

Remedial Investigation Report

Pines Area of Investigation
AOC II
Docket No. V-W-'04-C-784

CONTENTS

Acronyms

Standard Chemical Abbreviations

Disclaimer

EXECUTIVE SUMMARY..... 1

1.0 INTRODUCTION 1-1

1.1 Purpose of this Report.....	1-1
1.2 Area of Investigation Background	1-2
1.2.1 Location and Description.....	1-2
1.2.2 Yard 520	1-2
1.2.3 History.....	1-3
1.2.4 Overview of AOC II.....	1-4
1.3 Previous Investigations/Remedial Actions.....	1-6
1.3.1 Private Well Sampling by USEPA and IDEM.....	1-6
1.3.2 Municipal Water Service Extension (AOC I and AOC I, Amended).....	1-6
1.3.3 Bottled Water.....	1-7
1.3.4 Suspected CCB Sampling During Water Service Extension.....	1-7
1.3.5 CCB Sampling at Yard 520.....	1-7
1.4 Report Organization.....	1-8

2.0 FIELD INVESTIGATION ACTIVITIES 2-1

2.1 General Field Procedures.....	2-2
2.1.1 Access Agreements and Permits	2-2
2.1.2 Adjustments and Field Change Orders	2-3
2.1.3 Suspected CCB Terminology	2-4
2.1.4 Investigation Derived Waste Management	2-4
2.1.5 Contractors and Subcontractors.....	2-5
2.1.6 Surveying	2-6
2.1.7 Utility Clearance	2-7
2.1.8 Laboratories.....	2-7
2.2 Municipal Water Service Extension Sampling.....	2-8

2.3	Physical Characteristics.....	2-10
2.4	CCB Visual Inspections	2-11
2.5	CCB Sampling at Yard 520	2-12
2.6	Background Soil Sampling	2-13
2.7	Monitoring Well Installation.....	2-14
2.7.1	Vertical Profiling.....	2-15
2.7.2	Monitoring Well Drilling and Installation	2-16
2.7.3	Monitoring Well Development.....	2-18
2.8	Staff Gauge and Piezometer Installation	2-19
2.8.1	Staff Gauge Installation.....	2-19
2.8.2	Piezometer Installation.....	2-20
2.9	Water Level Measurements	2-21
2.9.1	Groundwater	2-21
2.9.2	Surface Water.....	2-21
2.9.3	Continuous Water Levels.....	2-22
2.9.4	Additional Water Level Monitoring.....	2-23
2.10	Surface Water Flow Rates.....	2-23
2.10.1	Field Methods	2-23
2.10.2	Data Analysis.....	2-24
2.11	Hydraulic Conductivity Testing	2-25
2.11.1	Testing Methods.....	2-25
2.11.2	Data Analysis.....	2-26
2.12	Groundwater Sampling.....	2-26
2.13	Surface Water Sampling.....	2-28
2.13.1	Field Reconnaissance for Surface Water Sampling Locations	2-28
2.13.2	Sampling Methods.....	2-28
2.14	Sediment Sampling.....	2-30
2.14.1	Field Reconnaissance for Sediment Sampling Locations	2-30
2.14.2	Sampling Methods.....	2-31
2.15	Private Well Sampling.....	2-33
2.16	Additional Soil Sampling for Arsenic	2-34
2.16.1	Sampling Methods.....	2-34

2.16.2 Results and Conclusions.....	2-35
2.17 Ecological Habitat Characterization	2-36
2.17.1 Ecological Habitat Literature Review	2-36
2.17.2 Field Inspection Methodology	2-37
2.18 Data Validation and Management.....	2-39
2.18.1 Data Validation	2-39
2.18.2 Uncertainties Reported with Radiological Data.....	2-42
2.18.3 Data Management.....	2-43
2.18.4 Data Usability Assessment	2-44
3.0 PHYSICAL CHARACTERISTICS	3-1
3.1 Demography and Land Use	3-1
3.2 Surface Features	3-2
3.3 Meteorology.....	3-2
3.4 Geology and Hydrogeology	3-2
3.4.1 Regional Geology and Hydrogeology.....	3-2
3.4.2 Geology and Hydrogeology of the Area of Investigation	3-5
3.4.3 Groundwater Occurrence and Flow	3-11
3.4.4 Aquifer Characteristics	3-18
3.4.5 Evaluation of Conditions in Southern Portion of the Area of Investigation	3-19
3.5 Surface Water Hydrology	3-22
3.6 Groundwater-Surface Water Interaction	3-24
3.7 Description of CCBs	3-27
3.7.1 Physical Description of CCBs in the Area of Investigation	3-30
3.7.2 Potential Locations of CCBs in the Area of Investigation	3-31
3.8 Ecological Habitat	3-33
3.9 Potential Receptors.....	3-34
3.9.1 Human Health Conceptual Site Model	3-34
3.9.2 Ecological Conceptual Site Model	3-35
4.0 NATURE AND EXTENT OF CONSTITUENTS	4-1
4.1 Risk-Based Comparison Levels	4-1

4.2	Background Soils	4-3
4.2.1	Physical Characteristics of Background Soils in the Area of Investigation	4-3
4.2.2	Chemistry of Background Soils in the Area of Investigation	4-4
4.2.3	Background Arsenic Levels in the United States	4-6
4.2.4	Summary of Background Soil	4-8
4.3	CCBs	4-9
4.3.1	General Chemistry of CCBs	4-9
4.3.2	Chemistry of the Suspected CCBs in the Area of Investigation	4-10
4.3.3	Potential for Migration from CCBs to Groundwater	4-14
4.4	Groundwater	4-14
4.4.1	Background Groundwater	4-15
4.4.2	Comparison of Groundwater Concentrations to Human Health Risk-Based Comparison Levels	4-19
4.4.3	General Chemistry of Groundwater	4-22
4.4.4	Occurrence and Relationships of Specific Constituents in Groundwater	4-26
4.4.5	Migration from CCBs to Groundwater	4-34
4.4.6	Concentration Trends over Time	4-35
4.4.7	Summary of CCB-Derived Constituents in Groundwater	4-38
4.5	Surface Water	4-40
4.5.1	Upgradient Surface Water – General Chemistry	4-41
4.5.2	Upgradient Surface Water – Metals and Other Constituents	4-46
4.5.3	Summary of Upgradient Surface Water Results	4-49
4.5.4	Brown Ditch Surface Water – General Chemistry	4-50
4.5.5	Brown Ditch Surface Water – Metals and Other Constituents	4-53
4.5.6	Summary of Brown Ditch Surface Water Results	4-59
4.6	Sediments	4-60
4.6.1	Upgradient Sediment Characteristics	4-61
4.6.2	Brown Ditch Sediment Characteristics	4-65
5.0	CONSTITUENT FATE AND TRANSPORT	5-1
5.1	Potential Migration from CCBs to Groundwater	5-2
5.2	Groundwater	5-3
5.3	Surface Water and Sediment	5-8
5.3.1	Transport Mechanisms	5-9
5.3.2	Fate Processes	5-10

5.4 Other Fate and Transport Processes.....	5-12
5.5 Summary	5-12
6.0 SUMMARY AND CONCLUSIONS.....	6-1
6.1 Field Investigations	6-1
6.2 Physical Characteristics.....	6-1
6.3 Nature and Extent of Constituents	6-4
6.4 Fate and Transport	6-8
6.5 Summary	6-9
6.6 Risk Assessments.....	6-11
7.0 REFERENCES	7-1

LIST OF TABLES

Table 2-1	Summary of Samples Analyzed
Table 2-2	MWSE Trench Sampling Analytical Results
Table 2-3	Results of Soil Sampling Physical Testing
Table 2-4	Yard 520 Type II (North) Area Sampling Analytical Results
Table 2-5	Background Surface Soil Sampling Analytical Results for Inorganics
Table 2-6	Monitoring Well Construction Information
Table 2-7	Monitoring Well Development Details
Table 2-8	Groundwater Level Data
Table 2-9	Surface Water Level Data
Table 2-10	Surface Water Flow Rate Data
Table 2-11	Results of Hydraulic Conductivity Testing
Table 2-12	Monitoring Well Sampling Analytical Results
Table 2-13	Monitoring Well Sampling Analytical Results – Radiological Parameters and Lithium
Table 2-14	Surface Water Sampling Analytical Results – Upgradient Sample Locations
Table 2-15	Surface Water Sampling Analytical Results – Brown Ditch Sample Locations
Table 2-16	Sediment Sampling Analytical Results
Table 2-17	Private Well Sample Locations and Information
Table 2-18	Private Well Groundwater Sampling Analytical Results
Table 2-19	Representative Natural Community Types Observed During Ecosystem Habitat Mapping
Table 2-20	Background Surface Soil Analytical Results for Radiological Parameters
Table 3-1	Hydraulic Head Differences between Groundwater and Surface Water
Table 3-2	Monthly Precipitation Data at Indiana Dunes National Lakeshore 1989 - 2008
Table 3-3	Post-RI Groundwater Level Data
Table 3-4	Post-RI Surface Water Level Data
Table 4-1	Human Health Screening Levels for Groundwater and Surface Water
Table 4-2	Human Health Screening Levels for Suspected CCBs, Soil, and Sediment
Table 4-3	Ecological Screening Levels for Surface Water
Table 4-4	Ecological Screening Levels for Sediment, Soil, and Suspected CCBs

LIST OF FIGURES

Figure 1-1	USGS Topographic Map
Figure 1-2	Area of Investigation Details
Figure 1-3	Town of Pines Street Map
Figure 1-4	Yard 520 Monitoring Locations
Figure 1-5	Areas Addressed Under AOCs
Figure 1-6	USEPA/IDEM Sampling Results for Boron in Private Wells
Figure 1-7	USEPA/IDEM Sampling Results for Molybdenum in Private Wells
Figure 2-1	RI Sample and Measurement Locations
Figure 2-2	MWSE Sample Locations
Figure 2-3	RI Visual Inspection Locations for Suspected CCBs
Figure 2-4	Yard 520 Type II (North) Area Boring Locations
Figure 2-5	Background Surface Soil Sample Locations
Figure 2-6	RI Vertical Profile Sample Locations
Figure 2-7	RI Monitoring Well Locations
Figure 2-8	RI Staff Gauge, Culvert, and Piezometer Locations
Figure 2-9	RI Water Level Gauging Locations
Figure 2-10	RI Continuous Water Level Monitoring Locations
Figure 2-11	RI Surface Water Flow Measurement Locations
Figure 2-12	RI Groundwater Sample Locations
Figure 2-13	RI Surface Water Sample Locations
Figure 2-14	RI Sediment Sample Locations
Figure 2-15	RI Private Well Sample Locations
Figure 2-16	RI Additional Soil Sample Locations
Figure 2-17	Ecological Habitat Assessment Area and Findings
Figure 3-1	Cross Section A-A'
Figure 3-2	Cross Section B-B'
Figure 3-3	Cross Section C-C'
Figure 3-4	Elevations of Top of Confining Clay
Figure 3-5	Groundwater Contour Map – August 2006

Figure 3-6	Groundwater Contour Map – October 2006
Figure 3-7	Groundwater Contour Map – January 2007
Figure 3-8 (a)	Groundwater Contour Map (Four Foot Contours) – April 2007
Figure 3-8 (b)	Groundwater Contour Map (One Foot Contours) – April 2007
Figure 3-9	Groundwater Contour Map – July 2007
Figure 3-10	Groundwater Level Data
Figure 3-11	Long-term Water Level Monitoring Results – Groundwater
Figure 3-12	Hydraulic Conductivity of Surficial Aquifer
Figure 3-13	Estimated Limit of Surficial Aquifer
Figure 3-14	Long-term Water Level Monitoring Results – East Branch Brown Ditch
Figure 3-15	Long-term Water Level Monitoring Results – West Branch Brown Ditch
Figure 3-16	Long-term Water Level Monitoring Results – Surface Water
Figure 3-17	Results of Suspected CCB Visual Inspections
Figure 3-18	Locations of Field Verified Suspected CCBs
Figure 3-19	Distribution of Suspected CCBs Based on Visual Inspections
Figure 3-20	Human Health Conceptual Site Model
Figure 3-21	Ecological Conceptual Site Model
Figure 3-22	Map Showing Surface Water Flow Rates
Figure 3-23	Cross Section D-D'
Figure 4-1	Boron in Groundwater
Figure 4-2	Molybdenum in Groundwater
Figure 4-3	Arsenic in Groundwater
Figure 4-4	Selenium in Groundwater
Figure 4-5	Iron in Groundwater
Figure 4-6	Manganese in Groundwater
Figure 4-7	Chloride in Groundwater
Figure 4-8	Nitrate in Groundwater
Figure 4-9	Sulfate in Groundwater
Figure 4-10	Ammonia in Groundwater
Figure 4-11	Bacteria in Groundwater
Figure 4-12	Radial Plots of Major Ions in Groundwater

Figure 4-13	Minor Ions and DOC in Groundwater, August 2006
Figure 4-14	Minor Ions and DOC in Groundwater, October 2006
Figure 4-15	Minor Ions and DOC in Groundwater, January 2007
Figure 4-16	Minor Ions and DOC in Groundwater, April 2007
Figure 4-17	Boron-Isotope Ratio Results in Groundwater
Figure 4-18	Migration of CCB-Derived Constituents to Groundwater
Figure 4-19	Estimated Boron in Groundwater above Comparison Levels
Figure 4-20	Specific Conductivity in Surface Water
Figure 4-21	Dissolved Organic Carbon in Surface Water
Figure 4-22	Boron in Surface Water
Figure 4-23	Total Aluminum in Surface Water
Figure 4-24	Total Aluminum vs. Total Suspended Solids in Upgradient Surface Water Samples
Figure 4-25	Total Iron in Surface Water
Figure 4-26	Molybdenum in Surface Water
Figure 4-27	Percent Solids and Total Organic Carbon in Sediment Samples
Figure 4-28	Various Constituents in Sediment Samples
Figure 4-29	Boron in Sediment Samples
Figure 4-30	Molybdenum in Sediment Samples
Figure 4-31	Boron in Background Surface Soil
Figure 4-32	Molybdenum in Background Surface Soil
Figure 4-33	Arsenic in Background Surface Soil
Figure 4-34	Estimated Boron in Groundwater
Figure 4-35	Estimated Molybdenum in Groundwater
Figure 4-36	Estimated Sulfate in Groundwater
Figure 4-37	Redox Conditions in Groundwater
Figure 4-38	Estimated Manganese in Groundwater
Figure 4-39	Estimated Arsenic in Groundwater
Figure 4-40	Total Manganese in Surface Water
Figure 4-41	Total Aluminum vs. Total Suspended Solids in Upgradient and Brown Ditch Surface Water Samples
Figure 4-42	Estimated Iron in Groundwater

Figure 4-43 Estimated Aluminum in Groundwater

Figure 4-44 Interpreted Boron and All Groundwater Sampling Results

LIST OF APPENDICES

Appendix A	Field Change Orders
Appendix B	Monitoring Well Purge Water IDW Laboratory Analysis Data
Appendix C	MWSE Utility Trench Boring Logs
Appendix D	Soil Physical Characteristics Laboratory Data
Appendix E	USEPA Correspondence
Appendix F	Yard 520 Type II (North) Area Boring Logs
Appendix G	Background Surface Soil Sample Summary
Appendix H	Monitoring Well Boring and Well Construction Logs
Appendix I	Piezometer Construction Logs
Appendix J	Surface Water Flow Collection Records
Appendix K	Slug Testing Data Analysis
Appendix L	Boron Trend Plots
Appendix M	Groundwater Sample Collection Records
Appendix N	Surface Water Sample Collection Records
Appendix O	Sediment Sample Collection Records
Appendix P	Private Well Sample Collection Records
Appendix Q	Additional Soil Sampling Boring Logs
Appendix R	Ecological Habitat Mapping Field Forms
Appendix S	Laboratory Analytical Data and Validation Memorandum
Appendix T	Data Usability Assessment
Appendix U	Ecological Habitat Observations
Appendix V	Groundwater Piper Diagrams
Appendix W	Sediment Plots – Concentration vs. Percent Fines
Appendix X	Pines Landfill (Owned by Waste Management) Monitoring Well Map
Appendix Y	Municipal Water Line Connections by Address
Appendix Z	Pines Area of Investigation Topographic Basemap
Appendix AA	USGS Geology and Hydrogeology Figures (from Shedlock, et al., 1994)
Appendix BB	Response to USEPA Comments dated August 22, 2008
Appendix CC	Long Term Water Levels in Yard 520 Monitoring Well Network

ACRONYMS

%	Percent (per hundred)
‰	Per mil (per thousand)
amsl	Above Mean Sea Level
AOC I	Administrative Order on Consent, 2003 and as amended, 2004; Docket No. V-W-03-730
AOC II	Administrative Order on Consent, 2004; Docket No. V-W-'04-C-784
bgs	Below Ground Surface
BOD	Biological Oxygen Demand
°C	Degrees Celsius
CAS	Columbia Analytical Services
CCB	Coal Combustion By-product
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	Cubic Feet per Second
cm	Centimeter
COC	Chain of Custody
COPC	Constituent of Potential Concern
CORS	Continuously Operating Reference Stations
CSM	Conceptual Site Model
del	δ (Greek small letter delta)
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOE	Department of Energy
DOT	Department of Transportation
DUA	Data Usability Assessment
EDD	Electronic Data Deliverable
ERA	Ecological Risk Assessment
°F	Degrees Fahrenheit
FCO	Field Change Order
FOD	Frequency of Detect
FSP	Field Sampling Plan

ft	Feet
ft/day	Feet per day
ft/ft	Feet per foot
ft/year	Feet per Year
g/cc	Gram per cubic centimeter
g/ml	Grams per milliliter
gal	Gallons
GEL	General Engineering Laboratories
gpm	Gallons per minute
GPS	Global Positioning System
GTC	Geochemical Technology Corporation
HASP	Health and Safety Plan
HHRA	Human Health Risk Assessment
ICP	Inductively Coupled Plasma
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
ICS	Interference Check Sample
ID	Identification
IDEM	Indiana Department of Environmental Management
IDNL	Indiana Dunes National Lakeshore
IDNR	Indiana Department of Natural Resources
IDL	Instrument Detection Limit
IDW	Investigation Derived Waste
IUPPS	Indiana Underground Plant Protection Service
K _d	Soil-water Partitioning Coefficient
km	Kilometer
km ²	Square kilometer
l	Liter
l/kg	Liter per kilogram
l/min	Liters per minute
LCS	Laboratory Control Sample
LCSD	Laboratory Control Sample Duplicate

m	Meter
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
MBAS	Methylene Blue Active Substances
MCL	Maximum Contaminant Levels
MDEQ	Michigan Department of Environmental Quality
MDL	Method Detection Limit
meq/l	Milliequivalents per liter
mg/kg	Milligrams per kilogram
mg/l	Milligrams per liter
ml	Milliliters
MS	Matrix Spike
MS/MSD	Matrix Spike/Matrix Spike Duplicate
mV	Millivolts
MWSE	Municipal Water Service Extension
NAVD	North American Vertical Datum
NCP	National Contingency Plan
NGS	National Geochemical Survey
NAD83	1983 North American Datum
NFG	National Functional Guidelines
ng/kg	Nanograms per Kilogram
NIPSCO	Northern Indiana Public Service Company
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTU	Nephelometric Turbidity Unit
NURE	National Uranium Resource Evaluation
NWI	National Wetlands Inventory
OLQ	Office of Land Quality
ORP	Oxidation Reduction Potential
PAH	Polycyclic Aromatic Hydrocarbon
PCDD	Polychlorinated Dibenzo-p-dioxin
PCDF	Polychlorinated Dibenzofuran

pCi/g	PicoCuries per gram
pCi/l	PicoCuries per liter
PDS	Post Digestion Spike
PEMC	Palustrine Emergent Marsh Seasonally Flooded
PFO1A	Palustrine Forested Broad-leaved Deciduous Temporarily Flooded
PFO1C	Palustrine Forested Broad-leaved Deciduous Seasonally Flooded
PPE	Personal Protective Equipment
ppm	Parts per Million
PVC	Polyvinyl Chloride
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QMP	Quality Management Plan
R _f	Retardation Factor
RAL	Removal Action Level
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
RL	Reporting Limit
ROW	Right-of-way
RPD	Relative Percent Difference
SAP	Sampling and Analysis Plan
SMS	Site Management Strategy
SOP	Standard Operating Procedure
SOW	Statement of Work
sq. mi.	Square Mile
STL	Severn Trent Laboratories
TAL	Target Analyte List
TAP	Technical Assistance Plan
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids

TU	Tritium Units
umhos/cm	Micromhos per Centimeter
uS/cm	MicroSiemens per Centimeter
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WQS	Water Quality Standard

STANDARD CHEMICAL ABBREVIATIONS

Ac	Actinium
Al	Aluminum
Ag	Silver
As	Arsenic
B	Boron
Ba	Barium
Be	Beryllium
Ca	Calcium
CaCO ₃	Calcium carbonate
Cd	Cadmium
Cl	Chloride
Co	Cobalt
CO ₃	Carbonate
Cr	Chromium
Cs	Cesium
Cu	Copper
E. coli	Escherichia Coli
F	Fluoride
Fe	Iron
Fe ₂ O ₃	Iron Oxide
³ H	Tritium
H ₂ O	Water
H ₃ BO ₃	Boric acid
HCO ₃	Bicarbonate
Hg	Mercury
K	Potassium
Li	Lithium
Mg	Magnesium
Mo	Molybdenum
MoO ₄ ⁻²	Molybdate ion

Mn	Manganese
N	Nitrogen
Na	Sodium
NaCl	Sodium chloride (mineral halite)
Ni	Nickel
NH ₄	Ammonia
NO ₃	Nitrate
Pa	Protactinium
Pb	Lead
Po	Polonium
PO ₄	Phosphate/Ortho-phosphate
Ra	Radium
S	Sulphur or Sulfide
Sb	Antimony
Se	Selenium
Si	Silicon or silica
SiO ₂	Silicon dioxide, silica
SO ₄	Sulfate
Sr	Strontium
Th	Thorium
Tl	Thallium
U	Uranium
V	Vanadium
Zn	Zinc

DISCLAIMER

This document is a document prepared under a federal administrative order on consent and revised based on comments received from the U.S. Environmental Protection Agency (USEPA). This document has been approved by the USEPA, and is the final version of the document.

EXECUTIVE SUMMARY

In April 2004, the USEPA and the Respondents (Brown Inc., Ddalt Corp., Bulk Transport Corp., and NIPSCO) signed an Administrative Order on Consent (AOC II) to conduct a RI/FS at the Pines Area of Investigation. The objectives of the RI include (AOC II, 2004):

“(a) to determine the nature and extent of contamination at the Site and any threat to the public health, welfare, or the environment caused by the release or threatened release of hazardous substances, pollutants or contaminants related to Coal Combustion By-products (“CCB”) at or from the Site”, and

“(b) to collect data necessary to adequately characterize...(i) whether the city water service extension installed pursuant to AOC I, as amended, is sufficiently protective of current and reasonable future drinking water use of groundwater in accordance with Federal, State, and Local requirements; (ii) any additional human health risks at the Site associated with exposure to CCBs; and (iii) whether CCB-derived constituents may be causing unacceptable risks to ecological receptors.”

This RI Report documents the results of the RI conducted at the Pines Area of Investigation in accordance with AOC II and the USEPA-approved RI/FS Work Plan (ENSR, 2005d-j). In addition to providing the results of the field investigation activities, the collected data have been interpreted to develop a conceptual site model for the CCB-derived constituents in environmental media at the Area of Investigation. The data collected during the RI will serve as the basis for the human health and ecological risk assessments which will be submitted to the USEPA after approval of this RI Report. The findings of the RI are summarized below.

Field Investigation - The RI consisted of an extensive field investigation including installation of groundwater monitoring wells; geologic and hydrogeologic studies; sampling and laboratory analysis of groundwater, surface water, sediments, background soils, and suspected CCBs; and evaluation of ecological habitats. Access agreements with property owners were needed to conduct much of this work, as many investigation locations were located on private property. Data were reviewed in accordance with approved quality assurance procedures (ENSR, 2005f).

Geology and Hydrogeology - Groundwater is present beneath the Area of Investigation in the shallow surficial aquifer made up primarily of wind-blown sands associated with the current and former shores of Lake Michigan. The base of the surficial aquifer is formed by a clay confining unit. The surficial aquifer is thickest beneath upland dune areas, is thinner beneath low-lying wetlands areas between the dunes (such as the Great Marsh in the Indiana Dunes National Lakeshore (IDNL), and pinches out completely to the south against the silts and clays of the Valparaiso Moraine and/or lacustrine sediments of Glacial Lake Chicago.

Groundwater occurs as a water table aquifer (in the surficial aquifer) at depths ranging from near the ground surface (in wetland areas) to approximately 25 feet beneath upland dune areas. Groundwater flow is generally from the upland areas to Brown Ditch and its tributaries and wetlands located in the low-lying areas, including the IDNL. In general, during both wet and dry periods, groundwater discharges to the Brown Ditch system (including associated tributaries and wetlands) throughout the Area of Investigation. The hydraulic conductivity of the surficial aquifer was tested during the RI (slug testing) with estimated values ranging from approximately 5 to 50 ft/day with a geometric mean of 14.7 ft/day, consistent with the fine sands of the surficial aquifer. A typical average linear groundwater velocity of approximately 0.5 ft/day was calculated.

Surface Water Hydrology - The Brown Ditch system is defined as the main branches of Brown Ditch, its associated tributaries and wetlands, including portions located within the IDNL, and makes up the low-lying wetland areas located both north and south of the Town of Pines. The system includes man-made ditches (e.g., Brown Ditch itself), excavated more than 100 years ago to provide drainage in these areas where the water table is shallow. Brown Ditch is a low-gradient channel with low surface water flow volumes and velocities. As measured during the RI, surface water flow rates range from less than one cubic foot per second (cfs) to more than five cfs. Flow rates vary in different branches of the ditch system and are generally higher in the winter and spring and lower in the summer. [Note that in this report, the use of the term "Brown Ditch" refers to the branches and tributaries of the ditch itself, and the term "Brown Ditch system" refers to Brown Ditch and its associated wetlands as described above.]

CCBs and Suspected CCBs - In addition to the CCBs placed in Yard 520 in accordance with its permit requirements, CCBs are reported to have been used as road sub-base material and/or fill in other areas in the Town of Pines. The inspection program conducted as part of the RI documented the presence of suspected CCBs along many roadways in the eastern portion of the Town of Pines, as well as Maple Street and Railroad Avenue. Suspected CCBs also appear to have been used on some private properties to surface driveways. In contrast, suspected CCBs are also present in certain locations over wider areas extending well beyond the roadways, suggesting they were used as fill. These areas are primarily located along East Johns Avenue, Second Place, Idaho Avenue, Columbia Avenue and Delaware Avenue.

Potential Human Receptors - Residents (adults and children) may potentially contact surface CCBs directly via incidental ingestion and dermal contact, or they may inhale CCB particulates entrained in dusts. Where groundwater is used as a source of drinking water (that is, outside the area of municipal water service), residents may ingest CCB-derived constituents that have migrated into groundwater. They may also potentially contact CCB-derived constituents in groundwater while bathing. Residential children who play in the local ditches/wetlands may contact CCB-derived constituents that have potentially entered the surface water and sediment with the groundwater (via incidental ingestion and dermal contact). Recreational visitors may be adults who fish in the local ditches/wetlands or children who play in the local ditches/wetlands. Recreational visitors may inhale CCB particulates entrained in dusts. Additionally, recreational visitors may contact CCB-derived constituents that have potentially

entered surface water and sediment with the groundwater (via incidental ingestion and dermal contact). Recreational fishers may also be exposed to CCB-derived constituents in fish tissue via consumption. Recreational visitors may also ingest groundwater as drinking water while in the Area of Investigation. Construction workers may potentially contact surface and subsurface CCBs directly via incidental ingestion and dermal contact, and they may inhale CCB particulates entrained in dusts. Construction workers may also directly contact CCB-derived constituents in groundwater via incidental ingestion and dermal contact if groundwater is encountered during an excavation. Construction workers may also ingest groundwater as drinking water. Outdoor workers may be exposed to surface CCBs where present via incidental ingestion and dermal contact and to CCBs where present in particulates that may be suspended in the air via inhalation. Outdoor workers might also potentially ingest groundwater as drinking water.

Potential Ecological Receptors – Ecological habitats were mapped as part of the RI. While there are no unique habitats in the area of ecological habitat assessment, the Area of Investigation is located adjacent to the IDNL. Important ecological habitats in the Area of Investigation include the Brown Ditch system, adjacent marsh and wetland areas, man-made ponds, and upland forested areas. Ecological receptors whose habitats include Brown Ditch (aquatic plants, benthic invertebrates, plants, amphibians, fish, piscivorous avians, and mammals) may be exposed to CCB-derived constituents in surface water and sediments of Brown Ditch and adjacent man-made ponds/basins. Avian and mammalian receptors (herbivores, omnivores, and carnivores) may be exposed to CCB-derived constituents in Brown Ditch and adjacent man-made ponds/basins through bioaccumulation by ingestion of food items (e.g., plants, fish). Upland vegetation and soil invertebrates may come in contact with CCB-derived constituents in upland terrestrial habitat areas if suspected CCBs are present in these areas. Terrestrial avian and mammalian receptors (herbivores, omnivores, insectivores, and carnivores) may also come into contact with CCB-derived constituents in upland terrestrial habitat areas if suspected CCBs are present in these areas. This later pathway would also include the exposure due to ingestion of grit by certain avian receptors.

Comparison Levels - Risk-based comparison levels for human health were presented in the HHRA Work Plan (ENSR, 2005h). Updated comparison levels for human health for aqueous media (i.e., groundwater and surface water) and for solid media (i.e., suspected CCBs, soil, and sediment) are provided here. The human health comparison levels are very conservative levels used in the RI to provide perspective on interpreting results. The actual evaluation of potential risks will be conducted in the formal Human Health Risk Assessment, in accordance with the RI/FS Work Plan (ENSR, 2005d-j).

The ecological comparison levels were identified based on the appropriate hierarchies provided in the ERA Work Plan (ENSR, 2005i). Where appropriate, ecological comparison levels were adjusted based on site-specific sediment TOC or water hardness. Ecological comparison levels were prepared and submitted to USEPA on June 19, 2007 (see Appendix E). Since then, updated comparison levels for Mn (April 2007), Se (July 2007), and Zn (June 2007) were published by USEPA and have been incorporated into the current ecological comparison levels.

Chemistry of Background Soil - The natural soils in the Area of Investigation include both granular soils (primarily dune sands, but also silts and clays) and organic soils, which may be mixed with granular materials. All of the natural geologic materials contain a wide variety of metals at different concentrations, such as Al, As, B, Ba, Ca, Cr, Fe, Pb, Mg, Na, Se, Sr, U, V, and Zn. Of all the metals, As was present in all the soil samples at concentrations above the risk-based comparison level for human health. This is not unexpected, as As is present at concentrations above risk-based comparison levels in most natural soils in the United States. Manganese and Tl were detected in one background soil sample at concentrations above the human health risk-based comparison level. Cobalt was also detected in one sample slightly above the human health risk-based comparison level. Levels of the radionuclides Pb-210, Ra-226, and Ra-228 were also greater than human health comparison levels in most samples. None of these soil samples is significantly affected by CCB-derived constituents; instead, the results reflect the natural and anthropogenic levels of metals and radionuclides in soils in the area.

Chemistry of Suspected CCBs - Most of the metals present in suspected CCBs are also present in background soils, although concentrations for some are higher in suspected CCBs. The As concentrations in all the suspected CCB samples were above the risk-based comparison level as were all of the As concentrations in the background soils. Iron was also present in many suspected CCB samples at concentrations above the risk-based comparison level for human health. Hexavalent Cr was detected and above the human health risk-based comparison level in all of the suspected CCB samples in which it was analyzed.

Chemistry of Groundwater - The natural background groundwater in the Area of Investigation includes many minerals, typical of most natural fresh waters in the world. These include major ions such as Ca, Mg, Na, Si, HCO₃, SO₄, and Cl, and minor and trace elements such as Al, Ba, B, Mn, Sr, and NO₃. Based on RI sampling, background concentrations of B in the surficial aquifer in the Area of Investigation range up to 0.119 mg/l; Mo up to 0.012 mg/l. The USGS has documented that natural levels of B in the deeper confined aquifers can be expected to be above both the USEPA's Removal Action Level (RAL) (USEPA, 1998) of 0.900 mg/l and the human health risk-based comparison level of 0.730 mg/l.

Based on the RI data, CCB-derived constituents in groundwater include B, SO₄, Ca, Mg, Sr, and Mo. Arsenic also appears to migrate from CCBs to groundwater, at least at Yard 520, but it is not transported any significant distance with the groundwater. Iron and Mn may also have the potential to migrate from CCBs to groundwater, but their mobility in groundwater is controlled by redox conditions. Of these, B, Mo, SO₄, As, Fe, and Mn are present in at least one groundwater sample at concentrations above human health risk-based comparison levels. Other constituents detected at least once at concentrations above comparison levels include Se, Cl, and NO₃, but these are not likely to be CCB-derived.

It is uncertain whether migration from CCBs to groundwater occurs where CCBs are used only as road sub-base. In at least one monitoring well location MW111), elevated CCBs occur in an area of known

road sub-base and underlying road fill combined (five feet of thickness as documented in the boring log for MW111; see Figure 4-18). Unverified larger accumulations of CCBs nearby (i.e., to the east of Illinois Avenue) may, however, also contribute to the groundwater concentration, as well as verified areas located around TP026 (greater than four and a half feet of CCB fill) and TP027 (greater than seven feet of CCB fill), which are located upgradient of MW111. Several wells are located in or downgradient from areas where suspected CCBs are present only as road sub-base, including MW107, MW108, MW114, and PW005. These wells do not show the presence of elevated levels of B (see Figure 4-18). In addition to the smaller amounts of suspected CCBs present, the paving of roadways may reduce groundwater recharge and migration of CCB-related constituents to groundwater.

The extent of CCB-derived constituents in groundwater has been documented throughout the RI. Concentrations of B, SO₄, Ca, Mg, Sr, and Mo are elevated at and downgradient from Yard 520. To the east, elevated concentrations of these constituents are present in the vicinity of areas where suspected CCBs may have been used as fill (that is, they are present well beyond the roadways), and downgradient to the south to the East Branch of Brown Ditch. All groundwater containing CCB-derived constituents is interpreted based on the RI data to flow into the Brown Ditch system, including its related tributaries and wetlands.

In addition, groundwater from Yard 520 flows into Brown Ditch and its related tributaries and wetlands in the immediate vicinity of Yard 520, and the hydrogeologic studies performed as part of the RI have demonstrated that groundwater does not flow from Yard 520 to the south beneath Brown Ditch. Also, based on the available information, CCB-derived constituents in groundwater do not extend northward into IDNL at levels of significance; this will be evaluated further in the ecological risk assessment (ERA).

Groundwater directly south of Yard 520 and Brown Ditch appears to be impacted by a landfill to the south (Pines Landfill, owned by Waste Management). Increased B concentrations in monitoring wells in this area are most likely a result of landfill contaminants. While Yard 520 is not a source of CCB-derived constituents in this area, without additional information, however, some contribution from other potential CCB sources cannot be ruled out.

In the area near the intersection of South Railroad Avenue and Ardendale where CCBs have been used in residential yards and driveways and as road sub-base, CCB impacts to groundwater might have occurred. One residential well was tested by EPA to be above the screening level for boron, although the private well located across the street (PW010) was sampled four times over the course of a year (2006 – 2007) and the boron concentrations were much below the comparison level. Therefore, in this part of the study area, which is not served by municipal water, CCB-derived constituents may have migrated into groundwater; this potential pathway will be evaluated in the HHRA.

In addition to CCB-derived constituents in groundwater, the groundwater in the surficial aquifer beneath the Area of Investigation shows evidence of other sources, including septic system

discharges, road salt, and the Pines Landfill (owned by Waste Management). Elevated concentrations of a number of non-CCB-derived constituents, such as Na, Cl, NO₃, NH₄, and bacteriological parameters, are present in many samples.

Chemistry of Surface Water - The upgradient (background) surface water contained measurable levels of metals and other constituents. The presence of these naturally occurring constituents in the surface water samples is not unexpected and, in many cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations as well as anthropogenic influences such as agricultural practices and run-off from roadways and railroads. The dissolved oxygen (DO) concentrations in upgradient locations were relatively low, especially in the summer and early fall, such that Brown Ditch would not support a coldwater fishery, and even warmwater fish may be seasonally stressed in some locations.

In upgradient surface water, concentrations of Al, Fe, Mn, and V were above the associated ecological comparison level in at least one sample. The concentration of Mn was above the human health comparison level in only one sample, and this was the only surface water sample with a constituent present at a level above a human health comparison level. The presence of Al in surface water is associated with suspended solids in the water, as measured by the TSS. Total Fe and Mn concentrations also are likely to be a function of the level of particulate matter in the sample. Dissolved Fe and Mn can be associated with low DO and associated redox conditions.

The Brown Ditch surface waters (that is, within the Area of Investigation, downgradient of the upgradient locations) also contained measurable levels of metals and other constituents. As with the upgradient locations, the presence of these naturally occurring constituents in the surface water samples is not unexpected and, in many cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations. However, concentrations of several metals were higher than in upgradient samples.

Concentrations of B in surface water were above the human health and ecological comparison levels in certain samples in the West, East, and Main Branches of Brown Ditch. Typically, higher concentrations were measured in the summer (dry period). On the West Branch, some of these samples also have Mo concentrations above the human health risk-based comparison level (but not the ecological comparison level). These elevated concentrations of B and Mo are most likely due to the contribution of groundwater containing CCB-derived constituents to the ditches.

Concentrations of Al were above its ecological comparison level in many surface water samples, both at upgradient and Brown Ditch locations. The Al appears to be associated with sediment and suspended particles in the samples as measured by the TSS. Al concentrations are generally higher in upgradient samples.

Concentrations of Fe and Mn were above the associated ecological comparison levels in many upgradient and Brown Ditch sample locations while only one Brown Ditch sample concentration of Fe was above the human health comparison level. The total fraction of these constituents may also be associated with suspended sediment in the samples; the dissolved fraction may be associated with locally low levels of DO in some segments of the ditches.

Chemistry of Sediments - In upgradient (background) locations, sediment samples are typically sandy with low levels of organic material. Boron was not detected in any upgradient sediment samples; however, the detection limit for B in sediments was elevated for all samples analyzed. Lead, Se, and Ba were above the ecological comparison levels in upgradient sediment samples, and As concentrations were above the human health comparison level. The presence of these metals in upgradient sediments shows that sediments outside of areas where they could be affected by CCB-derived constituents contain concentrations of some metals that are above risk-based comparison levels.

The sediments in Brown Ditch (that is, at locations within the Area of Investigation, downgradient of the upgradient locations) included both sandy and highly organic sediments. In contrast to the upgradient samples, the majority of the Brown Ditch samples contained greater than 1% total organic carbon (TOC). The percentage of fine-grained material (silts and clays) was also generally higher in downgradient samples. These differences reflect differences in the depositional environments between upgradient and the Brown Ditch locations.

The Brown Ditch sediments contained metals and other constituents. The presence of these naturally occurring constituents in the sediment samples is not unexpected and, in some cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations. Boron was detected in two sediment samples from Brown Ditch, SW022 and SW026; however, as noted above, the detection limit for B in sediments was elevated for all samples analyzed. Based on their locations and B concentrations, B in these sediments is likely associated with groundwater containing CCB-derived constituents; that is, the B in these sediment samples is likely to be associated with CCBs. There are no ecological risk-based comparison levels for B in sediment. The concentrations are below the human health risk-based comparison level.

In general, concentrations of other metals in the Brown Ditch sediments were greater than concentrations at upgradient locations, consistent with the finer-grained and more organic nature of many of the Brown Ditch system sediment samples. Concentrations of As, Ba, Cu, Fe, Pb, Mn, Ni, Se, V, and Zn in the Brown Ditch sediments for some locations were above associated ecological risk-based comparison levels, and results for Al, Cd, and Cr in the Brown Ditch sediments were below associated ecological risk-based comparison levels. All detected concentrations of As in the Brown Ditch sediments, some detected concentrations of Fe, and one detected TI concentration are above human health risk-based comparison levels.

The interpretation of some metals in Brown Ditch sediments may be confounded by the higher percentage of fines, higher TOC concentrations, lower percent solids, and presence of other potential sources in Brown Ditch sediments compared to upgradient sediments, but the concentrations of some metals are clearly elevated in samples located in proximity to significant CCB sources. When the percentage of fines is taken into account, concentrations of most metals (except for soluble CCB-related constituents such as B and Mo) are similar to upgradient concentrations and there is no consistent spatial pattern that can be attributed to CCB-derived constituents. Although the concentration of many metals in Brown Ditch sediments are similar to upgradient levels when percent fines are considered, concentrations of some inorganics that may be CCB-related increase up to five times the background concentrations in the Brown Ditch system downgradient of Yard 520 and other significant accumulations of CCBs. At locations most likely to be impacted by CCB-derived constituents (i.e., located physically closest to Yard 520 or larger areas of suspected CCBs), metal concentrations are generally consistent with upgradient locations (except for impacts due to constituents in groundwater such as B and Mo). A formal statistical comparison to upgradient concentrations will be conducted as part of the risk assessments.

Fate and Transport - Constituents present in environmental media will be affected by various attenuation processes as they migrate that will tend to reduce their concentrations. In groundwater, B, SO₄, Ca, Mg, and Sr are highly soluble and not very chemically reactive. Therefore, they are less likely to participate in chemical reactions that remove them from groundwater. They will typically be transported downgradient with the groundwater flow, with concentrations reduced primarily through dispersion. These constituents will then enter surface water in Brown Ditch from the groundwater. The fate and transport of Mo is similar, except that it appears to be subject to some additional attenuation processes, at least locally.

The fate and transport of Fe, Mn, and As in groundwater are controlled by redox conditions. Where groundwater is oxidized, these constituents will form insoluble molecules and will be removed from the groundwater system. Where groundwater is reduced, these molecules will dissociate and release the constituents into the groundwater. This process occurs with naturally-occurring Fe, Mn, and As in the native soils in the Area of Investigation as well as any Fe, Mn or As that might migrate from CCBs. Reducing conditions in groundwater are present locally throughout the Area of Investigation, most likely caused by organic inputs to the groundwater, such as septic system discharges, wetlands and highly organic soils, former gasoline stations, and the Pines Landfill (owned by Waste Management). Where such reducing conditions are present near the Brown Ditch system, including its associated wetlands, these constituents could be mobile and enter the ditch system with the groundwater. Where groundwater near the ditches is oxidized, Fe, Mn and As will not be mobile and, therefore, will not migrate into surface water.

In surface water, constituent concentrations tend to decrease with distance downstream from sources due to mixing and dilution. When constituents partition from the porewater into the sediments, they are less available to interact with ecological receptors. Uptake of nutrients by plant life can reduce concentrations in sediment and surface water. Biological processes in general can transform

constituents and affect their fate and mobility (e.g., denitrification). In addition, the potential ecological effects of some constituents in surface water can be hardness dependent. CCB-derived constituents are not considered bioaccumulative.

Risk Assessments - The data collected during the RI will be evaluated in the Human Health Risk Assessment and the Ecological Risk Assessment, in accordance with their respective work plans (ENSR, 2005h, 2005i). The risk assessments will include a comparison of the data to risk-based screening levels, and a comparison of the data to background soil, surface water, and sediment data. The focus of the risk assessments will be on those CCB-derived constituents that are present at concentrations above both risk-based screening levels and background levels.

1.0 INTRODUCTION

In April 2004, the United States Environmental Protection Agency (USEPA) and the Respondents (Brown Inc., Ddalt Corp., Bulk Transport Corp., and Northern Indiana Public Service Company (NIPSCO)) signed an Administrative Order on Consent (AOC II) (Docket No. V-W-'04-C-784) to conduct a Remedial Investigation and Feasibility Study (RI/FS) at the Pines Area of Investigation, as set forth in Exhibit I to AOC II, located in the environs of the Town of Pines, Indiana. AOC II (Section VII. 22) and its attachment, the Statement of Work (SOW) (Task 4), require the Respondents to develop a Remedial Investigation (RI) Report as a component of the RI/FS process. This document provides the RI Report for the Pines Area of Investigation, or the Area of Investigation. The RI Report follows the structure for RI reports established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (USEPA, 1988). It meets the requirements in AOC II and the SOW, and is consistent with the National Contingency Plan (NCP) (USEPA, 1990).

1.1 Purpose of this Report

The RI Report documents the findings of the RI. As stated in the SOW, the RI has been conducted (AOC II, 2004):

“(a) to determine the nature and extent of contamination at the Site and any threat to the public health, welfare, or the environment caused by the release or threatened release of hazardous substances, pollutants or contaminants related to Coal Combustion By-products (“CCB”) at or from the Site”, and

“(b) to collect data necessary to adequately characterize...(i) whether the city water service extension installed pursuant to AOC I, as amended, is sufficiently protective of current and reasonable future drinking water use of groundwater in accordance with Federal, State, and Local requirements; (ii) any additional human health risks at the Site associated with exposure to CCBs; and (iii) whether CCB-derived constituents may be causing unacceptable risks to ecological receptors.”

This RI consists of implementing an extensive field investigation outlined in the USEPA-approved Field Sampling Plan (FSP), Volume 2 of the RI/FS Work Plan (ENSR, 2005e), and evaluating and interpreting the information and data collected. The information and data and the interpretations presented in this RI Report will serve as the basis for the human health and ecological risk assessments. In turn, these assessments will be the basis for decision-making concerning additional actions to be taken, if any. If human health or ecological risks above risk targets are identified, the Feasibility Study (FS) will evaluate alternative remedial actions to address the risk.

1.2 Area of Investigation Background

This section provides the location and description of the Area of Investigation as well as a brief history of the Area of Investigation.

1.2.1 Location and Description

The extent of the Area of Investigation as defined by AOC II is shown in the United States Geological Survey (USGS) topographic map on Figure 1-1. The area is located primarily in the Town of Pines, in Porter County, Indiana. It is located immediately west of the city limits of Michigan City, Indiana, and approximately 4,500 feet (ft) south of the southern shore of Lake Michigan. The Indiana Dunes National Lakeshore (IDNL), managed by the National Park Service (NPS), is located between Lake Michigan and the Town of Pines. A small portion of the IDNL is included within the Area of Investigation. To create a basemap for the Area of Investigation, Air Maps, Inc. was contracted to fly over the Area of Investigation and generate an electronic version of the topography and features within the Area of Investigation (Air Maps, 2004). The Area of Investigation was flown on March 13, 2004, and the basemap is provided on Figure 1-2. A detailed street map of the Town of Pines is provided in Figure 1-3. Additionally, a large size basemap including topographic detail is provided in Appendix Z.

1.2.2 Yard 520

Yard 520 is located within the Area of Investigation (see Figure 1-2), and is a Restricted Waste Facility permitted by Indiana Department of Environmental Management (IDEM), in which CCBs have been disposed. Restricted waste sites are permitted to accept a single, non-hazardous restricted waste type with similar physical and chemical properties (329 IAC 10-9-4); these wastes are classified as Type I through Type IV restricted wastes based on the leachable concentrations of certain constituents. CCBs were legally disposed in the Yard 520 Restricted Waste Facility from the 1960s to 2001. Historically, an "insignificant" amount (less than 5%) of construction/demolition debris, such as concrete, lumber, steel, and brush, and steel-making wastes were also disposed at Yard 520 (Brown, 1981; Weaver Boos, 1996a).

Yard 520 consists of two areas: the northern portion which was permitted for Type II wastes, and is referred to as the Type II (North) Area; and the southern portion which was permitted for Type III wastes, and is referred to as the Type III (South) Area. The Type II (North) Area was in use until approximately 1986, and was closed in 1986-1987 (Weaver Boos, 1996b). Use of the Type III (South) Area started at that time. A 10-foot wide clay barrier was constructed between the Type II (North) and Type III (South) Areas. The Type III (South) Area was constructed into the clay confining unit with excavated clay forming the four sides (e.g., ATEC, 1989). The Closure Plan for the Type III (South) Area was approved in September 2003 (IDEM, 2003). The Type III (South) Area was closed in 2004 and the closure was approved by IDEM in August 2005. Uncapped fly ash materials were identified beyond the historical waste boundary for the Type II (North) Area in 2001 (Weaver Boos, 2003d). The

fly ash materials were located along the east, north and west boundaries of the Type II (North) Area. To address these materials, a Supplemental Closure Plan was submitted to IDEM in October 2003 (Weaver Boos, 2003d), and the plan was approved by IDEM in August 2005. This Supplemental Closure was completed in 2006-2007.

As part of the closure activities for both the Type II (North) and Type III (South) Areas, each area received a final cover in accordance with applicable regulations for an Indiana Type II or Type III Restricted Waste Site. The final cover for each area consisted of a minimum of 2 ft of compacted clay, which was then covered with a topsoil layer sufficient to support vegetation. A vegetation layer consisting of mixed grass and legume species to facilitate rapid growth and long-lasting durability was then planted in the topsoil layer. As part of the closure, the storm water management impoundment located east of the Type III (South) Area was also closed.

Groundwater monitoring has been conducted at Yard 520 since at least the early 1980s through the present (e.g., Weaver Boos, 2004). Figure 1-4 shows the locations of existing monitoring wells, piezometers, and staff gauges associated with Yard 520. Some of the existing Yard 520 monitoring locations were used to collect data as part of the RI field investigation. In addition, historic data from on-going Yard 520 monitoring were considered during the development of the FSP and the evaluation of the RI data.

1.2.3 History

The Town of Pines is located in Porter County, Indiana and has a population of approximately 800 (US Census, 2000). The Town of Pines is primarily a residential community with some commercial (e.g., restaurants, gas stations, motels, etc.) and industrial (e.g., Illiana Block) land use in addition to undeveloped and/or open space areas such as parks/playgrounds, wetland/swamp areas, wooded areas, ponds, and drainage ditches. Until recently, the water supply for the residences and businesses in the Town of Pines has been through domestic (private) wells located on individual properties which pumped groundwater from the shallow surficial aquifer and/or the deeper confined aquifers. In addition, there is no sewer service in the Town of Pines, so all septic wastes are presumed to be discharged to individual, subsurface septic systems.

Between 2000 and 2004, IDEM and USEPA conducted sampling of private wells in a portion of the Town of Pines. Boron (B) and molybdenum (Mo) were detected in some samples at concentrations above USEPA Removal Action Levels (RALs) (USEPA, 1998). USEPA suspected that these concentrations above USEPA RALs were derived from CCBs because CCBs have been disposed of at Yard 520 (see Figure 1-2), and CCBs were reported to have been used as fill in areas within the Area of Investigation outside of Yard 520.

To address the B and Mo detections above these USEPA RALs, the Respondents agreed to extend the municipal water service from Michigan City to designated areas in the Town of Pines. This

agreement was documented in an Administrative Order on Consent, referred to as AOC I, dated February 2003. Subsequent sampling of additional private wells within the Area of Investigation indicated some concentrations near or exceeding these RALs. To address these exceedances, the Respondents voluntarily approached the USEPA to extend the municipal water service to a larger area, under the AOC I, amended, dated April 2004. The areas that received municipal water service are identified and shown in Figure 1-5. In addition to extending the municipal water service, AOC I, amended, includes a provision to supply bottled water to those residences within the Area of Investigation not connected to municipal water who accepted the offer for this service.

Concurrently, USEPA and the Respondents entered into AOC II (April 2004). Under AOC II, the Respondents committed to conduct a RI/FS for the Area of Investigation. The specific components of the RI/FS program are detailed below.

1.2.4 Overview of AOC II

AOC II outlines the requirements of the RI/FS program as agreed upon between USEPA and the Respondents. The SOW, an attachment to AOC II, provides details and a schedule for each task to be performed to complete the RI/FS. These tasks include:

- Task 1 - RI/FS Site Management Strategy
- Task 2 - RI/FS Work Plan and Field Sampling Plan
- Task 3 - Remedial Investigation
- Task 4 - Remedial Investigation Report
- Task 5 - Human Health and Ecological Risk Assessment and Reports
- Task 6 - Identification of Remedial Action Objectives
- Task 7 - Development and Screening Alternatives Technical Memorandum
- Task 8 - Feasibility Study Report
- Task 9 - Progress Reports
- Task 10 - Community Relations and Technical Assistance Plan
- Task 11 - Project Meetings

Several of these tasks have been completed to date. A brief description of the tasks completed is provided below.

Task 1 under the SOW required the preparation of a Site Management Strategy (SMS). The SMS, which outlined a preliminary conceptual site model, data gaps, and the strategy for certain elements of the RI/FS, was approved by USEPA and finalized in January 2005 (ENSR, 2005a).

Task 2 of the SOW involved the preparation of the RI/FS Work Plan. The Work Plan is contained in seven volumes, which set forth the comprehensive approach and specific details for conducting the RI and Risk Assessments for the Area of Investigation. These volumes are as follows:

- Volume 1 - Work Plan Overview
- Volume 2 - Field Sampling Plan (FSP)
- Volume 3 - Quality Assurance Project Plan (QAPP)
- Volume 4 - Health and Safety Plan (HASP)
- Volume 5 - Human Health Risk Assessment (HHRA) Work Plan
- Volume 6 - Ecological Risk Assessment (ERA) Work Plan
- Volume 7 - Quality Management Plan (QMP)

The RI/FS Work Plan (ENSR, 2005d-j) was approved by USEPA in September 2005. The FSP (Volume 2) provides guidance for the RI field investigation by specifying in detail the sampling and data-gathering methods to be used to meet the objectives of the RI. The FSP serves as the basis for Tasks 3 and 4, the RI field investigation and RI Report.

Task 3 of the SOW involved conducting the Remedial Investigation in accordance with the USEPA-approved RI/FS Work Plan, and in particular, the FSP. The RI field investigation program was conducted in several phases from October 2005 through April 2008.

Task 4 of the SOW requires the preparation of the RI Report (this document), which presents the information and data collected during the RI field investigation. This RI Report presents the characterization of the Area of Investigation, including a description and background of the Area of Investigation, previous remedial actions (e.g., installation of municipal water service), a description of the physical systems (e.g., geology, groundwater, surface water bodies, CCB materials, etc.), nature and extent of CCB-derived constituents in groundwater and other media that may be impacted, potential receptors of CCB-derived constituents, and the fate and transport of CCB-derived constituents in the environment. This information and data are consolidated to form a conceptual site model, which will serve as the basis for the HHRA and the ERA (task 5). A draft RI Report was submitted to USEPA on May 19, 2008. Comments were received from USEPA on August 25, 2008 (dated August 22, 2008). Responses to the USEPA comments are included in Appendix BB, and the RI Report has been revised based on those comments.

This document completes Task 4 of the SOW. The next step under the SOW is Task 5, which requires an evaluation of potential risks (current and/or reasonably foreseeable future) to human health and ecological receptors at the Area of Investigation due to CCB-derived constituents. These evaluations will be documented in two reports: the HHRA and the ERA. In accordance with the SOW, these reports will be submitted to USEPA within 60 days after approval of this RI Report.

1.3 Previous Investigations/Remedial Actions

Several investigations and remedial actions were conducted in the Area of Investigation prior to the RI field investigation. These investigations and remedial actions are discussed in the sections below.

1.3.1 Private Well Sampling by USEPA and IDEM

Between 2000 and 2004, IDEM and USEPA conducted sampling of private wells in the Area of Investigation (IDEM, 2001; IDEM, 2002a; IDEM, 2002b; TetraTech, 2001; TetraTech, 2002). USEPA compared the B and Mo results in private well groundwater samples to 1998 RALs (USEPA, 1998), using these RALs as precautionary levels to determine whether bottled water should be offered to residents on a temporary basis. USEPA used the 1998 RALs in 2003 to determine that response actions in the form of supplying bottled water and extending the municipal water service were necessary in the Area of Investigation, and that conducting an RI/FS was necessary.

As noted in the SMS, the 1998 RALs for B and Mo do not take into account more current technical and toxicological developments and advancements made in the general understanding about potential health effects associated with these constituents. In accordance with the approved Human Health Risk Assessment (HHRA) Work Plan (Volume 5 of the RI/FS Work Plan), the most current USEPA dose-response values for these and all constituents will be used in the HHRA.

USEPA has agreed that the comparison levels for the HHRA for B and Mo would be based on one-tenth of the most current USEPA screening levels, which are the USEPA Regional Screening Levels (RSLs; USEPA, 2009) (see correspondence in Appendix E). Therefore, the human health comparison level for B in groundwater is 0.730 mg/l; this value is one-tenth the USEPA RSL (USEPA, 2009) for tap water of 7.30 mg/l. Similarly, for Mo, the human health comparison level is 0.018 mg/l, which is one-tenth the USEPA RSL for tap water of 0.180 mg/l. Figures 1-6 and 1-7 show the results of the USEPA/IDEM private well sampling for B and Mo, respectively, compared to the human health comparison levels and RSLs.

1.3.2 Municipal Water Service Extension (AOC I and AOC I, Amended)

Under AOC I, municipal water service was extended from Michigan City to portions of the Town of Pines. Water lines were installed from December 2003 to April 2004 in the Town of Pines, in the two areas as shown on Figure 1-5. Additional sampling by USEPA of other private wells in 2003 indicated

concentrations near or exceeding RALs in additional areas. In early 2004, the Respondents voluntarily approached USEPA to extend the municipal water service to a larger area. This extension is documented in the AOC I, amended (AOC I, 2004). The additional water service was installed from June 2004 to December 2005. The areas served by municipal water service provided in AOC I and AOC I, amended are shown on Figure 1-5.

As homes were connected to the municipal water service, private wells were closed by an Indiana-licensed driller. A list of addresses that were connected to the municipal water service is provided in Appendix Y. USEPA approved the final completion of work conducted under AOC I on December 30, 2004; and for work conducted under AOC I, amended, on March 1, 2006.

1.3.3 Bottled Water

In addition to extending municipal water service to the area shown in Figure 1-5, bottled water was supplied to those who accepted the offer as directed under AOC I, amended. Bottled water was supplied to private homeowners during the installation of the municipal water service. It was discontinued once the homeowner was connected to municipal water service. Bottled water was also offered to homeowners located within the Area of Investigation, but outside of the municipal water service area, as shown on Figure 1-5.

Beginning in November 2007, based on preliminary findings of the RI (presented in Section 3.4.5 below), and with the approval of USEPA, bottled water was discontinued to a portion of this area, specifically, south of County Road E 1675N on Ardendale Road and Old Chicago Road.

1.3.4 Suspected CCB Sampling During Water Service Extension

As documented in the SMS, there are reports of CCBs used as road sub-base and/or fill in certain locations in the Area of Investigation. During the installation of the municipal water service under AOC I, amended, utility trenches were excavated along many streets, including areas where CCBs were reported to have been placed. The excavations provided an opportunity to observe the nature of the subsurface in those areas and collect samples of both suspected CCBs and native soils. A Municipal Water Service Extension Sampling and Analysis Plan (MWSE SAP) was developed for sampling during the water service extension (ENSR, 2005c). More than 20,000 ft of trenches were excavated while implementing AOC I, amended; from these, suspected CCBs were observed and sampled over approximately 4,300 ft. Details of the data collected under the MWSE SAP are provided in Section 2.2 of this Report.

1.3.5 CCB Sampling at Yard 520

In addition to the field investigation conducted under the RI/FS Work Plan, a separate sampling program was conducted at Yard 520 to determine whether polycyclic aromatic hydrocarbons (PAHs),

polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDDs/PCDFs), or radionuclides, are present in CCBs at concentrations that would warrant further evaluation. The sampling approach is documented in the Yard 520 Sampling and Analysis Plan (SAP) (ENSR, 2005b). The results of this Yard 520 investigation are presented in a separate document, "Evaluation of the Data Collected Under the Yard 520 Sampling and Analysis Plan" (ENSR, 2008), and a brief summary is provided below.

The results of PAH analyses were compared to human health and ecological risk-based comparison levels. Because the results were below risk-based comparison levels, USEPA agreed that the RI analytical program would not include PAHs (see Appendix E).

The results of the PCDD/PCDF analyses were below human health risk-based comparison levels, and generally below ecological risk-based comparison levels. USEPA requested that a limited number of sediment samples be collected and analyzed for PCDDs/PCDFs and radionuclides. This work was conducted in October 2006, concurrently with the RI sediment sampling program. Based on the comparison of the PCDD/PCDF results to human health and ecological risk-based comparison levels, USEPA agreed that the RI analytical program would not include PCDDs/PCDFs (see Appendix E).

The radionuclide data from Yard 520 are presented in the "Evaluation of the Data Collected Under the Yard 520 Sampling and Analysis Plan" (ENSR, 2008). These data will be evaluated in the Human Health Risk Assessment and the Ecological Risk Assessment (Task 5 of the SOW for AOC II), using the results of the visual inspections for suspected CCBs (see Section 2.4), and the radionuclide results for the background soil samples (see Section 4.2).

1.4 Report Organization

The subsequent sections of this RI Report provide the following information:

- **Section 2.0** describes the field investigation implemented for the Area of Investigation and provides the data and results obtained during the investigation.
- **Section 3.0** provides the physical characteristics of the Area of Investigation, including a description of topography, climate, surface water hydrology, description of CCBs, geology and hydrogeology, groundwater-surface water interactions, demography and land use, ecological habitat, and potential receptors.
- **Section 4.0** details the nature and extent of constituents in the Area of Investigation.
- **Section 5.0** addresses the fate and transport of CCB-derived constituents present in the Area of Investigation.
- **Section 6.0** summarizes the results of the RI and presents conclusions based upon the results.

- **Section 7.0** identifies the references used in this RI Report.

2.0 FIELD INVESTIGATION ACTIVITIES

This section of the RI Report summarizes the field activities conducted in the Area of Investigation in accordance with the approved RI/FS Work Plan, specifically, the FSP (ENSR, 2005e), the QAPP (ENSR, 2005f), and subsequent USEPA-approved adjustments. The field activities conducted under the MWSE SAP are also summarized here.

