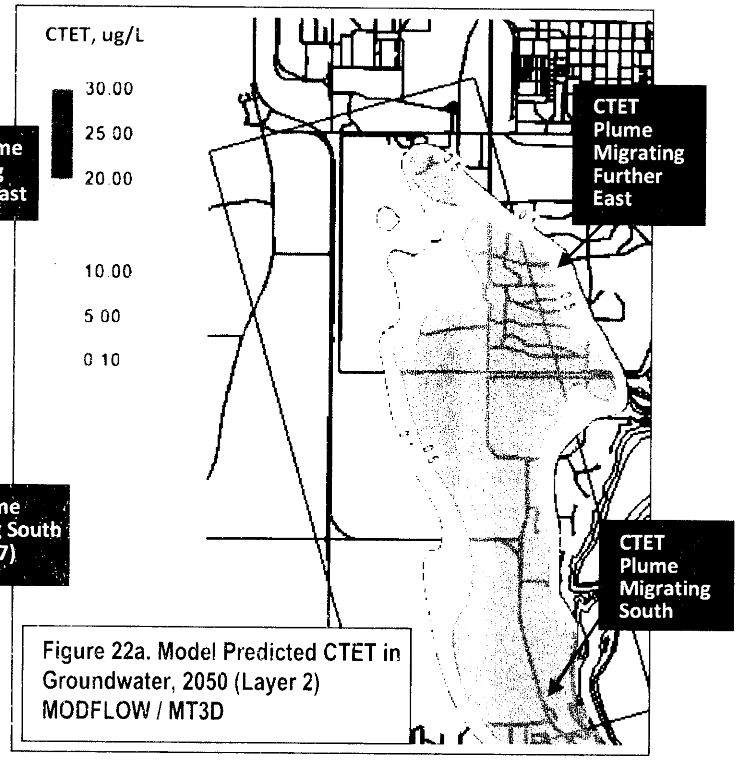


Figure 22a. Model Predicted CTET in Groundwater, 2050 (Layer 2) MODFLOW / MT3D

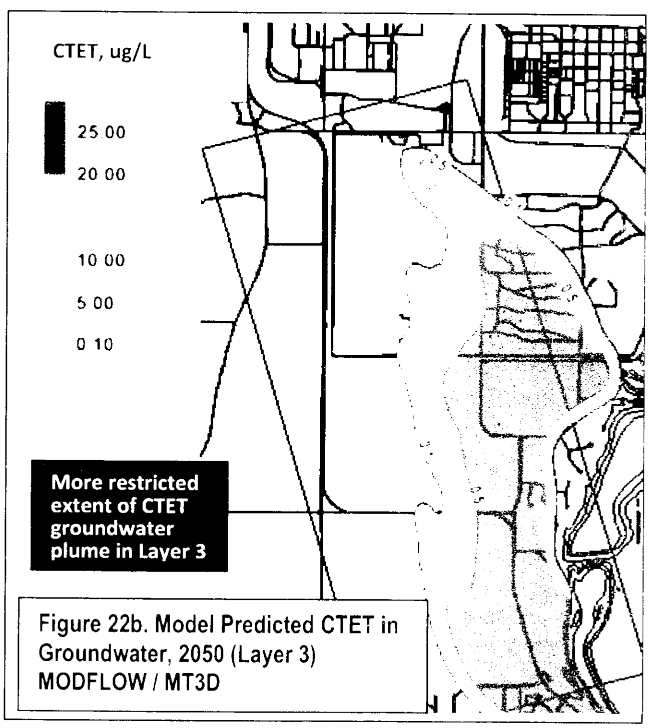


Figure 22b. Model Predicted CTET in Groundwater, 2050 (Layer 3) MODFLOW / MT3D

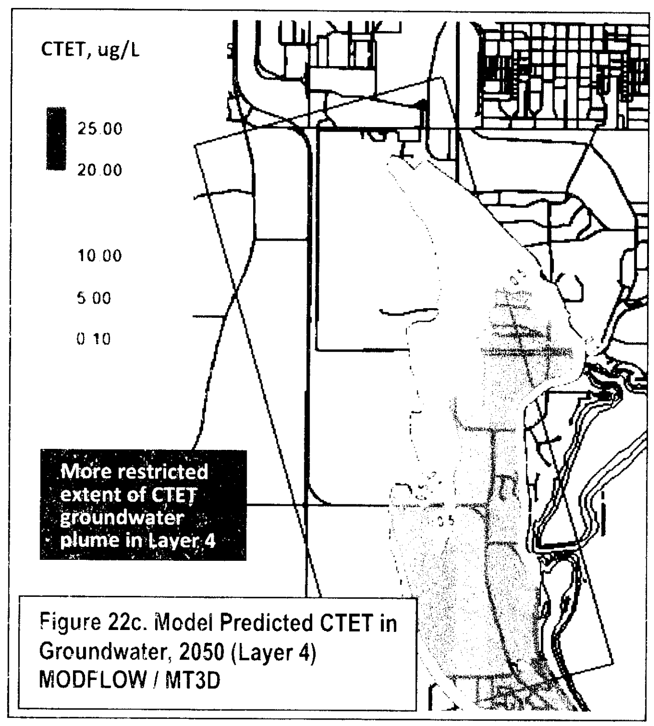


Figure 22c. Model Predicted CTET in Groundwater, 2050 (Layer 4) MODFLOW / MT3D

Study Limitations

This report has been prepared for Badger Technical Services, LLC. Reliance on the observations, findings, conclusions and recommendations contained herein by others without the expressed approval of Badger Technical Services, LLC is prohibited.

The completed solute transport modeling effort should be considered an order-of-magnitude estimate regarding how groundwater flow and the contaminant of concern (CTET) present within the PBG varies spatially over time. The model results obtained are directly related to the quality and accuracy of the model input parameters, and may be affected by the inherent variability often associated with investigation data collection and/or laboratory analysis of such data.

Contaminant plume occurrence as predicted by the current modeling effort is based on reasonable assumptions made during model set-up and execution. As needed, adjustments were made to the model parameters so plume configuration reasonably represented historical and more recent contaminant trends.

All models developed herein should be considered a reasonable depiction of existing site conditions. The results obtained are not to be considered to represent actual site conditions.

