Removal Action Investigation/Remedial Investigation Report West, Seep 2 and Seep 1 CKD Areas Revision 1.0 – July 31, 2009 Little Traverse Bay CKD Release Site Emmet County, Michigan

Table of Contents

Executive Summary xx

1.0 Introduction 1
1.1 Purpose of Report 1
1.2 Investigation Completeness 2
1.3 Site Background 3
1.3.1 Site Location 3
1.3.2 CKD and Site Description 3
1.3.2.1 West CKD Area 4
1.3.2.2 Seep 2 CKD Area 4
1.3.2.3 Seep 1 CKD Area 6
1.3.3 Site History 6
1.3.3.1 West CKD Area 7
1.3.3.2 Seep 2 CKD Area 7
1.3.3.3 Seep 1 CKD Area 7
1.3.4 Previous Investigations 8
1.3.4.1 1995 Hydrogeologic Investigation 8
1.3.4.2 Historical Seep 2 Collection Drain Construction and Operation 9
1.3.4.3 Treatment Plant Construction and Operation 9
1.3.4.4 Collection System Shutdown and Restart 10
1.3.4.5 2003 Geotechnical Investigation 10
1.3.4.6 MDEQ and U.S. EPA Investigations 11
1.3.4.7 Preliminary Non-intrusive Data Collection Activities 12
1.4 Conceptual Site Model 12
1.4.1 Source of Contamination 13
1.4.2 Potential Routes of Migration 13
1.4.2.1 West CKD Area 13
1.4.2.2 Seep 2 CKD Area and Guard Rail Area 14
1.4.2.3 Pine Court Seep Area 14
1.4.2.4 Seep 1 CKD Area 15
1.4.3 Potential Receptors 15
1.5 Report Organization 16

2.0 Expedited Removal Actions and Interim Response 17
2.1 Expedited Removal Actions 17
2.1.1 Implementation of the SCAMP 17
2.1.2 Targeted Shoreline Survey 17
2.1.3 Overflights 19
2.1.4 Removal Action Notification 20
2.1.5 Expedited Leachate Recovery 20

2.2 Interim Leachate Recovery System 20
2.2.1 Design 21
2.2.2 Installation 21
2.2.3 Augmentation 22
2.2.3.1 West CKD Area 23
2.2.3.2 Seep 2 CKD Area/Pine Court Seep Area 27
2.2.3.3 Seep 1 CKD Area 29
2.2.4 Operational Monitoring 32
2.2.4.1 ILRS Leachate Flow Monitoring 33
2.2.4.2 ILRS pH Monitoring 35
2.2.4.3 ILRS Piezometer pH 36
2.2.4.4 ILRS Piezometer Elevation 37
2.2.4.5 ILRS Leachate Quality 39
2.2.4.6 Collection Pipe Precipitate Characterization 40
2.2.4.7 Operational Lakeshore pH 40
2.2.5 Management of Recovered Leachate 40
2.2.6 Effectiveness Monitoring 41
2.2.7 Operation and Maintenance Plan 42
2.2.8 Interim Recovery System Contingency Plan 42

3.0 Study Area Investigation 43
3.1 Investigation Activities 43
3.1.1 Surface Features 44
3.1.1.1 Surveys 44
3.1.1.2 Aerial Thermometry Survey 45
3.1.2 Contaminant Source Investigations 45
3.1.2.1 Unconsolidated Material Sampling (CKD and Non-CKD) 47
3.1.2.2 Leachate 48
3.1.3 Meteorological Investigation 49
3.1.4 Surface Water Investigations 51
3.1.4.1 Lake/Pool Surface Water Sampling 51
3.1.4.2 Creek Monitoring and Sampling 52
3.1.4.3 Water Cycle Monitoring 53
3.1.4.4 Golf Pond Assessment 56
3.1.4.5 Bay Harbor Lake Assessment 57
3.1.4.6 Golf Course Drain Inventory 58
3.1.5 Geological Investigations 59
3.1.5.1 Drilling Methods 59
3.1.5.2 Borehole Geologic Logging 60
3.1.5.3 Borehole Geophysical Logging 61
3.1.5.4 Surface Geophysics 67
3.1.5.5 Rock Testing/Rippability Analysis 68
3.1.6 Groundwater Investigations 69
3.1.6.1 Borehole Packer Interval Sampling/Aquifer Testing 69
3.1.6.2 Well Installation 71
3.1.6.3 Aquifer Testing 74
3.1.6.4 Groundwater Sampling 78
3.1.6.5 Hydrogeologic Model 79
3.1.7 Ecological Investigations 79
3.1.7.1 Methods 79

3.1.7.2 Results for Benthic Invertebrates Characterization 80
3.1.7.3 Results for Periphyton Community Characterization 81
3.2 Waste and Leachate Management 86
3.2.1 Investigation Derived Waste Management 86
3.2.2 Interim Response Action Leachate Management 86
3.2.3 Environmental Release Reporting 86

4.0 Physical Characteristics of the Study Area 88
4.1 Surface Features 88
4.2 Meteorology 88
4.3 Surface Water 88
4.3.1 Surface Water Drainage 88
4.3.2 Water Cycle Monitoring 89
4.3.2.1 Creek Monitoring – Flow and Water Elevation Monitoring 89
4.3.2.2 Lake Michigan Elevation Monitoring 91
4.3.2.3 Infiltration and Evapotranspiration Study 93
4.4 Geology 95
4.4.1 Regional Geology 95
4.4.2 Site Bedrock Geology 95
4.5 Unconsolidated Materials 101
4.6 Hydrogeology 102
4.6.1 Aquifer Characteristics 103
4.6.1.1 Flow Direction and Gradient 103
4.6.1.2 Geology 104
4.6.1.3 Perched Groundwater 105
4.6.1.4 Porosity – Causes, Extent, and Interconnection 106
4.6.1.5 Aquifer Anisotropy 107
4.6.1.6 Hydraulic Conductivity / Heterogeneity 107
4.6.1.7 Water Level and Temperature Monitoring 108
4.6.2 Borehole Flow Logging 111
4.6.3 Aquifer Testing 114
4.6.3.1 Packer Testing 114
4.6.3.2 Slug Testing 116
4.6.3.3 Vertical Pumping Tests at Well Nests 116
4.6.4 Mechanisms of Flow 117
4.6.4.1 Recharge to the Aquifer System 117
4.6.4.2 Response to the City of Petoskey Well Pumping 118
4.6.4.3 Response to the Lake Stage Changes 119
4.6.4.4 Borehole Interval Classification 120
4.6.4.5 Fracture Projection 121
4.7 Demography and Land Use 122

5.0 Nature and Extent of Contamination 125
5.1 Data Evaluation 125
5.2 Contamination Source 125
5.3 Surface Water 125
5.3.1 Lake/Pool Surface Water Sampling 125
5.3.1.1 West CKD Area Surface Water Quality 126
5.3.1.2 Seep 2 CKD Area Surface Water Quality 126
5.3.1.3 Seep 1 CKD Area Surface Water Quality 127

5.3.2 Creek Sampling 128
5.3.2.1 West Unnamed Creek 128
5.3.2.2 East Unnamed Creek #1 129
5.4 Soils 130
5.5 Groundwater 133
5.5.1 Groundwater Quality – Borehole Water 133
5.5.2 Groundwater Quality – Monitoring Wells 133
5.5.2.1 West CKD Area 135
5.5.2.2 Seep 2 CKD Area 138
5.5.2.3 Seep 1 CKD Area 143

6.0 Cement Kiln Dust Characteristics and Leachate Chemistry 149
6.1 Cement Kiln Dust Characteristics 149
6.1.1 Physical Properties 149
6.1.2 Chemical Properties 150
6.1.3 CKD Weathering 153
6.1.3.1 CKD Weathering in the Saturated Zone 154
6.1.3.2 CKD Weathering in the Unsaturated Zone 155
6.2 Leachate Chemistry Discussion 156
6.2.1 Interactions between CKD and Water 156
6.2.1.1 Reactions Common to Portland Cement and CKD 157
6.2.1.2 Reactions Specific to CKD 159
6.2.2 Properties Imparted to Leachate by CKD Hydration 160
6.2.3 Interactions between Leachate and Environmental Media 160
6.2.4 Description of Site Data Using Stiff Diagrams 161

7.0 Contaminant Fate and Transport 163
7.1 Potential Site COCs 163
7.2 Potential Routes of Migration 176
7.2.1 Air 176
7.2.2 Surface Water 176
7.2.3 Unconsolidated Material (Non-CKD and CKD) 177
7.2.4 Groundwater/Leachate 177
7.3 Contaminant Persistence 177
7.4 Contaminant Migration 178
7.4.1 Leachate Generation 178
7.4.2 Flow Mechanisms 179
7.5 CKD Area Summary and COC Determination 180
7.5.1 West CKD Area 180
7.5.2 Seep 2 CKD Area 183
7.5.3 Seep 1 CKD Area 185

8.0 Summary and Conclusions 188
8.1 Summary 188
8.1.1 Interim Response and Effectiveness of ILRS 188
8.1.2 Nature and Extent of Contamination 189
8.1.3 Fate and Transport 190
8.2 Conclusions 191

9.0 References 192

List of Tables

Table 2-1 ILRS Collection Rate
Table 2-2 ILRS Collected Leachate pH
Table 2-3a West CKD ILRS Piezometer, Valve Box, and Standpipe pH
Table 2-3b Pine Court ILRS Piezometer, Valve Box, and Standpipe pH
Table 2-3c Guardrail ILRS Piezometer, Valve Box, and Standpipe pH
Table 2-3d Seep 2 ILRS Piezometer, Valve Box, and Standpipe pH
Table 2-3e Seep 1 ILRS Piezometer, Valve Box, and Standpipe pH
Table 2-4a West CKD ILRS Piezometer, Valve Box, and Standpipe Elevation
Table 2-4b Pine Court ILRS Piezometer, Valve Box, and Standpipe Elevation
Table 2-4c Guard Rail ILRS Piezometer, Valve Box, and Standpipe Elevation
Table 2-4d Seep 2 ILRS Piezometer, Valve Box, and Standpipe Elevation
Table 2-4e Seep 1 ILRS Piezometer, Valve Box, and Standpipe Elevation
Table 2-5a West CKD ILRS Leachate Quality Results
Table 2-5b Pine Court ILRS Leachate Quality Results
Table 2-5c Guard Rail ILRS Leachate Quality Results
Table 2-5d Seep 2 ILRS Leachate Quality Results
Table 2-5e Seep 1 ILRS Leachate Quality Results
Table 2-5f Edge Drain ILRS Leachate Quality Results
Table 2-5g ILRS Composite Sample Leachate Quality Results
Table 2-5h Targeted Leachate Collection Quality Results
Table 2-5i ILRS Frac Tank Leachate Quality Results
Table 2-6 ILRS Solids Quality Results

Table 3-1a West CKD Area Topographic and Locational Survey Summary
Table 3-1b Seep 2 CKD Area Topographic and Locational Survey Summary
Table 3-1c Seep 1 CKD Area Topographic and Locational Survey Summary
Table 3-2a West CKD Area Sample Summary
Table 3-2b Seep 2 CKD Area Sample Summary
Table 3-2c Seep 1 CKD Area Sample Summary
Table 3-3 Parameters, Methods and Detection Limits
Table 3-4 West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area Troll Datalogger Location Summary

Table 4-1 West CKD Area, Seep 2 CKD Area, Seep 1 CKD Area Creek Discharge Summary
Table 4-2 Summary of Fracture Density Data from Boreholes Logged with the BHTV
Table 4-3 Unconsolidated Borehole Data Summary – West CKD Area, Seep 2 CKD Area, Seep 1 CKD Area
Table 4-4 Unconsolidated Material Physical Properties Data Summary West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area
Table 4-5a West CKD Area Water Level Measurements
Table 4-5b Seep 2 CKD Area Water Level Measurements
Table 4-5c Seep 1 CKD Area Water Level Measurements
Table 4-6a West CKD Area Vertical Hydraulic Gradients
Table 4-6b Seep 2 CKD Area Vertical Hydraulic Gradients
Table 4-6c Seep 1 CKD Area Vertical Hydraulic Gradients
Table 4-7a West CKD Area Aquifer Testing Results (Slug and Packer Results)
Table 4-7b Seep 2 CKD Area Aquifer Testing Results (Slug, Packer & Pumping Test Results)
Table 4-7c Seep 1 CKD Area Aquifer Testing Results (Slug, Packer & Pumping Test Results)
Table 4-8 Summary of Water Level and Temperature Responses
Table 4-9 Borehole Flow Testing Calculations from B3014
Table 4-10 Evaluation of Flow Regime Indicated by Packer Test Response
Table 4-11 Summary of Projected Potential Conduits

Table 5-1a West CKD Area Surface Water Data
Table 5-1b Seep 2 CKD Area Surface Water Data
Table 5-1c Seep 1 CKD Area Surface Water Data
Table 5-2 Creek Monitoring Data Summary pH, Specific Conductance & Temperature West Unnamed Creek and East Unnamed Creek #1
Table 5-3 Creek Monitoring Analytical Data Summary
Table 5-4a West CKD Area Unconsolidated Material Analytical Data Summary
Table 5-4b Seep 2 CKD Area Unconsolidated Material Analytical Data Summary
Table 5-4c Seep 1 CKD Area Unconsolidated Material Analytical Data Summary
Table 5-5a West CKD Area Borehole Water/Leachate Analytical Data Summary
Table 5-5b Seep 2 CKD Area Borehole Water/Leachate Analytical Data Summary
Table 5-5c Seep 1 CKD Area Borehole Water/Leachate Analytical Data Summary
Table 5-6a West CKD Area Monitoring Well Groundwater Quality Data
Table 5-6b Seep 2 CKD Area Monitoring Well Groundwater Quality Data
Table 5-6c Seep 1 CKD Area Monitoring Well Groundwater Quality Data

Table 7-1a Identification of Site Chemicals of Concern (COC) for Groundwater – West CKD Area

Table 7-1b Identification of Site Chemicals of Concern (COC) for Soil (CKD) – West CKD Area

Table 7-2a Identification of Site Chemicals of Concern (COC) for Groundwater – Seep 2 CKD Area

Table 7-2b Identification of Site Chemicals of Concern (COC) for Soil (CKD) – Seep 2 CKD Area

Table 7-3a Identification of Site Chemicals of Concern (COC) for Groundwater – Seep 1 CKD Area

Table 7-3b Identification of Site Chemicals of Concern (COC) for Soil (CKD) – Seep 1 CKD Area

List of Figures

Figure 1-1 CKD Release Site Location
Figure 1-2 Site Area Layout
Figure 1-3 Historical Features
Figure 1-4a Conceptual Site Model West CKD Area (Winter)
Figure 1-4b Conceptual Site Model West CKD Area (Summer)
Figure 1-4c Conceptual Site Model Seep 2 CKD Area
Figure 1-4d Conceptual Site Model Pine Court Area (Winter)
Figure 1-4e Conceptual Site Model Pine Court Area (Summer)
Figure 1-4f Conceptual Site Model Seep 1 CKD Area
Figure 1-5 Potential Receptors WCKD, Seep 1, and Seep 2 CKD Areas

Figure 2-1a Site Layout Interim Leachate Recovery System
Figure 2-1b Interim Leachate Recovery System West CKD Area
Figure 2-1c Interim Leachate Recovery System Pine Court Area
Figure 2-1d Interim Leachate Recovery System Guard Rail Area
Figure 2-1e Interim Leachate Recovery System Seep 2 CKD Area
Figure 2-1f Interim Leachate Recovery System Seep 1 CKD Area
Figure 2-1g Interim Leachate Recovery System Targeted Leachate Collection
Figure 2-2a West CKD Area Flow
Figure 2-2b Seep 2 Forcemain Combined Flow
Figure 2-2c Edge Drain Flow
Figure 2-2d Seep 1 Forcemain Flow
Figure 2-2e Targeted Leachate Collection Flow
Figure 2-3a ILRS Average Daily pH
Figure 2-4a West CKD Area ILRS Piezometer, Valve Box, and Standpipe pH
Figure 2-4b Pine Court ILRS Piezometer, Valve Box, and Standpipe pH
Figure 2-4c Guard Rail ILRS Piezometer, Valve Box, and Standpipe pH
Figure 2-4d Seep 2 CKD Area ILRS Piezometer, Valve Box, and Standpipe pH
Figure 2-4e Seep 1 CKD Area ILRS Piezometer, Valve Box, and Standpipe pH
Figure 2-5a West CKD Area ILRS Piezometer, Valve Box, and Standpipe Elevations
Figure 2-5b Pine Court ILRS Piezometer, Valve Box, and Standpipe Elevations
Figure 2-5c Guard Rail ILRS Piezometer, Valve Box, and Standpipe Elevations

Figure 2-5d Seep 2 CKD Area ILRS Piezometer, Valve Box, and Standpipe Elevations
Figure 2-5e Seep 1 CKD Area ILRS Piezometer, Valve Box, and Standpipe Elevations

Figure 3-1a Boring Locations West CKD Area
Figure 3-1b Boring Locations Seep 2 CKD Area
Figure 3-1c Boring Locations Seep 1 CKD Area
Figure 3-2a Monitoring Well Locations West CKD Area
Figure 3-2b Monitoring Well Locations Seep 2 CKD Area
Figure 3-2c Monitoring Well Locations Seep 1 CKD Area
Figure 3-3 Weather Station Location
Figure 3-4a Surface Water Monitoring Locations West CKD Area
Figure 3-4b Surface Water Monitoring Locations Seep 2 CKD Area and Guard Rail Seep Area
Figure 3-4c Surface Water Monitoring Locations Pine Court
Figure 3-4d Surface Water Monitoring Locations Seep 1 CKD Area
Figure 3-5a Sample and Flow Monitoring Locations West Unnamed Creek
Figure 3-5b Sample and Flow Monitoring Locations East Unnamed Creek #1
Figure 3-5c Flow Monitoring Locations East Unnamed Creek #2
Figure 3-6 Stilling Well and Staff Gauge Locations

Figure 4-1a Site Topography and Geologic Cross Section Locations West CKD Area
Figure 4-1b Site Topography and Geologic Cross Section Locations Seep 2 CKD Area
Figure 4-1c Site Topography and Geologic Cross Section Locations Seep 1 CKD Area
Figure 4-2a Geologic Cross Section A-A’ West CKD Area
Figure 4-2b Geologic Cross Section B-B’ West CKD Area
Figure 4-2c Geologic Cross Section C-C’ West CKD Area
Figure 4-2d Geologic Cross Section D-D’ West CKD Area
Figure 4-2e Geologic Cross Section E-E’ West CKD Area
Figure 4-2f Geologic Cross Section F-F’ West CKD Area
Figure 4-3a Geologic Cross Section A-A’ Seep 2 CKD Area
Figure 4-3b Geologic Cross Section B-B’ Seep 2 CKD Area
Figure 4-3c Geologic Cross Section C-C’ Seep 2 CKD Area
Figure 4-3d Geologic Cross Section D-D’ Seep 2 CKD Area
Figure 4-3e Geologic Cross Section E-E’ Seep 2 CKD Area
Figure 4-3f Geologic Cross Section F-F’ Seep 2 CKD Area

Figure 4-3g Geologic Cross Section G-G' Seep 2 CKD Area
Figure 4-3h Geologic Cross Section H-H' Seep 2 CKD Area
Figure 4-3i Geologic Cross Section I-I' Seep 2 CKD Area
Figure 4-3j Geologic Cross Section J-J' Seep 2 CKD Area
Figure 4-4a Geologic Cross Section A-A' Seep 1 CKD Area
Figure 4-4b Geologic Cross Section B-B' Seep 1 CKD Area
Figure 4-4c Geologic Cross Section C-C' Seep 1 CKD Area
Figure 4-4d Geologic Cross Section D-D' Seep 1 CKD Area
Figure 4-4e Geologic Cross Section E-E' Seep 1 CKD Area
Figure 4-4f Geologic Cross Section F-F' Seep 1 CKD Area
Figure 4-4g Geologic Cross Section G-G' Seep 1 CKD Area
Figure 4-5 Bedrock Topography West CKD Area
Figure 4-6 Bedrock Topography Seep 2 CKD Area
Figure 4-7 Bedrock Topography Seep 1 CKD Area
Figure 4-8a Shale Contours West CKD Area
Figure 4-8b Shale Contours Seep 2 CKD Area
Figure 4-8c Shale Contours Seep 1 CKD Area
Figure 4-9 Histogram of Fracture Dips from all Areas
Figure 4-10 Idealized Fracture Depth Probability Plots
Figure 4-10a Low-Angle Fracture Depth Probability Plots for the West CKD Area
Figure 4-10b Medium-Angle Fracture Depth Probability Plots for the West CKD Area
Figure 4-10c High-Angle Fracture Depth Probability Plots for the West CKD Area
Figure 4-10d Low-Angle Fracture Depth Probability Plots for the Seep 2 CKD Area
Figure 4-10e Medium-Angle Fracture Depth Probability Plots for the Seep 2 CKD Area
Figure 4-10f High-Angle Fracture Depth Probability Plots for the Seep 2 CKD Area
Figure 4-10g Low-Angle Fracture Depth Probability Plots for the Seep 1 CKD Area
Figure 4-10h Medium-Angle Fracture Depth Probability Plots for the Seep 1 CKD Area
Figure 4-10i High-Angle Fracture Depth Probability Plots for the Seep 1 CKD Area
Figure 4-11a Bottom of CKD Contours West CKD Area
Figure 4-11b Bottom of CKD Contours Seep 2 CKD Area
Figure 4-11c Bottom of CKD Contours Seep 1 CKD Area
Figure 4-11d Top of CKD Contours West CKD Area
Figure 4-11e Top of CKD Contours Seep 2 CKD Area
Figure 4-11f Top of CKD Contours Seep 1 CKD Area

Figure 4-11g Saturated CKD West CKD Area
Figure 4-11h Saturated CKD Seep 1 CKD Area
Figure 4-12a Groundwater Elevation Contours July 10-11, 2006 West CKD Area
Figure 4-12b Groundwater Elevation Contours July 10-11, 2006 Seep 2 CKD Area
Figure 4-12c Groundwater Elevation Contours July 11-12, 2006 Seep 1 CKD Area
Figure 4-13a Groundwater Elevation Contours September 14, 2006 West CKD Area
Figure 4-13b Groundwater Elevation Contours September 14, 2006 Seep 2 CKD Area
Figure 4-13c Groundwater Elevation Contours September 14, 2006 Seep 1 CKD Area
Figure 4-14a Groundwater Elevation Contours January 3-4, 2007 West CKD Area
Figure 4-14b Groundwater Elevation Contours January 3-4, 2007 Seep 2 CKD Area
Figure 4-14c Groundwater Elevation Contours January 3-6, 2007 Seep 1 CKD Area
Figure 4-15a Groundwater Elevation Contours March 27-28, 2007 West CKD Area
Figure 4-15b Groundwater Elevation Contours March 27-28, 2007 Seep 2 CKD Area
Figure 4-15c Groundwater Elevation Contours March 27-28, 2007 Seep 1 CKD Area
Figure 4-16a Groundwater Elevation Contours July 2006 Cross Section B-B' WCKD Area
Figure 4-17a Groundwater Elevation Contours July 2006 Cross Section A-A' Seep 2 CKD Area
Figure 4-17b Groundwater Elevation Contours July 2006 Cross Section B-B' Seep 2 CKD Area
Figure 4-17c Groundwater Elevation Contours July 2006 Cross Section D-D' Seep 2 CKD Area
Figure 4-18a Groundwater Elevation Contours July 2006 Cross Section A-A' Seep 1 CKD Area
Figure 4-18b Groundwater Elevation Contours July 2006 Cross Section C-C' Seep 1 CKD Area
Figure 4-18c Groundwater Elevation Contours July 2006 Cross Section D-D' Seep 1 CKD Area
Figure 4-19a Groundwater Elevation Contours March 2007 Cross Section B-B' WCKD CKD Area
Figure 4-20a Groundwater Elevation Contours March 2007 Cross Section A-A' Seep 2 CKD Area
Figure 4-20b Groundwater Elevation Contours March 2007 Cross Section B-B' Seep 2 CKD Area
Figure 4-20c Groundwater Elevation Contours March 2007 Cross Section D-D' Seep 2 CKD Area
Figure 4-21a Groundwater Elevation Contours March 2007 Cross Section A-A' Seep 1 CKD Area
Figure 4-21b Groundwater Elevation Contours March 2007 Cross Section C-C' Seep 1 CKD Area
Figure 4-21c Groundwater Elevation Contours March 2007 Cross Section D-D' Seep 1 CKD Area
Figure 4-22a West CKD Area Comparison of Hydraulic Conductivity Estimates from Borehole Flow Logging and Packer Testing
Figure 4-22b Seep 2 CKD Area Comparison of Hydraulic Conductivity Estimates from Borehole Flow Logging and Packer Testing
Figure 4-22c Seep 1 CKD Area Comparison of Hydraulic Conductivity Estimates from Borehole Flow Logging and Packer Testing
Figure 4-23a West CKD Area Hydraulic Conductivity Distribution

Figure 4-23b Seep 2 CKD Area Hydraulic Conductivity Distribution

Figure 4-23c Seep 1 CKD Area Hydraulic Conductivity Distribution

Figure 4-24 Histogram of Hydraulic Conductivity Estimates

Figure 4-25a Relationship between Precipitation, ET, and Groundwater Levels for W1122, W1222, and W1422

Figure 4-25b Relationship between Precipitation, ET, and Groundwater Levels forW2150 and W2350