The RI consisted of collecting numerous environmental samples and performing analyses, tests, and studies. A summary of all of the locations where samples were collected and data and information obtained is shown on Figure 2-1 and summarized below:

- A total of 34 suspected CCB and 12 native soil samples were collected from utility trenches during the installation of the municipal water service.
- CCB visual inspections were conducted at over 3,800 inspection locations within rights-of-way (ROWs), as shown on Figure 2-3.
- CCB visual inspections were conducted at over 4,600 inspection locations on private property, as shown on Figure 2-3.
- Three samples of CCBs were collected from three borings drilled in the Type II (North) Area at Yard 520.
- A total of 25 background soil samples were collected from locations within and around the Area of Investigation.
- A total of five soil samples were collected from five soil borings located within the Area of Investigation.
- A total of 21 groundwater samples were collected from vertical profile intervals at five monitoring well locations.
- A total of 22 monitoring wells were installed within and around the Area of Investigation. An additional two borings were drilled, but monitoring wells were not installed due to the limited amount of groundwater at these locations.
- Two staff gauges were installed in two separate ponds located in the Area of Investigation.
- A total of 12 piezometers were installed within and around the Area of Investigation.
- Over 375 water level measurements were collected over a period of one year during five measuring events. In addition, over 300 additional water level measurements were collected over a one-year period during four measuring events following the RI monitoring period.

- Continuous water levels measurements were collected hourly over a period of one year at six locations within the Area of Investigation.
- Surface water flow rates were measured five times over a period of one year at six surface water locations within the Area of Investigation.
- Hydraulic conductivity testing (slug testing) was conducted at the 22 monitoring wells installed during the RI and at four existing Yard 520 monitoring wells.
- A total of 87 groundwater samples were collected over a period of one year during four sampling events from the 22 installed monitoring wells.
- A total of 38 groundwater samples were collected over a period of one year during four sampling events from up to 11 existing Yard 520 monitoring wells.
- A total of 92 surface water samples were collected over a period of one year during four sampling events from 23 locations.
- Shallow sediment samples were collected at 19 locations. At 8 of the 19 locations, sediment samples were collected at both shallow and deeper depths.
- A total of 33 groundwater samples were collected from private wells over a period of one year during four sampling events from up to nine locations.
- Ecological habitats were evaluated and documented in a portion (a 0.7-square-mile (sq. mi.) area) of the Area of Investigation.

Figure 2-1 shows sample locations for all the field investigations listed above. Because some of the sample locations are co-located or are relatively close together, the symbols for types of samples taken at a sample location may overlap and, therefore, may not show clearly. Details (including detailed figures of sample locations for each type of field investigation) of all of the sampling and evaluations conducted are provided below.

2.1 General Field Procedures

This section of the RI Report describes the overall procedures followed during the field investigation program. Procedures were implemented in accordance with the FSP (ENSR, 2005e).

2.1.1 Access Agreements and Permits

The Area of Investigation encompasses approximately 1,450 acres (2.3 sq. mi.) and includes a variety of public and private properties. To the extent possible, investigation samples under the RI were collected in public ROWs. Sampling locations that were not within ROWs required obtaining an access agreement from the individual private property owner. Due to the large number of properties requiring access agreements, several months were needed to identify property owners, contact them, and

obtain signed agreements. In addition to needing access agreements for sample locations, access agreements were also required for conducting visual inspections on private property. There were many more locations for the visual inspection work than sampling locations, and so these access agreements took longer to obtain.

The process of obtaining access agreements began with identifying potential sample locations and then determining the property owner of record with the aid of the Pine Township Trustee's office or through a title company (Ticor Title Insurance Company). Once the owner was identified, a formal access request was mailed to the owner via registered mail. For cases where signed access agreements were not returned promptly, attempts were made to contact owners by telephone or in person to discuss any questions or concerns. In a number of cases, the owners could not be contacted or refused to allow access to the property. In these instances, alternative locations were identified, approved by USEPA, and the access process implemented. No locations were accessed during the RI without obtaining an access agreement.

Under CERCLA §121(e)(1), permits to conduct the RI were not required. However, public entities were notified of the work prior to the commencement of field activities. As applicable, communications and notifications of work conducted under the RI were sent to:

- US Army Corps of Engineers, Detroit District;
- IDEM, Office of Water Management;
- National Park Service (at IDNL);
- State of Indiana Department of Transportation (DOT);
- Porter County and neighboring La Porte County; and
- The Town of Pines.

Additionally, in accordance with the AOC II, USEPA and IDEM were provided notice at least 15 days prior to the start of any significant field work conducted under the RI at the Area of Investigation.

2.1.2 Adjustments and Field Change Orders

During the implementation of the FSP, adjustments and changes to the FSP were necessary for reasons such as modifications to sampling procedures, sample locations, revisions to analytical procedures, or unexpected conditions. When the need for an adjustment was identified, field staff coordinated with the RI Task Manager to discuss the modification. USEPA approval of the adjustment was then requested. USEPA approved all the adjustments which were requested. Field changes were documented in accordance with ENSR Standard Operating Procedure (SOP) Number 100 Pines

and recorded on a field form. Copies of all Field Change Orders (FCOs) are included in Appendix A and, as appropriate, are discussed in the following sections.

2.1.3 Suspected CCB Terminology

A significant element of the RI field investigation was the identification of suspected CCBs, both as part of geologic logging and during suspected CCB visual inspections. These determinations were made from visual examinations performed by geologists and trained field staff based on the following general observations (implementing the USEPA approved protocol included in Appendix E). In the Area of Investigation, the appearance of materials suspected to be CCBs is generally different from the appearance of native soils, but not necessarily distinct from other types of fill. The native soils are typically tan colored sands in the dune uplands and dark-colored, fine-grained organic soils in the lowlands. CCBs are typically visually distinct. However, the identification by visual observation alone of whether a material is a CCB (versus another type of fill material) and, if so, what type of CCB (fly ash, boiler slag, etc.) cannot always be made conclusively in the field. For example, bottom ash from coal combustion (a CCB) may appear in the field similar to steel-making slag (not a CCB). Also, non-native materials may include other types of fill materials that are not CCBs, for example, re-worked soil materials, steel-making slag, gravel and rubble, etc. Any potential uncertainty is resolved for purposes of the RI by referring to non-native materials having a visual appearance consistent with CCBs as “suspected CCBs.” In addition, when suspected CCBs are encountered in the field, they are often mixed with native soils, especially sand. Therefore, the description of non-native materials as “suspected CCBs” is applied to a range of materials that includes a very small to a larger portion of “suspected CCB” material, and the suspected CCB material may include different amounts of various types of different CCBs. The presence of suspected CCBs noted in field logs should not necessarily be interpreted to mean that the material is entirely composed of suspected CCBs, or if indeed a CCB, that any particular type of CCB was identified.

2.1.4 Investigation Derived Waste Management

Investigation Derived Waste (IDW) produced during the RI was managed in accordance with the FSP, USEPA, and IDEM regulations. Below is a summary of how each IDW material was managed.

- Used personal protective equipment (PPE) such as sampling gloves, paper towels, or other similar materials were bagged and sealed prior to disposal as general refuse.
- Used disposable sampling equipment such as tubing and empty bottles were disposed of with the used PPE as general refuse.
- Drill cuttings from the installation of the GeoProbe® borings at Yard 520 and RI monitoring wells were containerized in 55-gallon drums. Cuttings that by visual inspection appeared to contain suspected CCB materials were placed in separate 55-gallon drums. Both soil and suspected CCB materials were disposed of by Republic Services, Inc. as non-hazardous waste. The materials

were transferred from 55-gallon drums to a roll-off container. The roll-off, containing approximately three cubic yards of material, was then transported to Republic Services, Inc.'s Forest Lawn landfill disposal facility located in Three Oaks, Michigan. The empty drums were disposed of as scrap metal.

- Groundwater generated during well development was containerized with the exception of MW119. With USEPA's approval, well development water from well MW119 (a background well) was discharged to the ground surface near the well location. All other development water was containerized in two 6,500-gallon Baker tanks. A sample of the collected development water was obtained from each tank and analyzed as requested by the Sanitary District of Michigan City. Based on the results (see Appendix B), the Sanitary District of Michigan City approved the discharge of approximately 11,000 gallons from both tanks to the sanitary sewer under the guidance of a Sanitary District employee. The water was discharged on August 23 and 24, 2006. Development water from monitoring well MW124, installed approximately two months later, was also containerized and through verbal approval from the Sanitary District of Michigan City, was discharged to the sanitary sewer.
- Decontamination fluids generated during field activities included visibly clear water and/or water mixed with a non-phosphate and non-borate (Detergent 8®) detergent. These fluids were discharged to the ground surface near the point of generation in accordance with the FSP.
- Purge water generated from Yard 520 monitoring wells during groundwater sampling was discharged immediately after sampling near the wellhead consistent with the normal Yard 520 monitoring procedures. To minimize the physical impact (that is, excess water) on the ground surface at private properties, purge water from the RI monitoring wells was containerized in 55-gallon drums and later discharged to the ground surface in the vicinity of MW122, located east of Yard 520 on property owned by Brown Inc. This procedure was approved by USEPA, and is documented in a FCO provided in Appendix A.

2.1.5 Contractors and Subcontractors

As required under AOC II, all service providers including all contractors, subcontractors, consultants, and laboratories which performed work for the RI were approved by USEPA. Qualifications for each service provider used during the RI were provided to USEPA. The approved service providers include:

- ENSR;
- Boart Longyear of Indianapolis, Indiana for well drilling and installation services;
- Enviro-Dynamics of Hebron, Indiana for GeoProbe® (soil boring) and HydroPunch® (vertical profiling) services;
- Columbia Analytical Services (CAS) of Rochester, New York for laboratory services;

- General Engineering Laboratories (GEL) of Charleston, South Carolina for laboratory services;
- TestAmerica Valparaiso (formerly Severn Trent Laboratories (STL) Valparaiso) of Valparaiso, Indiana for laboratory services;
- GeoTesting Express, Inc. of Boxborough, Massachusetts for laboratory services;
- University of Miami Tritium Laboratory of the Division of Marine and Atmospheric Chemistry at the University of Miami's Rosenstiel School of Marine and Atmospheric Science for laboratory services;
- Geochemical Technology Corporation (GTC) of Wheat Ridge, Colorado for laboratory services;
- Marbach, Brady & Weaver, Inc. of Elkhart, Indiana for professional land survey work; and
- Republic Services, Inc. of Merrillville, Indiana for disposal of soil and suspected CCB IDW generated during the RI field investigation activities.

2.1.6 Surveying

During the course of the RI field investigation, sample locations were surveyed by either Global Positioning System (GPS) or by an Indiana registered surveyor. Details of each survey method are discussed below.

2.1.6.1 GPS Survey

A GeoXT® Differential GPS was used to obtain horizontal coordinates (x and y) with an accuracy of ± 0.5 meters (m) for several types of locations within the Area of Investigation, including limits of suspected CCBs, HydroPunch® (vertical profiling), surface water, sediment, surface soil, and other sample locations. The data dictionary specified in the FSP was used during data collection. There were no accuracy issues associated with the data collected.

GPS positions were collected in the US State Plane System, Indiana West Zone North American Datum, 1983 (NAD83) (Continuously Operating Reference Stations (CORS) 96) datum. Data were then downloaded and converted to the Indiana West State Plane NAD83 coordinate system. Coordinates were then added to the project database.

For GeoProbe® borings, vertical elevations were also collected. Accuracy of vertical measurements with the GPS unit range from ± 1 meter to ± 2.5 meters. As necessary, data were corrected to account for measurement collection height. Vertical measurements were made in the North American Vertical Datum, 1988 (NAVD 88). Elevations were then added to the project database.

2.1.6.2 Civil Survey

A survey was conducted for the locations of all monitoring wells, staff gauges, and piezometers by an Indiana registered surveyor (Marbach, Brady & Weaver, Inc. of Elkhart, Indiana). At each location, horizontal coordinates were collected as well as vertical elevations. For monitoring wells and piezometers, the elevations of the top of casing and ground surface were surveyed. At staff gauges, the zero elevation on the gauge was surveyed. At fixed point locations (i.e., culverts), a white paint mark was placed at the measurement point which was then surveyed as the reference elevation.

Horizontal coordinates were surveyed to an accuracy of 0.1 ft and vertical elevations were surveyed to an accuracy of 0.01 ft. All horizontal measurements were made in the Indiana West State Plane NAD83 coordinate system. All vertical measurements were made in the NAVD 88. Coordinates and elevations were then added to the project database.

2.1.7 Utility Clearance

Prior to conducting intrusive subsurface activities, utility clearances were obtained from all appropriate utility companies (e.g., municipal water, electricity, cable, telephone, etc.) by contacting the Indiana Underground Plant Protection Service (IUPPS) a minimum of two full working days prior to the commencement of work. Where utility markings were not provided by utility companies on private property, field staff worked with property owners to supplement the IUPPS clearance.

2.1.8 Laboratories

The laboratory analyses of all samples collected were performed in accordance with USEPA-approved analytical protocols as specified in the RI QAPP (ENSR, 2005f), MWSE SAP (ENSR, 2005c), and Yard 520 SAP (and associated QAPP) (ENSR, 2005b). The table below indicates the laboratories used for the RI and analyses performed at each laboratory.

Sampling Event Laboratory and Location	Analyte
Aqueous samples (FSP)	
Columbia Analytical Services (CAS) Rochester, NY	Acid soluble sulfide, ammonia, anionic surfactants as methylene blue active substances (MBAS), bicarbonate alkalinity as CaCO ₃ , chloride, dissolved organic carbon (DOC), fluoride, hardness (calcium and magnesium), lithium, metals ¹ , nitrate as nitrogen, ortho-phosphate as phosphate, silica, sulfate, total suspended solids (TSS)
TestAmerica (formerly Severn Trent Laboratories) Valparaiso, IN	Bacteriology (Escherichia Coli (E. coli) and total coliform)
General Engineering Laboratories (GEL) Charleston, SC	Boron and total uranium (U) by inductively coupled plasma mass spectroscopy (ICP-MS); radium 226 (Ra-226), Ra-

Sampling Event Laboratory and Location	Analyte
	228, U-234, U-235, U-238
Geochemical Technology Corporation (GTC) Wheat Ridge, CO	Boron-isotope Ratio
University of Miami Miami, FL	Tritium
Sediment samples (FSP)	
CAS	Metals ² , sulfur, total organic carbon (TOC)
GEL	Grain size, bulk density, total U by ICP-MS
Suspected CCB and Native Soil samples (FSP)	
CAS	Arsenic
GEL	Grain size, bulk density
Suspected CCB (MWSE SAP) and Native Soil Samples (Yard 520 SAP)	
CAS	Metals ³ , hexavalent chromium, sulfur
CCBs at Yard 520 (FSP)	
CAS	Metals ⁴ , sulfur, TOC
GEL	Boron, total U by ICP-MS
GeoTesting Express Boxborough, MA	Grain size, bulk density
¹ Metals were Al, As, Ba, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Se, Si, Na, Sr, Ti, V, Zn ² In addition to the metals listed in footnote 1, B was also analyzed. ³ In addition to the metals listed in footnote 1, Sb, Be, B, Co, Hg, and Ag were also analyzed and Sr was not analyzed. ⁴ In addition to the metals listed in footnote 1, Sb, Be, B, Co, Hg, and Ag were also analyzed.	

2.2 Municipal Water Service Extension Sampling

As detailed in Section 1, municipal water service was extended from Michigan City to a large portion of the Town of Pines. The areas that received municipal water are shown in Figure 1-5. The municipal water lines were installed in two phases, from December 2003 through April 2004 (AOC I) and June 2004 through December 2005 (AOC I, amended). The installation of the municipal water lines in 2004-2005 provided the opportunity to observe the nature of the subsurface in certain areas and collect samples of native soil and suspected CCBs prior to the implementation of the RI. To conduct this investigation, the MWSE SAP was prepared (ENSR, 2005c). Implementation of the MWSE SAP included visual observation and collection of samples of suspected CCBs as well as native soils that were encountered during the MWSE installation. The purpose of this investigation was to provide general characterization of suspected CCBs. To accomplish this objective, the following tasks were conducted:

- Geologic logging of utility trenches with regard to the presence of suspected CCBs and native soils; and

- Collection of samples (both suspected CCBs and native soils) for laboratory analysis for selected metals and sulfur. Select samples of suspected CCBs were also analyzed for hexavalent chromium.

The native soil samples were collected to provide a baseline for comparison with the suspected CCB samples.

Samples of suspected CCBs and native soils were collected during the second phase of the installation of the water lines in 2004-2005. When suspected CCBs were encountered by the excavation contractor, ENSR field staff was notified. Upon arrival at the excavation location, field staff inspected the trench for suspected CCBs. The trenches were observed and the materials were logged on the appropriate field forms. Logging took place along the open trenches at fixed intervals: at 500-ft intervals where suspected CCBs were less than two ft thick and at 100-ft intervals where they were greater than two ft thick. Copies of the geologic logs are provided in Appendix C.

After the trench was visually inspected and logged, samples were collected from each logged location at 100-ft or 500-ft intervals, depending on the depth of the suspected CCBs. Sample collection procedures followed the protocols outlined in the MWSE SAP and are summarized below:

- For suspected CCBs, samples were collected from the side-wall of the trench at the mid-depth point of the suspected CCB horizon. Samples were collected at a minimum depth of one foot below ground surface (bgs) and a maximum depth of one foot above the base of the trench. In accordance with the MWSE SAP, samples were not collected below the water table (if present).
- For native soil samples, locations were selected where suspected CCBs were not encountered. Sample locations were selected to cover the general area in which the municipal water lines were installed and from a variety of native soil types (e.g., sand, peat). One to two samples were collected at each location. Sample depths ranged from one to seven ft bgs, depending on the trench depth and observed soil types, but above the water table (if present).
- The MWSE SAP provided for additional sampling between logged locations if the physical appearance of the suspected CCBs changed along the length of a trench. However, no such changes were observed during the sampling program and no additional samples were collected.

A total of 34 suspected CCB samples were collected from 34 trench locations, as shown on Figure 2-2. Samples were collected either directly from the sidewalls of the trench (where they were accessible from the ground surface) or by obtaining a sample from the contractor's excavation equipment (e.g., backhoe excavation bucket, etc.). Each sample was placed in a plastic bowl and homogenized prior to placement into laboratory-supplied sample containers. Samples were collected in accordance with ENSR SOP Number 7110 Pines as referenced in the MWSE SAP. As summarized on Table 2-1, samples were analyzed for metals and sulfur. Samples from 12 locations were also analyzed for

hexavalent chromium. After analytical laboratory results were evaluated, ten samples were selected and analyzed for grain size and bulk density.

A total of 12 native soil samples at various depths were collected from eight trench locations. Samples were collected either directly from the sidewalls of the trench (where they were accessible from the ground surface) or by obtaining a sample from the contractor's excavation equipment (e.g., backhoe excavation bucket, etc.). Each sample was placed in a plastic bowl and homogenized prior to placement into laboratory supplied sample containers. Samples were collected in accordance with ENSR SOP Number 7110 Pines as referenced in the MWSE SAP. Samples were analyzed for metals and sulfur (see Table 2-1). After analytical laboratory results were evaluated, eight samples were analyzed for grain size and bulk density.

In addition to the suspected CCB and native soil samples, a sample of the road base material (i.e., the layer just below the asphalt layer) was collected (identified as TP007). This sample was analyzed for metals and sulfur (see Table 2-1).

Appropriate quality assurance/quality control (QA/QC) samples were collected (e.g., duplicates). Decontamination of sampling equipment was not required because disposable sampling tools were used.

After each sample was collected, location coordinates were obtained with a handheld GeoXT® Differential GPS unit in accordance with procedures described in Section 2.1.6.1. Figure 2-2 shows the locations of all of the samples collected under the MWSE SAP, with the exception of TP007.

Based on the soil descriptions from geologic logging of the trenches, suspected CCBs encountered were typically dark grey to black sand-sized material, with some shiny, glassy, hard, black fragments. Samples of suspected CCBs may also include varying amounts of native soils, particularly sand. Native soils encountered were typically yellowish orange to tan fine sands or dark brown sandy organic peat. Of the more than 20,000 ft of utility trenches excavated (under AOC I, amended), suspected CCBs were observed and sampled along approximately 4,300 ft. Geologic logs are provided in Appendix C. Analytical results for the suspected CCBs and native soil samples are provided in Table 2-2 and are discussed in Sections 4.2 and 4.3.

2.3 Physical Characteristics

Samples of suspected CCBs and native soils were submitted for physical testing. Samples submitted for physical testing included samples from both the MWSE sampling (see Section 2.2) and the background soil sampling (see Section 2.6). After analytical laboratory results were evaluated, a subset of samples was selected for physical testing.

A total of ten suspected CCB samples were analyzed for grain size and bulk density.

A total of eight native soil samples (six granular (i.e., sand, silt, clay) and two organic (i.e., peat)) were selected for physical testing from the samples collected under the MWSE SAP. In addition, eight surface soil samples were selected for physical testing from the background soil samples (see Section 2.6). These native soil samples were analyzed for grain size and bulk density. In addition, the background surface soil samples were also analyzed for TOC.

A summary of the physical testing results is provided on Table 2-3. Copies of the laboratory testing results are included in Appendix D. The results of the physical testing are discussed in Section 3.4.2.

2.4 CCB Visual Inspections

As stated in the SMS Report (ENSR, 2005a), USEPA and IDEM files suggest CCBs may have been used as road sub-base and/or fill in areas of the Town of Pines. Figure 3 in the SMS Report shows areas of possible CCB distribution within the Area of Investigation based on anecdotal information. To establish the actual locations of suspected CCBs within the Area of Investigation, a field reconnaissance was conducted.

The field reconnaissance was conducted in two phases. In the first phase, all publically accessible roads and alleys were visually inspected for suspected CCBs within established ROWs. Where suspected CCBs were identified, the limits within the ROWs were documented. Based on the results of this first phase, available anecdotal information, and requests from property owners, a second phase of visual inspections was conducted on private properties where CCBs were suspected to be present and for which access was granted by the owners. Some owners did not agree to provide necessary access to their property, and therefore, visual inspections were not conducted at these properties. The visual inspections were also extended outside the Area of Investigation and into the IDNL on Central Avenue and Carolina Street because suspected CCBs were observed along Carolina Avenue, and the visual inspections were conducted until no further suspected CCBs were seen.

The specific procedures for the CCB visual inspections were approved by USEPA, and are set forth (including the qualifications of personnel performing them) in correspondence to USEPA dated August 15, 2007 (see Appendix E). At each location where a visual inspection took place, the location was surveyed with a handheld GeoXT® Differential GPS unit in accordance with procedures described in Section 2.1.6.1.

All locations inspected are shown on Figure 2-3. CCB visual inspections were conducted at over 3,800 locations within ROWs, and at over 4,600 locations on private property. The results of the inspections are discussed in Section 3.7.2.

2.5 CCB Sampling at Yard 520

In addition to the suspected CCB samples collected under the MWSE SAP discussed above, three additional samples were collected under the FSP at the request of USEPA from the Type II (North) Area at Yard 520. This sampling was conducted in advance of the full RI sampling program, and the purpose of this sampling was to further evaluate the list of analytical parameters for the RI.

The samples were collected by advancing three borings using GeoProbe® (direct-push) techniques. Sample locations were selected to provide a general cross-section through the Type II (North) Area, and to encompass a general range of time of placement of the CCB materials. The locations of the borings also provided a cross-sectional profile through the topographically high point of Yard 520. Additionally, a piezometer was installed in one of the borings to measure groundwater levels (see Section 2.8.2).

Three borings were advanced using GeoProbe® techniques on September 20, 2005. Borings were advanced until underlying native soils were encountered. As each boring was advanced, materials were logged on field forms in accordance with the ENSR SOP Number 7116 Pines as referenced in the FSP, Unified Soil Classification System (USCS) protocols, and IDEM guidance. One sample was collected for laboratory analysis from each boring. The depth of the sample interval, which was approved by USEPA in the field, was selected to exclude obvious non-CCB materials, such as concrete, brush, demolition debris, steel slag, native soils, and interim cover encountered during advancement of the boring. Samples were analyzed for parameters indicated on Table 2-1, and included metals and sulfur. Appropriate QA/QC samples were collected (e.g., duplicates) and submitted for analysis.

The boring logs prepared in the field for these three borings were misplaced. Therefore, the three borings were re-drilled on August 28 and September 5, 2006 to record soil classification information only; no soil samples were collected. Two of the borings (GP001 and GP002) were advanced on August 28, 2006 in the same locations as the previous borings. Due to heavy rain, the third boring (GP003A) was advanced on September 5, 2006. It had to be moved a short distance from the original location due to refusal. Each boring was logged on field forms in accordance with ENSR SOP Number 7116 Pines as referenced in the FSP, the USCS protocols, and IDEM guidance.

Between borings, all downhole equipment (e.g., drill rods) was decontaminated by removing gross materials with a scrub brush, followed by scrubbing with a mixture of Detergent 8® (a non-phosphate and non-borate detergent) and water, and then rinsed with potable water. Decontamination of sampling equipment (e.g., bowls and spoons) was not required since disposable sampling tools were used.

Coordinates were collected for the borings advanced in 2005 and 2006 with a handheld GeoXT® Differential GPS unit in accordance with procedures described in Section 2.1.6.1. Figure 2-4 shows

the locations of the borings installed in the Type II (North) Area at Yard 520. Boring logs from the 2006 advancements are provided in Appendix F.

The three CCB samples were analyzed for parameters indicated on Table 2-1, and included metals and sulfur. Analytical results are provided in Table 2-4 and discussed in Section 4.3. Sample results are from the original locations installed on September 20, 2005 and not from the re-drilled borings.

2.6 Background Soil Sampling

In addition to the native soil samples collected under the MWSE SAP (see Section 2.2), background surface soil samples were collected from locations believed to not contain suspected CCBs to determine site-specific background conditions.

All of the CCB-derived constituents under investigation at the Area of Investigation are also present naturally in many geologic materials in various parts of the world. CCBs originate from coals, which are a natural geologic material; therefore, all the chemical constituents in CCBs are also present in the original source coal. Therefore, to appropriately evaluate impacts associated with CCB-derived constituents, it is necessary to understand the natural levels of these constituents in soils in the vicinity of the Area of Investigation. The background soil sampling was conducted to provide these data. The work plan for this activity was included in the Yard 520 SAP (ENSR, 2005b).

Background surface soil samples were collected in areas believed to not contain suspected CCBs to determine typical background exposure point concentrations within the Area of Investigation. Sample locations were selected outside areas where suspected CCBs were used or placed, and where suspected CCBs were not present in the soils, based on visual inspection. Samples were collected from native soils, including two general soil types: granular soils (typically sand, but also including silt and clay) and organic soils (present in lowland and wetland areas). Note that the statistical treatment of background, and the classification of granular and organic soil types, will be addressed in the risk assessments. The background soil sample locations were approved by USEPA in correspondence dated April 16, 2007 (see Appendix E). Additionally, USEPA was present during the sampling, and adjusted some of the sample locations in the field. The final background soil sample locations are shown on Figure 2-5.

Surface soil samples were collected on April 30 and May 1, 2007 from the 25 approved background locations, including 15 samples of granular soils and 10 samples of organic soils. At each location, the soil material was visually inspected to minimize the possibility that suspected CCBs were present. The soils were observed and the materials were logged on field forms in accordance with the ENSR SOP Number 7110 Pines as referenced in the Yard 520 SAP, USCS protocols, and IDEM guidance. After the soils were logged, samples were collected at a depth of zero to six inches bgs. Surface litter, such as leaves and roots, were removed from the sample. The soil was homogenized then placed in laboratory-supplied containers. Appropriate QA/QC samples were collected (e.g., duplicates) and

submitted for analysis. Background samples were analyzed for metals (including total U), sulfur, and radionuclides as indicated on Table 2-1.

Following sample collection, any remaining soil was used to backfill the sample area. Decontamination of sampling equipment was not required because disposable sampling tools were used. Additionally, the location of each sample was surveyed with a handheld GeoXT® Differential GPS unit in accordance with procedures described in the Yard 520 SAP.

A summary of the surface soil sampling observations is provided in Appendix G. Background surface soil sample locations are shown on Figure 2-5. Analytical results for the background surface soil samples are provided in Tables 2-5 (metals and inorganic parameters) and Table 2-20 (radiological parameters) and are discussed in Section 4.2.

In addition, per USEPA request, a subset of five background soil samples (SS016, SS018, SS021, SS024, and SS025) were submitted for microscopic analysis to confirm the field visual inspection observations about the absence of CCB materials in the background samples. Samples were collected on February 11, 2010 from background soil material maintained in storage and submitted for analysis by polarized light microscopy, X-ray fluorescence, X-ray diffraction, and loss on ignition. Analytical results are discussed in Section 4.2 and a copy of the analytical summary report is provided in Appendix S.

2.7 Monitoring Well Installation

In accordance with the FSP, monitoring wells were installed within and around the Area of Investigation. The monitoring well locations were selected to meet the RI objectives; rationales for specific wells are presented in the FSP. The purpose of the monitoring well network was to obtain information on geologic and hydrogeologic conditions throughout the Area of Investigation, and to characterize groundwater chemistry conditions.

The well locations proposed in the FSP were approximate, and actual well locations were field-determined based on drill rig access and the presence of utilities. In addition, access agreements with private property owners were needed for many of the wells. In some cases, the owners did not allow a well on their property, and the well location had to be moved. Due to these factors, some final well locations were adjusted from those proposed in the FSP. Final well locations were submitted to and approved by USEPA (see Appendix E). One additional well, MW124, was also added to those proposed in the FSP as documented in a FCO dated August 18, 2006 (see Appendix A).

To select appropriate screened intervals for the monitoring wells, vertical profiling (see Section 2.7.1) at selected locations was conducted, and the results were used to evaluate the vertical variation in groundwater conditions. Based on the data obtained during the vertical profiling, screened intervals

were selected and approved by USEPA (see Appendix E). The monitoring wells were then installed and developed.

2.7.1 Vertical Profiling

Vertical profiling included collecting groundwater samples from multiple depths at several locations, and analyzing these screening-level samples for selected parameters to evaluate vertical variations in groundwater conditions. The FSP specified five locations for vertical profiling, as shown on Figure 2-6. The vertical profile locations were co-located with five of the proposed monitoring wells as indicated in the FSP. The objective of the vertical profiling was to evaluate the potential for significant variations in groundwater chemistry at different depths in the surficial aquifer. The results of the vertical profiling study were used to determine the screened intervals for the monitoring wells. A permanent monitoring well was subsequently installed adjacent to each vertical profile location, with one exception. Well MW115 was moved away from vertical profile location VP115 to a location upgradient from the homeowner's septic field as documented in the FCO dated June 5, 2006 (see Appendix A).

2.7.1.1 Sampling Methods

Vertical profiling was conducted on May 30 and 31, 2006 using HydroPunch® technology performed by Enviro-Dynamics of Hebron, Indiana. Temporary well screens were installed using direct-push methods (i.e., GeoProbe®) by advancing a retrievable stainless steel screen with a steel drop-off tip. The push rods were advanced at approximately five-foot intervals; the rod was then retracted two ft to expose a two-foot well screen. Groundwater was then pumped from within the drill rods at a low flow rate. The pumped water was passed through a flow-through cell to monitor field parameters including temperature, pH, dissolved oxygen (DO), oxidation reduction potential (ORP), specific conductivity, and turbidity. After approximately one well-volume of water was removed, a groundwater sample was collected. As summarized on Table 2-1, groundwater samples were submitted for laboratory analysis of B and Mo.

Field parameters were measured in accordance with the appropriate SOPs referenced in the FSP with the exception of turbidity. Turbidity was not measured with a separate instrument, instead it was measured by a probe within the flow-through cell. Sampling equipment was decontaminated between vertical profile locations in accordance with methods described in ENSR SOP Number 7600 Pines as referenced in the FSP.

Following the sampling at each location, coordinates were surveyed with a handheld GeoXT® Differential GPS unit in accordance with procedures described in Section 2.1.6.1.

2.7.1.2 Results and Conclusions

The results of the vertical profiling, and recommendations concerning well screen placement were submitted to the USEPA on June 21, 2006, and verbally approved by USEPA on June 30, 2006 (see Appendix E). A brief summary is provided here.

As expected from temporary well screens, turbidity in the samples was high. Concentrations of DO and ORP were generally typical of anaerobic (low-oxygen) conditions. The B and Mo concentration results did not strongly correspond to specific conductance, suggesting that specific conductance alone was not an appropriate indicator of the presence of B or Mo. However, the highest levels of B were consistently detected in the middle of the aquifer vertically. Based on these findings, the following recommendations were made concerning the screened interval for the monitoring wells:

- Where the saturated thickness of the aquifer was less than 15 ft, the monitoring well would be screened at the water table using a 15-ft screen with 10 ft set below the water table and 5 ft set above the water table.
- Where the saturated thickness was greater than 15 ft, the monitoring well would be set with a 10 ft screen in the center of the saturated thickness.

Data collected during the vertical profiling is only screening level data because the samples were not collected from properly constructed monitoring wells. Therefore, vertical profiling field parameters, B, and Mo data will not be used in the HHRA or ERA. Data from the monitoring wells subsequently installed at these locations will be used.

Data collected during the vertical profiling is summarized in a table included in the correspondence with USEPA and is provided in Appendix E. Locations of the vertical profiles are shown on Figure 2-6.

2.7.2 Monitoring Well Drilling and Installation

The FSP proposed the installation of monitoring wells by use of conventional drilling methods (e.g., hollow stem auger). During the procurement process for the drilling subcontractor, the installation method was changed to the sonic technology method for the following reasons:

- Running sands (heaving sands) were likely to be encountered during drilling in the surficial aquifer, which is predominantly fine sand. Use of a hollow stem auger in the presence of running sands would have made it difficult or impossible to collect representative soil cores over the full thickness of the aquifer. Use of the sonic technology method allowed continuous geologic cores to be collected, even in the presence of running sands.

- Using the hollow stem auger method in running sands would also make it difficult to install wells at the appropriate depths, and to emplace an appropriate gravel pack around the well screen. The running sands could be better controlled with the sonic technology method.
- The use of sonic instead of hollow-stem auger technology would have no impact on meeting the RI objectives.

Therefore, instead of a hollow stem auger, a mini-sonic drill rig was used. The mini-sonic rig drilled a six-inch diameter boring that allowed for continuous collection of soil cores. USEPA approved this change on a FCO dated June 16, 2006 (see Appendix A).

Drilling occurred between July 5 and 28 and on September 29, 2006 and was performed by Boart Longyear of Indianapolis, Indiana. Soil borings were extended down to the underlying clay confining unit so that the saturated thickness of the surficial aquifer could be determined. Continuous soil cores were collected during the advancement of each boring. The cores were examined and the materials were logged on field forms in accordance with ENSR SOP Number 109 Pines as referenced in the FSP, USCS protocols, and IDEM guidance. The data contained on the boring log forms were then uploaded to the project database. The data were then exported to a boring log program (STRATER[®] produced by Golden Software) and boring logs and well construction diagrams were generated. Monitoring well boring logs and well construction details are provided in Appendix H.

At borings that were advanced beyond the location of the screened interval, it was necessary to backfill the borehole up to the depth of screen placement. Where the surrounding formation materials were sand, the borehole was backfilled with clean silica sand up to the bottom of the screened interval. Where the surrounding material was clay, bentonite pellets or chips were used to backfill the borehole up to one foot below the bottom of the well screen. The space between the bentonite and screen was filled with clean silica sand.

Wells were constructed of two-inch diameter, schedule 40 polyvinyl chloride (PVC) piping with threaded joints. The screens used were 0.010-inch factory-slotted PVC and were set at the interval specified in Section 2.7.1.2. Clean silica sand (#5) was placed around the well screen to approximately two ft above the well screen. The FSP specified two ft of bentonite chips above the sand followed by grout to the ground surface. This procedure was modified so that bentonite chips were placed on top of the sand to approximately one foot below the ground surface (see approved FCO in Appendix A). Wells located in high traffic areas or as requested by the property owner were set with flush-mounted road boxes. All remaining wells were installed with a steel protective stand-up casing. Road boxes were set flush to the ground surface and cemented above the bentonite chips to the ground surface. Steel stand-up casings were installed to approximately two ft below the ground surface and cemented above the bentonite chips to the ground surface. All wells were then completed with a two-foot by two-foot cement apron to hold the road box or protective casing. The apron was mounded to direct surface water run-off away from the well. All wells were closed/sealed with a

locking well cap. Well construction details are provided in the well logs in Appendix H and summarized on Table 2-6.

Between boring locations, all downhole drilling equipment was decontaminated by steam cleaning according to the procedures in ENSR SOP Number 7600 Pines as referenced in the FSP. Drill cuttings were handled as IDW as described above in Section 2.1.4.

Monitoring wells were not set at two of the locations proposed in the FSP (SB112 and SB118) because of the thin saturated thickness of the aquifer at these two locations. The FSP specifies that wells would not be installed where less than five ft of saturated thickness was encountered. As documented on the drilling logs (see Appendix H), the saturated thickness encountered at these two locations was 2 and 2.5 ft, respectively. Therefore, wells were not installed at these two locations.

Following the installation of the monitoring wells, coordinates and elevations were surveyed by a registered Indiana surveyor in accordance with the methods described in Section 2.1.6.2. The locations of the RI monitoring wells are shown on Figure 2-7. Surveyed elevation data for the wells are included on Table 2-6.

2.7.3 Monitoring Well Development

After the installation of the monitoring wells, each well was developed to:

- Remove the fluids introduced during drilling;
- Remove silts and fine material from the well and filter pack;
- Establish good hydraulic connection with the formation;
- Restore the permeability of the formation in the area around the well; and
- Enable collection of representative groundwater samples.

Each well was developed in accordance with procedures outlined in ENSR SOP Number 7221 Pines as referenced in the FSP. Wells were developed using the surge-block method with alternative pumping to remove water and fines. The development process was continued until a minimum of three times the volume of water used during the well installation was removed. Turbidity was measured during the development process to ensure that values were below 50 Nephelometric Turbidity Units (NTU). At wells where turbidity was still above 50 NTU after three wells volumes were removed, additional development continued until turbidity values were below 50 NTU.

Details of the well development including the volume of water used during drilling, the volume removed during development, and the turbidity measurements were recorded during development. A summary of this information is provided on Table 2-7.

Purge water for well MW119 was discharged to the ground in the vicinity of the well with the approval of the USEPA as documented in a FCO dated July 10, 2006 (see Appendix A). Development water for all remaining wells was containerized and handled as IDW in accordance with procedures described in Section 2.1.4, above.

All down-well equipment used for well development was decontaminated according to the methods described in ENSR SOP Number 7600 Pines as referenced in the FSP.

After development was completed, all monitoring wells were allowed to re-equilibrate after development for a minimum of two weeks prior to well sampling.

The geologic information obtained during drilling is discussed in Section 3.4. Geologic logs are included in Appendix H. The well construction information is summarized on Table 2-6, and well locations are shown on Figure 2-7. The wells were used to collect data on aquifer hydraulic conductivity, water levels, and groundwater chemistry. These data are discussed in later sections of this report.

2.8 Staff Gauge and Piezometer Installation

Staff gauges and piezometers were installed within and around the Area of Investigation to measure surface water and groundwater levels. These water level measurements provide data on seasonal variations, and recharge and discharge locations, and to help characterize the hydrogeology and evaluate groundwater/surface water interactions. The methods used to install these devices are described below. In addition, existing structures at certain fixed locations (i.e., culverts) within and around the Area of Investigation were used as data points for surface water level measurements.

2.8.1 Staff Gauge Installation

At locations that did not have a fixed measuring point, a staff gauge was manually installed. In areas where fixed structures were available (i.e., culverts), these structures were used as a surface water measuring point. White paint was used to mark the surveyed reference elevation point for fixed structures.

On August 15 and 16, 2006, two staff gauges (SW013 and SW014) were installed in pond locations within the Area of Investigation, as shown on Figure 2-8. The installed staff gauges are constructed of stadia-marked gauges mounted on a fixed structure (i.e., PVC pipe) and graduated every 0.01 ft. The staff gauges were manually driven into the



Staff gauge at SW014

ground/sediment surface; an example is shown in the photograph to the right.

Following the installation of the two staff gauges, their locations and elevations and the location and elevations of the six culverts used as surface water measuring points were surveyed by a registered Indiana surveyor in accordance to methods described in Section 2.1.6.2. The locations of all eight surface water gauging locations are shown on Figure 2-8.

2.8.2 Piezometer Installation

Twelve piezometers were installed between June 12, 2006 and October 17, 2006 to monitor groundwater and surface water levels within and around the Area of Investigation. All but one of the piezometers (PZ001) were installed in surface water bodies to monitor both groundwater and surface water levels. Field conditions required some piezometers to be installed at modified depths (see approved FCOs in Appendix A).

All piezometers (except PZ001) are constructed of galvanized steel pipes with 2.5 ft stainless steel screens. They were manually driven into the ground/sediment surface to a depth at which the screen was two ft bgs or below the sediment surface. At SW031, the screen was set at 17 inches bgs due to hard ground (see FCO in Appendix A). Each piezometer (except PZ001) was capped with a non-locking screw cap, as approved by USEPA in a FCO dated June 12, 2006 (see Appendix A).

In addition to the piezometers in or near surface water bodies, one piezometer, PZ001, was installed on September 23, 2005 in the Type II (North) Area of Yard 520. PZ001 was installed adjacent to one of the GeoProbe® borings, GP002. The piezometer was constructed of a three ft screen set at a depth of 27 to 30 ft bgs, with a riser extending to the ground surface. Because the piezometer intercepted the cap of the Type II (North) Area, the piezometer was grouted from the ground surface to three ft bgs with hydrated granular bentonite. A locking protective steel casing was also installed around this piezometer. The steel casing and pad were installed on October 12, 2005, and the piezometer was developed, due to silt accumulation, in accordance with methods described in Section 2.7.3. The construction of PZ001 is documented on the log for GP002/PZ001 (see Appendix F). PZ001 was abandoned on May 5, 2008, as required by the FSP. A copy of the abandonment record is included in Appendix I.

Following the installation of the 12 piezometers, the locations and elevations were surveyed by a registered Indiana surveyor in accordance to methods described in Section 2.1.6.2. The locations of all 12 piezometers are shown on Figure 2-8 and copies of the construction logs are provided in Appendix I.

2.9 Water Level Measurements

Groundwater and surface water levels were measured five times during the RI (once per calendar quarter) over the period beginning with August 2006 and ending with July 2007. The data collected have been used to determine hydraulic gradients and groundwater flow directions in the surficial aquifer and evaluate groundwater-surface water interactions on a seasonal basis. Water levels were measured manually at surface water and groundwater data collection locations installed as part of the RI, at existing Yard 520 monitoring wells, and at selected USGS monitoring wells. Due to the number of locations, water levels were measured over two consecutive days.

In addition, groundwater levels were electronically recorded on an hourly basis for a one-year period at several locations within the Area of Investigation to provide data on short-term water level changes and variability between seasons (see Section 2.9.3 below).

The water level measurements were collectively used to generate groundwater contour maps (see Section 3.4.2). Details on each of the water level measurement methods are described below.

2.9.1 Groundwater

Groundwater level measurements were collected from up to 56 locations including the RI monitoring wells, Yard 520 monitoring wells, and four USGS monitoring wells. Groundwater levels were also collected from up to 12 piezometers. At locations where groundwater samples were collected, water level measurements were collected prior to purging and sampling.

Groundwater level measurements were collected using an electronic water level indicator fitted with a weighted cord, accurate to 0.01 ft. Depth to water was measured from the surveyed elevation mark on the well or piezometer riser. For piezometers, the depth to groundwater was measured to the water level inside the piezometer. Measurements were made and recorded in accordance with ENSR SOP Number 101 Pines as referenced in the FSP. The water level indicator was decontaminated between measurement locations according to the methods described in ENSR SOP Number 7600 Pines as referenced in the FSP.

Groundwater measurement locations are shown on Figure 2-9. Depth to water and groundwater elevations for all five water level measuring events are provided on Table 2-8. Groundwater contour maps and discussion of the data are provided in Section 3.4.2.

2.9.2 Surface Water

Surface water level measurements were collected from up to 23 locations on the Main Branch, East Branch, and West Branch of Brown Ditch, on tributaries to Brown Ditch, on Brown Ditch in the IDNL, on two ponds, and on Kintzele Ditch (see Figure 2-9).

At piezometers and culverts, surface water level measurements were collected in a manner similar to the groundwater level measurements. A weighted electronic water level indicator accurate to 0.01 ft was used to measure surface water levels. Depth to water was measured from a surveyed elevation mark on a fixed structure, such as a culvert, or from the top of the casing on the piezometer. For the piezometers, the depth to surface water was measured to the water on the outside of the piezometer. Measurements were made and recorded in accordance with ENSR SOP Number 101 Pines, and the water level indicator was decontaminated between measurement locations according to the methods described in ENSR SOP Number 7600 Pines as referenced in the FSP.

For the two staff gauges installed at pond locations and the existing Yard 520 staff gauges, measurements were read directly from the staff gauge at each location.

Surface water measurement locations are shown on Figure 2-9. Surface water measurements and elevations for all five water level measuring events are provided on Table 2-9. The data are discussed in Section 3.6.

2.9.3 Continuous Water Levels

Water levels were continuously measured at six locations (four groundwater and two surface water locations) for a one-year period to evaluate short-term water level changes and variability between calendar quarters. As specified by the FSP, the locations for continuous water level measurement were selected after evaluating the results of the first round of groundwater and surface water sampling; the locations were subsequently approved by USEPA (see Appendix E). Continuous water level measuring locations included groundwater in an upland area (MW106) and a wetland area (MW122), and two paired groundwater/surface water locations (MW111 with SW015, MW-3A with SW022). Monitoring both surface water and groundwater levels at the same location provides information on hydrologic interactions between the two systems, such as the response of groundwater and surface water to the same precipitation events. The wetland location was selected to evaluate evapotranspiration. The locations where continuous water levels were monitored are shown on Figure 2-10.

At each of the continuous water level measuring locations, In-Situ® Level TROLL® 300 pressure transducers with internal dataloggers were installed in accordance to the manufacturer's specifications. For monitoring well locations, each transducer was set securely (i.e., locked) within the well and protected from disturbance. For surface water locations, a stilling well was attached to the piezometer in which a transducer was securely placed and protected from any disturbance, as shown in the photograph on the right.



Piezometer SW015 at left with PVC stilling well at right in which transducer was installed.

The pressure transducers measure water levels at an accuracy of at least 0.01 ft. The pressure transducers and data loggers were programmed to record water levels once each hour. Data collection began on February 2, 2007 for all locations with the exception of MW122, which began on March 12, 2007. Several days after each transducer was installed, data were downloaded to ensure the equipment was functioning properly. Thereafter, data were downloaded on a monthly basis, and the programmed reference elevations were checked. Throughout the monitoring period, there were no discrepancies between the manual and the programmed water level readings. Therefore, the continuous water level data are considered accurate. Water level monitoring at these locations continued through April 11, 2008. The continuous water level data are discussed in Section 3.5.

2.9.4 Additional Water Level Monitoring

In addition to the five rounds of water levels collected in accordance with the FSP, monitoring of water levels continues on a regular basis (except at USGS wells). Through July 2008, four additional water level datasets are available, for October 2007, and January, April, and July 2008. Water levels are measured using the procedures described in the previous sections. The additional data are provided on Tables 3-3 and 3-4.

2.10 Surface Water Flow Rates

Surface water flow measurements were collected at six locations within the Area of Investigation to estimate groundwater discharge rates along the Main Branch, East Branch, and West Branch of Brown Ditch. Locations were selected as outlined in the FSP. During the first round of measurements (August 2006), one location originally selected (SW021) was not accessible due to high water (see FCO in Appendix A). Therefore, an alternate location was selected (SW030) just downgradient from the original location; and flow measurements were obtained at this location in subsequent measuring events. Surface water flow rates were measured five times during the RI (once per calendar quarter), in conjunction with groundwater and surface water level measurement events. Locations of flow measurement points are shown on Figure 2-11.

2.10.1 Field Methods

At each location, the surface water velocity was measured using a Marsh-McBirney Flo-mate Model 2000 current-meter. The current-meter is mounted on a top-setting, weighted rod and kept vertical during data collection with the field technician standing downstream of the measurement location. If necessary, prior to data collection, the area was cleared of obvious temporary debris, such as sticks, which could have interfered with the current-meter. At each surface water flow measurement location, the cross-section of the ditch was divided into five to ten compartments, depending on the width of the ditch at that location. Using the current-meter, the average velocity in each compartment was measured at 60% depth from the water surface. This series of measurements was performed twice at each location.

2.10.2 Data Analysis

Using the velocity measurements collected, surface water flow was calculated following procedures described in the USGS publication *Discharge Measurements at Gauging Stations* (USGS, 1969). Surface water flow in each compartment was calculated using the following equation:

$$q_x = v_x \left[\frac{b_x - b_{(x-1)}}{2} + \frac{b_{(x+1)} - b_x}{2} \right] d_x$$

Where, at each compartment:

x = Designates the particular compartment

q_x = Calculated flow at compartment x

v_x = Water velocity measured at compartment x

b_x = Measured distance from the reference bank to the center of compartment x

d_x = Water depth in the center of compartment x

After the surface water flow was calculated for each compartment at a surface water flow measurement point, the total flow for that location was calculated by summing each compartment's flow using the following equation:

$$Q = \sum q_x$$

Where:

Q = Total flow

q_x = Calculated flow at each compartment

The surface water flow measurement process was conducted twice at each location, and so two values of flow were computed which were averaged to obtain the reported surface water flow rate. Results are presented on Table 2-10. Field conditions and measurements were collected and recorded on collection forms in accordance with the FSP. Copies of the surface water flow rate collection forms are provided in Appendix J.

To evaluate the reliability of the surface water flow rates, the reproducibility of the two measurements at each location was evaluated. A relative percent difference (RPD) was calculated for each pair of measurements (similar to the evaluation performed with laboratory analyses of field duplicate

samples). Ideally, RPDs should be near zero. The RPDs show that there is often poor reproducibility, with many values greater than 20% and even up to 500%. The poor reproducibility is due to two primary factors: (1) at very low flow rates, measured velocities were at or near the sensitivity of the instruments; and (2) it was difficult to accurately measure ditch widths and depths in non-channelized reaches. The lack of reproducibility of the flow measurements shows that their accuracy is limited, and the limitations in the data should be recognized when they are considered in the RI.

2.11 Hydraulic Conductivity Testing

Hydraulic conductivity testing (slug testing) was conducted in monitoring wells within the Area of Investigation to estimate aquifer hydraulic conductivity. Slug testing was conducted in January and February 2007 at a total of 26 monitoring wells including the 22 RI monitoring wells and 4 existing Yard 520 wells (MW-6, MW-10, MW-11, and TW-18D). The FSP proposed slug testing at five Yard 520 wells, but MW-3A and MW-1 were damaged and could not be tested. MW-10 was proposed as an alternative to MW-1 but an acceptable alternative to MW-3A was not available. These changes were approved by USEPA (see FCO in Appendix A). Locations where slug testing was performed are shown on Figures 1-4 and 2-7.

2.11.1 Testing Methods

At the start of the slug test at each well, the static water level was measured (to 0.01 ft) using an electric water level meter. An electronic water level/pressure transducer (an In-Situ® MiniTROLL®) was then lowered to a depth of approximately one foot above the base of the well. The transducer was programmed to collect water level measurements (to 0.01 ft) at 0.5-second intervals. The water level in the well was measured to ensure it had returned to static conditions after installation of the transducer. Once the static water level was re-established, a PVC slug of known volume was lowered into the well just above the water table.

Rising and falling head tests were completed at each well. For quality control purposes each test was performed at least twice.

For the falling head tests, the slug was dropped into the well as quickly as possible so that its entire length was below the water table. The test continued until the water returned to its initial static level. A rising head test was then conducted by restarting the data logger and removing the slug completely from the well as quickly as possible. The rising head test was completed when the water rose back to its initial static level. A second set of falling and rising head tests was then performed following the same procedures.

Slug testing and associated data collection were conducted in accordance with ENSR SOP Number 102 Pines. Non-disposable field equipment used for slug testing was decontaminated between sampling locations in accordance with ENSR SOP Number 7600 Pines.

2.11.2 Data Analysis

Slug test data were analyzed using the AQTESOLV 4.5 software produced by HydroSOLVE, Inc. Data were matched against the Bouwer-Rice solution (Bouwer and Rice, 1976) for unconfined aquifers using the straight-line fitting method. In highly permeable aquifers, an oscillating water level response is sometimes observed, for which an alternative solution method would be needed (e.g., Springer and Gelhar, 1991). This type of response was not observed in any of the slug tests. The values of hydraulic conductivity calculated from the slug tests are presented in Table 2-11. Plots of all slug tests completed at each well and AQTESOLV output files, including graphs of the fitted lines, are provided in Appendix K.

Well-specific values used for the Bouwer-Rice solution, such as aquifer thickness and screened interval, were taken from field data and well logs. The maximum displacement observed during the slug testing (as recorded by the datalogger) was used as the initial displacement for line fitting.

Due to the relatively high permeability of the surficial aquifer, slug test data can exhibit pressure effects and other irregularities, which can make analysis problematic, especially for falling head tests. Slug tests that exhibited these types of behavior were not quantitatively analyzed, and so results are not included in Table 2-11, but the data are included in Appendix K for reference. Falling head tests are generally considered less accurate than rising head tests under certain circumstances. For this reason only values from the rising head tests have been used to compute the geometric mean for hydraulic conductivity for the Area of Investigation. However, the hydraulic conductivity values estimated from the falling heads are provided on Table 2-11 for reference. Based on the slug test data (rising head tests only), the calculated hydraulic conductivity of the surficial aquifer in the Area of Investigation ranged from 3.1 to 54.1 feet per day (ft/day), with a geometric mean of 14.7 ft/day.

2.12 Groundwater Sampling

Groundwater samples were collected from all RI monitoring wells and selected Yard 520 monitoring wells four times during the RI (once per calendar quarter) over the period beginning with August 2006 and ending with April 2007. Figure 2-12 shows the locations of the monitoring wells sampled. Groundwater samples were analyzed for metals, radionuclides, and other inorganic parameters, and for bacteriological parameters, as outlined in Table 2-1. Appropriate QA/QC samples were collected (e.g., duplicates, equipment blanks, etc.). Changes to the analytical lists were proposed for some sampling events, and were approved by USEPA (see Appendices A and E).

Groundwater samples were collected using low stress (low flow) purging and sampling procedures in accordance with ENSR SOP Number 7130 Pines. The details of the purging and sampling, including the field measurements collected, are provided on the Field Sampling Data Sheets included in Appendix M. Peristaltic pumps were used for purging and sampling each well, with the exception of MW105. The water column at MW105 was greater than the maximum hydraulic head for the peristaltic

pump for three of the four sampling events. Therefore, a Teflon® bladder pump was used for purging and sampling this well. Disposable polyethylene tubing was used in the peristaltic and bladder pump for each monitoring well. Pump intakes were set at the midpoint of the saturated screen and a minimum of two ft above the bottom of the well.

Water levels were monitored during purging using an electronic water level indicator. Drawdown and flow rate were monitored and recorded. During purging, flow rates did not exceed 0.5 liters per minute (l/min) and drawdown was stable and less than 0.3 ft (see Appendix M).

Groundwater was pumped through a flow-through cell during purging, and pH, specific conductivity, temperature, DO, and ORP were measured. Parameters were measured using a YSI 600XL water quality meter calibrated in accordance with manufacturer's specifications as described in ENSR SOP Number 105 Pines. Turbidity was measured separately using a LaMotte 2020 turbidity meter in accordance with ENSR SOP Number 108 Pines.

Parameter measurements were recorded approximately ten minutes after the flow-through cell was full and approximately every five minutes thereafter. Purging was complete and sampling began when three consecutive readings were within the limits set forth in the FSP. In general, the groundwater pumped from the wells in the Area of Investigation has relatively low turbidity. However, efforts were made to lower the turbidity to less than five NTU prior to sampling by reducing the purge rate, if necessary. Additionally, efforts were made to lower the turbidity to less than one NTU, if possible. When turbidity could not be lowered to less than five NTU, samples were collected after the measured parameters, including turbidity, were stable for three consecutive readings and the condition was noted on the groundwater sampling form.

The flow-through cell was disconnected prior to sample collection. Groundwater samples were placed in their respective laboratory-supplied sample containers, preserved, if necessary, and placed on ice. During all sampling events, samples designated for DOC analysis were field filtered by affixing a 0.45-micron, in-line, cartridge filter to the discharge tubing. Approximately 50 milliliters (ml) of groundwater were allowed to flow through the filter prior to filling the appropriate sample containers. In addition, during the October 2006 sampling event, samples for boron-isotope ratio analysis were also field filtered in the same manner. Field filtration was completed in accordance with ENSR SOP Number 7131 Pines. Because of the acceptable turbidity of the groundwater samples, no other groundwater samples were field filtered.

Field conditions and measurements were recorded on sample collection forms in accordance with ENSR SOP Number 7130 Pines. Copies of the groundwater collection forms are provided in Appendix M. Non-disposable field sampling equipment was decontaminated between sampling locations in accordance with ENSR SOP Number 7600 Pines.

The groundwater samples were analyzed for the parameters listed in Table 2-1. Samples were shipped to the analytical laboratories on ice using a commercial overnight courier. Samples to be analyzed for bacteriological parameters were delivered or couriered to STL, now TestAmerica.

The groundwater analytical results, including field parameters, from the four sampling events are provided in Tables 2-12 and 2-13 and discussed in Section 4.4.

2.13 Surface Water Sampling

Surface water samples were collected four times during the RI (once per calendar quarter) over the period beginning with August 2006 and ending with April 2007 from 23 locations in ditches and other surface water bodies located within and around the Area of Investigation. Installed markers (stakes) were set so that the samples were collected at the same locations at each event. Figure 2-13 shows the locations of the surface water sample collection points. Surface water samples were analyzed for metals (filtered and unfiltered) and other inorganic parameters, as outlined in Table 2-1. Appropriate QA/QC samples were collected (e.g., duplicates, equipment blanks, etc.). Changes to the analytical lists were proposed for some sampling events and were approved by USEPA (see Appendices A and E).

2.13.1 Field Reconnaissance for Surface Water Sampling Locations

Surface water sampling locations were initially identified and verified in the field as part of a field reconnaissance conducted by ENSR on October 21, 2004. The field reconnaissance was attended by representatives of the Respondents, USEPA, and the NPS. The objectives of the field reconnaissance were to identify, mark out, and survey the locations of surface water (and sediment) samples in Brown Ditch, and make observations on relevant characteristics and features of the ditches and associated biota.

Based on this reconnaissance, consensus was reached on the location of 24 surface water sampling locations, as indicated in the FSP. One of the proposed locations, in the Yard 520 storm water management impoundment, was unavailable because it had been filled in as part of the Yard 520 Closure Activities (see FCO in Appendix A). Therefore, surface water samples were collected at 23 locations during each of the four sampling events.

2.13.2 Sampling Methods

Fixed surface water sample collection locations were established by installing stakes at each sample location so that samples were collected at the same location for each sampling event. Surface water samples were collected at downstream locations first, then at upstream locations. In the event that the sample location required the field technician to wade into the water, the technician positioned

him/herself downstream from the sample locations so that disturbed sediment was not included in the sample.

Prior to sample collection, water quality parameters were measured at each surface water sample collection location. A YSI 600XL Water Quality Meter was used to measure pH, specific conductivity, temperature, DO and ORP in accordance with ENSR SOP Number 105 Pines. Turbidity was measured separately using a LaMotte 2020 turbidity meter in accordance with ENSR SOP Number 108 Pines. Field parameters were measured by submerging the instrument probe in flowing surface water and recording the measurements after stabilization. In pond environments, shallow and deep measurements were collected to evaluate potentially stratified conditions. Visual observations including color, biota, and estimated water velocity were also made and recorded.

Depending on conditions at the sample collection location, one of two methods was used to collect the surface water samples. Where locations were accessible, samples were collected using a clean, disposable 1-liter (1-l) polyethylene bottle as a sampler. The capped bottle was immersed slowly into the water to the mid-channel, mid-depth point, and was then uncapped and allowed to fill completely, capped, and then slowly lifted out of the water. Care was taken not to disturb sediments during surface water sample collection. The collected surface water sample was then transferred from the sampler into its appropriate laboratory-supplied sample containers, preserved, if necessary, and placed on ice. The 1-l polyethylene samplers were disposed of after each sampling location. The second method of surface water sample collection was used for inaccessible locations and used a peristaltic pump to pump surface water directly from the surface water body into the appropriate sample containers. The pump was placed on the land surface and disposable polyethylene tubing was placed directly in the surface water body with the intake point at the mid-depth, mid-channel sample location point. Prior to filling the sample containers, surface water was pumped through the tubing for approximately 30 seconds. Care was taken to not disturb sediment with the pump intake during sampling.

Samples to be analyzed for dissolved parameters (e.g., selected metals) were filtered by using a peristaltic pump with clean polyethylene tubing to pump water from the disposable sampler, if used, or directly from the surface water body through a 0.45-micron, in-line, cartridge filter into the appropriate sample containers. Approximately 50 ml of surface water were allowed to flow through the filter prior to filling the sample containers. Field filtration was completed in accordance with ENSR SOP Number 7131 Pines.

Field conditions, measurements, and calculations were collected and recorded in the field logbook and on appropriate sample collection forms in accordance with ENSR SOP Number 103 Pines. Copies of the surface water collection forms are provided in Appendix N. Decontamination of sampling equipment was not required because disposable sampling tools were used.

The surface water samples were analyzed for the parameters listed in Table 2-1. Samples were shipped to the analytical laboratories on ice using a commercial overnight courier.

The surface water sample analytical results, including field parameters, from the four sampling events are provided in Tables 2-14 and 2-15 and discussed in Section 4.5.

2.14 Sediment Sampling

In accordance with the FSP, 19 sediment samples were collected in October 2006 from locations in ditches and other surface water bodies located within and around the Area of Investigation. The USEPA was present during the second day of the sediment sampling, and observed the procedures and methods. Most of the sediment samples were co-located with surface water samples. Figure 2-14 shows the locations of the sediment sample collection points. Sediment sample collection locations were identified as described below. Shallow (0 to 0.5 ft) sediment samples were collected from all 19 locations. At eight locations, an additional sample was collected at a greater depth (0.5 to 1 ft) based on the field reconnaissance described below. Sediment samples were analyzed for metals, sulfur, TOC, and physical parameters, as outlined in Table 2-1. Appropriate QA/QC samples were collected (e.g., duplicates, equipment blanks, etc.). Changes to some sediment sampling locations, parameters analyzed, and time of sampling were proposed and were approved by USEPA (see Appendices A and E).