References

ABB-Environmental Services, Inc. (ABB-ES), 1993. Final Remedial Investigation Report. Volumes I-II, Volumes 1-7 Appendices.

Nishino, Shirley F., Jim C. Spain, Urvi Tulsiani, John Fortner and Joseph Hughes, 2005. *Final Report on Residual Dinitrotoluenes in Settling Ponds and Spoils Disposal Area Soils at Badger Army Ammunition Plant: Microcosm and Soil Column Studies*. School of Civil and Environmental Engineering, Georgia Institute of Technology

Shaw Environmental Inc., (Shaw), 2005. *Draft Technical Memorandum, Performance Assessment and Recommended Disposition of the Biologically Enhanced Subsurface Treatment System; Propellant Burning Ground, Badger Army Ammunition Plant, Baraboo, Wisconsin*

T N & Associates (TN&A), 2000. *Technical Memorandum, Groundwater Flow Model for the Propellant Burning Ground, Badger Army Ammunition Plant, Baraboo, Wisconsin*. Revision 3, March, 2000.

U.S. Army Corps of Engineers, 2008. *Conceptual Model for the Transport of Energetic Residues from Surface Soil to Groundwater by Range Activities*, Table A1, Physical and Chemical Properties of Explosives and Other Compounds. ERDC/CRREL TR-06-18

Woodward Clyde (W-C), 1995. *Groundwater Modeling Technical Memorandum*, January, 1995.

Zheng, C., 1990. *A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion and Chemical Reaction of Contaminants in Groundwater Systems*. University of Alabama.