Figure 4-26a Water Level and Temperature in Lake Michigan and Groundwater Levels and Temperatures in W1117, W1317, and W1417

Figure 4-26b Water Level and Temperature in Lake Michigan and Groundwater Levels and Temperatures in W2138 and W2438

Figure 4-26c Water Level and Temperature in Lake Michigan and Groundwater Levels and Temperatures in W3116, W3216, W3316, and W3416

Figure 4-26d Water Level and Temperature in Lake Michigan and Groundwater Levels and Temperatures in W1114 and W1414

Figure 4-27 Hydrographs and Temperature Plots for W2150 and W2350

Figure 4-28a West CKD Area Net Changes between Flow Logging Stations under Ambient Conditions

Figure 4-28b West CKD Area Net Changes between Flow Logging Stations under Pumping Conditions

Figure 4-28c Seep 2 CKD Area Net Changes between Flow Logging Stations under Ambient Conditions

Figure 4-28d Seep 2 CKD Area Net Changes between Flow Logging Stations under Pumping Conditions

Figure 4-28e Seep 1 CKD Area Net Changes between Flow Logging Stations under Ambient Conditions

Figure 4-28f Seep 1 CKD Area Net Changes between Flow Logging Stations under Pumping Conditions

Figure 4-29a West CKD Area Differences between Flow Pumping and Ambient Conditions

Figure 4-29b Seep 2 CKD Area Differences between Flow Pumping and Ambient Conditions

Figure 4-29c Seep 1 CKD Area Differences between Flow Pumping and Ambient Conditions

Figure 4-30a Illustration of Observed Response to Pumping During the Packer Tests in the West CKD Area

Figure 4-30b Illustration of Observed Response to Pumping During the Packer Tests in the Seep 2 CKD Area

Figure 4-30c Illustration of Observed Response to Pumping During the Packer Tests in the Seep 1 CKD Area

Figure 4-31 Histogram of Pumping Rates from the Packer Tests

Figure 4-32 Response of Water Levels in the W2x50 Well Nest to a Single Precipitation Event

Figure 4-33a Portions of the Hydrographs from W1x30 with Construction Details for this Nest and Petoskey Well 3

Figure 4-33b Portions of the Hydrographs from W2x44 with Construction Details for this Nest and Petoskey Well 5

Figure 4-33c Portions of the Hydrographs from W3x20 with Construction Details for this Nest and Petoskey Well 5

Figure 4-34a Potential Conduits in the West CKD Area

Figure 4-34b Potential Conduits in the Seep 2 CKD Area

Figure 4-34c Potential Conduits in the Seep 1 CKD Area

Figure 4-35a Projected Potential Conduits in the West CKD Area

Figure 4-35b Projected Potential Conduits in the Seep 2 CKD Area

Figure 4-35c Projected Potential Conduits in the Seep 1 CKD Area

Figure 5-1a Water Quality Data Summary Chloride Exceedances West CKD Area

Figure 5-1b Water Quality Data Summary Chloride Exceedances Seep 2 CKD Area

Figure 5-1c Water Quality Data Summary Chloride Exceedances Seep 1 CKD Area

Figure 5-2a Water Quality Data Summary Nitrogen, Ammonia as N Exceedances West CKD Area

Figure 5-2b Water Quality Data Summary Nitrogen, Ammonia as N Exceedances Seep 2 CKD Area

Figure 5-2c Water Quality Data Summary Nitrogen, Ammonia as N Exceedances Seep 1 CKD Area

Figure 5-3a Water Quality Data Summary Total Dissolved Solids Exceedances West CKD Area

Figure 5-3b Water Quality Data Summary Total Dissolved Solids Exceedances Seep 2 CKD Area

Figure 5-3c Water Quality Data Summary Total Dissolved Solids Exceedances Seep 1 CKD Area

Figure 5-4a Water Quality Data Summary Sulfate Exceedances West CKD Area

Figure 5-4b Water Quality Data Summary Sulfate Exceedances Seep 2 CKD Area

Figure 5-4c Water Quality Data Summary Sulfate Exceedances Seep 1 CKD Area

Figure 5-5a Water Quality Data Summary pH Exceedances West CKD Area

Figure 5-5b Water Quality Data Summary pH Exceedances Seep 2 CKD Area

Figure 5-5c Water Quality Data Summary pH Exceedances Seep 1 CKD Area

Figure 5-6a Water Quality Data Summary Total Phosphorus Exceedances West CKD Area

Figure 5-6b Water Quality Data Summary Total Phosphorus Exceedances Seep 2 CKD Area

Figure 5-6c Water Quality Data Summary Total Phosphorus Exceedances Seep 1 CKD Area

Figure 5-7a Water Quality Data Summary Aluminum Exceedances West CKD Area

Figure 5-7b Water Quality Data Summary Aluminum Exceedances Seep 2 CKD Area

Figure 5-7c Water Quality Data Summary Aluminum Exceedances Seep 1 CKD Area

Figure 5-8a Water Quality Data Summary Arsenic Exceedances West CKD Area

Figure 5-8b Water Quality Data Summary Arsenic Exceedances Seep 2 CKD Area

Figure 5-8c Water Quality Data Summary Arsenic Exceedances Seep 1 CKD Area

Figure 5-9a Water Quality Data Summary Chromium Exceedances West CKD Area
Figure 5-9b Water Quality Data Summary Chromium Exceedances Seep 2 CKD Area
Figure 5-9c Water Quality Data Summary Chromium Exceedances Seep 1 CKD Area
Figure 5-10a Water Quality Data Summary Iron Exceedances West CKD Area
Figure 5-10b Water Quality Data Summary Iron Exceedances Seep 2 CKD Area
Figure 5-10c Water Quality Data Summary Iron Exceedances Seep 1 CKD Area
Figure 5-11a Water Quality Data Summary Lead Exceedances West CKD Area
Figure 5-11b Water Quality Data Summary Lead Exceedances Seep 2 CKD Area
Figure 5-11c Water Quality Data Summary Lead Exceedances Seep 1 CKD Area
Figure 5-12a Water Quality Data Summary Manganese Exceedances West CKD Area
Figure 5-12b Water Quality Data Summary Manganese Exceedances Seep 2 CKD Area
Figure 5-12c Water Quality Data Summary Manganese Exceedances Seep 1 CKD Area
Figure 5-13a Water Quality Data Summary Mercury Exceedances West CKD Area
Figure 5-13b Water Quality Data Summary Mercury Exceedances Seep 2 CKD Area
Figure 5-13c Water Quality Data Summary Mercury Exceedances Seep 1 CKD Area
Figure 5-14a Water Quality Data Summary Nickel Exceedances West CKD Area
Figure 5-14b Water Quality Data Summary Nickel Exceedances Seep 2 CKD Area
Figure 5-14c Water Quality Data Summary Nickel Exceedances Seep 1 CKD Area
Figure 5-15a Water Quality Data Summary Selenium Exceedances West CKD Area
Figure 5-15b Water Quality Data Summary Selenium Exceedances Seep 2 CKD Area
Figure 5-15c Water Quality Data Summary Selenium Exceedances Seep 1 CKD Area
Figure 5-16a Water Quality Data Summary Silver Exceedances West CKD Area
Figure 5-16b Water Quality Data Summary Silver Exceedances Seep 2 CKD Area
Figure 5-16c Water Quality Data Summary Silver Exceedances Seep 1 CKD Area
Figure 5-17a Water Quality Data Summary Sodium Exceedances West CKD Area
Figure 5-17b Water Quality Data Summary Sodium Exceedances Seep 2 CKD Area
Figure 5-17c Water Quality Data Summary Sodium Exceedances Seep 1 CKD Area
Figure 5-18a Water Quality Data Summary Vanadium Exceedances West CKD Area
Figure 5-18b Water Quality Data Summary Vanadium Exceedances Seep 2 CKD Area
Figure 5-18c Water Quality Data Summary Vanadium Exceedances Seep 1 CKD Area

Figure 6-1 Dissolution of Fatty Acids
Figure 6-2 Sample Stiff Diagram
Figure 6-3 Attenuation of Leachate pH by Groundwater

Figure 6-4 Attenuation of Leachate Mercury by Groundwater
Figure 6-5a Geologic Cross Section A-A' West CKD Area Water Quality Data
Figure 6-5b Geologic Cross Section B-B' West CKD Area Water Quality Data
Figure 6-5c Geologic Cross Section C-C’ West CKD Area Water Quality Data
Figure 6-5d Geologic Cross Section D-D' West CKD Area Water Quality Data
Figure 6-6a Geologic Cross Section A-A' Seep 2 CKD Area Water Quality Data
Figure 6-6b Geologic Cross Section B-B' Seep 2 CKD Area Water Quality Data
Figure 6-6c Geologic Cross Section C-C' Seep 2 CKD Area Water Quality Data
Figure 6-6d Geologic Cross Section D-D' Seep 2 CKD Area Water Quality Data
Figure 6-6e Geologic Cross Section E-E' Seep 2 CKD Area Water Quality Data
Figure 6-6f Geologic Cross Section F-F' Seep 2 CKD Area Water Quality Data
Figure 6-6g Geologic Cross Section I-I' Seep 2 CKD Area Water Quality Data
Figure 6-6h Geologic Cross Section J-J’ Seep 2 CKD Area Water Quality Data
Figure 6-7a Geologic Cross Section A-A' Seep 1 CKD Area Water Quality Data
Figure 6-7b Geologic Cross Section B-B' Seep 1 CKD Area Water Quality Data
Figure 6-7c Geologic Cross Section C-C' Seep 1 CKD Area Water Quality Data
Figure 6-7d Geologic Cross Section D-D' Seep 1 CKD Area Water Quality Data
Figure 6-7e Geologic Cross Section E-E' Seep 1 CKD Area Water Quality Data

List of Appendices

Appendix 1-1	U.S. EPA Requests and Approvals of Modifications
Appendix 1-2	Historical Photos, Sanborn Maps and Construction Drawings
Appendix 1-2a	Development Utility Construction Drawings
Appendix 1-2b	Golf Course Features and Utilities
Appendix 1-2c	Historical Photos and Sanborn Maps
Appendix 1-2d	Golf Course Surface Drainage
Appendix 1-3	Previous Investigations
Appendix 2-1	Targeted Shoreline Survey Data Summary
Appendix 2-1a	Spring 2005 Targeted Shoreline Survey Data Summary
Appendix 2-1b	Fall 2005 Targeted Shoreline Survey Data Summary
Appendix 2-1c	Spring 2006 Targeted Shoreline Survey Data Summary
Appendix 2-2	Overflight Photographs
Appendix 2-2a	West CKD Area Overflight Photographs
Appendix 2-2b	Seep 2 CKD Area Overflight Photographs
Appendix 2-2c	Seep 1 CKD Area Overflight Photographs
Appendix 2-3	ILRS Record Drawings
Appendix 2-4	ILRS Piezometer and Valve Box Construction Data
Appendix 2-4a	West CKD Piezometer and Valve Box Construction Data
Appendix 2-4b	Pine Court Piezometer and Valve Box Construction Data
Appendix 2-4c	Guard Rail Piezometer and Valve Box Construction Data
Appendix 2-4d	Seep 2 CKD Area Piezometer and Valve Box Construction Data
Appendix 2-4e	Seep 1 CKD Area Piezometer and Valve Box Construction Data
Appendix 2-5	Pine Court Pilot Carbon Dioxide Injection System
Appendix 2-5a	Pine Court Pilot Carbon Dioxide Injection System, Technical Memorandum
Appendix 2-5b	Pine Court Pilot Carbon Dioxide Troll 9500 Raw Data
Appendix 2-6	Leachate Chemical Equilibrium Modeling, Technical Memorandum
Appendix 2-7	Lakeshore Operational Monitoring Results

Appendix 2-8	Effectiveness Monitoring Results
Appendix 2-8a	2005 Effectiveness Monitoring Data and Figures
Appendix 2-8b	2006 Effectiveness Monitoring Data and Figures
Appendix 2-8c	2007 Effectiveness Monitoring Data and Figures
Appendix 2-8d	2008 Effectiveness Monitoring Data and Figures
Appendix 2-8e	2009 Effectiveness Monitoring Data and Figures
Appendix 3-1	Aerial Thermometry Survey Memorandum
Appendix 3-2	Climate and Weather Station Data
Appendix 3-2a	Climate and Weather Station Data
Appendix 3-2b	Raw Weather Data
Appendix 3-3	Bay Harbor Lake Assessment Report
Appendix 3-4	Boring Logs
Appendix 3-4a	West CKD Area Boring Logs
Appendix 3-4b	Seep 2 CKD Area Boring Logs
Appendix 3-4c	Seep 1 CKD Area Boring Logs
Appendix 3-5	Monitoring Well Logs and Abandonment Record
Appendix 3-5a	West CKD Area Monitoring Well Logs
Appendix 3-5b	Seep 2 CKD Area Monitoring Well Logs
Appendix 3-5c	Seep 1 CKD Area Monitoring Well Logs
Appendix 3-5d	Well Abandonment Records
Appendix 3-6	Surface Geophysical Data
Appendix 3-6a	2004 Surface Geophysical Data
Appendix 3-6b	2004 Surface Geophysical Report
Appendix 3-6c	May 2007 Surface Geophysical Results and Procedures
Appendix 3-6d	July 2007 Surface Geophysical Results and Procedures
Appendix 3-7	RESPEC Engineering Laboratory Report
Appendix 3-8	Well Development Logs
Appendix 3-8a	West CKD Area Well Development Logs
Appendix 3-8b	Seep 2 CKD Area Well Development Logs
Appendix 3-8c	Seep 1 CKD Area Well Development Logs
Appendix 3-9	TriMatrix-Barr Field Logs for Monitoring Well Sampling
Appendix 3-9a	West CKD Area TriMatrix-Barr Field Logs for Monitoring Well Sampling

Appendix 3-9b	Seep 2 CKD Area TriMatrix-Barr Field Logs for Monitoring Well Sampling
Appendix 3-9c	Seep 1 CKD Area TriMatrix-Barr Field Logs for Monitoring Well Sampling
Appendix 3-10	Aquifer pH Profiling Graphs
Appendix 3-10a	West CKD Area Aquifer pH Profiling Graphs
Appendix 3-10b	Seep 2 CKD Area Aquifer pH Profiling Graphs
Appendix 3-10c	Seep 1 CKD Area Aquifer pH Profiling Graphs
Appendix 3-11	Ecological Investigation
Appendix 3-12	Release Management
Appendix 3-12a	Environmental Release Record Summary
Appendix 3-12b	Hydraulic Fluid Spill Analytical Data
Appendix 4-1	Lake Elevation
Appendix 4-1a	Stilling Well Data (former Figure 4-6 Stilling Well and Staff Gage Lake Elevation should be included here with no figure number)
Appendix 4-1b	Water Elevation Comparison
Appendix 4-1c	Ice Cover Discussion
Appendix 4-2	Downhole Geophysical Logging Data
Appendix 4-2a	Downhole Geophysical Logging Century Data
Appendix 4-2b	Downhole Geophysical Logging Norcal Discussion on Century Data
Appendix 4-2c	Downhole Geophysical Logging Norcal Data – Supplemental Investigation
Appendix 4-2d	Downhole Geophysical Logging Norcal Discussion – Supplemental Investigation
Appendix 4-3	Soil Engineering Testing Laboratory Reports
Appendix 4-4	Water Elevation Summaries and Charts
Appendix 4-4a	Water Level Meter Data
Appendix 4-4b	MiniTroll Data
Appendix 4-5	Borehole Flow Zone Evaluation Summaries
Appendix 4-5a	West CKD Area Borehole Flow Zone Evaluation Summaries
Appendix 4-5b	Seep 2 CKD Area Borehole Flow Zone Evaluation Summaries
Appendix 4-5c	Seep 1 CKD Area Borehole Flow Zone Evaluation Summaries
Appendix 4-6	Aquifer Test Methods and Results
Appendix 4-6a	Aquifer Test Analysis Methods
Appendix 4-6b	Packer Test AQTESOLV Print-outs

Appendix 4-6c Slug Testing AQTESOLV Print-outs
Appendix 4-6d Pumping Tests at Well Nests AQTESOLV Print-outs

Appendix 5-1 Analytical Laboratory Reports
Appendix 5-1a Surface Water and Creek Analytical Data Reports
Appendix 5-1b Groundwater Analytical Data Reports
Appendix 5-1c Borehole GW Analytical Data Reports
Appendix 5-1d Soils Analytical Data Reports
Appendix 5-1e Untreated Frac Tanks Analytical Data Reports

Appendix 5-2 Creek Data

Appendix 6-1 Stiff Diagrams
Appendix 6-1a West CKD Area Stiff Diagrams
Appendix 6-1b Seep 2 CKD Area Stiff Diagrams
Appendix 6-1c Seep 1 CKD Area Stiff Diagrams

Executive Summary

This Removal Action/Remedial Investigation (RI) Report has been prepared on behalf of CMS Land Company and CMS Capital, LLC to describe the investigation activities conducted at the portions of the Little Traverse Bay Cement Kiln Dust (CKD) Release Site identified as the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area (referred to collectively as the Site for this RI Report). The RI activities were conducted in accordance with the Administrative Order on Consent for Removal Action (AOC) (Docket No. VW-05-C-810, February 22, 2005). Additionally, a summary is included of expedited removal actions and interim response activities for the Site which began in April 2005.

The LTB CKD Release Site is located along five miles of shoreline on Little Traverse Bay of Lake Michigan, approximately five miles west of the City of Petoskey, Michigan.

The Site RI activities were planned to generate the data necessary to complete the Site characterization and evaluate final remedy alternatives for addressing current and potential threats to public health, welfare and the environment from CKD waste material. The RI activities presented in this report were conducted between August 17, 2005 and May 31, 2009. The RI activities at the Site built upon the results of previous investigations, and focused on data collection via borehole and well placement, down-hole geophysical methods, and aquifer and surface water testing, sampling, and analysis.

Analytical data for Site samples were evaluated against potentially applicable criteria to identify potential Site contaminants of concern (COCs). The extent of CKD at the Site and the extent of CKD leachate impacts in Little Traverse Bay have been defined as a result of the RI. The mechanisms of migration from the CKD Areas to Little Traverse Bay have also been defined allowing CMS to evaluate and select appropriate remedies for the Site. The data collected have allowed CMS to identify preferential groundwater pathways and to determine aquifer characteristics in order to evaluate the feasibility and engineering requirements to successfully design and implement final remedial systems. This evaluation is included in the Alternatives Evaluation Report.

Potential COCs may be released from the CKD piles through leaching (dissolution) by infiltration or groundwater. Particulates carried along as solids, suspended sediment in runoff, or airborne particulates are not considered a significant route of migration for the potential COCs under current Site conditions as the CKD is being effectively isolated by the soil barrier that was placed over it during development of the Site. Surface water investigations of Lake Michigan indicate that surface

water is not a source of significant exposure to potential COCs other than pH. The interim response measures implemented at the Site are effectively mitigating the release of potential COCs to the lake. The results of remedial investigations for the two creeks within the Site indicate that they are not impacted by the CKD.

All of the potential Site COCs identified are inorganic and are not subject to biodegradation with the possible exception of ammonia. Many of the COCs are subject to changes in oxidative states or may react in precipitation or adsorption reactions. Results of chemical analyses suggest that leachate is variously attenuated by dilution, precipitation, adsorption, and neutralization by groundwater acidity. Site analytical data indicate a correlation between mercury and total organic carbon concentrations within leachate.

Analysis of data from the RI indicates that the predominant migration mechanism is the movement (advection) of leachate/groundwater in areas of downward or lateral gradients. Elevated pH levels in groundwater and at the Lake Michigan beach at the Site are caused by leachate generated from within the CKD piles. Leachate can be generated by infiltration of rainfall/melted snow or irrigation water into the CKD piles or through contact with groundwater within the CKD piles. There are several different possible migration pathways for leachate to follow to the beach. The CKD piles are located on top of differing configurations of soil, limestone, and/or shale bedrock and are subject to varying perched and regional water table elevations. Migration may occur through interflow, and/or migration through perched or unperched groundwater through CKD, soil, or bedrock. Both density-driven migration and diffusion will be countered by dilution and upward groundwater flows.

Prior to the installation of the interim systems, elevated pH was present in near-shore areas that may have been high enough to irritate skin upon exposure. The interim systems have been extremely effective at reducing the pH in surface water to less than 9.0 standard units (s.u.), except for minor, intermittent exceedances typically less than 9.6 s.u.

1.0 Introduction

1.1 Purpose of Report

This Removal Action/Remedial Investigation (RI) Report has been prepared on behalf of CMS Land Company and CMS Capital, LLC (referred to collectively as CMS) to describe the investigation activities conducted in accordance with the Administrative Order on Consent for Removal Action (AOC), Little Traverse Bay Cement Kiln Dust (CKD) Release Site (LTB CKD Release Site) (Docket No. VW-05-C-810, February 22, 2005) at the portions of the LTB CKD Release Site identified as the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area (referred to collectively as the Site for this RI Report). The Removal Action Investigation/Remedial Investigation Report for the East CKD Area portion of the LTB CKD Release Site was originally published on February 15, 2006 (Rev. 0.0), revised based on regulator comments and published again on August 17, 2006 (Rev. 1.0), and then updated on June 4, 2008 (Rev. 2.0) (Barr, 2008e).

The Site RI activities were planned to generate the data necessary to complete the Site characterization and evaluate final remedy alternatives for addressing current and potential threats to public health, welfare and the environment from CKD waste material.

The overall Site characterization objectives of the RI were to:

> "*Evaluate all other areas along the lakeshore of the Site with pathways for releases to surface waters, including Lake Michigan, with the objective of identifying additional CKD leachate release areas which may not have been identified, but may be causing a threat of direct contact or threat of release of high pH releases to surface water, including Lake Michigan.*"
>
> and
>
> *"Investigate the nature and extent of hazardous substances, pollutants or contaminants at the Site to determine the nature and extent of current and potential threats to public health, welfare or the environment from CKD Waste Material…."* (AOC, 2005)

CMS has agreed to conduct activities required by the AOC. This RI Report provides a description of, and summarizes the results of, the investigation activities conducted at the Site as required by the AOC. Recommended investigation activities for the Site were presented as part of the July 2005 Final Approved Removal Action Work Plan (Work Plan), LTB CKD Release Site, Emmet County, Michigan (Barr, 2005c). Recommended expedited removal actions and interim response (IR) activities for the Site were also presented in the Work Plan.

An initial version of the Work Plan (Revision 0.0) was submitted to the U.S. EPA on March 3, 2005. In accordance with informal verbal comments received from the U.S. EPA on March 21, 2005 and the "Interim Response/Remedial Investigation/Feasibility Study Outline" provided to CMS on March 30, 2005, the Work Plan was revised (Revision 1.0, April 4, 2005). Additional verbal comments were provided to CMS on April 12, April 20, and May 6, 2005 and the Work Plan was revised (Revision 2.0). The U.S. EPA provided written comments to Revision 2.0 of the Work Plan in correspondence dated June 14 and June 16, 2005. The Work Plan was revised based on U.S. EPA comments and Section 4.0 of the Work Plan was re-submitted to the U.S. EPA on June 23, 2005 and the balance of the Work Plan was re-submitted to the U.S. EPA on July 14, 2005. Section 4.0 of the Work Plan was approved with comments in an U.S. EPA letter dated July 11, 2005 and the balance of the Work Plan was approved with comments on July 28, 2005. All letters documenting modification requests and approvals are included in Appendix 1-1.

Additionally, this RI Report provides a description and results summary of the expedited removal actions, IR, and augmentation activities conducted prior to May 31, 2009. Recommended augmentation activities for the Site were presented as the Seep 2 CKD Area Augmentation Pilot System Design Report Targeted Leachate Collection, April 29, 2008 (Barr, 2008a), the Seep 1 CKD Area Augmentation Conceptual Design Report Barrier System, May 1, 2008 (Barr, 2008b), the West CKD Area Augmentation Final Design, September 15, 2008 (Barr 2008i), and the Pine Court Area Augmentation – ILRS Modification Work Plan, April 10, 2009 (Barr, 2009b).

The LTB CKD Release Site location is shown on Figure 1-1. Additionally, Figure 1-1 shows the location of the West CKD Area, Seep 1 CKD Area, and Seep 2 CKD Area relative to the entire LTB CKD Release Site. Figure 1-2 shows the Site layout which includes the following three areas: West CKD Area, Seep 1 CKD Area, and Seep 2 CKD Area.

1.2 Investigation Completeness

The Site RI investigation activities met the objective of generating the data necessary to complete the Site characterization in order to evaluate final remedy alternatives to address current and potential threats to public health, welfare and the environment from CKD waste material. The evaluation of final remedy alternatives will be presented as the Alternatives Evaluation Report.

The extent of CKD at the Site and the extent of CKD leachate impacts in Little Traverse Bay have been defined. The mechanisms of migration from the CKD Areas to Little Traverse Bay have also

been defined allowing CMS to evaluate the feasibility and engineering requirements to successfully design and implement final remedial systems.

1.3 Site Background

1.3.1 Site Location

The LTB CKD Release Site is located along five miles of shoreline on Little Traverse Bay of Lake Michigan (Figure 1-1). The LTB CKD Release Site is approximately five miles west of the City of Petoskey, and located in Resort Township, Emmet County, Michigan (Township 34N, Range 6W, Sections 2 through 10). The West CKD Area, Seep 2 CKD Area and Seep 1 CKD Area (Site) are located in Sections 8 and 9.