2.14.1 Field Reconnaissance for Sediment Sampling Locations

A field reconnaissance was conducted on October 21, 2004 to identify surface water and sediment sample collection locations. A second field reconnaissance of Brown Ditch was conducted on November 2, 2005 with representatives of USEPA and USGS to identify sediment sample collection locations in the ditch system. As noted in the FSP, sample locations were selected to be preferentially in depositional environments where available. For the selection of a sediment sample collection location in the IDNL, a representative of the NPS also participated.

The field reconnaissance activities were conducted in mid-fall to take advantage of better access to and visibility of the tributary system due to lower water levels and decreased foliage. The objectives of the field reconnaissance activities were to finalize, mark out, and survey locations of sediment samples in Brown Ditch, including one sample location on Brown Ditch within the IDNL (SW027); inspect the southern bank of the East Branch of Brown Ditch for possible presence of dredge spoils (none were found); examine the depth and nature (e.g., sand, clay, organic, etc.) of soft sediment at sediment sample locations to select locations where collection of both shallow (0 to 0.5 ft) and deep (0.5 to 1 ft) sediment samples would be obtained; and make observations and field notes on relevant characteristics and features of the ditches and associated biota.

Based on this reconnaissance activity, through email correspondence on October 17, 2006, USEPA approved (see Appendix E) the location of 20 sediment sample collection locations at which samples were collected in October 2006 (see Figure 2-14). One of the proposed locations, in the Yard 520 storm water management impoundment, was unavailable because it had been filled in as part of the

Yard 520 Closure Activities (see FCO in Appendix A). Therefore, sediment samples were collected at 19 locations during the October 2006 sampling event.

2.14.2 Sampling Methods

Sediment samples were collected at the same time as the second groundwater and surface water sampling event in October 2006. Surface water samples were collected prior to sediment samples to minimize the potential for entraining suspended sediments in the water samples. Sediment samples were collected from downstream to upstream locations, similar to surface water sample collection.

The methods used to collect sediment samples varied depending on the depth of the water body where the sediment samples were being collected. Where water was less than three inches deep, a stainless steel trowel was used to directly collect the sample. Where water was greater than three inches, but shallow enough to allow wading, a Russian Peat Borer was utilized to collect the sample. All in-stream sediment samples were collected using the Russian peat borer. The Russian Peat Borer is a side-filling, chambered sampler that is manually inserted to the desired depth, then rotated to collect a sample (see photograph below).



Sediment samples from locations within ponds too deep for wading were collected from a boat using an Eckman Dredge. The Eckman Dredge is a spring loaded clam-shell sampler (see photograph).



Eckman Dredge used to collect sample from SW013.

Shallow sediment samples were collected from all locations at a depth of 0 to 0.5 ft below the surface of the sediment. At 8 of the 19 locations (as agreed during the field reconnaissance), additional samples were also collected at a greater depth of 0.5 to 1 ft. Sediment sample locations are shown on Figure 2-14, which also shows the locations at which the deeper samples were collected.

Once the sediment samples were recovered, the length was measured (if collected using the Russian Peat Borer), physical properties were logged on the appropriate field forms, and the sample was placed in a stainless steel bowl for dewatering. The sampling instrument was filled a sufficient number of times at each sample location to obtain a sufficient sample volume for analysis. Dewatering was performed using a combination of decanting and filtering using a stainless steel colander lined with Whatman #4 filter paper. Samples were set into the colander in a thin layer and allowed to drain for approximately ten minutes to remove as much water as possible. The dewatered sample was homogenized in a separate stainless steel bowl and then placed into appropriate laboratory-supplied sample containers. Sample collection, dewatering, and homogenization were completed in accordance with ENSR SOP Number 103 Pines.

Field conditions and measurements were recorded on appropriate sample collection forms in accordance with ENSR SOP Number 103 Pines. Copies of the sediment collection forms are provided in Appendix O. Non-disposable field sampling equipment was decontaminated between sampling locations in accordance with ENSR SOP Number 7600 Pines.

The sediment samples were analyzed for the parameters listed in Table 2-1. Samples were shipped to the analytical laboratories on ice using a commercial overnight courier.

The sediment sample analytical results are provided in Tables 2-16 and discussed in Section 4.6.

2.15 Private Well Sampling

Samples from private wells were collected four times during the RI (once per calendar quarter) over a period beginning with August 2006 and ending with April 2007, from up to nine locations. Figure 2-15 shows the locations of the private wells sampled. During the second sampling event (October 2006) a sample of the Michigan City public water supply was also collected (for analysis of boron-isotope ratios).

Prior to sampling, private well owners were contacted and permission obtained to conduct the sampling. During the first sampling event, private well owners were interviewed to obtain available information regarding well location, depth and construction, and information about the water distribution system in the house. These details are summarized in Table 2-17. At that time, the specific sampling location for each private well was chosen. Sampling locations were chosen as close to the wellhead as possible, and from locations that are not treated (i.e., before hot water and water softening systems). The locations selected were typically outdoor spigots. Purge water was discharged to the ground in the vicinity of the spigot, with owner approval.

Samples from private wells were analyzed for metals, other inorganic parameters, and bacteriological parameters, as outlined in Table 2-1. Appropriate QA/QC samples were collected (e.g., duplicates, etc.). Changes to the analytical lists and sample locations were proposed for some sampling events and were approved by USEPA (see Appendices A and E).

For each private well, the water at the selected sample location (typically the outdoor spigot) was run for approximately 15 minutes prior to sampling to flush stagnant water out of the piping. Purging duration and estimated flow were recorded on the sample collection form. Field parameters were measured from water collected into a clean plastic container after the 15-minute purge. A YSI 600XL Water Quality Meter was used to measure pH, specific conductivity, temperature, DO, and ORP in accordance with ENSR SOP Number 105 Pines. Turbidity was measured separately using a LaMotte 2020 turbidity meter in accordance with ENSR SOP Number 108 Pines. Appropriate laboratory-supplied sample bottles were filled directly from the spigot at the sampling location, preserved as required, and placed on ice. Water was allowed to run continuously between sample bottles and not turned off. Private well sampling activities were completed in accordance with ENSR SOP Number 106 Pines.

Field conditions and measurements were collected and recorded in the field logbook and on appropriate sample collection forms in accordance with ENSR SOP Number 106 Pines. Copies of the private well sample collection forms are provided in Appendix P. Decontamination of sampling equipment was not required because samples were collected directly from the spigot at each sample collection location.

The private well samples were analyzed for the parameters listed in Table 2-1. Samples were shipped to the analytical laboratories on ice using a commercial overnight courier. Samples to be analyzed for bacteriological parameters were delivered or couriered to STL, now TestAmerica, in Valparaiso, Indiana.

The private well groundwater analytical results, including field parameters, from the four sampling events are provided on Tables 2-18 and discussed in Section 4.4. When requested, sampling results were provided to the individual homeowners.

2.16 Additional Soil Sampling for Arsenic

USEPA requested that additional soil samples be collected and analyzed for arsenic (As) as part of the RI because it was suggested by the Technical Advisor to the local Technical Assistance Plan (TAP) group (P.I.N.E.S.) that there could be impacts to soils beneath and/or downgradient from CCBs due to leaching of CCB-derived constituents, and that these soils could accumulate higher concentrations of constituents than the original CCB material. Specifically, the Technical Advisor hypothesized that As concentrations in soils beneath and/or downgradient from CCBs could be elevated above the concentrations measured in CCBs. USEPA requested that the Respondents evaluate this hypothesis by conducting additional soil sampling. A sampling plan was submitted to USEPA on November 20, 2007, which was subsequently approved by USEPA (see Appendix E). Details of the sampling are provided below.

2.16.1 Sampling Methods

Soil samples were collected within the Area of Investigation in areas reported or observed to have at least five ft vertically of suspected CCBs present. Samples were collected from native soils, including both granular soils (typically sand) and organic soils (present in lowland and wetland areas) present beneath or downgradient from suspected CCBs. The final sample locations were approved by USEPA in correspondence dated November 28, 2007 (see Appendix E). Additionally, USEPA was present during the sampling, and participated in field decisions to further adjust the sample locations. The final soil sample locations are shown on Figure 2-16.

Soil borings were advanced using GeoProbe® techniques on December 19, 2007 at the five approved locations, in accordance with ENSR SOP Number 7116 Pines as specified in the RI FSP. At each location, borings were advanced through any observed suspected CCBs and into the underlying native soils. The soils were observed and the materials logged on field forms in accordance with ENSR SOP Number 7116 Pines as referenced in the FSP, USCS protocols, and IDEM guidance. After the soil materials were logged, samples were collected from the interval one to two ft beneath the suspected CCBs. The soil was homogenized, and then placed in laboratory-supplied containers. Appropriate QA/QC samples (e.g., duplicates, equipment blanks, etc.) were also collected and submitted for analysis. Samples were submitted to the laboratory for analysis of As.

Following sample collection, any remaining soil was used to backfill the borehole and sample area. Decontamination of sampling equipment was conducted by manually scrubbing and washing (see FCO in Appendix A).

The location of each sample was surveyed with a handheld GeoXT® Differential GPS unit in accordance with procedures described in Section 2.1.6.1. Soil boring logs are provided in Appendix Q. Soil sample locations are shown on Figure 2-16.

2.16.2 Results and Conclusions

Data collected during the soil sampling is summarized in a table included in the correspondence with USEPA (dated February 21, 2008), and is provided in Appendix E.

The reported As concentrations in the soil samples ranged from not detected in two of the samples to a maximum of 11.7 mg/kg.

To evaluate these results, the concentrations of As in the samples collected were compared to As concentrations in background soil samples as well as As concentrations in suspected CCB samples collected from the Area of Investigation. The concentrations of As in 34 suspected CCB samples (plus three field duplicates) collected during the installation of the municipal water service lines ranged from 3.6 J to 92.7 mg/kg. Concentrations of As in 25 background surface soil samples (plus three field duplicates) ranged from not detected to 29.5 mg/kg.

These data demonstrate that soils beneath or downgradient from suspected CCBs do not contain elevated concentrations of As compared to suspected CCBs. The data also establish that concentrations of As in soils beneath or downgradient of suspected CCBs are within the range of background concentrations of As. Therefore, based on these results, no further evaluation was conducted.

In addition, to address the concern that As concentrations in soils downgradient from Yard 520 could become significantly greater, this hypothetical situation was evaluated. Groundwater from Yard 520 flows downward into the native soils beneath Yard 520, then outward from there. These native soils are located at the base of the surficial aquifer, as shown by the higher concentrations of CCB-derived constituents in the deep relative to shallow wells (e.g., TW-15S/D, TW-16S/D, TW-18S/D). Therefore, the hypothetical phenomenon of elevated As concentrations in soils would occur also at the base of the surficial aquifer. Arsenic is not detected in the shallow wells of these pairs, which are screened down to depths ranging from 21 to 30 feet below the ground surface (see Table 2-6). Arsenic is elevated in TW-15D (but not detected in TW-16D and TW-18D). These wells are screened at depths ranging between 28 and 47 ft below the ground. Therefore, As is present and being attenuated in groundwater at depths greater than 20 ft. Soils at these depths would not be accessible for human contact.

However, the potential for As accumulation in shallow soils downgradient from significant CCB deposits will be examined in the risk assessment to determine, qualitatively, whether there are potential risks to residents, workers, or the environment from exposure to these soils. In addition, potential future groundwater chemistry changes that could result in As returning to solution in groundwater will be evaluated for human health and ecological risks in the risk assessments.

2.17 Ecological Habitat Characterization

To support the ERA, the RI included identification and characterization of ecological habitats within a portion of the Area of Investigation (ENSR, 2005e). The ecological habitat inspection area for the Area of Investigation is shown in Figure 2-8 of the FSP, and outlined on Figure 2-17 here. To identify ecological habitat, applicable methods for general habitat evaluation and wildlife identification for non-wetland or mixed wetland/upland habitats were used. This procedure consisted of developing a preliminary ecological habitat map of the inspection area by analysis of available aerial photographs, maps, and relevant project documents, followed by a field inspection to confirm, refine, and finalize the map. These methods are explained below.

2.17.1 Ecological Habitat Literature Review

To create a preliminary ecological habitat map, available literature and maps were reviewed. These documents included a recent aerial photograph of the Area of Investigation (flown on March 13, 2004), other available aerial photographs, U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) maps, USGS topographic maps, town assessor maps, regional wildlife records, and other project information to identify areas of general habitat types. Based on a review of these documents, seven general habitat or land use types were identified within the habitat inspection area, including:

- *Residential.* This land use type includes private homes, driveways, maintained lawns, and backyards. Limited vegetated areas (e.g., hedges, landscaped areas) were included in this classification. Residential areas were delineated from aerial photographs (PCRTPC, 1970; NIRPC, 1980, 1990, 2000; AirMaps, 2004).
- *Commercial/Disturbed.* Commercial and disturbed areas include businesses, parking lots, unpaved areas of exposed soils, poorly vegetated filled land, junkyards, and other areas containing stockpiles, rubble, or abandoned equipment. Commercial and disturbed areas were identified using aerial photographs.
- *Agricultural.* Upland areas with fields, row crops, or tree farms were delineated as agricultural lands. Any buildings located adjacent to agricultural land were included in the delineation of agricultural lands. Agricultural lands were delineated based on aerial photographs.
- *Maintained Grass.* Aerial photographs were reviewed to identify undeveloped upland areas lacking woody vegetation, and that appeared to be periodically disturbed or periodically mowed.

These areas do not include residential lawns, backyards, or commercial landscaping, but may include pastures, and areas apparently managed for hunting purposes, or other purposes.

- *Forested or Scrub-Shrub.* All remaining upland areas within the Area of Investigation comprised of undeveloped and vegetated land was mapped as forested or scrub-shrub. This habitat type includes hardwoods, conifers, and mixed hardwoods-conifers.
- *Wetlands.* Wetlands identified for this habitat assessment include ditches and other water features, and vegetated wetlands such as marshes, shrub swamps, or forested swamps. Wetlands were initially identified on the USFWS 1987 NWI Map (USFWS, 1987) with a variety of designations including: Palustrine Forested Broad-leaved Deciduous Temporarily Flooded (PFO1A), Palustrine Forested Broad-leaved Deciduous Seasonally Flooded (PFO1C), and Palustrine Emergent Marsh Seasonally Flooded (PEMC). Wetland areas were mapped using the basemap of the Area of Investigation (see Figure 1-2), and checked against the aerial photograph of the same area.
- *Open Water.* Open water areas mapped in the Area of Investigation are generally ponds and ditches. Open water areas were also identified using the USFWS 1987 NWI maps, and using the basemap of the Area of Investigation (see Figure 1-2). These maps were checked against the aerial photograph of the same area.

Based on the results of this mapping, the preliminary ecological habitat map was completed and submitted to USEPA in July 2006 (see Appendix E). The preliminary ecological habitat map was then confirmed by field inspection by a qualified ecologist in August 2006, as described below.

2.17.2 Field Inspection Methodology

The preliminary ecological habitat map was field verified through a field inspection conducted on August 15-17, 2006. Field verification was conducted by comparing the preliminary habitat assessment to relevant field observations, which were made through a combination of windshield surveys (i.e., visual observations made from a vehicle) in the more residential areas, and by excursion into some interior locations that were not observable from the roadway. Some field verification was completed during previous reconnaissance work and observations made during inspection and identification of surface water and sediment sampling locations (e.g., see Sections 2.13.1 and 2.14.1), and so, for this field inspection, emphasis was placed on review of upland areas, locations near residential areas in the northeastern portion of the Area of Investigation, and those areas not previously visited.

A street-by-street windshield survey was used to review the preliminary ecological habitat types adjoining streets in an area bounded by the north to West Dunes Highway (Route 12), to the east by County Line Road, to the south by Second Place, and to the west by Ardendale Avenue. Windshield surveys were also conducted along all sections of Railroad Avenue, between County Line Road and Birch Street. Additional observations were made at eight locations in less populated areas that were

selected as representative of the common habitat areas in that portion of the Area of Investigation (see Figure 2-17 and Appendix U).

Because the purpose of the field investigation was to identify general habitat features to support selection of generalized ERA receptors, a systematic inventory of all species and vegetation was not conducted. Instead, dominant vegetation and wildlife observed (i.e., visual, signs, calls) were noted. Field notes were made on field data forms (adopted for use from MADEP, 2006) and are provided in Appendix R. Community types identified were based on the *Natural Communities of Indiana* (Jacquart et al., 2002). Relevant community types described below are shown on Table 2-19. Field observations of important habitat parameters, included:

- Determination of natural community type;
- Slope, aspect, and topography throughout the habitat area of analysis and adjacent areas;
- Vegetative characteristics (percent ground cover and dominant indicator species);
- Specific habitat feature analysis (brushpiles, snags, den trees, standing dead timber, mast- and fruit-producer abundance, herbaceous or cereal vegetation);
- Observation of wildlife sign, including tracks, scat, burrows, rubs and scrapes, spawning activity;
- Analysis of habitat feature requirements for specific species as required (e.g., perch types, substrate type and depth, etc.);
- Habitat type interspersed and habitat edge feature analysis (e.g., area of contiguous habitat; integrity of existing habitat); and
- Level of disturbance, proximity to roads and human settlement, or other potential habitat impairment factors.

Based on the field inspection, the preliminary ecological habitat map provided in Appendix U was updated, and the ecological habitats are shown on Figure 2-17. Agricultural, commercial/disturbed, and residential areas are not shaded because these areas are areas of active human activity and disturbance and are, therefore, not considered viable ecological habitat areas. The field inspection did not result in any major change in the land types identified as part of the preliminary (remote-based) habitat classification, only some of the habitat boundaries were refined. The habitats found interspersed within the residential areas located north of Second Place were found to be fragmented habitats of small size, separated by roadways and residences. Also, clarification was made of lands where vegetation had been managed for wildlife habitat rather than agricultural purposes. The field inspection revisions were generally limited to areas north of the East and West Branches of Brown Ditch. The results of the ecological habitat evaluation are further discussed in Section 3.8. Note that the evaluation of Yard 520 as ecological habitat will be addressed in the Ecological Risk Assessment

Report. The ERA will be prepared in accordance with USEPA's guidance "Ecological Risk Assessment Guidance for Superfund, Process for Designing and Conducting Ecological Risk Assessments (EPA 540-R-97-006)."

2.18 Data Validation and Management

This section details the procedures that were used to document, manage, and review data collected during the RI to ensure data integrity, defensibility, and retrieval. This section also discusses the usability of the analytical results, based on the results of the data validation process.

2.18.1 Data Validation

Data validation was performed by ENSR to evaluate whether the analytical data collected for the RI were scientifically defensible, properly documented, of known quality, and met RI objectives.

2.18.1.1 Validation Procedures

Data validation included the review of analytical procedures, quality control (QC), calibration, data reduction, and completeness of the laboratory data package as specified in the RI/FS QAPP (ENSR, 2005f), Yard 520 QAPP (ENSR, 2005b), and MWSE SAP (ENSR, 2005c). Deficiencies noted were communicated to the laboratory and the resolutions were documented in the data validation reports. If appropriate, data were qualified for use as described later in this section.

All laboratory data packages received were reviewed in accordance with the investigation-specific QAPP or SAP. Geochemical data (i.e., physical parameters) were reviewed for completeness only. All chemical, radiological, and bacteriology data were subjected to validation. The validation procedures included a combination of full validation, which involved a comprehensive review of both the summary forms and raw data, and a more limited validation based on information presented on summary forms. The relevant FSP, SAP, or QAPP for each investigation specified the percentage of each type of validation (see Section 2.18.1.2). The table below indicates the review elements evaluated for full or limited validation, where applicable to the method:

Review Element	Full Validation	Limited Validation
Completeness of deliverable	√	√
Agreement of analyses conducted with chain-of-custody (COC) requests	√	√
Holding times and sample preservation	√	√
Initial and continuing calibrations	√	√*
ICP-MS tuning	√	√*
Chemical yield (tracers and carriers)	√	√
Laboratory and field blank contamination	√	√

Review Element	Full Validation	Limited Validation
Field and laboratory duplicates	√	√
Matrix spike/matrix spike duplicate (MS/MSD) recoveries and relative percent differences (RPDs)	√	√
Post-digestion spike (PDS) recoveries	√	√
Laboratory control sample (LCS) and laboratory control sample duplicate (LCSD) recoveries	√	√
ICP-MS internal standard performance	√	√*
Inductively Coupled Plasma (ICP) serial dilution results	√	√*
ICP interference check sample (ICS) results	√	√*
Calculation and transcription verifications (i.e., verifying summary data against raw data)	√	

*Parameter not required by RI/FS QAPP, but checked for first and second sample collection events to provide additional confidence in the data quality.

The following validation guidelines and documents served as the basis for the actions taken during validation:

- USEPA Contract Laboratory Program. National Functional Guidelines for Inorganic Data Review (February 1994 and October 2004).
- Department of Energy (DOE). Evaluation of Radiochemical Data Usability (1997).
- Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP). July 2004.

The criteria used to determine what validation actions were required were based on the analytical method and the investigation-specific QAPP or SAP, whichever was more stringent.

Validation reports were prepared for each data package validated. The validation reports are included in Appendix S and were submitted to USEPA quarterly throughout the RI. The reports summarize the samples reviewed, parameters reviewed, nonconformances with the established criteria, and validation actions (including application of data qualifiers). Validation data qualifiers were based on the above referenced USEPA, DOE, and/or MARLAP validation guidelines/documents, and consist of the following:

Qualifier	Definition
J	The result is an estimated quantity; the associated numerical value is the approximate concentration of the analyte in the sample.
J+	The result is an estimated quantity, but the result may be biased high.
J-	The result is an estimated quantity, but the result may be biased low.
U	The analyte was analyzed for, but was not detected above the sample reporting limit.
UJ	The analyte was not detected above the sample reporting limit; and the reporting limit is approximate.
R	The data are unusable. The sample result is rejected due to serious deficiencies. The

Qualifier	Definition
	presence or absence of the analyte cannot be verified.

For certain analyses, the laboratory assigned “B” qualifiers to detected results at concentrations between the instrument detection limit (IDL) and the project reporting limit (RL). These “B” qualifiers were replaced with “J” qualifiers as a result of the data validation to indicate the results were estimated due to uncertainty below the RL.

2.18.1.2 Data Validation by Field Program

The type of validation and the percentage of data receiving full or limited validation were specified in the appropriate FSP, SAP, or QAPP for each sampling event (i.e., MWSE, Yard 520, and four RI sampling rounds). Whenever possible, full validation was performed early in the validation process to identify any significant issues that could potentially affect the limited validation. A summary of the validation for each investigation is provided below.

MWSE SAP

The MWSE SAP specifies that a minimum of ten percent of the data were to be subjected to full validation and the remainder to receive limited validation. Approximately 25% of the data received full validation, exceeding the goal established in the SAP. The remaining data received limited validation.

Yard 520 SAP

The Yard 520 SAP and QAPP specify that a minimum of ten percent of the data, except TOC, grain size and bulk density, were to be subjected to full validation and the remainder was to receive limited validation. Due to the distribution of data within data packages, the majority of the data received full validation. The table below indicates the distribution of data which received full validation by matrix and analysis:

Percentage of Yard 520 SAP Data Subjected to Full Validation			
Analysis	Matrix	Analysis	Matrix
	Soil		Soil
Metals, Total	90%	Total uranium by ICP-MS	100%
Boron by ICP-MS	100%	Sulfur	99.6%

The remaining data for the above parameters were subjected to a limited review.

A limited review was performed on all of the TOC data which were used only for soil characterization informational purposes. The /bulk density data were checked for completeness only, which was consistent with the requirements of the QAPP.

RI FSP

The RI/FS QAPP specifies that a minimum of ten percent of the data were to be subjected to full validation and the remainder to receive limited validation. In addition, the percentage of data selected for full validation was to be representative of all matrices and analyses. This goal was achieved, as indicated in the following table:

Percentage of RI FSP Data Subjected to Full Validation					
Analysis	Matrix		Analysis	Matrix	
	Aq	Sed		Aq	Sed
Metals, Total	17%	12%	Anionic Surfactant as MBAS	29%	NA
Metals, Dissolved	19%	NA	Dissolved Organic Carbon	16%	NA
Boron by ICP-MS	12%	NA	Silica	22%	NA
Total uranium by ICP-MS	31%	13%	Bicarbonate Alkalinity as CaCO ₃	16%	NA
Hardness	20%	NA	Total Suspended Solids	21%	NA
Sulfate	16%	NA	Lithium	50%	NA
Nitrate as Nitrogen	16%	NA	Total Organic Carbon	NA	15%
Chloride	16%	NA	Radium-226	31%	NA
Fluoride	16%	NA	Radium-228	31%	NA
Ortho-phosphate as Phosphate	16%	NA	Isotopic Uranium (U-234, U-235, U-238)	31%	NA
Ammonia	16%	NA	Sulfur	NA	12%
Acid Soluble Sulfide	17%	NA			
Aq – aqueous Sed – sediment NA – Not applicable					

The remaining data for the above parameters were subjected to a limited validation.

All of the bacteriology, tritium, and boron-isotope ratio data received limited validation. The grain size and bulk density data were checked for completeness only. These levels of review were consistent with the requirements of the QAPP.

Validated data were provided to USEPA in monthly progress reports and validation memoranda were provided on a quarterly basis throughout the RI. All analytical data included in this RI Report, including data validation memoranda, are provided in Appendix S.

2.18.2 Uncertainties Reported with Radiological Data

As noted on Tables 2-13 and 2-20, analytical results for radiological parameters are reported by the laboratory with associated uncertainties. With regard to radiological data, uncertainty refers to the "measurement uncertainty" associated with a result. The term used by MARLAP is defined in the Guide to the Expression of Uncertainty in Measurement (ISO 1995) as a "parameter, associated with

the result of a measurement, that characterizes the dispersion of values that could reasonably be attributed to the measurand" (the quantity being measured). For this project, the measurement uncertainty associated with the radiological results is a 2-sigma standard deviation counting uncertainty, which represents an interval around the result that can be expected to contain the true value with a specified high probability.

2.18.3 Data Management

Data management activities included data collection, handling and management, and tracking and control.

Data related to sample collection and field measurements were recorded on standardized field forms (as per the FSP), in bound logbooks, and as electronic files. Field records were reviewed to ensure the accuracy and completeness of the data. Analytical data were received from the laboratory as hard-copy reports and as electronic data deliverables (EDDs). Analytical results were validated according to the procedures described in Section 2.18.1.

The EQuIS® environmental data management software from Earthsoft, Inc. was used to manage the data for the RI. Subsets of the field data, including spatial data (horizontal coordinates and elevations) and water quality measurements, were loaded into the database either directly using an EQuIS® import utility or via entry into electronic templates. EDDs from the laboratory, provided in the ENSR-specific four-file format, were imported into the project database. Upon completion of validation, data qualifiers were entered into the database and the database was finalized.

Quality control checks were performed throughout the process to ensure the integrity of the data. These checks included:

- Audits to ensure that laboratories reported all requested analyses;
- Checks that all analytes were consistently and correctly identified;
- Reviews to ensure that units of measurement were provided and were consistent;
- Queries to determine that any codes used in the database were documented properly;
- Reports to review sample definitions (depths, dates, locations);
- Proofing manually-entered data against the hard-copy original; and
- Reports to review groupings of sampling locations and coordinate systems.

The database is maintained on a secure network drive which is backed up regularly. Access to the database is limited to authorized users and controlled by password access. The paper or electronic

files constituting the final evidence files (as defined by the QAPP) are maintained under the conditions defined in the QAPP and in accordance with AOC II.

2.18.4 Data Usability Assessment

As required under the RI/FS QAPP, a Data Usability Assessment (DUA) was prepared for the data collected under the RI. The DUA describes the procedures used to evaluate the acceptability of data for use in the RI, which consists of data from the MWSE, Yard 520, and RI sampling events. The samples were collected and analyzed according to the MWSE SAP, Yard 520 SAP, and RI FSP. The primary objective of the data review and usability evaluation was to ensure that appropriate data were used in the evaluation of the RI investigation results. The DUA is provided in Appendix T, and a brief summary is provided below.

The QC goals specified in the QAPP and SAPs were met, except for two instances which had no impact on achieving the project objectives. For the sampling under the MWSE SAP, the field duplicate frequency of 1 per 10 field samples was not achieved since four field duplicates were collected for 47 field samples rather than the required five. There was no impact on the data usability because the sampling representativeness was verified by the four field duplicate pairs. For the RI sampling, three aqueous samples could not be analyzed for boron-isotope ratios due to the low B concentration in the samples. The purpose of the boron-isotope ratio data was to evaluate the potential source of the water. The B concentrations in these three samples were consistent with background B concentrations, and so there was no impact on the RI objectives.

Of all the data collected under the MWSE SAP, Yard 520 SAP, and RI FSP only one result was rejected: the thallium (TI) result from a private well in the August 2006 RI sampling event. However, usable TI data for this private well were generated during the October 2006 and January 2007 RI sampling events, therefore, there was no impact to the overall data usability. All the other data generated under the MWSE SAP, Yard 520 SAP, and RI FSP were determined to be valid, and considered to be usable and reliable for decision-making.

3.0 PHYSICAL CHARACTERISTICS

This section describes the physical characteristics of the Area of Investigation and surrounding area, including the topography, climate, surface water hydrology, geology, and hydrogeology. This information is important in interpreting the potential impacts of CCB-derived constituents in environmental media, because the physical characteristics influence the movement of the constituents and how they might affect possible receptors.

3.1 Demography and Land Use

The limits of the Area of Investigation as defined in AOC II are shown in Figure 1-2. The area covers approximately 1,450 acres and is located primarily in the Town of Pines, in Porter County, Indiana. It is located immediately west of the city limits of Michigan City, Indiana and about 4,500 ft south of the southern shore of Lake Michigan. The IDNL, managed by the NPS, is located between Lake Michigan and the Town of Pines. A small portion of the IDNL is included within the Area of Investigation. Figure 1-1 is a USGS topographic map showing specific features in the vicinity of the Area of Investigation.

The land use in the Area of Investigation consists primarily of residential, commercial (e.g., restaurants, gas stations, motels, etc.), and industrial (e.g., Illiana Block) activities within the Town of Pines. There are also undeveloped and/or open space areas such as parks/playgrounds, wetland/marsh areas, wooded areas, ponds, and surface water ditches. The land use outside the Area of Investigation varies from the relatively undeveloped areas of the IDNL, where the land has been preserved for recreational uses, to the highly developed industrial zones such as Burns Harbor and Michigan City. Industrial land use includes coal-fired power generating stations and fully-integrated steel mills. Residential areas such as the Town of Pines and Beverly Shores, which is located north of the Town of Pines along the shore of Lake Michigan, may have individual private wells and septic systems or may be connected to municipal water and/or sewer. In other areas, including Michigan City and a large portion of the Town of Pines, a municipal water distribution service supplies drinking water, and in Michigan City, a sewage collection system treats sewage. The areas shown on Figure 1-5 in the Town of Pines are served by municipal water from Michigan City, but are not served by a municipal sewer system, and so are presumed to use individual septic systems as described in Section 3.4.3.

At the time of the 2000 Census, the Town of Pines had a population of 798 persons (US Census, 2000). For the Area of Investigation, the population was estimated by counting the number of residential addresses within the Area of Investigation (348 households) and multiplying this number by the average number of persons per household for Porter County (2.62 persons; US Census, 2000). This calculation yielded an estimate of 912 persons residing within the Area of Investigation (US Census, 2000).

3.2 Surface Features

The topography of the Area of Investigation is characterized by local uplands (dunes or moraines) and lowlands (wetlands and marshes between the uplands) drained by man-made ditches (see Figures 1-1 and 1-2). The surface elevation of the region ranges from approximately 700 ft above mean sea level (amsl) at the northern edge of the Valparaiso Moraine south of the Area of Investigation to approximately 580 ft at Lake Michigan. Surface drainage in the Area of Investigation is primarily through Brown Ditch to Lake Michigan.

3.3 Meteorology

The Area of Investigation is located in the Midwestern region of the United States, which is in the northern temperate climate zone. The average annual temperature is 58.3°F, measured in the Wanatah 2 WNW weather station in Porter County, Indiana. The coldest month is January, averaging 28.9°F and the warmest month is July, averaging 82.9°F (World Climate, 2005).

The National Oceanic and Atmospheric Administration (NOAA) has collected precipitation data at the Indiana Dunes National Lakeshore since 1989. Between 1989 and 2008, the maximum annual precipitation measured at Indiana Dunes was 61.3 inches (1990), the minimum was 25.6 inches (2005), and the average was 39.5 inches. The amount of precipitation measured at the Indiana Dunes station during the RI monitoring period (August 2006 to July 2007) was 50.6 inches (NOAA, 2008), representing a relatively wet period. The monthly precipitation data recorded at this station are shown on Table 3-2.

3.4 Geology and Hydrogeology

The Area of Investigation is located within the physiographic province called the "Calumet Lacustrine Plain" located between Lake Michigan and the Valparaiso Morainal Area. This area occupies the lake bottom of former Glacial Lake Chicago (Fenelon, et al., 1994). This area is bounded on the south by the Valparaiso Morainal Area, which consists of the Valparaiso, the Tinley, and the Lake Border moraines. The Calumet Lacustrine Plain consists of unconsolidated geologic materials, including varying amounts of lacustrine sediments, wind-blown sand dunes, and organic wetland sediments.

3.4.1 Regional Geology and Hydrogeology

For reference, copies of several of the figures from a regional study performed by the USGS (Shedlock, et al., 1994) are included in Appendix AA, including a hydrogeologic cross-section and a groundwater contour map.

The depth to bedrock in the vicinity of the Area of Investigation is greater than 120 ft below land surface (Shedlock, et al., 1994) and can be up to 250 ft deep. The bedrock consists of shale and

carbonate rocks of Mississippian, Devonian, and Silurian age. Based on cross-sectional diagrams prepared by Shedlock, et al. (1994), parallel to the Lake Michigan shoreline, the depth to bedrock is fairly consistent. Perpendicular to the shoreline, the bedrock surface has a slight dip to the north; that is, the elevation of the bedrock is higher beneath the Valparaiso Moraine and lower at the lake shore. Beneath the Area of Investigation, the bedrock consists of the Antrim Shale, a brownish black, non-calcareous marine shale of Devonian age (Fenelon, et al., 1994). Because it originated in a marine environment, its chemistry is likely to reflect those conditions, that is, relatively high in salts, including B.

The unconsolidated materials above the bedrock consist of 100 ft or more of glacially-derived materials such as tills, glacio-fluvial deposits, and lacustrine deposits associated with Glacial Lake Chicago (Fenelon, et al., 1994). These Pleistocene deposits are overlain by Holocene (post-glacial) deposits associated with the Lake Michigan shoreline. These Holocene deposits include dune-beach complexes alternating with low-lying marsh and wetland areas (Fenelon, et al., 1994; Shedlock, et al., 1994). In the vicinity of the Area of Investigation, there are three dune-beach complexes: the Lakeshore/Tolleston Dune-Beach Complex forming the current shore of Lake Michigan, the Calumet Dune-Beach Complex on which the Town of Pines was developed, and the Glenwood Dune-Beach Complex, which is located to the south of the Town of Pines. The three dune-beach complexes represent the current and previous locations of the Lake Michigan shoreline. The geology of the dune-beach complexes consists of wind-blown sands and beach sands with small lenses of silts and clays or peat representing small, intradunal wetlands (Shedlock, et al., 1994).

Between the higher-elevation dune-beach complexes are low-lying swamps or marshes. To the north of the Town of Pines, the Great Marsh, located within the IDNL, is one of these lowlands (see Figure 1-1). Within the Town of Pines and the Area of Investigation, another low-lying marsh area is drained by Brown Ditch (see Figures 1-1 and 1-2). The hydrology of the Brown Ditch system, including tributaries and wetlands, is described in Section 3.5. The geology of these low-lying marsh areas consists of peat and muck at the surface which overlie sands of the dune-beach complexes (Shedlock, et al., 1994).

Beneath these Holocene deposits are lacustrine silts and clays deposited by Glacial Lake Chicago and glacial tills. The thickness of the dune complexes overlying the lower permeability silts, clays and tills ranges from more than 100 ft beneath the dunes of the current Lake Michigan (Shedlock, et al., 1994), to approximately 2 to 25 ft in the area of Brown Ditch (Shedlock and Harkness, 1984). To the south, there are no dune sands present, and the silts/clays and/or tills are present at the ground surface (Shedlock, et al., 1994).

Regional USGS studies document three to four aquifers separated by confining units in this area of northwest Indiana (Shedlock, et al., 1994; Fenelon, et al., 1994). One of these aquifers, the Valparaiso Aquifer, exists only south of the Little Calumet River (that is, more than three miles south of the Area of Investigation); therefore, it is not present in or near the Area of Investigation. The remaining aquifers from the bedrock up to the ground surface have been termed the basal sand aquifer, the sub-till aquifer, and the surficial aquifer (Shedlock, et al., 1994). A cross-section showing the three aquifers is

provided in Appendix AA (Shedlock, et al., 1994). For the purposes of the RI, only the surficial aquifer is important, but the others are briefly described here for context.

The bedrock beneath the unconsolidated materials is the Antrim Shale, a brownish black marine shale characterized by very low yield (less than 10 gallons per minute (gpm)) (Arihood, 1975), and it forms a confining unit. The first aquifer overlying the bedrock is a unit called the basal sand aquifer. It is characterized by discontinuous sandy zones. It is thickest and most extensive in the area of Porter County. Because of its depth, its extent is less well-known compared to the aquifers above it. However, it is expected to be present in the Area of Investigation (Shedlock, et al., 1994). The water quality in the basal aquifer is affected by upward leakage from the Antrim Shale, leading to elevated concentrations of constituents such as Na, Cl, F, and B (Shedlock, et al., 1994).

Above the basal sand aquifer are glacial deposits, in which the unit known as the subfill aquifer is located. This aquifer is characterized by several relatively small and discrete, sandy, permeable layers. These layers are surrounded by a till that is typically clay, but can also include silt. The subfill aquifer may be locally present beneath the Area of Investigation, but it may not be continuous regionally (Fenelon, et al., 1994).

The most shallow aquifer is the surficial aquifer, which includes the dune-beach complexes described above. The surficial aquifer consists of lacustrine and eolian sands, with an average hydraulic conductivity of 50 ft/day (Shedlock and Harkness, 1984). It is generally the most laterally extensive of the three aquifers in northwest Indiana, and is termed the Calumet Aquifer to the west. The saturated thickness in the surficial aquifer ranges from 0 (at the ground surface) to 80 ft generally increasing from the east (Michigan City, Indiana) to the west (Gary, Indiana) (Shedlock, et al., 1994). In the vicinity of the Area of Investigation, the saturated thickness is about 2 to 30 ft (Fenelon, et al., 1994; Shedlock, et al., 1994). Calcareous clay lenses or organic silt/clay/peat may function locally as confining layers (Shedlock, et al., 1994). The surficial aquifer extends an unknown distance northward beneath Lake Michigan (Fenelon, et al., 1994).

The surficial aquifer rests on and pinches out to the south against lacustrine silts and clays of Glacial Lake Chicago and/or glacial tills of the Valparaiso Moraine, as discussed in Section 3.4.5. This material is laterally continuous in northwestern Indiana and forms the base of the surficial aquifer (Fenelon, et al., 1994). This confining unit is described by Shedlock et al. (1994) as a clay layer separating the surficial aquifer from the underlying aquifers. The clay unit has been observed and is considered a confining unit in the vicinity of the Area of Investigation (Fenelon, et al., 1994).

The surficial aquifer forms a water table aquifer except where it may locally be confined by lenses of lower permeability material. The depth to groundwater ranges from 0, where groundwater is at the ground surface, up to 60 ft below the ground surface beneath high dunes (Shedlock, et al., 1994). Depth to groundwater tends to be greater beneath the dune-beach complexes. Groundwater is closer to or at the ground surface in the low-lying wetlands.

Regional groundwater studies (Fenelon, et al., 1994; Shedlock, et al., 1994) indicate groundwater in the surficial aquifer flows from the dune-beach uplands to the low-lying areas, with discharge into man-made ditches. These local-scale flow systems divert groundwater into these ditches, and there does not appear to be any direct connection between the surficial aquifer and Lake Michigan except at the immediate edge of the lake. In deeper confined aquifers, the regional flow is northward to the lake, so vertical gradients are generally upward from lower units including bedrock into the surficial aquifer (Shedlock, et al., 1994; Shedlock and Harkness, 1984).

3.4.2 Geology and Hydrogeology of the Area of Investigation

The geology beneath the Area of Investigation was studied as part of this RI, as described in Section 2.7. Additional information is also available from investigations at Yard 520 and the Pines Landfill (owned by Waste Management; shown on the map in Figures 1-1 and 1-2), and from studies conducted by the USGS (e.g., Shedlock, et al., 1994; Fenelon, et al., 1994, etc.). The observed geology and hydrogeology in the Area of Investigation are consistent with the regional geology and hydrogeology described by the USGS (e.g., Shedlock, et al., 1994) and summarized above (Section 3.4.1).

During drilling in the Area of Investigation, the primary geologic material encountered was the medium to fine sands of the dune complexes (see geologic and well construction logs in Appendix H). Within these dune sands, varying amounts of interbedded organic peat or silts and clays were occasionally encountered. At all locations drilled, a dense clay deposit was encountered beneath the dune sands. The depth to clay encountered during the RI drilling program ranged from less than 10 ft to a maximum of 45 ft. The depth to clay recorded in Yard 520 documents ranges from approximately 11 to 47 ft (ENSR, 2005a). Observed depths to clay are summarized on Table 2-6.

Physical testing of native soils (described in Section 2.3) shows that native granular samples are generally well-sorted fine sand typically with little finer material (silt or clay). The percent of fines (silt and clay fraction) is less than 10% for the granular samples in the upland dune areas. The granular samples from locations further to the south (e.g., SS019, SS021) have greater fines (13 to 76%) consistent with the presence of more silt and clay in the lacustrine sediments and Valparaiso Moraine deposits. For the native organic samples, the results are more variable, with percent fines ranging from 13 to 85%. The percentage of solids is generally higher in granular samples, and TOC results are higher in organic materials, however, there is considerable overlap between the two types of soils. The highly organic materials are clearly physically distinct from the dune sands, but there are several native soils that are not as distinct. For example, organic soil from TP030 has only 13% fines, a characteristic that is more typical for granular soils, and granular soils from SS021 have 4% organic content, close to the range observed for the organic soils. Therefore, while the planned sampling was based on two distinct soil types (dune sands vs. peaty materials in the lowlands), the results indicate more of a continuum in the types of soils encountered.

None of the drilling for the RI extended through the clay unit. However, deeper borings have been installed as part of Yard 520 investigations, for the installation of some of the private drinking water wells in the area, and by the USGS. Based on these studies, one or more sandy aquifers appear to be present beneath the clay confining unit.

In addition to the natural geologic materials, CCBs have been disposed at Yard 520, and CCBs are reported to have been used as road sub-base and/or fill in other areas within the Area of Investigation, as noted in the SMS (ENSR, 2005a) and documented through visual inspections during the RI (see Section 3.7). The presence and nature of CCBs are described in detail in Section 3.7. The Type II (North) Area of Yard 520 is closed and has been capped with a vegetated clayey soil cover (Weaver Boos, 1996a). Based on the borings conducted during the RI (see Section 2.5), the thickness of fill material at the Type II (North) Area ranges from 30.5 to 36.5 ft. In the Type II (North) Area, these materials are located on top of a thin layer of peat on top of the sands of the surficial aquifer.

During construction of the Type III (South) Area, IDEM required construction of a clay barrier wall between the two disposal areas (the Type II and Type III Areas). As stated in the Construction Quality Assurance Report (Weaver Boos, 1995), the clay barrier constructed was 1700 ft in length, 17 ft in height, a minimum of 10 ft in width, with a design permeability of 1×10^{-6} cm/s or less.

Other Yard 520 documents discuss the construction of the other walls (e.g., Weaver Boos, undated). In 1987-1988, the sands of the surficial aquifer in the Type III (South) Area were excavated to a depth of approximately 15 ft, which was approximately 3 ft into the underlying clay confining unit. In addition to the compacted clay barrier wall to the north, compacted clay walls were also installed on the eastern, southern, and western sides of the Type III (South) Area. The design hydraulic conductivity for these three sides was the same as the barrier wall (less than 1×10^{-6} cm/sec), and the design thickness was at least 3 ft.

According to representatives from Weaver Boos (the design engineer for Yard 520), the clay cap installed during closure of the Type III (South) Area was constructed to tie into the clay side walls. This is documented in the as-built drawing for the eastern wall of the Closure Certification Report (Weaver Boos, 2005). The eastern wall was constructed inside the original eastern barrier wall, based on the final location of filling activities (i.e., filling did not extend to the original barrier wall to the east). The cap was constructed similarly for the other three sides of the Type III (South) Area.

Based on the construction of the Type III (South) Area, it is expected to have little, if any, interaction with the surrounding groundwater system. Any potential leakage through the walls would be on a scale so small as to be completely masked by groundwater in the surficial aquifer and groundwater migrating from the Type II (North) Area of Yard 520. The hydraulic conductivity of the clay barrier wall was measured at 7×10^{-8} cm/sec (Weaver Boos, 1995) or 2×10^{-4} feet/day. This represents more than a 100,000-fold decrease over the hydraulic conductivity of the surficial aquifer (geometric mean of 15 feet/day). Even assuming a relatively steep hydraulic gradient across the walls, the potential

contribution of water from the Type III (South) Area to the groundwater system would be several orders of magnitude smaller than the volume of water in the groundwater system.

Historical seeps at the Type III (South) Area have been discussed, however, no record of any seeps that post-date closure of the Type III (South) Area in 2004 have been identified. Prior to that time, the Final Site Inspection Report (Tetra Tech, 2002) and occasional IDEM inspections make note of "leachate". A sample said to be leachate was collected by TetraTech, but there is no description provided of what was observed in the field; it is not described as a seep. The location of the sample was in the northwest corner of the Type III (South) Area. This was an active waste management area prior to closure in 2004. There is no indication that this sample represents liquid released to the environment (i.e., outside the limits of the waste management areas). The Type III (South) Area was designed and configured such that free water would flow to the stormwater retention area (previously located in the eastern portion of the Type III Area). Most of the flow was from covered slopes and not from disposal areas. Runoff was retained in the storm-water retention area to allow for the settlement of solids before discharge into Brown Ditch, in accordance with the Yard 520 operating permit. The USEPA interpretation of this information is provided in Section 3.4.2.1.

USEPA comments on the RI Report (see Appendix DD) note that the concentrations of CCB-derived constituents present in MW-3 and in Brown Ditch on the south side of the Type III (South) Area indicate leakage from this area. However, the assumption that these concentrations represent leakage (which if occurring, would be very small in volume due to the clay walls) is not the only explanation. In fact, it is not the most plausible explanation. Instead, groundwater migrating from the Type II (North) Area is a more likely source. First, the groundwater levels at MW-3 and MW-4 are higher than nearby Brown Ditch. In this narrow remnant strip of aquifer between Yard 520 and the ditch, it is unlikely that leakage from the Type III (South) Area and the small amount of recharge would provide water sufficient to maintain these high levels. Another source of water clearly exists. Furthermore, even if the Type III (South) Area were to be replaced by a block of completely impermeable material, groundwater would still be present in this remnant aquifer area. The most likely source of that groundwater is the area north of the Type III (South) Area, that is, the Type II (North) Area of Yard 520.

Calculations were performed to provide a simplified evaluation of the significance of potential leakage from the Type III (South) Area. Darcy's Law was used to calculate potential volumes of leakage, using actual parameter values, where known. The most important unknown is the groundwater level within the Type III Area. Therefore, a range of possible values was used (i.e., akin to a sensitivity analysis) for the difference in water levels between the Type III Area and the surrounding groundwater. The calculation results provide a range of potential leakage rates, from 0 to 56 ft³/day. Details of the calculations are provided in Attachment 3 of Appendix BB.

Two different approaches were used to evaluate the potential effect of the calculated leakage:

- Leakage that may occur from the Type III Area will mix with the surrounding groundwater and flow into Brown Ditch. Therefore, the calculated leakage rates were compared to flow rates measured in Brown Ditch during the RI. Under low flow conditions, the maximum potential leakage from the Type III Area represents 0.15% of the flow in Brown Ditch; under high flow conditions, it is an order of magnitude lower, 0.013%. In all cases, the rate of leakage from the Type III Area is less than 0.2% of the flow in Brown Ditch.
- The calculated leakage range was also compared to groundwater flow rates using a groundwater flow tube representing groundwater flow from the south into Brown Ditch (see Attachment 3 of Appendix BB). The calculated groundwater discharge through this flow tube (100 ft wide) is 376 ft³/day. The calculated discharge through a 100-ft wide section of the clay barrier wall ranges from 1 to 3 ft³/day. Therefore, the potential leakage is less than 1% of a comparable groundwater flow rate.

These calculations demonstrate that if there is leakage from the Type III (South) Area, it is a very minor part of the overall groundwater flow system. Further interpretation provided by the USEPA of conditions in this area are presented in Section 3.4.2.1.

To aid in interpreting the geology and hydrogeology beneath the Area of Investigation, three hydrogeologic cross-sections have been prepared (Figures 3-1, 3-2, and 3-3), one oriented east-west through the area, and two oriented north-south. These are discussed in the context of hydrogeology below.

The hydrogeologic conditions observed during the RI are typically consistent with the regional hydrogeology discussed above. The primary aquifer of interest for the Area of Investigation is the water table surficial aquifer, a generally sandy formation underlain by a continuous clay confining unit. The cross-sections show the following interpretation of the hydrogeologic conditions:

- The surficial aquifer is present throughout most of the Area of Investigation, at varying thicknesses up to approximately 40 ft. The surficial aquifer is not present in the southern portion of the Area of Investigation, where the dune sand pinches out against the underlying lacustrine sediments of Glacial Lake Chicago and/or the tills of the Valparaiso Moraine.
- The top of the clay confining unit (and, therefore, the bottom of the surficial aquifer) generally dips northward towards Lake Michigan.
- At some locations, the base of the surficial aquifer consists of a transitional zone, with lenses of silts and clays interbedded with the sands.
- At locations where borings have extended to a greater depth, a deeper, confined sandy aquifer has been encountered. Because there is limited information, this aquifer and any others encountered below the confining unit have not been differentiated on the cross-sections.

- Groundwater is present in the surficial aquifer as an unconfined water table aquifer. Groundwater elevations are generally highest beneath the dune uplands and lowest at the ditches.
- Section B-B' (Figure 3-2) passes through Yard 520. It shows that the Type II (North) Area of Yard 520 is located above native sands and peat, and so the surficial aquifer is present in this area.
- In contrast to the Type II (North) Area, the Type III (South) Area was constructed so that it extends down to the clay confining unit and is surrounded by clay walls. Based on the construction of the Type III (South) Area, it is expected to have little, if any, interaction with the surrounding groundwater system. Any potential leakage through the walls would be on a scale so small as to be completely masked by groundwater in the surficial aquifer and groundwater migrating from the Type II (North) Area of Yard 520. The hydraulic conductivity of the clay barrier wall was measured at 7×10^{-8} cm/s (Weaver Boos, 1995) or 2×10^{-4} feet/day. This represents more than a 100,000-fold decrease over the hydraulic conductivity of the surficial aquifer (geometric mean of 15 feet/day). Even assuming a relatively steep hydraulic gradient across the walls, the potential contribution of water from the Type III (South) Area to the groundwater system must be several orders of magnitude smaller than the volume of water in the groundwater system. Therefore, while the Type II (North) Area may interact with the groundwater system, the Type III (South) Area has limited or no interaction.

Locally, the surficial aquifer is very thin at some locations, especially to the south where it pinches out. Also, in the center of the Area of Investigation, the saturated thickness at MW122, MW114, and SB112 ranges from less than five ft to approximately ten ft. In addition, the Indiana Department of Natural Resources (INDR) well database (http://www.in.gov/dnr/water/ground_water/well_database/) documents both private wells in this area that are very shallow (less than 15 ft) and wells that are screened in the deeper confined aquifer because there was insufficient water in the surficial aquifer. The USGS also documented saturated thicknesses as little as two ft in the area of Brown Ditch (Shedlock and Harkness, 1984).

Because of the importance of the underlying clay confining unit on the hydrogeology of the surficial aquifer, a contour map representing the top of the clay has been developed (Figure 3-4). This map was based on data collected during the RI, geologic information from Yard 520 (ENSR, 2005a), the USGS (e.g. Shedlock, et al., 1994), and the IDNR database of well records (http://www.in.gov/dnr/water/ground_water/well_database/). As shown on the figure, the top of the clay confining unit dips gradually towards Lake Michigan, with the highest elevations (greater than 640 ft) at or near the ground surface to the south, and the lowest elevations (less than 580 ft) to the northwest beneath the Great Marsh within IDNL. In addition to this general trend, there is an area of lower relief in the southern portion of the Area of Investigation (i.e., wells MW113, MW121, and beneath Pines Landfill). The distance between the water table and the top of the clay defines the saturated thickness of the surficial aquifer, which in turn affects its transmissivity. The saturated thickness is thin to the south, where the clay is near the ground surface. It is also thin beneath much of the wetland areas surrounding the East and West Branches of Brown Ditch where groundwater levels are low (for

example, at locations MW122, MW114, SB112). In general, there will be less available water in these areas, compared to areas where the saturated thickness is greater. Groundwater generally flows more readily through areas of higher transmissivity.

3.4.2.1 USEPA Approvable Language

In addition to the interpretations developed by the Respondents, the USEPA has provided the following additional interpretations related to the Type III (South) Area at Yard 520 (see Appendix DD). The Respondents do not necessarily agree with these statements, or do not believe there is sufficient information to support these interpretations.

- A water sample collected by TetraTech for EPA in May 2002 from the yard 520 Type III (South) Area described as leachate was taken from a seep located partly up the western slope. Additionally, the TetraTech report prepared at the time notes that the leachate sample was taken from beneath an “outfall”, which is consistent with sampling from a seep. The sample location as described in the TetraTech Report (at the extreme western edge of the Type III (South) Area of Yard 520) is also consistent with a seep. Furthermore, field personnel who collected the sample described it as a seep. This sample had more than 6 mg/l of B, clearly indicating that at the time of this sampling (May 2002) this seep water present at the land surface in the extreme western part of the Type III (South) Area of Yard 520 had extensive contact with the CCBs prior to its appearance at the land surface.
- Although leachate seeps have not been observed in the Type III (South) Area of Yard 520 since closure, historical data indicates, at the least, the potential for a “bathtub” effect in the Type III (South) Area of Yard 520. Movement of leachate outside of the boundaries of the Type III (South) Area over or through the clay wall but beneath the top of clay cap may be occurring.
- In the absence of water levels from a well in the Type III (South) Area, well data from the Type II (North) Area, water-quality information, and information from other landfill sites will be used to indicate the most likely set of conditions at the Type III (South) Area of Yard 520. The “weight of evidence” supports the position that some amount of mounding in the Type III (South) Area, and leachate migration from the Type III (South) Area to groundwater, is occurring. In addition, although the hydraulic effects of leachate migration from the Type III (South) Area of Yard 520 are likely minimal, they are not non-existent. Given the high concentration of various constituents in the leachate, the chemical effects of this process may be fairly substantial.
- Based on the existing monitoring well data it is highly likely that leachate to Brown Ditch from Yard 520 is, at least in part, seepage from the Type III (South) Area.

3.4.3 Groundwater Occurrence and Flow

Groundwater in the surficial aquifer originates from a number of sources. The primary source is infiltration from precipitation. Other natural sources of recharge to the surficial aquifer include upward flow from deeper, confined aquifers and northward flow from the Valparaíso Moraine. In addition, there are man-made contributions to the groundwater in the surficial aquifer, most notably, the discharge from residential septic systems. Prior to 2003, a number of residences were served by private wells drawing from the surficial aquifer. The amount of groundwater drawn by these wells was roughly equivalent to the amount of water discharged to the septic systems, resulting in a net water balance. In areas that are now served by municipal water, the septic system discharges represent an addition to the groundwater in the surficial aquifer.

Groundwater in the surficial aquifer is discharged primarily to Brown Ditch and its related tributaries and wetlands systems. Groundwater is also lost through evapotranspiration during the growing season.

As described in Section 2.9, water levels were measured five times in the Area of Investigation during the RI, including August and October 2006, and January, April, and July 2007. These measurement events generally cover the expected seasonal variability in water levels from the wet period of the year (winter and spring) to the dry period of the year (summer and fall, the growing season). These water levels have been used to evaluate groundwater occurrence, hydraulic gradients, and groundwater flow directions. In addition, after the formal RI monitoring period, water levels continued to be monitored on a regular basis (except at the USGS wells). Data from four subsequent monitoring rounds have been included in this report (see Tables 3-3 and 3-4) including October 2007, and January, April, and July 2008.

The depth to groundwater measured in wells and piezometers in the Area of Investigation ranges from 0 (i.e., groundwater is at or near the ground surface) to approximately 25 ft bgs. Groundwater is closer to the ground surface in the lowlands, near swamps, and near or at Brown Ditch. The greatest depths to water are generally at wells located in upland dune areas, such as MW119 and MW105, as well as one piezometer, PZ001 located at Yard 520 (see Figure 2-8). Water levels were also measured at two USGS wells screened in the deeper confined aquifer (203D and 213, see Figure 2-9). Both these wells are flowing artesian wells with water levels above the top of the well, indicating upward hydraulic groundwater gradients.

The measured depths to water (groundwater and surface water) were used to calculate water elevations and to develop groundwater contour maps. Contour maps using a four-foot contour interval were developed for each of the five RI water level measurement rounds (see Figures 3-5 through 3-9). A contour map using a one-foot contour interval was also developed for one of the rounds (April 2007) to provide more detail (see Figure 3-8(b)). This more detailed map was prepared using the April 2007 data, because this dataset represents high water levels measured during the RI. The maximum hydraulic heads (groundwater elevations) were in wells located to the south, including MW113 and

MW121 (see Figure 2-9). The lowest hydraulic heads were in wells adjacent to Brown Ditch or in wetlands (e.g., MW111, MW120) and piezometers installed within the ditch. Groundwater elevations are generally higher in the upland dunes and lower in the vicinity of the ditches.

Seasonally, water levels were highest in the winter and spring (January and April 2007, January and April 2008), representing the wet period. The lowest water levels were in the summer and fall (August 2006, July and October 2007, and July 2008), representing the dry period of the year during the growing season with maximum evaporation and water uptake by plants (evapotranspiration). Water levels in October 2006 were in between the highs and lows. October would typically represent the dry period, but the RI monitoring in October 2006 followed a period of significant rainfall, so water levels were higher than normal for this time of year. At a number of wells, the water levels measured in July 2008 were significantly lower than the previous two years (2006 and 2007).

Excepting the data from July 2008, the maximum change in water levels over the monitoring period was relatively small, ranging from approximately 0.5 to 2.5 ft. The largest changes occurred in wells in the uplands (MW102, MW115, MW119, etc.), and the smallest changes occurred in wells in or adjacent to Brown Ditch and/or wetlands (MW120, MW122, etc.). This indicates that hydraulic gradients from the uplands to the lowlands are slightly steeper during the wet periods compared to dry periods. In July 2008, water levels in many wells (but not all) dropped to levels that were three to five ft lower than in the summer of 2006 and 2007. This change is shown graphically for selected wells in Figure 3-10.

The graphs in Figure 3-10 show groundwater levels measured over time in several wells in selected areas of the Area of Investigation. These graphs visually depict the higher groundwater levels in the winter and spring and lower water levels in the summer. The graphs show that groundwater levels are changing similarly in all wells, including wells both within (graphs A and B) and outside (graph D) the areas where municipal water was recently provided. This demonstrates that if any notable change in water levels resulted from the closure of the private wells in these areas, the effect has already occurred and groundwater levels have since stabilized in response. There is no indication that groundwater levels in areas where private wells have been taken out of service are currently rising in response to a decline in withdrawals. Instead, water levels in these areas are fluctuating seasonally similar to areas outside the water service areas. This is also shown in more detail at MW106 on the graph in Figure 3-11, and discussed in more detail below. In addition, annual precipitation and available water levels were examined dating before the installation of the municipal water service to evaluate whether or not the closure of the private wells may have contributed to a rise in groundwater levels. National Weather Service records on precipitation in Indiana from 1998 to Oct 2009 were reviewed (NWS, 2009) and summarized as follows:

Year	Precipitation Classification
1998	Normal
1991 – 2001	Not Available
2002	Above Normal
2003	Above Normal
2004	Above Normal
2005	Much Below Normal
2006	Much Above Normal
2007	Above Normal
2008	Much Above Normal
Through October 2009	Above Normal

The municipal water service was installed in 2003 to 2004, and the precipitation since then, with the exception of 2005, has been above normal (three years) or much above normal (two years).

Additionally, water levels collected over a longer period of time (e.g., pre-dating the RI) in monitoring wells surrounding Yard 520 were evaluated. A comparison was made between water levels near the water service area (i.e., well pairs north of Yard 520) and water levels further from the water service area (e.g., MW-10) before and after the water service went on line. Significant differences between the two datasets might indicate changes due to the water service installation. Note that the municipal water service was installed in this area in 2003 to 2004, and the wells nearer the water service area were installed in August of 2002, so there is limited data for such a comparison. As shown on the graphs in Appendix CC, the long term water level data from the Yard 520 monitoring well network were graphed over time.

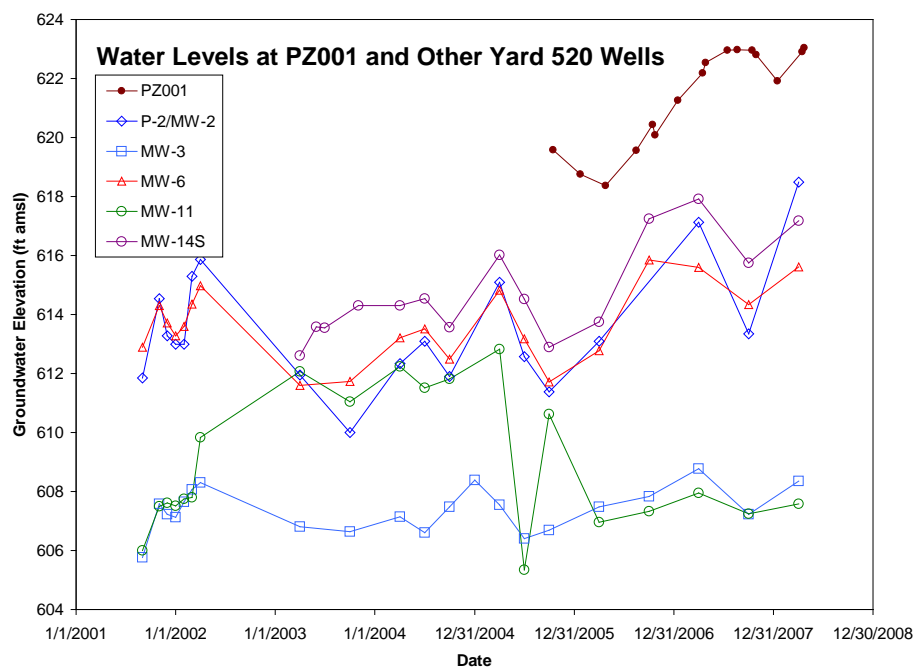
A comparison of water levels suggests some conclusions may be drawn about the area's response to precipitation. In addition to the water level data, annual precipitation is shown for each year and the

regional average of 39.5 inches per year is also shown. These data suggest that in almost every well there is a good correlation between the water levels changes over the years with the annual precipitation value. That is, the water level trends roughly parallel the precipitation trends. Note that total annual precipitation has been greater than the 39.5 inch average for three of the last four years.