1.3.2 CKD and Site Description

CKD is a by-product of Portland cement production. In the United States, the manufacture of Portland cement typically involves roasting a finely ground proportional mix of raw materials in a rotary kiln (U.S. Dept. of the Interior, 2004). Water contacting CKD typically exhibits the following downgradient groundwater characteristics: elevated pH with respect to background, high specific conductivity, high total dissolved solids and sulfate, and elevated concentrations of arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, nickel, sodium, and selenium (U.S. EPA, 1998). Water contacting CKD-containing fill deposits resulted in downgradient CKD leachate plumes with these characteristics at 13 CKD disposal sites examined by the U.S. EPA (U.S. EPA, 1998).

The Site is currently a multi-use area with mixed residential, commercial, open space, and recreational (golf course) land uses (Boyne Golf, 2004) and is currently owned by a combination of private property owners (primarily residences or open lots), CMS, Bay Harbor Golf Club, Inc. (golf course), and Bay Harbor Company (roads, commercial, and undeveloped/open space).

Existing available information regarding public utilities throughout the Site are shown on construction drawings provided by Bay Harbor Development included in Appendix 1-2a. Underground public utilities within the Site include watermain, sanitary sewer, storm sewer, natural gas, telephone, and electric. Most of the utilities are located within the residential properties and roadways, and are outside of CKD limits. In addition to the public service utilities a system of subsurface drains exists beneath the Bay Harbor golf course. These drains were installed at the time

of the golf course construction to prevent ponding of surface water runoff. Available information regarding drain locations are shown in Appendix 1-2b. Available information regarding golf course surface drainage is summarized in Appendix 1-2d. Surface runoff collected in the drain system ultimately outfalls to Lake Michigan at several locations throughout the Site. Additionally, the golf course has a subsurface water distribution system that supplies water to a sprinkler irrigation system which services the entire golf course (Appendix 1-2b). The pump intake for the irrigation system is located in Bay Harbor Lake.

1.3.2.1 West CKD Area

The West CKD Area includes the pile of CKD and the undeveloped rocky beach area north of the pile as shown on Figure 1-2. Based on boring information and the results of an electromagnetic survey the West CKD pile covers an area of about 5.4 acres and contains approximately 100,000 cubic yards of CKD. The West CKD Area is currently owned by Bay Harbor Golf Club, Inc. (which owns and operates a golf course on the Site). A golf course fairway and rough areas have been constructed over the CKD pile. The West CKD Area is bounded by Lake Michigan and undeveloped residential lots on the north, developed and undeveloped residential properties to the west and south, and the golf course club house to the east. West-unnamed creek flows from U.S. Highway 31 north through a constructed pond (Pond #1) located south of the West CKD Area. Pond #1 drains into Lake Michigan along the east side of the West CKD Area (Figure 1-2).

Existing public utilities near the West CKD Area include water main, sanitary sewer, storm sewer, natural gas, telephone, and electric service (Appendix 1-2a). Most utilities are located within residential properties and roadways to the south and west of the West CKD pile footprint.

1.3.2.2 Seep 2 CKD Area

The Seep 2 CKD Area includes the pile of CKD and the developed and undeveloped rocky beach area north of the pile as shown on Figure 1-2. The Seep 2 CKD Area also encompasses the Pine Court and the Guard Rail Seep areas. The Seep 2 CKD pile covers an area of about 34.8 acres and contains approximately 1.1 million cubic yards of CKD. The area is currently owned by Bay Harbor Golf Club, Inc, private property owners, CMS, and Bay Harbor Company. Golf course fairways and rough areas have been constructed over the CKD pile. The Seep 2 CKD Area is bounded by Lake Michigan and undeveloped and developed residential lots on the north, developed and undeveloped residential properties to the west, east, and south, and Coastal Ridge Drive and the Seep 1 CKD Area to the east. Wetland Area #1 is also located to the southwest of the Seep 2 CKD Area (Figure 1-2).

Existing public utilities in the Seep 2 CKD Area include water main, sanitary sewer, storm sewer, natural gas, telephone, and electric service (Appendix 1-2a). Most of these utilities are located beneath Coastal Ridge Drive to the north and east of the Seep 2 CKD Area pile and beneath Coastal Woods Court to the south of the Seep 2 CKD Area pile.

An interceptor drain was constructed on the southeast side of the Seep 2 CKD Area pile as part of the golf course construction. The drain was constructed to collect groundwater inflow upgradient of the CKD pile (Figure 1-2).

A leachate collection edge drain was constructed in 1997 in the Seep 2 CKD Area (Appendix 1-2c). The Edge Drain runs approximately 1200 feet along Coastal Ridge Drive in the northeast portion of the Seep 2 CKD Area pile. The Edge Drain is constructed of 8-inch diameter perforated polyvinyl chloride (PVC) pipe and lies at a depth of 4 to 17 feet below the ground surface. Leachate collected from the Edge Drain is pumped through a 2-inch PVC force main to the Bay Harbor Pre-Treatment Plant (Treatment Plant) located outside of the Seep 2 CKD Area (Barr, 2005e).

Pine Court Seep Area

The Pine Court Seep Area consists of the rocky beach area located north of several residential properties (lots 3-6) located along Pine Ridge Court as shown on Figure 1-2. The Pine Court Seep Area is bounded by Lake Michigan on the north, privately owned undeveloped properties to the east and west, and bounded to the south by residential properties and, across Coastal Ridge Drive, golf course fairway and rough areas. This area is located adjacent to the area identified as the Seep 2 CKD Area and will be considered as part of the Seep 2 CKD Area for investigation purposes.

Guard Rail Seep Area

The Guard Rail Seep Area consists of the rocky beach area located north of Coastal Ridge Drive as shown on Figure 1-2. The private roadway adjacent to the Guard Rail Seep Area is owned by Bay Harbor Company. The Guard Rail Seep Area is bounded by Lake Michigan on the north and undeveloped properties to the east and west. The Guard Rail Seep Area is bounded to the south by Coastal Ridge Drive and the Seep 2 CKD pile. This area is located within the area identified as the Seep 2 CKD Area and will be considered as part of the Seep 2 CKD Area for investigation purposes.

1.3.2.3 Seep 1 CKD Area

The Seep 1 CKD Area includes the pile of CKD and the undeveloped rocky beach area north of the pile as shown on Figure 1-2. Based on boring information and the results of an electromagnetic survey the Seep 1 CKD Area pile covers an area of about 15.5 acres and contains approximately 550,000 cubic yards of CKD. The Seep 1 CKD Area is currently owned by Bay Harbor Golf Club, Inc. (golf course), CMS, and private property owners. Golf course fairway and rough areas have been constructed over the CKD pile. The Seep 1 CKD Area is bounded by Lake Michigan on the north and by developed and undeveloped residential properties to the west, east, and south. East-unnamed creek #1 borders the Seep 1 CKD Area on the east and discharges into Lake Michigan (Figure 1-2).

Existing public utilities near the Seep 1 CKD Area include water main, sanitary sewer, storm sewer, natural gas, telephone, and electric service (Appendix 1-2a). These utilities are located within residential properties and roadways to the south, west, and east of the Seep 1 CKD Area.

The Bay Harbor golf course irrigation system raw water intake is located east of the Seep 1 CKD Area in Bay Harbor Lake. Water is pumped from the intake in Bay Harbor Lake to a pump house located on the eastern end of the Seep 1 CKD pile. From the pump house water is reportedly distributed through a sprinkler irrigation system to the golf course tee boxes, fairways, and greens.

1.3.3 Site History

The Site's historical land use was summarized based upon aerial photographs, geologic guidebooks, historical topographic maps, and previous construction and investigation reports. Previously the majority of the Site was designated for industrial use and included mining operations and cement production. The first evidence of industry at the Site was quarries documented in 1902. No information related to the Site use is available prior to this date. The Work Plan provides a more detailed account of property ownership within the Site from 1904 to present (Barr, 2005c). Copies of the aerial photographs reviewed (EDR, 2004a) are included in Appendix 1-2c. Copies of the Sanborn Fire Insurance Maps (EDR, 2004b) are included in Appendix 1-2c.

The dominant features associated with the historical property use include a former cement plant, shale quarry, central limestone quarry, eastern limestone quarry, and three separate CKD piles as shown on Figure 1-3. CKD was stockpiled on the Site from approximately 1921 to 1980 (NTH, 1994). The CKD piles' approximate boundaries are shown on Figure 1-2.

1.3.3.1 West CKD Area

The earliest historical record of mining operations near the West CKD Area is the Bell Quarry documented in 1930 (Kesling, 1974). The Bell Quarry was at the location of the shale quarry shown on Figure 1-3, southwest of the current West CKD pile. The first aerial documentation of mining operations in the West CKD Area is an aerial photograph from 1965 (ERI, 2005). The 1965 photograph shows the former Bell Quarry, haul roads, and an overburden pile to the north adjacent to Lake Michigan. The aerial photograph from 1973 shows the first evidence of the West CKD pile in the north-east portion of Section 8. Based on aerial photographs, mining operations in the West CKD Area and surrounding areas appears to undergo expansion through 1981 (EDR, 2004a; ERI, 2005).

1.3.3.2 Seep 2 CKD Area

The earliest historical record of mining operations in the Seep 2 CKD Area is described in the 1974 Kesling report, which includes a description of quarries observed in 1902 along Little Traverse Bay (Kesling, 1974). The report listed the Bay Shore Lime Company Quarry 1 located west of the current Seep 2 CKD Area as shown on Figure 1-3. It does not appear that this quarry was active at the time of the 1938 aerial photograph. No further information was readily available on this quarry's operational history.

The first aerial documentation of mining operations within the Seep 2 CKD Area is evident in the aerial photograph from 1965. This photograph shows a haul road along the southern portion of the current CKD pile and limited operations directly within the Seep 2 CKD Area. The aerial photograph from 1973 shows an increase in mining operations and the first evidence of the Seep 2 CKD pile in the northern portion of Section 9. Based on aerial photographs, mining operations in the Seep 2 CKD Area and surrounding areas appears to undergo expansion through 1981 (EDR, 2004a; ERI, 2005).

1.3.3.3 Seep 1 CKD Area

The earliest available record of mining operations near the Seep 1 CKD Area is the Rose/W.E. Smith Quarry first observed in 1902 (Kesling, 1974). Observations made in 1974 describe the quarry as being covered in spoil piles making its approximate location near the Seep 1 CKD Area (Figure 1-3). No further information was readily available on this quarry's location or operational history. The first aerial photograph with evidence of mining operations directly within the Seep 1 CKD Area is from 1952 (ERI, 2005). This photograph shows an area with no vegetation just west of the central limestone quarry lying adjacent to the current Seep 1 CKD pile. This area is connected to the central quarry by a haul road and is labeled as "overburden from the limestone quarry" in published

environmental reports (Johnson, 1988). This area is also labeled as a gravel pit in a historical topographic map from 1958 (USGS, 1958). The Seep 1 CKD pile first becomes evident in the 1965 aerial photograph and shows significant expansion in the 1973 aerial photograph (ERI, 2005). CKD was likely piled in the Seep 1 CKD Area until approximately 1980.

Aerial photographs from 1938 show evidence of mining operations east of the Seep 1 CKD Area in the central limestone quarry. Additionally, the 1938 photograph shows the former cement manufacturing plant buildings' locations. Based on aerial photographs these were the only structures located on the Site during the plant's operational phase. The central limestone quarry is a dominant feature on aerial photographs and appears to expand from 1938 through the 1980s (EDR, 2004a; ERI, 2005). The quarry was later transformed into what is currently Bay Harbor Lake. The cement plant was operational until approximately 1980. The plant's buildings were later demolished as part of Bay Harbor Development construction (Barr, 2005c).

1.3.4 Previous Investigations

All pH monitoring data discussed below and in subsequent sections of this RI report are recorded in standard pH units (s.u.). For ease of communication, the s.u. labels are omitted.

1.3.4.1 1995 Hydrogeologic Investigation

During January 1995 to April 1995, NTH Consultants, Ltd. (NTH) conducted a hydrogeologic investigation at the Bay Harbor Development. The purpose of the investigation was to evaluate hydrogeologic conditions and monitor groundwater quality in the area of the "central-western" CKD pile and associated seep (the area currently defined as the Seep 2 CKD Area). A total of 21 test pits and eight test borings were advanced to characterize subsurface conditions and allow collection of groundwater samples. The approximate locations of these test pits, test borings, and monitoring wells are shown on Appendix 1-3 Figure 1a, Appendix 1-3 Figure 1b, and Appendix 1-3 Figure 1c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Table 1 of Appendix 1-3 summarizes the soils observed in the test pits and test borings during this investigation. The locations of the NTH wells are also shown on Figure 1-3.

The test pits were excavated to depths ranging from 1 foot to 16.3 feet below ground surface. During excavation, soil conditions were logged by a NTH field geologist. Field measurements of pH were performed in selected test pits where groundwater was encountered. Measurements of pH ranged from 8.0 at TP-2 to 10.2 at TP-1. Test borings were advanced to depths ranging from 21 feet to

56 feet below ground surface and were completed with monitoring wells. Five wells (OW-1 through OW-5) were installed to monitor the shallow portion of the bedrock aquifer. Three wells (OW-1AR, OW-2A, and OW-3A) were installed to monitor groundwater quality in the deeper portions of the bedrock aquifer. Static water levels at the well locations were measured by NTH personnel on two occasions following well installation. Based on these water level measurements, groundwater flow was interpreted to be towards the north-northeast to Lake Michigan. NTH collected one round of groundwater samples from the monitoring wells. The samples were submitted for laboratory analysis of pH, total dissolved solids (TDS), and various metals. Based on the results of groundwater sampling, NTH concluded that the extent of CKD-impacted groundwater was limited to a localized area on the northeast side of the "central-western" CKD pile.

The data were submitted to and reviewed by MDEQ, and the parties agreed to install a collection line as negotiated in the Administrative Agreement and Covenant Not to Sue (AA/CNTS) entered into between CMS, MDEQ and the State of Michigan (AA/CNTS, July 11, 1994).

1.3.4.2 Historical Seep 2 Collection Drain Construction and Operation

In response to the findings of the hydrogeologic investigation and the terms of the AA/CNTS, a drain system ("Edge Drain") was installed near the base of the Seep 2 CKD Area pile in 1997 to intercept seep water before it entered Lake Michigan. The collection drain runs approximately 1,200 feet along Coastal Ridge Drive. It is constructed of an 8-inch diameter, perforated, rigid PVC pipe. The pipe is surrounded by 24 inches of drain stone and is wrapped in a geotextile cloth. The depth of the pipe varies from approximately four feet at the western end to 17 at the deepest point. A heavy plastic liner was installed at the bottom and on the Lake Michigan side of the trench. Collected leachate flowed to a sump (currently called the lower lift station), where it was pumped through a 2-inch PVC force main to the City of Petoskey sewer system.

1.3.4.3 Treatment Plant Construction and Operation

In 2003 CMS contractors designed and constructed the Treatment Plant to adjust the pH of the CKD leachate collected at the Edge Drain. The original force main was disconnected from the municipal sewer and extended to the Treatment Plant location via the "upper lift station". The pH of the leachate is adjusted by using concentrated sulfuric acid to neutralize the leachate to acceptable pH levels. Three pH probes are currently used to monitor pH levels as the leachate enters and exits the Treatment Plant. The probes that measure treated leachate have two alarm set points for low pH and high pH. The alarm points are set at between 6.0 and 7.0 for low pH and between 9.0 and 10.0 for

high pH. The pH of both probes is recorded and the probes are regularly cleaned and calibrated. The treated leachate was then delivered to the municipal sewer by a newly constructed discharge line. A daily log was kept to ensure that water quality standards for the City of Petoskey were met. The Treatment Plant was designed to handle 50 gallons per minute or 72,000 gallons per day. The Treatment Plant is monitored and maintained on a daily basis by CMS personnel or subcontractors. A copy of the "Pre-Treatment Facility Basis of Design" was included in Appendix G of the Work Plan (Barr, 2005c).

1.3.4.4 Collection System Shutdown and Restart

In December of 2003 the Treatment Plant began to experience reduced pumping capacity at the upper lift station as a result of increased head loss and the pumps at the upper lift station could not keep up with the water volumes from the lower lift station. In January 2004 the Treatment Plant was shut down to correct this problem. Over the next few months an extensive investigation was conducted of the entire system. This process was hampered by severe winter weather conditions. It was finally discovered that the discharge line between the Treatment Plant and the municipal sanitary sewer line was becoming clogged with an unknown precipitate. By June 2004, CMS cleaned and modified the discharge line to ensure that the problem would not repeat itself. At that time, the City of Petoskey (City) requested that automatic volume and alarm shutdowns be installed. CMS and City negotiated and entered into a Consent Decree enabling the restart of discharge from the Treatment Plant in early September 2004. On September 7, 2004 the collection system was restarted and has only been shut down for short periods for routine maintenance and cleaning since that date.

1.3.4.5 2003 Geotechnical Investigation

During November 2003 and December 2003, Hanson Engineering P.C. conducted a geotechnical investigation and slope evaluation following a slope failure that occurred during a period of high rainfall that summer (Hanson, 2003). The slope failure was located in the area that is now defined as the Seep 2 CKD Area between Hole No. 7 of the Links Golf Course and the Coastal Ridge Site Condominium Lots 10 and 11. The purpose of the investigation was to evaluate the probable cause of the slope movements and to provide recommendations on how to stabilize the slope face. To characterize the subsurface conditions, three test borings (TB-1, TB-2, and TB-3) were advanced to depths between 47.5 and 69 feet below the ground surface. Samples were taken using a split-barrel sampler (SS) and Shelby Tubes. Samples were then sent to a laboratory for classification and testing. The locations of the test borings are shown on Appendix 1-3 Figure 1b.

Hanson Engineering P.C. found the subsurface conditions relatively uniform. The ground surface was covered with approximately six inches of organic topsoil followed by a layer of sand and gravel fill that extends to a depth of approximately 1.5 feet. Underlying the surface cover was a thick deposit of CKD fill that was only penetrated by boring TB-2 at a depth of 48.5 feet. Beneath the CKD in boring TB-2 was a layer of medium compact sand that extended to 60 feet followed by nine feet of weathered limestone and gravel. Auger refusal was reached at 69 feet.

The consistency of the CKD was extremely variable ranging from loose to dense material, which is expected for a fill that was placed in an uncontrolled manner. The water content of the CKD ranged from 39% to 105% and the dry unit weight of the material ranged from 51 to 70 pounds per cubic foot (pcf). SEM (Scanning Electron Microscope) scans of the CKD material indicated that it has a very large surface area to which the moisture could adhere. CKD cohesion values ranged from 2,200 to 3,750 pounds per square foot (psf). Groundwater was not encountered while the borings were advanced, however drilling water was lost in TB-1 and TB-3 at depths of 40 to 44 feet.

Hanson Engineering P.C.'s evaluation of slope stability indicated that the safety factors were acceptable for the slope of the CKD material. The safety factors of the cover material, located above the CKD, however were inadequate and slope failure of the overlying material was predicted with increased moisture and pore pressure. Therefore, the critical failure surface is located at the interface between the cover material and the CKD surface.

1.3.4.6 MDEQ and U.S. EPA Investigations

In August 2004, reddish-brown discoloration was observed along the shoreline of the Little Traverse Bay of Lake Michigan. The MDEQ conducted investigations of the shoreline of Lake Michigan and documented pH measurements exceeding 12. Following MDEQ investigations of the CKD leachate releases into Lake Michigan, U.S. EPA conducted several monitoring and sampling events across the entire LTB CKD Release Site. On September 30, 2004 U.S. EPA personnel and contractors conducted field pH monitoring along the shore of the Little Traverse Bay, downgradient of the Seep 1 and Seep 2 CKD Areas. Within shoreline areas exhibiting discoloration, pH values ranged from 10.02 to 13.06. On November 4, 2004, two discrete areas of pooled leachate with elevated pH levels were investigated by CMS and the U.S. EPA in the Seep 2 CKD Area and Seep 1 CKD Area. Elevated pH measurements (pH >9.0) were recorded in some of the beach pools in both of these areas. On November 22, 2004, the U.S. EPA conducted monitoring at the Seep 1 and 2 CKD Areas. The Seep 2 CKD Area pH data points ranged from 8.87 to 12.75 and the Seep 1 CKD Area pH data

points ranged from 12.97 to 13.13. On March 11 and 15, 2005 U.S. EPA conducted an investigation of Lake Michigan surface water, just off-shore, downgradient of the Seep 2 CKD Area, Seep 1 CKD Area, and the East CKD Area. Monitoring and sampling was conducted at locations where the ice sheet thickness was either reduced or absent, indicating the location of a possible seep. In addition, the investigation, including laboratory analysis of samples, identified impacted portions of Lake Michigan associated with the Seep 1 CKD Area further east than previously measured.

The previous investigation data for the Site is included in Appendix 1-3. Data obtained in the laboratory and in the field are included in tables presented in Appendix 1-3. These tables contain data from the historical record for the Site, as well as data obtained by the U.S. EPA and CMS. Each sample is labeled with the available sampling location information. For samples collected by CMS, the GPS coordinates are typically included. Copies of the U.S. EPA reports are also included in Appendix 1-3. The locations of the monitoring wells referred to in the data tables are shown on Figure 1-3. Historical data are labeled with the location information that was contained in the historical record.

1.3.4.7 Preliminary Non-intrusive Data Collection Activities

Concurrent with discussions with the MDEQ, CMS began preliminary non-intrusive data gathering activities at the Site starting on November 4, 2004. These activities consisted of geophysical investigations, review of available information regarding the Site setting, a preliminary lakeshore evaluation, limited beach pool sampling, etc. This data collection was suspended on December 2, 2004 during negotiations with U.S. EPA as to the AOC. Previous investigation analytical data are included in Appendix 1-3. The geophysical data collected in 2004 are discussed in Section 4.6.

1.4 Conceptual Site Model

The conceptual Site model is based on the preliminary non-intrusive data identified in Section 1.3.4.7, geologic and hydrogeologic data collected according to the Work Plan (Barr, 2005d), and during the installation and operation of the IR collection drains at the West, Seep 2, and Seep 1 CKD Areas. Specific data collection activities and data are further described in later sections of this RI Report. The objective of the conceptual Site model is to qualitatively summarize the source(s) of contamination, potential routes of migration, and potential receptors as described in the U.S. EPA Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (EPA, 1988).

1.4.1 Source of Contamination

The source of contamination at the Site is CKD. Potential COCs (listed in Section 7.1) may be released from the CKD through leaching (dissolution) by infiltrated water or groundwater or from a breach of cover soils.

1.4.2 Potential Routes of Migration

Once released from the source area, COCs can move along potential exposure pathways as leachate in groundwater, leachate, particulates transported as a solid, suspended sediment in runoff, or as an airborne particle. Of these five potential migration routes, only leachate in groundwater and leachate are likely (Section 7.2 provides a detailed evaluation of all potential exposure pathways). Due to variations in geology, groundwater, and CKD location, the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area each exhibit distinctly different groundwater/leachate migration routes. The following subsections describe the flow of groundwater and leachate for each CKD area.

1.4.2.1 West CKD Area

The West CKD pile is generally prism-shaped with a near-horizontal upper surface, and a lower surface that deepens northward, toward an escarpment at the beach. The majority of the West CKD pile is located above the regional groundwater table. The exception is the northern toe of the central portion of the CKD pile which appears to be seasonally saturated by the regional groundwater table. CKD that was previously on the beach in this area was removed in 2008/2009.

The leachate observed at the beach from the West CKD pile is generated in the center and eastern portions of the pile. The clay layer beneath the center of the CKD pile perches water above allowing it to contact CKD and subsequently generate leachate. Interflow may be occurring along the top of the West CKD pile, producing leachate that emerges near the bottom of the escarpment. In addition to interflow generating leachate in the central and eastern portions of the West CKD pile, leachate migrates downward in the eastern portion of the West CKD Area, where the clay layer is not present. This leachate mixes with the regional groundwater, flows toward the beach seasonally, and is collected in the collection drain. The regional groundwater within the West CKD Area is under the influence of an upward hydraulic gradient and releases within close proximity of the shoreline. Regional groundwater flow is seasonally variable due to the City of Petoskey groundwater pumping. Figures 1-4a and 1-4b illustrate groundwater and leachate flow at the West CKD Area for winter and summer seasons, respectively. Leachate flows to the beach are intercepted by the collection drain.

1.4.2.2 Seep 2 CKD Area and Guard Rail Area

The Seep 2 CKD pile is situated parallel to Lake Michigan. The entire Seep 2 CKD Area is underlain by limestone, with a marker shale layer approximately 30 feet beneath the limestone surface. The shale generally appears to dip to the south under the western side of the pile, and to the north under the eastern side of the pile. Groundwater is locally perched on the shale, which likely acts as a leaky aquitard. The majority of the CKD at the Seep 2 CKD Area lies above the regional groundwater table. Variable saturated CKD can be found along the northern edge of the CKD pile in the vicinity of the "Edge Drain".

The primary mechanism for leachate production at the Seep 2 CKD Area is perched groundwater interacting with the CKD pile with subsequent leachate migration northward to the beach. Leachate at the Seep 2 CKD Area typically follows an indirect path on its way north. While the shale is an effective barrier to downward flow in some locations, leachate migrates downward through the leaky shale in other locations. It is also likely that leachate is produced by interflow occurring along the top of the CKD pile and along the limestone surface (where CKD rests on the limestone), producing leachate that emerges near the bottom of the escarpment. The regional groundwater within the Seep 2 CKD Area is under the influence of an upward hydraulic gradient and releases within close proximity of the shoreline. Figure 1-4c illustrates groundwater and leachate flow at the Seep 2 CKD Area. Leachate flow is intercepted by one of the collection drains in the Seep 2 CKD Area.

1.4.2.3 Pine Court Seep Area

The main mechanisms of leachate generation at Pine Court are a combination of interflow occurring along the top of the CKD pile and along the limestone surface (where CKD rests on the limestone) and saturation of CKD via perched groundwater. The marker shale layer rises in elevation near Pine Court, perching groundwater and providing a "shelf" where it ends, driving groundwater toward the Pine Court area. This leachate mixes with the regional groundwater and flows toward the beach seasonally. Regional groundwater flow is seasonally variable due to the City groundwater pumping. The regional groundwater within the Pine Court Seep area is under the influence of an upward hydraulic gradient and releases within close proximity of the shoreline. Figures 1-4d and 1-4e illustrate groundwater and leachate flow at the Pine Court Seep area for winter and summer seasons, respectively. Leachate flow is intercepted by one of the collection drains in the Pine Court Seep area.

1.4.2.4 Seep 1 CKD Area

The Seep 1 CKD Area consists of one CKD pile situated parallel to Little Traverse Bay. The western and central portion of the Seep 1 CKD pile lies on limestone bedrock at its southern half, and soil at its northern half. The eastern side of the pile lies on soil above limestone bedrock. Two bedrock depressions at the center of the pile contain CKD saturated by the regional groundwater table. The marker shale is largely absent in the Seep 1 CKD Area. Hence, the shale is not a significant factor in leachate flow in this area. Although the shale at the west end of the pile may potentially seasonally perch groundwater, it likely acts as a leaky aquitard.

The primary mechanisms for leachate production at the Seep 1 CKD Area are CKD saturated by the regional groundwater table and interflow. Regional groundwater contacts the CKD pile in a small isolated area. This small area of saturated CKD is located upgradient of a channelized section of the beach with approximately six feet of silt, sand, and gravel filling the bedrock channel. A preferential flow path for leachate exists within this portion of the Seep 1 CKD Area. In addition to the contribution from saturated CKD, shallow leachate migrates towards the regional groundwater table and Little Traverse Bay by infiltrating through the CKD pile and underlying soil. The regional groundwater within the Seep 1 CKD Area is under the influence of an upward hydraulic gradient and releases within close proximity of the shoreline. Figure 1-4f illustrates groundwater and leachate flow at the Seep 1 CKD Area. Leachate flow in this area is intercepted by the collection drain at the beach.

1.4.3 Potential Receptors

Although the routes of migration vary for each CKD Area, the potential receptors are the same. These include surface water users (such as swimmers, fisherman, wading individuals, municipalities) who use the beach and near-shore areas and/or use the lake as a water supply; fish consumers; groundwater users (municipalities the lake as a water supply); in the case of direct contact exposure, golfers, residents, and golf course personnel; and in the case of airborne particulates, downwind receptors. As described in Section 7.2, the risk of COCs reaching most of these receptors is low.

Release mechanisms, potential exposure pathways, and potential receptors for all CKD Areas are shown graphically on Figure 1-5.

1.5 Report Organization

This RI report for the West, Seep 1 and Seep 2 CKD Areas has been prepared to include the following sections:

Section 2.0 summarizes the expedited removal actions, interim responses, and augmentation activities.

Section 3.0 summarizes the methods and procedures followed during the implementation of field activities for the Site investigation.

Section 4.0 summarizes the physical characteristics of the Site as determined during the field investigation.

Section 5.0 describes the characteristics and extent of the CKD pile and CKD leachate.

Section 6.0 discusses CKD and leachate chemistry and characteristics.

Section 7.0 discusses contaminant fate and transport for the potential chemicals of concerns and the production and migration of leachate at the various seeps.

Section 8.0 summarizes the results of the RI and presents conclusions.

2.0 Expedited Removal Actions and Interim Response

This section parallels Section 4.0 of the Work Plan summarizing both expedited removal and interim response actions (including augmentation activities).

2.1 Expedited Removal Actions

Expedited removal actions were those actions taken by CMS prior to formal approval of the entire Work Plan (Barr, 2005c) dated July 28, 2005. Specifically, these actions were portions of the Work Plan individually approved, such as implementation of a Site Control and Access Management Plan (SCAMP), targeted shoreline survey, overflights, removal action notification, and leachate recovery.

2.1.1 Implementation of the SCAMP

The SCAMP (Barr, 2005a), dated April 4, 2005, and approved by U.S. EPA letter dated April 19, 2005, was implemented at the Site, for those areas requiring access restriction to high pH leachate. In accordance with the AOC, CMS has installed, fencing or other engineering controls approved by U.S. EPA, posted warning signs, and implemented other measures approved by the U.S. EPA to restrict access. During the course of the removal action the Site conditions have significantly improved. As a result, access restriction measures have been modified through various CMS request and U.S. EPA approval letters, including the complete removal of fencing and signage at the Seep 2 CKD Area, and partial removal at the West CKD Area and Seep 1 CKD Areas.

2.1.2 Targeted Shoreline Survey

Targeted shoreline surveys were conducted to evaluate the boundaries of the areas in Lake Michigan affected by the discharge of leachate in accordance with Section 4.1.2 of the Work Plan and as outlined in U.S. EPA's letter approval dated May 2, 2005. Monitoring data showing specific conductance, pH, temperature, and location coordinates are included in Appendix 2-1.

Three targeted shoreline water quality survey events were completed adjacent to the Site. The May/June 2005 (Spring 2005) targeted shoreline survey was expedited in order to provide the only nature and extent information for Interim Leachate Recovery System (ILRS) design prior to construction. Two additional targeted shoreline survey events were conducted in October/November 2005 (Fall 2005) and May/June 2006 (Spring 2006). The Spring 2005 and Spring 2006 targeted

shoreline surveys provide a comparison of pre-ILRS and post-ILRS for nearly the entire Site showing significant improvement in lakeshore water quality. As per the U.S. EPA approval dated August 11, 2005, the September 2005 Targeted Lakeshore Survey was not conducted.

The targeted shoreline water quality surveys were conducted in the following manner:

- Initial survey points were located using GPS methods. The 25-foot horizontal intervals between survey points were measured using a hand-held laser range finder or a rigid spacing device.

- At each survey point, the location was recorded using a GPS. Specific conductance, pH, and temperature of the water were measured using a YSI Model 556 MPS Water Quality Monitoring System. The measurements were made in water approximately two inches deep. If elevated pH (i.e., pH > 9.0) was measured, additional measurements were collected moving out into the Lake Michigan approximately perpendicular to the shore at horizontal intervals of approximately five feet. Measurements were continued at approximately 5-foot intervals out into Lake Michigan until pH < 9.0 was measured. The measurements were made as close as possible to the lake bottom. The 5-foot spacing between locations was measured with a rigid spacing device. In addition to moving north at 5-foot intervals, the investigation also moved south, up the beach, to pools on the beach.

- The survey also included measurements of specific conductance, pH, and temperature in pools. A visual survey was conducted at and between each survey point to determine the presence or absence of pools. This visual survey extended from the shore/lake water interface to the southern boundary of the beach. When any pools were identified, the approximate quantity of pools was determined. If there were five or fewer pools identified at the survey point, the water quality parameters were measured in each pool. If there were more than five pools, the water quality parameters were measured in at least five pools, with a bias towards zones appearing most dark brown or otherwise discolored. No fewer than 10% of the total number of pools, or five zones (whichever was greater) were surveyed at any one survey point. In portions of the shore with relatively few pools, a best effort was made to identify and survey each pool. The geographic coordinates were collected at each pool surveyed, and a unique identifier was assigned so that the pool could be located in future shore survey events.

- The field instrument was maintained and calibrated according to the standard operating procedure for the YSI Model 556 in the QAPP and the instrument was operated according to the manufacturer's directions.

Locations for the three target shoreline water quality survey events are presented in Appendix 2-1. The following table summarizes the total number of sample locations, the number of pH exceedances, and pH exceedance percentages:

Targeted Shoreline Surveys

Sample Event	Spring 2005		Fall 2005		Spring 2006	
Number of Sample Locations	2133		858		984	
	Number of Exceedances	Exceedance Percentage	Number of Exceedances	Exceedance Percentage	Number of Exceedances	Exceedance Percentage
pH > 9	571	26.8%	96	4.5%	42	2.0%
pH > 10	143	6.7%	25	1.2%	14	0.7%
pH > 11	83	3.9%	15	0.7%	5	0.2%
pH > 12	33	1.5%	11	0.5%	0	0.0%

2.1.3 Overflights

Overflights were conducted at the Site for the purpose of observing and documenting existing and potential leachate releases in accordance with Section 4.1.3 of the Work Plan (Barr, 2005d). Copies of the overflight photographs are included in Appendix 2-2. The initial overflights were completed at approximately 14-day intervals. CMS requested approval to suspend the 14-day interval overflight schedule in a letter dated August 31, 2005. The U.S. EPA approved this schedule modification in a letter dated September 6, 2005 (Appendix 1-1).

The overflights were completed on days when wind, waves and light conditions were most conducive to good visualization of the shoreline features. Anderson Aerial Photography of Traverse City, Michigan was contracted in June 2005 to photograph the Site and provide digital images. Overflights were completed on June 26, July 9, July 23, August 6, August 22, September 9, October 1, October 21, and November 12, 2005; April 13, June 2, and October 7, 2006; and April 28, 2007.

Discoloration has been identified in the photographs taken during 2005 that corresponds to the impacted areas as defined by the Targeted Shoreline Survey. However, photographs taken in 2006 and 2007 show much less discoloration. The observed pattern would be expected, as the IRLS collection trenches would have been installed and in operation by the time the later photographs were taken.

A MDEQ survey of the East CKD Area indicated that dark areas off-shore from the East CKD Area are likely zebra mussel colonies.

2.1.4 Removal Action Notification

In accordance with Section 4.1.4 of the Work Plan, notification of the removal action was provided to the U.S. Army Corp of Engineers and the State of Michigan for work within the shoreline of Lake Michigan. While a joint permit application and revisions were submitted during May 2005, no shoreline work-related permits have been issued for the removal action. During final remedy evaluation in the Alternatives Evaluation Report, each candidate remedial alternative will be assessed in terms of all applicable and appropriate requirements, including shoreline work permitting.

2.1.5 Expedited Leachate Recovery

In accordance with Section 4.1.5 of the Work Plan as approved by U.S. EPA letter dated May 2, 2005, vacuum recovery activities were conducted at accessible portions of the Site. Vacuum recovery of leachate began on May 11, and May 19, 2005, at the Seep 1 and Seep 2 CKD Areas, respectively. In addition, vacuum recovery was initiated at the Guard Rail seep area during the week of June 13, 2005; however, the leachate recovered was negligible. Recovered leachate from the Seep 1 CKD Area, Seep 2 CKD Area, and Guard Rail was neutralized on Site and shipped offsite for disposal. Vacuum recovery operations at all seep areas ceased on July 12, 2005.

During construction of an access road at the Seep 1 CKD Area on May 12, 2005, shallow unsaturated groundwater flow was encountered within two feet of the existing ground surface in soil. This discharge is termed the ‘road seep’ or ‘seep sump’ and was confined to an area approximately five feet by five feet. During vacuum recovery of leachate at the Seep 1 CKD Area, this seep was collected in a temporary at-grade storage tank and managed with vacuum recovered leachate. During dry weather, the discharge from this seep averaged an estimated 700 gallons per day (0.5 gpm). The flow however, was observed to vary in response to rainfall events. The pH of this water was typically above 12. During the 63 days of vacuum operations a total of 158,000 gallons (2,500 gallons per day average) of leachate were collected based on disposal manifests. More than one third of this volume was collected from the ‘road seep’.

2.2 Interim Leachate Recovery System

An ILRS was designed and constructed, and is in operation at the Site as required by the AOC. Collection trenches have been installed in the West CKD Area, Pine Court, Guard Rail, Seep 2 CKD Area, and Seep 1 CKD Areas. The locations of the ILRS collection trenches are provided on Figure 2-1a, with further detail provided on Figures 2-1b through 2-1g.

2.2.1 Design

Design of the ILRS was conducted in accordance with Section 4.2 of the Work Plan. The design basis provided in Section 4.2 of the Work Plan included installation of collection trench piping at an elevation of 577.5 MSL or a minimum of 2½ feet below ground surface, whichever was deeper. The horizontal extents of the collection trenches were established by the Spring 2005 targeted shoreline survey. The anticipated collection rate from a unit length of trench was estimated in the Work Plan to be 0.02 gallons per minute per foot of collection trench.

2.2.2 Installation

The ILRS was constructed in accordance with Section 4.2.3 of the Work Plan. In general, the ILRS consists of segmented collection trenches built to various depths below the ground surface. The collection trenches were constructed in bedrock and unconsolidated material to various depths, and lengths along the shoreline as summarized below.

Collection Trench Segment	Generalized Collection Trench Geology	Approximate Trench Length (feet)	Approximate Trench Bottom Elevation (feet MSL)	In-service Date
West CKD-West	Unconsolidated	400	576	5/22/06 (1st extension) 10/18/06 (2nd extension)[1]
West CKD-East	Bedrock	280	576	12/22/05[1]
Pine Court-West	Bedrock	290	576	12/22/05[2]
Pine Court-East	Bedrock	250	576	12/22/05[2]
Guard Rail	Bedrock	170	577	10/10/05
Seep 2-West	Bedrock	240	573 to 577	10/10/05
Seep 2-East	Bedrock	260	577	10/10/05
Seep 1-West	Bedrock	820	573 to 577	10/10/05
Seep 1-East	Unconsolidated	210	577	10/10/05
Seep 1-Road Seep	Unconsolidated	100	580 to 593	10/10//05

[1] The West CKD-West collection drain was removed on 1/5/09 to facilitate the West CKD Phase I & II Augmentation – Soil/CKD Removal, and the West CKD-East collection drain was removed on 4/10/09. The entire collection trench was reconstructed and operating on 5/11/09.

[2] The Pine Court-East and Pine Court-West collection drains were operated from December 22, 2005 through June 23, 2006 and July 12, 2006, respectively. Operation of the Pine Court Pilot Carbon Dioxide System commenced June 28, 2006. Collection from both the Pine Court-East and Pine Court-West collection drains resumed May 1, 2009.

Collection trenches were excavated and backfilled with a pea gravel drainage rock from a local source and perforated high density polyethylene (HDPE) drainage tubing. A physical barrier, consisting of HDPE sheeting, was installed along the lakeside excavation sidewall of the collection trenches.

Lift stations were constructed to convey the leachate through forcemain piping to the existing Treatment Plant. During ILRS construction, the Treatment Plant was expanded to treat the Work Plan anticipated collection rate. Construction of the ILRS included modifications from the Work Plan based on field observations. The ILRS construction modifications are summarized as follows:

- Deepened portions of the Seep 1 CKD, Seep 2 CKD, Pine Court, and West CKD Area collection trench piping depths to a minimum depth of 576.5 feet MSL (collection trench to an elevation of 576).
- Extended the Pine Court eastern collection trench to the east to mitigate the potential for creation of a leachate pathway to Lake Michigan as a result of the Pine Court lift station construction near shore.
- Installed a bentonite barrier at the western trench of the Pine Court Seep area. This barrier was implemented instead of high density polyethylene sheeting proposed in the Work Plan based on field observations of each barrier's lake water isolation effectiveness.
- Installed a temporary barrier layer over unconsolidated materials downgradient of the West CKD Area.
- Piezometer installation in each segment of collection trench was implemented to assess further water/leachate elevations along the trench alignment.

Piezometers installed at various locations throughout the ILRS are used to monitor collection trench operation. The piezometers are constructed of perforated PVC pipe and are hydraulically connected to the collection trench.

Construction drawings recording the ILRS work are provided in Appendix 2-3. ILRS piezometer and valve box construction information is summarized in Appendix 2-4.

2.2.3 Augmentation

Augmentation refers to activities conducted to improve ILRS performance following construction. As of May 31, 2009, augmentation has been implemented by CMS at all areas. Augmentation has consisted of the following activities:

Area	Augmentation Activities
West CKD Area	• expanding the West CKD ILRS (WILRS) • removal of the downgradient soil and CKD mixture (soil/CKD) • reconstruction of the WILRS • installation of a low permeability modified fill zone (MFZ) • installation of a geosynthetic clay liner (GCL) cover system
Seep 2 CKD Area/Pine Court Area	• design, installation, operation, and modification of a pilot carbon dioxide injection system • installation of a targeted leachate collection system (TLC) • replacement of weir gates with stand pipes (except at the Pine Court Seep area. • installing a temporary forcemain and frac tanks for collection of leachate
Seep 1 CKD Area	• additional monitoring • sampling and analysis • cleaning • increased collection • installation of low permeability barrier wall • installation of a geosynthetic clay liner (GCL) cover system

2.2.3.1 West CKD Area

Several phases of augmentation have been implemented by CMS at the West CKD Area. These augmentation phases include: Initial WILRS Augmentation – expansion of the WILRS; soil/CKD removal downgradient of the WILRS trench; WILRS reconstruction and installation of a low permeability flow barrier (modified fill zone, MFZ); and installation of a GCL cover system. Record drawings of the augmentation construction are included in Appendix 2-3.

Initial WILRS Augmentation

The first section of the WILRS was operational as of December 22, 2005 (West CKD-East). Soil samples were collected from the West CKD Area collection trench during construction. Samples were collected from the collection trench alignment at stations 29+70, 30+50, and 33+00. The samples at stations 29+70 and 30+50 were collected in November 2005 when potential CKD was encountered during collection trench installation. This location is along the alignment where the bedrock dips to the west and the collection trench transitioned from bedrock to an unconsolidated excavation. The collection trench soil samples confirmed the presence of a CKD and soil mixture along portions of the WILRS trench alignment.

CMS submitted a limited subsurface investigation plan, approved by U.S. EPA on January 27, 2006, to assess conditions encountered during installation of the West CKD Area collection trenches. This limited investigation was conducted in the shoreline area at West CKD Area, accessible to CMS in early 2006. The initial portion of the collection system was quickly augmented with the installation of the "West 300" on May 22, 2006 and the "West 75" on October 18, 2006. During collection trench augmentation in May 2006 an additional sample was collected from soil excavated to construct the trench at station 33+00. Sample 33+00 did not appear to be CKD based on field pH and potassium concentrations in the solid phase. In addition, during West CKD Area collection drain extension work in 2006, a temporary barrier layer (geotextile and rock cover material) was installed to minimize surficial soil disturbance and erosion of the soil/CKD located immediately downgradient of the collection trenches.

Downgradient Soil/CKD Removal

Soil/CKD located downgradient of the WILRS was removed in the winter of 2008/2009, to fulfill the U.S. EPA order requirement to augment the existing WILRS. A conceptual augmentation plan describing this augmentation of the WILRS was submitted to the U.S. EPA on February 4, 2008. On March 26, 2008, the U.S. EPA approved the conceptual approach as submitted on February 4, 2008 and further described during the March 10 and 18, 2008 CMS/U.S. EPA meetings and in the CMS schedule submittal dated March 19, 2008. On April 8, 2008, the U.S. EPA provided a modification to the March 26, 2008 approval with specified augmentation milestones and completion dates.

A series of design documents; West CKD Area Augmentation Conceptual Design Report – Downgradient Soil/CKD Removal dated May 1, 2008 (Barr, 2008c), West CKD Area Augmentation Preliminary Design Report dated July 1, 2008 (Barr, 2008a), and West CKD Area Augmentation Plan Final Design dated September 2008 (Barr, 2008i) were developed as the augmentation work scope was refined and were submitted to U.S. EPA. Final comments on the West CKD Area Augmentation Conceptual Design Report were received on June 12, 2008 from the U.S. EPA, and CMS responded to those comments on June 13, 2008 and in the West CKD Area Augmentation Preliminary Design Report. On October 1, 2008, U.S. EPA provided approval of the West CKD Area Augmentation Final Design and completion date extension with comments. CMS responded to the comments by letter dated October 15, 2008.

Downgradient soil/CKD removal activities included installation and maintenance of a temporary sediment containment system, removal of overlying beach cover and service path rock, excavation of

soil/CKD, transportation and disposal of removed soil/CKD, management of excavation water, backfilling the excavation, and restoration of the service path and beach cover.

A temporary sediment containment system berm (berm) was constructed along the lakeside edge of the excavation area. The berm was used to provide protection from wave action and ice movement during excavation and backfill operations. In addition, the berm provided control of suspended sediment in the excavation water that passed through the berm to Lake Michigan. The berm consisted of a geotextile core with two layers of filter rock. During the beach cover restoration, the berm was removed.

Prior to soil/CKD removal, the overlying beach cover and service path rock was stripped, mechanically segregated, and stockpiled. The service path rock was removed first and was used to build the berm. Following berm construction, the beach cover rock was removed. Finer material recovered from the segregation processes was managed as soil/CKD.

The planned horizontal and vertical extent of the downgradient soil/CKD to be removed from the beach was initially provided in the West CKD Area Augmentation Design Reports (Barr, 2008c; Barr, 2008a; and Barr, 2008i) and was based on all investigation work completed through summer of 2008. The planned vertical removal limits included a west side removal area that extended to an elevation of 575 ft. MSL and an east side removal area that extended to bedrock. Actual removal limits did not extend as far horizontally and vertically as originally planned. The extent of the soil/CKD removal is included in the record drawings (Appendix 2-3) and Figure 2-1b. The actual removal limits varied slightly from the planned extent based on encountered field conditions as follows:

- The horizontal removal limit extended further north between approximate stations 31+40 and 32+25 where soil/CKD impacts were observed in the shallow soils in the area.

- The east side removal area was shallower than anticipated as the competent top of the bedrock surface observed during the excavation was shallower than observed in the soil boreholes. The more highly fractured shallow bedrock in the beach area closely resembled a cobble zone in drill cores. The observed bedrock surface within the east excavation is included in the record drawings.

Soil samples were collected along the north side of the excavation and were field screened for pH. The pH results from these samples were used to guide removal activities. The locations of the soil samples and the pH measurements are included in the record drawings.

The soil/CKD was removed in two phases: the first phase included the removal of soil/CKD located north of the WILRS, and the second phase included the removal of soil/CKD within the WILRS area to the southern extent/toe of the West CKD pile. The excavation was conducted "in the wet" in accordance with the West CKD Area Augmentation Design Reports (Barr, 2008c; Barr, 2008g; and Barr, 2008i). A total of 12,435 tons of soil/CKD was removed from the beach. The soil/CKD was transported to Waters Landfill (operated by Waste Management and located in Frederic, MI) for disposal.

Management of the excavation water was performed in accordance with the West CKD Area Augmentation Design Reports (Barr, 2008c; Barr, 2008g; and Barr, 2008i). During the soil/CKD removal, the pH of the water in the excavation was monitored daily. Sodium bicarbonate was used to neutralize excavation water that was above a pH of 10.0 prior to backfill. Sodium bicarbonate was applied and mixed using the excavator at a rate of 1 to 3 pounds per 50 gallons of water.

Clean granular fill was imported to the West CKD Area and used as backfill in the completed portions of the excavation. The backfill was placed to grades and dimensions included in the record drawings (Appendix 2-3). The upper backfill layer overlying the granular fill north of the WILRS was restored as beach cover. The restored beach cover consisted of salvaged beach cover rock, temporary berm rock, and imported beach cover rock. The service path was reconstructed over the granular fill and consisted of a layer of geotextile and an overlying layer of service path rock. The service path rock consisted of temporary berm rock, imported haul road rock, and imported dense graded aggregate (DGA).

WILRS Reconstruction

The WILRS remained in service throughout the duration of the excavation. However, the west portion (west of approximate station 29+90) of the WILRS was removed during the second phase of excavation to facilitate complete removal of the downgradient soil/CKD. The west portion was taken out of service on January 5, 2009, and the remaining east portion of the WILRS was removed on April 10, 2009.

In spring of 2009, the entire WILRS was reconstructed as shown on Figure 2-1b and Appendix 2-3. The depth and alignment of the new collection drain were consistent with the original drain. The new collection drain was constructed of perforated HDPE drain pipe and peastone. Two isolation sections were installed on the west portion at approximate station 33+00 and 33+50 to allow for potential future drain operation modifications if warranted. New piezometers were installed to monitor water levels in the trench. To control the water level in the collection trench, a standpipe was installed inside the lift station in place of the previous valve boxes. The new piezometers and standpipe construction information is included in Appendix 2-4. The reconstructed WILRS was operational on May 13, 2009.

Low Permeability MFZ and GCL Cover System

As a part of the augmentation activities, a low permeability MFZ and a GCL cover system were constructed. The low permeability MFZ was installed to minimize recovery of water from the lakeward side of the WILRS trench, and the GCL cover system was installed to minimize infiltration of stormwater. The alignment of the MFZ and the extent of the GCL cover system are included in record drawings (Appendix 2-3).

Approximately 420 feet of MFZ was constructed downgradient of the WILRS. The MFZ consisted of granular fill mixed with approximately 20 percent bentonite by dry weight. The bentonite was mechanically mixed into the existing granular fill using an excavator. The east portion of the MFZ (approximate station 0+50 to 2+25) was keyed into the weathered bedrock and extended to the competent bedrock. The west portion of the MFZ (approximate station 2+25 to 4+69) was keyed a minimum of two feet into the existing soft clayey soils underlying the granular fill. The west end of the MFZ was terminated about ten feet past the excavation/backfill extent into the existing soft soils at station 4+69, and the east end of the MFZ was terminated on the bedrock outcrop at station 0+50.

The GCL cover system was constructed above the collection trench alignment, and spanned the area between the MFZ and the fenceline/toe of the slope. The GCL cover system is graded to drain toward Lake Michigan. The northern edge of the GCL was keyed into the MFZ to provide a continuous barrier.