After the water service installation (2003-2004) there is no appreciable difference in water level responses to precipitation compared to before the installation. This suggests that if there was a systematic water level rise after the water service installation, it is small compared to water level rises seen as a result of wetter than average years.

Note also that wetland restoration activities are being conducted in the IDNL. The USGS has been studying the effect these restoration activities may have on groundwater levels in Beverly Shores (<http://in.water.usgs.gov/projects/beverlyshores.html>) the community adjacent to the Town of Pines. This long term study of water levels in this area, when available, may also help with the understanding of regional water level trends.

In general, groundwater levels fluctuate similarly throughout the Area of Investigation, as shown on Figure 3-10. That is, water levels in all wells drop during the growing season and rise at the end of the growing season. The only exception to this is at PZ001, located in the Type II (North) Area at Yard 520. There appears to be a lag in time between water level fluctuations in PZ001 compared to the rest of the wells. This is shown more clearly in the following graph (based on data provided by Weaver Boos for Yard 520 monitoring, which covers a longer time period than the RI monitoring). The final datapoint on this graph is for April 2008, just prior to the abandonment of PZ001.



As can be seen from this graph, water levels in PZ001 respond in a pattern that is very similar to other Yard 520 wells. Similar increases and decreases are easily observed in both datasets. However, the responses in PZ001 occur later in time than in the other wells. For example, the seasonal low in the fall of 2005 in the other wells did not occur in PZ001 until the spring of 2006. The dip in water levels that occurred in the fall of 2007 did not occur in PZ001 until January 2008. The water levels in PZ001 are fluctuating seasonally, the same as wells in the surficial aquifer, but with a slight time lag. The time lag is attributed to the reduced permeability of the Yard 520 cap and fill materials.

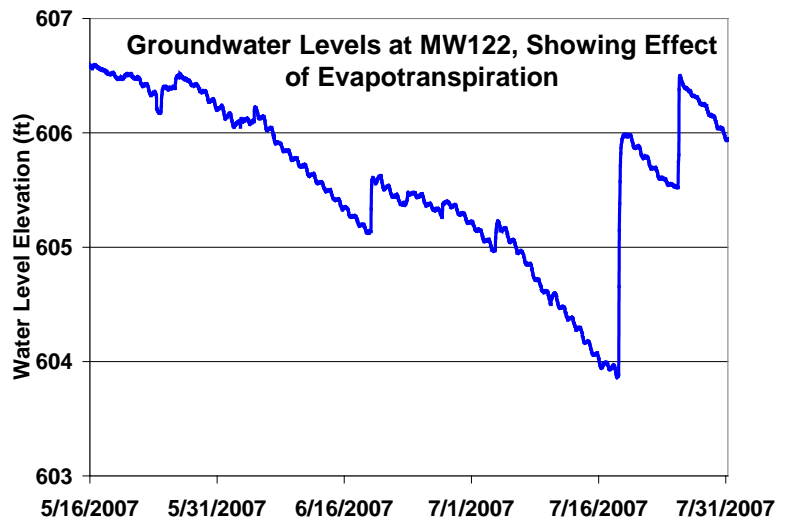
A groundwater contour map was prepared for each of the five RI water level gauging events (see Figures 3-5 through 3-9). Although groundwater levels change slightly from event to event as discussed above, there is very little change in the hydraulic gradients over the measurement period. Groundwater flow is from the upland areas to Brown Ditch and its related tributaries and wetlands systems. South of Brown Ditch, groundwater flow is northward towards Brown Ditch or its tributaries and wetlands. Note that because of the low permeability clay surrounding the Type III (South) Area at Yard 520, groundwater contours are oriented perpendicular to its boundaries, indicating groundwater flows around this area.

Vertical gradients can also be evaluated at locations where wells are installed in pairs and at locations where both surface water and groundwater levels can be measured. There are a number of well pairs screened in the surficial aquifer north of Yard 520 (see Figure 1-4). In general, the head differences between the shallow and deep wells in these pairs indicate vertical gradients downward, consistent with uplands and recharge areas. At groundwater/surface water pairs, head differences between groundwater and surface water indicate upward vertical gradients, consistent with discharge areas (as discussed further in Section 3.6). In addition, based on the water levels measured during the RI in the two USGS wells in the confined aquifers, the gradient from the deeper aquifers is upward toward Lake Michigan and the shallow aquifer, consistent with regional interpretations by the USGS (e.g., Shedlock, et al., 1994).

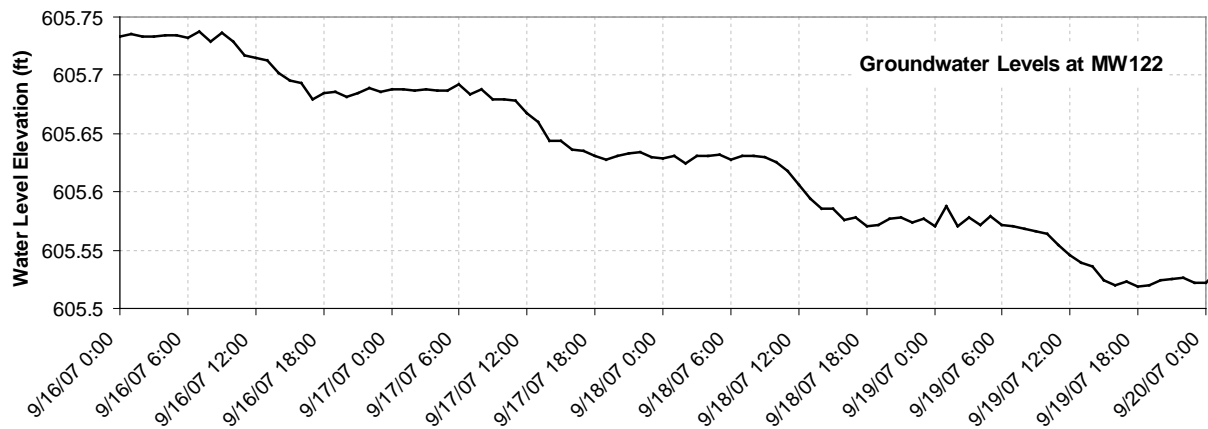
Figure 3-23 shows hydraulic gradients through a cross-section that passes through Yard 520 (Section D-D'). In the surficial aquifer outside of Yard 520 and away from Brown Ditch, groundwater gradients are predominantly horizontal. In the vicinity of Brown Ditch, there are upward vertical gradients, representing flow from groundwater to the ditch. Within the Type II (North) Area at Yard 520, gradients are interpreted to be predominantly downward with some lateral component, as suggested by the hydraulic heads at PZ001 and MW-2/P-2 (recognizing that the two wells are not located adjacent to one another) and the concentrations of CCB-related constituents in nearby wells.

Groundwater levels were measured continuously at selected locations over a one-year period, as discussed in Section 2.9.3. The data obtained are shown on the graph in Figure 3-11. The following observations about groundwater levels can be made from this graph.

- As discussed above, Figure 3-11 shows that groundwater levels generally drop during the growing season (summer and fall) and rise during the winter and spring. This is especially apparent at MW106 and MW-3A located farther from ditches and wetlands.
- In addition to these overall seasonal fluctuations, groundwater levels are responding to precipitation in the short-term. Each of the rapid rises in water levels is due to infiltration of rainwater to the groundwater. This can be seen by comparing the groundwater levels to daily precipitation on the graph. Some precipitation events contribute only small amounts to groundwater; others are more significant, such as the change in groundwater elevations observed in mid-April 2007. In between these precipitation events, groundwater levels gradually drop.
- Both MW111 and MW122 are located in wetland areas. Groundwater levels at these wells are more variable compared to MW-3A and MW106, both located outside of wetland areas. Water levels in wetland areas are more directly affected by precipitation, as run-off from rainfall is likely to accumulate in these low-lying areas.
- Well MW106 is located in an area where municipal water has been provided. The data on Figure 3-11 for MW106 confirm that there is no on-going increase in groundwater levels in this area in response to the arrival of municipal water. Instead, water levels at MW106 are fluctuating in response to both short-term (rainfall) and longer-term (seasonality) effects. Water levels rise and fall in response to rainfall, gradually drop throughout the growing season, then rise in the winter and spring, outside the growing season. This graph shows there is no long-term trend of increasing water levels at this well.
- The data from all wells, but particularly MW122, show the effect of plants removing water from the groundwater system (i.e., evapotranspiration). Evapotranspiration is greater in wetland areas due to the shallow groundwater, the high density of plants, and the presence of water-loving plants that tend to grow in these wetland areas. The figure to the right provides a close-up of the fluctuations in the water levels shown in Figure 3-11 for MW122. A close examination of the water level data from MW122 shows very small daily fluctuations, with water levels dropping during the day while plants are active, and stabilizing at night. These small daily fluctuations have been observed to a lesser extent at all other wells where transducers are present (MW3A, MW106, and MW111). In 2007, these daily fluctuations occurred, to a greater or lesser extent, between roughly March and December.



The following figure shows a close up of the transducer data from MW122 over the period of September 16, 2007 to September 20, 2007. Over this period, water levels drop during the day (9:00 AM to 6PM) and stabilize at night. Over these four days, the water level dropped an average of 0.0525 feet per day. Due to the daily pattern seen in the water levels, much of the change can be explained by evapotranspiration. However, there are factors that will affect the water level changes, including groundwater movement into and away from the area, recharge to the groundwater (e.g., following rainfall), or runoff and ponding in wetland areas.



Section 3.6 contains additional discussion related to groundwater-surface water interactions.

3.4.3.1 USEPA Approvable Language

In addition to the interpretations developed by the Respondents, the USEPA has provided the following additional interpretations related to the Type III (South) Area at Yard 520 (see Appendix DD). The Respondents do not necessarily agree with these statements, or do not believe there is sufficient information to support these interpretations.

- Note that groundwater flow contours presented here in the RI Report are different than those on the potentiometric surface map included in Appendix C of the SMS (ENSR, 2005a). Groundwater flow contours based on data collected during the RI Report are different than those that would likely have been present prior to construction of Yard 520, which included construction of the Type II (North) and Type III (South) Areas, re-routing of Brown Ditch to the south, and installation of a low-permeability barrier wall surrounding the Type III (South) Area. This construction caused groundwater to build up beneath the Type II (North) Area and altered the natural southward flow of groundwater beneath the Type II (North) Area toward the former location of Brown Ditch. Data from the RI reflect current conditions of flow from the Type II (North) Area of Yard 520 to the north, east, and west, as well as toward the Type III (South) Area of Yard 520 and Brown Ditch (refer to Figures 3-5 through 3-9).

- Groundwater flow is expected to be controlled by the presence of the barrier wall in the immediate vicinity of the barrier wall, but not in the larger Yard 520 area. There is a point of high water levels along the slurry wall away from which water levels decline along the slurry wall. There is no reason to assume that water levels associated with this type of no-flow boundary would be likely to be the maximum water levels in the Yard 520 area. Higher water levels in the aquifer beneath the central part of the Type II (North) Area of Yard 520 are likely, given the potential for recharge from the fill.
- The difference in water levels between wells PZ001 and P2 may indicate that there is the potential for downward flow from the fill into the underlying aquifer beneath the Type II (North) Area of Yard 520. Water level contours indicate that flow in the aquifer beneath the Type II (North) Area is to the north toward the Town of Pines and south to the barrier wall, then east and west to eventually Brown Ditch. In the absence of additional data to support the theory, a downward gradient can only be surmised.
- CCBs placed in groundwater may wick upward to create, at least in part, the mound evidenced by PZ001. This would result in a groundwater divide and closed groundwater high or divide conforming to the topography of the Type II (North) and Type III (South) Areas. Acknowledgement of this possibility in landfills in humid areas would have generated a groundwater high more representative of the landfill topography.

3.4.4 Aquifer Characteristics

Various data were collected during the RI to quantify aquifer characteristics such as hydraulic conductivity, hydraulic gradients, etc.

Horizontal hydraulic gradients can be estimated from the groundwater contour maps (see Figures 3-5 through 3-9). Generally, the hydraulic gradients in the north-south directions are in the range of approximately 0.007 to 0.009 feet per foot (ft/ft) as measured perpendicularly between interpreted contours on the maps (e.g., from the vicinity of MW106 to the north and south, the vicinity of MW113 to the north, and the vicinity of MW101 to the north). This includes the area south of Brown Ditch where the gradients are to the north (i.e., groundwater flows from the south to the north), the upland areas on the east (near MW106) where groundwater flows to both the north and the south, and the upland areas on the west (near MW101) where groundwater flows to the north. Because the Brown Ditch system is oriented mainly east-west, the primary gradients towards it are from the north and south. The short Main Branch is oriented north-south. The hydraulic gradient in this section from the uplands to the east is smaller than the north-south gradients as shown on the groundwater contour maps. In addition, hydraulic gradients to the east and west of Yard 520 are relatively steep, due most likely to the lower permeability of the materials in Yard 520 compared to the surrounding sands.

The USGS developed a regional average hydraulic conductivity for the surficial aquifer of approximately 50 ft/day, based on specific-capacity tests at 18 USGS wells (Shedlock and Harkness, 1984). Previous Yard 520 studies include permeability testing of a sample of the surficial sands (at MW-2), with a measured hydraulic conductivity of 0.88 ft/day (ATEC, 1989). The hydraulic conductivity of the surficial aquifer was also investigated during the RI by conducting a number of aquifer slug tests (see Section 2.11). Hydraulic conductivities for the surficial aquifer calculated from RI slug tests ranged from approximately 5 to 50 ft/day with a geometric mean of 14.7 ft/day, consistent with fine sands (see Table 2-11). The hydraulic conductivity calculated at each well is shown on the map in Figure 3-12. In general, higher values (greater than 10 ft/day) tend to be from wells located in the uplands (e.g., MW119, MW101, MW106), with lower values (less than 10 ft/day) from wells located in the lowlands, such as MW109, MW111, MW114, and MW122 near Brown Ditch, and MW120 located in IDNL. Although there are no apparent differences between the materials observed during drilling at these different locations; the geographic distribution of the differences does not appear to be random. It is possible that they represent slightly different depositional environments, with the uplands being the primary shoreline dunes and the lowlands including more finer grained material in interdunal or back-dune deposition. It is also possible that hydraulic conductivities of the surficial aquifer may be lower to the south, as it becomes thinner and approaches the contact with the underlying lacustrine clay/tills. The lower hydraulic conductivities range from 3.1 to 9.1 ft/day, with a geometric mean of 5.5 ft/day; the higher hydraulic conductivities range from 9.6 to 49 ft/day, with a geometric mean of 21.2 ft/day.

The hydraulic conductivity of the clay confining unit was tested as part of an assessment at Yard 520 (ATEC, 1989; ENSR, 2005a). Twelve laboratory tests were performed, with vertical hydraulic conductivities ranging from 3.91×10^{-5} ft/day to 8.82×10^{-5} ft/day, with a median of 6.63×10^{-5} ft/day.

Based on the hydraulic gradients and hydraulic conductivities measured for the surficial aquifer, an estimate can be made of groundwater velocities. Assuming a typical gradient of 0.008 ft/ft, a geometric mean hydraulic conductivity of 15 ft/day, and an assumed porosity of 25%, the average linear groundwater velocity is approximately 0.5 ft/day. This value likely represents a typical groundwater velocity. Actual velocities can vary considerably depending on local conditions, being greater where gradients and/or conductivities are greater, with lower velocities where gradients and/or conductivities are lower.

3.4.5 Evaluation of Conditions in Southern Portion of the Area of Investigation

A portion of the Area of Investigation that extends southward including areas on the south end of Ardendale Road, on Old Chicago Road, and on County Road E 1675N is referred to as the "southern portion" of the Area of Investigation (see Figure 3-13, and the street map in Figure 1-3). These areas were included because during USEPA's sampling of private wells in this area, B and/or Mo were detected at concentrations near or above the RALs (see Section 1.3.1). However, USGS regional geologic information indicated that the sands of the surficial aquifer in the southern portion pinch out against the lower permeability silts and clays of the Valparaiso Moraine/lacustrine sediments. In addition, wells screened in the deeper, confined aquifers in this southern portion were shown to have

naturally higher concentrations of B and Mo (Shedlock, et al., 1994; Buszka, et al., 2007). Therefore, as detailed in the FSP, a hypothesis was developed that the elevated B and Mo concentrations in private wells in this southern portion might be due to those wells drawing water from the confined aquifer(s), and that the inclusion of the southern portion in the Area of Investigation may not be warranted.

To evaluate this hypothesis, regional information and literature sources were reviewed, and sampling was performed as detailed below.

- Well records from the IDNR well record database (http://www.in.gov/dnr/water/ground_water/well_database/) were reviewed to determine depths to clay and the screened intervals of wells. Records for wells within the southern portion of the Area of Investigation and wells in the surrounding areas were reviewed. Copies of many of these records are included in the SMS (ENSR, 2005a). For the southern portion, well records were obtained for 10 locations. At five of these locations, the confining clay was present at the ground surface; at the remaining five locations, the thickness of the overlying sand ranged from 5 to 13 ft. The IDNR database also included records for several additional wells located south of the southern portion. At all of these wells, the confining clay was encountered within two ft of the ground surface. These data establish that the amount of sand overlying the clay in this area is thin. Where groundwater might be present in these sands (forming the surficial aquifer), there is not sufficient water to use private wells for drinking water due to the limited saturated thickness. This is shown visually in the geologic cross-sections in Figures 3-2 and 3-3.
- USGS regional geologic and hydrogeologic studies (e.g., Shedlock, et al., 1994; Fenelon, et al., 1994) document that the sands of the surficial aquifer are thinner at greater distances from the lakeshore until they pinch out against the Valparaiso Moraine and/or lacustrine sediments associated with Glacial Lake Chicago. In the Area of Investigation, the location of the pinch-out is between US Rte 20 and I-94.
- IDEM files were reviewed for information concerning well construction and groundwater analytical data for the Pines Landfill (owned by Waste Management) and Lawrence Dump, two waste disposal sites located in the Area of Investigation (locations of both shown on Figure 1-1). While no detailed information was found concerning the Lawrence Dump, the Screening Site Inspection Report (Ecology and Environment, Inc., 1991) indicates that domestic waste was disposed at the Lawrence Dump. The report also suggests that wastes other than household wastes may have been disposed, but that this was not confirmed. Geologic logs, monitoring well construction information, and groundwater analytical data were located for the Pines Landfill (WMNA, 1988). In 1986-1987, eight borings and five monitoring wells were installed surrounding the Pines Landfill. At the southernmost locations, B-4/G-2, the confining clay was encountered at a depth of 13 ft. In 1989, the measured depth to water in this well was approximately 5 ft, indicating the saturated thickness of the surficial aquifer in this area was approximately 8 ft. The depth to clay and saturated thicknesses increase to the north.

- Available regional data on natural levels of B and Mo were researched (e.g., Shedlock, et al., 1994). Since the approval of the FSP by USEPA, the USGS published the results of its boron-isotope study conducted in nearby areas (Buszka, et al., 2007). This USGS study clearly documents different boron-isotope ratios between groundwater from wells screened in the deeper confined aquifers and other groundwater (including from wells in the vicinity of Yard 520). Based on the diagnostic boron-isotope ratios, the USGS concluded that certain wells in the Beverly Shores/Town of Pines vicinity with B concentrations above the RALs were also screened in the deeper confined aquifers. Because they are screened in the deeper confined aquifers, the B in these wells is naturally occurring and not related to CCBs. This conclusion is further confirmed by the low tritium concentrations in these wells, demonstrating the groundwater is relatively older and not in recent contact with the atmosphere (discussed further in Section 4.4). The USGS study documents that the deeper confined aquifers have naturally occurring higher levels of B, which include levels above the USEPA RAL.
- During the RI, an attempt was made to install one monitoring well (SB118) in the southern portion of the Area of Investigation to evaluate the depth to clay and saturated thickness of the aquifer and to serve as a background monitoring location. During drilling of soil boring SB118, the confining clay unit was encountered at a depth of 10 ft and only 2.5 ft of groundwater was encountered. Due to these conditions, and in accordance with the FSP, a well was not installed. These data corroborate the general information about the hydrogeology of the southern portion, that there is little or no sand present above the confining clay; and that where present, the saturated thickness is small, indicating that it contains little available groundwater.
- During the RI, water samples were collected from three private wells in the southern portion (PW009, PW012, and PW013) (see Figure 2-15). Based on IDNR well records, PW009 and PW012 are known to be screened in the deeper, confined aquifer; no well record was found for PW013. Samples from these three wells were analyzed for the standard RI parameter list. They were also analyzed for tritium and boron-isotope ratios to help determine where the wells were screened and the natural levels of B and Mo in the deeper confined aquifers. The sampling results are included on Table 2-18 and discussed in detail in Section 4.4. Briefly, the results of these analyses confirm that PW013 is also screened in the confined aquifer, based on the low concentration of tritium present (indicating relatively older groundwater with no recent contact with the atmosphere) and on overall chemistry similar to PW012. Therefore, no private wells in the southern portion have been found which are screened above the deeper confined aquifers.

The objective of this evaluation was to determine whether further investigation of the southern portion was needed. Based on the information and data compiled, Figure 3-13 was prepared. It summarizes the various types of information and the available data. The map was then used to estimate the southern limits of the surficial aquifer (i.e., where the surficial sands are likely to consistently have a saturated thickness sufficient to provide water to private wells). This information was provided to USEPA, with the following conclusions (correspondence dated March 7, 2007, Appendix E):

- Based on the geologic information from multiple sources, the surficial aquifer pinches out to the south. In the southern portion of the Area of Investigation, it is either not present, or where present, has a limited saturated thickness and thus does not provide a sufficient source of drinking water.
- Based on geologic, well construction, and chemical data, private wells located in this area are screened in the deeper confined aquifer(s).

Based on the information, data, and these conclusions, it was recommended to USEPA that no further evaluation of the southern portion was warranted under the RI. On April 16, 2007, USEPA agreed that water sampling at the three private wells was no longer needed under the RI. Also, in November 2007, USEPA approved discontinuing bottled water to residents located south of County Road E 1675N (see correspondence in Appendix E).

It should also be noted that during the visual inspections completed in the Area of Investigation, no suspected CCBs were identified to be present to the south of County Road E 1675N (discussed in Section 3.7 below).

3.5 Surface Water Hydrology

The major significant surface water feature in the Area of Investigation is Brown Ditch (see Figure 1-1). Brown Ditch is an interconnected network of man-made channels extending into locally-significant interdunal wetlands, including the eastern portions of the Great Marsh in the IDNL. Brown Ditch is only one of a number of channels that were excavated in northwest Indiana in the early 1900s to drain and convey water from these wetland areas (e.g., Burns Ditch, Derby Ditch, Kintzele Ditch) (Arihood, 1975; Shedlock and Harkness, 1984). Brown Ditch is a legal drain under the jurisdiction of the drainage board of Porter County (Shedlock and Harkness, 1984).

Brown Ditch has several long east-west channels south of the Calumet Dune-Beach Complex. It crosses the dune ridge in a short north-south channel just prior to entering the IDNL. From there, Brown Ditch flows northeast through the Great Marsh to join Kintzele Ditch (see Figure 1-1). Inspection of aerial photographs of the period 1970-1990 indicates that a portion of the western channel of Brown Ditch was relocated between the photographs taken in 1980 and 1990 (PCRTPC, 1970; NIRPC, 1980, 1990, 2000). Yard 520 documents indicate that the segment of the channel that had previously crossed through the middle of the current Yard 520 (Figure 1-1) was relocated in 1989 (ATEC, 1989) to the south to run along the southern border of Yard 520 parallel to Railroad Avenue (see Figure 1-2). The original channel is rejoined just east of Yard 520. This work consisted of excavating soil materials to re-locate the channel of the ditch, not dredging of an existing channel.

Brown Ditch is a low-gradient channel having representative slopes between 0.03 and 0.11% in the areas south of the IDNL (i.e., upstream) and about 0.2% between West Dunes Highway and its confluence with Kintzele Ditch. This low-gradient profile and small watershed area translates into

generally low flow and velocity conditions, with several sections subject to ponding upstream of the IDNL (Shedlock and Harkness, 1984). The drainage basin for Brown Ditch is estimated at 4.7 sq. mi., with approximately 1.0 sq. mi. located in the IDNL (Shedlock and Harkness, 1984).

Flow in Brown Ditch is typically low. Flow measurements were taken in the 1970s and 1980s near the north-south channel which crosses through the Calumet Dune ridge prior to its entry into the IDNL (Arihood, 1975; Shedlock and Harkness, 1984). The reported measured flow values were 1.02 cubic feet per second (cfs) (October 15, 1973) and 0.79 cfs (July 16, 1982) during low flow months and 18.6 cfs (January 22, 1974) and 2.6 cfs (April 23, 1974) during winter-spring conditions. These values are similar to those measured during the RI (see Section 2.10), which range from 0.90 to 6.25 cfs for this branch of Brown Ditch. Using an estimated area for the Brown Ditch watershed prior to its entry into the IDNL of 3.7 sq. mi. (as noted above), the average flow per square mile in the ditch during low flow conditions is approximately 0.21 to 0.28 cfs/sq. mi. based on the USGS data from the 1970s and 1980s.

The main sources of water to Brown Ditch are precipitation, surface water run-off, and groundwater discharge. Shallow groundwater discharge into Brown Ditch comes from the low relief water table mounds located below the dune ridges (Shedlock and Harkness, 1984). As of 1982, the East Branch of Brown Ditch is cut through the organic peat layer with shallow penetration into the sand layer in sections closer to the lakeshore (Shedlock and Harkness, 1984). In 1982, The Town of Pines requested that the ditch be dredged to help mitigate springtime flooding (Shedlock and Harkness, 1984). In 1983, the East Branch of Brown Ditch was dredged down into the sand layer to improve drainage and reduce flooding (Shedlock and Harkness, 1984). The dredged section of Brown Ditch is located east of Ardendale Avenue, and south of East Johns Avenue and Second Place.

The Brown Ditch tributary system is a complex network of natural drainages, man-made channels, ponded areas, and related wetlands, including portions located in the IDNL (see Figure 1-2). This includes many temporary seasonal or ephemeral streams or drainage swales that carry water only during the winter and spring or stormwater run-off from precipitation events. These temporary streams or drainage swales often dry up during summer and fall months but provide seasonal aquatic habitat for mammals, fish, birds, amphibians, reptiles, aquatic and riparian plants, and macroinvertebrates. Throughout the course of Brown Ditch and through the annual cycle of wet and dry periods, it is likely that the system and wetlands it supports are alternately characterized by losing and gaining reaches both spatially and temporally, though characterization of all of these components was not an objective of the RI. However, investigation of groundwater and surface water interactions for Brown Ditch and adjacent wetlands was a component of the RI. For the purposes of the RI, the use of the term "Brown Ditch system" refers to the network of all of these features including their interaction with local groundwater recharge and discharge. When used singly, "Brown Ditch" refers to the ditch and its immediate tributaries.

For the purposes of the RI, Brown Ditch was sub-divided into segments and monitoring locations were established in each of these segments. These segments are shown in Figure 1-1.

- **West Branch of Brown Ditch** – this designation refers to the system consisting of ditches located in the southwest portion of the Area of Investigation which coalesce into a larger channel that passes under the railroad corridor and flows south of Yard 520 (within the relocated channel) and then to the northeast, where it joins the East Branch of Brown Ditch at a point just south of the US Highway 20 highway bridge. Monitoring locations for the West Branch (moving approximately from upgradient to downgradient) include (Figure 2-13 except where noted): SW001, SW002, SW019, SW020, SW021, SW030 (Figure 2-8), SW022, SW023, SW024, and SW031 (Figure 2-8).
- **East Branch of Brown Ditch** – this designation refers to the man-made channel located in the eastern portion of the Area of Investigation which flows east to west in the major interdunal lowland located between Railroad Avenue and Second Place in the Town of Pines. It joins the West Branch of Brown Ditch at a point just south of the US Highway 20 highway bridge. Monitoring locations for the East Branch (moving approximately from upgradient to downgradient) include (Figure 2-13 except where noted): SW014 (pond), SW026, SW013 (pond), SW015, SW028 (Figure 2-8), and SW016.
- **Southern Tributary of Brown Ditch** – this designation refers to the tributary system which drains the central area of the southern portion of the Area of Investigation, located to the west of Ardendale Road south of South Railroad Avenue. The flow in this system is from south to north, and this system joins the West Branch of Brown Ditch just before its confluence with the East Branch. Monitoring locations for the southern tributary (moving approximately from upgradient to downgradient) include (Figure 2-13): SW003, SW018, and SW017.
- **Main Branch of Brown Ditch** - this designation refers to the segment of Brown Ditch downstream of the confluence of the East and West Branches. This segment flows north under US Highway 20 and Route 12 (West Dunes Highway) and into the IDNL. Monitoring locations for the Main Branch (moving from upgradient to downgradient) include (Figure 2-13 except where noted): SW012, SW011, SW010 (see Figure 2-8), SW009, and SW008 (Figure 2-8).

Kintzele Ditch is a drainage system located to the east of the Brown Ditch system (see Figure 1-1). Kintzele Ditch was selected as a reference waterbody with a watershed that was similar in topography and land use to that of Brown Ditch. This ditch system is located outside of the Area of Investigation with the exception of a small area at the extreme eastern end, just east of County Line Road. Monitoring locations for the Kintzele Ditch tributary system (moving approximately from upgradient to downgradient) include (Figure 2-13 except where noted): SW006, SW005, SW004, SW007 and SW029 (Figure 2-8).

3.6 Groundwater-Surface Water Interaction

As discussed in Section 3.4.2, groundwater in the surficial aquifer in the Area of Investigation flows primarily towards Brown Ditch and its related tributaries and wetlands systems. Therefore, the Brown Ditch system is the primary groundwater discharge point within the Area of Investigation.

Understanding the interactions between groundwater and the Brown Ditch system is important in evaluating potential impacts of CCB-derived constituents in groundwater.

The USGS conducted a detailed study of groundwater-surface water interactions along Brown Ditch in the early 1980s (Shedlock and Harkness, 1984). This study confirms that Brown Ditch and its tributary system are hydraulically connected to the shallow groundwater and serve as a discharge point for shallow groundwater. Discharged groundwater is then conveyed downstream.

The RI included evaluations of the groundwater-surface water interactions throughout the Area of Investigation. Groundwater and surface water levels were measured at designated points in time (see Figure 2-9), and continuously at selected locations (see Figure 2-10). Surface water flow rates were measured to estimate rates of groundwater discharge (see Section 2.10). This section presents the interpretation of groundwater-surface water interactions based on the data collected.

A number of piezometers were installed within the bed of Brown Ditch (see Figure 2-8). These piezometers allow the measurement at the same location of both surface water in the ditch and groundwater beneath the ditch. The difference between the hydraulic head (represented by the water elevations) in surface water and groundwater indicates whether groundwater is discharging into the ditch or if surface water is recharging groundwater. Monitoring wells located near the ditch can provide additional information on the hydraulic head. Water level data were collected at locations in the East, West and Main branches of Brown Ditch. The hydraulic head differences between surface water and groundwater are calculated on Table 3-1. With the very few exceptions discussed below, the hydraulic head differences demonstrate that groundwater discharges to surface water at all locations.

- Hydraulic head differences which suggest that surface water may be recharging groundwater were measured at three locations in January 2007 (SW015, SW022, SW028) and during two other monitoring events at piezometer SW022. However, there are nearby monitoring wells at two of the three locations (MW111 near SW015, MW-3 and MW-3A near SW022). The data from these wells show that groundwater discharges to surface water. The piezometers are driven into the bed of the ditch; the wells are located on the banks. Therefore, while some data from the piezometers suggests a local seasonal condition where surface water recharges groundwater, the data from the wells shows that this effect does not extend any significant distance from the ditch.
- Only one measurement, taken at PZ005 in April 2007, suggests surface water is recharging groundwater. PZ005 is installed in a swampy, wet area located upgradient from the Main Branch of Brown Ditch in the IDNL (see Figure 2-8). It is typical in such areas that standing water during the wet season (winter and spring) provides seasonal recharge to groundwater. Conversely, during the growing season, wetland vegetation typically extracts groundwater through evapotranspiration. At most of the wetland piezometer locations, there was no surface water observed during the gauging events.

To evaluate groundwater-surface water interactions at times between the five gauging events, water levels were continuously measured between February 2007 and April 2008 at the following groundwater-surface water pairs: surface water at SW022 and groundwater at MW-3A located on the south side of Brown Ditch; surface water at SW015 and groundwater at MW111; and groundwater at MW122, located in a wetland area (see Figure 2-10). The details of the monitoring program are presented in Section 2.9.3. Graphs showing the water level changes over time are presented in Figures 3-11, 3-14, 3-15, and 3-16. The following observations about groundwater-surface water interactions are based on these data and the graphs:

- Both groundwater and surface water respond to precipitation events, which is seen by comparing water levels to the daily precipitation data included on the graphs. Surface water tends to respond quickly, showing a rapid increase in water levels followed by a relatively rapid drop. Groundwater responds slower, rising more gradually and falling much more gradually. Also, the changes in surface water levels tend to be greater than changes in groundwater levels for the same precipitation event.
- On the East Branch of Brown Ditch at SW015 and MW111, the groundwater hydraulic heads are typically greater than the surface water heads, indicating that groundwater discharges to surface water (see Figure 3-14). There was a short period in late February and early March 2007 (a few weeks) when the hydraulic heads at the two locations were very similar and groundwater discharge might have been minimized or reversed.
- On the West Branch of Brown Ditch at SW022 and MW-3A, the groundwater heads are always substantially greater than surface water heads (see Figure 3-15). This location is near the southeast corner of Yard 520. These data indicate that the hydraulic gradient in this area does not reverse; that is, that groundwater south of Brown Ditch (i.e., MW-3A) always flows northward and discharges to Brown Ditch. Therefore, groundwater from the north side of Brown Ditch, including at Yard 520, discharges to Brown Ditch and does not flow beneath it to the south.
- Water levels at both surface water locations SW022 and SW015 appear to be affected by nearby beaver dams (see Figure 3-16). Beavers have regularly built dams at various locations along the Brown Ditch system throughout the RI. The rapid changes in water levels that are not associated with precipitation events, which are then sustained for a longer period, are mostly likely due to beaver activity and removal of their dams by humans.

Surface water flow rates measured during the RI can also be used to evaluate the groundwater-surface water connection. Flow rates were measured at an upstream and a downstream station in each Brown Ditch branch, as shown on Figure 2-11. The differences in flow between these stations and between the different branches can be used to assess groundwater and surface water interactions. In systems where groundwater discharges to surface water, surface water flow rates increase with greater distance downstream. These systems are known as gaining water bodies (as the volume of flow increases). Conversely, losing water bodies are those that have reduced volumes of flow, typically because the surface water is lost into the surrounding groundwater system. In

temperate, humid areas of the US (including Indiana) outside of limestone and karst terranes, most surface water systems are gaining water bodies. It is the groundwater discharge into rivers that keeps them flowing during the summer and other dry periods in the absence of rainfall.

To show the geographic patterns in surface water flow rates, some of the surface water flow data are shown on the map in Figure 3-22, including data for October 2006, April 2007, and July 2007. Data for August 2006 and January 2007 are not shown, because of missing data from stations and poor RPDs (more than 25%) at many stations. The most reliable data are from October 2006 and April 2007. However, the measurements collected in October 2006 followed significant rainfall, and so the data include substantial rainfall runoff. The data from April 2007 are representative of the wet period of the year, and so also include contributions to Brown Ditch from the many associated minor tributaries, drainage ditches, and wetlands. Because both of these datasets represent wet periods and include non-groundwater inputs to Brown Ditch, data for July 2007 are also shown, although there are poor RPDs for many of the stations (due most likely to the velocities that are low and difficult to measure accurately). The following interpretations are based on surface water flow data although there are limits to the quantitative use of some of the data (see Table 2-10 and Figure 3-22):

- In general, the differences between upstream/downstream pairs of stations show that downstream flows are greater than upstream flows. This demonstrates that Brown Ditch is a gaining water body, and so groundwater discharges to the ditch. In the few instances where data suggest the opposite, there is poor reproducibility and/or very low flows that are difficult to measure accurately.
- The calculated median flow rates at each station (which are less affected by inaccuracies in individual data points) also show increasing flow rates further downstream.
- Differences in surface water flow rates were the highest in January 2007, a period of greater rates of groundwater discharge. As discussed in Section 3.4.3, this is also the time at which groundwater levels were the greatest and the groundwater gradients were the steepest.

In summary, all the collected data indicate that groundwater typically discharges to the Brown Ditch system. Any reversal that might occur, with surface water recharging groundwater, is only local and only for short periods of time. Furthermore, it is highly unlikely that the gradients ever reverse on the West Branch of Brown Ditch south of Yard 520, thus groundwater does not flow beneath the ditch to the south.

3.7 Description of CCBs

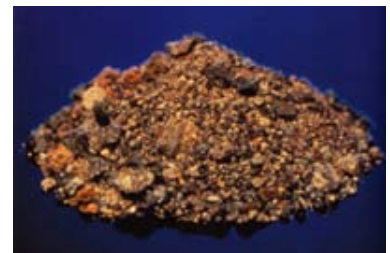
Coal-burning power plants supply more than half of the electricity used in the United States (USGS, 2001). When coal is burned to produce power, unburned residues are left, which are re-usable by-products and therefore are termed CCBs. CCBs include fly ash, bottom ash, and boiler slag. These residues are considered to be by-products because there are many beneficial re-uses for these materials (USGS, 2001). For example, approximately 19 million metric tons of fly ash were used in

concrete, structural fill, and waste stabilization in 1999 (USGS, 2001). Fly ash is used in major construction projects, for example, high-strength concrete buildings, decks and piers of highways, major dams, and concrete pavements (USGS, 2001). The use of fly ash to partially replace portland cement in concrete significantly reduces the emissions of carbon dioxide to the atmosphere (for example, a reduction of seven million metric tons in 1998; USGS, 2001). Five million metric tons of bottom ash were used in 1999 primarily in structural fill, snow and ice control, road sub-bases, and concrete (USGS, 2001). About two million metric tons of boiler slag, representing nearly all the boiler slag produced in 1999, was used in blasting grit and roofing applications (USGS, 2001). In addition, USEPA has used fly ash in the construction of a “green” building in their New England Regional Laboratory located in Chelmsford, Massachusetts. The use of fly ash in concrete construction materials in this building accounted for 126 tons of fly ash being recycled and not disposed of as part of the waste stream (USEPA, 2007).

There is a great deal of literature available on the physical and chemical nature of CCBs. This information was summarized in the SMS (ENSR, 2005a). There are three types of CCBs potentially relevant for the Area of Investigation. Their classification is based on how and when they are generated in the coal combustion process. Bottom ash and boiler slag settle to the bottom of the combustion chamber. Fly ash is also generated in the combustion chamber, but it is lighter and finer than the bottom ash and boiler slag and so is transported in the flue gas and ultimately collected by air emission controls (e.g., electrostatic precipitators or other gas scrubbing systems) (USGS, 2001).

Below are composite descriptions for fly ash, bottom ash, and boiler slag from a number of sources (Kalyoncu, 1999; USGS, 2001; OSM; CARRC) including pictures of the products (CARRC, <http://www.undeerc.org/carrc/html/whatiscoalahash.html>).

- Bottom ash consists of agglomerated ash particles that are too large to be carried in the flue gases and instead adhere to the boiler walls or fall through open grates to an ash hopper at the bottom of the boiler. Bottom ash is typically a gray to black, coarse, granular material with a porous surface texture. Bottom ash is coarser than fly ash with grain sizes spanning from fine sand to fine gravel (3/8-inch). It is usually a small portion of the total ash produced by the boiler.
- Boiler slag is similar to bottom ash, but represents material that has been melted during combustion in cyclone boilers. It is collected at the base of the boilers and is quenched with water causing it to shatter into black, angular particles that have a smooth glassy appearance. Boiler slag is generally a black, granular, vitreous material and is coarser than fly ash.



- Fly ash is coal ash that exits from a combustion chamber in the flue gas and is captured by air pollution control equipment, such as electrostatic precipitators, baghouses, or wet scrubbers. Fly ash is a fine powder formed from the mineral matter in coal plus a small amount of unburned carbon that remains from incomplete combustion. It is composed primarily of very small, amorphous, glassy spheres of alumina and silica oxides. It is generally light tan in color and consists mostly of silt-sized and clay-sized glassy spheres. The consistency of fly ash resembles talcum powder.



Fly ash has cementitious and/or pozzolanic properties that make it attractive as a building material. Fly ash with a high calcium content is cementitious, meaning that it will harden like concrete when mixed with water. Cementitious ashes are typically generated from low sulfur, western coals. Fly ash with lower calcium content is said to be pozzolanic, meaning that it will harden when mixed with both calcium and water. Pozzolanic ashes are typically generated from high-sulfur, eastern and mid-western coals.

The following table presents a brief summary of physical and chemical properties of CCBs.

Physical and Chemical Variability of CCBs (from Pflughoeft-Hassett, et al., 2000)

CCB Type	Particle Size	Particle Morphology	Color	Major Composition	Trace Element Composition
Bottom ash	Range from granular to ½ in	Angular	Tan to black	Depends on coal source	Low concentrations
Boiler slag	Granular	Approx. spherical	Black	Depends on coal source	Low concentrations of most trace elements
Fly ash	High percentage smaller than 325 sieve	Spherical	Tan to gray	Depends on coal source	Enriched in trace elements

Based on these descriptions, fly ash should be visually distinguishable from bottom ash and boiler slag. However, if these materials were mixed (either with other CCBs or soils) or if some cementation of the fly ash takes place, they may be less distinguishable based on their appearance.

At NIPSCO's Michigan City Generating Station, CCB management was consistent with industry and regulatory standards. Fly ash was collected from gas in the stack in emission control devices (such as electrostatic precipitators). Prior to 1998, CCBs were flushed from the boiler systems using water. The mixture of water and CCBs was piped to settling ponds at the plant. The CCBs managed this way may have been a mixture of fly ash and bottom ash/boiler slag. In the settling ponds, the CCBs were allowed to settle out of the water. Approximately twice a year, the settling ponds became filled to

capacity with CCBs. At that point, the CCBs were removed from the ponds and typically transported to Yard 520 for disposal. At the time of disposal, the CCBs would have been a wet slurry. In 1992, NIPSCO changed the source of the coal used at Michigan City from a high-sulfur Illinois Basin coal to a low-sulfur Powder River coal. In 1998, the Michigan City Generating Station switched to a system that managed the CCBs in dry form. Also, it appears that there were occasions when NIPSCO contracted with other entities (not Brown) for CCB-related services. A chronology of operations at Yard 520 and the Michigan City Generating Station was presented in Appendix D of the SMS (ENSR, 2005a).

3.7.1 Physical Description of CCBs in the Area of Investigation

A significant element of the RI field investigation was the identification of suspected CCBs, both as part of geologic logging and during suspected CCB visual inspections. These determinations were made from visual examinations performed by geologists and trained field staff based on the following general observations (implementing the approved protocol included in Appendix E). In the Area of Investigation, the appearance of materials suspected to be CCBs is generally different from the appearance of native soils, but not necessarily distinct from other types of fill. The native soils are typically tan colored sands in the upland dunes and dark-colored, fine-grained organic soils in the lowlands. CCBs are typically visually distinct. However, the identification by visual observation alone of whether a material is or is not a CCB (versus another type of fill material) and, if so, what type of CCB (fly ash, boiler slag, etc.) cannot always be made conclusively in the field. For example, bottom ash from coal combustion (a CCB) may appear in the field similar to steel-making slag (not a CCB). Also, non-native materials may include other types of fill materials that are not CCBs, for example, re-worked soil materials, steel-making slag, gravel and rubble, etc. Any potential uncertainty is resolved for purposes of the RI by referring to non-native materials having a visual appearance consistent with CCBs as “suspected CCBs.” In addition, when suspected CCBs are encountered in the field, they are often mixed with native soils, especially sand. Therefore, the description of non-native materials as “suspected CCBs” is applied to a range of materials that includes a very small to a larger portion of “suspected CCB” material, and the suspected CCB material may include different amounts of various types of different CCBs. The presence of suspected CCBs noted in field logs should not necessarily be interpreted to mean that the material is entirely composed of suspected CCBs, or if indeed a CCB, that any particular type of CCB was identified. It is also recognized that the absence of CCBs cannot be conclusively made in the field.

During the RI, CCBs or suspected CCBs were observed in the Type II (North) Area at Yard 520, the Type III (South) Area at Yard 520, and in various areas within the Area of Investigation. The physical characteristics of the CCBs or suspected CCBs in the three different locations are summarized below. Specific locations of suspected CCBs are discussed in the following section.

Type II (North) Area. The CCBs in this area, observed during drilling, are generally very fine grained (slit/clay) and dark-grey to black in color. Records indicate the material in Yard 520 is predominantly

fly ash (Brown, 1981). Small amounts of other fill materials are also present, such as steel-making slag and wood.

Type III (South) Area. The CCBs encountered during drilling consist of very fine-grained (silt and clay) tan colored material mixed with larger (medium to fine sand) black materials. The lighter-colored CCBs were generated in the Michigan City plant after 1992, when the coal used at the plant was switched from a high-sulfur Illinois Basin coal to a low-sulfur coal from the Powder River Basin. More information on the work performed in this area is presented in the "Evaluation of the Data Collected Under the Yard 520 Sampling and Analysis Plan" (ENSR, 2008).

Town of Pines. The suspected CCBs encountered in utility trenches and at the ground surface in portions of the Town of Pines consist primarily of coarse-grained (sands and gravel) black materials with varying, smaller amounts of finer grained (silt and clay) black materials. These are often mixed with varying amounts of native soils and other fill (e.g., steel-making slag). Physical characteristics for these materials are included on Table 2-3, which shows median values for ten CCB samples: bulk density of 1.31 grams per milliliter (g/ml); 6.3% fines (silt and clay); 93.7% coarse-grained (sand and gravel). The percent fines ranged from 2.6 to 12.8%, indicating the suspected CCBs are composed primarily of sand and gravel-sized particles, as observed in the field. Specific types of CCB were not identified in the field, so these samples could include varying amounts of fly ash, bottom ash, and/or boiler slag, as well as other types of fill such as steel slag. The suspected CCBs observed during the visual inspections typically included a higher percentage of materials not identified as suspected CCBs, that is, most of the samples contained a greater percentage of native soils compared to suspected CCBs. The inspections focused on the surface soils, where there may be mixing with other materials (e.g., sand, roadway materials, topsoil/leaf litter, mulch, and other types of fill). Of all of the properties inspected, only seven had locations classified as having suspected CCBs in the 51-75% range; no locations were classified as having 76-100% suspected CCBs present.

Because CCBs represent the residues after burning of coal, they are expected to have a relatively low content of residual carbon.

3.7.2 Potential Locations of CCBs in the Area of Investigation

CCBs are known to have been disposed in the Yard 520 Restricted Waste Facility under a permit issued by IDEM. In addition, CCBs are reported to have been used by the Town of Pines as road sub-base to fill in low-lying areas beneath roadways, and by individual property owners for fill and/or driveway surfacing. Of all the properties that were visually inspected, suspected CCBs were identified adjacent to a building on only five properties. Available documentation indicates these activities took place in the early to mid-1970s (e.g., Appendix F of the SMS). The use of CCBs as road sub-base and/or fill was not carried out by Brown or by NIPSCO. Sources of information on suspected CCB locations prior to the RI are summarized in the SMS (ENSR, 2005a).

The locations of suspected CCBs within the Area of Investigation were determined through a visual inspection program, as described in Section 2.4. The results of this inspection program are shown on Figures 3-17, 3-18, and 3-19. Figure 3-17 shows whether suspected CCBs were or were not observed at each inspection location. Figure 3-18 shows only those inspection locations where suspected CCBs were observed. Finally, Figure 3-19 shows the extent of suspected CCBs observed during the inspections (solid lines). All three figures also show the inferred extent of suspected CCBs (dashed lines) in areas where inspections were not performed. Areas that were not inspected were typically because access agreements were not received. In the absence of visual inspections, the areal extent of suspected CCBs was estimated based on information such as visual inspection results on neighboring properties, historic information about possible CCB filling, topographic features, geologic logs, and examination of aerial photos. The visual inspection program identified the presence or absence of suspected CCBs at a location. Where suspected CCBs are present at a location, they are usually not 100% suspected CCBs, but most often a mixture of suspected CCBs and other materials, such as sand or soil (which are typically present at greater percentages than the suspected CCBs). In addition, specific types of CCB were not distinguished in the field, so the suspected CCBs could include fly ash, bottom ash, and/or boiler slag.

Figure 3-19 shows that locations with suspected CCBs are primarily along roadways in the eastern portion of the Town of Pines. In general, the suspected CCBs appear to have been used to create sub-bases for roads through wetlands and low-lying areas. Also, suspected CCBs were observed on Railroad Avenue and Maple Street, and suspected CCBs appear to have been used to surface driveways on a number of private properties.

In a number of areas, the limits of suspected CCBs extend well beyond the roadways and ROWs. It is likely that larger volumes of suspected CCBs were used as fill in these areas. These suspected CCB fill areas are located on Columbia, Delaware, Idaho, Florida, and East Johns Avenues, Second Place, east of the unpaved portion of Illinois, and at the corner of County Line Road and Railroad Avenue.

In addition to investigating the horizontal extent of suspected CCBs, the thickness of placement was documented in a number of locations. During the municipal water line installation in 2004, thicknesses of zero to seven ft (TP027) were documented (see Appendix C), with a median thickness of approximately two ft in the 44 utility trenches. Suspected CCBs were encountered during drilling of MW106, MW107, MW108, MW109, MW111, and MW117 at thicknesses ranging from 1.5 to 6 ft (see Appendix H). Observations during the municipal water line installation in 2003 suggest the presence of 11 to 12 ft of suspected CCBs below the roadway along Columbia Avenue, and more than eight ft at the south end of Florida Avenue (ENSR, 2005a). Additional anecdotal information suggests that during the installation of a new septic system at the Town Hall, at least six ft of suspected CCB material was observed below the ground surface (ENSR, 2005a). The USGS documented up to five ft of suspected CCBs beneath the unpaved portion of Illinois Avenue (Shedlock and Harkness, 1984). In addition, the thickness of fill in some locations can be estimated from the topographic basemap (Figure 1-1), based on current ground surface levels above the natural grade.

3.8 Ecological Habitat

Ecological habitats were identified and characterized as part of the RI, and will be used to evaluate the potential exposure of ecological receptors to CCB-derived constituents as part of the ERA. Methods for identification and characterization of ecological habitat, including the field reconnaissance, are described in Section 2.17. Based on these methods, an Ecological Habitat Assessment Map was prepared (see Figure 2-17). Principal findings include:

- There are no unique habitats in the area of ecological habitat assessment (refer to Figure 2-8 in the FSP). However, the Area of Investigation is located adjacent to the IDNL. The natural community types observed in the Area of Investigation are listed in Table 2-19, and include:
 - Forested habitats: Dry-Mesic Upland Forest, Wet-Mesic Floodplain Forest, and Wet Floodplain Forest;
 - Wetland habitats: Marsh and Scrub-Shrub Swamp; and
 - Stream habitat: Low-Gradient Creek.
- In the area north of Second Place and East Johns Avenue between County Line Road and Ardendale Avenue, there is generally marginal to good habitat for wildlife receptors due to the presence of contiguous undeveloped lots in an otherwise residential area. This area tends to be fragmented by street and highway corridors and locations with denser residential usage. Wildlife receptors likely to be encountered here would be those species that co-exist successfully with human influences (e.g., crow, deer, rabbit, raccoon).
- The ecological habitats south of Second Place and East Johns Avenue and north of the East Branch of Brown Ditch are a mixture of good quality habitats, mostly wetland or wet-mesic conditions (see Observations #4 and #5, Figure 2-17). There is an increased amount of disturbed and/or maintained land located at the eastern end of the East Branch of Brown Ditch. There is also open water emergent marsh edge habitat provided by several man-made ponds located south of Second Place. Wildlife receptors likely to be encountered here would be those species found in wet-mesic forests and along wetland marsh and low gradient stream habitats (e.g., muskrat, raccoon, mink, mallard, heron, kingfisher).
- The ecological habitats south of the East Branch of Brown Ditch between Country Line Road and Yard 520 and bounded on the south by Railroad Avenue are of good quality, with a large area of contiguous undisturbed habitat, except along edges of roadways at Ardendale Road and Railroad Avenue (see Observations #6 through #8, Figure 2-17). Wildlife receptors likely to be encountered here would be those species found in wet-mesic forests and in open field areas (e.g., shrew, red fox, red-tailed hawk, robin, meadowlark, raccoon, mink).

Detailed descriptions and summaries of the habitat qualities of the ecological habitats observed at the eight locations shown on Figure 2-17 are provided in Appendix U. The results of the habitat evaluation, including the information presented on Figure 2-17, will be used in the ERA.

3.9 Potential Receptors

The risk assessment conceptual site model (CSM) is a subset of the CSM for the Area of Investigation, and is used to guide identification of appropriate exposure pathways and receptors for evaluation in the risk assessments. The purpose of the risk assessment CSM is to identify source areas, potential migration pathways of constituents from source areas to environmental media where exposure can occur, and potential human and ecological receptors. This section summarizes the CSM for both human and ecological risk assessments and provides justification for identification of receptors proposed for use in the risk analysis.

3.9.1 Human Health Conceptual Site Model

The CSM for human health is used to guide identification of appropriate exposure pathways and receptors for evaluation in the Human Health Risk Assessment.

The first step in developing the human health CSM is the characterization of the setting of the Area of Investigation and surrounding area. Next, current and potential future land uses and potential receptors are identified (i.e., residential or industrial receptors who may contact the impacted environmental media of interest). Then, potential exposure scenarios identifying relevant environmental media and exposure pathways for current and potential future land uses and receptors are developed. Those potential exposure pathways that are or may be complete and for which constituents of potential concern (COPCs) are identified are evaluated quantitatively in the risk assessment.

Potential human receptors include local residents, recreational receptors (i.e., people who visit the Area of Investigation but do not reside in the area), and construction workers. Potential receptors and how they may contact CCBs are described in greater detail below, and are summarized on Figure 3-20. The receptors and pathways identified here are much the same as the ones proposed in the SMS and HHRA Work Plan (ENSR, 2005a, 2005h). The large amount of data collected in the RI does not significantly change the CSM for human health. The main exception is that the residential wells south of County Road E 1675N on Ardendale Road and Old Chicago Road are not screened in the surficial aquifer and, therefore, there is no complete groundwater pathway in that area.

- **Residents.** Residents (adults and children) might potentially contact surface CCBs directly via incidental ingestion and dermal contact and might potentially inhale CCB particulates entrained in dusts. Where groundwater is used as a source of drinking water, residents might potentially ingest CCB-derived constituents that have migrated into groundwater or might potentially contact CCB-derived constituents in groundwater while bathing. Potential drinking water pathways are not

complete for residents who are serviced by municipal water and had their wells abandoned. However, there are currently no institutional controls to prevent future groundwater use in this area. The possibility of groundwater use in the future cannot be ruled out. Residential children who play in the local ditches/wetlands might potentially contact CCB-derived constituents in surface water and sediment via incidental ingestion and dermal contact. Ingestion of CCB-derived constituents in homegrown produce may occur where gardens are present in areas where CCBs may occur at the ground surface.

- **Recreational Visitors.** Recreational visitors may be adults who fish in the local ditches or children who play in the local ditches/wetlands. Recreational visitors might potentially inhale CCB particulates entrained in dusts. Recreational visitors might potentially contact CCB-derived constituents in surface water and sediment via incidental ingestion and dermal contact. Recreational fishers might also potentially be exposed to CCB-derived constituents in fish tissue via consumption. Finally, recreational visitors might also potentially ingest groundwater as drinking water while in the Area of Investigation.
- **Construction Workers.** Construction workers might potentially contact surface and subsurface CCBs directly via incidental ingestion and dermal contact and construction workers might potentially inhale CCB particulates entrained in dusts. Construction workers might potentially also directly contact CCB-derived constituents in groundwater via incidental ingestion and dermal contact if groundwater is encountered during an excavation. Construction workers might also potentially ingest groundwater as drinking water.
- **Outdoor Workers.** Outdoor workers may be exposed to surface CCBs where present via incidental ingestion and dermal contact and to CCBs where present in particulates that may be suspended in the air via inhalation. Outdoor workers might also potentially ingest groundwater as drinking water.

These potential receptors and exposure pathways will be evaluated in more detail in the HHRA.

3.9.2 Ecological Conceptual Site Model

An ecological CSM was developed to provide a clear and concise description of how ecological receptors may come into contact with CCB-derived constituents via release mechanisms and exposure to soil, sediment, and/or surface water. A preliminary ecological CSM was provided in the ERA Work Plan (ENSR, 2005i). The ecological CSM has been updated, based on data and information obtained during the RI. The updated CSM identifies the ecological receptors to be considered for evaluation in the ERA. The ecological communities and potential receptors are described and discussed below, and are summarized on Figure 3-21.

The ecological CSM provides a schematic representation of the potential CCB-derived constituent release mechanisms, the exposure pathways, and potential ecological communities or wildlife receptors to be assessed. The two primary release mechanisms for CCB-derived constituents at the

Area of Investigation to reach potential aquatic ecological receptors are (1) the infiltration and percolation of CCB-derived constituents into the groundwater, with secondary migration/transfer occurring when groundwater flows into surface water and transport to the shallow saturated zones in wetlands; and (2) surface run-off, erosion, or transport of CCB-derived constituents into surface water bodies (e.g., man-made ponds) or shallow soils.

Migration to surface water might potentially lead to increases in constituent concentrations in various aquatic media (i.e., surface water, sediments, and fish tissue) and might potentially result in exposure pathways to higher trophic level ecological receptors. Concentrations of CCB-derived constituents might potentially be transported via groundwater in the shallow saturated zone and might potentially lead to wetland plant root uptake and translocation into leafy plant tissue. This might potentially result in exposure to wetland plants and to foraging herbivores.

The other major potential release mechanism is the migration of CCB-derived constituents from areas of historic placement as fill or road sub-base into upland soil within sections of the Area of Investigation. This might potentially result in the exposure of terrestrial ecological receptors where suspected CCBs are present within appropriate habitat.

The relevant potential exposure pathways identified in the preliminary ecological CSM include:

- Potential exposure of aquatic plants, benthic invertebrates, amphibians, fish, piscivorous avians, and mammals to CCB-derived constituents in the surface water of the Brown Ditch tributary system and adjacent man-made ponds/basins;
- Potential exposure of aquatic plants, benthic invertebrates, amphibians, fish, birds and mammals to CCB-derived constituents in sediments or porewater of the Brown Ditch tributary system and adjacent man-made ponds/basins;
- Exposure of wetland vegetation to CCB-derived constituents through root uptake of groundwater from the shallow saturated zone will be evaluated through the comparison of wetland soil/sediment and shallow groundwater concentrations to phytotoxicity-based benchmarks;
- Potential exposure of avian and mammalian receptors (herbivores, omnivores, and carnivores) to CCB-derived constituents in the Brown Ditch tributary system and adjacent man-made ponds/basins through bioaccumulation by ingestion of food items (e.g., plants, invertebrates, fish);
- Potential exposure of upland vegetation and soil invertebrates to CCB-derived constituents in upland terrestrial habitat areas where suspected CCBs are present in these areas; and
- Potential exposure of terrestrial avian and mammalian receptors (herbivores, omnivores, insectivores, and carnivores) to CCB-derived constituents in upland terrestrial habitat areas where suspected CCBs are present in these areas.

As requested by USEPA, consumption of CCB-containing material by birds for use as grit in the gizzard represents an additional potential exposure pathway to be evaluated in the ERA. In evaluating these exposure pathways, the ERA will consider information on specific species which are sensitive to CCB-derived constituents, and the more sensitive life stages in selection of representative receptor species. These potential exposure pathways will be further detailed and evaluated in the ERA, which will be prepared in accordance with USEPA guidance "Ecological Risk Assessment Guidance for Superfund, Process for Designing and Conducting Ecological Risk Assessments (EPA 540-R-97-006)," using the conservative approach to identifying diet for each receptor provided in Section 2.2.1 of the document.

4.0 NATURE AND EXTENT OF CONSTITUENTS

This section of the RI report provides a description of the CCB-derived constituents and their distribution in environmental media in and around the Area of Investigation. Because all of the CCB-derived constituents are naturally-occurring inorganic constituents, background levels in each medium (soil, groundwater, surface water, etc.) must be considered. In addition, to provide perspective, the observed concentrations are compared to human health and ecological risk-based comparison levels. The following information is included in this section:

- **Section 4.1** presents and discusses the risk-based comparison levels used to provide some context to the analytical results in the RI.
- **Section 4.2** discusses the concentrations of constituents in background soils, including reference to the risk-based comparison levels for soils, and information about the range of arsenic concentrations in soils throughout the United States;
- **Section 4.3** discusses the concentrations of constituents in suspected CCBs with reference to background soil concentrations, risk-based comparison levels for soils, and literature information about CCBs;
- **Section 4.4** presents observations and interpretations of conditions in groundwater, based on data from both monitoring wells and private wells. Background groundwater conditions are discussed, and groundwater data are compared to risk-based comparison levels. The distribution and patterns of occurrence of various constituents are discussed, which serve as the basis for interpreting the extent of CCB-derived constituents in groundwater in the Area of Investigation.
- **Section 4.5** discusses the constituent concentrations in surface water, with reference to upgradient (background) concentrations and risk-based comparison levels. Observations about the occurrence of specific parameters are made and used to provide an interpretation of the distribution of CCB-derived constituents in surface water in the Area of Investigation.
- **Section 4.6** discusses the constituent concentrations in sediment, with reference to upgradient (background) concentrations and risk-based comparison levels.

4.1 Risk-Based Comparison Levels

In this RI Report, comparison levels are referred to in discussing some of the RI results to provide perspective on interpreting these results. All of the CCB-derived constituents are naturally-occurring inorganic constituents. As a result, their simple presence in environmental media is not necessarily of interest; rather, they are of interest when concentrations are elevated (e.g., relative to background or to screening levels). While risk-based screening levels are used as the basis for the comparison levels, this use of comparison levels to provide context in the RI is not the formal screening process in that it does not serve to identify the constituents to be evaluated quantitatively in the risk assessments; the

identification of constituents of potential concern (COPC) will occur as part of the formal risk assessment process.

Risk-based screening levels are conservative levels or concentrations of constituents in environmental media that are used to evaluate site-specific data. Both human health and ecological risk-based screening levels are available from a variety of federal and state agency sources. Sources of human health and ecological screening levels were identified in the USEPA approved RI/FS Work Plan (ENSR, 2005d-j). The screening levels are very conservative levels used simply to identify those constituents to be included in the full quantitative baseline risk assessment. If a constituent is present at concentrations below risk-based screening levels, it does not pose a significant risk, and so will not be evaluated further. If a constituent is present at concentrations above a risk-based screening level, it does not mean it poses an unacceptable risk, but only that further evaluation is appropriate. The screening levels from various sources have been used to develop the comparison levels used in the RI Report. The actual screening levels will be updated and specific comparisons to screening levels will be made when the evaluation of potential risks is conducted in the formal risk assessments, in accordance with the RI/FS Work Plan (ENSR, 2005d-j).

Table 4-1 provides the comparison levels for human health for aqueous media (i.e., groundwater and surface water) and Table 4-2 provides the same for solid media (i.e., suspected CCBs, soil, and sediment). The comparison levels are conservative levels used simply to identify those constituents present at concentrations that may be of interest. The actual evaluation of potential risks will be conducted in the formal risk assessment, in accordance with the RI/FS Work Plan (ENSR, 2005d-j).

The human health comparison levels are based on published agency information, including the USEPA Regional Screening Levels (RSLs; USEPA, 2009), and the USEPA drinking water standards known as Maximum Contaminant Levels (MCLs) (USEPA, 2006). Neither B nor Mo has an MCL, and USEPA has agreed that the human health comparison levels for B and Mo in groundwater would be based on the most current USEPA screening levels, which are the RSLs for tap water (see correspondence in Appendix E). The RSLs for tap water are concentrations that are protective of daily drinking water use throughout a lifetime. In response to USEPA's request, and to provide a conservative evaluation for B and Mo, the level used for comparison will be one-tenth of the RSL. Therefore, the human health comparison level for B in groundwater is 0.73 mg/l; this level is one-tenth the USEPA RSL (USEPA, 2009) for tap water of 7.30 mg/l. Similarly, for Mo, the human health comparison level is 0.018 mg/l, which is one-tenth the USEPA RSL for tap water of 0.180 mg/l. For the RI Report discussions, the unadjusted RSLs for the remaining constituents are used for selecting the comparison levels. However, to identify COPCs in the HHRA, the screening levels will be adjusted to one-tenth the RSL for all noncarcinogens, and MCLs will not be used in the screening process.

The ecological risk-based comparison levels were identified based on the appropriate hierarchies provided in the ERA Work Plan (ENSR, 2005i). Where appropriate, ecological comparison levels were adjusted based on site-specific sediment TOC or water hardness. Ecological comparison levels were prepared and submitted to USEPA on June 19, 2007 (see Appendix E). Since then, updated

screening levels for Mn (April 2007), Se (July 2007), and Zn (June 2007) were published by USEPA and they have been incorporated into the current ecological screening levels, as presented in Table 4-3 (surface water) and Table 4-4 (solid media).

4.2 Background Soils

All of the CCB-derived constituents are naturally occurring inorganic constituents (e.g., metals and salts), most of which are expected to be present naturally in the environmental media tested during the RI. Therefore, for the purposes of the RI/FS, it is only of significance if they are elevated compared to background levels, and, if present above background levels, if these concentrations are also greater than the comparison levels discussed in Section 4.1. Observed concentrations are interpreted with respect to both background concentrations and comparison levels.

The soil sampling consisted of collection of background or native soils, that is, soils not affected by CCB-derived constituents. Background or native soils were sampled during the RI to provide an understanding of the background levels of constituents in soils in the vicinity of the Area of Investigation. The data considered are from both the 25 background soil samples collected during the RI field investigation (see Section 2.6) and the 12 native soil samples collected during the installation of the municipal water lines (see Section 2.2).

4.2.1 Physical Characteristics of Background Soils in the Area of Investigation

When planning the RI, the native soils in the Area of Investigation were expected to be either granular soils (predominantly dunes sands) or organic soils (peaty soils of the lowlands). However, based on the sampling results, the categories were not as distinct as expected, with overlap between the two groups. The two general categories are:

- Granular soils, consisting predominantly of sand, silt, or clay. In much of the Area of Investigation, these granular soils are the fine sands of the dunes that were the former shores of Lake Michigan. These dunes sands often include small amounts of interbedded silts, clays, and/or peat. Farther to the south and east, the granular soils are finer grained silts and clays associated with the Valparaiso Moraine and the lacustrine sediments of former Glacial Lake Chicago.
- Organic soils, having a relatively high content of organic matter such as peat. These soils are typically encountered in low-lying, swampy, and wetland areas. The organic soils also include varying amounts of inorganic granular materials such as sand, silt, and clay.

In general, the granular soils tend to have a lower moisture content, lower organic content, and higher density compared to the organic soils. However, the information on the physical characteristics of these soils (discussed in Section 3.4.2), shows that there is overlap between the two groups. Some of the granular soils have organic content that approaches that of the organic soils. Many of the organic

soils have densities or moisture contents similar to granular soils, indicating that even though they have a high organic content, these soils include a significant percentage of granular materials.

Note that the description of background soil samples above is used in this RI Report. The statistical treatment of background, and the consideration of granular and organic soil types, will be addressed in the risk assessments.

4.2.2 Chemistry of Background Soils in the Area of Investigation

The results of the background soil analyses are provided on Tables 2-5 and 2-20. As with the physical differences, there are also chemical differences between soil samples. Generally, soil samples with higher organic content or higher content of silts and clays tend to have higher concentrations of both primary and trace metals, for example, Al, Fe, Cu, and Zn, typical of low-energy depositional environments. However, similar to the physical differences between the two soil categories, the chemical differences between them overlap, representing a continuum rather than two distinct groups. Therefore, the background soils are evaluated and discussed here as a single group, without distinguishing between granular and organic soils.

Soil is composed of minerals that are formed from various combinations of metals and other elements. The analytical chemistry data for the background soils confirms that many metals occur naturally in soils. The metals with the highest concentrations in background soils are Al and Fe, followed by Ca, Mg, and Si. Each of these is present in many of the background soil samples at concentrations typically greater than 1,000 milligrams per kilogram (mg/kg). The following table briefly summarizes the various metals and the typical concentrations observed in the background soil samples:

Constituents	Typical Concentration Range (mg/kg)
Al, Ca, Fe, Mg, Si	> 1,000
Mn, K, Na	100 – 1,000
Ba, Pb, Sr, Zn, S	10 - 100
As, B, Cr, Cu, V	1 - 10
Cd, Se, Tl, U	< 1
Sb, Be, Co, Hg, Mo, Ni, Ag	Typically not above detection limits

The constituent concentrations in these samples can also be compared to the human health risk-based comparison levels (see Table 4-2). This comparison shows that many, but not all of the metals naturally occurring in background soils are present at concentrations that are below risk-based

comparison levels. Of note is that background levels of As in the soils within and around the Area of Investigation are above the human health risk-based comparison level of 0.39 mg/kg. The As concentration in all but two of the 37 background soil samples are above the risk-based comparison level. Also, although As was not detected in the two exceptions, the detection limits were above the risk-based comparison level. The occurrence of As in these background soils is not unexpected; natural As levels in many native soils throughout the United States are elevated above the risk-based comparison level, as discussed further below. One of the background soil samples, SS025, also contained Mn and Tl at levels above human health risk-based comparison levels. This sample is an organic soil with a relatively high percentage of silts and clays (85% fines). Additionally, background soil sample SS016 contained Co slightly above the human health risk-based comparison levels. This sample is also an organic sample located just east of the IDNL.

Figures 4-31 through 4-33 are maps showing the concentrations of B, Mo, and As, respectively, in each of the background soil samples.

In addition to inorganic constituents, the background soil samples were analyzed for radionuclides (see Table 2-20). Radionuclides are naturally occurring in soil minerals. Radionuclide analyses are expressed in in picoCuries (pCi) for the individual isotopes. The following table briefly summarizes the activity ranges observed for the radionuclides in the background samples.

Radionuclides	Typical Range of Activity (pCi/g)
Pb-210, Po-210	<1 to 10
Ra-226, Ra-228, Th-228, Th-230, Th-232, U-234, U-235, U-238	<1
Ac-227, Pa-231	Not detected above reporting limits

The activity of some of the radionuclides in the background soil samples were above human health risk-based comparison levels. All detected activities of Pb-210 were above the comparison level. The activities of both Ra-226 and Ra-228 were above their comparison levels in 19 of 28 samples analyzed (including duplicates). The activity levels of the other radionuclides were below human health comparison levels.

In addition, per USEPA request, a subset of background soil samples was submitted for microscopic analysis to confirm the field visual inspection observations about the absence of CCB material in the samples. The results indicate that three of the samples (SS021, SS024, and SS025) contain less than 0.25% fly ash, and two samples contain bottom ash, one sample at 0.75% (SS021) and one at 1% (SS024). The presence of CCB materials was not identified in two samples (SS016 and SS018).

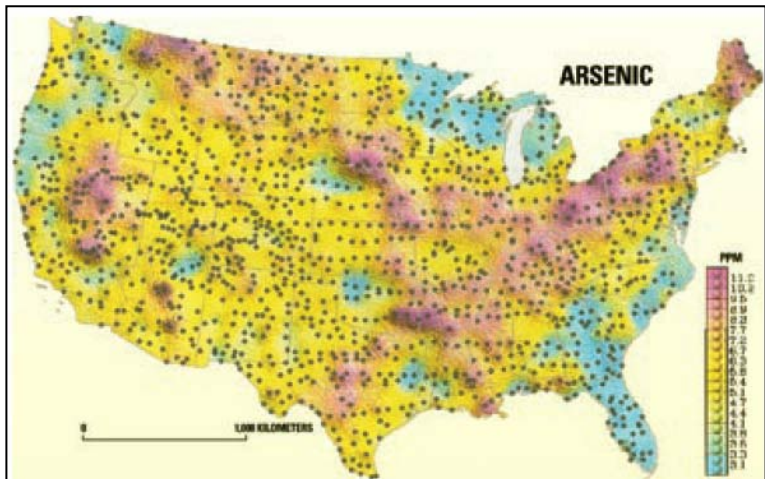
Based on these results, the very low amounts (i.e., less than 1%) of CCB materials identified in some of the background samples indicates that the constituent concentrations in the samples are representative of background conditions.

4.2.3 Background Arsenic Levels in the United States

Arsenic is naturally occurring in soils throughout the United States, often at levels that are above risk-based comparison levels. Background levels of metals including As have been evaluated throughout the United States in large scale (national) and smaller scale (regional) studies. These data are provided as context for As levels in background soil samples for the Area of Investigation, and are not used quantitatively in the RI Report, nor will they be in the risk assessments. A summary of several national and regional studies is presented below:

- The most frequently used dataset for soils across the conterminous United States is made up of 1,323 samples collected during the 1960s and 1970s by the USGS (Shacklette and Boerngen, 1984). This dataset contains background concentrations of more than 40 elements (metals and other trace elements) from soil samples that were collected at a depth of 20 centimeters (cm) (approximately 0.5 ft) and approximately every 80 kilometers (km) (approximately every 50 miles) across the United States. Samples were collected primarily from non-cultivated fields with native vegetation. Under this study, a total of 1,257 samples were analyzed for As, with results ranging from <0.1 to 97 mg/kg (or parts per million, ppm) with a geometric mean of 5.2 mg/kg. Arsenic data from this study are presented in the figure to the right (USGS, 2003b).

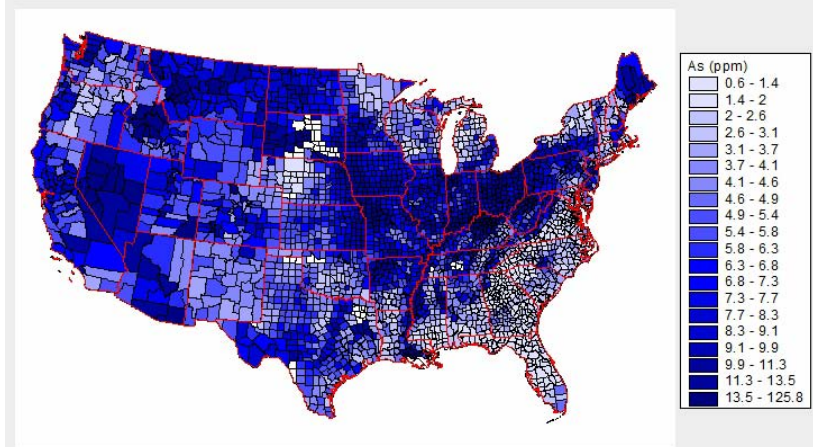
Sample locations from across the United States are shown as black dots and As concentrations ranging from 3.1 to 3.8 mg/kg are shown in blue, 3.8 to 7.2 mg/kg in yellow, and 7.2 to greater than 11.0 mg/kg in purple. Every one of the concentrations shown on the figure are above the human health risk-based comparison level.



- In October 2002, the USGS began the Geochemical Landscapes Project which is intended to develop a new, higher-density national-scale soil geochemical survey of North America to supplement the Shacklette dataset (USGS, 2003a; USGS, 2003b). Currently, the USGS has completed a regional-scale and a continental-scale pilot study. The complete North American survey has yet to be started. Details of the two pilot studies are provided below.

- Regional-scale Pilot Study – This study was conducted in northern California where 100 soil samples were collected along a transect from Marin County (north of San Francisco) to the Nevada border. In addition, the study included analysis of 2,000 archived soil samples from the National Uranium Resource Evaluation (NURE) program. Arsenic concentrations up to 80 mg/kg were detected in the soil samples (USGS, 2003a).
 - Continental Pilot Study – This study included the collection of soil samples along two continental transects in North America: the north-south transect extended from the United States-Mexico border near El Paso, Texas into northern Manitoba, Canada and included 105 samples; the east-west transect extended from the Maryland coast to near San Francisco, CA and included 160 samples. Samples were collected approximately every 40-km (25 miles) along each transect. At each location, the sample was collected from the most representative landscape within 1 km (0.6 miles) for the most common soil type. Samples were collected from up to four soil depths including the surface layer and three subhorizons. Each sample was analyzed for 42 major and trace elements, including As. Arsenic results from all horizons ranged from not detected to 23 mg/kg, with an average of 5.3 mg/kg (Goldhaber, et al., undated).
- In addition to the Geochemical Landscapes project, the USGS established the National Geochemical Survey (NGS). The NGS was established to produce a geochemical dataset for the United States (all 50 states) and is primarily based on stream sediment data. The goal of the NGS is to have at least one stream sediment sample from every 289 square kilometers (km²) in the United States, and supplement areas with other solid media (e.g., soil) where necessary. The compiled dataset contains 72,709 samples of various media (e.g., pond, lake, soil, spring, stream) (USGS, 2007). Results for As from the NGS dataset for the conterminous United States are shown in the figure to the right. Every one of the concentrations shown, including the minimum value of 0.6 mg/kg, is above the As human health risk-based comparison level. A total of seven samples were collected from Porter County, Indiana. The As results in these samples range from 6 to 47 mg/kg, with a mean of 18 mg/kg, all of these concentrations are above the As human health risk-based screening level.
- In 1998, the Association for the Environmental Health of Soil conducted a survey of state regulations related to As in soils (AEHS, 1998). The study included 34 states that provided

Arsenic in Counties of the Conterminous States



information on background As levels in soil, among other information. This study provided the range of naturally occurring background concentrations for As in soil for each state participating in the study. On a national scale, reported background As levels ranged from non-detect to 350 mg/kg. At a regional level, for states in the same geographic region as Indiana (Indiana did not participate in this study), Illinois reported background As levels from 0.35 to 24.0 mg/kg; Michigan reported background As levels from 0.1 to 11.0 mg/kg; and Ohio reported levels from non detect to 30 mg/kg. The background levels for Illinois and Ohio were based on background data reported and provided to agencies from site investigations. For Michigan, background data was established through a soil survey conducted by the Michigan Department of Environmental Quality Waste and Hazardous Materials Division. Details of the Michigan study are provided below.

- In 2005 the Michigan Department of Environmental Quality (MDEQ) conducted a survey of metals in background soils in the state of Michigan, adding to a background soil dataset previously collected in 1991. The dataset is comprised of background soil data collected from regulated hazardous waste treatment, storage, and disposal facilities as well as background samples collected by the agency. Samples were collected and analyzed for up to 25 various metals. For As, a total of 926 samples were collected (which is by far the most number of samples collected for any metal analyzed in this study). Based on this study, As results for Michigan background soils ranged from 0.47 to 27.7 mg/kg with a geometric mean of 3.6 mg/kg (MDEQ, 2005).
- Additionally, ENSR has recently presented data on background As in soils based on background sampling at 189 sites in seven states, including NY, PA, MD, VA, WV, KY, and OH (Vosnakis, et al., 2008). The samples were collected under a USEPA Superfund Administrative Order on Consent which required specific QA/QC procedures, laboratories approved by USEPA, and strict data validation requirements. Based on results from over 1,600 samples, As concentrations ranged from 1.1 mg/kg to 89 mg/kg with a median of 7.6 mg/kg. Every one of these results is above the risk-based comparison level.

4.2.4 Summary of Background Soil

The conditions of the background soils in the Area of Investigation can be summarized as follows:

- The background soils are made up of granular (sand, silt, clay) and organic materials which contain metals and other constituents. Many of the constituents detected in the samples of suspected CCBs collected as part of the municipal water service extension (see Table 2-2 and discussed in Section 4.3) are also present in the background soils.
- Arsenic is present in the background soils at concentrations above the human health risk-based comparison level. This finding is consistent with the presence of As at concentrations above risk-based comparison levels in many soils throughout the United States.
- In one background soil sample, Mn and Tl are also present at concentrations above human health risk-based comparison levels.

- Cobalt was detected slightly above its human health risk-based comparison level in one sample.
- The background soil data will be considered in the risk assessments.

Per the approved HHRA Work Plan and ERA Work Plan, a formal statistical evaluation of the background soil data will be provided in the risk assessment reports.

4.3 CCBs

The physical description and locations of the suspected CCBs observed in the Area of Investigation are discussed in Section 3.7.1 above. Figure 3-19 shows the distribution of suspected CCBs documented in the Area of Investigation during the RI. This section describes the chemistry of the suspected CCBs.

4.3.1 General Chemistry of CCBs

CCBs are the unburned residue of coal used as fuel to generate electricity. Coal was derived from ancient swamp-lands, primarily from organic matter, that is, peat or un-decomposed plant material. Through geologic processes over time, these organic materials became coal, which can be mined and burned for energy. In addition to plant materials, there are many other contributions to swamps. Silts and clays are deposited in swamps from time to time. In addition, groundwater interaction with swamps provides constituents to the swamps that were originally dissolved in the groundwater. During the transformation of the swamp-lands into coal, many chemical changes took place, resulting in the formation of numerous minerals. These non-plant materials (inorganics) become CCBs when coal is burned.

As described in the SMS (ENSR, 2005a), the chemistry of the coal fed to the boiler at a power plant will affect the chemistry of the CCBs. In general, western coals have a high calcium content and low sulfur content. Eastern and mid-western coals have generally low calcium and high sulfur content. The relative amounts of sulfur and calcium will affect the pH of water in contact with the CCBs. Trace element content also varies with coal source and type of CCB.

The primary constituent content of CCBs is similar to the minerals present in the coal they were derived from. Most minerals, especially clays, are alumino-silicates, and their primary constituents are Al and Si, and other major constituents are Ca, Mg, K, Fe, and Na (e.g., EPRI, 1987). Other constituents occurring in much lower concentrations are known as trace elements, and include As, B, Be, Cd, Co, Cr, Sb, Cl, F, S, and Se (e.g., EPRI, 1987; CCSD). Levels of trace elements tend to be higher in fly ash than in bottom ash or boiler slag and tend to increase with decreasing particle size (EPRI, 1993). High sulfur eastern coals tend to have higher levels of many trace elements (USGS, 2002) because they are present in the coal as sulfide minerals, such as pyrite.

The form in which CCBs occur affects their behavior in the environment. Boiler slag originates as a molten liquid and all constituents are blended together. As it cools, generally by quenching with water, the liquid mixture solidifies and shatters into black angular particles with a smooth glassy appearance. Therefore, boiler slag is chemically homogeneous, and its constituent components are bound up in a relatively inert matrix that is stable and does not exhibit much reactivity. Fly ash consists primarily of tiny spheres of alumina and silica oxides with trace elements largely deposited as surface coatings on the spheres (e.g., EPRI, 1993). The spheres have a larger surface area resulting in greater opportunities for reactions. Because bottom ash has not been melted, and does not have the surface coatings of fly ash, its stability and reactivity is between that of boiler slag and fly ash.

The most likely material to be confused with CCBs in the Area of Investigation, both within and outside of Yard 520 is steel slag, which is generated in large quantities in northwest Indiana, and used locally for many purposes. Steel slag is comprised of approximately 40-50% calcium oxide, 10-20% silicon dioxide, and 10-40% iron oxide with smaller amounts of manganese oxide, magnesium oxide, aluminum oxide, phosphorous oxide, sulfur, metallic iron, and other impurities that may have been present in the iron ore. Slag is produced during several different steps of the steel fabrication process and may undergo refinement within the mill to recapture ferrous and other metals or flux materials (lime and dolomitic lime). These factors affect the actual slag composition (USDOT, 1998).

4.3.2 Chemistry of the Suspected CCBs in the Area of Investigation

Suspected CCBs from Utility Trenches

During the installation of the municipal water service, a number of samples of suspected CCBs were collected from the utility trenches and submitted for laboratory analysis, as described in Section 2.2. The results of those analyses are discussed here. These samples consist primarily of coarse-grained (sands and gravel) black materials with varying, smaller amounts of finer grained (silt and clay) black materials, that could include varying amounts of different types of CCBs (i.e., fly ash, bottom ash, boiler slag). In addition, these suspected CCBs encountered in the utility trenches were often mixed with varying amounts of native soils and other fill (e.g., steel-making slag).

CCBs are derived primarily from the minerals present in the original coal, which were not consumed during burning for the generation of power. As expected, the metals with the highest concentrations in the suspected CCBs included Al, Ca, Fe, Mg, K, Si, and Na, common to most natural geologic materials (e.g., see Section 4.2.2 on background soils).

Arsenic and Fe were detected in most of the suspected CCBs samples at levels above the human health risk-based comparison levels. Arsenic was also present in the background soils above the risk-based level, as discussed in Section 4.2, above. The only other metal present in suspected CCBs above human health risk-based comparison levels is hexavalent Cr. Hexavalent Cr was detected and

above the human health risk-based comparison level in all of the suspected CCB samples in which it was analyzed.

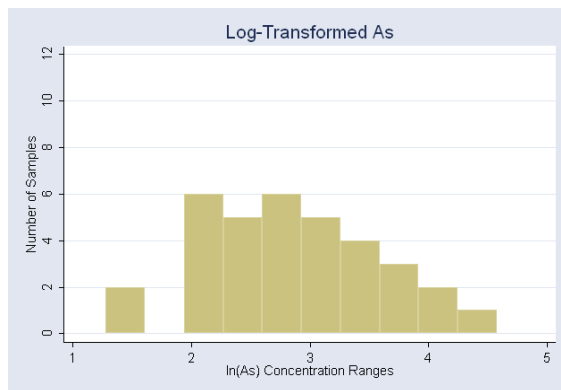
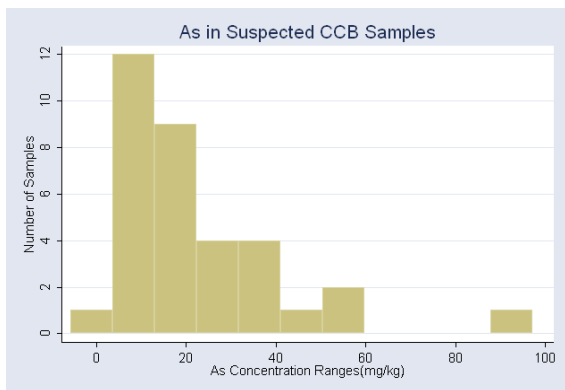
Most of the other metals detected in suspected CCB samples are the same ones present in the background soils, including Ba, Mn, Zn, Cr, Cu, Pb, B, Se, Tl, and V. Five constituents (Be, Co, Hg, Mo, and Ni) typically not detected in background soils were detected in samples of suspected CCBs. While the concentrations are generally higher than in the background soils, concentrations of all of these constituents are below human health risk-based comparison levels.

Constituents	Typical Concentration Range in Suspected CCBs (mg/kg)
Al, Ca, Fe, Mg, K, Si, Na	> 1,000
Ba, Mn, Zn	100 – 1,000
As, B, Cr, Co, Cu, Pb, Ni, S, V	10 - 100
Be, Cd, Mo, Se, Tl	1 – 10
Hg	< 1
Sb, Ag	Typically not above detection levels

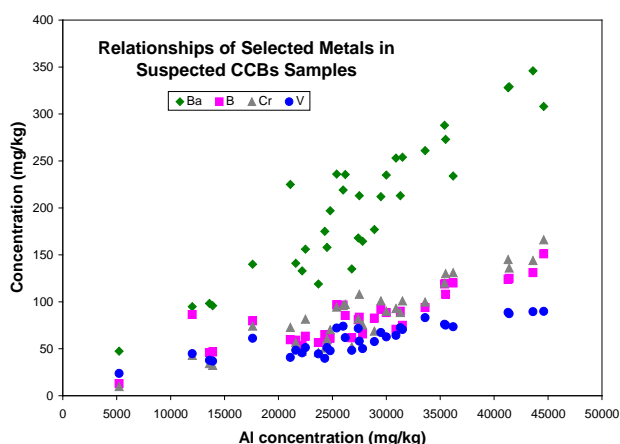
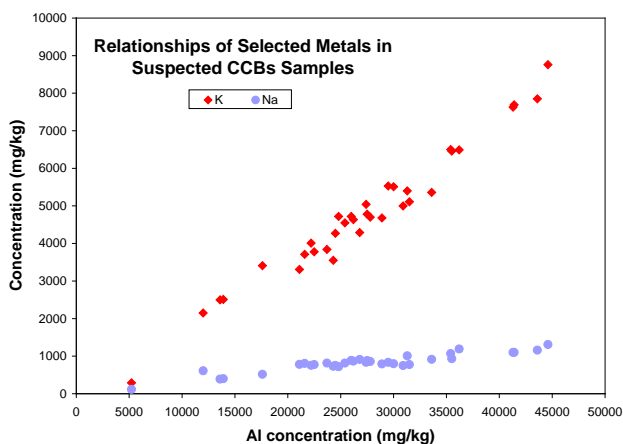
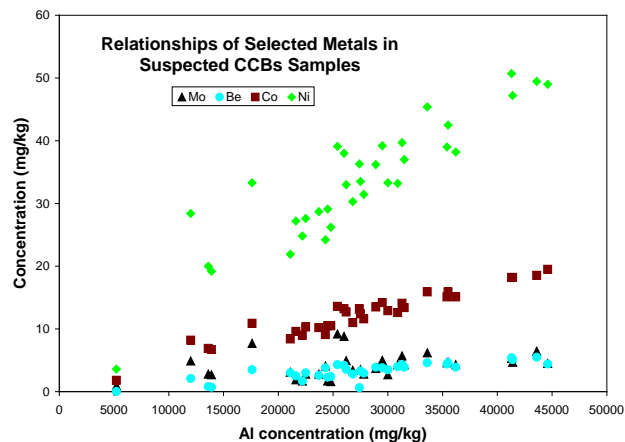
The concentrations of metals in the suspected CCB samples from the utility trenches will be evaluated further in the risk assessments, which will also include a comparison to concentrations in background soil samples.

The data from these samples can be used to assess the overall chemistry of suspected CCBs and the relationship among the constituents. The data were evaluated both graphically and statistically, resulting in the following observations and conclusions:

- The datasets for most of the metals are normally distributed. A few of the datasets are log-normally distributed, for example, As, as shown in the first histogram to the left below. When the concentrations for As are log-transformed, the dataset is clearly normally distributed, as shown on the second histogram on the right, below. Under a log-normal distribution, the maximum concentration of As of 97.2 mg/kg, is consistent with the overall dataset and is not an outlier.



- There are high correlations among certain metals, meaning that higher concentrations of several metals tend to occur in the same samples, and lower concentrations tend to occur in other samples. For example, the concentrations of As, Pb, and Zn are correlated. Also, the group of Al, Ba, B, Cr, Co, Fe, Ni, K, Na, and V are all highly correlated with each other. The adjacent graphs show some of these relationships.



- Based on these observations, the samples of suspected CCBs collected in the utility trenches appear to belong to a single population. The concentrations of metals in all the samples vary over a relatively constrained range, and they are either normally or log-normally distributed. There are no samples that appear significantly different from the other suspected CCB samples, either with particularly high or low concentrations.

Additionally, a subset of suspected CCBs samples were analyzed for pH, with results ranging from 6.95 (at TP002) to 8.05 (at TP026). Analytical results for the suspected CCB samples are presented on Table 2-2.

Inorganics in CCBs in the Type II (North) Area at Yard 520

As described in Section 2.5, three samples were collected from borings in the Type II (North) Area at Yard 520 and the results of those samples are discussed here. Note that these borings were re-drilled at a later date for geologic logging purposes, and that the analytical data are from the samples collected from the original borings. While the Type II (North) Area consists primarily of CCBs, it is known that small amounts of other materials are also present, including brush, demolition debris, steel-making slag, and interim cover materials. The collected samples had the visual appearance consistent with CCBs, but it is possible they could also include some of these other materials.

Beneath the 2-ft clay cover, the materials observed at these borings consisted primarily of light gray to black fine material (silt-clay size), with sand observed at various depths (especially GP002). Wood debris was also observed in some cores.

As expected from their origin as CCBs, the metals with the highest concentrations in the samples from Yard 520 include Al, Ca, Fe, Mg, K, Si, and Na, similar to the suspected CCBs sampled in the utility trenches, and to most natural geologic materials (see Section 4.2.2 on background soils). Antimony and Fe were detected in GP001 at levels above the human health risk-based comparison levels. Arsenic and TI were detected in GP002 and GP003 at levels above the human health risk-based comparison levels. Note that As was also present in the background soils above the risk-based level, as discussed in Section 4.2, above.

Comparing the analytical results for the three samples (see Table 2-4), the chemistry in the sample from GP001 is different than the chemistry at GP002 and GP003. The difference in chemistry may be related to the different type of materials which may be present within the Type II (North) Area at Yard 520, such as steel slag or interim cover. The chemistry of the samples collected from the Type II (North) Area is also different from the suspected CCBs from the utility trench samples, as discussed above. Generally, concentrations of certain constituents are greater in the samples from Yard 520 (especially GP002 and GP003) compared to the utility trenches, including As, B, Cr, Cu, Mo, S, and Zn.

4.3.3 Potential for Migration from CCBs to Groundwater

The findings of research on the potential for CCB-derived constituents to migrate to groundwater are summarized in the SMS (ENSR, 2005a). They indicate a potential for certain constituents to migrate from CCBs (particularly fly ash, as opposed to boiler slag or bottom ash) under certain circumstances. Many of these constituents are subsequently attenuated in the ash and/or groundwater system.

The RI included an evaluation of the potential for CCB-derived constituents to migrate from suspected CCBs to groundwater in the Area of Investigation, as described in Section 2.1.7 of the FSP (ENSR, 2005d). This evaluation included installing and sampling monitoring wells in the immediate vicinity of Yard 520 and near suspected CCB deposits in other areas of the Area of Investigation. The evaluation considered data from the following wells:

- MW-3, MW-10, MW-6, MW-8, and TW-12 immediately surrounding Yard 520 (see Figure 1-4);
- TW-15S, TW-15D, TW-16S, TW-16D, TW-18S, TW-18D, (see Figure 1-4) and MW122 (see Figure 2-8) located slightly downgradient from Yard 520; and
- MW101, MW106, MW107, MW108, MW109, MW111, and MW117 (see Figure 2-8) all drilled through suspected CCBs at thicknesses ranging from less than one ft up to six ft.

In addition, the regular groundwater monitoring data collected at Yard 520 from 1989 to the present (Weaver Boos, 2004) were evaluated.

The interpretation of these data with respect to potential migration from CCBs is discussed in detail in Section 4.4 concerning groundwater.

4.4 Groundwater

The RI for the Area of Investigation was conducted in response to the detection of B and Mo in groundwater. Therefore, a significant portion of the RI was devoted to investigating and interpreting groundwater conditions. Samples of groundwater were collected from monitoring wells at Yard 520, background monitoring wells, monitoring wells throughout the Area of Investigation, and from private wells.

This section discusses the groundwater chemistry in and around the Area of Investigation, including:

- Background groundwater chemistry, that is, groundwater outside of the Area of Investigation;
- Constituent concentrations in groundwater compared to human health risk-based comparison levels for drinking water;

- Constituent concentrations in private wells compared to human health risk-based comparison levels for drinking water;
- The patterns of occurrence of various groups of constituents and how these patterns are interpreted;
- Identification of indicators that suggest groundwater has been affected by CCB-derived constituents;
- The potential for migration of CCB-derived constituents to groundwater;
- Other sources within the Area of Investigation and their impacts on groundwater chemistry;
- Trends in concentrations over time; and,
- An overall summary of the extent of CCB-derived constituents in groundwater in the Area of Investigation.

4.4.1 Background Groundwater

All of the CCB-derived constituents are naturally-occurring constituents. In order to accurately assess potential impacts associated with CCB-derived constituents, it is necessary to understand natural, background levels of these constituents in groundwater in the vicinity of the Area of Investigation. Groundwater in the Area of Investigation originates from a number of different sources, including rainfall, groundwater from the deeper confined aquifers, and upgradient groundwater in the surficial aquifer itself. In addition, the Michigan City municipal water (which originates from Lake Michigan) is provided to many homes in the Area of Investigation and is entering the groundwater system via discharge to septic systems. While the septic system discharges are not a natural source, they are one source of water to the groundwater system.

In order to evaluate background groundwater conditions, the RI included installation of monitoring wells located upgradient and outside the Area of Investigation. Specific background monitoring wells include MW119, MW120, and MW121 (see Figure 2-12). MW113 is also deemed a background monitoring well, based on the findings that the surficial aquifer pinches out to the south and no suspected CCBs have been identified in this area (see Section 3.4.1). Each of these wells is located in different areas relative to the groundwater flow system, so differences in chemistry between them are expected. MW119 is in an upland recharge area; MW120 is in a low-lying discharge area and is located within a major wetland area (the Great Marsh). Both MW113 and MW120 are located upgradient from the Area of Investigation.

Analytical data collected from these four background monitoring wells are included on Tables 2-12 and 2-13. None of the concentrations of constituents in background groundwater from these background wells were above the human health risk-based comparison levels for any constituents, including B and

Mo. However, total coliform, and specifically, *E. coli*, were detected in MW120 in the October 2006 sampling event. This could be an indication of septic, other human or wildlife impact.

General Chemistry of Background Groundwater

The analytical data from the background monitoring wells show that the groundwater in the vicinity of the Area of Investigation contains many metals (cations) and other ions, such as chloride and sulfate (SO_4), as is typical of most natural waters (e.g., Hem, 1992). The primary cations in natural (fresh) waters include Ca, Mg, and Na; the primary anions are Cl, SO_4 , and bicarbonate (HCO_3 , measured as bicarbonate alkalinity). Silica (SiO_2) is a neutral, uncharged species, and is also present at similar concentrations. These ions are commonly referred to as the major ions as they typically make up more than 95% of the total dissolved solids in most natural waters (e.g., Hem, 1992). Minor ions are also common in natural fresh waters, but at lower concentrations than the major ions; the minor ions vary in different regions or aquifers, but generally include carbonate (CO_3), F, Fe, K, nitrate (NO_3), Sr, and B. Other ions are present in groundwater at lower concentrations; these are termed trace compounds and may include metals such as As, Cu, Zn, Ba, Mn, etc. All of these constituents are found in natural fresh waters, although not all are present everywhere or at the same concentrations. The total amount of dissolved ions in a water sample is determined by measuring the Total Dissolved Solids (TDS) or the specific conductance of the sample.

The general chemistry of the background groundwater samples from the Area of Investigation is consistent with most natural fresh waters. The primary ions include Ca, Mg, Na, Si, HCO_3 , SO_4 , and Cl. Minor and trace constituents present in the groundwater include Al, Ba, B, Mn, Sr, NO_3 , phosphate (PO_4), and ammonia (NH_4). Iron is also present in MW120. In general, the lowest concentrations occurred in MW119. Naturally-occurring ions in groundwater tend to increase in concentration as groundwater migrates through the surrounding geologic materials. As it flows, it interacts with more and more of these materials, resulting in increasing levels of ions with greater distances travelled. MW119 is located in an upland area of expected groundwater recharge, where groundwater has had relatively little contact with geologic materials. Groundwater in this area will subsequently flow downgradient to the low-lying ditch system and wetland areas, such as where MW120 is located (see Figure 2-12). During this migration, natural levels of ions in the groundwater increase. This process results in naturally higher concentrations of ions in monitoring wells such as MW120 and MW121 compared to MW119.

Boron

Boron concentrations in the background monitoring wells sampled during the RI range from 0.019 to 0.119 mg/l (see Table 2-12). The lowest concentrations are present in MW119; the highest in MW120. MW119 is located in a groundwater recharge area; MW120 is located where groundwater will have migrated some distance through the surrounding geologic materials (see Figure 2-12). As discussed above, this phenomenon results in natural differences in B concentrations (and all other ions) between wells such as MW119 and MW120.

The USGS (e.g., Shedlock, et al., 1994) has documented that groundwater in the deeper, confined aquifers beneath the Area of Investigation has higher concentrations of metals and other ions, including B. The cause of these higher, natural concentrations may be that the deeper groundwater has travelled for a long time through hundreds of feet of geologic materials. This greater interaction between the groundwater and geologic materials can result in higher concentrations of these constituents in groundwater. The USGS (Shedlock, et al., 1994) has also suggested the elevated B could be originating from the bedrock, a brownish-black marine shale. As documented in the SMS (ENSR, 2005a; Shedlock, et al., 1994), median values of B in the deeper aquifers are 0.365 mg/l (subtill aquifer) and 0.730 mg/l (basal sand aquifer).

Recently, the USGS conducted a study to evaluate elevated B concentrations in private wells in and around Beverly Shores, Indiana (Buzska et al., 2007). This study is locally known as the boron-isotope study due to the primary diagnostic test used in the study. The results of the study demonstrate that elevated levels of B (that is, at concentrations above the USEPA's RAL of 0.900 mg/l and the human health risk-based comparison level of 0.730 mg/l) in private wells sampled in the USGS study is associated with naturally occurring B in the deeper, confined aquifers. Based on the data collected during that study, the B concentrations in the basal sand aquifer (the deepest aquifer) ranged from 0.656 to 1.8 mg/l. The study also provided data on groundwater known to be impacted by septic systems discharges. In these samples, the B concentrations ranged from 0.084 to 0.387 mg/l.

The presence of B in background RI monitoring wells installed in the surficial aquifer shows that B is naturally-occurring in the shallow groundwater in the Pines Area of Investigation. The most likely source of most of this B is through upward flow from deeper groundwater. This natural process is creating the background levels of B in the shallow aquifer. However, these background levels in the surficial aquifer are generally below risk-based comparison levels, and so elevated levels of B in shallow groundwater cannot be completely attributed to background or as being contributed from the deeper groundwater.

Two samples of water from the Michigan City municipal water system were analyzed for B. The results are included on Table 2-18 and show the B concentration to be just under 0.030 mg/l (0.0289 and 0.0297 mg/l), which is probably representative of the B in Lake Michigan.

Molybdenum

Molybdenum concentrations in the background monitoring wells sampled during the RI ranged from not detected in most of the samples to 0.012 mg/l in MW121 (see Table 2-12). The USGS documented regional background levels of Mo in the surficial aquifer ranging from not detected to 0.023 mg/l (Hardy, 1981).

Groundwater samples were not analyzed for Mo in the USGS boron-isotope study (Buszka et al., 2007). However, based on the findings of the study, the USGS concluded that the level of Mo in the

Pine Township School well (0.011 mg/l based on USEPA sampling (Buszka, et al., 2007)) was most likely naturally-occurring. The Pine Township School is located at the intersection of County Road N 500E and County Road E 1600N, as shown in Figure 3-13. This suggests that background levels of Mo in the deeper confined aquifers are in the range of slightly above 0.010 mg/l.

Molybdenum was not detected in the sample of municipal water from Michigan City (see Table 2-18).

MW120

MW120 is located within INDL, to the west and outside the Area of Investigation. It is located in an area of groundwater discharge and in a significant wetland area (the Great Marsh). The presence of coliform and E. coli in a sample from this well indicates groundwater in this area may be impacted by septic systems, or other human or wildlife influences. The concentrations of most other parameters in MW120 are within the range of concentrations observed in the other background wells. For example, among the background wells, the concentrations of NH₄, Ba, HCO₃, Ca, DOC, Fe, Mg, Mn are typically greatest at MW113. The maximum concentrations of Cl, Mo, NO₃, and Na are present at MW121. At MW120, As was detected once (0.0021 mg/l), and was not detected in any other background samples. The concentrations of Sr at MW120 are typically greater than at the other background wells. Therefore, in general, the chemistry at MW120 is not noticeably distinct compared with the other background wells. The causes of the variability among background wells are most likely due to different conditions of the local groundwater: recharge or discharge area, local geochemical conditions, upgradient contributions, presence of wetlands, and other local factors.

Summary of Background Groundwater

- The groundwater in the Area of Investigation includes many naturally occurring ions, typical of most natural fresh waters in the world.
- Based on RI sampling, background concentrations of B in the surficial aquifer in the Area of Investigation range up to 0.119 mg/l.
- Based on RI sampling, background concentrations of Mo in the surficial aquifer in the Area of Investigation range up to 0.012 mg/l.
- Where groundwater has been impacted by septic discharges, the USGS has documented B concentrations up to about 0.390 mg/l.
- The USGS has documented that natural levels of B in the deeper confined aquifers are expected to be above both the USEPA's RAL of 0.900 mg/l and the human health risk-based comparison level of 0.730 mg/l. Although data are limited, the natural levels of Mo in these deeper aquifers are likely to be greater than 0.010 mg/l.

- The B concentrations in samples of city water from Michigan City were just under 0.030 mg/l (0.0289 and 0.0297 mg/l); Mo was not detected in Michigan City water.
- None of the constituent concentrations in background groundwater from the four RI background monitoring wells were above the human health risk-based comparison levels for any constituents, including B and Mo.

4.4.2 Comparison of Groundwater Concentrations to Human Health Risk-Based Comparison Levels

The following discussion is based on the comparison of groundwater data obtained during the RI from both monitoring wells and private wells to human health risk-based comparison levels for drinking water. This comparison was performed to identify parameters of interest in the RI. If a parameter is present at concentrations that are similar to background levels (i.e., concentrations that are roughly the same as the concentrations measured in background wells based on data inspection, not based on a formal statistical evaluation) or below risk-based comparison levels, and it is not a useful indicator parameter, it is not further addressed in this discussion of the RI results.

Parameters detected at concentrations above the human health risk-based comparison levels are discussed further below. Concentrations above these comparison levels do not necessarily mean there is an unacceptable risk, but rather that there will be further evaluation. Locations of the wells with results above human health risk-based comparison levels and the data from these wells are shown on Figures 4-1 through 4-11. All of the groundwater data are shown on Tables 2-12, 2-13 and 2-18.

Private Wells

As part of the RI, groundwater samples were collected from up to nine private wells, as described in Section 2.15, with the analytical results presented on Table 2-18. Comparing these data to human health risk-based comparison levels for drinking water (see Table 4-1) shows that none of the samples from the private wells contained constituents, including B and Mo, at concentrations above the human health comparison levels. Total coliform and E. coli were detected in PW012 in the October 2006 sampling event. The owner was notified of this result by USEPA.

Boron

Boron was detected in several monitoring wells at concentrations above the human health risk-based comparison level of 0.730 mg/l as shown in Figure 4-1. The highest concentrations of B were in monitoring wells located in the immediate vicinity of Yard 520 (e.g., MW-3, MW-6, MW-8, MW-10, and TW-12). These wells, and MW122, are the only locations where B was detected at concentrations above the tap water RSL of 7.3 mg/l. Lower concentrations of B (but still above the human health comparison level) were present in monitoring wells downgradient from Yard 520 (MW105, TW-15S, TW-15D, TW-16D, TW-18D). Other monitoring wells with B concentrations above the comparison

levels, on at least one occasion, include MW101 located on Maple Street, MW106 located on Columbia Avenue near the Town Hall, MW109 located on the south side of East Johns Avenue, and MW111 located on the unpaved portion of Illinois Avenue south of East Johns Avenue where Illinois Avenue crosses the East Branch of Brown Ditch (see Figure 2-12). Geographically, all of these occurrences are associated with the presence of CCBs or suspected CCBs.

Molybdenum

Molybdenum was detected in several wells at concentrations above the human health risk-based comparison level of 0.018 mg/l (see Figure 4-2). None of the Mo concentrations were above the tap water RSL of 0.180 mg/l. The highest concentration of Mo was present in monitoring well MW106, located on Columbia Avenue near the Town Hall. Concentrations above the comparison level were also present in monitoring wells in the immediate vicinity of Yard 520 (MW-6, MW-8), and downgradient from Yard 520 (MW122, TW-15D, TW-15S, and TW-18D). Other monitoring wells with concentrations of Mo above the comparison level on at least one occasion include MW108, located on the south side of Second Place, and MW117 located near the intersection of Henry Street and Ardendale Avenue (see Figure 2-12). All of these occurrences are geographically associated with the presence of CCBs or suspected CCBs.

Arsenic

Arsenic was detected above its human health risk-based comparison level of 0.010 mg/l in monitoring wells in the immediate vicinity and slightly downgradient from Yard 520 (MW-6, MW-8, MW122, TW-15D) as shown in Figure 4-3. These occurrences of As are geographically associated with CCBs at Yard 520. The only other detection of As above the comparison level was on one occasion at MW111. Suspected CCBs were observed in the vicinity of this well, however, the As concentrations are relatively low (maximum of 0.011 mg/l compared to the comparison level of 0.010 mg/l). The behavior of As in groundwater systems is complex, as discussed further in Section 5.

Selenium

Selenium was detected in one monitoring well, MW106, at concentrations above its human health risk-based comparison level of 0.050 mg/l. This monitoring well is located on Columbia Avenue near the Town Hall, as shown on Figure 4-4. Selenium was typically not detected in wells at and downgradient from Yard 520.

Iron and Manganese

The locations of monitoring wells with Fe and Mn above comparison levels are shown in Figures 4-5 and 4-6, respectively. Iron and Mn were detected above the human health risk-based comparison levels (26 mg/l for Fe and 0.880 mg/l for Mn) in MW111. Manganese was detected above its

comparison level in monitoring wells TW-16D and TW-18D located downgradient from Yard 520, but not in any of the monitoring wells closer to Yard 520 (e.g., MW-6, MW-8).

Chloride and Nitrate

Chloride was detected in TW-15D, TW-15S, TW-16D, TW-18D, MW110 and MW123 at concentrations above its human health risk-based comparison level of 250 mg/l (see Figure 4-7). Nitrate was detected on at least one occasion above its comparison level of 10 mg/l at MW101, MW104, MW106, and MW117 as shown on Figure 4-8. As described in the SMS (ENSR, 2005a), neither Cl nor NO₃ are likely CCB-derived constituents.

Sulfate

Sulfate was detected at MW-6, MW111, and MW122 at concentrations above its comparison level of 250 mg/l as shown on Figure 4-9. These occurrences appear to be geographically associated with the presence of CCBs or suspected CCBs.

Ammonia

There is no human health comparison level for NH₄, and so the ecological comparison level of 2.1 mg/l was used for this comparison. Ammonia is present in a few monitoring wells and private wells at elevated concentrations (that is, greater than at most other wells), as shown on Figure 4-10, including monitoring wells MW104, MW107, MW111, and MW115, and private wells PW007 and PW008. Geographically, these occurrences of NH₄ do not appear to be related to the presence of CCBs or suspected CCBs. The lack of a human health comparison level for NH₄ indicates that the concentrations, although elevated, do not pose an unacceptable risk to human health.

Fluoride

Fluoride was detected in Michigan City water (sample location PW002) at a concentration of 1 mg/l. The concentrations in groundwater are typically 0.1 to 0.3 mg/l, where detected, including background groundwater and deep groundwater. Fluoride is often added to municipal water to promote oral hygiene.

Bacteriological Parameters

Total coliform and E. coli bacteria were detected in a number of the groundwater samples from monitoring wells and private wells. Their occurrence is shown on the map in Figure 4-11. The bacteriological parameters are not related to the presence of CCBs or suspected CCBs.

Further interpretation and discussion of the presence of CCB-related constituents and other constituents in groundwater are provided in the following sections.

Constituents Not Evaluated as Part of the RI

The RI addresses only CCB-derived constituents, in accordance with the requirements of AOC II. Both USEPA and IDEM have tested private wells in the Area of Investigation and detected certain other, non-CCB-derived constituents above drinking water standards, including benzene (IDEM, 2001). Because these other constituents are not CCB-derived, their sources and locations, and their nature and extent are not addressed in this RI Report.

4.4.3 General Chemistry of Groundwater

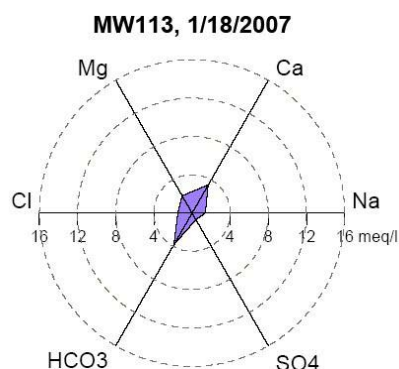
All of the CCB-derived constituents are naturally-occurring inorganic constituents and there are a number of different possible sources for many of them, as discussed in more detail in the SMS (ENSR, 2005a). For example, B occurs naturally in both the shallow and deeper groundwater in the Area of Investigation; it is associated with CCBs; and it can enter the groundwater through septic system discharges because it is present in food and in many detergent products. Thus, not all B detected in groundwater is CCB-derived. One of the objectives of the RI was to identify ways in which to distinguish the CCB-derived constituents that originate from CCBs from the same constituents originating from other sources, including background. Evaluation of both the general chemistry of the groundwater and the occurrence of specific constituents can aid in this objective.

In this section, the major and minor ion chemistry of different samples is compared to identify specific relationships and patterns that could be helpful in interpreting groundwater conditions. The following section (Section 4.4.4) discusses the occurrence and interpretation of specific parameters and groups of parameters that may be useful as indicators of different sources.

As discussed above (Section 4.4.1), groundwater contains many ions (e.g., Hem, 1992). The major cations in natural (fresh) waters include Ca, Mg, and Na; the major anions are Cl, SO_4 , HCO_3 . Silica is a neutral, uncharged species, and is also present at similar concentrations. These major ions typically make up more than 95% of the total dissolved solids in most natural waters (e.g., Hem, 1992). Minor ions are typically present at lower concentrations, and may include CO_3 , F, Fe, K, NO_3 , Sr, and B. Other trace ions are also present in groundwater, such as Cu, Zn, Ba, Mn, etc. All of these constituents are found in natural fresh waters, although not all are present everywhere or at the same concentrations.

Major Ion Chemistry, Radial Plots – Radial plots are one method used to represent differences in major ion chemistry in different samples. Radial plots have six axes arranged in a circle, each axis representing one of the six major ions (Ca, Mg, Na, Cl, HCO_3 , and SO_4). The amount of each ion (in milliequivalents per liter (meq/l)) in the sample is plotted on its axis – higher concentrations are plotted

farther from the center. Milliequivalents represent the chemical equivalence or chemical importance of an ion in a solution ($\text{meq/l} = \text{mg/l}$ times the ion valence divided by the atomic weight in grams), and thus are often used for evaluation of aqueous solutions. The points on each axis of the radial plot are then connected to each other to form a distinctive shaped polygon, as shown on the example to the right. The shape of the polygon will vary depending on the relative concentrations among all six ions. Also, larger polygons represent higher concentrations.



The radial plots for all groundwater samples collected in January 2007 are presented in Figure 4-12. (This sampling event was selected because it was the most comprehensive.) The radial plots for some groundwater samples show different shaped and sized polygons. For example, the radial plots for MW-6 and MW-8, located at Yard 520, show a relatively large hourglass shape, with higher concentrations of Ca, Mg, SO_4 , and HCO_3 and very low concentrations of Na and Cl. In contrast, the radial plot for MW123 is different with high concentrations of Na and Cl creating an elongated polygon extended to the right and left. Observations based on these radial plots and their geographic distributions are provided below.

- Many wells have generally low concentrations of these major ions, as shown by the very small polygons, for example, at the background wells MW119, MW120, MW121 and at other wells including MW102, MW124, and MW116.
- The hourglass pattern seen for MW-6 and MW-8 located at Yard 520, is also seen for MW106, but the smaller size of the polygon represents lower concentrations. The polygon for MW111 appears also be similar to the hourglass, but with the leg on the SO_4 axis missing. However, SO_4 concentrations at MW111 were lower in January and April 2007 compared to August and October 2006.
- The elongated polygon representing elevated concentrations of Na and Cl is seen for MW123, MW110, and TW-15S.
- Several wells show polygons that appear to be a combination of the hourglass shape and the elongated Na-Cl shape, including TW-15D, TW-16D, and MW105. TW-18D has the hourglass shape plus a high concentration of Na, but not Cl (however, Cl concentrations in this well are higher in the other three sampling events). MW122 appears to be the hourglass shape with the addition of slightly higher concentrations of Na and Cl, but the latter not significantly elongated.
- Private wells PW007 and PW008 show a distinctly different shape with a relatively high concentration of HCO_3 and low concentration of SO_4 . These wells are located south of the West Branch of Brown Ditch.

- Some wells have very similar levels of each of the ions, represented by a nearly circular polygon, including MW101 and MW117. MW109 is similar, but with slightly lower levels of SO_4 .
- The radial plots for PW012 and PW013 are very similar to each other. PW012 is known to be screened in the deeper confined aquifer. The similarity of their radial plots suggests that the source of water to PW013 is the same as PW012, and so PW013 is likely screened in the confined aquifer.

Further interpretation of these patterns is provided in the discussions in Section 4.4.4 below.

Major Ion Chemistry, Piper Diagrams - Piper diagrams provide another means of graphically showing the differences in major ion chemistry among several samples. Samples with distinct chemical differences will fall into different areas of the Piper diagram. Therefore, Piper diagrams may be used as a tool to distinguish between different water sources. Piper diagrams do not show absolute concentrations (like the radial plots), but rather the percent contribution of each ion to the sample. Piper diagrams have been prepared for each of the four RI sampling events at the Area of Investigation on which are plotted all groundwater samples (both monitoring wells and private wells) as shown in Appendix V. In addition, PW002, which is a sample of Michigan City water, is included on each diagram for reference, although this sample was not obtained as part of the four RI sampling events.

The Piper diagrams generally show a wide range of variations in the water chemistry. There are a group of samples with a higher proportion of the cations $\text{Na}+\text{K}$ (i.e., greater than 40%) that also tend to have greater proportions of the anion Cl . These plot on the right hand side of the upper quadrilateral on the Piper diagram, and represent the higher Na and Cl also seen on the radial plots. Other than these wells, the remaining samples tend to be grouped together, with no significant differences standing out. For example, this large grouping of samples includes samples from the confined aquifer, from the immediate vicinity of Yard 520, and from background wells. This suggests that the use of Piper diagrams to show relative differences in the chemistry of the major ions may not be a strong diagnostic tool for distinguishing among sources of water at the Area of Investigation (compared to the radial plots).

Because separate Piper diagrams have been prepared for each sampling event, they can also be used to evaluate relative changes in ion chemistry over time. For most wells, there is only a slight difference in where they plot on the diagram for each sampling event. The Piper diagrams are presented in Appendix V for reference; additional information about the use and interpretation of Piper diagrams can be found in references such as Hem (1992).

Minor Ions, Bar Charts - In addition to using the major ions to help interpret groundwater conditions, it is useful to consider minor ions and other indicator parameters. Because of their lower concentrations, minor ions do not lend themselves to radial plots or Piper diagrams. However, bar charts showing the concentrations (in mg/l) of several minor ions (B , Sr , NO_3 , NH_4 , and Fe) and DOC are shown on the

graphs in Figures 4-13 through 4-16. These parameters were selected for the bar charts because they show differences between wells, and they may be useful indicator parameters (e.g., B as an indicator of CCB-related constituents). However, for the bar graphs, it is also important that the parameters shown have relative concentrations that are appropriate for the scale of the graphs. For example, parameters with very low concentrations (e.g., phosphate) would not be visible on the graphs, and major ions such as Ca would overwhelm the scale.

Similar to the radial plots, the visual patterns in these bar graphs can aid in interpreting groundwater conditions. The bars on the graphs represent the concentrations of each parameter in each well. The different parameters are shown in different colors, with the concentrations measured on the y-axis. Each well is shown across the x-axis. On each of the graphs, the background and deep wells, and other wells with low concentrations of these minor ions and indicators, are plotted to the left. Next, the wells with the highest B concentrations are plotted together, followed by the wells with the highest NO_3 concentrations. To the far right of the graph, the wells with the highest NH_4 are plotted. For ease of comparison, the wells are shown in the same order in all four graphs.

The following observations are based on the bar charts:

- Wells MW115, PW007, and PW008 consistently have the highest levels of NH_4 . Iron and DOC are also present in these wells. These wells are located to the south of the West Branch of Brown Ditch. The only other wells with significant amounts of NH_4 are MW104 (in October 2006 and January 2007 only), MW107, and MW111.
- The wells with the highest B concentrations are typically those located downgradient from suspected CCBs, including wells at and downgradient from Yard 520 (for example, MW-6, MW-8, MW122, TW-15D, TW-16D, TW-18D, MW105) and at other locations where suspected CCBs have been observed (MW106, MW109, MW111). The highest concentrations of Sr are also present in many of these wells. High concentrations of Fe are present in some of these wells (MW122, MW111, TW-15D, MW109); NO_3 is higher in other wells (MW105, TW-15S, MW106).
- Nitrate is present at higher concentrations in many of the wells located in residential areas, such as MW101, MW104, MW105, MW106, MW117, TW-15S, and TW-18S. Some of these wells have B at levels above the human health risk-based comparison levels (MW105, MW106). None of these wells have elevated concentrations of Fe (compared to other wells).
- DOC is present in all wells, with concentrations ranging from very low in the deep wells and background wells to over 30 mg/l in wells such as PW007, PW008, MW122, and MW104. DOC concentrations appear to be greatest in August 2006 and lowest in April 2007.

pH - The pH of the groundwater samples was recorded in the field during groundwater sampling; data are provided on Table 2-12. Groundwater pH is roughly neutral, ranging between approximately 6 and 8. Wells with consistently the lowest pH (less than about 6.5) include MW107 (6.07-6.22), MW108 (6.10-6.31), MW122 (5.99-6.61), and MW101 (6.25-6.50). Wells with consistently the highest pH

(greater than 7.75) include MW120 (7.79-8.06), MW121 (7.88-8.11), PW003 (7.32-7.88), and PW006 (7.60-7.86) in the surficial aquifer. Two of the private wells screened in the confined aquifer also have pH values in this higher range (PW009 and PW013, with PW012 having slightly lower pH).

In the following section, the occurrence of specific constituents is discussed and interpreted. As appropriate, those discussions will refer back to the figures and observations presented in this section to help interpret groundwater conditions.

4.4.4 Occurrence and Relationships of Specific Constituents in Groundwater

This section details observations about the patterns of occurrence of various constituents and groups of constituents. From this, an interpretation of the groundwater chemistry at the Area of Investigation is developed, including distinguishing different groundwater sources.

Boron – B was detected at concentrations above the human health risk-based comparison level of 0.730 mg/l, but concentrations greater than the tap water RSL of 7.3 mg/l are only present at some wells in the immediate vicinity of Yard 520 (see Figure 4-1). Boron concentrations above the comparison level of 0.730 mg/l, but less than the RSL, were detected in several other wells. In all cases, where B was detected in groundwater above the comparison level in RI groundwater samples, it is geographically associated with the presence of CCBs or suspected CCBs. Wells MW105, TW-15S, TW-15D, TW-16D and TW-18D are all located downgradient from Yard 520. Wells MW101, MW106, MW109, and MW111 are all located in areas where suspected CCBs were encountered during drilling and were observed during the visual inspection program. Figure 4-34 shows the estimated distribution of B in groundwater. Also indicated on Figure 4-34 is an estimated area of B concentrations around 0.5 mg/L that is located south of Yard 520 and south of Brown Ditch. Based on available data, B in groundwater in this area appears to originate from Pines Landfill (owned by Waste Management). This area and these results are discussed in more detail under the subheading “Indicators of Municipal Landfills” later in this section, and will be addressed in the HHRA.

At the well pairs in the vicinity of Yard 520, concentrations of B tend to be higher in the deeper wells compared to the shallow wells. This can be seen visually on the cross-section in Figure 3-23. In addition, the shallow and deep wells tend to plot in different places on the various graphs comparing water chemistry (e.g., the bar charts in Figures 4-13 to 4-16; the radial plots in Figure 4-12; the Piper diagrams in Appendix V; etc.). This vertical difference is caused by the groundwater flow system in the vicinity of Yard 520 and as discussed in Section 3.4.3. Within the Type II (North) Area of yard 520, the predominant direction of groundwater flow is vertically downward into the sands underlying the Yard 520 fill materials. Once groundwater reaches these sands, it then flows outward beyond the limits of Yard 520. Therefore, the B present in this groundwater is carried with the groundwater flow in the deeper portion of the surficial aquifer to the east, northeast and west, as shown by the B distribution in Figure 4-34.