2.2.3.2 Seep 2 CKD Area/Pine Court Seep Area

Several phases of augmentation have been implemented by CMS at the Seep 2 CKD Area and the Pine Court Seep area. These augmentation phases include: the Pine Court CO_2 Pilot, Seep 2 CKD

Area Targeted Leachate Collection, and Temporary Pine Court Area Beach Collection. Record drawings of the augmentation construction are included in Appendix 2-3.

Pine Court CO_2 Pilot

The Pine Court ILRS in service date was December 22, 2005. Based on effectiveness monitoring, it was clear that this system was ineffective at controlling pH exceedances in Lake Michigan. Also, it was apparent early in 2006 that mixing leachate from Pine Court with leachate from the other seeps resulted in rapid precipitation within the collection drains and force mains, thereby compromising the entire collection system. CMS prepared, and the U.S. EPA approved on May 30, 2006, a plan to augment the Pine Court system through carbon dioxide (CO_2) injection (CO_2 Pilot). The CO_2 augmentation system was installed in the eastern segment of the Pine Court ILRS and became operational on June 28, 2006. An initial assessment of the CO_2 Pilot was submitted to U.S. EPA on August 16, 2006, in accordance with the approved Pine Ridge Court Pilot Carbon Dioxide Pilot Injection System Work Plan (Barr, 2006f). Based on the first month of data, additional operation was proposed. The CO_2 system put into place was further augmented with a “three tube” configuration in order to target lake pH measurement areas greater than 9.0 along specific areas of the CO_2 injection system on December 16, 2006. While the CO_2 Pilot was somewhat effective in reducing pH in the Pine Court Seep area, delivery of CO_2 to the trench was unable to completely control the high flow rate of low level pH in certain areas of the shoreline. As a result, CMS requested that the CO_2 Pilot Injection System be terminated in a letter dated February 13, 2009 and the U.S. EPA approved this request in a letter dated April 8, 2009.

Results for the CO_2 Pilot through April 8, 2009, namely, lakeshore monitoring, trench data (water quality and level), and carbon dioxide mass injection rates are provided in Appendix 2-5.

Seep 2 CKD Area Targeted Leachate Collection

The conceptual plan for Targeted Leachate Collection (TLC) was first submitted to the U.S. EPA on February 4, 2008. On March 26, 2008 the U.S. EPA approved this conceptual plan. The Seep 2 CKD Area Augmentation Pilot System Design Report Targeted Leachate Collection dated April 29, 2008 was submitted to the U.S. EPA on April 30, 2008. The objective of the TLC system was to lower the potentiometric surface of perched leachate in the vicinity of W2125 to reduce the flow of high pH leachate toward Lake Michigan. In May 2008, CMS installed the TLC Pilot System including one pumping well at S2-RW1 and associated discharge piping and structures. The TLC Pilot System was

operational beginning May 29, 2008. CMS requested, and the U.S. EPA approved (September 8, 2008), to continue operation of the TLC Pilot Study.

CMS submitted the Seep 2 CKD Area Augmentation Targeted Leachate Collection Phase 5 Final Design Report – Pilot System Installation, Data Collection, and Future Recommendations on December 15, 2008 which described the installation of the TLC system, presented data collected during the Pilot Study system operation, and presented recommendations for future operation of the TLC System.

CMS prepared, and the U.S. EPA approved on April 6, 2009, a plan to modify the TLC System to enhance collection of high pH (greater than 12) leachate perched on the marker shale upgradient of the Pine Court area. In April 2009, CMS expanded TLC to include collection from wells S2RW-1, S2RW-4, and S2RW-5. The new S2RW-4 and S2RW-5 pumps and forcemains were connected to the existing discharge piping at MH-3. Figure 2-1g shows the TLC System alignment. Record drawings for the TLC System are included in Appendix 2-3. The upscaled TLC system was operational on April 30, 2009.

Temporary Pine Court Area Beach Collection

CMS prepared, and the U.S. EPA approved on April 6, 2009, a conceptual plan to modify the Pine Court ILRS to include a dedicated temporary forcemain and frac tanks for Pine Court beach collection. The temporary forcemain and frac tanks allow for the segregation of the low pH leachate from the Pine Court area. Mixing the low pH Pine Court Seep area leachate with high pH leachate from the other seep areas resulted in rapid precipitation within the ILRS system historically. CMS submitted the Pine Court Area Augmentation ILRS Modification Work Plan on April 10, 2009 and in late April 2009 installed the temporary forcemain and frac tanks to resume collection of leachate from the Pine Court Seep area. This temporary system was operational May 1, 2009. No changes were made to the existing collection drains. Existing forcemain and gravity discharge piping from the West CKD Area lift station to the Seep 2 CKD Area lift station were connected to transmit the West CKD Area leachate through the Pine Court Seep area (Appendix 2-3).

2.2.3.3 Seep 1 CKD Area

The Seep 1 CKD Area ILRS became operational on October 10, 2005. Initially the east 200 feet of the Seep 1 CKD Area ILRS contained pH measurements less than 9.0 and, therefore, the isolation valve remained closed for this section. In approximately April 2006 pH levels increased in this

section of the ILRS and CMS opened the isolation valve and began collecting from this area. Seep 1 CKD Area augmentation has included: varying the operation of the system as constructed; installing additional monitoring wells; sampling groundwater to assess leachate migration near shore; and installing a low permeability barrier wall at the east end of the Seep 1 CKD Area ILRS to address lakeshore pH exceedances. This work has included completion of several small scale pumping evaluations along the Seep 1 CKD Area beach and a geophysical survey to define bedrock topography. In addition, augmentation alternatives have been evaluated in terms of estimated effectiveness and practicability through routine Site status meeting discussions with U.S. EPA.

A low permeability barrier wall (barrier wall) was constructed on the east end of the Seep 1 CKD Area ILRS in October 2008, to fulfill the U.S. EPA order requirement to augment the existing Seep 1 CKD Area ILRS. A conceptual augmentation plan describing this augmentation of the Seep 1 CKD Area was submitted to the U.S. EPA by letter on February 4, 2008. U.S. EPA approved the concept and did not approve the schedule by letter on February 29, 2008. U.S. EPA formally approved the augmentation scope of work and schedule by letters dated March 26, 2008 and April 8, 2008.

A series of design documents; Seep 1 CKD Area Augmentation Conceptual Design Report – Barrier System dated May 1, 2008 (Barr, 2008b), Seep 1 CKD Area Augmentation Plan – Preliminary Design Report dated June 2008 (Barr, 2008d), and Seep 1 CKD Area Augmentation Plan – Final Design dated July 2008 (Barr, 2008f) were developed as the augmentation work scope was refined and were submitted to U.S. EPA. Final comments on the Seep 1 CKD Area Augmentation Conceptual Design Report were received on June 12, 2008 from the U.S. EPA, and CMS responded to those comments on June 13, 2008. On September 10, 2008, U.S. EPA provided approval of the Seep 1 CKD Area Augmentation Final Design with comments via e-mail. CMS responded to the comments on September 19, 2008 via e-mail. As requested by U.S. EPA in the September 10, 2008 e-mail, the Pre-Construction Testing Plan was provided from CMS to U.S. EPA on October 9, 2008.

The barrier wall was constructed to provide a physical barrier from high pH leachate flow toward the lake. The barrier wall construction operations included installation of a temporary sediment containment system, construction of a working platform, installation of the barrier wall, installation of GCL cover system, and construction of the shoreline protection. Record drawings of the augmentation construction are included in Appendix 2-3.

A temporary sediment containment system (berm) was installed to provide sediment and erosion control and protection from Lake Michigan during construction. The berm was constructed of clean

import rock and geotextile fabric. During restoration, the berm was incorporated into the final shoreline protection as the toe of the shoreline riprap.

A 20-foot-wide working platform was constructed along the alignment of the barrier wall to provide a level working surface for the barrier wall construction operations. The working platform consisted of clean imported clay and was built to the approximate elevation of 581.5 ft. MSL as shown on the record drawings.

Approximately 340 feet of barrier wall was installed from approximate station 9+25 to 12+50 of the Seep 1 CKD Area ILRS in October 2008. The barrier wall was installed downgradient of the existing collection drain and to the depth and alignment shown on the record drawings. The barrier wall extended to competent bedrock and was keyed into rock that was removable with a conventional excavator. The barrier wall was constructed using conventional slurry methods that include excavation of the bentonite slurry filled trench and backfilling the trench with soil-bentonite (SB) backfill. The bentonite slurry consisted of 9% bentonite mixed with lake water. A sample of the water used in the slurry (sample name, S1-SW-water) was collected for construction documentation. The sample was sent to the lab to be analyzed for hardness, pH, and total dissolved solids. The bentonite slurry was mixed onsite in a mixing plant and was frequently tested onsite to meet the requirements of the quality control testing plan included in the Seep 1 Augmentation Design Reports (Barr, 2008b; Barr, 2008d; and Barr, 2008f). The SB backfill was placed in completed portions of the trench. The SB backfill consisted of bentonite slurry mixed with imported clay and was mixed and placed using an excavator. The SB backfill was mixed onsite and frequently tested to meet the requirements of the quality control testing plan.

A GCL cover system was installed to minimize infiltration of the stormwater to the east end of the Seep 1 CKD Area ILRS. The GCL cover system was constructed above the collection trench alignment and spanned the area between the barrier wall and the toe of the slope. The GCL cover system was graded to drain toward the lake. The northern edge of the GCL was keyed into clay to provide a continuous barrier. Shoreline protection was installed to protect the barrier wall from Lake Michigan. The shoreline protection consisted of a geotextile layer, a filter stone layer, and an armor stone layer (Appendix 2-3).

2.2.4 Operational Monitoring

Operation of the ILRS includes monitoring the elevation of liquids in the collection trenches, Lake Michigan elevation, and pump performance. In addition, overflow weir structures are used to control the elevation of leachate within the collection trench. Adjustments can be made to the overflow weir structure to vary the elevation in the collection trench. The Interim Leachate Recovery System Operation and Maintenance Plan, Rev 0.0 (Barr, 2007b), dated December 14, 2007 (O&M Plan) provides additional details regarding the types and frequency of the ILRS operational activities implemented at the Site.

The most significant finding during the initial operation of the ILRS is the leachate instability both in the collection trench and in the forcemain piping. Based on maintenance records, the forcemain piping which formed precipitate at the greatest rate is downstream of the Pine Court lift station. The high frequency of cleaning necessary to remove precipitate rendered this portion of the system unreliable and reduced the collection rates for both Pine Court and West CKD Area portions of the ILRS.

In addition to forcemain precipitation, rapid formation of persistent precipitate was also observed in the collection trenches at the Seep 2 and Seep 1 CKD Areas. At both the Seep 2 and Seep 1 CKD Area collection trenches, precipitate formation has occurred within the bedrock excavation which has been filled with pea gravel and in the perforated drainage pipe. At the Seep 2 CKD Area, a partial precipitate blockage was removed in the summer of 2007. At the Seep 1 CKD Area, precipitate blockages were removed near the control structures on August 13, 2006 and again on March 20, 2007. All three collection trench blockages required re-excavation of a section of collection trench and installing a new section of perforated drainage pipe and imported pea gravel. See Appendix 2-6 for additional discussion regarding the formation of precipitate in the ILRS system.

The ILRS system has been monitored since installation. Monitoring conducted by CMS to effectively operate the system includes both Work Plan and non-Work Plan data. The Work Plan required operational monitoring includes the following:

- Daily leachate volume collected
- Daily composite leachate pH
- Lake Michigan lake elevation

In addition to the required monitoring parameters described in the Work Plan, additional parameters are monitored to further assist in understanding and optimizing the existing ILRS. These non-Work Plan parameters are the following:

- Collection trench piezometer pH
- Collection trench piezometer elevations
- Leachate analytical quality
- Collection trench solids quality
- Lakeshore pH

Table 2-1 and Table 2-2 show the daily collection rate in gallons and daily pH for each collection pipe at the Treatment Plant, respectively. The three collection drains entering the Treatment Plant include: (1) the combined flows from the Seep 2 CKD Area, Guard Rail Seep area, Pine Court Seep area (prior to July 12, 2006), and West CKD Area (Seep 2 Combined Flows); (2) a dedicated line from the Seep 1 CKD Area; and (3) a dedicated line from the Edge Drain..

2.2.4.1 ILRS Leachate Flow Monitoring

The data from all flow meters is collected and stored electronically at the Treatment Plant.

ILRS Collection Drain	Date of Operation	Data Summary Location	Location of Flow Monitoring	Daily Average (gpd)	Maximum Collection Rate (gpd)	Date of Maximum Collection Rate and Comments
Edge Drain	July 6, 2006 to May 31, 2009	Figure 2-2c	Treatment Plant	19,278	30,513	October 30, 2006 after numerous rain events
Seep 2 Combined	October 10, 2005 to May 31, 2009	Figure 2-2b	Treatment Plant	36,262	131,599	April 11, 2008 (combined flow 125,167 gallons)

ILRS Collection Drain	Date of Operation	Data Summary Location	Location of Flow Monitoring	Daily Average (gpd)	Maximum Collection Rate (gpd)	Date of Maximum Collection Rate and Comments
Seep 1 CKD Area	October 10, 2005 to May 31, 2009	Figure 2-2d	Treatment Plant	24,120	80,920	May 16, 2009 (0.82" of rain in 4-days) and increase in collection from Seep 1-East after barrier wall installation)
West CKD Area	June 9, 2006 to May 31, 2009	Figure 2-2a	West CKD Area lift station	15,600	50,455	March 26, 2007 during a snowmelt event (6 days above 32°F) and rain of 1.5 inches over 5 days (including a 0.6 inch event on March 26, 2007).
Pine Court Area	May 1, 2009 to May 31, 2009	--	Based on Manifests	7,597		

Between December 4, 2007 and July 7, 2008 West CKD Area flows recorded were found to be an overestimate of actual flows as a result of a programming issue with the flow meter (backflow through the meter was not considered). Also, between December 4, 2007 and October 27, 2008 flows greater than 50 gpm were not recorded by the flow meter due to a programming problem resulting in a potential underestimate of West CKD Area flows.

All flows show a seasonal trend of the highest flows in the spring, while decreasing throughout the summer finishing with fall increases. Flow correlates directly with rainfall/snowmelt and the regional groundwater elevation. All drains exhibited a flow increase response as a result of snowmelt and rainfall. The greatest and least responsive in terms of rate of flow increase due to rainfall/snowmelt were the Pine Court Seep area and the Edge Drain, respectively.

2.2.4.2 ILRS pH Monitoring

Three pH measurements are continuously recorded for the ILRS system collection trenches: (1) Seep 2 Combined Flow (composite of West CKD Area, Pine Court (pre July 12, 2006), Guard Rail, and Seep 2 CKD Area), (2) Edge Drain, and (3) Seep 1 CKD Area. Daily pH measurements are also recorded for the TLC System. These measurements are summarized on Figure 2-3a.

The pH for the Seep 2 Combined Flows varied between approximately 9 and 12 and was always the lowest pH of those measured. By contrast, the Edge Drain pH and the TLC pH are typically the highest, ranging from approximately 12.5 to 13.5. The Seep 1 CKD Area collection trench pH ranged from approximately 12 (once in-service) to 13.5 during the winter of 2006/2007. The highest Seep 1 CKD Area pH measurements correlate with high trench elevations in January and February 2007, due to a plug in the collection trench

The data show an annual cycle in terms of long-term average pH decreasing in summer and increasing in the winter for all collection trenches through the summer of 2008. This trend is obscured in the composite pH for the Seep 2 CKD Area prior to July 2006 as a result of flow contributions from the Pine Court Seep area which exhibits a pH in the collection trenches between 9 and 10. Essentially, Pine Court leachate dilutes Seep 2 CKD Area and West CKD Area leachate mixtures within the forcemain piping and lift stations. In the winter of 2008/2009 pH levels continued to decline in the Seep 2 CKD Area Combined Flows.

In addition, to the annual cycle, sharp pH reductions are evident and correlate well with rainfall and snowmelt. This can be seen in all three measurements for several wet periods, in the middle of October 2006, snowmelt in mid-December 2006, snowmelt early- to mid-March 2007, and mid-November 2007.

Numerous smaller order effects can be seen in the variability around the long-term seasonal trend, these are attributed to smaller rainfall events, clean water used during jetting and collected within the trenches, and/or smaller Lake Michigan elevation changes.

The ILRS shows a seasonal pH trend, with high pH in the winter attributed to reduced regional dilution and the temperature dependency of alkaline salt solubility observed at other similar sites (Roadcap, et. al., 2005). Other significant effects, observed on shorter timescales, are rainfall/snowmelt, Lake Michigan elevation, and leachate elevation impacted by precipitate build-up.

2.2.4.3 ILRS Piezometer pH

Piezometer pH is monitored within the collection trenches for the purpose of operational and Site characterization. The pH data is used to assess Site seasonality and whether overflow weir structure adjustment is warranted within segments of the ILRS. Locations of piezometers are provided on Figures 2-1b through 2-1f. Piezometer, valve box, and standpipe construction information is summarized in Appendix 2-4. West CKD Area, Pine Court Seep area, Guard Rail Seep area, Seep 2 CKD Area, and Seep 1 CKD Area piezometer pH data are illustrated on Figures 2-4a to 2-4e and the data are summarized in Tables 2-3a to 2-3e.

ILRS Location	Piezometer	Comments
West CKD Area	WCKD-PZ1	pH generally between 12 and 13
	WCKD-PZ2	Seasonal variations with elevated pH in fall/winter (~11 to 12.5) and lower pH in summer (~ 9 to 10.5 except in May-July 2007 when pH values peaked at 12.5). This trend is similar to the groundwater pH variations in adjacent well W3119.
	WCKD-PZ3 and WCKD-PZ4	pH generally between 11 and 13.
	WCKD-PZ5	pH generally between 10.9 and 13 except during June-October 2006 when pH was 7 to 11. This pH increase is likely due to the expansion of the WILRS in October 2006.
	WCKD-PZ6	Seasonal variations with pH 7.5 to 9 in the winter/spring and 9 to 11.5 in the summer/fall.
Reconstructed WILRS (since May 2009)	WCKD-PZ1N and WCKD-PZ6R	pH generally between 11 and 13.
	WCKD-PZ2R, WCKD-PZ3R, and WCKD-PZ4R	pH generally between 10 and 12.
	WCKD-PZ7R	pH generally ~8.
Pine Court	PC-PZ1 and PC-PZ3	Some seasonal variation with pH values generally <8.5 June - October and a wider variation the remainder of the year (6.5 to 10.5).
	PC-PZ2	pH values from 8 to 10 during the first half of 2006, followed by a decrease in pH (6 and 7) during the summer of 2006 through September 2007 due to the operation of the CO_2 Pilot (Appendix 2-3). After October 2007 pH varied seasonally (<8 in the summer and 8 to 10 in the fall, winter, and spring).
	PC-PZ5	pH generally between 7 to 9 with no indication of seasonal variation.
	PC-PZ4	Decrease in pH during the first half of 2006 and then generally between 7 and 8.

ILRS Location	Piezometer	Comments
Guard Rail	GR-PZ1	pH decreased from an average of approximately 8.5 to 8 from November 2005 to May 2009.
	GR-PZ2	pH decreased from 9 - 12.5 to approximately 8 - 9.5 from November 2005 to May 2009.
	GRPZ-3	pH decreased from an average of approximately 9 to 8.5 from November 2005 to May 2009.
Seep 2 CKD Area	S2-PZ1	Decreasing pH trend from ~8.5 in the fall/winter of 2005 to an < 8 by May 2009.
	S2-PZ2	Decreasing pH trend from ~11 in the fall/winter of 2005 to near 9.5 in the fall/winter 2008. Summer pH values range between 8 and 10.
	S2-PZ3	Decreasing pH trend from ~9 in the fall/winter of 2005 to an average close to 8.5 by May 2009.
Seep 1 CKD Area	S1-PZ1	pH generally between 7.5 to 9.
	S1-PZ2, S1-PZ3, and S1-PZ4	Typically dry and yield less useful pH information.
	S1-PZ5 and S1-PZ6	pH generally between 11 and 13.
	S1-PZ7	pH increases in the spring and decreases in the late summer/early fall. In the spring of 2006, 2008, and 2009 S1-P7 pH values spike to values between 11 and 13 and then gradually decrease to near 9 by winter.

Piezometer leachate pH is directly affected by rainfall/snowmelt and the data show a general Site seasonality trend, where pH usually increases significantly in the winter.

2.2.4.4 ILRS Piezometer Elevation

In general, piezometer leachate elevation data was collected to further understand the ILRS operation and Site characteristics. Data from September 2005 through January 2006 was collected during significant construction and initial start-up phases of the ILRS system. As such, there is significant influence from construction, operational evaluation, and start-up which is not representative of data collected after January of 2006. Elevation data after January 2006 are more representative of typical observations and are controlled by either overflow weir structures identified as ‘valve boxes’ or stand pipes. Piezometer leachate elevation data are provided in Tables 2-4a through 2-4e and on Figures 2-5a through 2-5e.

ILRS Location	Piezometer	Comments
West CKD Area	WCKD-PZ1 and WCKD-PZ2	Completed in December 2005 and show leachate elevations ranging from 576 to 578.5 feet MSL. Typically remain near or below lake level.
	WCKD-PZ3, WCKD-PZ4, and WCKD-PZ5	Installed in May 2006, and show overall leachate elevations ranging from 576.5 to 577.5 feet MSL. Typically remain near or below lake level.
	WCKD-PZ6	Overall leachate elevations ranging from 577 to 580 feet MSL. This portion of the WCKD-West collection trench was obstructed initially after construction and again in March 2008 due to precipitation. Subsequent cleaning of the collection line allowed leachate elevation to lower to near 577 feet MSL.
Reconstructed WILRS (since May 2009)	WCKD-PZ1N, WCKD-PZ2R, and WCKD-PZ3R	In the bedrock portion of the WILRS. Leachate elevations are approximately 576.5 feet MSL.
	WCKD-PZ4R, WCKD-PZ5R, WCKD-PZ6R, and WCKD-PZ7R	In the unconsolidated portion of the WILRS, leachate elevations are approximately 577.0 feet MSL.
Pine Court	PC-PZ1, PC-PZ2, PC-PZ3, PC-PZ4, and PC-PZ5	Leachate elevation between ~576.5 to 579 feet MSL from the in-service date through July 2006. The leachate elevation range is greater compared to the other seep areas and is the result of high responsiveness to rainfall/snowmelt events and frequent precipitate that occurred within the Pine Court ILRS. In July 2006, the Pine Court-East drain was converted to the CO2 Pilot. As a result, the Pine Court elevations show seasonal fluctuations with leachate elevations ranging from 578 to 580 feet MSL from July 2006 through April 2009. These fluctuations are directly related to rainfall/snowmelt events. Collection from both the Pine Court-East and Pine Court-West collection drains resumed May 1, 2009 and piezometer elevations have been at approximately 579 feet MSL.
Guard Rail	GR-PZ1 and GR-PZ2	Leachate elevations range from 577.5 to 578.5 feet MSL and are near lake level during the summer months and ~0.5 feet above the lake level in winter/spring months.
	GRPZ-3	Leachate elevations range from 578.5 to 579.5 feet MSL and are near lake level during the summer months and ~0.5 feet above the lake level in winter/spring months.
Seep 2 CKD Area	S2-PZ1 and S2-PZ2	Leachate elevations range from 576 to 577 feet MSL with several short-term high and low fluctuations. Data show little correlation with local rainfall/snowfall patterns. Precipitate forms within the collection drain particularly at the overflow weir structures and in piping from the overflow weir structure to the lift station. When precipitate forms to a significant degree, leachate elevations increase until subsequent cleaning/jetting is performed.

ILRS Location	Piezometer	Comments
	S2-PZ3	Leachate elevations range from 577 to 578 feet MSL. Data show little correlation with local rainfall/snowfall patterns. Precipitate forms within the collection drain particularly at the overflow weir structures and in piping from the overflow weir structure to the lift station. When precipitate forms to a significant degree, leachate elevations increase until subsequent cleaning/jetting is performed.
Seep 1 CKD Area	S1-PZ1 and S1-PZ5	Leachate elevation typically at or below lake elevation ranging from approximately 576.5 to 577.5 feet MSL. The exception is in the winter of 2007/2008 when lake levels dropped below 576.5 feet MSL resulting in S1-PZ1 and S1-PZ5 elevations greater than 0.5 foot above lake elevation.
	S1-PZ2, S1-PZ3, and S1-PZ4	Typically dry and can only record data during short-term increases in leachate elevations typically from precipitation build-up in the collection trench.
	S1-PZ6 and S1-PZ7	Leachate elevation between 577 and 578.5 feet MSL (generally at or somewhat above lake elevation). Exceptions are the winter of 2007/2008 when lake levels dropped below 576.5 feet MSL resulting in S1-PZ6 and S1-PZ7 elevations one foot above lake elevation and May 2009 following construction of the barrier wall when S1-PZ6 & S1-PZ7 elevations were maintained one foot below lake elevation.

2.2.4.5 ILRS Leachate Quality

Non-Work Plan samples were collected to characterize further the leachate quality in the various segments of the ILRS. One sampling event (April) was in 2006 and three sampling events (March, June, and August) were conducted during 2007. Samples were collected from the elevation control structures (e.g., valve boxes) located on each individual collection trench segment. The analytical results are provided in Tables 2-5a through 2-5g. Leachate quality samples were taken at the TLC system S2RW-1, and are provided in Table 2-5h. Additionally untreated leachate samples were obtained from the frac tanks at the Treatment Plant (Table 2-5i).