Other Indicators of CCBs – In addition to B, the constituents SO₄, Ca, Mg, Sr, and Mo were detected at elevated concentrations (that is, generally greater than at most other wells) in the wells adjacent to Yard 520 and in wells downgradient from observed suspected CCBs. The presence of these constituents at elevated concentrations does not mean there is an unacceptable risk. The occurrence of higher concentrations of these constituents together with the B in wells downgradient from observed suspected CCBs suggests that this group of constituents may be useful as an indicator of migration from CCBs to groundwater. Several of these wells show the hourglass pattern on the radial plots due to the Ca, Mg, and SO₄ (Figure 4-12). They also show higher concentrations of the minor elements B and Sr on the bar graphs (Figures 4-13 through 4-16). Figures 4-35 and 4-36 show the estimated distributions of Mo and SO₄ in groundwater. These figures and Figures 4-2 and 4-9 show that higher concentrations of Mo and SO₄ are generally associated with the higher concentrations of B, with the extent of Mo and SO₄ being slightly smaller than the extent of B.

In addition, although Mn, As, and Fe are naturally occurring in groundwater in the area and their concentrations in water can be affected by geochemical conditions, the highest concentrations of Mn and Fe in wells occur downgradient from large accumulation of CCBs as identified in this RI Report. This relation indicates that Mn, Fe, and As can be derived from CCBs. However, these constituents are not always indicators of CCBs, as other factors such as geochemistry and wetlands can also serve to explain in part their presence in certain areas within the Area of Investigation.

Indicators of Septic Impacts – There are other constituents that are typical indicators of impacts to groundwater from septic system discharges, including nitrogen (in the form of NO₃ and/or NH₄), DOC, surfactants (MBAS), PO₄, Na, Cl, and bacteriological parameters (see, for example, LeBlanc, 1984; Panno, et al., 2006; Buszka, et al., 2007). These constituents originate from their use in businesses and homes, and their presence in human diets. Therefore, they are commonly present in household wastewater and discharged to the subsurface via septic systems discharges, where they can also impact groundwater. A number of these septic system discharge indicator constituents were detected at high concentrations (relative to other groundwater samples) in wells sampled during the RI. The following table lists the wells in which at least three of these septic indicator parameters were detected at elevated concentrations (relative to other wells); the x indicates which parameters were elevated in which wells:

Well	NH ₄	NO ₃	DOC	MBAS	PO ₄	Na-Cl	Bacteria
MW101		x	x	x			
MW104	x	x	x	x	x		X
MW105		x	x	x		x	x
MW106		x		x			x
MW107	x		x	x	x		x
MW108			x	x			x
MW122			x	x	x	x	
TW-15S		x		x	x	x	
TW-15D				x	x	x	x
TW-18S		x			x	x	x

All of these wells (except MW122) are located within or downgradient from areas of high population density and, therefore, a concentration of septic systems. Several of these wells show the left-to-right elongation on the radial plots due to high concentrations of Na and Cl. On the Piper diagrams, they fall in the area representing relatively high concentrations of Na and Cl compared to other major ions. Sodium and Cl can also be elevated due to the use of halite (salt) for road de-icing, as discussed further below.

Ammonia is present in household wastewater in the form of urea (humans eliminate nitrogen from the body in the form of urea). As a result, NH_4 in groundwater can be an indication of septic system discharges. In leachfields, the NH_4 is transformed to NO_3 , which is also an indicator of septic system discharges. Nitrate is elevated (relative to background) in many wells located in the residential areas, as shown on the bar graphs in Figures 4-13 through 4-16. Ammonia is elevated in a few of them. The source for the elevated levels of these nitrogen species in groundwater is most likely septic system discharges in these areas of high population density.

Some of the septic waste indicators are elevated in wells where the CCB indicators are also elevated, such as MW101, MW105, MW106, MW111, TW-15D, and TW-18D. These results indicate that in these areas, the groundwater may be affected by both sources. This is consistent with the hydrogeology in these areas, as they are located downgradient from both observed CCBs and from areas of high population density. Many of these wells show a mixed pattern on the radial plots (see Figure 4-12) including both the hourglass shape indicating CCBs and the elongated shape representing Na and Cl. On the bar graphs (see Figures 4-13 through 4-16), many show the presence of B as an indicator of CCBs and NO_3/NH_4 as an indication of the septic system discharges.

Indicators of Municipal Landfills – High concentrations (relative to other wells sampled) of several constituents were found in private wells PW007 and PW008, including NH_4 , DOC, Na, HCO_3 , and Fe. Many of these constituents, along with Cl and specific conductance, are recognized as common indicators of leachate from municipal landfills (see, for example, Panno, et al., 2006). Barium is also elevated in samples from these wells. These constituents are also present at MW115, located in the same area, but at lower concentrations.

These wells are all located downgradient from the Pines Landfill (owned by Waste Management), an inactive municipal landfill (see Figures 1-1 and 1-2). Groundwater monitoring data from the Pines Landfill in the late 1980s shows the presence of this group of constituents (e.g., WMNA, 1988). The following concentration ranges were measured in monitoring well G03 (as shown on the map in Appendix X) located downgradient and to the northwest of the Pines Landfill between September 1987 and September 1989 (Waste Management, 1987-1989). This well is located between the Pines Landfill and MW115, PW007, and PW008.

Parameter	Concentration Range at Pines Landfill Monitoring Well G03 (mg/l)
Alkalinity	961 - 1500
Cl	203 - 340
NH ₄	40.1 - 73
SO ₄	<5 - 7.2
TDS	1200 - 1700
TOC	34.1 - 47
Specific Conductance (micromhos per Centimeter (umhos/cm))	2040 - 2850
Ba	<0.050 - 0.216
Fe	20.1 - 26.8
Na	146 - 197
B	0.378 - 0.506

The shape of the radial plots (see Figure 4-12) for these wells, with a long tail on the HCO₃ axis and very low SO₄, distinguishes them. The wells also plot together on the Piper diagrams (Appendix V). On the bar graphs (Figures 4-13 through 4-16), these wells are shown on the right-hand side, with the elevated concentrations of NH₄. As shown on Figure 4-34, the concentrations of B over 0.500 mg/l present in wells on the south side of Brown Ditch (MW115, PW007, PW008) appear to be associated with the Pines Landfill.

Road Salt – The mineral halite (NaCl) is the primary component of salts used for road de-icing in the winter. As ice and snow are melted, run-off from the roadways carries Na and Cl to the land adjacent to the roads, and into drainage systems, including Brown Ditch. When run-off infiltrates into the ground and reaches groundwater, it introduces elevated concentrations of Na and Cl into the groundwater. Therefore, in addition to impacts from septic systems and municipal landfill leachate, another source of Na and Cl to groundwater is from de-icing of roadways. Wells with elevated Na and Cl include MW105, MW110, MW122, MW123, TW-15S, TW-15D, TW-16D, TW-18S, and TW-18D.

Tritium – As explained in the USGS boron-isotope study (Buszka, et al., 2007), the presence of tritium in groundwater is an indicator of groundwater age and exposure to the atmosphere. Tritium is an isotope of hydrogen (³H) that is only generated by human activity. It started appearing in the atmosphere in the 1950s due to the testing of nuclear weapons. Once in the atmosphere, it was incorporated into rainwater, and as rainfall it entered the hydrologic system and the groundwater. Therefore, substantial amounts of tritium in groundwater indicate that the groundwater is less than 50

years old. Older groundwater that is isolated from the atmosphere is expected to have little or no tritium.

The tritium measured in most of the groundwater samples collected during the RI shows the groundwater in the surficial aquifer is relatively young (i.e., less than 50 years old), with tritium ranging from 5.98 to 10.7 tritium units (TU). Tritium levels in two of the private wells (PW012 and PW013) were very low, indicating the groundwater is older and has not had recent contact with the atmosphere. PW012 is known to be screened in the deeper, confined aquifer (tritium at 0.13 TU). The very low tritium levels in PW013 (tritium at 1.59 TU) establish that this well, too, is screened in the deeper confined aquifer.

In addition, the tritium concentrations are greatest in PW007 and PW008 (27.1 and 21 TU, respectively) suggesting the source of this groundwater is distinct from other groundwater in the Area of Investigation. Tritium has been identified as a possible indicator of municipal landfill leachate (see, for example, Panno, et al., 2006).

Boron-isotope Ratio Results – Testing for boron-isotope ratios was used successfully by the USGS to distinguish among different groundwater sources in nearby Beverly Shores, Indiana (Buszka, et al., 2007). Therefore, the RI included analyzing groundwater samples for boron-isotope ratios as another diagnostic tool in interpreting groundwater in the Area of Investigation. There are two naturally-occurring isotopes of boron, ^{10}B and ^{11}B . Different sources of water can have different ratios of these isotopes (shown as $\delta^{11}\text{B}$ on Table 2-12; note that δ is an abbreviation for δ , the Greek small letter for delta, representing the difference in the ratios of the two isotopes). If the isotope ratios are significantly different between the source waters, these differences can potentially be used to identify the source or sources of water at a particular well or location, by collecting a sample from that location and comparing the analyzed boron isotope ratios to those in the potential source waters. The USGS used boron-isotope testing to identify the source of water at a number of private wells that had B concentrations above the USEPA RAL of 0.900 mg/l. Based on the boron-isotope ratios, the USGS demonstrated that the source of water (and therefore B) to these wells was the natural deep confined aquifers, and not other sources, such as CCBs or septic systems.

The results of the boron-isotope analyses performed during the RI are provided on Tables 2-12 and 2-18 and shown graphically on Figure 4-17. The boron-isotope ratio is reported in units of per mil (‰). The following observations and conclusions are based on the boron-isotope results:

- The boron-isotope ratios in the background wells (MW113, MW119, MW120, and MW121) span nearly the entire range measured, from approximately 2 to 28‰. Unfortunately, the wide range of background ratios makes it difficult to use the boron-isotope ratio as a diagnostic tool for the Area of Investigation since ratios from most of the locations tested fall within the background range.

- The boron-isotope ratio results in wells PW012 and PW013 are very similar to each other. PW012 is known to be screened in the deeper confined aquifer. These results provide further supporting evidence that PW013 is also screened in the deeper confined aquifer.
- The boron-isotope ratios for the wells in the immediate vicinity of Yard 520 (MW-3, MW-6, MW-8, MW-10, TW-12, and MW122) range from approximately 0 to 12‰.
- The largest measured boron-isotope ratios are from wells PW007 and PW008 (36.8‰ and 31.7‰, respectively), which are located downgradient from the Pines Landfill (owned by Waste Management) and appear to show the influence of municipal landfill leachate. The boron-isotope ratio data support the interpretation that the source of the B in these wells is distinctly different from the B in the rest of the wells, and distinctly different from the B in the vicinity of Yard 520, which is hydraulically separated from these wells by Brown Ditch. MW115, also located downgradient from the Pines Landfill, also has a relatively high boron-isotope ratio.
- Further distinctions between the origins of groundwater based on the boron-isotope ratio results are not possible for the majority of the wells sampled during the RI. However, the remaining samples likely represent some combination of deep groundwater, background shallow groundwater, septic waste impacts, and/or CCBs.

Iron and Manganese – Both of these constituents are naturally occurring in soil and groundwater in the Area of Investigation, and both have been detected in a few wells at concentrations above human health risk-based comparison levels. The occurrence of these constituents in groundwater is affected by geochemical conditions and so their behavior is complex (as discussed further in Section 5 below). Under aerobic or oxidizing conditions (when groundwater contains oxygen), these parameters are likely to form insoluble molecules and thus precipitate out of solution and not be present or mobile in groundwater. However, under anaerobic or reducing conditions (when there is little or no oxygen in groundwater), Fe and Mn are present in a soluble form. This behavior is discussed below and in more detail in Section 5 below.

A comparison of the concentration of Fe in groundwater samples with information on the redox condition of the groundwater (based on the field parameters DO and ORP) shows that Fe is typically not detected in samples from locations where groundwater is oxidized. In contrast, where groundwater is anaerobic, Fe is present in groundwater samples, sometimes at concentrations above the human health risk-based comparison level. Manganese is typically present at higher concentrations where Fe also occurs at higher concentrations (analytical data are provided on Table 2-12). The graphs in Figure 4-37 show Fe and Mn plotted against ORP for all groundwater samples collected, which show graphically that higher concentrations of Fe and Mn tend to be present in samples where the ORP measured in the field tends to be lower. As shown on Figures 4-5 and 4-6 and Table 2-12, elevated concentrations of these constituents were detected in wells downgradient from the Pines Landfill (owned by Waste Management) (PW007, PW008, MW115); background well MW113; MW111 located near suspected CCBs and in a wetland area; MW107 which also appears impacted by septic system discharges; wells downgradient from Yard 520 (MW122, TW-15D, TW-18D for Mn only); but not in

wells closer to Yard 520. Figure 4-38 shows the estimated distribution of Mn in groundwater. Figure 4-42 shows the estimated distribution of Fe in groundwater. Although elevated concentrations of Mn and Fe are present in some wells that also have elevated B as discussed above, the overall distributions of Mn and Fe are different than B and other CCB-derived constituents. It is clear that while some of the occurrences of elevated Mn and/or Fe are present in wells downgradient from suspected CCBs, many of the elevated concentrations cannot be attributed to CCBs, but instead are more likely to be naturally-occurring Fe and Mn that are being mobilized due to reducing conditions.

Although Mn and Fe are naturally occurring in groundwater in the area, the highest concentrations of Mn and Fe in wells occur downgradient from large accumulations of CCBs as identified in this RI Report. Therefore, although CCBs may contribute to Fe and Mn in groundwater, their presence is more a result of the redox conditions of the groundwater.

Arsenic – Similar to Fe and Mn, As is affected by groundwater redox conditions, as discussed in more detail in Section 5. Typically, As was not detected in groundwater samples in the Area of Investigation. However, it was detected at concentrations below the human health risk-based comparison level at MW104 which appears to be impacted by septic system discharges (As=0.0041 mg/l, DO=0.35, mg/l ORP=84.9 mV, see Table 2-12), and at MW120 a background well located within wetlands (DO and ORP both low, see Table 2-12). Also, at MW111 which is located in a wetland and near suspected CCBs, As was detected below the comparison level three times and once just above the comparison level (see Figure 4-3; DO and ORP both low, see Table 2-12). Both septic wastes and wetlands can create anaerobic conditions in groundwater.

Arsenic was consistently detected at concentrations above the human health risk-based comparison level only in wells at and downgradient from Yard 520 (see Figure 4-3 and Figure 4-39). However, even in the area of Yard 520, the As concentrations decrease significantly in wells farther downgradient, showing that As is attenuated and does not migrate any distance. As shown on Figure 4-39, elevated As is present in groundwater only in the immediate vicinity of Yard 520, such as at well MW-6. At wells further downgradient, As concentrations are significantly lower, and frequently not detected, even at wells where B continues to be elevated. The following table compares As and B concentrations in wells at and downgradient from Yard 520 for the April 2007 (most recent) sampling event:

Well	B (mg/l)	As (mg/l)
MW-6	30.6	0.275
MW-8	14.4	0.011
MW122	13.8	0.0065
TW-18D	4.51	ND
TW-15D	2.49/2.55	0.0079/0.0096
MW105	2.02	ND
TW-16D	1.62	ND

It is clear from these data that the As is being attenuated in the groundwater, and does not migrate as far from Yard 520 as does the B (and other CCB-derived constituents).

Therefore, while some of the elevated As in groundwater appears to be associated with CCBs, such as in the vicinity of Yard 520, other As is likely naturally occurring and is present in groundwater due to locally anaerobic/reducing conditions.

Selenium - Se was detected at one monitoring well, MW106, at concentrations above the human health risk-based comparison level. This well is located near observed CCBs, and Se can be associated with CCBs (ENSR, 2005a). However, elevated Se does not appear to be related to CCBs in the Area of Investigation. If Se were associated with CCBs in the Area of Investigation, it is likely elevated concentrations would be observed in the vicinity of Yard 520. Instead, Se is typically not detected in wells at and downgradient from Yard 520.

Copper, Lead, and Zinc – The highest concentrations of Cu and the only detected values of Pb and Zn were found in samples from private wells (for example, PW003, PW005, PW007, PW009). These concentrations are likely from the plumbing in the water distribution system within the residences and not actual groundwater conditions. All detected concentrations are below human health risk-based comparison levels for drinking water.

Aluminum - The maximum concentration of Al detected in groundwater samples was 0.592 mg/l in TW-18S, which is well below the risk-based comparison level for human health. However, the Al concentrations are highly variable at many wells, ranging from not detected to over 0.100 mg/l in different sampling events. No other constituent concentrations in groundwater vary in this way. It appears that the higher concentrations of Al are associated with higher turbidity in the samples. For example, the sample with the concentration of 0.592 mg/l at TW-18S had a turbidity of 3.85 NTU. Samples from the other three sampling events at this well had lower turbidity (less than 1 NTU) and much lower Al concentrations (less than 0.030 mg/l). Only at wells MW107 and MW108 does Al appear to be actually present (i.e., in a dissolved form) in the groundwater (due to its consistency in all four sampling events) rather than being associated with particulate matter entrained in the sample. Aluminum concentrations in these two wells range from 0.165 to 0.394 mg/l. Figure 4-43 shows the estimated distribution of Al in groundwater.

Aluminum in groundwater does not appear to be related to CCBs. Published literature does not indicate Al as a likely CCB-derived constituent in groundwater (SMS, ENSR, 2005a). This is supported by the data collected during the RI: Al is not typically elevated in wells where other CCB-derived constituents (e.g., B, Mo) are present.

Steel Slag - As previously noted, small amounts of steel-making slag are present in the Type II (North) Area of Yard 520, and were observed on roadsides throughout the Area of Investigation. Steel slag can result in elevated concentrations of many constituents in groundwater, including Ca, K, Na, Cl, Mg,

and S. Trace elements associated with slag-affected aquifers include Al, Ba, Cr, Co, Cu, C, Mn, Hg, Ni, and V. Alkalinity and total suspended solids also tend to be high, and pH may be elevated (USGS, 1998) in groundwater impacted by steel slag. The RI has not included any formal evaluation of whether groundwater in the Area of Investigation has been impacted by steel slag.

4.4.5 Migration from CCBs to Groundwater

The RI included an evaluation of the potential for CCB-derived constituents to migrate from suspected CCBs to groundwater. Because the chemistry within CCBs is complex and affected by site-specific factors (as described in the SMS (ENSR, 2005a)), the RI relied on a direct approach to evaluating this migration: the sampling of groundwater located beneath and downgradient from Yard 520 and other locations of suspected CCBs. These data were used directly to identify which constituents in CCBs have the potential to migrate to groundwater in the Area of Investigation, and under what conditions.

Based on the data collected during the RI and the constituent relationships discussed above, the following conclusions can be made about potential migration of constituents from CCBs to groundwater in the Area of Investigation. All of these constituents are also present naturally in groundwater, and so their presence in groundwater is not necessarily related to CCBs. To reasonably conclude that a constituent is derived from CCBs, the constituent must be present at elevated concentrations (relative to background and to other wells) and other constituents that are also derived from CCBs must also be present as discussed above.

- The primary constituents that migrate from CCBs to groundwater include B, Ca, Mg, SO₄, Mo, and Sr. All of these constituents are also naturally present in groundwater. Only B and Mo are present in some locations at concentrations above human health risk-based comparison levels.
- Arsenic migrates from CCBs to groundwater, based on its occurrence in groundwater near Yard 520. Arsenic also occurs naturally in groundwater in the Area of Investigation under certain conditions. However, As clearly attenuates in groundwater and does not migrate significant distances (see Figure 4-39).
- Although Mn, As, and Fe are naturally occurring in groundwater in the area and their concentrations in water can be affected by geochemical conditions, the highest concentrations of Mn and Fe in wells occur downgradient from large accumulation of CCBs as identified in this RI report. This relation indicates that Mn, Fe, and As can be derived from CCBs. However, these constituents are not always indicators of CCBs, as other factors such as geochemistry and wetlands can also serve to explain in part their presence in certain areas within the Area of Investigation.
- Although Fe and Mn may be partially related to CCBs, their presence in groundwater is more a factor of the redox conditions in the groundwater. For example, while elevated concentrations were detected in monitoring wells downgradient of Yard 520 (e.g., TW-15D), these wells are also

impacted by septic system discharges. Also, concentrations are actually lower in monitoring wells closer to Yard 520 (MW-6, MW-8). Elevated concentrations are also present in MW111, which is located near observed CCBs. It is unlikely that the CCBs are creating the anaerobic conditions at MW111 which mobilize the Fe and Mn. Instead, this well is located in a wetland area. The reducing environment in the wetland (or other factors) could be leading to the elevated concentrations of Fe and Mn.

- The data collected during the RI indicate that Se in groundwater is not related to CCBs in the Area of Investigation.
- CCB-related constituents appear to migrate to groundwater where there are larger amounts of suspected CCB fill material present, for example, at Yard 520 or in certain areas where the suspected CCB fill extends substantially beyond roadways. Figure 4-18 brings together information on the locations of suspected CCBs and the presence of B in groundwater (as an indicator of CCB-derived constituents). As shown on this map, CCB-derived constituents (as represented by elevated concentrations of B) are present downgradient from Yard 520 and in wells MW106, MW109, and MW111, all located near or downgradient from larger areas of suspected CCBs along Idaho, East Johns, Columbia and Delaware Avenues. In contrast, it is uncertain whether migration from CCBs to groundwater occurs where used only as road sub-base. In at least one monitoring well location, elevated CCBs occur in an area of known road sub-base and underlying road fill combined (five feet of thickness as documented in the boring log for MW111; see Figure 4-18). Unverified larger accumulations of CCBs nearby (i.e., to the east of Illinois Avenue) may, however, also contribute to the groundwater contamination, as well as verified areas located around TP026 (greater than four and a half feet of CCB fill) and TP027 (greater than seven feet of CCB fill), which are located upgradient of MW111. There does not seem to be substantial migration to groundwater where suspected CCBs were used in smaller volumes, such as for only road sub-base material or driveway surfaces. Several wells are located in or downgradient from such areas, including MW107, MW108, MW114, and PW005. These wells do not show the presence of elevated levels of B (see Figure 4-18). In addition to the smaller amounts of suspected CCBs present, the paving of roadways may reduce groundwater recharge and migration of CCB-related constituents to groundwater.

In addition to these constituents, there are a number of other constituents that may be elevated in groundwater in certain areas of the Area of Investigation and are clearly not related to CCBs, including NO_3 , Cl, NH_4 , bacteria, etc. These may be naturally elevated, or may be associated with other sources, such as municipal landfills or other dumping, septic system discharges, road salt, current or former gasoline stations, etc.

4.4.6 Concentration Trends over Time

The groundwater sampling under the RI included four sampling events in one year over four calendar quarters, including both the wet and dry periods of the year. The concentration of any parameter in a

groundwater sample from any one well is seldom the same from sampling event to sampling event. Concentrations are expected to fluctuate over time due to small changes in hydrogeologic conditions.

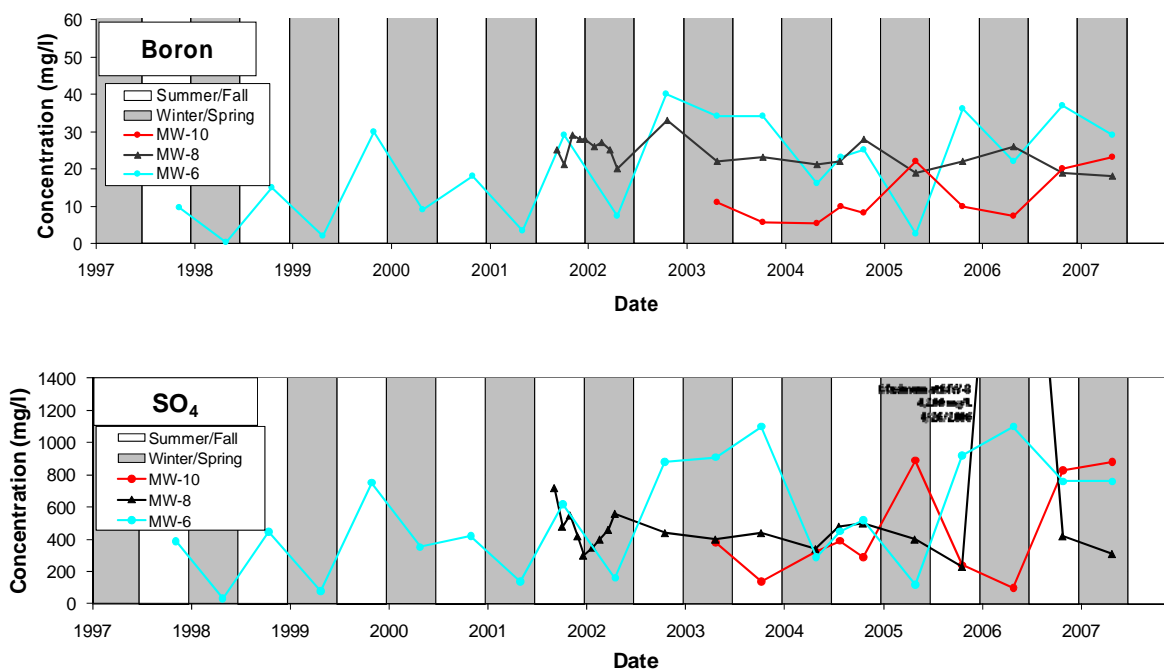
In general, concentrations of CCB-derived constituents were similar at most wells over the four sampling events. That is, the concentrations fluctuated, but not significantly. Only a few consistent trends in CCB-derived constituents were observed in groundwater during the RI:

- At MW101, concentrations of B decreased consistently from 1.79 mg/l in August 2006 to 0.249 mg/l in April 2007. Other CCB-related parameters (Ca, Mg, Sr, SO₄, Mo) decreased similarly.
- At MW105, concentrations of B increased consistently from 0.593 mg/l in August 2006 to 2.02 mg/l in April 2007. Other CCB-related parameters (Ca, Mg, Sr, SO₄) also increased. Mo was not detected in this well.
- At MW122, concentrations of B decreased consistently from 20.4 to 13.8 mg/l between August 2006 and April 2007. Other CCB-related constituents also decreased. Mo concentrations in this well increased slightly from 0.025 to 0.129 mg/l.

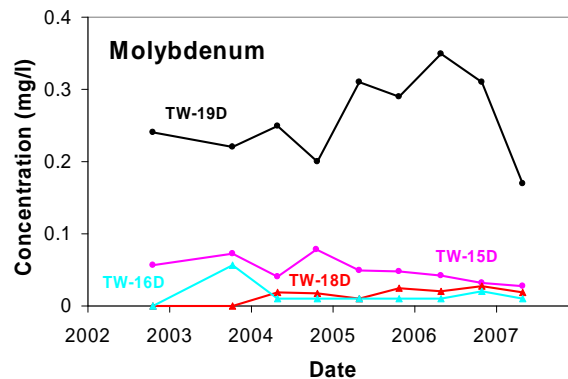
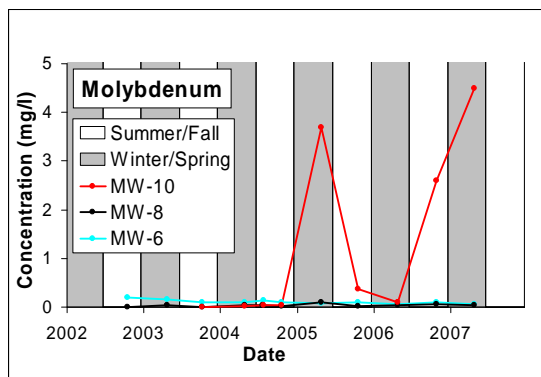
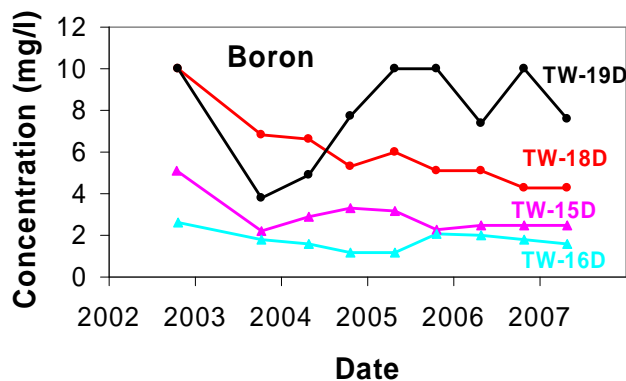
While short-term trends may be observed from this dataset, it is not scientifically meaningful to translate these trends into a long-term context, that is, to know whether such trends are typical and ongoing. It is possible that the observed changes are seasonal or they could represent long-term changes that will continue.

Groundwater data are available over the long term from monitoring at Yard 520. Because these data cover many years (from 1989 to the present for some wells), it is possible to evaluate potential long-term trends, seasonality, and other factors. The sampling methods for the Yard 520 monitoring are different than methods used for the RI, because the samples are collected under IDEM-approved work plans. Thus, parameter concentrations in the Yard 520 dataset may not be directly comparable to concentrations measured in the RI. However, the Yard 520 data do provide information on relative changes in the underlying groundwater conditions. The following graphs and observations are based on the groundwater monitoring data from Yard 520 (e.g., Weaver Boos, 2004).

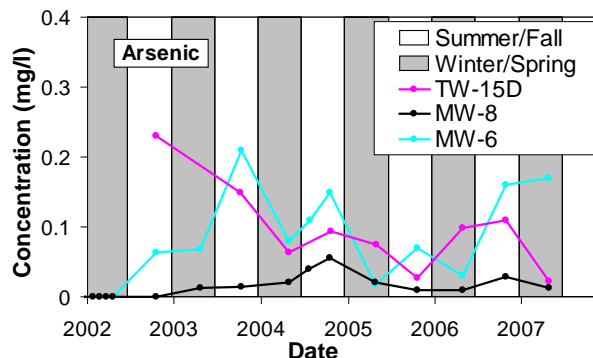
- For some wells and some parameters, concentrations appear to fluctuate seasonally. Generally, higher concentrations are observed in the summer and fall (dry period) and lower concentrations are observed in the winter and spring (wet period). This appears to be the case for B and As at MW-6 and B at MW-8. Concentrations of B over time at select wells are shown below; concentrations of B over time for all RI monitoring wells are presented in Appendix L. Sulfate in these two wells also appears to fluctuate on a seasonal basis (data on Ca, Mg, and Sr are limited in the Yard 520 dataset, so trends cannot be evaluated).



- Overall, there is no consistent trend (either consistently upward or downward) in concentrations of CCB-derived constituents at Yard 520 wells over time. All constituent concentrations fluctuate. Some parameters at some wells appear to be increasing (e.g., B in MW-6, Mo in TW-18D); some to be decreasing (B in TW-15D and TW-18D); and some to be stable. The data do not suggest significant changes in migration of CCB-derived constituents from Yard 520.



- While concentrations will fluctuate, there is no information to indicate concentrations of CCB-derived constituents in groundwater downgradient from Yard 520 are likely to change significantly over the course of the next few years.



4.4.7 Summary of CCB-Derived Constituents in Groundwater

Based on all the information and interpretations provided in this section of the RI, an overall interpretation can be developed for the nature and extent of CCB-derived constituents in groundwater. The fact that CCB-derived constituents have migrated to groundwater does not imply a potential risk to human health, as many of the CCB-derived constituents do not pose a risk, or are not present at concentrations above human health risk-based comparison levels. Potential risks associated with CCB-derived constituents will be evaluated in the risk assessments.

The following conclusions concern the nature and extent of CCB-derived constituents in groundwater in the Area of Investigation.

- Figure 4-19 shows the interpreted extent of B in groundwater at concentrations above the risk-based comparison level (0.730 mg/l) and the tap water RSL of 7.3 mg/l. The B isoconcentration lines shown on this figure were developed considering all the data collected during the RI, including B concentrations in monitoring and private wells, groundwater hydraulic gradients, B concentrations in surface water, and the locations of suspected CCBs that have the potential to migrate to groundwater (see Figure 4-18). Groundwater monitoring data from Yard 520 were also considered. Within the areas where the B concentration in groundwater is interpreted to be greater than the comparison level of 0.730 mg/l, other CCB-derived constituents (SO₄, Ca, Mg, Mo, and Sr) also tend to be elevated. Because of the presence of these indicators, Figure 4-19 shows the general distribution of CCB-derived constituents in groundwater.
- The interpreted extent of B in groundwater is also shown on Figure 4-44, which also shows all available groundwater sampling data, including RI data (Figure 4-1) and USEPA/IDEM data from private wells (Figure 1-6).
- Arsenic is a CCB-derived constituent in groundwater in the Area of Investigation, when it occurs in combination with the other indicators. However, its extent is much more limited than the others; it

does not appear to be transported any significant distance downgradient from the CCBs. The fate and transport properties of As are discussed further in Section 5.

- Migration of constituents from CCBs to groundwater occurs where large volumes of CCBs are present, such as at Yard 520 and in areas where suspected CCBs extend substantially beyond roadways (e.g., near wells such as MW106, MW109, and MW111), as shown on Figure 4-18. It is uncertain whether migration from CCBs to groundwater occurs where used only as road sub-base. In at least one monitoring well location, elevated CCBs occur in an area of known road sub-base and underlying road fill combined (five feet of thickness as documented in the boring log for MW111; see Figure 4-18). Unverified larger accumulations of CCBs nearby (i.e., to the east of Illinois Avenue) may, however, also contribute to the groundwater contamination, as well as verified areas located around TP026 (greater than four and a half feet of CCB fill) and TP027 (greater than seven feet of CCB fill), which are located upgradient of MW111. In general, in the vicinity of smaller amounts of CCBs, for example, used only as a road sub-base material (and not in road areas where CCBs were used more extensively as fill, for example along the length of Illinois as it crosses the wetland and Brown Ditch to the south of East Johns Avenue), CCB-derived constituents do not appear to migrate to groundwater to a significant or detectable extent (represented by wells such as MW107, MW114, and PW005). The paving of roadways may also help reduce rainfall infiltration and groundwater recharge and, thus, also reduce migration of CCB-derived constituents to groundwater.
- Groundwater downgradient of Yard 520 flows into the Brown Ditch system in the immediate vicinity of Yard 520, and the hydrogeologic studies performed as part of the RI demonstrate that groundwater does not flow from Yard 520 to the south beneath Brown Ditch.
- Groundwater in the area south of Brown Ditch (south of South Railroad Avenue) does not have elevated concentrations of CCB indicators (B, SO₄, Ca, Mg, Sr, and Mo); however, does appear to be impacted by leachate from the Pines Landfill, an old municipal waste landfill owned by Waste Management. While Figure 4-18 does show suspected CCBs present at the surface along Railroad Avenue, this area is north and downgradient of PW006, PW007, PW008, and MW115. These wells are downgradient of the Pines Landfill (owned by Waste Management) and as noted above and in Section 4.4.4, the concentrations of B (and many other parameters) in these wells are consistent with the concentrations in groundwater downgradient from the Pines Landfill. While it cannot be ruled out that there may be some small component of CCB impact to these wells, the weight of evidence suggests that the Pines Landfill is the predominant source of elevated B (and other constituents) in these wells.
- In the area near the intersection of South Railroad Avenue and Ardendale Road where CCBs have been used in residential yards and driveways and as road sub-base, CCB impacts to groundwater might have occurred. One residential well was tested by USEPA to be above the comparison level for B, although the private well located across the street (PW010) was sampled four times over the course of a year and the B concentrations were much below the comparison level. Therefore, in this part of the study area, which is not served by municipal water, CCB-derived constituents may

have migrated into groundwater; this potential pathway will be evaluated in the human health risk assessment.

- Based on currently available data, substantial concentrations of CCB-derived constituents are not present in groundwater entering the IDNL. CCB-derived constituents are; however, present upgradient of the IDNL.
- Based on the RI analytical and hydrogeologic data, it is interpreted that groundwater with CCB-derived constituents flows into the Brown Ditch system (including its tributaries and wetland areas). Data is interpreted to indicate that groundwater at Yard 520 flows to the West and Main Branches of Brown Ditch. Groundwater in areas where larger amounts of CCBs were used as fill (see Figure 4-18) flows to the East Branch of Brown Ditch.
- Groundwater in areas where private wells are located outside the area currently supplied by municipal drinking water does not currently appear to be impacted by CCB-derived constituents, based on available data. At best, the data may reflect a very minor impact which any CCBs at the ground surface might have on groundwater in this area. This potential pathway will be evaluated in the human health risk assessment.
- As detailed in Section 3.4.5 above, the portion of the Area of Investigation to the south of County Road E 1675N was excluded from further investigation under the RI, based on evidence that the surficial aquifer pinches out to the south and so there is no use of the shallow groundwater in this area. The chemical information for groundwater presented in this section provides additional support for this conclusion. Specifically, all private wells south of County Road E 1675N are screened in the confined aquifer. One private well, PW013, whose screened interval was unknown, has been shown to be screened in the confined aquifer based on its chemical similarity to PW012 (screened in the confined aquifer), low levels of tritium, and boron-isotope ratios similar to PW012.
- The presence of CCB-derived constituents (B, Mo, As, SO₄, Ca, Mg) in groundwater will be further evaluated in the risk assessments.

4.5 Surface Water

An important element of the RI for the Area of Investigation is the characterization of CCB-derived constituents in the surface water of local ditch systems. Accordingly, a significant portion of the RI has been devoted to investigating and interpreting surface water conditions. This section discusses the surface water chemistry in the Area of Investigation, including:

- The background surface water chemistry from sampling locations outside or upgradient from the Area of Investigation;
- Constituent concentrations in surface water compared to risk-based comparison levels for human health and ecological receptors;

- The relationship between surface water characteristics and the quality of habitat for aquatic organisms;
- The spatial patterns of various groups of constituents in the surface water and how these patterns are interpreted;
- Seasonal variations in surface water concentrations; and
- An overall summary of the extent of CCB-derived constituents in surface water in the Area of Investigation.

Surface water chemical and physical properties reflect the influence of many different factors, both natural and anthropogenic (man-made). Natural water chemistry results from the combination of the dissolved ions contained in natural precipitation and groundwater, weathering of geological formations or soils in a watershed, and biological transformation (e.g., bacterial denitrification). Basal water chemistry is also influenced by impacts from anthropogenic sources such as air pollution, industrial discharges, agricultural practices, lawn fertilizers and pesticides, non-point stormwater, septic system disposal practices, and other man-made sources.

Spatial patterns are discernible due to the different types of water bodies and watersheds sampled as part of the RI. The RI sampling locations included a variety of surface water environments: intermittent and perennial ditches with locations that drain small upland areas and those that drain wetland areas; ponds; locations near roads subject to road run-off or other non-point sources; and locations in relatively undeveloped areas. The effect of these local influences is also relevant to the interpretation of the patterns of surface water chemistry for the Area of Investigation.

4.5.1 Upgradient Surface Water – General Chemistry

To evaluate the nature and extent of CCB-derived constituents in surface water, it is important to be able to identify upgradient (background) conditions, since many of the CCB-derived constituents are expected to be present in surface water due to common natural or anthropogenic sources. Therefore, a number of locations upgradient of Yard 520 and suspected CCBs were identified in the Brown Ditch tributary systems as follows (see Figure 2-13):

- West Branch of Brown Ditch – SW001, SW002, SW019, and SW020;
- East Branch of Brown Ditch – none, there are no upgradient areas for the East Branch; and
- Southern Tributary of Brown Ditch – SW003, SW017, and SW018.

In addition, upgradient samples were taken within the nearby Kintzele Ditch system:

- Kintzele Ditch – SW004, SW005, SW006, and SW007.

These locations are shown on the map in Figure 2-13. Comparison of upgradient sample results to those in the remainder of Brown Ditch were used to distinguish the CCB-derived influence from other influences in the overall watershed, as discussed in Section 4.5.5.

The surface water chemistry of the upgradient locations was established through four sampling events and data are provided on Table 2-14. The four sampling events conducted under the RI covered a one-year period to account for seasonal variations and different hydrologic conditions. For example, the August 2006 sampling was conducted under seasonal low flow conditions, while the October 2006 sampling reflects the influence of several days of precipitation prior to sampling. Differences in land use found in some locations of the watershed may also influence some constituent concentrations. For example, the proximity to major roadways (US Highways 12 and 20) and associated stormwater should be considered when assessing differences in CI content.

The following sections consider the analytical results for surface water samples collected from the upgradient locations. Field measurements, alkalinity and hardness, nutrients, and DOC, which provide information on general water quality and habitat value, are discussed first in order to describe the general water quality conditions. In the following section (Section 4.5.2), metals and other constituents in upgradient samples are discussed. In Section 4.5.5, the results from the upgradient sampling locations are compared to the other surface water samples collected in the Area of Investigation (i.e., Brown Ditch samples) to attempt to distinguish the CCB-derived influences from those found in the overall watershed.

Field Measurements

Field measurements consisted of in-situ measurements of temperature, DO, ORP, pH, specific conductivity, color, and turbidity. These parameters provide general information regarding the water body and are useful in the interpretation of the possible causes of spatial or temporal patterns of other constituents. In addition, temperature and DO are critical factors in determining the nature of the fish community and general habitat quality.

As noted in Section 3.5, Brown Ditch is a low-gradient ditch, with much of the hydrological input coming from groundwater discharge, particularly during late summer months. Because groundwater temperatures are stable, the groundwater inputs can provide a stabilizing influence on surface water temperatures (thermal buffering). However, despite this potential effect, there was considerable temperature variation of surface water during the RI sampling events. The field temperature readings reflected the seasonal pattern, ranging from slightly below freezing (-0.1°C) at SW006 in January 2007 to up to 28°C at SW018 during August 2006 (see Table 2-14). The variation observed among the upgradient locations during the sampling period is probably due to a number of site-specific factors, including climate and weather, time of sampling, local vegetative cover, flow, etc.

Dissolved oxygen also varies seasonally due to a combination of temperature, water depth, potential for turbulent mixing, and biological activity (i.e., bacterial decomposition or primary producer photosynthesis). Field measurements of DO ranged from 2.1 mg/l at SW018 during August 2006 to 13.4 mg/l at SW017 during January 2007 (see Table 2-14). The amount of oxygen that can dissolve in water varies depending upon the water temperature, with colder water able to hold more oxygen than warmer water. Generally, the lowest DO values were seen in the August 2006 sampling and the highest in January 2007, as would be expected from the temperature patterns.

The Indiana Water Quality Standards (WQS), like most other states, contain a sliding scale of DO standards based on the nature of the fish community. The 5.0 mg/l standard is the minimum DO level for a warmwater fish community. Values of 5.0 mg/l and above are assumed to be protective of warmwater fish, while extended periods when DO is less than 5.0 mg/l may lead to impacts to the fish community. Low DO is regarded as a deficiency of the water body to meet its designated aquatic habitat support water use. As can be seen in the record of temperature and DO from the seasonal sampling in the upgradient locations, there were several locations where the DO standard of 5.0 mg/l was not met.

Dissolved oxygen levels in five upgradient locations were below the Indiana WQS warmwater DO standard of 5.0 mg/l during August 2006 (SW002, SW005, SW006, SW018) and October 2006 (SW002) (see Table 2-14). Below this level of DO, fish and other aquatic life will become stressed. The depressed DO levels indicate that warmwater species like bluegill would be stressed in portions of the ditch during the summer months. The low and non-turbulent flow within the ditch is not conducive to aeration of the water, and high in-stream temperatures observed in the summer also would make this a poor habitat for coldwater species such as trout.

Turbidity and color of the surface water are affected by suspended particles and dissolved substances in the water. Turbidity values ranged from zero (several locations) to a maximum of 45 NTU at SW004 during October 2006 (see Table 2-14). Most turbidity values were high during August 2006 and October 2006 and declined sharply in January 2007 and April 2007, suggesting that most of the turbidity may be due to the influence of summer growth (i.e., algae/bacteria) or detritus (i.e., autumnal leaf fall). Color observations were not quantitative, consisting of a visual observation of the apparent color of the surface water samples. There were some distinct differences between color in some of the tributary systems: samples from the more upgradient locations (SW001, SW002 and SW003) are consistently clear; those from the lower southern tributary (SW017 and SW018) occasionally have light-yellow color; and those from Kintzele Ditch (SW004 through SW007) showed the greatest color, ranging from iron-red to very dark brown. The higher degree of color in the Kintzele Ditch samples may result from a greater wetland influence which results in the presence of more tannins and organic materials, compared to other tributary systems.

Specific conductivity is a general measure of the amount of dissolved substances in water. It is often used as a relative indicator of anthropogenic influence, with pristine waters containing lesser amounts (<50 microSiemens per centimeter (uS/cm)) and higher values found in more developed areas.

Specific conductivity often varies seasonally due to flow conditions, with higher values seen in the summer or low flow months. There are several potential causes of this rise in specific conductivity during low flow conditions: (1) there is less surface water run-off, and more constant loadings (e.g., groundwater contributions) have a greater influence, (2) the increased surface water temperatures lead to increased transpiration of water by riparian and aquatic vegetation, (3) greater temperatures also lead to greater rates of bacterial decomposition of organic material, and (4) the reduced volume of water and longer residence time increases the contact and interaction of water with sideslopes and bottom sediments which can increase desorption from the sediments.

Specific conductivity values over the sampling period are presented on Table 2-14 and shown in Figure 4-20. In the upgradient locations, the lower values are generally found in the headwater areas of the ditches (e.g., SW002; SW003, SW006; SW018). However, specific conductivity in the upgradient locations ranges up to 891 uS/cm at SW007 indicating the presence of dissolved ions and likely reflecting localized influences of the natural groundwater inputs, agricultural practices, or non-point run-off from local roadways or railroad tracks.

Field measurements of pH indicate that Brown Ditch is consistently alkaline with a range of 7.1 to 8.3 (see Table 2-14). This consistency in the measurements demonstrates the well-buffered nature of the ditch system. For example, the acidic nature of winter snowmelt and spring run-off often leads to low pH values in many surface water bodies, but there is little indication of this occurring in these upgradient locations. In addition, this slightly basic pH range helps reduce the ecological effects of certain pH-sensitive constituents, such as NH_4 or Al, to aquatic species.

Hardness and Alkalinity

Hardness is the sum of calcium (Ca^{+2}), magnesium (Mg^{+2}), and bicarbonate ($\text{H}_2\text{CO}_3^{-1}$) ions in a system. Hardness is an important parameter for interpreting water quality because the ecological effects of many metals is hardness dependent. This is reflected, for example, in the use of hardness data to adjust surface water quality criteria (e.g., Indiana WQS; 327 IAC 2-1-6) for several metals (Cd, Cu, Pb, Ni, Zn). The average hardness (as CaCO_3) varied seasonally in the upgradient ditch locations from 120 mg/l in October 2006 to 205 mg/l in August 2006, with an average over the four sampling events of 154 mg/l. This average hardness level will be used to adjust the surface water comparison levels when the upgradient samples are evaluated in the ERA. This hardness level is higher than the default hardness level used to adjust federal water quality comparison levels (e.g., USEPA uses a default of 100 mg/l) indicating that the hardness present in the upgradient surface water is likely to reduce the potential ecological effects of some metals.

Bicarbonate alkalinity is another way of measuring the buffer capacity of a waterbody. In the upgradient locations, alkalinity (as CaCO_3) ranged from 36.5 mg/l in January 2007 to 223 mg/l in August 2006, with the majority of the values greater than 80 mg/l, and an average value of 122 mg/l, indicative of a well-buffered system (i.e., able to absorb inputs of acids or bases with large variations in

pH) (see Table 2-14). Measures of the hardness of the surface water also are consistent with that expected of a well-buffered system.

Nutrients

Several of the constituents detected in surface water samples are essential nutrients for humans or ecological wildlife receptors, including Ca, Mg, K, and Na. Several additional constituents are also important as nutrients for aquatic primary producers (e.g., phytoplankton, periphyton, rooted macrophytes) including nitrogen (N), measured as NO_3 and NH_4 , silicon/silica (Si/SiO_2), and ortho-phosphate (PO_4). High levels of N and phosphate nutrients are usually due to anthropogenic influences and can lead to the over-fertilization or eutrophication of a waterbody, resulting in excessive algal or plant growth.

The upgradient N measurements were generally low-to-moderate in concentration (see Table 2-14). Nitrate was measured in a range from 0.054 mg/l to 1.04 mg/l, with an average of 0.417 mg/l. Ammonia was measured in a range from 0.052 mg/l to 1.02 mg/l, with an average of 0.264 mg/l. Some portion of this N may come from current or historic anthropogenic influences (such as agricultural practices) in the upgradient watersheds.

In addition to being a primary constituent of sand (the mineral quartz, SiO_2) and most other minerals, Si is critical to the growth of a major algal group, the diatoms (i.e., *Bacillariophyceae*), which need the Si to produce their exterior shells or frustules. Silicon and SiO_2 are naturally released into the water as sand and rocks are weathered by exposure to precipitation and wind. The upgradient surface water concentrations of SiO_2 ranged from 6.8 mg/l to 17.3 mg/l, with an average of 11.45 mg/l. The upgradient surface water concentrations of Si ranged from 1.49 mg/l to 16 mg/l, with an average of 5.98 mg/l. The presence of silicon and silica in the surface water of the ditches is likely due to the natural weathering of rocks and sand and their presence in local groundwater which flows into the ditch.

The upgradient surface water concentrations of PO_4 ranged from 0.004 mg/l to 0.250 mg/l, with an average of 0.056 mg/l. This value is moderate-to-high and could indicate that the upgradient locations could be subject to some degree of eutrophication from their watersheds. Levels above the average were measured in August and October 2006 at SW002, SW003, SW004, SW005, and SW006 and in August 2006 at SW007. However, overt signs of eutrophication (overabundant macrophyte or attached algae growth) were not typically seen at these locations during the RI sampling.

Dissolved Organic Carbon

The DOC present in surface water represents the cumulative contribution of heterogeneous organic materials including decaying leaf material, tannic and humic acids, and migration from porewater associated with peaty sediments or woody debris. For example, drainage from a wetland area would

be expected to have higher DOC levels due to the organic soils in the wetland. One implication of elevated DOC (e.g., >10 mg/l) is that it often represents un-decomposed organic material that may have a biochemical oxygen demand (BOD) and lead to low DO conditions. In addition, DOC has been shown to complex with many divalent metals (e.g., Cu, Cr, Pb, and Zn) making them less available to aquatic organisms.

Levels of DOC in the upgradient locations ranged from 6.8 mg/l to 78.3 mg/l, with an average of 17.7 mg/l. For comparison, a median value of about 15 mg/l DOC is considered representative of wetland-marshes (Wetzel, 2001). The highest DOC value was observed at SW006, located in Kintzele Ditch which drains a large wetland area located just north of US Highway 20 (see Figure 4-21). Higher values were observed at upgradient locations generally during the summer (August 2006) and fall (October 2006) sampling events, as might be expected due to the greater biological activity in warmer weather and seasonal leaf fall.

4.5.2 Upgradient Surface Water – Metals and Other Constituents

Metals and other constituents were measured in surface water during all four sampling events as indicated on Table 2-1. All constituents were analyzed in unfiltered samples, and some were also analyzed in filtered samples (see Table 2-1). Results of filtered samples typically reflect the concentrations of constituents dissolved in the water, the dissolved fraction. The unfiltered samples also include particulate and sediment matter that is carried with the surface water flow, thus representing the total fraction.

Several metals were not detected in the unfiltered samples at all upgradient surface water sample locations including: Cd, Cr, Mo, Ni, and Tl; or were found at very a low frequency of detection (FOD) (i.e., one or two detections per 33 or 44 samples), including As and Se (see Table 2-14). In the dissolved fraction, the following constituents were either not detected or found at very low FOD: As, Cd, Cr, Pb, Ni, Se, and Zn (not all constituents were analyzed in the dissolved fraction).

Metals which were detected in upgradient surface water samples at a greater frequency included total Al, Ba, B, Cu, Fe, Pb, Mn, Sr, V, and Zn, and dissolved Al, Cu, Fe, and Mn. In addition, the nutrients Ca, Mg, and Na were detected in all samples and K was detected in nearly every sample (41 detections in 44 samples). All of these are naturally occurring constituents, and so, as with soil and groundwater, their presence in the surface water samples is not unexpected. The presence of many of these constituents in surface water can be attributed to weathering and erosion of local soils, sediments, and geologic formations. In addition, there may be contributions to these upgradient samples from sources such as rainwater, groundwater that flows into the ditch, agricultural practices, or non-point run-off from local roadways or railroad tracks. Because of the locations of the upgradient samples, none of the detected metals are derived from CCBs.

The concentrations of these constituents were compared to human health and ecological risk-based comparison levels (see Tables 4-1 and 4-3). Of these metals, Al, Fe, Mn, and V concentrations are above the ecological risk-based comparison levels in at least some of the upgradient surface water samples. When compared against human health risk-based comparison levels, only one concentration of Mn was above the comparison level, and only at one location, SW018. Each of these constituents detected above a comparison level and B are discussed briefly below. This comparison does not substitute for the human health or ecological risk assessments. It is simply being used to identify constituents whose concentrations are greater than the comparison levels in the upgradient surface water. Concentrations that exceed risk-based comparison levels do not indicate a risk, but will be evaluated further in the risk assessments.

Boron - Boron was detected in 37 of the 44 upgradient surface water samples analyzed (Table 2-14). Boron concentrations ranged from 0.037 to 0.186 mg/l; with an average of 0.084 mg/l (see Figure 4-22). The seasonal patterns indicated that higher concentrations were found during the summer low flow conditions, when groundwater may make up a greater portion of the surface water flow. None of these detected values were above either the ecological risk-based comparison level of 0.750 mg/l or the human health risk-based comparison level of 0.730 mg/l.

Boron can be a CCB-derived constituent, and it is also naturally present in background groundwater in and around the Area of Investigation. Due to the locations of the upgradient samples, the B detected in these samples represents a background condition and is not associated with CCBs.

Molybdenum – Molybdenum was not detected in any of the upgradient surface water samples.

Aluminum - Aluminum is a ubiquitous element in the earth's crust and is a common constituent of natural surface water chemistry. It was detected in most total (i.e., unfiltered) Al upgradient surface water samples (FOD of 42 of 44), and in 5 of 11 samples analyzed for dissolved (i.e., filtered) Al. Total Al concentrations ranged from 0.036 to 6.46 mg/l; with an average of 0.793 mg/l (Table 2-14). Some of the higher values were found in the Kintzele Ditch tributary locations (see Figure 4-23). Virtually all of the background upgradient surface water concentrations were above the ecological comparison level of 0.087 mg/l for total Al. Only two non-detects, estimated at one-half the detection limit, were recorded at concentrations below the ecological comparison level. Since the detection limits ranged widely from 0.0086 to 0.259 mg/l, some of the non-detects were identified as exceeding the aluminum surface water criteria. No total Al surface water concentrations were above the human health comparison level for Al.

Examination of the total Al surface water concentrations indicates that there is considerable variation at individual sample locations, including over a 20-fold difference at some locations (e.g., SW005; SW019). While some of this variation is expected to be flow related, there is another potential cause for this high level of variation. Figure 4-24 shows surface water concentrations for total Al plotted against TSS for upgradient samples. This figure shows a cluster with most of the data points at lower TSS values (i.e., less than 15 mg/l). However, there are several samples which are higher in total Al

than other upgradient samples. These elevated total Al concentrations are associated with high levels of TSS, and a simple linear regression of total Al against TSS provides a highly significant relationship ($r^2 = 0.82$). The most likely explanation for this relationship is that high TSS represents re-suspended bottom clays and particulate material (including aluminum oxides and aluminosilicate mineral particulates) that are being carried by the surface water.

These observations are supported by the lower concentrations of Al in filtered samples. As noted above, total Al was detected in 42 of 44 samples over all four quarters with concentrations which ranged from 0.0359 to 6.460 mg/l with a mean of 0.793 mg/l, while dissolved Al was detected in 5 of 11 samples with concentrations which ranged from 0.0371 to 0.218 mg/l with a mean of 0.0789 mg/l. (Note that dissolved Al was only analyzed in samples collected in April 2007.) While the sample size is limited (many of the dissolved samples are non-detects, data from one quarter), where both unfiltered and filtered samples were analyzed and measurable, the results show that Al concentrations in filtered samples are much lower.

Iron and Manganese - Iron was detected in all 44 upgradient surface water samples analyzed for total Fe, and in all 11 upgradient surface water samples analyzed for dissolved Fe (see Table 2-14). Total Fe concentrations ranged from 0.448 to 8.49 mg/l, with an average of 2.288 mg/l (see Figure 4-25). Dissolved Fe concentrations ranged from 0.252 to 1.3 mg/l, with an average of 0.767 mg/l. Nearly all of the total Fe concentrations (39 of 44 samples), and 4 of the 11 dissolved Fe concentrations were above the ecological comparison level for Fe of 1 mg/l. No Fe surface water concentrations were above the human health risk-based comparison level for Fe.

Manganese was detected in all 44 upgradient surface water samples analyzed for total Mn, and in all 11 upgradient surface water samples analyzed for dissolved Mn (see Table 2-14). Figure 4-40 is a map showing total Mn concentrations in the upgradient (and Brown Ditch) surface water samples. Total Mn concentrations in the upgradient samples ranged from 0.038 to 2.54 mg/l; with an average of 0.197 mg/l. In the upgradient samples, dissolved Mn concentrations ranged from 0.038 to 0.341 mg/l; with an average of 0.116 mg/l. Over half of the total Mn concentrations (24 of 44 samples) and 3 of the 11 dissolved Mn concentrations were above the ecological comparison level for Mn of 0.120 mg/l. Only one Mn concentration (SW018 in August 2006) was above the human health comparison level of 0.18 mg/l.

Both of these constituents are naturally occurring in both soil and groundwater in the Area of Investigation and they were found in both the total and dissolved fractions of surface water in the upgradient locations. The differences between the filtered (dissolved) and unfiltered (total) concentrations of these constituents reflect the difference between the fractions dissolved in the surface water and the portion attributed to sediments and particulates being carried by the water in the ditch. Dissolved concentrations of these constituents in the water column may reflect mobilization of these elements under low redox conditions that may result from stagnant flow and low DO levels or may indicate higher relative amounts of anaerobic groundwater that flows into surface water.

Vanadium - Vanadium was detected in 16 of 44 samples and concentrations ranged from 0.0013 to 0.0123 mg/l; with an average of 0.0046 mg/l. One sample result was slightly above the ecological comparison level of 0.012 mg/l at SW006, located in the Kintzele Ditch system, which is located next to US Highway 20. It is not uncommon for metals to be elevated in such a location due to the influence of highway run-off. Vanadium concentrations were not above the human health risk-based comparison level.

Other Constituents - Other constituents that were detected in upgradient surface water during the RI included Cl, F, SO₄, and sulfide (see Table 2-14). All of these are naturally occurring ions commonly present in natural waters. Chloride could also be contributed to surface water systems from anthropogenic sources such as road run-off. The sulfur ions could also originate from sulfur in the atmosphere and be present in rainwater. Sulfide was detected in 5 of 33 samples and concentrations ranged from 1.01 to 1.68 mg/l; with an average of 1.18 mg/l. None of the remaining constituents for which comparison levels are available was detected at a level above human health or ecological risk-based comparison levels.

4.5.3 Summary of Upgradient Surface Water Results

The following conclusions summarize the conditions of the upgradient surface water in the Area of Investigation:

- Field measurements support the identification of the system as a low gradient ditch. Temperature and DO vary seasonally due to a variety of site-specific factors including local vegetative cover, water depth, potential for mixing, and seasonal biological activity (i.e., algal growth, decomposition of leaf litter). At times during the summer and early fall, DO levels are naturally low enough (<5 mg/l) to potentially stress fish and other aquatic organisms.
- Local influences such as wetlands, agricultural practices, and non-point run-off from roadways or railroad tracks often affect water quality conditions. As discussed above, specific conductivity is generally lower in the upgradient locations, which also tend to be located in less developed areas. DOC levels and qualitative color observations appear to relate to the relative wetland influence near these areas. Total suspended solids and turbidity were more elevated in August and December and likely reflect both biological activity and lower flow conditions. Generally, most values were greatest during the low flow sampling event (August 2006).
- The background surface water samples contained measurable levels of metals and other constituents, including B. The presence of these naturally occurring constituents in the surface water samples is not unexpected and, in many cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations as well as anthropogenic influences such as agricultural practices and run-off from roadways and railroads.
- Concentrations of B in upgradient surface water were not above the human health or ecological risk-based comparison levels in any samples. Molybdenum was not detected in any sample.

- Concentrations of Al, Fe, Mn, and V were above the associated ecological comparison level in at least one sample. Manganese was above the human health comparison level in only one sample, and this was the only surface water concentration result that was above a human health comparison level. These constituents will be evaluated in the risk assessments. The presence of elevated Al in surface water appears to be associated with suspended solids in the water, as measured by the TSS. Total Fe and Mn concentration results may also be due to particulate matter. Dissolved Fe and Mn results may be associated with low DO conditions.

4.5.4 Brown Ditch Surface Water – General Chemistry

The surface water chemistry of Brown Ditch and tributaries within the Area of Investigation was characterized with regard to the potential nature and extent of CCB-derived constituents through the RI surface water sampling program as described in Section 2.13. The surface water analytical data for Brown Ditch sampling locations are presented on Table 2-15. The following section considers the water quality results, organized by the following groupings of parameters: field measurements, alkalinity and hardness, nutrients, DOC, metals, and other constituents.

For the purposes of this discussion, “Brown Ditch” refers to the West, East, and Main Branches of Brown Ditch downstream from the upgradient sample locations discussed above. Specific sampling locations include (see Figure 2-13):

- West Branch of Brown Ditch – SW021, SW022, SW023, and SW024;
- East Branch of Brown Ditch – SW013 and SW014 (ponds), SW026, SW015, and SW016; and
- Main Branch of Brown Ditch – SW012, SW011, and SW009.

This section will discuss the results of the surface water sampling, compare them to human health and ecological risk-based comparison levels and upgradient concentrations, and provide an interpretation of CCB-derived constituents in surface water in the Area of Investigation.

Field Measurements

The field temperature readings in Brown Ditch reflected the seasonal pattern observed in the upgradient locations (described in Section 4.5.1); ranging from slightly below freezing (-0.8°C) at SW012 in January 2007 to up to 25.5°C at SW024 and SW026 during August 2006. Water temperatures in locations in Brown Ditch run a little bit higher than upgradient locations (see Section 4.5.1), probably due to the decreased amount of overhead cover (i.e., canopy) found at downgradient locations or to the decreased percentage of groundwater discharge (as flows increase downstream, a smaller percentage of the total surface water flow is made up of groundwater that has just entered the ditch).

Field measurements of DO ranged from 3.0 mg/l at SW009 in August 2006 to 13.8 mg/l at SW022 in January 2007. (A DO recording of 19.9 mg/l from SW016 in January 2007 appears to be unnaturally high and is assumed to be an error.) The lowest DO levels were recorded in the August 2006 sampling and the highest in January 2007, as would be expected from the amount of potential oxygen saturation based on water temperature. As detailed above, DO provides an indication of the nature of the fish community and general habitat quality. Similar to upgradient conditions, DO levels at several locations in Brown Ditch were below the Indiana WQS of 5.0 mg/l during August 2006 (SW009, SW013, SW016, SW021, SW026), October 2006 (SW013) and April 2007 (SW021). This indicates that the low and non-turbulent flow conditions and lack of aeration discussed in the upgradient locations (see Section 4.5.1) are also present within Brown Ditch. Therefore, similar to the upgradient locations, these conditions in the summer would make Brown Ditch a poor habitat for coldwater species such as trout and could lead to stressed conditions for warmwater fish like bluegill.

Turbidity ranged from 1.5 NTU at SW013 in January 2007 to 47 NTU at SW024 during August 2006. Most turbidity values were higher during August 2006 and October 2006 and declined sharply in January 2007 and April 2007, similar to the pattern observed at the upgradient locations. The brownish color observed in many of the surface water locations in August 2006 may indicate a possible influence of iron influx from groundwater; the yellow-yellowish brown color in most of the surface water locations in the fall (October 2006) suggests the chemistry is affected by leaf material. A green color associated with an algal bloom was seen on one of the pond locations (SW014) in August 2006.

Specific conductivity values in Brown Ditch over the RI sampling period are shown in Figure 4-20. Specific conductivity ranged from 80 uS/cm at SW016 in January 2007 to 844 uS/cm at SW009 in August 2006. Highest measurements were observed during low flow conditions, which is a typical pattern since there is less water for dilution of dissolved materials at such times. Most values during other seasons of the year were generally from 350 to 500 uS/cm. Overall, the specific conductivity in Brown Ditch was greater than that measured in upgradient locations, indicating increased input of dissolved ions to the surface water, which may be both natural and anthropogenic.

Field measurements of pH indicate that the water in Brown Ditch is alkaline with a range from 6.5 to 8.6 similar to the range of values in the upgradient locations. Some low pH values recorded during the sampling (i.e., 3.1 to 5.1 in January 2007) are unnaturally low and appear to be due to equipment calibration problems and were not considered in this discussion. The pH range of 6.5 to 8.6 is consistent with that of a well-buffered system. As detailed above, this basic pH range helps reduce the potential ecological effects of certain pH-sensitive constituents such as NH_4 or Al.

Hardness and Alkalinity

Hardness (as CaCO_3) varied seasonally in Brown Ditch samples from an average of 183 mg/l in January 2007 to 262 mg/l in August 2006 with an average over the four sampling events of 211 mg/l. This average hardness level will be used to adjust the surface water comparison levels for when the Brown Ditch samples are evaluated in the ERA. These hardness values are slightly higher than in the

upgradient samples, consistent with the overall increased specific conductance in the downgradient samples. Because hardness is a measure of Ca and Mg, and these are both indicators of CCBs, the increase in hardness may also reflect the contribution of groundwater containing CCB-derived constituents to the surface water. Additionally, hardness values were used to adjust the ecological comparison values (i.e., surface water quality criteria) for several hardness-sensitive metals analyzed in the Brown Ditch samples (see discussion in 4.5.1).

Alkalinity for samples in Brown Ditch ranged from 119 mg/l as CaCO_3 at SW009 and SW011 in January 2007 to 280 mg/l as CaCO_3 at SW013 in April 2007 with an average value of 174 mg/l as CaCO_3 ; that is indicative of a well-buffered system. These values are similar to the levels in the upgradient samples.

Nutrients

The essential nutrients Ca, Mg, K, and Na were detected in most or all of the samples in Brown Ditch, consistent with their importance in natural waters, and with their presence in upgradient samples. Concentrations are generally slightly higher than the concentrations measured in the upgradient samples. These slightly higher levels may be due to a natural increase in TDS as water flows away from the headwaters, or could be due to anthropogenic inputs such as CCBs and roadway run-off. More elevated levels of Na in particular may be associated with run-off from road salt used in road de-icing.

Nitrogen fractions in samples in Brown Ditch were generally found in low-to-moderate concentrations (see Table 2-15). Nitrate ranged from 0.086 mg/l at SW026 in October 2006 to 1.15 mg/l at SW009 in August 2006, with an average of 0.588 mg/l. Ammonia ranged from 0.052 mg/l at SW016 in April 2007 to 1.82 mg/l at SW013 in October 2006, with an average of 0.391 mg/l. All of these values are similar to those measured at upgradient locations.

Silica in samples in Brown Ditch ranged from 2.37 mg/l at SW014 in August 2006 to 13.6 mg/l at SW011 and SW022 in August 2006, with an average of 10.1 mg/l. Similarly, silicon ranged from 1.2 mg/l at SW014 in August 2006 to 19.6 mg/l at SW022 in August 2006, with an average of 5.16 mg/l. These levels are slightly lower than levels measured in the upgradient locations.

Phosphate ranged from 0.008 mg/l at SW014 in April 2007 to 0.381 mg/l at SW013 in October 2006, with an average of 0.044 mg/l. The average PO_4 value is moderate-to-high and could indicate that Brown Ditch could be subject to some degree of eutrophication from the surrounding watershed, similar to the upgradient locations.

Dissolved Organic Carbon

DOC in samples in Brown Ditch ranged from 12 mg/l at SW021 in August 2006 and January 2007 to 79.2 mg/l at SW013 in April 2007, with an average of 23.4 mg/l (Table 2-15). In general, higher values were observed at locations during the summer and fall sampling periods, as might be expected due to the greater biological activity and seasonal leaf fall. The highest value was observed at SW013 which is located in a pond upgradient of the East Branch of Brown Ditch (see Figure 4-21). As noted above, the higher levels of DOC may reduce the potential ecological effects of some metals in the water column. These DOC values are similar to the values measured in upgradient samples.

4.5.5 Brown Ditch Surface Water – Metals and Other Constituents

Samples from Brown Ditch were analyzed for metals and other constituents as indicated on Table 2-1. Some metals were analyzed in both total and dissolved fractions. Results where the detected concentrations were above risk-based comparison levels (ecological and human health, as appropriate) are discussed below, and these data will be further evaluated in the risk assessments.

Many metals were never detected in the total fraction in any of the samples analyzed in Brown Ditch including: Cd, Cr, Ni, and Tl. Both As (one detection in 48 samples) and Pb (one detection in 36 samples) were found at FOD rates below 5% (Table 2-15). In the dissolved fraction, the following metals were not detected: As, Cd, Cr, Pb, Ni, and Zn.

Metals which were detected in samples at a greater frequency included total Al, Ba, B, Cu, Fe, Mn, Mo, Se, silicon, silica, Sr, V, and Zn; and dissolved Al, Cu, Fe, Mn, and Se. Most of these are the same metals also detected in upgradient samples, except that Mo and Se were not detected or were detected only at low frequency in upgradient samples. In addition, the nutrients Ca, Mg, K, and Na were detected in all samples. As discussed above, these are naturally occurring constituents, so their presence in the surface water samples is not unexpected. The presence of many of these constituents in surface water can be attributed to weathering and erosion of local soils, sediments, and geologic formations. In addition, there may be contributions to these samples from sources such as rainwater, groundwater discharge, agricultural practices, or non-point run-off from local roadways or railroad tracks.

The concentrations of these parameters were compared to ecological risk-based comparison levels (see Table 4-3). Of these metals, concentrations of Al, B, Fe, and Mn were above the ecological risk-based comparison levels in at least some of the samples. Recall that concentrations of Al, Fe, and Mn were also above the ecological risk-based comparison levels in upgradient samples. When compared to human health risk-based comparison levels (see Table 4-1), only concentrations of B, Fe and Mo in some samples were above the comparison level. Each of these parameters is discussed briefly below. This comparison does not substitute for the human health or ecological risk assessments. It is simply being used to identify constituents whose concentrations are greater than the comparison levels in the

surface water. Concentrations that exceed risk-based comparison levels do not indicate a risk, but will be evaluated further in the risk assessments.

Boron - Boron was detected in all samples in Brown Ditch (similar to all the upgradient samples), as shown on Figure 4-22. Boron ranged from 0.079 mg/l at SW021 in October 2006 to 1.820 mg/l at SW024 in August 2006; with an average of 0.470 mg/l (see Table 2-15). Boron is a CCB-derived constituent, and it is also naturally present in background groundwater and surface water in and around the Area of Investigation. The concentrations detected in a number of samples from Brown Ditch are greater than in upgradient samples, and some of these levels are above the ecological risk-based comparison level of 0.750 mg/l.

There was considerable spatial and temporal variation in the distribution of B in the surface water systems. Boron in the West Branch of Brown Ditch increases from upgradient to downgradient as the surface water flows by Yard 520 (see Figure 4-22). Elevated B concentrations were greatest at SW023 and SW024 (August 2006) located just downgradient of Yard 520. The concentrations are above the human health and ecological risk-based comparison levels. These patterns are consistent with the historic disposal of CCBs in Yard 520. Additionally, B concentrations in groundwater are also elevated relative to risk-based comparison levels (both human health and ecological) in the vicinity of Yard 520, and this groundwater flows into Brown Ditch. The B concentrations measured in surface water samples in Brown Ditch are significantly lower than in nearby groundwater indicating that other surface water contributions to the system (e.g., flow from upstream, precipitation, surface run-off) are significantly diluting groundwater contributions of B.

In the East Branch of Brown Ditch, B concentrations above the human health and ecological comparison levels were detected at least once during the four sampling events at SW026 and in one of the two ponds (SW014). Concentrations in the downgradient sampling locations (SW015 and SW016) were lower in B, suggesting that hydrologic inputs (both surface water from the south and groundwater) were reducing B concentrations in the East Branch of Brown Ditch and that the higher B concentrations were mostly coming from more upstream sources.

In the Main Branch of Brown Ditch, B concentrations above ecological comparison levels were detected during the August 2006 sampling event in samples from SW009 and SW011. Boron concentrations at these locations appear to represent the mixing of water from the West and East Branches, since the concentrations of B in the Main Branch are typically between that of B in the West and East Branches.

Seasonal patterns in the concentrations of B indicate that the highest concentrations and most of the detections above risk-based comparison levels were observed during the summer low flow conditions (August 2006). With the exception of the pond location SW014, there were no repeated detections above risk-based comparison levels in any subsequent sampling round. This suggests that the elevated B concentrations in the ditches are associated with groundwater contributions, which tend to be subject to much less dilution by ditch surface water during low flow or dry conditions.

The persistent elevated concentrations of B in the pond location at SW014 throughout all four sampling events (ranging from 0.746 to 0.906 mg/l), even under varying seasonal conditions, suggests that this pond may respond differently to rain/flow events than other portions of the Brown Ditch system. The B concentrations at the other pond (SW013) are also relatively stable over the four sampling events, but lower (ranging from 0.424 to 0.732 mg/l). Since the pond at SW014 does not have permanent tributaries or established outlets, but has a large volume relative to precipitation inputs or direct shoreline runoff, it is likely that groundwater discharge is the major source of B in the surface water.

Aluminum – Total Al was detected in 45 of the 48 samples in Brown Ditch and in 6 of 12 samples analyzed for dissolved Al. Total Al in Brown Ditch ranged from 0.042 mg/l at SW026 in August 2006 to 3.28 mg/l at SW024 in August 2006; with an average of 0.339 mg/l (see Figure 4-23). Nearly all of the detected samples (and some of the non-detects) were above the Al ecological comparison level of 0.087 mg/l for total Al, as were nearly all of the upgradient samples. As noted earlier, elevated total Al concentrations are typically associated with high levels of TSS (see Figure 4-24) for upgradient samples. In Figure 4-41, the Al data for the Brown Ditch samples has been added to the previous graph showing data from upgradient samples (Figure 4-24). Figure 4-41 shows the Brown Ditch samples exhibit the same pattern as the upgradient samples, with Al concentrations related to TSS.

Dissolved Al was detected less frequently than total Al and at lower concentrations. For example, total Al was detected in 45 of 48 Brown Ditch samples over all four quarters with concentrations ranging from 0.0415 to 3.280 mg/l in samples with a mean of 0.339 mg/l, while dissolved Al was detected in 6 of 12 samples with concentrations ranging from 0.0362 to 0.129 mg/l with a mean of 0.0828 mg/l. (Note that dissolved Al was only analyzed on samples collected in April 2007.) Therefore, most of the Al detected in surface water in the Area of Investigation appears not to be dissolved in the water, but is associated with particulates being carried by the surface water, including naturally-occurring aluminum oxides, alumino-silicates.

Iron and Manganese - Iron and Mn were found in both the total and dissolved fractions of surface water samples in Brown Ditch. Total and dissolved Fe were detected in all samples in Brown Ditch (48 total Fe samples and 12 dissolved Fe samples; see Table 2-15), similar to the frequency in the upgradient samples. This is not unexpected given the ubiquitous nature of this element in geologic and soil formations and its potential for mobilization under low redox conditions in the low-gradient channel system.

Total Fe ranged from 0.180 mg/l at SW014 in April 2007 to 25.5 mg/l at SW022 in August 2006; with an average of 3.640 mg/l (see Figure 4-25). Dissolved Fe ranged from 0.561 mg/l at SW012 in April 2007 to 5.69 mg/l at SW013 in April 2007; with an average of 1.237 mg/l. The majority of the total Fe concentrations (43 of 48 samples) and 2 of the 12 dissolved Fe concentrations were above the ecological comparison level of 1 mg/l. This is similar to the detected results above risk-based comparison levels in the upgradient samples although the average levels observed in Brown Ditch samples are slightly higher than those in the upgradient samples.

The concentration of Fe was above the human health comparison level at only one location (SW022 in August 2006). This sampling location is adjacent to Yard 520. While the August 2006 sample result was significantly higher than other Brown Ditch samples, total Fe levels at this station over the remaining three quarters were much more consistent with those found at other stations in the West Branch of Brown Ditch (Figure 4-25).

As a means of looking at the temporal and spatial patterns between different areas of the Brown Ditch tributary system, the ranges of total Fe concentrations in surface water (in mg/l) in selected samples in the Brown Ditch and Kintzele Ditch tributary system are given in the table below. This table does not include some of the upgradient sampling locations in the southern areas (i.e., SW001, SW002, SW003, SW017, SW018) and the pond locations (SW013, SW014). This table indicates that total Fe concentrations are variable between sampling events, but tend to be higher during low flow conditions in August at most locations. There is a slight increase in total Fe concentrations going from locations upgradient to past Yard 520. The total Fe concentrations in the downstream Main Branch tend to decrease back to concentrations (i.e., 2-3 mg/l) comparable to upgradient concentrations.

Iron concentrations in mg/l

Sampling Date	West Branch upgradient of Yard 520	West Branch near Yard 520	Main Branch Brown Ditch	East Branch Brown Ditch	Kintzele Ditch
Stations:	SW019 SW020	SW021 SW022 SW023 SW024	SW009 SW011 SW012	SW015 SW016 SW026	SW004 SW005 SW006 SW007
August 2006	7.18 – 7.79	3.97 – 25.55	2.29 – 2.67	4.67 – 5.12	1.86 – 5.17
October 2006	1.71 – 2.36	3.17 – 3.95	2.19 – 3.02	1.50 – 6.67	0.78 – 6.23
January 2007	1.94 – 2.67	2.76 – 3.11	2.05 – 2.11	1.28 – 14.8	1.79 – 2.14
April 2007	1.55 – 2.22	2.63 – 2.94	1.98 – 2.3	0.87 – 6.94	1.52 – 2.18

On the East Branch, station SW026 has noticeably higher concentrations of total Fe in surface water samples. This location is in a deep section of Brown Ditch with low sluggish flows occurring over highly organic sediments (low percent solids, and high TOC; Figure 4-27). These conditions are conducive to low redox conditions. In addition, the sediments at this location have the highest concentrations of Fe (87,000-96,000 mg/kg; Figure 4-28) in Brown Ditch. This combination would promote the leaching of Fe out of sediment and transfer to the surface water phase, which is observed. In contrast, the lowest total Fe concentrations in surface water over all stations were observed at the deep pond sample (SW014) which ranged from 0.180 to 0.790 mg/L. Groundwater is likely the principal hydrologic source of water in this pond, and the concentration of Fe in the sediment (79,000 mg/kg) is also high. The low surface water concentrations observed suggest that under oxidizing conditions in an open pond, Fe is more likely to form oxides and precipitate out of the water column.

This indicates that it is not only a source of Fe that is important but also the occurrence of low redox conditions which is necessary for release of Fe.

Total and dissolved Mn fractions were detected in all samples in Brown Ditch (48 unfiltered samples and 12 filtered Mn samples). Similar to Fe, Mn is a very commonly found constituent of geologic and soil formations. Figure 4-40 displays total Mn concentrations in surface water from the upgradient and Brown Ditch locations. In the Brown Ditch samples, total Mn concentrations ranged from 0.015 mg/l at SW014 in January 2007 to 0.658 mg/l at SW016 in August 2006; with an average of 0.182 mg/l. Dissolved Mn ranged from 0.013 mg/l at SW014 in April 2007 to 0.345 mg/l at SW013 in April 2007; with an average of 0.095 mg/l. Over half of the total Mn concentrations (27 of 48 samples) and 2 of the 12 dissolved Mn concentrations were above the ecological comparison level for Mn in surface water of 0.120 mg/l. This is similar to the detected results above risk-based comparison levels in the upgradient samples although the average concentrations observed in the Brown Ditch samples are slightly lower than those in the upgradient samples. No surface water concentrations for Mn were above the human health comparison level.

The ranges of total Mn concentrations in surface water (in mg/l) in selected samples in the Brown Ditch and Kintzele Ditch tributary system are indicated in the table below and on Figure 4-40. This table does not include some of the upgradient sampling locations in the southern areas (i.e., SW001, SW002, SW003, SW017, SW018) and the pond locations (SW013, SW014).

Manganese concentrations in mg/l

Sampling Date	West Branch upgradient of Yard 520	West Branch near Yard 520	Main Branch Brown Ditch	East Branch Brown Ditch	Kintzele Ditch
Stations:	SW019 SW020	SW021 SW022 SW023 SW024	SW009 SW011 SW012	SW015 SW016 SW026	SW004 SW005 SW006 SW007
August 2006	0.167 – 0.233	0.196 – 0.574	0.271 – 0.438	0.043 – 0.658	0.191 – 0.310
October 2006	0.070 – 0.074	0.099 – 0.124	0.126 – 0.148	0.128 – 0.165	0.129 – 0.205
January 2007	0.070 – 0.079	0.079 – 0.099	0.105 – 0.118	0.133 – 0.306	0.086 – 0.157
April 2007	0.038 – 0.072	0.056 – 0.061	0.090 – 0.123	0.058 – 0.164	0.067 – 0.335

As with Fe, the highest Mn concentrations typically tend to be found during the low flow conditions of the August sampling. There is a slight increase in the West Branch Brown Ditch Mn concentrations near or downstream of Yard 520, but not for all quarters. The ranges of concentrations of the East Branch Mn samples generally exceed those from the West Branch. The intermediate concentration ranges found in the Main Branch stations likely reflect the confluence and mixing of the two tributaries. Looking at the Mn concentration ranges in Kintzele Ditch indicates that levels in the Main Branch are comparable to upgradient conditions.

As described above, these constituents are naturally occurring in both soil and groundwater in the Area of Investigation and they were found in both the total and dissolved fractions of surface water in the upgradient locations. The differences between the filtered and unfiltered concentrations of these constituents reflect the difference between the fractions dissolved in the surface water and the portion attributed to sediments and particulates being carried by the ditch. Dissolved concentrations of these constituents in the water column may reflect mobilization of these elements under low redox conditions that may result from stagnant flow and low DO concentrations and may indicate higher relative amounts of groundwater contribution to surface water.

Molybdenum - Molybdenum was detected in over half of the samples from Brown Ditch (in 26 of 48 samples; Table 2-15) at concentrations ranging from 0.002 mg/l at SW021 in January 2007 to 0.123 mg/l at SW024 in August 2006; with an average of 0.026 mg/l (see Figure 4-26). Molybdenum is a trace element that is ecologically important as a required co-factor for several key bacterial enzymes (e.g., nitrogenase) involved in N transformations. Where detected, Mo concentrations in samples in Brown Ditch were not above the ecological risk-based comparison level of 0.370 mg/l.

Molybdenum concentrations in several samples located in the West Branch of Brown Ditch at and downgradient from Yard 520 were above the human health risk-based comparison level of 0.018 mg/l. This comparison level is one-tenth the value of the tap water RSL for Mo of 0.180 mg/l. The RSL is based on a drinking water exposure scenario. None of the surface water concentrations are above the tap water RSL, and surface water in Brown Ditch is not used for drinking water.

Molybdenum can be a CCB-derived constituent. Its presence in Brown Ditch surface water at levels greater than in upgradient locations and at concentrations above the human health risk-based comparison levels is most likely due to its presence in groundwater that flows into the ditch.

Other Constituents - Other constituents that were detected in Brown Ditch surface water during the RI included Cl, F, SO₄ and sulfide (see Table 2-15). As discussed previously, all of these are naturally occurring ions commonly present in natural waters. Chloride could also be contributed to surface water systems from anthropogenic sources such as septic system discharges and run-off. The sulfur ions could originate from sulfur in the atmosphere and be present in rainwater and may also be present in surface water as a CCB-derived constituent discharging with groundwater.

Chloride was measured in a range from 18.2 to 102 mg/l, with an average of 45.5 mg/l. While this average is higher than was observed in the upgradient samples, the maximum upgradient concentration (119 mg/l) is higher than that observed in Brown Ditch. The highest levels of Cl in Brown Ditch were at SW016 which most likely reflects the influence of road run-off from US Highway 20 near Ardendale Avenue. Fluoride ranged from 0.106 to 0.284 mg/l, with an average of 0.160 mg/l, which is slightly above the upgradient average of 0.125 mg/l. Sulfate ranged from 4.2 to 112 mg/l, with an average of 38.1 mg/l. The range of sulfate concentrations in the upgradient samples was slightly higher (ranging from 6.2 mg/l to 126 mg/l), but the average sulfate level in the upgradient samples (31.0 mg/l) was lower than the average in Brown Ditch.

4.5.6 Summary of Brown Ditch Surface Water Results

The following conclusions summarize the conditions of Brown Ditch surface water in the Area of Investigation:

- For both upgradient and Brown Ditch surface water samples, the field water quality measurements support the identification of Brown Ditch as a low gradient ditch. Temperature and DO vary seasonally due to a variety of site-specific factors including seasonal climate change, local vegetative cover, water depth, potential for mixing, and seasonal biological activity (i.e., algal growth, decomposition of leaf litter). At times during the summer and early fall, DO levels are low enough (<5 mg/l) to potentially stress fish and other aquatic organisms in both upgradient and Brown Ditch locations.
- Local land uses such as wetlands, agricultural practices, and non-point run-off from roadways or railroad tracks have an influence on water quality conditions. This is most evident in parameters such as color, specific conductivity, DOC, TSS, and N.
- Brown Ditch surface water samples contained measurable levels of metals and other constituents. The presence of these naturally occurring constituents in the surface water samples is not unexpected and, in many cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations.
- Concentrations of B in surface water were above the human health and ecological comparison levels in certain samples in the West Branch, East Branch, and Main Branch of Brown Ditch. Typically, higher concentrations were measured in the summer (dry period). On the West Branch, some of these samples also have Mo concentrations above the human health risk-based comparison level (but not the ecological level). These elevated concentrations of B and Mo are most likely due to their presence as CCB-derived constituents in groundwater that flows into the ditches.
- Concentrations of Al were above the ecological comparison level in many surface water samples, both at upgradient and Brown Ditch locations. The Al appears to be largely associated with sediment and suspended particles in the samples as measured by the TSS. Aluminum concentrations are generally higher in upgradient samples.
- Concentrations of Fe and Mn were above the associated ecological comparison levels in many upgradient and Brown Ditch samples while only one Brown Ditch sample concentration of Fe was above the human health comparison level. The highest concentration of Fe in the Area of Investigation (three to five times background) was detected at sample SW022, immediately downgradient from Yard 520 during the initial August 2006 sampling event. The subsequent sampling event was conducted during the fall when dilution of all samples due to increased precipitation can be expected. The total fraction of these Fe and Mn may also be associated with suspended sediment in the samples; the dissolved fraction may be associated with locally low levels of DO in some segments of the ditches.

- Concentrations of dissolved metals (Al, Fe, Mn), those most likely to affect aquatic organisms, are generally low and, in some instances, occur in the presence of mitigating factors (e.g., basic pH conditions mitigating the ecotoxicity of Al). Potential risks associated with these parameters will be evaluated in the risk assessments. As detailed above, several of these constituents in the samples in Brown Ditch are also found at comparable levels in the upgradient locations and statistical tests will be conducted as part of the risk assessments to determine if Brown Ditch levels of metals are consistent with upgradient levels.

4.6 Sediments

The investigation of CCB-derived constituents in upgradient (background) and Brown Ditch sediments is an important part of the RI for the Area of Investigation. This investigation provides information about the nature and extent of constituents in sediments, which will be used for both the human health and ecological risk assessments. This section discusses the sediment chemistry in the Area of Investigation, including:

- Background sediment quality, including both physical and chemical parameters, for ditch locations outside of or upgradient from the Area of Investigation;
- General sediment chemistry in the Brown Ditch tributary system and other water bodies in the Area of Investigation;
- The patterns of various groups of constituents in the sediment and how these patterns may be interpreted;
- Comparison of constituents found in shallow vs. deep sediment samples; and
- Constituent concentrations in sediments compared to human health and ecological risk-based comparison levels.

An evaluation of both sediment chemistry and physical properties is critical because these parameters affect each other and reflect the influence of both natural and anthropogenic conditions. In general, the chemistry of sediments is similar to that of the soil and geologic materials within the local watershed as sediments are primarily derived from these materials. The size structure of the substrate (e.g., cobble, sand, organic mucks) is further dictated by the hydraulic gradient and flow velocity of the surface water, with more coarse sediments found under conditions of higher velocity flow and more fine-grained sediments (silts and clays) found in low energy conditions (that is, depositional environments). Ditch segments with in-stream primary producers (e.g., attached stream algae (periphyton), rooted aquatic vegetation (macrophytes)) can be enriched in organic materials due to breakdown and decay of this plant material. In addition to these natural factors, land use practices within the watershed, which contribute to run-off, erosion, and sedimentation, can also significantly alter sediment composition.

Like soils in the area, sediments in Brown Ditch upgradient and within the Area of Investigation include sands and organic peats. Brown Ditch consists of man-made low gradient channels that rarely experience high velocity flows. As a result, the substrate materials tend to be finer grained in texture, including silts, clays, and organic material. Some ditch segments located near road crossings contain coarse cobble or stone that has been emplaced to stabilize the channel bed and to protect the concrete footings of the bridges.

Sediment quality in the upgradient (background) ditches and Brown Ditch was established through sampling conducted at the 19 locations as shown on Figure 2-14 and in accordance with the methods described in Section 2.14. Sediment sampling was conducted in October 2006 which allowed easier channel access for sediment sampling. Sediment samples were collected for laboratory analyses for a variety of chemical and physical parameters, as indicated on Table 2-1.

Sediment samples were collected from the surficial layer (0-6 inches deep) at all locations. In addition, at eight of these locations, deeper sediments (6-12 inches deep) were also collected (see Figure 2-14). The sediment thickness at upgradient locations tended to be thinner, therefore, no deep samples could be obtained from these locations.

4.6.1 Upgradient Sediment Characteristics

Six locations were used for establishing upgradient sediment conditions (see Figure 2-14). Based on their locations, constituents in upgradient sediments are believed to be unrelated to CCBs (i.e., substantial amounts of CCBs are not present in these locations). These upgradient shallow sediment sampling locations are as follows:

- West Branch of Brown Ditch – SW001 and SW020;
- Southern Tributary of Brown Ditch – SW003 and SW017; and
- Kintzele Ditch – SW005 and SW007.

4.6.1.1 Upgradient Sediment Physical Properties

Some of the most important characteristics of sediment are their physical properties, such as grain size. Fine-grained sediments (i.e., silts, clays, mucks) often naturally contain large amounts of organic constituents and, due to their large surface area, may bind ions and particularly divalent cations (that is, ions with valence of +2) tightly. Because fine-grained sediments accumulate in depositional environments, the natural concentrations of metals are generally higher in these areas. Conversely, coarse-grained sediments (i.e., sands, cobbles) usually contain lower amounts of such constituents. Such coarse-grained materials have lower surface areas and tend to contain fewer reactive groups (e.g., organics, negatively-charged clays). Grain size is also often important to the nature and quality of the benthic community (e.g., macroinvertebrate populations), which tends to be more diverse and

productive in areas with a large diversity of substrate sizes and water flow conditions. Another indicator of the nature of the sediment is the percent solids, which gives a measure of how tightly compressed the sediments are in the channel. Sediments with low percent solids typically have more organic or silty material and tend to be flocculent or fluffy in nature, while sediments with high percent solids are usually composed of a higher percentage of coarser grained, inorganic materials such as sand and gravel, with most of the water contained in freely draining void space.

Grain size analyses indicate that the surficial sediments sampled in the upgradient locations were all very sandy in composition, with 91 to 96% of the samples (by weight) in the sand size fraction (laboratory data are provided in Appendix S). Similarly, the upgradient sediments exhibited a relatively high percent solids content ranging from 65.3% (at SW020) to 81.9% (at SW005) as shown on Figure 4-27. There was little differentiation between the upgradient Brown Ditch locations and Kintzele Ditch with regard to sediment physical characteristics. These characteristics measured in a laboratory are consistent with the field observations of the sampled sediments.

TOC is the measure of the organic portion of the sediments. TOC is capable of adsorbing or binding many metals and/or hydrophobic organic constituents. Accordingly, sediments with high TOC concentrations often contain the higher range of chemical constituents. Another important factor is that the presence of high levels of organic carbon can significantly reduce the bioavailability and potential effects of both metals and organic compounds to aquatic or benthic receptors.

Sources of TOC include both detritus associated with out-of-channel (allochthonous) and in-channel (autochthonous) primary production, including leaf litter, twigs, woody debris, submerged aquatic macrophytes, attached algae (periphyton), and floating algae (phytoplankton). High TOC values are typically found in depositional areas (pools, backwaters, etc.) where slower flow conditions allow settlement of fine-grain sediments carried by the surface water. High TOC concentrations also usually denote sediments composed mostly of fine materials and are inversely correlated with sandy or coarse-grained substrates. The TOC values in the upgradient sediments were generally less than 1% with a range of 0.236% (at SW017) to 1.21% (at SW001) as shown on Figure 4-27, reflecting the mostly coarse-grained, inorganic nature of these sediments.

4.6.1.2 Upgradient Sediment – Metals and Other Constituents

Sediment samples were analyzed for metals, nutrients, and sulfur as indicated on Table 2-1. Sediment analytical results are reported in Table 2-16.

Metals and Other Constituents

A large number of metals were measured in the upgradient sediments as indicated on Table 2-16. Typical concentrations of the metals analyzed in upgradient sediments are provided below.

Constituents	Concentration Range in Upgradient Sediment (mg/kg)
Al	1160 - 3330
As	1.4 – 7.7
Ba	9.1 – 50.1
Ca	1020 – 5120
Cr	2.3 – 10.1
Cu	3.5 – 13.3
Fe	2100 – 19200
Pb	1.9 – 42.5
Mg	716 – 2140
Mn	15.7 – 203
K	280 – 530
Se	0.685 – 1.8
Si	801 – 2010
Na	190 – 190
U	0.16 – 0.21
V	8.8 – 14.7
Zn	12.1 – 53.8
S	11.1 – 375
B, Cd, Mo, Ni, Sr, Tl	Not detected

The detected constituents are all naturally occurring, and so their presence in the sediment samples is not unexpected. These constituents may be present in the sediments due to weathering and erosion of local soils, sediments, and geologic formations or from sources such as rainwater, groundwater discharge, agricultural practices, or non-point run-off from local roadways or railroad tracks. Based on their locations, constituents in upgradient sediments are believed to be unrelated to CCBs (i.e., suspected CCBs were not observed in these locations).

The concentrations of these detected constituents were compared to human health and ecological risk-based comparison levels (see Tables 4-2 and 4-4). This comparison does not substitute for the human health or ecological risk assessments. It is simply being used to identify constituent concentrations that are greater than the comparison levels in the upgradient sediments.

Concentrations that exceed risk-based comparison levels will be evaluated further in the risk assessments.

The following constituents were detected in the upgradient sediments but concentrations were not above human health and ecological risk-based comparison levels: Al, Cr, Cu, Fe, Mn, U, V, and Zn. Comparison of the constituent concentrations in upgradient sediment samples to the ecological comparison levels show that concentrations of Ba, Pb, and Se were above the comparison levels in at least one of the upgradient samples. The detected concentrations of As were above the human health comparison level, but not the ecological comparison level.

Barium results are above the ecological risk-based comparison level of 0.7 mg/kg at all upgradient sediment locations. Barium concentrations ranged from 9.1 mg/kg (at SW005) to 50.1 mg/kg (at SW001) with an average of 24.1 mg/kg. Concentrations of Pb ranged from 1.9 mg/kg (at SW017) to 42.5 mg/kg (at SW007) with an average of 10.8 mg/kg. Lead was detected slightly above the ecological comparison level of 35.8 mg/kg at only one location, SW007. Concentrations of Se ranged from 0.685 mg/kg (at SW003) to 1.8 mg/kg (at SW020) with an average of 1.32 mg/kg. All four detected Se concentrations were above the ecological comparison level of 0.29 mg/kg. All As results were above the human health comparison level of 0.39 mg/kg, ranging from non-detect (at SW003 and SW017) to 7.7 mg/kg (at SW020), with an average detected concentration of 4.3 mg/kg. Results for Ba, Pb, Se, and As are shown on Figure 4-28.

The presence of these metals in upgradient sediments shows that sediments outside of areas where they could be affected by CCBs contain concentrations of some metals that are above risk-based comparison levels for human health and/or ecological receptors.

Nutrients

Several of the constituents detected in upgradient sediment samples are essential nutrients for human and ecological receptors, including Ca, Mg, K, and Na. Silicon, a natural component of weathering rocks and sand, is also detected in the upgradient sediments. These naturally occurring constituents do not have human health or ecological comparison levels.

Sulfur

Sulfur is another common constituent of many soils and sediments. Under some anaerobic conditions, the presence of S in sediments becomes important since it combines with many divalent metals (valence of +2) to form insoluble sulfide salts. The formation of sulfide effectively reduces the bioavailability and, therefore, the potential ecological effects, of these metals. Sulfur was detected in all of the upgradient sediment samples at levels ranging from 11.1 mg/kg at SW017 to 375 mg/kg at SW020; with an average of 130.8 mg/kg. Sulfur in sediment does not have a human health or ecological comparison level; but it is used to assess potential effects of other constituents.

4.6.1.3 Summary of Upgradient Sediment

The following conclusions summarize the conditions of the upgradient sediment in the Area of Investigation:

- The upgradient sediment depths are shallow (all sediment samples were collected from 0-0.5 ft) and mostly sandy in nature (>90% sands) and the solids content ranges from 65.3 to 81.9%. TOC levels are generally less than 1%, and reflect the mostly coarse-grained, inorganic nature of the upgradient sediments.
- The upgradient sediments contain metals and other constituents. Most of the constituents analyzed are present in the upgradient sediments, including Al, Fe, Ca, Mg, and Si, and trace metals such as As, Ba, Cr, Pb, Mn, and Zn.
- Boron and Mo were not detected at any upgradient sediment samples.
- The concentrations of Pb, Se, and Ba are above the ecological comparison levels in upgradient sediment samples, and As concentrations are above the human health comparison level. The presence of these metals in upgradient sediments shows that sediments outside of areas where they could be affected by CCBs contain concentrations of some metals that are above risk-based comparison levels.

4.6.2 Brown Ditch Sediment Characteristics

Sediment sampling locations in Brown Ditch (East, West, and Main Branches) were established to evaluate the potential nature and extent of CCB-derived constituents in the sediments. These sediment sampling locations, going from upgradient to downgradient on the following tributary systems (see Figure 2-14), are as follows:

- West Branch of Brown Ditch – SW021, SW022, SW023, and SW024;
- East Branch of Brown Ditch – SW013 and SW014 (ponds), SW026, SW015, and SW016; and
- Main Branch of Brown Ditch – SW012, SW011, SW009, and SW027.

4.6.2.1 Brown Ditch Sediment Physical Properties

Brown Ditch sediments were analyzed for grain size and total solids (see Table 2-16). Grain size analyses are reported in laboratory data provided in Appendix S, and total solids results are provided in Table 2-16. There was considerable variability in the physical characteristics of the sediments, with differences seen between sediment from different tributaries, location along the ditches, and depth (i.e., shallow vs. deep).

In the West Branch of Brown Ditch, the most upgradient station, SW021, was primarily sandy in nature, consistent with sediment samples further upgradient. The location just south of Yard 520, SW022, was dominated by fine silts and clay in both shallow and deep samples, which is typical of areas where deposition is taking place. Further downgradient, the shallow sediment of SW023 was dominated by silts and clays, but the deeper material was predominantly sand. Sand also dominated the surficial sample collected at SW024. Percent solids in this branch ranged from 32% (at SW022) to 66% (at SW021) and are well correlated with the percentage of sand and gravel in the sediments (see Figure 4-27), which ranged from 28.2% to 89.8%.

There are many factors potentially causing generally higher silt and clay content in the Brown Ditch compared to the upgradient sediment samples. Primarily, the upgradient samples are collected in headwaters areas, where the ditches are erosional in nature, and they are eroding into the underlying sandy soils. Further downgradient, more deposition is taking place, resulting in the accumulation of fine-grained sediments. In addition, much of Brown Ditch was placed through low-lying wetland areas, where the natural sediment is very fine grained and organic. While erosion of CCB materials could also be present in ditch sediments, they are likely to be a minor factor in the differences in fines content.

In the East Branch of Brown Ditch, the substrate of SW015 is mostly sand, with the highest percent solids for this branch at 67%. The shallow and deep sediment samples at SW026 had the lowest percent solids content at 28% and 29%, respectively (see Figure 4-27), and the lowest percentage of sand and gravel at 54.7% and 52.7%, respectively. The characteristics of the samples at SW016 were between SW015 and SW026.

The shallow sediments in the two pond environments (SW013 and SW014) are overlain by more than five ft of water depth (and considerably greater at SW014). The sediments in SW013 were mixed in composition (63% sand and 37% silts and clays). In contrast, the bottom sediment from the deeper pond (SW014) was a deep, black muck that contained fine grained materials (95% silt and clay). The percent solids content for sediments from these two pond environments were 18% to 22% respectively, and were the lowest values observed among all sediment samples (see Table 2-16). Such an observation is common in muck-like pond sediments.

Along the Main Branch of Brown Ditch, sediments were fairly sandy at SW012 and SW011. These samples had more fine-grained material at the surface (17 and 33.6% fines) than the very sandy (3.2 and 6.3% fines) deeper sediments. This may be due to the higher flow velocities found near the two highway crossings (see Figure 4-27). At SW009, the channel widens as Brown Ditch enters a small pool area where deposition is more likely. The percentage of fines (silt and clay) here ranged from 30% in the shallow sample to 50% in the deeper sample. At SW027, located in the INDL, both the shallow and deeper sediments were dominated by sandy material (76 to 86% sand).

TOC values in Brown Ditch sediments ranged from 0.21% in the deep sample at SW023 to 16.2% in the deep sample at SW009, as shown on Figure 4-27. In general, TOC concentrations greater than

10% denote high organic sediments composed mostly of fine (silt and clay) materials. TOC concentrations greater than 1% were measured at 11 of the 13 sampling locations. For those locations at which a shallow and deep sample were taken, the deeper sediments generally had a higher percent solids content and lower TOC content (see Figure 4-27). Visual observation confirmed that deeper sediments were often sandier in nature. The TOC levels in Brown Ditch were much higher than the TOC levels observed in the upgradient locations (i.e., as high as 1.21% TOC at SW001). The low velocity conditions in Brown Ditch encourage settling of fine-grained sediments into depositional areas of the ditch.

In general, the physical characteristics of sediments in Brown Ditch were more highly variable compared to the upgradient samples, which reflects the greater variability in the nature of the ditch channel, historical construction and dredging, and current depositional environments. The differing physical conditions will lead to variations in chemistry. Because of the differences in the physical conditions in upgradient compared to the Brown Ditch sample locations, the upgradient dataset is not a fully appropriate reference dataset for direct comparison of metals in sediments. As noted above, finer grained and organic sediments are expected to have naturally higher levels of metals. Also, due to the lower percentage of fine-grained material (silts and clays), the concentrations of metals in the upgradient samples is expected to be lower. This needs to be accounted for in considering the chemical data obtained from Brown Ditch, as described below.

4.6.2.2 Brown Ditch Sediment Chemical Constituents

Brown Ditch sediment samples were analyzed for metals, nutrients, and sulfur as indicated on Table 2-1. Sediment chemistry analytical results are reported in Table 2-16.

Metals and Other Constituents

Samples of Brown Ditch sediments were analyzed for a large number of metals as indicated on Table 2-16. Metals that were not detected in Brown Ditch sediments included Cd and Tl. Constituents that were detected at least once include: Al, As, Ba, B, Cr, Cu, Fe, Pb, Mn, Mo, Ni, Se, Sr, U, V, and Zn.

As indicated above, the detected constituents are all naturally occurring, and their presence in the sediment samples is not unexpected. These constituents may be present in the sediments due to weathering and erosion of local soils, sediments, and geologic formations or from sources such as rainwater, groundwater discharge, agricultural practices, or non-point run-off from local roadways or railroad tracks.

The concentrations of these detected constituents were compared to human health and ecological risk-based comparison levels (see Tables 4-2 and 4-4). This comparison does not substitute for the human health or ecological risk assessments. It is simply being used to identify constituent concentrations that are greater than the comparison levels in the Brown Ditch sediments.

Concentrations that exceed risk-based comparison levels will be evaluated further in the risk assessments.

Only three constituents, As, Fe and Tl, were detected in Brown Ditch sediments at concentrations above the human health risk-based comparison level. All detected concentrations of As were above the human health comparison level of 0.39 mg/kg. Refer to Section 4.2.3 for a detailed discussion on background levels of As in soils of the United States. Concentrations of Fe in sediments were above the human health comparison level of 55,000 mg/kg in 2 of 13 sample locations. Thallium was detected just above the human health comparison level of 5.1 mg/kg at only one location (SW014).

The following constituents were detected in at least one sediment sample at a concentration above their ecological comparison level: As, Ba, Cu, Fe, Pb, Mn, Ni, Se, V, and Zn. There are no ecological risk-based comparison levels for B or Mo for sediments. Each of these constituents is discussed below.

Boron was only detected in sediment samples SW022 and SW026 as shown on Figure 4-29. Both of these locations are expected to receive CCB-derived constituents from groundwater, possible surface erosion, and/or runoff of CCBs from adjacent areas. SW022 may also receive CCB-derived constituents from seeps from Yard 520. However, levels of surface erosion and runoff are expected to be low due to the flat and well-vegetated riparian zones that border SW026 and, to a lesser degree, at SW022.

Molybdenum was also detected in these samples, and at SW024 and SW009, as shown on Figure 4-30. There are no ecological comparison levels for these parameters in sediments. It is likely that their occurrence in sediment is related to CCB-derived constituents in groundwater that flows into the ditch.

Arsenic was detected in most of the Brown Ditch samples, and concentrations were above the ecological comparison level of 9.79 mg/kg in 7 of the 13 sampling locations. Concentrations of As ranged from 4 mg/kg in the shallow sample at SW011 to 57.8 mg/kg in the shallow sample at SW026 (see Figure 4-28). All detected concentrations of As are above the human health risk-based comparison level of 0.39 mg/kg.

Barium was detected in all samples and concentrations were above the ecological comparison level of 0.7 mg/kg in all 13 sampling locations. Barium concentrations in the Brown Ditch samples ranged from 15.5 mg/kg in the deep sample at SW011 to 260 mg/kg in the shallow sample at SW022 (see Figure 4-28) and were generally above the concentrations observed in the upgradient locations. All detected Ba concentrations are below the human health risk-based comparison level.

Copper was detected in most of the Brown Ditch samples and concentrations were above the ecological comparison level of 31.6 mg/kg in 4 of the 13 sampling locations. Concentrations of Cu

ranged from 4 mg/kg in the deep sample at SW023 to 46.2 mg/kg in the shallow sample at SW014 (see Figure 4-28). All detected Cu concentrations are below the human health risk-based comparison level.

Iron was detected in all of the Brown Ditch samples and concentrations were above the ecological comparison level of 2,000 mg/kg in 10 of the 13 sampling locations. Concentrations of Fe ranged from 1,720 mg/kg in the deep sample at SW011 to 96,000 mg/kg in the shallow sample at SW026 (see Figure 4-28). Iron concentrations are above the human health risk-based comparison level of 55,000 mg/kg in 2 of 13 sample locations. Concentration of Fe ranged from 77,900 to 96,000 mg/kg in the shallow samples at SW014 and SW026, respectively, and was detected at 87,000 in the deep sample collected at SS026.

Lead was detected in all of the Brown Ditch samples and concentrations were above the ecological comparison level of 35.8 mg/kg in 4 of the 13 sampling locations. Concentrations of Pb ranged from 2.6 mg/kg in the shallow sample at SW021 to 40 mg/kg in the shallow sample at SW014 (see Figure 4-28), similar to the range of concentrations in the upgradient locations. All detected Pb concentrations are below the human health risk-based comparison level.

Manganese was detected in all of the Brown Ditch samples and concentrations were above the ecological comparison level of 460 mg/kg in 2 of the 13 sampling locations. Concentrations of Mn ranged from 14.4 mg/kg in the deep sample at SW011 to 1130 mg/kg in the shallow sample at SW022 (see Figure 4-28). All detected Mn concentrations are below the human health risk-based comparison level.

Nickel was detected in over half of the Brown Ditch samples and concentrations were above the ecological comparison level of 22.7 mg/kg in 3 of the 13 sampling locations. Concentrations of Ni ranged from 8.6 mg/kg in the shallow sample at SW027 to 26.8 mg/kg in the deep sample at SW022 (see Figure 4-28). All detected Ni concentrations are below the human health risk-based comparison level.

Selenium was detected in nearly all 13 of the Brown Ditch samples and all detected concentrations were above the ecological comparison level of 0.29 mg/kg. Concentrations of Se ranged from 0.96 mg/kg in the deep sample at SW012 to 9.3 mg/kg in the deep sample at SW022 (see Figure 4-28). All detected Se concentrations are below the human health risk-based comparison level.

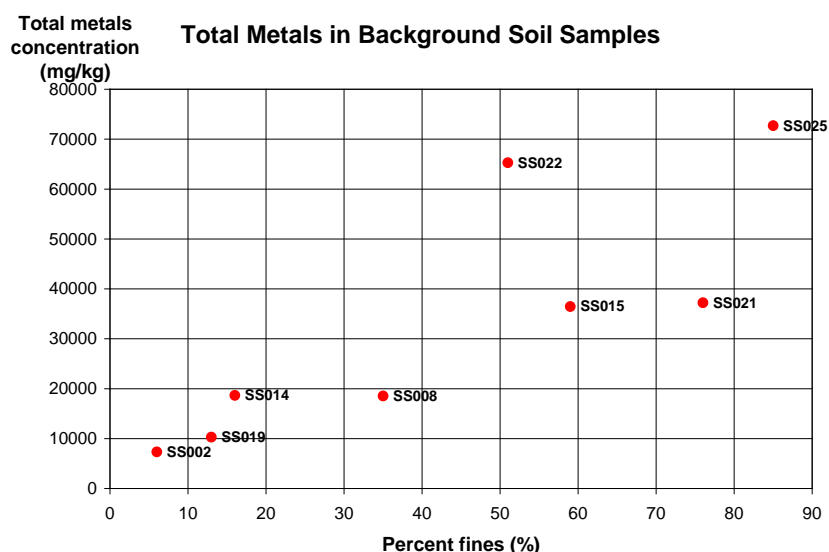
Vanadium was detected in all of the Brown Ditch samples and concentrations were above the ecological comparison level of 50 mg/kg in 2 of the 13 sampling locations. Concentrations of V ranged from 8.3 mg/kg in the deep sample at SW011 to 76.9 mg/kg in the shallow sample at SW014 (see Figure 4-28). All detected V concentrations are below the human health risk-based comparison level.

Zinc was detected in all of the Brown Ditch samples and concentrations were above the ecological comparison level of 121 mg/kg in 6 of the 13 sampling locations. Concentrations of Zn ranged from 15.7 mg/kg in the deep sample at SW011 to 189 mg/kg in the shallow sample at SW022 (see Figure 4-28). All detected Zn concentrations are below the human health risk-based comparison level.

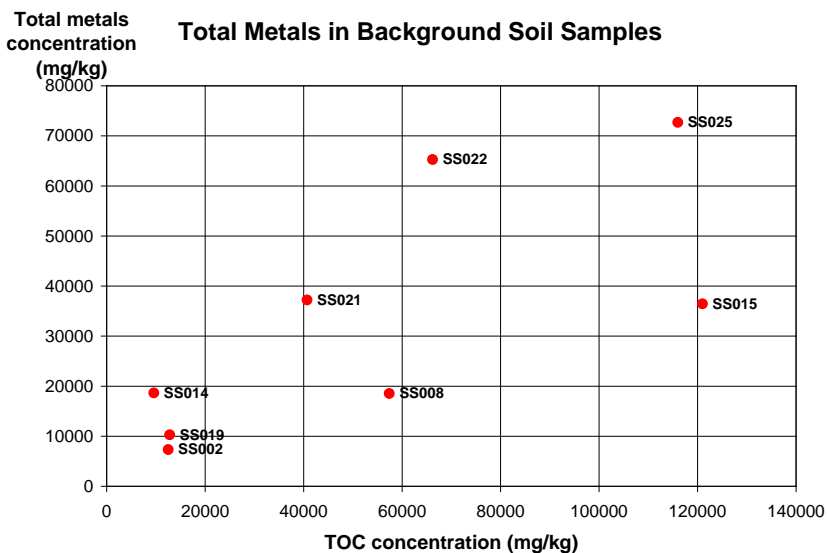
Interpretation of Metals in Brown Ditch Sediment

Several metals, including As, Ba, Cu, Fe, Pb, Mn, Ni, Se, V, and Zn, are present in Brown Ditch sediments at concentrations above ecological risk-based comparison levels. Barium, Pb, and Se were also detected in upgradient sediments at concentrations above the ecological comparison levels. The interpretation of the concentrations of metals in sediments, and particularly in evaluating potential impacts of CCB-derived constituents, is confounded by several factors:

- As detailed above, fine-grained sediments naturally contain higher concentrations of many metals. Mineralogically, clays are alumino-silicates, and thus they contain more Al. Also, the structure of the clays is such that they attract and sorb or incorporate many metals into their mineral structure. In addition, fine-grained materials accumulate in depositional areas within the channel, where many other types of materials can also be deposited. As described above, the sediments in Brown Ditch generally contain a higher percentage of fine-grained materials compared to the upgradient samples, and therefore, they can be expected to contain higher concentrations of metals, even in the absence of impact from CCB-derived constituents.
- This relationship is shown in the graph below, which shows total metals concentrations in background soil samples (not affected by CCB-derived constituents) in relation to the percent fines in the samples. It is easily seen on this graph that finer-grained samples tend to have higher concentrations of metals. Similar patterns can be expected for sediments.



- In addition, organic materials in sediments also tend to sorb metals, particularly divalent metals such as Ba, Cu, Pb, Mn, Ni, and Zn. In addition to their fine-grained content, the Brown Ditch sediment samples also generally contain higher organic carbon (measured as TOC) compared to the upgradient samples. This means that the Brown Ditch samples are likely to contain higher concentrations of metals compared to the upgradient samples. The graph to the right shows the relationship between total metals and TOC for the background soil samples (not affected by CCB-derived constituents).



- CCB-derived constituents in solid media do not have a distinct signature or group of indicator parameters. The constituents present in CCBs are generally also present in background soils and sediments. This is due to the origin of CCBs, that is, they are the unburned mineral content of the original coal. The coal itself originated from highly organic swamps, not dissimilar to the materials in the low-lying areas within the Area of Investigation. Therefore, there is neither a single parameter nor a group of parameters that is a strong indicator of CCB-derived constituents in solid media (including sediment).
- Finally, laboratory analytical procedures can cause additional confusion in evaluating sediment concentrations. The laboratory reports metals concentrations on a dry-weight basis. For samples that contain significant water, like many sediment samples do, this introduces a complicating factor and a potential bias in evaluating the results. This issue with the sediment matrix is common and not unexpected due to the relatively high moisture content of many sediments. The percent solids results for all samples are reported by the laboratory in Table 2-16. It is the low percent solids that have caused the increased detection limits for B in many of the samples. The detection limit for B in many of the Brown Ditch samples is too high to compare to background concentrations and interpret whether CCB-derived constituents are entering the IDNL. Many of the Brown Ditch samples have lower percent solids than the upgradient samples, which further confounds the interpretation of the sediment data.

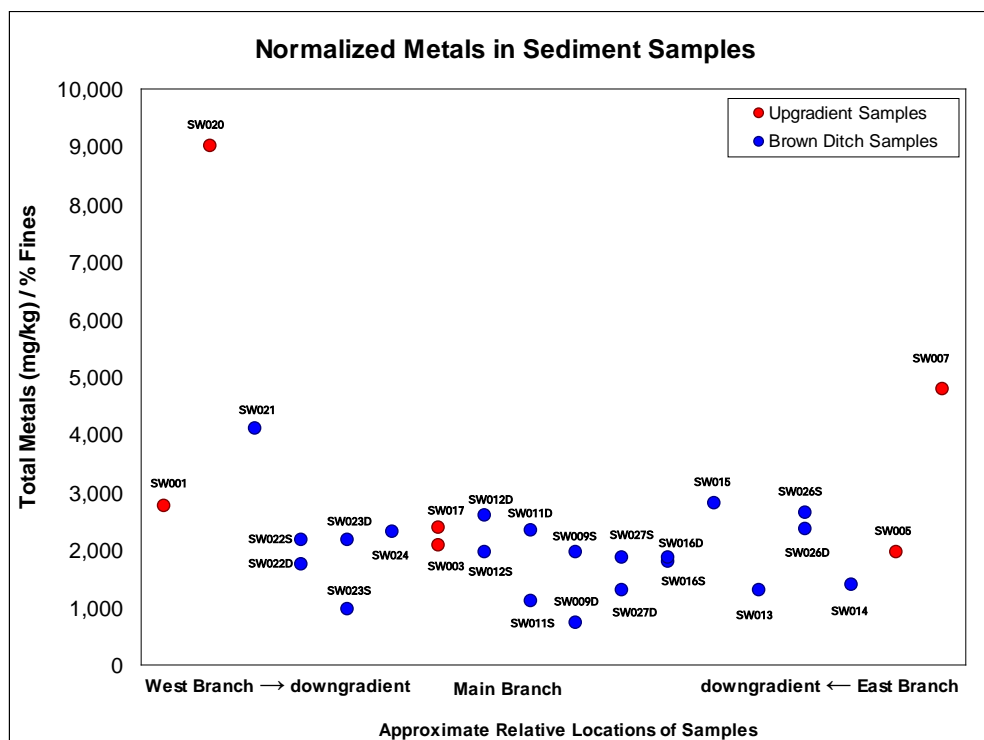
All of these factors must be recognized in interpreting the metals concentrations in sediments, particularly with respect to evaluating potential CCB-derived constituents. These factors show that the upgradient sample dataset is not a fully representative reference dataset for the Brown Ditch

sediments, because these samples have distinctly different physical characteristics, which can influence their chemistry. Therefore, a simple comparison between constituent concentrations in upgradient and Brown Ditch sediments is overly simplistic and not appropriate, as such a comparison does not account for these other factors.

In addition to potential CCB-derived constituents affecting sediment concentrations, there are several other sources in and around the Area of Investigation that are likely to influence sediments. Groundwater that is impacted by these other sources can affect the sediments as the groundwater flows into the surface water. Groundwater has been shown to be affected by septic system discharges, road salt, and the Pines Landfill (owned by Waste Management). Run-off from railroads and roadways is directed towards the Brown Ditch system; run-off transports all the constituents deposited along railroads and roadways, including many metals, petroleum-related constituents, and salt used for roadway de-icing. At SW007, the elevated concentration of Pb and Cu (compared to other upgradient sediment samples) is most likely due to run-off from West Dunes Highway, located just upgradient from this sample location. Along the East Branch of Brown Ditch, the junk shop located on 3026 Second Place and other waste materials located to the east of the junkyard are likely to impact sediment quality (in addition to groundwater and surface water).

A method for evaluating sediment concentrations without the influence of the fines is to “normalize” the concentrations; that is, to divide concentrations by percent fines to generate results in mg/kg per percent fines. To compare sediment concentrations, while recognizing the effects of grain size, the sediment results for all detected metals were plotted on graphs against the percentage of fines (silt and clay) in each sample. These graphs are provided in Appendix W. (Graphs were not prepared for Cd and Tl, which were not detected in any of the sediment samples.) Normalized results that are high indicate metals concentrations that are relatively high for the fines content; low normalized results indicate low concentrations for the fines content. As expected and observed in background soil samples, sediment samples with higher percent fines also typically had higher concentrations of individual metals. The Brown Ditch samples that had percent fines similar to upgradient locations (less than about 10% fines), generally had metals concentrations that were also similar to upgradient concentrations.

To assess the cumulative effects of potential metals enrichment, normalized total metals concentrations are graphically displayed below in an approximate geographic orientation with sediment samples from West Branch to the left (with upgradient samples located at the extreme left), the Main Branch in the center, and the East Branch displayed on the right (with upgradient samples at the extreme right). The locations on the x-axis represent approximate relative locations moving downgradient and not actual stream distances. Both upgradient and Brown Ditch tributary sediment samples are shown along with the sediments from the two pond environments. The graph also shows sediment concentrations at both shallow and deep locations, where available.



This figure is a distribution of points with a few somewhat higher values at the upgradient ends (i.e., extreme left or right). The higher normalized concentrations at SW001, SW07, SW020 and SW021 reflect the very sandy nature of these sediments (that is, the metals concentrations are relatively high for the small amount of fines present). However, the majority of sediment samples, located in Brown Ditch sediments in the Area of Investigation, fall between approximately 1000 to 3000 mg/kg total metals per percent fines. There is no strong trend of increasing values going from upstream to downstream in either the West Branch or East Branch. The results are consistent with elevated metals concentrations being associated with higher fines content. In addition, downgradient sediment samples do not show pronounced metals enrichment per fines content.

One of the ways that sediments can be impacted by CCB-derived constituents is when groundwater containing these constituents flows into surface water through the sediments. This mechanism may explain the presence of B and Mo in sediments samples SW026, SW022, and SW024, all located in areas where CCB-derived constituents are present in groundwater. Given the elevated detection limits for these parameters, they may also be present at concentrations below the detection limits in other sediment samples in contact with CCB-impacted groundwater. Other CCB-derived constituents in groundwater include Ca, Mg, and Sr. Based on the graphs in Appendix W, these constituents appear to be elevated in sediment samples from SW022 and SW013, both also located in areas where CCB-derived constituents are present in groundwater. These locations plot on the graphs (see Appendix W) at concentrations that appear to be generally higher than suggested by the overall relationship between concentration and percent fines. It seems that these concentrations are associated with

CCB-derived constituents in groundwater. Therefore, the interpreted conceptual model for the presence of these CCB-derived constituents in sediments of Brown Ditch is primarily via migration with groundwater containing these constituents.

These CCB-related constituents that appear to be present at higher concentrations in sediment samples (B, Mo, Ca, Mg, Sr) are all very soluble. This affects their mobility in groundwater which leads to migration to surface water, and also their mobility and persistence in sediment. Because they are so soluble, they are unlikely to sorb to and accumulate in sediment materials. Therefore, their concentrations in sediments can be expected to be highest where the sediments are hydraulically connected to groundwater containing CCB-related constituents, that is, adjacent to areas where CCB-related constituents (especially B) are elevated in groundwater.

Other than the parameters clearly related to groundwater as discussed above, there is little or no clear evidence of the presence of other constituents in sediments that could be related to CCBs. Alternative transport mechanisms could include either direct placement or erosion of CCBs into waterways. No direct placement of CCBs into waterways is known to have occurred. Erosion of CCBs into the ditches is unlikely to be taking place under current conditions because of the stable and well-vegetated riparian buffer zones associated with the channels that reduce and filter erosion runoff. However, it is possible that erosion has occurred in the past. It should be noted that the Type III (South) Area at Yard 520 was constructed such that until closure, runoff from the operating areas was directed to a stormwater retention basin, where fine sediments were settled out. Thus, there is not likely to have been significant erosion and runoff from this area into Brown Ditch. Elevated concentrations of some metals in certain samples (based on examination of the graphs) are typically also related to higher percentages of fines, higher TOC, lower percent solids, and other sources such as roadways. The sample locations most likely to show the influence of CCB-derived constituents based on their locations are SW023, located in the West Branch of Brown Ditch downgradient from the Type II (North) Area at Yard 520, and SW015, located on the East Branch of Brown Ditch, adjacent to suspected CCBs used as road sub-base (Illinois Avenue) and fill. Both of these samples are physically located closest to suspected CCBs. SW015 has a relatively small percentage of fines (6.6%), and metals concentrations in this sample are similar to upgradient concentrations except for As. Its normalized concentration of total metals is also consistent with most other sediment samples. The As concentration in this sample is 13 mg/kg, compared to a range of less than 1.2 to 7.7 mg/kg in upgradient samples. The shallow sample at SW023 has one of the highest percentage of fines (71.8%), but metals concentrations do not appear to be elevated. Therefore, at the two locations most likely to be impacted by CCB-derived constituents, metals concentrations (except for groundwater influences) are typically not elevated relative to upgradient samples, except for what is most likely due to the higher content of fine-grained material. A formal statistical comparison between Brown Ditch and upgradient samples will be conducted as part of the risk assessments.