Quality of leachate was found to be scale forming with respect to calcium carbonate, however, to varying degrees in each collection trench. Chemical equilibrium modeling conducted on leachate stability is provided in Appendix 2-6. The samples were also used to determine the constituents in the leachate as further discussed in Section 6.2. Additionally, leachate quality samples were used in evaluating the mass of COC removed from the Site by the ILRS.

2.2.4.6 Collection Pipe Precipitate Characterization

Precipitation samples collected from the West CKD Area lift station pump and the Seep 2 CKD Area forcemain were obtained in January and April 2006, respectively. The WCKD Pump sample was collected to assess the materials which had collected on the pump shortly after initial West CKD Area ILRS construction. This sample was wet, black in color, and soft. The WCKD Pump sample contained approximately 34% by dry weight calcium. The sample collected from the Seep 2 CKD Area forcemain was much harder and dark brown to black in color. This sample contained 31% calcium, less than 13,000 μg/kg sulfate, aluminum (0.05%), and silicon (0.04%). Both samples became reddish to light brown in color and friable once air dried.

The high dry weight of calcium and low sulfur, aluminum, and silicon supports a calcium carbonate precipitation. Clearly, the leachate at the West CKD Area is unstable as well as mixtures of West CKD Area with any leachate from Pine Court Seep area, Guard Rail Seep area, and/or Seep 2 CKD Area. Table 2-6 summarizes the solids analytical results.

2.2.4.7 Operational Lakeshore pH

Monitoring of the lakeshore pH has been conducted at the Site to assess the operational performance of the ILRS during various conditions observed at the Site. Operational lakeshore pH monitoring is not required by the Work Plan; however, the data are useful with regard to understanding ILRS performance. For example, effectiveness monitoring can only be conducted during calm lake conditions as defined in the Work Plan (≤ 2-inch waves). The wave condition of two inches or less is not usual for the average wave condition of Lake Michigan. The operational monitoring has provided additional pH observations at times with waves greater than two inches. The data providing operational lakeshore pH data are provided in Appendix 2-7.

In general the data shows the continued effectiveness of the ILRS and is used by the ILRS operators in operating and maintaining the ILRS.

2.2.5 Management of Recovered Leachate

Recovered leachate is currently managed off-site at licensed disposal facilities. Section 4.2.4.1 of the Work Plan requires that CMS must demonstrate compliance with all applicable laws, regulations, and U.S. EPA guidance in writing to U.S. EPA prior to disposal at a publicly owned treatment works (POTW) or elsewhere. Copies of the disposal facility approval letters are included in Appendix 1-1.

2.2.6 Effectiveness Monitoring

Investigation activities at the Site are called either "monitoring" or "sampling." Monitoring is generally considered to be field measurements. Sampling is generally considered to be the collection of samples for laboratory analyses. As the laboratory analytical results from the sampling events do not factor into the ILRS effectiveness, they are discussed in subsequent sections of the report.

The Work Plan contains two sections relating the requirements of monitoring the ILRS, namely, Section 4.2.5.1 Effectiveness Monitoring and Section 4.2.5.2 Monitoring Program. ILRS effectiveness monitoring is conducted in accordance with the Work Plan, as amended. The elements of effectiveness monitoring include:

- Documentation of onshore accumulation zones (i.e., pools).
- Monitoring surface water downgradient of seep area.
- Aerial overflights – see Section 2.1.3.

The Work Plan effectiveness monitoring has been modified to reduce the frequency of surface water monitoring events (specifically one event in early spring and one in late fall) downgradient of those seep areas which U.S. EPA has determined to be acceptable. U.S. EPA approval was confirmed via CMS email dated July 31, 2007. These seep areas with a reduced frequency of surface water monitoring include: West CKD, Seep 2/Guard Rail—entire ILRS, and Seep 1—except the eastern 200 feet.

All other remaining segments of the ILRS are monitored on a monthly basis as environmental conditions permit. In addition, all pH monitoring of pools and surface water is conducted according to the Site QAPP.

Effectiveness monitoring of surface water at the seep areas has been conducted in accordance with the Work Plan. Lakeshore effectiveness monitoring pH measurements were not collected during ice over. They were collected during dry weather and as feasible during wave height conditions less than two inches. Specifically, the conditions which produce waves at the shoreline less than two inches are not common in this section of Little Traverse Bay, and at times are short in duration not allowing an effectiveness monitoring event to be completed during the same day in some instances. Effectiveness of the ILRS is a function of the following parameters:

- Wave height, i.e., controlling mixing of discharge with Lake Michigan water.

- Lake Michigan elevation, i.e., affects hydraulic gradient into and out of the near shore zone and attenuation distance as the shoreline varies throughout lake stage.
- Rainfall and snowmelt, a greater volume of leachate over a wider lakeshore extent is observed following recharge events.
- Elevation of liquids in the collection trench, affects groundwater in and below the collection trench affected by overflow weir settings and/or precipitate build-up.
- Elevation of regional groundwater table, affects hydraulic gradient and flow paths near shore discharge.
- Hydraulic conductivity of the subsurface media between the collection trench and lakeshore, in particular small scale heterogeneity.

Effectiveness monitoring data summaries and figures for both lakeshore and pools pH are presented in Appendix 2-8. Tables are included which show the dates of effectiveness monitoring events, total number of lake samples, and summary of pH measurement ranges. Most of the data points collected show the continued effectiveness of the ILRS. The occasional and low-level exceedances do not pose any threat to public health and safety or the environment. As the recently augmented areas of the ILRS continue to operate, CMS expects to see a continued decline in the number of pH exceedances.

2.2.7 Operation and Maintenance Plan

The operation of the ILRS is based on control of the liquid level within the collection trenches. The liquid elevation in the collection trench is manually adjusted to achieve the AOC goal. An operations and maintenance (O&M) plan (Barr, 2007b) has been prepared which provides additional information regarding the ILRS operation and maintenance. This O&M plan was prepared in accordance with Section 4.1.6 of the Work Plan and was submitted to U.S. EPA on December 14, 2007.

2.2.8 Interim Recovery System Contingency Plan

An interim recovery system contingency plan was prepared for the Site in accordance with Section 4.2.7 of the Work Plan. This plan was submitted to the U.S. EPA on September 29, 2005.

3.0 Study Area Investigation

3.1 Investigation Activities

Building on the results of the preliminary non-intrusive data gathering and water quality survey as discussed in Section 1.3.4 and IR construction observations; the RI activities at the Site focused on data collection via borehole and well placement, down-hole geophysical methods, aquifer and surface water testing, sampling and analysis and by non-intrusive methods (e.g., mapping, targeted shoreline water quality survey).

Field activities were generally performed according to procedures presented in the Work Plan (Barr, 2005c), Supplemental Investigation Activities document (Barr, 2007a), West CKD Beach Area Delineation and Characterization Plan (Barr, 2005f), and Surface Water/Water Cycle Monitoring Work Plan (Barr, 2006a). If a specific activity could not be completed as proposed in the Work Plan (e.g., utilities or slope precluded placing a borehole at the location presented in the Work Plan), Barr consulted with U.S. EPA Environmental Response Team (ERT) staff prior to deviating from the Work Plan. These field changes and consultations were documented in the geologist field notes, via e-mail communications, or by field memoranda (Appendix 1-1).

Site field activities were completed according to the Site-specific Quality Assurance Project Plan – Revision 1.0 dated April 26, 2005, Addendum 1.0 dated August 5, 2005, and Addendum 2.0 dated September 8, 2006 (QAPP) (Barr, 2005d), the Project Health and Safety Plan – Revision 4.0 dated August 31, 2005 (Revision 5.0 dated May 1, 2006) (PHASP) (Barr, 2005b), and the SCAMP Revision 1.0 dated April 4, 2005 (Barr, 2005a). The QAPP and PHASP were approved by the U.S. EPA in letters dated May 4, 2005. The SCAMP was approved in a letter dated April 19, 2005 becoming effective upon approval of the PHASP on May 4, 2005. In addition, all investigation and related work was completed according to Barr's Quality Management Plan (QMP) for Data Collection and Management of Contaminated Site Assessment and Remediation Projects (Barr, October 3, 2003) which was approved by Ida Levin, U.S. EPA in an October 1, 2003 memorandum to Tim Drexler, U.S. EPA Remedial Project Manager. All letters documenting U.S. EPA modification requests and approvals are included in Appendix 1-1.

The Site investigation kick-off meeting and Site visit was held on August 17, 2005.

3.1.1 Surface Features

3.1.1.1 Surveys

Topographic and locational surveys were conducted at the Site as proposed in Section 5.2.1 of the Work Plan (Barr, 2005c). Borehole and monitoring well location and topographic data are summarized in Tables 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 1 CKD Area, and Seep 2 CKD Area, respectively.

Topographic Survey

Aerial photogrammetric methods were used to obtain a topographic map of the Site and sufficient area around the Site to facilitate investigation of potential Site impacts and design of potential remedies. The mapping was completed in accordance with national map standards and shows spot elevations and surface elevation contours, buildings, roads, vegetation area limits, water bodies, and other significant Site features visible from aerial photography. Mapping was completed based on the state plane coordinate system (NAD 83) and MSL vertical datum (NAVD 88) at a scale suitable for the intended uses. The survey was flown by Air-Land Surveys on April 5, 2005, while the control survey was completed in the fall of 2004.

In general, the ground surface at the Site slopes from south to north (toward Lake Michigan). The regional topography as it existed in 1983 after cement plant operations were discontinued, but prior to redevelopment of the Site, is shown on Figure 1-3 (USGS, 1983a; b). Based on the lakeshore slopes in the surrounding area, it is likely that the pre-development topography at the three CKD areas sloped gently downward toward Lake Michigan, with the slope becoming steeper and forming a bluff or steep slope in the vicinity of the lakeshore.

Plan views of the current topography at the West CKD Area, Seep 1 CKD Area, and Seep 2 CKD Area are shown on Figures 3-1a to 3-1c.

Locational Survey

Borehole, monitoring well, and water measurement locations were surveyed using either a Trimble Pro-XRS backpack GPS system or a 4700/4800 Trimble GPS Real-Time Kinematic unit. The Trimble Pro-XRS GPS unit is a mapping-grade GPS receiver capable of sub-one meter accuracy. Ground surface elevations were measured using the Trimble GPS RTK which is accurate to less than 1/10 foot vertical. Top-of-well-casing elevations were surveyed using traditional rod and level survey methods.

Survey control for the Site was established using control points published by the National Geodetic Survey (NGS). Horizontal survey control is based on North American Datum of 1983 Michigan State Plane Coordinates. Vertical survey control is based on North American Vertical Datum of 1988. Specific control points used at the Site include permanent identifier numbers (PID) QK0453, QK0451, and QK0450. Additional information on control points established by the NGS can be found at the NGS website (NGS, 2007). The ground surface elevation at each boring location was surveyed to the nearest 0.1 foot, and the groundwater elevation measuring point was surveyed to the nearest 0.01 foot. After wells were installed, the ground surface and top-of-casing elevations were surveyed relative to the Site benchmark to the closest 0.1 foot and 0.01 foot, respectively. For all Site wells, the groundwater elevation measuring point was the top of casing on the north side of the well.

3.1.1.2 Aerial Thermometry Survey

Water temperature mapping was attempted as proposed in Section 5.2.2 of the Work Plan (Barr, 2005d). An aerial thermometry survey was performed by Argon ST, Inc. in an attempt to identify any preferred zones of subsurface water discharge to Lake Michigan. This aerial survey included infrared and visual imagery of the near-shore lake areas along the shoreline of the Site. Data from the May/June 2005 survey are provided in Appendix 3-1. Results are shown on figures contained in this appendix.

The aerial thermometry survey was intended to provide additional information on the subsurface water and surface water interaction in the vicinity of the CKD disposal areas. The thermometry survey did not prove to be very useful in detecting the presence of preferred subsurface water discharge zones into Lake Michigan. A report was prepared and submitted to the U.S. EPA on September 1, 2005 discussing the technical interpretation of the aerial thermometry survey results. The report included discussion of the reasons why the aerial thermometry survey was not effective. A copy of this report is included in Appendix 3-1.

3.1.2 Contaminant Source Investigations

Investigation boreholes and monitoring wells, designed to determine the extent and character of the CKD material and leachate which constitute the contaminant source at the Site, were completed as proposed in Sections 5.2.3 and 5.2.4 of the Work Plan (Barr, 2005c). The boreholes also characterized the soil at the Site. Boreholes advanced by rotasonic, direct push (Geoprobe®), and hand auger drilling techniques were used to characterize and define the extent, thickness, and degree of saturation of the unconsolidated material at the Site. Unconsolidated material consists of both

CKD and non-CKD material. Borehole locations are shown on Figures 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Many of the rotasonic boreholes were subsequently completed as monitoring wells. Monitoring well locations are shown on Figures 3-2a, 3-2b, and 3-2c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. The following table outlines the number of borings and monitoring wells by area:

	West CKD Area	Seep 2 CKD Area	Seep 1 CKD Area
Proposed number of borings	20	52	33
Actual number of borings	76	98	45
Number of well nests	11	39	23
Number of wells in nests	43	126[a]	85
Number of temporary wells	5[b]	1	1
Number of well nests abandoned	0	1	3

[a] Includes one 6-inch well
[b] Temporary wells were 1-inch in diameter

Nomenclature

As discussed in sections 5.2.3 and 5.2.4 of the Work Plan (Barr, 2005c), boreholes and monitoring wells were identified using the following format: Bxzyy, or Wxzyy. In this numbering scheme, B indicates a borehole, and W indicates a monitoring well. The letter x is a number from 1 to 4 which identifies the area that the borehole or monitoring well was completed in – “1” means that the borehole was completed in the Seep 1 CKD Area, “2” indicates the Seep 2 CKD Area, “3” indicates the West CKD Area, (and “4” indicates the East CKD area). The letter z is a number that identifies a particular well in a nest, from shallowest to deepest, and yy refers to the sequential borehole or monitoring well number. For example, “W2325” identifies a monitoring well in the Seep 2 CKD Area, the third deepest well in the nest, at monitoring well location 25.

Unconsolidated material and water/leachate samples were collected and analyzed to define the chemical and physical properties of the contaminants as described in Section 5.3 of the Work Plan (Barr, 2005d). The only contaminants identified at the Site are those associated with the CKD piles. Naturally occurring (e.g. TDS, magnesium) and background level (e.g. chloride, mercury) general parameters and metals were also observed at the Site. Tables 3-2a, 3-2b, and 3-2c were prepared to summarize the following: quantity of samples, sampling location, sample date, and analyses performed for each sampled matrix (i.e., CKD, unconsolidated soil, bedrock, surface water, creek water, monitoring well water, and borehole testing water).

3.1.2.1 Unconsolidated Material Sampling (CKD and Non-CKD)

Unconsolidated materials (including soil) were collected and analyzed to define the chemical and physical properties of the materials. These materials were described in the field by a qualified geologist, technician, or geological engineer as discussed in Section 5.2.3 and 5.3.3 of the Work Plan (Barr, 2005d). Non-CKD unconsolidated materials and soil were described according to American Society for Testing and Materials (ASTM) D2488 and CKD was generally described according to the standard procedure described in the QAPP (Barr, 2005b). CKD materials are identified by the "FL" identifier on the borehole logs. Unconsolidated materials were examined for moisture content and pH in the field. Representative samples of non-CKD and CKD material were collected and analyzed for both chemical and physical properties.

Chemical Property Analyses

The proposed number of CKD and non-CKD samples from each area to be analyzed for chemical properties were presented in Section 5.3.1.1 and Section 5.3.3.1 of the Work Plan (Barr, 2005d). Samples for chemical analyses were collected directly from the core samples and placed in laboratory supplied containers. Sample containers were labeled with boring number, depth interval, and date and time of collection. Samples were shipped to TriMatrix Laboratories on ice following chain-of-custody procedures. Samples were analyzed for the volatile organic compound (VOC), semi-volatile organic compound (SVOC), metals, and other parameters shown in Table 3.3. More samples were analyzed than planned with the exception of CKD samples collected at the Seep 2 CKD Area. At the Seep 2 CKD Area, 17 CKD samples were proposed and 16 were analyzed, this was appropriate due to the homogenous nature of the CKD. Overall, more unconsolidated samples were analyzed than required by the Work Plan. The following table summarizes the planned and actual numbers of unconsolidated samples analyzed for chemical properties:

Area	Number of CKD Samples		Number of Non-CKD Samples	
	Planned	Actual	Planned	Actual
West CKD Area	11	18	11	29
Seep 2 CKD Area	17	16	17	29
Seep 1 CKD Area	12	12	12	18

Results of chemical property analysis for CKD and non-CKD samples are discussed in Section 5.0.

Physical Property Analyses

The proposed number of CKD and non-CKD samples from each area to be analyzed for physical properties were presented in Section 5.3.1.2 and Section 5.3.3.2 of the Work Plan (Barr, 2005d). Samples for physical property analyses were collected either from the core samples and placed in cloth soil bags or concrete cylinders, or collected with a split barrel sampler lined with a brass collection tube. Brass collection tubes were capped and samples were submitted to the laboratory in the tubes. Attempts were made to collect samples of unconsolidated material with a thin-walled sampler (Shelby Tube), however, the material was too stiff or dense and the thin-walled samplers were crushed. Physical property samples were labeled with the boring number, depth interval, and collection date and submitted to Soil Engineering and Testing (SET) for analyses. Tests performed on these samples included porosity, vertical and horizontal permeability, unconsolidated undrained (UU) triaxial compression, and grain size distribution. Test procedures were conducted according to ASTM test methods D5084, D5856, D2434, D2850 and D422, as appropriate. Additionally, tail water from a permeability test conducted on a West CKD Area augmentation design sample was analyzed for pH by SET using the ASTM test method 4972.

Less physical property samples were analyzed than planned, this was appropriate due to the homogenous nature of the CKD and the limited amount of non-CKD unconsolidated material encountered. The following table summarizes the number of samples planned for analyses at each area, and the number of samples actually analyzed:

	Number of CKD Samples		Number of non-CKD Samples	
Area	**Planned**	**Actual**	**Planned**	**Actual**
West CKD Area	11	10	11	18
Seep 2 CKD Area	17	13	17	12
Seep 1 CKD Area	12	8	12	13

The results of physical property testing are summarized in Section 4.5.

3.1.2.2 Leachate

Vertical aquifer sampling (vertical profiling - pH and specific conductivity) was conducted as the boreholes were advanced for the purpose of characterizing the vertical extent of CKD leachate using procedures defined in Section 5.2.5.2 of the Work Plan (Barr, 2005c). Vertical aquifer sampling conducted after October 23, 2005 was completed according to a modified procedure approved by

U.S. EPA ERT staff. A copy of the "Proposed Modifications to Drilling Program" procedure is included in Appendix 1-1. Additionally, leachate and groundwater samples were also collected from the Site monitoring wells after installation and development to evaluate their quality as per Sections 5.2.4 and 5.3.5 of the Work Plan (Barr, 2005c).

Samples were collected from the boreholes for laboratory analyses when borehole packer interval testing was conducted in rotasonic boreholes from August 2005 through March 2006. Borehole packer interval sampling/aquifer testing was performed according to procedures presented in Section 5.2.5.2 of the Work Plan, and then according to the modified procedures approved by U.S. EPA ERT staff after Sept. 29, 2005. Samples were not collected when packer intervals went dry before stabilization was complete, or when stabilization could not be achieved as pH measurements continued to decline as pumping was conducted; however, these events were rare. Samples were not collected for laboratory analyses during the Supplemental Investigation in 2007 and subsequent investigations when packer interval testing/aquifer testing was conducted or when borehole packer interval testing was not conducted in a borehole. Samples were analyzed for the parameters listed in Table 3-3. Samples were collected from 144 borehole locations at the time the boreholes were drilled: 25 from the West CKD Area, 76 from the Seep 2 CKD Area, and 43 from the Seep 1 CKD Area.

3.1.3 Meteorological Investigation

A meteorological station was installed and has been in service at the Site since July 20, 2006. Climatic conditions at the Site are monitored with a Campbell Scientific UT10 Weather Station. The weather station's monitoring equipment consists of an R.M. Young 05013 Wind Monitor, an Apogee CS300 Pyranometer, a Campbell Scientific CS215 Temperature and Relative Humidity Probe, a Vaisala CS105 Barometer, a Met One 385 Rain and Snow Gage, and a Campbell Scientific CR 1000 Measurement and Control Data Logger. The weather station's anemometer measures wind speed and wind direction from a height of approximately three meters above the ground surface. Figure 3-3 shows the individual components of the weather station and its location relative to the Site. This meteorological station was installed at the Bay Harbor equestrian center approximately 2,500 feet southeast of the center of the Seep 2 CKD pile.

Meteorological data including wind speed and direction, solar radiation, air temperature, relative humidity, barometric pressure, and rainfall/snowfall is collected in 15 minute intervals. The weather station is programmed to output daily and hourly averages from the 15 minute data. Daily peak

measurements for total rainfall/snowfall, wind speed, and temperature are also recorded. A table of daily measurements of temperature, wind speed, solar radiation, relative humidity, and calculated Site-specific potential evapotranspiration (ET) for the study period is included in Appendix 3-2a.

The data were used along with stream runoff data to calculate infiltration and ET estimates that are specific to the Site for the study period. Estimates of infiltration and ET that are based on long-term temperature averages vary from the Site specific estimates.

The weather station temperature and rainfall/snowfall data collected at the Site were compared with City of Petoskey data from the Midwest Regional Climate Center (MRCC) for the same time period, and this table is located in Appendix 3-2a. The City of Petoskey monthly average temperatures are generally slightly warmer than at the Site. Monthly rainfall/snowfall totals for the Site and City of Petoskey show good agreement being within at least 0.1-0.5 inches of each other. During the winter season of December 2006-February 2007 the Site rain gauge experienced a malfunction that prevented the measurement of the water equivalent snowfall explaining the large decrease in rainfall/snowfall at the Site compared to the City of Petoskey during the early winter of 2007. Therefore, the City of Petoskey data is considered during this period rather than Site data.

Wind roses were produced for the Site and nearby weather stations:

Location	Date Range	Dominant Wind Direction	Average Daily Wind Speed	Direction from the Site	Distance from the Site
Site	2007 - 2008	Southerly and northwesterly	6.66 mph at 3 meters above the ground	--	--
Traverse City	1996 - 2007	Northerly and southwesterly	7.1 mph	Southwest	56 miles
Gaylord	1998 - 2007	Westerly and southwesterly	7.9 mph	Southeast	30 miles
Pellston	2000 - 2007	West and northwesterly	7.7 mph	Northeast	19 miles

The wind roses can be found in Appendix 3-2a and the data used to generate them are in Appendix 3-2b on the CD included with this report.

The wind data were considered in the evaluation of Lake Michigan elevations and lakeshore mixing.

Monthly temperature and rainfall/snowfall data provided by the NCDC (2004-2005) for the cities of Petoskey and Pellston, Michigan are summarized and included in Appendix 3-2a. National Oceanic and Atmospheric Administration (NOAA) records for the 30-year period 1970 to 2000, measured at Alpena, Houghton Lake, and Grand Rapids, Michigan (NOAA, 2005) are also included in Appendix 3-2a.

While the climate in the region surrounding the Site is moderated by the adjacent Lake Michigan, annual temperatures range from as high as 99 degrees Fahrenheit (°F) to as low as -19 °F seasonally. The annual average maximum temperature is 53 °F and the annual average minimum is 36 °F based on 1952 to 1980 measurements recorded at the Petoskey, Michigan meteorological station (Michigan State Climatologist, 2005). The region receives between 27 and 35 inches of precipitation annually, based on NOAA records for the 30-year period 1970 to 2000, measured at Alpena, Houghton Lake, and Grand Rapids, Michigan (NOAA, 2005).

Based on historical records, the greatest amount of precipitation occurs from July through November. The lowest precipitation months are typically February and March. During December through early March the ground is generally frozen and, therefore, the majority of precipitation infiltration to groundwater must occur during the period from April through November.

3.1.4 Surface Water Investigations

The following surface water assessments were conducted: targeted shoreline surveys (discussed in Section 2.1.2), lake/pool surface water sampling, creek monitoring and sampling, water cycle monitoring, effectiveness monitoring (discussed in Section 2.2.6), golf pond assessment, Bay Harbor Lake assessment, overflights (discussed in Section 2.1.3), and golf course drain inventory.

3.1.4.1 Lake/Pool Surface Water Sampling

Surface water samples were collected as part of the targeted shoreline water quality surveys as required by Sections 5.2.6.2 and 5.3.6 of the Work Plan (Barr, 2005c) and the U.S. EPA May 2, 2005 approval letter. The surface water samples were collected both from Lake Michigan and the pools on the beach adjacent to each of the CKD areas. One of the samples collected from Lake Michigan was from a location where the pH was $\leq$ 9.0. The other four samples were collected where the pH was > 9.0. The monitoring and sampling was completed during times of calm winds and wave heights of less than two inches.

Surface water samples were also collected as part of effectiveness monitoring as required by Section 4.2.5.1 Effectiveness Monitoring and Section 4.2.5.2 Monitoring Program of the Work Plan (Barr, 2005c).

Sample locations are shown on Figures 3-4a, 3-4b, 3-4c, and 3-4d for West CKD Area, Seep 2 CKD/Guard Rail Seep Area, Pine Court Seep area, and Seep 1 CKD Area, respectively. The samples were collected following the methods described in 5.3.6 of the Work Plan (Barr, 2005c). These samples were analyzed for the list of metals (total concentrations) and general parameters shown in Table 3-3. These surface water data are discussed in Section 5.3.