In contrast, there are certain samples that appear to have elevated concentrations of certain metals, that is, concentrations are higher than would be expected due to the fines alone. For example:

SW007:	Pb (an upgradient location)
SW012:	Na
SW013:	Cu
SW016:	Pb
SW022:	Cu, Mn, K, Si
SW026:	As, Cu, Fe, Pb

None of these apparently elevated concentrations suggest specific impacts to sediments from CCB-derived constituents. Many of these are located in areas where they may be affected by other sources (e.g., road salt, road and railroad runoff, etc., as listed above). They may also be affected by higher TOC concentrations and very low percent solids.

Of the parameters present at concentrations above risk-based comparison levels (As, Ba, Cu, Fe, Pb, Mn, Ni, Se, V, and Zn), the higher levels of Ba, Ni, Se, V, and Zn appear to be largely explained by the higher content of fine-grained materials in the samples. None of the sediment samples appear to have elevated concentrations of these parameters, when the percent fines is also considered (however, a formal statistical background evaluation will be conducted as part of the risk assessments).

As discussed above, the higher metals concentrations in the Brown Ditch samples are typically present in areas where the sediments contain higher concentrations of silts and clays (meaning higher Al concentrations) and higher TOC. Both of these parameters (Al and TOC) act on metals in sediments to reduce their bioavailability and, therefore, potential effects to ecological receptors.

The higher concentrations of many of these other metals (e.g., excluding soluble CCB-related constituents such as B and Mo) in Brown Ditch sediment samples, as compared to upgradient ditch locations, are not unexpected, given the differences in the physical characteristics (i.e., coarse- vs. fine-grained sediments), amount of TOC, and greater presence of depositional environments in the Brown Ditch tributaries. In addition, many of these constituents have sources in the watershed other than CCBs.

One sediment sample was located within the IDNL (SW027). In this sample, Ba and Se (in both shallow and deep samples) were present at concentrations above ecological risk-based comparison levels, but at concentrations that are similar to upgradient samples. Concentrations of B, Cd, and Mo in SW027 are non-detect (Ni was detected), although detection limits for B and Mo are slightly elevated. The fines content found at that location is 14.1% in the shallow sample and 23.6% in the deeper sample and the sediment concentrations correspond well. This range of fines places these samples in an intermediate range between background areas (3.1- 8.8%) and the Brown Ditch samples (6.3 -94.6%), which would be expected to result in the intermediate metal values observed at this location. Therefore, recognizing the limits of the dataset, there is no evidence that CCB-derived constituents are present in sediments in Brown Ditch as it enters IDNL.

The data on metals in sediment will be considered quantitatively in the risk assessment, including a formal statistical comparison between upgradient and Brown Ditch samples.

Nutrients

Several of the constituents detected in Brown Ditch sediment samples are essential nutrients, including Ca, Mg, K, and Na. Silicon, a natural component of weathering rocks and sand, is also detected consistently in the Brown Ditch sediments. Average concentrations of all of these nutrients are higher in Brown Ditch sediments than in upgradient sediments, likely consistent with grain size differences. These naturally occurring constituents do not have risk-based comparison levels, and they are not expected to pose an adverse risk to human health or ecological receptors.

Sulfur

Sulfur is another common constituent of many soils and sediments. Sulfur was measured in the Brown Ditch sediments from 34.8 mg/kg at SW021 to 2800 mg/kg at SW014; with an average of 869 mg/kg. Average sulfur concentrations in the Brown Ditch sediments are higher than in the upgradient sediments. Sulfur in sediment does not have a human health or ecological comparison level; it is used to assess potential effects of other metals.

4.6.2.3 Summary of Brown Ditch Sediment

The following conclusions summarize the conditions of the Brown Ditch sediment in the Area of Investigation:

- The Brown Ditch sediments included both shallow (0 to 6 inches) and deep (6 to 12 inches) sediments and included both sandy and highly organic sediments. TOC values ranged from 0.21 to 16.2% with the majority of the samples containing greater than 10% TOC. (TOC was generally <1% in upgradient locations.) The percentage of fine-grained material in the Brown Ditch samples was also typically greater than in the upgradient samples. The physical characteristics of the Brown Ditch sediments were more highly varied than the upgradient sediment samples. Therefore, the upgradient dataset is not an appropriate reference dataset for direct comparison with the Brown Ditch sediments.
- The Brown Ditch sediments consist of granular (sand, silt, clay) and organic materials which contain metals and other constituents. The presence of these naturally occurring constituents in the sediment samples is not unexpected and, in some cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations.
- Boron was not detected at most Brown Ditch sediment sampling locations with the exception of SW022 and SW026. However, samples SW009, SW012, SW013, SW014, SW016, SW022, and SW023 all potentially contain B concentrations that are CCB-derived. The detection limit for these

samples was too high to determine if CCB-related constituents were present in these samples. Based on their locations and B concentrations, it is most likely that the B in these sediments is associated with the presence of CCB-derived constituents in groundwater flowing through the sediments. Other groundwater indicators of CCBs, including Mo, Ca, Mg, and Sr, were also elevated in areas where groundwater containing CCB-derived constituents is flowing into the ditches.

- More elevated concentrations of many other constituents were observed in Brown Ditch samples relative to the upgradient locations, consistent with the finer-grained and more organic nature of many of the Brown Ditch sediment samples. Concentrations of As, Ba, Cu, Fe, Pb, Mn, Ni, Se, V, and Zn in Brown Ditch sediments for some locations were above associated ecological risk-based comparison levels. All detected concentrations of As and some detected concentrations of Fe are above human health risk-based comparison levels. Only one detected concentration of TI was detected above the human health risk-based comparison level.
- The interpretation of the metals in Brown Ditch sediments is confounded by the higher percent fines, higher TOC, lower percent solids (leading to elevated detection limits for some parameters), and presence of other potential sources in the Brown Ditch sediment samples compared to upgradient sediments. When the percent fines are taken into account, concentrations of most metals (except for soluble CCB-related constituents such as B and Mo) are similar to upgradient levels. A few of these other metals appear elevated in some specific samples, but there is no consistent spatial pattern that can be attributed to CCB-derived constituents. At locations most likely to be impacted by CCB-derived constituents (e.g., located physically closest to Yard 520 or larger areas of suspected CCBs), concentrations are generally consistent with background (except for soluble CCB-related constituents such as B and Mo which are likely to be migrating to the ditches with groundwater). Although the concentration of many metals in Brown Ditch sediments are similar to upgradient levels, concentrations of some inorganics that may be CCB-related increase up to five times the background concentrations in the Brown Ditch system downgradient of Yard 520 and other significant accumulations of CCBs.
- Potential risks associated with constituents detected in sediment will be evaluated in the risk assessments. The sediment risk evaluation will included statistical tests to determine if levels of metals in Brown Ditch sediments are consistent with upgradient levels.

5.0 CONSTITUENT FATE AND TRANSPORT

Fate and transport is an evaluation of the changes that take place in constituents and concentrations as they move through different environmental media. Understanding the fate and transport of CCB-derived constituents is important in evaluating their potential impacts to receptors. Transport is the simple movement of the constituents, for example, with the flow of groundwater or surface water. Fate is a summary of all the physical and chemical processes that act on the constituents during transport.

The primary components of the fate and transport of CCB-derived constituents at the Area of Investigation include:

- Potential migration from CCBs to groundwater - When CCBs are placed in the environment (either within or outside of Yard 520), some of the constituents within the CCBs can dissolve in rainwater that infiltrates into the CCBs. As this rainwater continues to infiltrate further into the subsurface, the CCB-derived constituents can migrate and reach groundwater.
- Within the groundwater system - Dissolved constituents are transported with groundwater flow, but there are numerous processes in the groundwater system that act to decrease concentrations during groundwater transport, including precipitation reactions, sorption onto the aquifer matrix, mixing with surrounding groundwater through dispersion, and others. At the Area of Investigation, the data are interpreted to indicate that all groundwater that contains CCB-derived constituents moves downgradient and flows into the Brown Ditch system, including its related tributaries and wetlands, as described in Section 4.4.7. Any CCB-derived constituents present in the groundwater at that point will enter the sediments and/or surface water of Brown Ditch.
- Surface water and sediments - As the groundwater interacts with sediment and surface water in Brown Ditch, the chemistry changes significantly. Certain constituents can partition into the sediments and not reach the surface water. Depending on the nature of the constituents and their fate and transport characteristics, concentrations of some constituents may tend to increase in sediments over time. Other constituents may reach surface water, but then they may be diluted and/or chemically transformed due to the mixing of groundwater and surface water. Once in the surface water system, CCB-derived constituents will be transported downstream with the flow of the water in the ditch. Dilution will take place as the water flows downstream, reducing constituent concentrations. Other reactions may also take place that can either chemically transform and/or reduce availability of constituents, including partitioning into the sediment solids, uptake by plants, and denitrification. None of the CCB-derived constituents is considered bioaccumulative.

Each of these components of the fate and transport of CCB-derived constituents is discussed in more detail in this section.

5.1 Potential Migration from CCBs to Groundwater

In the Area of Investigation, actual groundwater data are used to evaluate migration of CCB-derived constituents to groundwater. As described in the literature about CCBs (ENSR, 2005a), the chemical conditions within and surrounding CCBs in the environment can be variable, thus resulting in variable behavior of CCB-derived constituents. Instead of relying on theoretical concepts of which constituents may migrate and why, the RI uses actual data from groundwater beneath and downgradient from CCBs within the Area of Investigation to identify constituents that actually have migrated to groundwater.

Based on the data collected during the RI, the following CCB-derived constituents have the potential to migrate from CCBs to groundwater:

- B, SO₄, Ca, Mg, Sr, As, and Mo, and possibly Fe and Mn

While CCBs contain other constituents, these are the ones that have been observed in groundwater at elevated concentrations (relative to background and other wells). Boron, Ca, Mg, SO₄ and Sr are very soluble in water, so they will dissolve in rainwater that is infiltrating through the CCBs or groundwater in contact with CCBs. Based on literature about CCBs (see the SMS, ENSR, 2005a), As, B, and Mo appear to be present on the outer surfaces of CCBs, especially fly ash, thus making them more available to interact with infiltrating rainwater or groundwater. Iron and Mn are commonly found in many natural groundwater systems, including background groundwater at the Pines Area of Investigation.

Based on data collected during the RI, CCB-derived constituents appear to migrate to groundwater where there is significant suspected CCB material present, for example, at Yard 520 or in certain areas that were filled along Idaho, East Johns, Columbia and Delaware Avenues (based on data from monitoring wells MW106, MW109, and MW111). In at least one monitoring well location, elevated CCBs occur in an area of known road sub-base and underlying road fill combined (five feet of thickness as documented in the boring log for MW111; see Figure 4-18). Unverified larger accumulations of CCBs nearby (i.e., to the east of Illinois Avenue) may, however, also contribute to the groundwater contamination, as well as verified areas located around TP026 (greater than four and a half feet of CCB fill) and TP027 (greater than seven feet of CCB fill), which are located upgradient of MW111. In contrast, there does not seem to be significant migration to groundwater where suspected CCBs were used in much smaller volumes, such as only for road sub-base material or driveway surfaces. Several monitoring wells were located in or downgradient from such areas, such as MW107, MW114 and private well PW005. These wells do not show the presence of elevated levels of CCB-derived constituents. The paving of roadways may also reduce the migration of CCB-derived constituents to groundwater by reducing groundwater recharge.

5.2 Groundwater

As constituents in groundwater move through the groundwater system, a number of different processes act on them. These processes as a group are often referred to as attenuation processes, because they tend to result in decreased concentrations of constituents. That is, at greater distances from source areas, constituents are attenuated in the groundwater system. In this section, these processes are described, followed by the specific behavior of individual constituents.

Advective Transport – This is the term used for the simple transport of constituents with the groundwater flow. Advective transport results in the migration of constituents in certain directions with the groundwater flow, but does not affect concentrations. All the remaining processes described below take place in addition to this advective transport. Advective transport is determined by evaluation of hydraulic gradients and groundwater flow directions.

Dispersion – Hydrodynamic dispersion is the process whereby groundwater containing dissolved constituents must move around individual sand grains or other heterogeneities (variations) in the aquifer during groundwater flow. As a result of this, the specific path and velocity of any molecule of water is highly variable. This results in effective dilution and spreading over space of constituent concentrations in groundwater plumes, as groundwater moves along these variable paths and mixes with other groundwater. The concentrations within the plume will decrease, while the area covered by the plume will increase as it migrates away from a source area. The maximum concentration in the center of a plume will be surrounded by groundwater with gradually decreasing concentrations up to the limits of the plume, where concentrations are consistent with background. Dispersion is quantified by a measurement of the aquifer's dispersivity in three dimensions, the x-direction parallel to the groundwater flow, the y-direction perpendicular to the flow in the horizontal plane, and the z-direction perpendicular to flow vertically. While the dispersivity is a property of the aquifer, it is also scale-dependent. That is, the dispersivity typically changes depending on the scale over which it is measured. At greater scales, dispersivities tend to be greater because more heterogeneities are encountered.

Retardation/Soil Partitioning – Based on their chemical characteristics, many constituents will partition between the soil and the water phases. There is an equilibrium level at which some percentage of the constituent will be dissolved in groundwater and some percentage will sorb onto the surface of the solid materials in the aquifer. In general, organic constituents will prefer to sorb onto organic material (TOC) in the aquifer. The partitioning of metals can be affected by pH and other chemical conditions of the system. The partitioning is quantified through the soil-water partitioning coefficient (K_d) which is simply the ratio of the concentration in the soil to the concentration in water at equilibrium conditions. Although there are site-specific factors that will influence partitioning, literature values are available for many constituents.

The effect of partitioning is to reduce the overall velocity of the constituents dissolved in groundwater relative to the groundwater itself. This effect is called retardation. A retardation factor (R_f) can be calculated from the partitioning coefficient:

$$R_f = 1 + \frac{\rho_b K_d}{n}$$

Where: R_f – retardation factor
 ρ_b – bulk density of the aquifer
 n – porosity of the aquifer
 K_d – soil water partitioning coefficient

As an example, As has a partitioning coefficient of 290 liter per kilogram (l/kg) at a pH of 7.0 (USEPA, 1996a). A retardation factor of approximately 2000 can be calculated (using a bulk density of 1.75 gram per cubic centimeter (g/cc) and a porosity of 0.25). This indicates that the rate of migration of As in groundwater is approximately 2,000 times slower than the groundwater itself. A typical groundwater velocity in the Area of Investigation was calculated as 0.5 ft/day. Based on this, the velocity of As in the groundwater system would be 0.00025 ft/day or 0.09 feet per year (ft/year).

The following table provides a list of partitioning coefficients (USEPA, 1996a) and estimated retardation factors for several metals present in the groundwater in the Area of Investigation, although most are not CCB-derived.

Constituent	K_d (l/kg)	R_f
As	290	2000
Ba	420	2900
Se	4.3	31
Tl	740	5200
V	1000	7000

Degradation – Within groundwater systems, there are microbes that are capable of breaking down many constituents. This is the process that provides treatment of septic wastes from septic system discharges. In general, degradation is a process that applies to organic constituents only, when they are broken down into smaller and simpler molecules by bacteria. Therefore, it is not one of the primary attenuation mechanisms for the inorganic CCB-derived constituents. However, this biological activity can affect the chemistry of the groundwater system, which in turn can affect attenuation of inorganics, for example, by changing redox conditions (see below).

Chemical reactions - Inorganic constituents can be transformed through many other different types of reactions. Different forms of some constituents are stable in different chemical environments. Many

metals are more soluble and, therefore, more mobile in groundwater systems, at lower pH levels. Cation exchange is a reaction where metals (cations) in solution replace different cations that are part of a mineral structure. Some metals can form complexes, either inorganic or organic, by binding with other molecules if present in groundwater. These complexes create a new compound with potentially very different fate and transport properties compared to the original metal. One of the most important influences on inorganic chemistry in groundwater in the Area of Investigation is the effect of redox, as described below.

Oxidation/Reduction (Redox) Effects – Many metals are able to form ions of two or more valence states. Iron is one of the most familiar of these. Iron can occur as ferrous iron (Fe^{+2}) or as ferric iron (Fe^{+3}). The Fe^{+3} form is called the oxidized form (and it frequently occurs in combination with oxygen in iron oxide minerals such as Fe_2O_3). The Fe^{+2} form is called the reduced form (as the valence state has been reduced). For many of these metals, the fate and transport properties for the different valence states are completely different. Thus, their behavior in groundwater is dependent on their valence state, which is a function of the available oxygen in the groundwater.

Background geochemical conditions in the surficial aquifer in the Area of Investigation are typically aerobic or oxidizing (containing oxygen), due to its shallow depth and regular recharge from rainwater. However, there are a number of different factors that can lead to locally anaerobic or reducing conditions (depleted in oxygen), including any factors that restrict recharge or consume oxygen. The most common way for oxygen to be consumed is during degradation of organic materials, for example, in septic systems, municipal landfills, or highly organic wetland soils. In addition, releases of organic chemicals to the subsurface causes the oxygen in groundwater to be consumed, for example, due to releases from current or former gasoline stations or other petroleum storage. When recharge is restricted, for example, at Yard 520 or the Pines Landfill (owned by Waste Management) due to their caps, then limited oxygen is replenished to the groundwater. In addition, the groundwater in the deeper confined aquifer is likely to be under reducing conditions due to its age and separation from the atmosphere.

The primary metals affected by redox in the Area of Investigation are Fe, Mn, and As. Under aerobic or oxidizing conditions (when groundwater contains oxygen), these constituents are likely to form insoluble molecules and thus precipitate out of solution and not be present or mobile in groundwater. However, under anaerobic or reducing conditions (when there is little or no oxygen in groundwater), they are present in a soluble form that is then mobile in the groundwater.

The fate and transport properties of individual constituents in groundwater at the Area of Investigation are described below.

Boron – Based on the chemistry of the groundwater in the Area of Investigation, B is most likely to be present primarily as boric acid (H_3BO_3) (e.g., Hem, 1992). Because this is an uncharged species (valence of 0), it has less of a tendency to interact with other constituents in groundwater and the aquifer matrix. Therefore, it is less affected by many attenuation processes. The primary fate and

transport processes affecting B are advective transport with the groundwater flow and dispersion in the groundwater. There is likely to be little sorption or chemical reaction. It is due to this lack of reactivity that B is the most laterally extensive of the CCB-derived constituents (in addition to SO_4).

As shown on the map in Figure 4-19, B that originates with CCBs or suspected CCBs is interpreted to migrate with groundwater downgradient towards Brown Ditch and its related tributaries and wetlands. Lower concentrations of B are present in groundwater in a zone around the higher concentrations, which is caused by dispersion.

Boron is an essential nutrient for plant growth (although it can be harmful to plants at high concentrations). Therefore, where plants are able to remove groundwater directly through evapotranspiration (that is, where groundwater is relatively shallow and can be accessed by plants' roots), B can also be removed from the groundwater by the plants.

In summary, B as a CCB-derived constituent in groundwater is interpreted to travel with the groundwater flow into the Brown Ditch system.

Sulfate – Sulfate is an anion (negatively charged ion), with a valence of -2. As with uncharged species such as B, the chemical reactivity for anions is also relatively limited. In highly anaerobic systems, SO_4 can be reduced to sulfide (S^{-1}), however, data collected during the RI indicate this is not a significant process. Therefore, SO_4 in groundwater has a tendency to behave conservatively (that is, its attenuation is limited) just as B does. Therefore, SO_4 that is related to CCBs is interpreted to migrate with B and with the groundwater flow into the Brown Ditch system.

Calcium, Magnesium, and Strontium – These metals are all alkaline earth metals, with a valence of +2, so their fate and transport properties are similar. Because they are cations (positively charged ions), they participate in more chemical interactions. All of these ions can be attenuated through cation exchange with clay minerals. In some chemical environments, they can combine with SO_4 to create an insoluble minerals. However, although they are more chemically active, these are also highly soluble ions, as represented by their presence in background groundwater and, therefore, their attenuation is limited. Calcium and Mg are essential nutrients in plant growth, so they can be removed from groundwater during evapotranspiration.

Similar to B and SO_4 , the cations Ca, Mg, and Sr that are related to CCBs is interpreted to migrate downgradient with the groundwater flow into the Brown Ditch system.

Molybdenum – Molybdenum is a transition metal that can occur in several valence states ranging from +3 to +6. According to Hem (1992), at pHs greater than about 5 (consistent with the groundwater in the Area of Investigation), the predominant form of Mo in solution is MoO_4^{-2} . This form of Mo is relatively mobile (being an anion), but it can react with Fe or Ca (Hem, 1992) or other cations in

solution. Molybdenum is an essential nutrient in plant growth (although it can be harmful to plants at high concentrations), so it can be removed from groundwater during evapotranspiration.

Based on observed concentrations in groundwater in the Area of Investigation, the Mo in groundwater appears to be more affected by attenuation processes compared to other CCB-derived constituents such as B. For example, while elevated levels of B and other CCB-derived constituents are present at wells such as MW101, MW109, MW111, and TW-16D, concentrations of Mo in these wells are not elevated and are consistent with background (less than 0.010 mg/l). Therefore, it appears that there are chemical conditions present in the Area of Investigation that are attenuating Mo.

Iron and Manganese – Iron and Mn are both metals that can occur in different valence states (Fe^{+2} , Fe^{+3} , and Mn^{+2} , Mn^{+4}). Both of these ions are affected by redox conditions, as described in more detail above. Although both have complicated Eh-pH relationships (Hem, 1992), put more simply, when groundwater is aerobic or oxidized, Fe and Mn ions will each form molecules that are relatively insoluble (Eh is a measure of the redox potential). Conversely, under anaerobic or reducing conditions, they are dissociated and are present as soluble ions in groundwater. Therefore, these constituents tend to be present and mobile in groundwater that is anaerobic, but immobile and not present in groundwater that is aerobic.

The redox conditions of groundwater can vary a great deal, due to local influences of septic system discharges, municipal landfills, former gasoline stations, and marshes and wetland areas. All of these input organic carbon to the environment. When microbes work at breaking down these organic constituents, they consume oxygen. Therefore, the oxygen levels in the groundwater become depleted. Under these types of conditions, Fe and Mn can be expected to be present in groundwater. This occurrence is not necessarily related to any anthropogenic sources of Fe or Mn. Both of these constituents are naturally present in most geologic materials, and they are present in the background soils in the Area of Investigation. Where groundwater is reducing, the natural Fe and Mn present in these soils will dissolve and appear in the groundwater.

However, as Fe and Mn migrate with the groundwater flow, the groundwater can move into an area that is oxidized, thus mixing with the oxidized groundwater. At this point, Fe and Mn would be expected to form molecules that are relatively insoluble and, therefore, no longer be present in the groundwater.

The fate and transport of Fe and Mn is dependent on local redox conditions, which are variable throughout the Area of Investigation. They will only be transported with groundwater where that groundwater is anaerobic. If groundwater is anaerobic adjacent to Brown Ditch (for example, in wetland areas), then Fe and Mn can expect to enter the ditch system (sediments and/or surface water) with the contribution of groundwater.

Arsenic – The geochemistry of As in groundwater is more complicated than the other parameters discussed here. It occurs in multiple valence states (+3 and +5) and is affected by redox conditions. The most common process that occurs in groundwater is sorption and/or co-precipitation controlled by redox. Arsenic is naturally present in many aquifers as part of iron oxide minerals (that is, sorbed onto these minerals or co-precipitated with them). Under reducing conditions, the Fe in these minerals is reduced, the minerals dissociate, and the Fe is present as a soluble ion in the water. When the Fe minerals dissolve, the As that is associated with them is also released into the groundwater. This process is the most likely cause of the lower levels of As observed in some of the groundwater in the Area of Investigation (for example, in background wells).

Similar to Fe and Mn, an anthropogenic source of As is not necessary. However, if As does migrate to groundwater from anthropogenic sources, for example, as seen in the groundwater in the vicinity of Yard 520, the same processes take place. Under oxidizing conditions, as the Fe forms insoluble molecules and leaves the groundwater, the As is also removed.

Based on the groundwater data in the vicinity of Yard 520, attenuation processes appear to be very effective in removing As from groundwater. Arsenic is present at the highest concentrations only in the immediate vicinity of Yard 520 (MW-6). At greater distances downgradient (approximately 100 to 300 ft), concentrations decrease (TW-15D, MW122) until they are below human health risk based comparison levels (TW-16D, TW-18D).

5.3 Surface Water and Sediment

Fate and transport of constituents in surface water and sediment were characterized to provide a better understanding of the changes that take place in CCB-derived constituents as they move through these environmental media. As detailed above, understanding the fate and transport of these constituents is important in characterizing their potential nature and extent and in evaluating exposure to potential human or ecological receptors. It is useful to consider transport mechanisms and fate processes for surface water and sediments together, as the transfers and partitioning of constituents between these two media may be critical to determining the potential bioavailability of a specific constituent.

CCB-derived constituents can enter the surface water and sediments of Brown Ditch predominately via groundwater contributions. Important transport mechanisms for constituents within the surface water and sediment of the Area of Investigation include:

- Transport downstream with surface water flow through the Brown Ditch system;
- Erosion and deposition of sediments within the ditches; and
- Movement of constituents into deeper sediments by incremental sedimentation, bulk transport, or biotic factors (e.g., bioturbation).

Important fate processes for constituents within the surface water and sediment in the Area of Investigation include:

- Reduction (attenuation) of surface water concentrations with distance from source areas through mixing;
- Changes in constituent concentrations as redox chemistry changes when groundwater enters surface waters;
- Reduction of bioavailability in surface water due to adsorption and binding;
- Partitioning of materials between sediment porewater and sediments; and
- Biological uptake and transformations.

5.3.1 Transport Mechanisms

Surface water flow in the Brown Ditch system occurs as a result of surface run-off and groundwater influx from the watershed. Groundwater influx to surface water is discussed at length in earlier sections of this report. CCB-derived constituents can also enter the Brown Ditch system from erosion and surface transport of soil particles. In some areas, CCB-derived constituents in soil particles may be dislodged and erode downhill and eventually enter the Brown Ditch system. To the east, the large, flat wetland area surrounding the East Branch of Brown Ditch channel likely reduces the amount of particles that enter the ditch. Yard 520 is covered with a vegetative cover, so erosion of soil particles containing CCB-derived constituents is unlikely. However, in the past, this process may have occurred in the Type II (North) Area. The design for the Type III (South) Area included a sedimentation basin that would have limited the run-off of particulates into Brown Ditch.

Surface water flows uniformly from the upgradient tributaries into the East and West Branches and eventually to the Main Branch of Brown Ditch. There are no known significant water withdrawals from or point source discharges to the ditch. Also, based on the conceptual model for hydrogeology in the Area of Investigation (discussed in Section 3.6), there is no significant amount of groundwater recharge from the ditch channel (i.e., it is not a “losing” system). The flow is essentially unidirectional from the groundwater to the surface water and then downstream, eventually entering the IDNL and finally joining Kintzele Ditch. Constituents that are dissolved in or being carried by the surface water will be transported with the downstream flow.

Given the low topography of the Brown Ditch tributary watershed (and other local watersheds), the hydraulic gradient within the ditches is relatively low and resulting in-stream flow velocities are also low, as measured during the RI. This has several implications for bulk transport of suspended material, as lower flows will not carry larger particles downstream nor regularly scour out the channel bed. This will result in sedimentation of materials within the ditch channel and the accumulation of silt and organic sediments in deeper sections of the ditch. Sediment accumulations can also occur

upstream of flow constrictions (e.g., pipes or culverts) or other obstacles (e.g., beaver dams). Materials that accumulate in such places may eventually move downstream during very large flow events (storms) or slowly become incorporated into the sediment matrix.

Sedimentation will lead to the accumulation of material in the channel which, over time, may become overlain with freshly deposited material. This material may be re-suspended during high velocity scours and be carried downstream to be re-deposited. On occasion, disturbance of the sediments by burrowing benthic organisms (bioturbation) can lead to mixing of older and newer sediments. However, given the quiescent nature of Brown Ditch, much of the sediment will likely stay where deposited such that older sediments are found in the deeper layers. In the past, dredging of Brown Ditch has periodically occurred to facilitate drainage of agricultural fields and/or reduce local flooding. Such dredging disturbs the sediment column. However, for the sediment sampling locations in Brown Ditch, the deeper samples were presumed to represent older depositional layers. The shallow sediments collected during the RI usually contained higher constituent concentrations than deeper sediments.

The low hydraulic gradient also means that the residence time of water in the ditch system is relatively long, particularly during the summer time when surface flows are very sluggish. This increases the potential for interaction of surface water and sediments and/or the potential for biological transformations.

Brown Ditch crosses several roads, state highways, and railroad corridors. While the amount of impervious surface represented by these areas is not great relative to more developed or urban watersheds, these areas can contribute localized inputs of road or embankment run-off directly to the local ditches during storms. Road run-off from these areas may contain constituents which are also found in CCBs such that water quality or sediment samples at these locations may reflect this influence (e.g., Na, Cl, TSS, metals).

5.3.2 Fate Processes

Acting together with the transport mechanisms that dictate the general movement of CCB-derived constituents through the ditch systems in the Area of Investigation are several fate processes which can alter the nature or concentration of the CCB-derived constituents. The major fate processes are considered further below.

One of the major fate processes is the dilution of the concentration of CCB-derived constituents as they travel downstream from potential source areas. The conceptual model indicates potential sources of CCB-derived constituents include Yard 520 and historic fill placed in other locations in the Area of Investigation. Brown Ditch receives inputs of water (groundwater and surface water tributaries) from areas where no suspected CCBs have been identified. There is a general reduction in surface water

concentrations of CCB-derived constituents in the downgradient sampling locations (e.g., B, see Figure 4-22; Mo, Figure 4-26) consistent with this dilution and mixing.

As documented during the RI, groundwater in the Area of Investigation is locally anaerobic (low in oxygen). One process that significantly affects the nature of constituents is the movement of dissolved constituents in this groundwater under low redox conditions into the higher redox conditions (aerobic) found in surface water. This shift in redox condition can lead to transformation of reduced forms such as ferrous iron (Fe^{+2}) into ferric iron (Fe^{+3}). One result of this redox-mediated shift is rapid complexation of Fe with other constituents to form insoluble forms (e.g., iron sulfide, iron hydroxide) that lead to precipitation of these minerals within the sediment and accumulation of rust-colored flocculent material on the sediment. Similar transformations may occur for other redox-sensitive constituents, such as Mn.

One of the important properties of surface water for determining the potential ecological effects of certain divalent metals (e.g., Cu, Cd, Pb, Ni, and Zn) in surface water is the hardness of the water. Higher levels of hardness reduce the potential bioavailability of the dissolved fraction of these metals (hence comparison values are hardness-adjusted). Hardness increases going downstream in Brown Ditch; therefore, the potential ecological effects of selected metals also decrease downstream.

Another fate process is the partitioning of materials between sediment porewater and sediments. Dissolved constituents in groundwater initially enter the void spaces (pores) between the bottom sediments as part of the sediment porewater. This is also where adsorption and partitioning of constituents can take place. Adsorption of ionic fractions onto fine silts and clays can occur, as can the uptake of materials into the organic carbon. This can result in the net transfer of materials from the porewater into the sediment fraction, as evidenced by the higher concentrations of constituents in the sediment containing higher TOC. This sorption process also reduces the mobility of these constituents and their bioavailability, that is, their ability to be taken up by ecological receptors.

Biological uptake and transformations are additional processes that transform the constituents in the surface water and sediments. Uptake of nutrients by bacteria and primary producers (e.g., phytoplankton, periphyton, rooted macrophytes) in the ditch and riparian vegetation could reduce the amount of N, phosphorus, silica, etc. Uptake could take place directly from the water column (e.g., periphyton), from the sediments (e.g., emergent wetland plants), or from the sediment porewater (e.g., bacteria). Other potential bacterial transformations could include denitrification (loss of N from system) or growth of iron-reducing bacteria. These activities tend to affect the water chemistry but are expected to have limited effects on most CCB-derived constituents.

Uptake of essential nutrients (including micronutrients such as Fe, B, and Mo) from surface water by plants during the growing season and/or root uptake from sediments by riparian and aquatic wetland plants could also detain some of these constituents in plant biomass during the growing season. While a portion of these constituents could leach out into the surface water during biological decay of the

plant material in the fall, some is likely to be incorporated into the organic matrix of the detritus, which may be transported downstream or accumulate in the sediments.

5.4 Other Fate and Transport Processes

This section has discussed the major pathway of release of constituents from suspected CCBs to the environment, including potential migration to groundwater via infiltration of precipitation. Subsequent migration pathways within the groundwater and into the Brown Ditch system have also been discussed. There are additional, likely minor, pathways of CCB-derived constituent movement, as identified in the conceptual site models for the human health and ecological risk assessments (see Figures 3-20 and 3-21). CCBs at the surface could potentially be entrained into the air as dust; this pathway will be evaluated in the human health risk assessment. CCBs could be transported via surface run-off from areas of fill and eventually reach surface water and sediment; this pathway has been directly evaluated by the collection of surface water and sediment samples in Brown Ditch.

Finally, uptake of constituents through the different levels of the wildlife food chain (trophic levels) can occur through the process of bioaccumulation. Bioaccumulative chemicals can significantly increase in concentration up the food chain, typically having greatest concentrations in the tissue of tertiary level carnivorous or piscivorous (fish-eating) receptors. However, the CCB-derived constituents are not considered to be bioaccumulative, as defined by the Great Lakes Water Quality Initiative (Federal Register, 1995), such that this fate process is of minor importance in the Area of Investigation.

5.5 Summary

The CCB-derived constituents that have migrated to groundwater in the Area of Investigation include B, SO₄, Ca, Mg, Sr, Mo, and As. Once in groundwater, they are transported downgradient with the groundwater flow, and are interpreted to migrate into the Brown Ditch system, including its tributaries and wetlands. In both the groundwater and surface water systems, various attenuation processes will act on the CCB-derived constituents to reduce their concentrations as they migrate.

In groundwater, B, SO₄, Ca, Mg, and Sr are highly soluble and not very chemically reactive. Therefore, they are less likely to participate in chemical reactions that remove them from groundwater. Instead, they will typically be transported downgradient with the groundwater flow, with concentrations reduced primarily through dispersion. It is interpreted that these constituents will then enter surface water in Brown Ditch with the groundwater. The fate and transport of Mo is similar, except that it appears to be subject to some additional attenuation processes, at least locally.

The fate and transport of Fe, Mn, and As in groundwater are controlled by redox conditions. Where groundwater is oxidized, these constituents will form insoluble molecules and will be removed from the groundwater system. Where groundwater is reduced, these molecules will dissociate and release the constituents into the groundwater. This process occurs with naturally-occurring Fe, Mn, and As in the

native soils in the Area of Investigation as well as any Fe, Mn or As that might migrate from CCBs. Reducing conditions in groundwater are present locally throughout the Area of Investigation, most likely caused by organic inputs to the groundwater, such as septic system discharges, wetlands and highly organic soils, former gasoline stations, and the Pines Landfill (owned by Waste Management). Where such reducing conditions are present near Brown Ditch, these constituents could be mobilized and enter the ditch system with the groundwater. Where groundwater near the ditches is oxidized, Fe, Mn and As will not be mobile and, therefore, will not migrate into surface water.

In surface water, constituent concentrations tend to decrease with distance downstream from sources due to mixing and dilution. In addition, the potential ecological effects of some constituents in surface water is reduced when hardness is greater. When constituents partition from the porewater into the sediments, they are less available to interact with ecological receptors. Uptake of nutrients by plant life can reduce concentrations in sediment and surface water. Biological processes in general can transform constituents and affect their fate and mobility (e.g., denitrification). CCB-derived constituents are not considered bioaccumulative.

6.0 SUMMARY AND CONCLUSIONS

This RI Report documents the results of the RI conducted at the Pines Area of Investigation in accordance with the USEPA-approved RI/FS Work Plan, AOC II and the SOW, and the NCP. In addition to providing the results of the RI field investigation activities, the collected data have been interpreted to develop a conceptual site model for the CCB-derived constituents in environmental media at the Area of Investigation. The findings of the RI are summarized below.

6.1 Field Investigations

The RI consisted of an extensive field investigation including installation of groundwater monitoring wells; geologic and hydrogeologic studies; sampling and laboratory analysis of groundwater, surface water, sediments, background soils, and suspected CCBs; and evaluation of ecological habitats. Access agreements were needed to conduct much of this work, as many investigation locations were located on private property.

Data were reviewed and validated in accordance with approved quality assurance procedures (ENSR, 2005f). A data usability assessment was prepared (Appendix T); the conclusion was that with the exception of one rejected result, the data collected under the RI program are considered to be usable and reliable for RI decision-making.

6.2 Physical Characteristics

Geology and Hydrogeology - Groundwater is present beneath the Area of Investigation in the shallow surficial aquifer made up primarily of wind-blown sands associated with the current and former shores of Lake Michigan. The base of the surficial aquifer is formed by a clay confining unit. The surficial aquifer is thickest beneath upland dune areas, is thinner beneath low-lying wetlands areas between the dunes (such as the Great Marsh in the IDNL), and pinches out completely to the south against the silts and clays of the Valparaiso Moraine and/or lacustrine sediments of Glacial Lake Chicago.

Groundwater occurs as a water table aquifer (in the surficial aquifer) at depths ranging from near the ground surface (in wetland areas) to approximately 25 ft beneath upland dune areas. Groundwater flow is generally from the upland areas to Brown Ditch and its tributaries and wetlands located in the low-lying areas, including the IDNL. In general, during both wet and dry periods, groundwater discharges to the Brown Ditch system (including associated tributaries and wetlands) throughout the Area of Investigation. While there may be some instances where this gradient is reversed, these conditions are short-term and local, and do not affect the overall groundwater flow.

Seasonally, groundwater levels fluctuate approximately one to two ft (although a greater drop was observed in July 2008), with water levels lower in the summer and fall (growing season) and higher in

the winter and spring. Based on data collected during the RI, the hydraulic gradients and directions of groundwater flow do not change seasonally.

The hydraulic conductivity of the surficial aquifer was tested during the RI (slug testing) with estimated values ranging from approximately 5 to 50 ft/day with a geometric mean of 14.7 ft/day, consistent with the fine sands of the surficial aquifer. An average linear groundwater velocity of approximately 0.5 ft/day was calculated.

Surface Water – The Brown Ditch system is defined as the main branches of Brown Ditch, its associated tributaries and wetlands, including portions located within the IDNL, and makes up the low-lying wetland areas located both north and south of the Town of Pines. The system includes man-made ditches (e.g., Brown Ditch itself), excavated more than 100 years ago to provide drainage in these areas where the water table is shallow. Brown Ditch is a low-gradient channel with low surface water flow volumes and velocities. As measured during the RI, surface water flow rates range from less than one cubic foot per second (cfs) to more than five cfs. Flow rates vary in different branches of the ditch system and are generally higher in the winter and spring and lower in the summer.

CCBs and Suspected CCBs - In addition to the CCBs placed in Yard 520 in accordance with its permit requirements, CCBs are reported to have been used as road sub-base material and/or fill in other areas in the Town of Pines. The inspection program conducted as part of the RI documented the presence of suspected CCBs along many roadways in the eastern portion of the Town of Pines, as well as Maple Street and Railroad Avenue. Suspected CCBs also appear to have been used on some private properties to surface driveways. In contrast, suspected CCBs are also present in certain locations over wider areas extending well beyond the roadways, suggesting they were used as fill. These areas are primarily located along East Johns Avenue, Second Place, Idaho Avenue, Columbia Avenue and Delaware Avenue.

Ecological Habitats - General ecological habitat types were initially identified using desk-top resources (aerial photographs, USFWS NWI maps, USGS topographic maps, town assessor maps, regional wildlife records, and other project information). The preliminary map generated was ground-truthed in the field. Habitats were classified as residential, commercial/disturbed, agricultural, maintained grass, forested or scrub-shrub, wetlands or open water. Areas identified as maintained grass, forested or scrub-shrub, wetlands or open water were considered to be land uses suitable for evaluation of ecological habitat. North of Second Place and East Johns Avenue between County Line Road and Ardendale Avenue, there is generally marginal to good habitat for wildlife receptors due to presence of contiguous undeveloped lots in an otherwise residential area. However, these areas tend to be fragmented by street and highway corridors as well as areas of denser residential usage. Wildlife receptors likely to be encountered here would be those species that co-exist successfully with human influences (e.g., crow, deer, rabbit, raccoon). The ecological habitats between Second Place/East Johns Avenue and the East Branch of Brown Ditch represent a mixture of good quality habitats, mostly wetland or wet-mesic conditions. There is an increased amount of disturbed and/or maintained land located at the eastern end of the East Branch of Brown Ditch. Wildlife receptors likely to be

encountered here would be those species found in wet-mesic forests and along wetland marsh and low gradient stream habitats (e.g., muskrat, raccoon, mink, mallard, heron, kingfisher). There is also open water emergent marsh edge habitat provided by several man-made ponds located south of Second Place. The ecological habitats south of the East Branch of Brown Ditch between Country Line Road and Yard 520 and bounded on the south by Railroad Avenue are good quality habitats with a large area of contiguous undisturbed habitat, except along edges of roadways at Ardendale Road and Railroad Avenue. Wildlife receptors likely to be encountered here would be those species found in wet-mesic forests and in open field areas (e.g., shrew, red fox, red-tailed hawk, robin, meadowlark, raccoon, mink).

Potential Human Receptors - Residents (adults and children) may potentially contact surface CCBs directly via incidental ingestion and dermal contact, or they may inhale CCB particulates entrained in dusts. Where groundwater is used as a source of drinking water (that is, outside the area of municipal water service), residents may ingest CCB-derived constituents that have migrated into groundwater. They may also potentially contact CCB-derived constituents in groundwater while bathing. Residential children who play in the local ditches/wetlands may contact CCB-derived constituents that have potentially entered the surface water and sediment with the groundwater (via incidental ingestion and dermal contact). Recreational visitors may be adults who fish in the local ditches/wetlands or children who play in the local ditches/wetlands. Recreational visitors may inhale CCB particulates entrained in dusts. Additionally, recreational visitors may contact CCB-derived constituents that have potentially entered into surface water and sediment with groundwater (via incidental ingestion and dermal contact). Recreational fishers may also be exposed to CCB-derived constituents in fish tissue via consumption. Recreational visitors may also ingest groundwater as drinking water while in the Area of Investigation. Construction workers may potentially contact surface and subsurface CCBs directly via incidental ingestion and dermal contact, and they may inhale CCB particulates entrained in dusts. Construction workers may also directly contact CCB-derived constituents in groundwater via incidental ingestion and dermal contact if groundwater is encountered during an excavation. Construction workers may also ingest groundwater as drinking water. Outdoor workers may be exposed to surface CCBs where present via incidental ingestion and dermal contact and to CCBs where present in particulates that may be suspended in the air via inhalation. Outdoor workers might also potentially ingest groundwater as drinking water.

Potential Ecological Receptors – Important ecologic habitats in the Area of Investigation include the Brown Ditch system, adjacent marsh and wetland areas, man-made ponds, and upland forested areas. Ecological receptors whose habitats include Brown Ditch (aquatic plants, benthic invertebrates, plants, amphibians, fish, piscivorous avians, and mammals) may be exposed to CCB-derived constituents in surface water and sediments of Brown Ditch and adjacent man-made ponds/basins. Avian and mammalian receptors (herbivores, omnivores, and carnivores) may be exposed to CCB-derived constituents in the Brown Ditch system and adjacent man-made ponds/basins through bioaccumulation by ingestion of food items (e.g., plants, fish). Upland vegetation and soil invertebrates may come in contact with CCB-derived constituents in upland terrestrial habitat areas where suspected CCBs are present in these areas. Terrestrial avian and mammalian receptors (herbivores, omnivores,

insectivores, and carnivores) may also come into contact with CCB-derived constituents in upland terrestrial habitat areas where suspected CCBs are present in these areas. This later pathway would also include the exposure due to ingestion of grit by certain avian receptors.

6.3 Nature and Extent of Constituents

Background Soil - The natural soils in the Area of Investigation include both granular soils (primarily dune sands, but also silts and clays) and organic soils, which may be mixed with granular materials. All of the natural geologic materials contain a wide variety of metals at different concentrations, such as Al, As, B, Ba, Ca, Cr, Fe, Pb, Mg, Na, Se, Sr, U, V, and Zn. Of all the metals, As was present in all the soil samples at concentrations above the risk-based comparison level for human health. This is not unexpected, as As is present at concentrations above risk-based comparison levels in most natural soils in the United States. Manganese and Tl were detected in one background soil sample at concentrations above the human health risk-based comparison level. Cobalt was also detected in one sample slightly above the human health risk-based comparison level. Levels of the radionuclides Pb-210, Ra-226, and Ra-228 were also greater than human health comparison levels in most samples. None of these soil samples is significantly affected by CCB-derived constituents; instead, the results reflect the natural and anthropogenic levels of metals and radionuclides in soils in the area.

Suspected CCBs - Most of the metals present in suspected CCBs are also present in background soils, although concentrations for some are higher in suspected CCBs. The As concentrations in all the suspected CCB samples were above the risk-based comparison level as were all of the As concentrations in the background soils. Iron was also present in many suspected CCB samples at concentrations above the risk-based comparison level for human health. Hexavalent Cr was detected and above the human health risk-based comparison level in all of the suspected CCB samples in which it was analyzed.

Groundwater - The natural background groundwater in the Area of Investigation includes many minerals, typical of most natural fresh waters in the world. These include major ions such as Ca, Mg, Na, Si, HCO₃, SO₄, and Cl, and minor and trace elements such as Al, Ba, B, Mn, Sr, and NO₃. Based on RI sampling, background concentrations of B in the surficial aquifer in the Area of Investigation range up to 0.119 mg/l; Mo up to 0.012 mg/l. The USGS has documented that natural levels of B in the deeper confined aquifers can be expected to be above both the USEPA's RAL of 0.900 mg/l and the human health risk-based comparison level of 0.730 mg/l.

Based on the RI data, CCB-derived constituents in groundwater include B, SO₄, Ca, Mg, Sr, and Mo. Arsenic also appears to migrate from CCBs to groundwater, at least at Yard 520, but it is not transported any significant distance with the groundwater. Iron and Mn may also have the potential to migrate from CCBs to groundwater, but their mobility in groundwater is controlled by redox conditions. Of these, B, Mo, SO₄, As, Fe, and Mn are present in at least one groundwater sample at concentrations above human health risk-based comparison levels. Other constituents detected at

least once at concentrations above comparison levels include Se, Cl, and NO₃, but these are not likely to be CCB-derived.

It is uncertain whether migration from CCBs to groundwater occurs where CCBs are used only as road sub-base. In at least one monitoring well location MW111), elevated CCBs occur in an area of known road sub-base and underlying road fill combined (five feet of thickness as documented in the boring log for MW111; see Figure 4-18). Unverified larger accumulations of CCBs nearby (i.e., to the east of Illinois Avenue) may, however, also contribute to the groundwater concentration, as well as verified areas located around TP026 (greater than four and a half feet of CCB fill) and TP027 (greater than seven feet of CCB fill), which are located upgradient of MW111. Several wells are located in or downgradient from areas where suspected CCBs are present only as road sub-base, including MW107, MW108, MW114, and PW005. These wells do not show the presence of elevated levels of B (see Figure 4-18). In addition to the smaller amounts of suspected CCBs present, the paving of roadways may reduce groundwater recharge and migration of CCB-related constituents to groundwater.

The extent of CCB-derived constituents in groundwater has been documented throughout the RI. Concentrations of B, SO₄, Ca, Mg, Sr, and Mo are elevated at and downgradient from Yard 520. To the east, elevated concentrations of these constituents are present in the vicinity of areas where suspected CCBs may have been used as fill (that is, they are present well beyond the roadways), and downgradient to the south to the East Branch of Brown Ditch. All groundwater containing CCB-derived constituents is interpreted based on the RI data to flow into the Brown Ditch system, including its related tributaries and wetlands.

In addition, groundwater from Yard 520 flows into Brown Ditch and its related tributaries and wetlands in the immediate vicinity of Yard 520, and the hydrogeologic studies performed as part of the RI have demonstrated that groundwater does not flow from Yard 520 to the south beneath Brown Ditch. Also, based on the available information, CCB-derived constituents in groundwater do not extend northward into IDNL at levels of significance; this will be evaluated further in the ecological risk assessment (ERA).

Groundwater directly south of Yard 520 and Brown Ditch appears to be impacted by a landfill to the south (Pines Landfill, owned by Waste Management). Increased B concentrations in monitoring wells in this area are most likely a result of landfill contaminants. While Yard 520 is not a source of CCB-derived constituents in this area, without additional information, however, some contribution from other potential CCB sources cannot be ruled out.

In the area near the intersection of South Railroad Avenue and Ardendale where CCBs have been used in residential yards and driveways and as road sub-base, CCB impacts to groundwater might have occurred. One residential well was tested by EPA to be above the screening level for boron, although the private well located across the street (PW010) was sampled four times over the course of a year (2006 – 2007) and the boron concentrations were much below the comparison level. Therefore,

in this part of the study area, which is not served by municipal water, CCB-derived constituents may have migrated into groundwater; this potential pathway will be evaluated in the HHRA.

In addition to CCB-derived constituents in groundwater, the groundwater in the surficial aquifer beneath the Area of Investigation shows evidence of other sources, including septic system discharges, road salt, and the Pines Landfill (owned by Waste Management). Elevated concentrations of a number of non-CCB-derived constituents, such as Na, Cl, NO₃, NH₄, and bacteriological parameters, are present in many samples.

Surface Water - The upgradient (background) surface water contained measurable levels of metals and other constituents. The presence of these naturally occurring constituents in the surface water samples is not unexpected and, in many cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations as well as anthropogenic influences such as agricultural practices and run-off from roadways and railroads. The DO concentrations in upgradient locations were relatively low, especially in the summer and early fall, such that Brown Ditch would not support a coldwater fishery, and even warmwater fish may be seasonally stressed in some locations.

In upgradient surface water, concentrations of Al, Fe, Mn, and V were above the associated ecological comparison level in at least one sample. The concentration of Mn was above the human health comparison level in only one sample, and this was the only surface water sample with a constituent present at a level above a human health comparison level. The presence of Al in surface water is associated with suspended solids in the water, as measured by the TSS. Total Fe and Mn concentrations also are likely a function of the level of particulate matter in the sample. Dissolved Fe and Mn results can be associated with low DO and associated redox conditions.

The Brown Ditch surface waters (that is, within the Area of Investigation, downgradient of the upgradient locations) also contained measurable levels of metals and other constituents. As with the upgradient locations, the presence of these naturally occurring constituents in the surface water samples is not unexpected and, in many cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations. However, concentrations of several metals were higher than in upgradient samples.

Concentrations of B in surface water were above the human health and ecological comparison levels in certain samples in the West, East, and Main Branches of Brown Ditch. Typically, higher concentrations were measured in the summer (dry period). On the West Branch, some of these samples also have Mo concentrations above the human health risk-based comparison level (but not the ecological level). These elevated concentrations of B and Mo are most likely due to the contribution of groundwater containing CCB-derived constituents to the ditches.

Concentrations of Al were above its ecological comparison level in many surface water samples, both at upgradient and Brown Ditch locations. The Al appears to be associated with sediment and

suspended particles in the samples as measured by the TSS. Aluminum concentrations are generally higher in upgradient samples.

Concentrations of Fe and Mn were above the associated ecological comparison levels in many upgradient and Brown Ditch sample locations while only one Brown Ditch sample concentration of Fe was above the human health comparison level. The total fraction of these constituents may also be associated with suspended sediment in the samples; the dissolved fraction may be associated with locally low levels of DO in some segments of the ditches.

Sediments - In upgradient (background) locations, sediment samples are typically sandy with low levels of organic material. Boron was not detected in any upgradient sediment samples; however, the detection limit for B in sediments was elevated for all samples analyzed. Lead, Se, and Ba were above the ecological comparison levels in upgradient sediment samples, and As concentrations were above the human health comparison level. The presence of these metals in background sediments shows that sediments outside of areas where they could be affected by CCB-derived constituents contain concentrations of some metals that are above risk-based comparison levels.

The sediments in Brown Ditch (that is, at locations within the Area of Investigation, downgradient of the upgradient locations) included both sandy and highly organic sediments. In contrast with the upgradient samples, the majority of the Brown Ditch samples contained greater than 1% TOC. The percentage of fine-grained material (silts and clays) was also generally higher in downgradient samples. These differences reflect differences in the depositional environments between upgradient and Brown Ditch locations.

The Brown Ditch sediments contained metals and other constituents. The presence of these naturally occurring constituents in the sediment samples is not unexpected and, in some cases, can be attributed to weathering and erosion of local soils, sediments, and geologic formations. Boron was detected in two sediment samples from Brown Ditch, SW022 and SW026; however, as noted above, the detection limit for B in sediments was elevated for all samples analyzed. Based on their locations and B concentrations, B in these sediments is likely associated with groundwater containing CCB-derived constituents; that is, the B in these sediment samples is likely to be associated with CCBs. There are no ecological risk-based comparison levels for B in sediment. The concentrations are below the human health risk-based comparison level.

In general, concentrations of many metals in the Brown Ditch sediments were greater than concentrations at upgradient locations, consistent with the finer-grained and more organic nature of many of the Brown Ditch system sediment samples. Concentrations of As, Ba, Cu, Fe, Pb, Mn, Ni, Se, V, and Zn in the Brown Ditch sediments for some locations were above associated ecological risk-based comparison levels, and results for Al, Cd, or Cr in Brown Ditch sediments were below associated ecological risk-based comparison levels. All detected concentrations of As in the Brown Ditch sediments, some detected concentrations of Fe, and one detected TI concentration are above human health risk-based comparison levels.

The interpretation of some metals in Brown Ditch sediments may be confounded by the higher percentage of fines, higher TOC concentrations, lower percent solids, and presence of other potential sources in Brown Ditch sediments compared to upgradient sediments, but the concentrations of some metals are clearly elevated in samples located in proximity to significant CCB sources. When the percentage of fines is taken into account, concentrations of most metals (except for soluble CCB-related constituents such as B and Mo) are similar to upgradient concentrations and there is no consistent spatial pattern that can be attributed to CCB-derived constituents. Although the concentration of many metals in Brown Ditch sediments are similar to upgradient levels when percent fines are considered, concentrations of some inorganics that may be CCB-related increase up to five times the background concentrations in the Brown Ditch system downgradient of Yard 520 and other significant accumulations of CCBs. At locations most likely to be impacted by CCB-derived constituents (i.e., located physically closest to Yard 520 or larger areas of suspected CCBs), metal concentrations are generally consistent with upgradient locations (except for impacts due to constituents in groundwater such as B and Mo). A formal statistical comparison to upgradient concentrations will be conducted as part of the risk assessments.

6.4 Fate and Transport

Constituents present in environmental media will be affected by various attenuation processes as they migrate that will tend to reduce their concentrations. In groundwater, B, SO₄, Ca, Mg, and Sr are highly soluble and not very chemically reactive. Therefore, they are less likely to participate in chemical reactions that remove them from groundwater. They will typically be transported downgradient with the groundwater flow, with concentrations reduced primarily through dispersion. These constituents will then enter surface water in the Brown Ditch system with the groundwater. The fate and transport of Mo is similar, except that it appears to be subject to some additional attenuation processes, at least locally.

The fate and transport of Fe, Mn, and As in groundwater are controlled by redox conditions. Where groundwater is oxidized, these constituents will form insoluble molecules and will be removed from the groundwater system. Where groundwater is reduced, these molecules will dissociate and release the constituents into the groundwater. This process occurs with naturally-occurring Fe, Mn, and As in the native soils in the Area of Investigation as well as any Fe, Mn or As that might migrate from CCBs. Reducing conditions in groundwater are present locally throughout the Area of Investigation, most likely caused by organic inputs to the groundwater, such as septic system discharges, wetlands and highly organic soils, former gasoline stations, and the Pines Landfill (owned by Waste Management). Where such reducing conditions are present near the Brown Ditch system, including its associated wetlands, these constituents could be mobile and enter the ditch with the groundwater. Where groundwater near the ditches is oxidized, Fe, Mn and As will not be mobile and, therefore, will not migrate into surface water.

In surface water, constituent concentrations tend to decrease with distance downstream from sources due to mixing and dilution. When constituents partition from the porewater into the sediments, they are

less available to interact with ecological receptors. Uptake of nutrients by plant life can reduce concentrations in sediment and surface water. Biological processes in general can transform constituents and affect their fate and mobility (e.g., denitrification). In addition, the potential ecological effects of some constituents in surface water can be hardness dependent. CCB-derived constituents are not considered bioaccumulative.

6.5 Summary

The RI consisted of an extensive field investigation that included the collection and analysis of groundwater, sediment, surface water and suspected CCB samples. The analytical results provide a comprehensive dataset with which to evaluate the nature and occurrence of CCB-derived constituents within the Area of Investigation. Data were reviewed and validated in accordance with approved quality assurance procedures (ENSR, 2005f). The primary objective of the data validation (Appendix S) and of the data usability evaluation (Appendix T) was to ensure that appropriate data were used in the evaluation of the RI investigation results. With the exception of a single rejected result, all data generated under the MWSE SAP, Yard 520 SAP, and RI FSP were determined to be valid, and considered to be usable and reliable for decision-making.

The constituents present in CCBs are metals and inorganics that are naturally found in soil, groundwater, surface water, and sediment. Analysis of samples collected from background and reference locations for these media confirmed this.

Based on the RI data, the CCB-derived constituents in groundwater include:

- B, SO₄, Ca, Mg, Sr, Mo, and As, and possibly Fe and Mn.

It is important to note that all of these constituents are also present in groundwater unaffected by CCBs.

Of these, B, Mo, SO₄, As, Fe, and Mn are present in at least one groundwater sample at concentrations above human health comparison levels. The groundwater data will be evaluated further in the risk assessments.

Migration from CCBs to groundwater appears to occur where large volumes of CCBs are present, such as at Yard 520 and areas where suspected CCBs extend significantly beyond roadways. It is uncertain whether migration from CCBs to groundwater occurs where used only as road sub-base. In at least one monitoring well location, elevated CCBs occur in an area of known road sub-base and underlying road fill combined (five feet of thickness as documented in the boring log for MW111; see Figure 4-18). Unverified larger accumulations of CCBs nearby (i.e., to the east of Illinois Avenue) may, however, also contribute to the groundwater contamination, as well as verified areas located around TP026 (greater than four and a half feet of CCB fill) and TP027 (greater than seven feet of CCB fill),

which are located upgradient of MW111. In general, in the vicinity of smaller amounts of CCBs, for example, used only as a road sub-base material, CCB-derived constituents do not appear to migrate to groundwater. Importantly, CCB-derived constituents in groundwater do not currently appear to extend to areas where private water wells are located outside the area currently supplied by municipal drinking water, based on available data (see Figure 4-19). At best, the data may reflect a very minor impact which any CCBs at the ground surface might have on groundwater in this area.

Where CCB-derived constituents are present in groundwater, they may flow into surface water. Concentrations of B in surface water were above the human health and ecological comparison levels in certain samples in the West, East, and Main Branches of Brown Ditch. Typically, higher concentrations were measured in the summer (dry period). On the West Branch, some of these samples also have Mo concentrations above the human health risk-based comparison level (but not the ecological level). These elevated concentrations of B and Mo are most likely due to the contribution of groundwater containing CCB-derived constituents to the ditches. While concentrations of some other constituents in surface water are above human health and/or ecological comparison levels, the presence of these constituents in surface water do not appear to be related to CCBs. Surface water data will be evaluated further in the risk assessments.

There was no evidence during the RI investigation that suspected CCBs were emplaced in Brown Ditch or its tributaries. Historically, erosion may have contributed CCBs to the ditches. However, it is unlikely to be taking place under current conditions because of the stable and well-vegetated riparian buffer zones associated with the channels that reduce and filter erosion runoff. CCB-derived constituents in groundwater that flows to surface water may adsorb onto sediments. The interpretation of the metals in Brown Ditch sediments is confounded by the higher percent fines, higher TOC, lower percent solids, and presence of other potential sources (e.g., septic systems, roads railroads, and stormwater runoff) in Brown Ditch sediments compared to upgradient sediments. When the percentage of fines is taken into account, concentrations of most metals (except for soluble CCB-related constituents such as B and Mo) are similar to upgradient concentrations and there is no consistent spatial pattern that can be attributed to CCB-derived constituents. At locations most likely to be impacted by CCB-derived constituents (e.g., located physically closest to Yard 520 or larger areas of suspected CCBs), concentrations are generally consistent with background (except for impacts due to constituents in groundwater). For example, B was only detected in sediment samples SW022 and SW026 as shown on Figure 4-29. Both of these locations are expected to receive groundwater containing CCB-derived constituents. Molybdenum was also detected in these samples, and at SW024 and SW009, as shown on Figure 4-30. There are no ecological comparison levels for these parameters in sediments, but the concentrations are below human health comparison levels. It is likely that their occurrence in sediment is related to CCB-derived constituents in groundwater. Therefore, other than in localized areas where groundwater flows into the ditches, CCB-derived constituents are not present in sediments in the Area of Investigation. The sediment data will be evaluated further in the risk assessments.

Data for CCBs and suspected CCBs are available from the samples of suspected CCBs collected during the municipal water service extension under the MWSE SAP (for metals and inorganics), and from samples of CCBs collected from the South (Type III) Area of Yard 520 (for radionuclides). These data will be compared to data from the background soil samples to determine whether any of the CCB constituents are present in CCBs above background levels as part of the risk assessments.

6.6 Risk Assessments

One stated purpose of the RI/FS, and the purpose of the risk assessments is:

“to adequately characterize...(i) whether the city water service extension installed pursuant to AOC I, as amended, is sufficiently protective of current and reasonable future drinking water use of groundwater in accordance with Federal, State, and Local requirements; (ii) any additional human health risks at the Site associated with exposure to CCBs; and (iii) whether CCB-derived constituents may be causing unacceptable risks to ecological receptors.”

To achieve this goal, the data collected during the RI will be evaluated in the Human Health Risk Assessment and the Ecological Risk Assessment, in accordance with their respective work plans (ENSR, 2005h, 2005i). The risk assessments will include a comparison of the data to risk-based screening levels, and a comparison of the data to the background soil, surface water, and sediment data. The focus of the risk assessments will be on those CCB-derived constituents that are present at concentrations above both risk-based screening levels and background levels. In accordance with the requirements of AOC II, the risk assessments will be submitted to USEPA 60 days after approval of this RI Report.

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