3.1.4.2 Creek Monitoring and Sampling

In an effort to provide data for the development of the Site hydrogeologic model, creek monitoring and sampling were conducted in accordance with Sections 2.1.1 and 2.1.2 in the U.S. EPA-approved Surface Water/Water Cycle Monitoring Work Plan Revision 1.0 (Barr, 2006a). The monitoring was triggered by specific climatic events listed below.

- Spring Thaw – defined as conditions where greater than 1 inch of water equivalent snow pack is present and air temperatures exceed 40°F for at least 12 hours over 48 hours (one corresponding monitoring/sampling event).
- Moderate Rainfall – defined as ¼-inch to 1-inch rainfall event within a 12-hour period (two corresponding monitoring/sampling events).
- Heavy Rainfall – defined as >2-inch rainfall event within a 12-hour period (one corresponding monitoring/sampling event).
- Baseline Conditions – defined as no rainfall within 72 hours of monitoring/sampling (two corresponding monitoring/sampling events).

Creek monitoring for the four climatic events described above was conducted and the following parameters were recorded: pH, specific conductance, and temperature. A total of six sampling/monitoring events were completed. The measurements were taken, at approximately 25-foot intervals, starting at the discharge points of each creek at Lake Michigan extending to locations approximately 100 feet upgradient of their respective CKD piles. The approximate locations of survey points for West Unnamed Creek and East Unnamed Creek #1 are shown on Figure 3-5a and Figure 3-5b, respectively. Locations were determined using GPS methods. The

25-foot horizontal intervals between sampling points were measured using a hand-held laser range finder or a rigid spacing device. The pH, temperature, and specific conductivity of the water in the creek at the survey point were measured using a YSI Model 556 MPS Water Quality Monitoring System or instrument with equivalent capability. The field instrument was be maintained and calibrated according to the standard operating procedure for the YSI Model 556 in the QAPP and the instrument was operated according to the manufacturer's directions.

Additionally, three water samples were collected and analyzed within the West Unnamed Creek during all six of the monitoring/sampling events. For East Unnamed Creek #1, three water samples were collected on April 5, 2006, April 19, 2006 and May 18, 2006, two samples were collected on August 26, 2006, and one sample was collected on September 13, 2006. These water samples were sent to the laboratory for analysis of the metals (total and dissolved concentrations) and general parameters shown in Table 3-3. The analytical data are discussed in Section 5.3.2.

3.1.4.3 Water Cycle Monitoring

In an effort to quantify the surface-hydrology water-balance components of recharge and discharge to the saturated zone, water cycle monitoring was conducted as described in Section 5.2.6.1 of the Work Plan (Barr, 2005d). The procedures to accomplish long-term, continuous monitoring are outlined in the Surface Water/Water Cycle Monitoring Work Plan (Barr, 2006a). The specific objectives to be addressed by the data collection activities are as follows:

- Establish procedures to routinely measure pH, conductivity, temperature, flow rate, and water levels within each creek at the Site.
- Establish procedures to routinely measure pH, conductivity, temperature, and water levels within each of the screened intervals within a nested well location at each CKD area.
- Establish a means to measure water elevations in Lake Michigan on a long-term basis.

Water cycle monitoring included the routine measurement of the following parameters: pH, conductivity, temperature, flow rates, and water levels within each Site creek, and within each of the screened intervals within nested well locations. In addition, one long-term continuous water level monitoring station was established within Lake Michigan.

Creek Monitoring – Flow and Water Elevation Monitoring

As discussed in the Surface Water/Water Cycle Monitoring Work Plan (Barr, 2006b), flow and water elevation monitoring were conducted at each of the three Site creeks to provide data for the

hydrogeologic model. Specifically, data was collected to (a) determine flow conditions in response to spring thaw and rain events, (b) determine baseline flow conditions, and (c) determine if the creeks are "gaining" or "losing" hydrologically.

Existing culverts were used as flow measurement stations where available. The velocity and cross-sectional area were measured to calculate flow. The velocity was measured using a Marsh McBirney Flow Mate 2000, or equivalent. The following is a location description of the flow measurement stations for each creek:

Creek Designation Monitoring Locations

West Unnamed Creek	1. Downstream of the West CKD Area. 2. Culvert in the golf course. 3. Culvert beneath Quarry Ridge Rd.
East Unnamed Creek #1	1. Downstream of the Seep 1 CKD Area. 2. Upstream of the Seep 1 CKD Area. 3. Culvert beneath Wildwinds Dr.
East Unnamed Creek #2	1. Downstream of the East CKD Area. 2. Culvert beneath the former railroad tracks. 3. Culvert beneath Hwy. 31.

Flow and water elevations were recorded at each station at nine events on the following dates: March 24, 2006, April 3, 2006, April 6, 2006, April 18, 2006, May 18, 2006, July 19, 2006, August 4, 2006, August 25, 2006, and September 12, 2006. The four climatic events were represented during the nine monitoring events as discussed in Section 3.1.4.2. For each creek, the flows at the three stations were compared to determine if it is a losing or gaining stream at baseflow and how storm flows alter this dynamic (i.e., does it stay a gaining or losing stream and does the magnitude of the gain or loss change). Results of the creek flow monitoring are discussed in Section 4.3.2.1.

Well Nest Monitoring – Water Elevation and Temperature Monitoring

As described in the Surface Water/Water Cycle Monitoring Work Plan (Barr, 2006a), the water elevation and temperature data were collected in the well nests to (a) evaluate flow conditions in response to spring thaw and rain events, (b) quantify baseline flow conditions, (c) evaluate the relationship between groundwater elevations and surface water elevations at the Site, and (d) define the hydraulic gradients (vertically and laterally) at the Site. The monitoring began June 1, 2006 at the

minimum following locations in each CKD area: one upgradient well nest, one of the well nests within the CKD footprint, and one downgradient well nest. MiniTrolls® manufactured by In Situ, Inc. were used for this monitoring. Data were downloaded from the MiniTrolls® approximately monthly. The dataloggers were removed from the wells and placed on clean plastic sheeting prior to sampling and reset in the wells after sampling is completed. The date and location that each datalogger was put into use is presented in Table 3-4, Troll Datalogger Location Summary. Water elevations were also measured manually in all Site wells approximately monthly. Results of the monitoring are discussed in Section 4.6.1.7, Water Level and Temperature Monitoring.

Lake Michigan Elevation Monitoring

As described in the Surface Water/Water Cycle Monitoring Work Plan (Barr, 2006a), Lake Michigan water elevation monitoring has been conducted using both a staff gauge and a stilling well. The staff gauge was installed in Lake Michigan near the Seep 2 CKD Area lift station. The staff gauge was removed in January 2008 due to ice on Lake Michigan and has not been reinstalled. The staff gauge was surveyed into place relative to an existing benchmark using traditional (level) survey techniques. Lake Michigan elevations were determined by noting where the water intersects the staff gauge and calculating the corresponding water elevation. Lake Michigan elevations were recorded daily (weekday and non-holidays) during open water (non-ice cover) conditions.

The stilling well has been installed in both Bay Harbor Lake and in Village Harbor Marina, at the locations shown on Figure 3-6. The location of the stilling well during its operational periods is summarized in the table below.

Stilling Well Location

Stilling Well Location	Time Period
Bay Harbor Lake	4/23/2006 – 12/4/2007
Bay Harbor Lake	4/19/2007-11/13/2007
Village Harbor Marina	11/13/2007-1/29/2008
Village Harbor Marina	4/14/2009 – publication date of this report

The stilling well consists of a vertical PVC pipe secured to a permanent object and placed in the water. The pipe is fitted with a Level TROLL 500 pressure transducer set to record the elevation of Lake Michigan at a specified time interval. At each location, the stilling well was surveyed into place relative to an existing benchmark using traditional (level) survey techniques.

Ice cover conditions on Lake Michigan are documented in NOAA Technical Memorandum GLERL-125; Great Lakes Ice Cover, First Ice, Last Ice, and Ice Duration: Winters 1973 -2002 (Assel, 2003) and are discussed in Section 4.3.2.2.

Water level data for the LTB CKD Release Site did not exist prior to installation of the staff gauge and stilling well. In order to appropriately understand the water level for time periods preceding 2006; an analysis was performed to correlate the known data for Little Traverse Bay with that at other NOAA stations along the Lake Michigan coast line. Results of the water elevation monitoring and analysis are discussed in Section 4.3.2.2.

Infiltration and Evapotranspiration Study

As discussed in Section 5.2.6.1 of the Work Plan (Barr, 2005c), infiltration and ET studies were conducted. ET is the transfer of water from the earth's surface to the atmosphere by evaporation and transpiration from plants. The standard method for calculating daily ET of water is the American Society of Civil Engineers and Environmental and Water Resources Institute (ASCE-EWRI) standardized Penman-Monteith ET equation. This equation provides a standard method of calculating ET in any climate and over any crop-type surface. It requires simple daily weather data; specifically wind speed, temperature, solar radiation, and relative humidity, in its calculation. This method was used with data from the Site weather station. As discussed in section 4.3.2.3; however, this method assumes unlimited soil moisture and does not take into account winter conditions such as snow cover. As a result, ET estimates using the Penman-Monteith equation with site weather station data would tend to provide an upper end estimate of potential ET at the Site. As discussed in section 4.3.2.3, an alternative, long-term, temperature-based ET estimate for the Site was calculated using Malmstrom's equation and monthly average temperatures for the City of Petoskey. The annual infiltration was estimated by subtracting the long-term ET estimate and the estimated surface runoff (see Section 4.3.2.3) from the average annual precipitation in the Petoskey area. A water balance approach was used in the golf course areas to attempt to estimate the rate of infiltration induced by irrigation.

3.1.4.4 Golf Pond Assessment

At the request of Bay Harbor Golf Club, the golf ponds were monitored in order to evaluate exposure risk to golfers. This additional monitoring event and assessment were not a part of the AOC. The ponds at the golf course were monitored at 161 locations for pH, temperature and conductivity. Results shown in the table below do not appear elevated for pH or conductivity, as would be

expected if the ponds contained CKD or were impacted by CKD or CKD-generated leachate. Additionally, no CKD was visually observed in the ponds or at the ground surface adjoining the ponds.

Based on the results shown below, it was determined that the golf course ponds have not been impacted by CKD and no further monitoring was necessary.

Golf Pond Monitoring Results

Sample Date	pH, Range	Conductivity, Range (μS/cm)	Temperature, Range (°C)
5/16/05 – 5/27/05	6.41 – 8.37	527 – 1398	8.7 – 27.99

3.1.4.5 Bay Harbor Lake Assessment

The overall objective of the Bay Harbor Lake Assessment was to implement a phased monitoring and sampling approach to determine if CKD or CKD leachate was present within or impacting Bay Harbor Lake. The Bay Harbor Lake Assessment was conducted by the Bay Harbor Lake Assessment Team (BHLAT), a multi-stakeholder work group in accordance with the Bay Harbor Lake Conceptual Field Monitoring and Sampling Work Plan, dated May 16, 2006. The assessment field work was conducted in May, June, and October 2006. The Assessment Report for Bay Harbor Lake was compiled by Weston Solutions, Inc. in June 2007 (Weston Solutions, 2007). The report was prepared by the participants of the BHLAT. A copy of the report is located in Appendix 3-3.

Assessment field activities included two rounds of shoreline surveys, two rounds of underwater dive surveys, and the collection and taxonomic characterization of an “unknown white substance” and algal samples. Michigan surface water quality standards require surface water pH to be between 6.5 and 9.0 for human contact and aquatic ecosystem protection.

All pH measurements along the Bay Harbor Lake shoreline in May and October 2006 ranged from 7.4 to 8.3, which are within the range of acceptable water quality standards. The shoreline study involved 561 water quality measurements spread across two miles of shoreline. Measurements were collected near shore at depths of up to 18 inches and from boats offshore in water as deep as 14 feet. Several storm water drains were also monitored, with the results in a comparable pH range.

Over 15 hours of underwater dive surveys were conducted in June and October 2006 to evaluate the offshore and deeper portions of Bay Harbor Lake. Divers collected real time water quality data and

inspected the walls and offshore bottom of select portions of Bay Harbor Lake for CKD or CKD-related impacts to the physical and biological environment. Overall, the pH of Bay Harbor Lake during the dives ranged from 6.9 to 8.7. The species of fish, invertebrates, and algae observed during the dives, and in the laboratory following the dives, are common species that have been reported to occur in the near shore areas of Lake Michigan.

Based on the results of the Bay Harbor Lake assessment, there are no signs that CKD or leachate is present in or is currently impacting Bay Harbor Lake. All the water quality measurements indicate normal conditions, and no unusual physical or biological features were encountered.

3.1.4.6 Golf Course Drain Inventory

Inventories of the golf course drains were conducted for the purpose of observing and documenting how surface water drains and is collected/routed as proposed in Section 5.2.6.1 of the Work Plan (Barr, 2005d). Two inventories were performed at the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area; a preliminary investigation was performed in August 2006 and a detailed drain inventory was performed in May 2007.

The preliminary investigation included visually identifying drain locations and field verifying surface drainage using electronic two-foot topographic data. Drain locations and generalized surface drainage directions were marked on a hard copy plan sheet. Features such as precipitate buildup on pipes and potential porous inverts were also noted.

The detailed drain inventory included a more thorough documentation of the golf course drains. Each drain was provided with a unique identification number, photographed, and located with a GPS unit. The following information was also recorded: drain size (diameter); construction materials; depth to structure invert; orientation, depth to, and size of inlets/outlets; presence of and flow direction of water; assumed flow direction (if no flow was present); structural defects; and precipitate buildup. Outlet locations and depressed areas where ponding might occur during heavy rains were identified and located with a GPS unit. Inspection staff met with staff from the former contractor who installed the drain network and performed Site earthwork, to determine the construction materials, backfill practices, and general routing patterns.

The data collected from the drain inventories were used in conjunction with Site data, including electronic two foot topography and digitized course features, to develop drainage divides and storm-

water routing patterns. The results of the golf course surface drainage studies are summarized in Appendix 1-2d.

3.1.5 Geological Investigations

Investigation activities designed to determine the geologic properties of the unconsolidated materials and bedrock were completed as proposed in Sections 5.2.3, 5.2.4, and 5.2.5 of the Work Plan (Barr, 2005d). Boreholes were advanced by direct-push (Geoprobe®) and rotasonic drilling techniques. The direct-push boreholes were completed to characterize the unconsolidated material and determine the elevation of the bedrock surface. Rotasonic boreholes were advanced at the locations intended for further bedrock investigative activities and at some locations where direct-push methods did not encounter the bedrock surface. Downhole geophysical logging and surface geophysical logging were completed to provide additional information regarding bedrock conditions and to further refine the subsurface model for the Site. Borehole locations are shown on Figures 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively.

3.1.5.1 Drilling Methods

Boreholes were advanced by direct-push (Geoprobe®) and rotasonic drilling techniques.

Direct-push Drilling Methods

Direct-push drilling was conducted by advancing a 4-foot long, 2.2-inch outside diameter macro-core sampler, with a 1.5-inch diameter PVC liner. All sample material was collected within the liner.

Rotasonic Drilling Methods

Rotasonic drilling was conducted by advancing a 10 or 20-foot long core barrel to collect samples of unconsolidated material and/or bedrock. When drilling in unconsolidated material, a steel casing with a larger diameter than the core barrel was advanced into the borehole before the core barrel was removed to prevent collapse of the borehole. In general, the outer steel casing was advanced several feet into competent bedrock, and the rest of the boring was advanced using only the core barrel in order to leave the bedrock portion of the borehole open to conduct geophysical logging and aquifer testing. However, bedrock portions of boreholes occasionally collapsed, or circulation of drilling water was lost so drill cuttings could not be washed from the hole which in turn caused the core barrel to get stuck in the borehole, requiring advancement of the outer casing further into bedrock.

Rotasonic drilling conducted at the outset of the investigation employed a 4-inch inside diameter (ID) core barrel (approximately 4.8-inch outside diameter (OD)) and a nominal 6-inch OD outer casing (4X6 method). All rotasonic borings at Seep 1 CKD Area and most rotasonic borings at Seep 2 CKD Area and West CKD Area were advanced with this system. At several of the borings drilled with the 4X6 method, the outer casing was advanced relatively deep into bedrock in order to free core barrels that became stuck at depth while drilling. Because of the depth of the outer casing, geophysical logging and aquifer testing were not possible within large portions of those boreholes.

In an effort to prevent stuck core barrels and thereby reduce the need to push casing into the bedrock, a different system was used from approximately February 2006 to April 2006. The new system employed a 3-inch ID core barrel and a nominal 5-inch OD outer casing (3X5 method). The 3-inch diameter core barrel was used to drill the boring; each 10-foot run with the 3-inch diameter core barrel was followed by the 5-inch outer casing in order to prevent the core barrel from getting stuck during drilling. The 5-inch diameter casing was always 10-feet higher than the core barrel to allow the vertical profiling to be completed immediately following each 10-foot drilling run. Additionally, a 6-inch OD outer casing was advanced through the unconsolidated material and seated several feet into bedrock. After the borehole drilling was complete, the 5-inch OD casing was removed from the borehole while the 6-inch OD casing remained in place to prevent collapse of the unconsolidated material. While this method did allow more of the bedrock borehole to remain uncased, post-drilling borehole collapse occasionally occurred and hindered the ability to conduct geophysical logging and aquifer testing in borings drilled using either 3X5 or 4X6 methods.

Most rotasonic drilling conducted subsequent to April 2006 was conducted using the 4X6 method. The exception occurred at the Seep 2 CKD area during April 2008, where recovery wells were installed using a 7-inch ID core barrel and a nominal 8-inch OD outer casing (7X8), because larger diameter boreholes were required in order to accommodate the 4-inch diameter wells. Subsequent boreholes have been advanced using the 4X6 method.

3.1.5.2 Borehole Geologic Logging

Borehole geologic logging was performed to determine the bed thickness, weathering, presence of solution features, lithology, stratigraphy, and fracture frequency and orientation as discussed in Section 5.2.5.1 of the Work Plan (Barr, 2005c). Borehole logs for the Site are included in Appendix 3-4, and well logs are included in Appendix 3-5. Well abandonment records are included in Appendix 3-5d. Symbols indicating the locations of soil samples (analytical and geotechnical) and

borehole water samples (analytical) are included on the borehole logs. Borehole locations are shown on Figures 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Monitoring well locations are shown on Figures 3-2a, 3-2b, and 3-2c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Recovery and observation wells are shown on Figure 3-2b for the Seep 2 CKD Area.

Unconsolidated materials and bedrock samples were described in the field by a qualified geologist, technician, or geological engineer. Non-CKD unconsolidated materials were described according to ASTM D2488 and CKD was generally described according to the standard procedure described in the QAPP (Barr, 2005d). Bedrock samples were examined for bed thickness, weathering, presence of solution features, lithology, stratigraphy, and fracture frequency and orientation, dependent on the quality of the sample.

Angle borings were not advanced in the West CKD Area, Seep 1 CKD Area, and Seep 2 CKD Area as described in Section 5.2.4.2 of the Work Plan. The intended purpose of these angle borings was to provide information on spacing of the near-vertical fractures in bedrock away from the unconfined surfaces of natural outcrops and old quarry walls. Angle borings were attempted at the East CKD Area portion of the LTB CKD Release Area Site and it was found that the angle borings were not able to serve the intended purpose due to the geologic conditions at the Site. CMS prepared a letter dated January 13, 2006 addressed to the On Scene Coordinator (OSC) requesting U.S. EPA approval to eliminate angle borings from the Work Plan. The U.S. EPA approved this request in a letter dated January 27, 2006. Copies of these letters are included in Appendix 1-1, U.S. EPA Requests and Approvals of Modifications.

Rock types (lithologies) and rock quality were described in the field. Drilling characteristics, including loss of drilling fluid were noted. Occasionally, intact core samples were recovered that had vertical or high angle fractures, with staining/discoloration that indicated the fractures were natural (not caused by the drilling). Horizontal and low-angle bedding plane fractures with staining were also observed. None of these fractures appeared to be greatly enlarged by dissolution. Vuggy zones/layers were observed within the rock, however, the vugs were scattered and not strongly interconnected, and typically appeared to be related to dissolution of fossils.

3.1.5.3 Borehole Geophysical Logging

The primary purpose of borehole geophysical logging was to identify and measure the orientation of fractures and bedding planes, in-situ borehole flow conditions, and hydraulically conductive fracture

or shear zones. The borehole geophysical logging results also supplement the borehole geologic logging descriptions in characterizing the geologic nature of the bedrock. Downhole geophysical logging was conducted as proposed in Section 5.2.5.1 of the Work Plan. Seventy bedrock boreholes were logged at the Site: 21 at the Seep 1 CKD Area, 39 at the Seep 2 CKD Area, and 10 at West CKD Area.

Century Geophysical (Century) conducted the geophysical logging until April 2006 under contract with Barr through Prosonic Corporation, the drilling contractor for the project. All logging was conducted by an experienced Century logging technician using Century instruments and logging tools. A logging truck outfitted with an electronic console, onboard PC, printer, portable electric winch and steel armored cable with mechanical and electronic depth counters was used in data collection.

Barr, Pescador, and Schnabel Engineering personnel observed and documented the data collection activities of Century. Barr provided continuous field oversight for the logging crew, field interpretation and data transfer. Norcal Geophysical Consultants, Inc. (Norcal) provided quality control, log processing and interpretation. Oversight personnel and the Century personnel conducted log interpretation in the field to the extent necessary to assist decisions regarding additional testing such as the locations of static flow meter measurements and aquifer testing intervals.

Norcal performed the borehole geophysical logging conducted in April and May 2007. Barr provided direction for Norcal in the field.

Data from the geophysical logging are discussed in results Sections 4.4.2 and 4.6.

Geophysical Logging Tool Summary and Limitations

Borehole geophysical logging was conducted using several different logging tools. The Work Plan proposed down-hole measurements of temperature, caliper, streaming potential (SP), resistivity, flow meter, natural gamma, and sonic, as well as optical televiewer logging. An acoustic televiewer log was substituted for the optical televiewer because initial tests indicated borehole water clarity was too low for high quality optical televiewer data. A fluid resistivity log was added to help identify hydraulically active zones. Century performed all the above-mentioned logging tasks.

The logging tasks and methods were modified slightly for borehole logging work performed by Norcal during the supplemental investigation work conducted in April and May 2007, based on

analyses of previously collected data. Norcal performed downhole measurements of temperature, caliper, flow meter, natural gamma, and optical or acoustic televiewer logging (dependent on the clarity of water in the borehole). Measurements of induced conductivity and fluid conductivity were made in place of resistivity and fluid resistivity, and a heat-pulse flow meter was used instead of an Electromagnetic Induction (EM) flow meter as used by Century. Sonic and SP data were not collected.

Data collected with each of the geophysical logging tools is summarized in the following table.

Borehole Geophysical Method	Data Obtained
Temperature Log	Borehole fluid temperature and in-hole flow zones.
Fluid Resistivity or Conductivity Log	Borehole fluid electrical resistivity/conductivity and in-hole flow zones.
Caliper Log	Borehole diameter and fracture locations.
Streaming Potential Log (SP)	Vertical variations in water quality and lithology.
Resistivity or Conductivity Log	Lithologic data, potentially useful in identifying high conductivity bedrock fracture zones.
Flow Meter Log (EM flow log or heat-pulse flow log)	In-hole flow, location and apparent hydraulic conductivity of permeable bedrock intervals.
Natural Gamma Log	Lithology in both cased and uncased portions of the borehole
Sonic Log	Porosity and lithology, rock strength.
Acoustic or Optical Televiewer Log (borehole televiewer, BHTV)	Location, orientation, and character of fractures and solution openings in bedrock, strike and dip of bedding planes.

Each bedrock borehole was drilled to a nominal diameter of 5 inches. Bedrock fracturing associated with drilling activities resulted in borehole diameters exceeding 8 inches in some intervals. Most of the borehole geophysical logging tools provided useful information in the open bedrock borehole (length of borehole between the bottom of the temporary metal casing and the base of the borehole or top of the collapsed zone) but not in the cased portion of the borehole. Only the natural gamma log provided useful logs in the metal-cased portions of the borehole.

Most of the logging tools only functioned in borehole fluid (generally meaning below the water table in open boreholes). Only the caliper and natural gamma logs provided useful information in the dry borehole sections.

Calibration

Century performed daily calibration of all logging tools when they performed the logging in 2005 and 2006. Each probe output was calibrated to span the range of anticipated values given the field conditions. Calibration of conventional logging tools (electrical resistivity, SP, natural gamma, and caliper) was conducted using various jigs (e.g., resistor box, mV source) and secondary sleeves (e.g., caliper rings).

Temperature/fluid conductivity tool response was validated against a calibrated water conductivity/temperature meter. Acoustic televiewer calibration consisted of verifying the north direction against a compass measurement by aligning a water-filled aluminum jig to magnetic north, placing the televiewer tool in the jig, and determining the tool response indicated the correct orientation.

In addition to the main log section, the lower 30 feet or so of each borehole log was repeated for the caliper, SP, electric normal, gamma, neutron, and acoustic televiewer logs to demonstrate the stability of the logging system and specific tools. Repeat logs were displayed at the same scales to provide a visual display of log repeatability.

The stability and statistical variation of the natural gamma detector was evaluated by conducting a three minute time-driven log while the probe was held stationary in the open bedrock borehole section (30-100 feet below ground surface). This test was performed each time a natural gamma probe was mobilized to the Site.

Century reviewed all calibration results with the field representative. All instrument calibration data were retained by Century. All log repeats were saved electronically with the standard log runs.

Norcal's logging conformed to the general outline of logging protocols performed by Century within the time constraints of the investigation. Norcal did repeat televiewer logs, compass checks of the televiewers, gamma, caliper and temperature calibrations and select repeat logs of these log types throughout the survey.

Borehole Geophysical Logging Procedures

The first logging measurement was conducted by Century in each borehole with a down-going temperature-fluid conductivity-EM flow probe. Conductivity curves displayed and recorded in real time were corrected to standard temperature (25 degrees Celsius). Subsequently, continuous caliper,

electric normal, SP, gamma and sonic logs were conducted in the up-hole direction from total depth to the surface. The logging speed was 10 to 12 feet per minute. As a control on speed, minute tick marks appear on the depth axis of each field log. A standard application programming interface (API) header was created at the start of each field log which contained the borehole identification, location, tool serial number, recording parameters and calibration file names. All conventional logging data were recorded with a digital depth sample interval of 0.05 feet.

Acoustic televiewer logs were conducted at a logging speed of 3.5 feet per minute. A real-time grey-scale plot was produced coincident with logging. This log contains both the travel-time and amplitude plots.

EM flowmeter measurements were made by continuous logging or “trolling” of the borehole and by flowmeter measurements made at discrete depths. The number and depths of the flow meter measurement stations were dependent on the quantity of flow anomalies and fracture intervals indicated by other geophysical logs. Typically each borehole had six to 12 measurement stations. These stations were positioned above and below suspected flow points. Flow was monitored at each station until stabilization. The representative flow rate at each measurement station was the stabilized measurement of flow rate.

Logging equipment was decontaminated between logging of highly contaminated boreholes. Logging equipment was subject to a trisodium phosphate (TSP) scrub and deionized water rinse between each borehole.

All logs were printed in the field and provided to the field observer on the day logging was completed for a borehole. Draft logs were analyzed in the field and used to make immediate decisions, such as determination of stationary flow logging intervals. Files of the original logs were provided in digital format for analysis. The electronic log traces were provided in standard API log plot ASCII format. The field logs were also supplied in electronic image (TIF) format.

Norcal performed field measurements following the standard procedures for each method, as described above.

Borehole Log Compilation and Interpretation

Geophysical log compilation and quality control were conducted by Norcal. Separate electronic logs were combined and plotted side by side in a single depth plot format using the program WellCAD. The geophysical logs include the following:

- Continuous traces: caliper, natural gamma, 16- and 64-inch normal resistivity, single point resistance, SP, fluid temperature, differential fluid temperature, EM trolling and fluid resistivity.
- Acoustic or optical televiewer image log plot as a false color plot of returned amplitude values oriented to magnetic north.
- EM or heat pulse stationary logs presented as a bar graph. The bar position represents the depth of the measurement, positive values indicate vertical upward flow, negative values indicate down flow in gallons per minute.
- The full waveform sonic plots were provided separately for each borehole. The plots contain borehole compensated transit time, variable full waveform display of the near and far detectors, and a natural gamma trace.

Acoustic televiewer data were analyzed electronically to identify fracture and bedding features. Orientation of these features was determined by fitting a sinusoid over the trace of fracture or bedding planes intersecting borehole. Attitude (dip direction and dip magnitude) of features corrected for magnetic declination at the Site, bearing and deviation from vertical of the borehole was determined for each feature. Each feature was characterized as either a (1) fracture, (2) bedding plane, or (3) low angle (< 15 degrees) fracture. These low angle fractures are possibly associated with bedding and characterized by borehole breakouts or enlargements.

A summary of the analysis results with orientation of fractures and bedding for each borehole plotted as poles to planes on the southern half of the projection sphere is discussed in Section 4.4.2. These illustrations show the depth interval, the number of features in each of the subclasses and mean orientation within each subclass. The column to the left of each polar plot shows the fracture and bedding plane sinusoids plotted with depth or, in some cases, “tadpole” markers representing the fracture. The head of the tadpole indicates the degree of dip and the tail of the tadpole shows the direction of dip.

Bedrock at the Site consists of limestone, shaley limestone, and shale. Porosity and permeability are dependent on the degree of fracturing and a complex interconnection of fractures. The borehole formed a temporary connection between fracture reservoirs. The primary purpose of the fluid logging was to determine permeable zones within the borehole that may be associated with flow. Flow in the borehole is indicated by changes in the temperature and/or fluid resistivity profile, changes in the flow rate between flow meter stations or abrupt changes in the trolling flow meter log. These logs provide a direct indication of flow in the borehole. Geophysical logs that support identification of sources of flow in the borehole are caliper, acoustic or optical televiewer and point resistance. An association with a fracture or fracture zone was essential to identify specific depths of flow sources.

3.1.5.4 Surface Geophysics

Surface geophysical surveys were conducted at the Site on two separate occasions to provide supporting data of geologic conditions as discussed in Section 1.3.3.6 of the Work Plan (Barr, 2005c) and Sections 2.2 and 2.4 of the Supplemental Investigation Work Plan (Barr, 2007a). Extensive surveys were conducted in November and December 2004 across at the Site for use in the development of the Work Plan's conceptual model. Additional surveys were conducted in the Seep 1 and Seep 2 CKD Areas in April 2007 as part of the Supplemental Investigation.

Schnabel Engineering was subcontracted by Barr to assist with the survey conducted in 2004 in order to evaluate the following: 1) the potential locations and depths of CKD, 2) the locations of bedrock features, and 3) seep and subsurface water distribution. The geophysical surveys were conducted using several different methods, including: EM; SP; Very Low Frequency EM (VLF); Direct Current Resistivity Imaging (DCR); Multi-channel Analysis of Surface Waves (MASW); and seismic refraction.

Zonge Geosciences, Inc. (Zonge) was subcontracted by Barr to conduct seismic refraction geophysical surveys at the Seep 1 and Seep 2 CKD Areas in April 2007. A seismic refraction survey was conducted on the shoreline of the Seep 1 CKD Area to determine depth to the top of competent rock and to evaluate material properties of soil and rock. The purpose of this geophysical survey was to provide near-shore bathymetry data and to provide bedrock elevations between and north and south of existing monitoring well nests. A Fast-Sampling Time-Domain EM Surveying Method (TDEM) was conducted at the Seep 2 CKD Area in an attempt to delineate the shale bedrock unit generally encircled by borings B2008, B2042, B2044, B2026, and B2027. The TDEM method was

not successful in determining the depth and/or location of the shale. The Zonge reports presenting the methods, data, and analyses are included in Appendix 3-6.

Results of surface geophysical investigation activities are included in Appendices 3-6a to 3-6d. This appendix also includes written summaries of the methods used in the geophysical investigations, the methods used in interpreting the data collected (including methods used to avoid biasing the investigation results due to the presence of subsurface utilities), and summaries of the findings from the investigations.

3.1.5.5 Rock Testing/Rippability Analysis

In developing the design for the Seep 1 CKD Area augmentation barrier wall, limestone rock cores were taken to observe the material along the proposed barrier wall alignment. Select samples of rock were collected from the core samples and placed in either cloth soil bags or concrete cylinders. Samples were submitted to RESPEC Engineering (RESPEC) in Rapid City, South Dakota for unconfined compression testing. The laboratory report from RESPEC is included in Appendix 3-7. Samples were selected for testing and were picked based on suitable dimensions for testing and to provide general spatial and depth distribution along the barrier wall alignment. The results of the unconfined compression tests were compared to the rippability chart in ETL 1110-2-282. Additionally, Rock Quality Designation (RQD) values were taken in the field using ASTM D6032.

The unconfined compression strengths ranged between 14,100 and 19,200 psi. Based on the rippability chart in ETL 1110-2-282, these unconfined compressive strengths correspond to an extremely hard rock. As a result, ripping of the limestone rock to provide a key for the base of the Seep 1 CKD Area augmentation barrier wall was to be controlled by the presence and orientation of existing fractures. Additionally, RQD values were used as a general guide for estimated ease of rippability. The RQD values are summarized in the table below.

Summary of Field Measured Rock Quality Designation (RQD) Values[1,2]

B1042		B1041		B1040		B1039		B1037		B1038	
Depth (ft.)	RQD	Depth (ft.)	RQD	Depth (ft.)	RQD	Depth (ft.)	RQD	Depth (ft.)	RQD	Depth (ft.)	RQD
10-15	12	9-14	7	10-15	0	5-10	30	5-10	8	10-15	25
15-18	19	14-19	60	15-20	0	10-15	31	10-15	47	15-20	68
20-25	12	19-24	0	20-25	57	15-20	58	15-20	25	20-25	30
25-30	29	24-29	25	25-30	61	20-25	68	20-25	48	25-30	7
						25-30	45	25-30	0	30-35	76
								30-35	45		
								35-40	60		

[1] All RQD values determined from field measurements during the June 2008 investigation.
[2] All RQD values determined in accordance with ASTM D6032.

3.1.6 Groundwater Investigations

Hydrogeologic investigation activities were completed as per Sections 5.2.4 and 5.2.5 of the Work Plan (Barr, 2005c). The boreholes described in Section 3.1.5 were used for aquifer testing, monitoring well installation, observation well installation, recovery well installation, and to provide information regarding hydrogeologic properties. The water quality parameters determined for each groundwater sample (permanent monitoring wells) for each interval in the field included: dissolved oxygen, temperature, pH, conductivity, oxidation reduction potential (ORP), turbidity, physical appearance, and odor. Monitoring well locations are shown on Figures 3-2a, 3-2b, and 3-2c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Recovery and observation well locations are shown on Figure 3-2b for the Seep 2 CKD Area.

3.1.6.1 Borehole Packer Interval Sampling/Aquifer Testing

Borehole packer interval sampling/aquifer testing was conducted to determine water quality in isolated sections of boreholes and to determine aquifer parameters including hydraulic conductivity. Borehole packer interval sampling/aquifer testing was performed according to procedures presented in Section 5.2.5.2 of the Work Plan, and then according to the modified procedures approved by U.S. EPA ERT staff after Sept. 29, 2005. A copy of the “Aquifer Testing Procedures” memorandum is included in Appendix 1-1, EPA Requests and Approvals of Modifications. Samples were not collected for laboratory analyses during aquifer testing conducted in May 2007, as presented in the Supplement Investigation Work Plan. Therefore, aquifer tests conducted during the Supplemental Investigation were performed in accordance with procedures presented in memorandum “Aquifer

Testing Modifications" dated April 30, 2007. A copy of the "Aquifer Testing Modifications" memorandum is also included in Appendix 1-1.

Up to three borehole packer intervals were selected for sampling and aquifer testing in each bedrock borehole based on the results of the geologic logging, vertical aquifer profiling, and geophysical logging. The borehole packer intervals were selected based on the following criteria presented in the Work Plan, and approved by U.S. EPA ERT personnel before testing was conducted:

- One borehole packer interval was to have been placed at a non-impacted depth where the pH is <9.0 (if encountered).
- One borehole packer interval was to have been placed at a depth where the highest pH is recorded based upon the vertical aquifer sampling.
- The additional borehole packer interval was to have been placed in a zone within the borehole exhibiting the highest groundwater flow and a pH >9.0.
- In the event that during the vertical aquifer sampling, pH measurements are < 9.0, then one borehole packer interval was to be placed at the water table, one borehole packer interval was to be placed at the depth where the highest pH was recorded, and one borehole packer interval was to be placed at the zone exhibiting the highest groundwater flow.

The borehole packer intervals to be sampled/aquifer tested were isolated with inflatable packers. Both single packer and double packer systems were used. The single packer was designed to isolate intervals near the bottom of boreholes that could not be effectively isolated by the double packer system, due in part to the length of the double packer system or to test intervals longer than the distance between the packers on the double packer system. The packer assemblies included pressure transducers beneath each inflatable packer. A pressure transducer was manually lowered into the borehole above the upper packer. These pressure transducers were connected to a Hermit 3000 datalogger manufactured by In Situ, Inc. to monitor hydraulic head above, within, and below the isolated sampling/testing zone. A submersible sampling pump was installed between the packers on the double packer system, and below the packer on the single packer system.

Purging, stabilization, and sampling of the borehole packer intervals were completed in accordance with Section 5.2.5.2 of the Work Plan, in accordance to the modified procedures approved by U.S.

EPA ERT staff after September 29, 2005 (Appendix 1-1, EPA Requests and Approvals of Modifications). Samples collected from each borehole packer interval were analyzed for the parameters listed in Table 3-3.

After sampling, the pump in the packer assembly was turned off and the total pumping time and volume purged were recorded. Water level recovery in the pumped interval was monitored via the pressure transducers and recorded by the Hermit datalogger. Recovery was allowed to continue until the hydraulic head in the pumped interval had returned to at least 90% of the pre-pumping level, or reached a static level.

The final measurement (prior to sample collection) for water quality parameters collected in the field (dissolved oxygen, temperature, pH, conductivity, ORP, turbidity, physical appearance, and odor) for each groundwater sample are summarized in Tables 5-6a–5-6c.

Aquifer test data (drawdown and recovery) were analyzed to determine the hydraulic conductivity (K) and other aquifer parameters using AQTESOLV. Results will be discussed in Section 4.6.3.

3.1.6.2 Well Installation

Permanent and temporary monitoring wells were installed at the Site to obtain information on groundwater elevations as discussed in Section 5.2.4 of the Work Plan (Barr, 2005c). Monitoring well nests were installed to evaluate vertical and horizontal hydraulic gradients and vertical differences in water geochemistry.

Recovery wells were installed at the Seep 2 CKD Area as described in the Seep 2 CKD Area Augmentation Pilot System Design Report, Targeted Leachate Collection (Barr, 2008a). The purpose of the recovery wells was to collect leachate in the vicinity of boring B2025. An observation well was installed near the recovery wells to monitor the effectiveness of the recovery wells at collecting leachate and to further delineate the area geology.

Data from the borehole logging, geophysical logging, and borehole packer interval aquifer testing were evaluated and used to select screened intervals for the installed monitoring well nests. The screened intervals for all monitoring well nests were selected based on the following criteria presented in the Work Plan and approved by U.S. EPA ERT personnel:

- One screened interval was placed at a depth to transect the water table.

- One screened interval was placed at a depth where the pH was <9.0.
- One screened interval was placed at a depth where the highest pH was recorded based upon the vertical aquifer sampling.
- Additional screened intervals were to be placed within zones exhibiting pH > 9.0 and/or depths to screen the intervals within the borehole exhibiting the highest groundwater yields.
- In the event that during the vertical aquifer sampling, pH measurements were < 9.0, then one screened interval was to have been placed at the water table, one screened interval was to have been placed at the depth where the highest pH was recorded, and the remaining interval(s) were to be placed in the zones exhibiting the highest groundwater yield(s).

Data from geologic logging and vertical aquifer sampling was used to select screen locations for the recovery and observation wells at the Seep 2 CKD Area. Screens in the recovery and observation wells were placed to coincide with high-pH leachate in the perched aquifer.

All permanent monitoring wells were installed via rotasonic drilling techniques. Permanent monitoring wells are constructed with 2-inch-diameter polyvinyl chloride (PVC) riser pipe and a 2-inch-diameter PVC screen (no. 10 slot), except wells deeper than 150 feet at borehole locations B2022 and B2025 that were constructed with stainless steel riser pipe and screens. All wellheads were completed as flush mounts.

Temporary wells were installed with a 1-inch diameter PVC riser pipe and screen. The temporary wells are identified in Tables 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 1 CKD Area, and Seep 2 CKD Area, respectively.

Recovery wells at the Seep 2 CKD Area were installed using 4-inch diameter PVC riser and screen; the recovery wells were completed as above-grade stickups. The observation well at the Seep 2 CKD Area was installed using 2-inch diameter PVC riser and screen. The observation well was completed as a flush mount. The locations of the permanent monitoring wells are shown on Figures 3-2a, 3-2b, and 3-2c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. The locations of recovery and observation wells at the Seep 2 CKD Area are shown on Figure 3-2b.

Surveyed elevations of the ground surface and top of casing for each monitoring well, recovery well, and observation wells are summarized in Tables 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively.

Well Development

Monitoring, recovery, and observation wells were developed by pumping and surging techniques described in the Standard Operating Procedures for Developing Monitoring Wells which was included in Appendix E of the Work Plan (Barr, 2005c). Airlifting was the primary method for developing the wells. However, wells with water levels too deep for airlifting were developed using a submersible pump or arch pump. Wells that recovered very slowly were developed using a bailer.

Prior to approximately May 2007, while the wells were being developed, grab samples were collected every 30-60 minutes and checked to see if the water was visibly clear of solids. When the water was clear, development was considered complete. Following well development, Barr personnel measured total well depth and checked for solids present at the bottom of the well. If a well contained solids, additional development was completed until the well discharge was determined to be free of suspended solids by visual means. The adequacy of the development was further verified by measuring and recording stabilization parameters during monitoring well sampling. The following stabilization parameters were recorded prior to monitoring well sampling:

Parameter	***Stabilization Criteria (within 3 successive readings 3-5 minutes apart)***
pH	±0.1
Specific Conductance	±3%
Oxidation Reduction Potential (ORP)	±10 mV
Dissolved Oxygen	±10%
Turbidity	±10% or below 20 NTUs

All monitoring wells met the stabilization criteria prior to sampling. Prior to May 2007, the amount of water removed at each well during development was not recorded; however, the typical volume of water removed from each well was approximately 500 gallons.

The temporary wells were developed with a peristaltic pump and/or a bailer to remove excess solids from the wells and create a better hydraulic connection between the well screen and aquifer.

After May 2007 development completeness was assessed by monitoring temperature, specific conductivity, pH, turbidity (NTU), and appearance/odor. The total volume of water removed was generally recorded. Well Development Logs for wells developed after May 2007 are included in Appendix 3-8.

Well Abandonment

The four wells nested at the B2042 location were abandoned. Wells W2142 and W2242 were abandoned on October 23, 2007. Wells W2342 and W2442 were abandoned on October 24, 2007. The four wells nested at the B1031, B1034, and B1035 boring locations were abandoned on October 4, 2008 to allow for the construction of the Seep 1 CKD Area augmentation barrier wall.

Wells were abandoned with bentonite chips. Surface protection (pads and vaults) were removed and the well casings were cut (or the uppermost section of riser pipe was removed) approximately 1.5 to 10 feet below ground surface. Well abandonment records are included as Appendix 3-5d.

3.1.6.3 Aquifer Testing

Hydraulic conductivity testing was completed in the borehole packer intervals as described in Section 3.1.7.3, and Section 5.2.5.3 of the Work Plan (Barr, 2005c). Additionally, vertical pumping tests were performed in the monitoring well nests at the B1034, B2042, and B2044 locations. Slug tests were performed in temporary monitoring wells and most permanent monitoring wells where borehole packer tests were not conducted and in the wells installed in 2009.

Slug Tests

Slug tests are a commonly used, practical means of obtaining near-well hydraulic conductivity values when care is taken in data collection and analysis. All field methods and data analysis were conducted using the most current and widely accepted techniques including those outlined in Butler (Butler, 1997) and ASTM Standard D 4044-96 (ASTM, 2002).

Temporary well points were installed in saturated unconsolidated material in order to assess the hydrogeologic properties of these materials. PVC temporary well points were placed in the Geoprobe® boreholes and the unconsolidated materials were allowed to collapse around the screen. If the formation did not collapse around the well screen, a sand pack was placed around the screen. A bentonite seal was placed above the screened interval. After installation, the temporary well was

developed to ensure a good hydraulic connection to the surrounding saturated material. Slug tests were also conducted in select permanent monitoring wells and the monitoring wells installed in 2009.

Pressure transducers were used to monitor/record water levels during the tests at high enough frequencies to capture aquifer responses as directed in ASTM Standard D 4044-96 (ASTM, 2002). For slug tests conducted prior to 2009, a pressure transducer was connected to a Hermit 1000C datalogger, manufactured by In-Situ, Inc. Slug test data for the 2009 investigation wells was collected using pressure transducers with built-in datalogging capabilities (Level TROLL® 500 or Level TROLL® 700 manufactured by In-Situ, Inc.).

Slug tests were conducted using either solid slugs or a pneumatic slug tester for test initiation. Solid slugs act to raise the water level in a well when lowered below the water table or lower the water level when removed from below the water table. The pneumatic slug tester can be used only to lower the water table and does so by pressurizing the air column above the water level in a well, pushing the level down as the water moves out of the well and into the aquifer. Water levels were measured and recorded in each well prior to the initiation of the tests.

For solid slug testing, a solid 5-foot-long PVC rod (a.k.a., a slug) was used to displace the water. First, the slug was rapidly lowered below the water level in the well (slug-in or falling-head test). After the water level returned to equilibrium, the slug was rapidly removed and the changes in water level were again recorded (slug-out or rising-head test). For every well, slug tests were conducted in series resulting in multiple tests of varying imposed initial displacements. Fractions of the 5-foot-long slug were lowered or raised to achieve varying displacements (e.g., ½ slug tests) in order to evaluate aquifer/well responses with variable displacements and to provide information for evaluating the appropriateness of the data analysis method to be used (Butler, 1997). Prior to 2009, a slug test series consisted of one full in/out test, one ½ in/out test, and one ¾ in/out test. For the 2009 investigation wells, a slug test series consisted of two full in/out tests and ½ out test.

Pneumatic slug testing was completed in select 2009 monitoring wells using a Pneumatic “Hi-K” Slug manufactured by Midwest GeoSciences Group. The pneumatic slug tester is considered the most appropriate method of test initiation for high hydraulic conductivity formations because it removes the challenge of displacing water rapidly enough relative to the speed of the aquifer response (Butler, 1997). The apparatus was attached to the well casing and sealed air-tight. The air column above the water level in the well was then pressurized and the water level in the well was allowed to reach equilibrium. Once equilibrium was achieved, a valve was opened to release the air pressure near-

instantaneously and the rise of water level in the well was monitored/recorded with a pressure transducer. Three tests were completed for each pneumatic slug test series employing two different degrees of displacement. Two tests were conducted with pressurization to 60 inches of water and one test was conducted to 30 inches of water.

Analyses were completed using models available in Aqtesolv® for Windows® Professional – Version 3.5 (Duffield, 2003). Data are discussed in Section 4.6.3.

Vertical Pumping Tests

Short-duration vertical pumping tests were conducted in the well nests at the B2042 and B2044 locations to evaluate the hydraulic connection between vertical intervals of the saturated bedrock. There are four wells at each of the B2042 and B2044 well nests. Two wells in the B2044 nest are above a layer of shale, and two wells are below the shale. At B2042, one well was screened above the shale, one well was screened within the shale layer, and two wells were screened below the shale.

The pumping tests consisted of pumping from the deepest well in the well nest and monitoring water levels in all wells within the nest with pressure transducers. A Hermit 3000 data logger was used to record water levels measured by the transducers before, during, and after pumping. The tests were conducted at pumping rates of 3 to 4.5 gpm for two to four hours. Water levels were monitored with the data logger for two to three hours after the pump had shut off until water levels returned to static conditions. Water was pumped to a holding tank then disposed with the drilling water.

Results are discussed in Section 4.6.3.

Pumping Tests at Lakeshore Wells at the Seep 1 CKD Area

Short-duration vertical pumping tests were conducted in the four wells of the monitoring well nest at the B1034 location as described in Section 2.4 of the Supplemental Work Plan (Barr, 2007a). Tests were conducted by installing a submersible pump in one well within the nest and monitoring water levels in all wells in the nest with pressure transducers. A Hermit 3000 data logger was used to record water levels measured by the transducers before, during, and after pumping. Troll data loggers manufactured by In Situ, Inc. were also installed at each of the wells at the adjacent well nest (B1031), and water levels were monitored before, during, and after pumping at each well at B1034. Water levels were occasionally measured manually with a water level indicator before, during, and after pumping at each well in the nests at B1034, B1031, B1035, and B1036.

At least one vertical pumping test was conducted in each of the wells at the B1034 nest. Tests were conducted at pumping rates of 0.7 to 5 gpm for two to four hours, dependent on drawdown within the wells. Water levels were monitored with the data logger for two to 16 hours after the pump had shut off until water levels returned to static conditions. Water was pumped to a holding tank during the tests. After the recovery portion of the tests were complete, water was disposed into the Seep 1 CKD Area ILRS at low flow rates (<3 gpm).

Results are discussed in Section 4.6.3.

Pilot Study in the Seep 2 CKD Area

Aquifer testing was completed as part of the TLC Pilot. The aquifer testing consisted of:

- Short-duration vertical pumping tests conducted at W2125 to evaluate the potential for installing a TLC system.
- Pumping/recovery testing within the boreholes directly above the marker shale to evaluate the potential for leachate collection at each borehole location.
- Multi-week pumping at varying rates at S2RW-1 to evaluate the influence of pumping on the pooled leachate as described in Sections 2.0 and 3.0 of Final Design Report (Barr, 2008f).

Results of the pilot study are described in detail in Sections 3.0 and 4.0 of Final Design Report (Barr, 2008f). The primary conclusions of the pilot study are as follows:

- The hydraulic conductivity of the limestone in the vicinity of borehole B2025 ranges from approximately 50 to 300 ft/day; mean hydraulic conductivity is 150 ft/day.
- Water elevations (increases) and pH levels (decreases) in the vicinity of borehole B2025 respond very quickly to rainfall events, suggesting that the perched water above the shale is very responsive to rainfall events and this perched water dilutes the leachate.
- The maximum sustainable pumping rate in the pilot well (S2RW-1) is approximately 6 gpm.

- Pumping at S2RW-1 was shown to reduce the water elevation near the lip of the shale by approximately two feet.

- Pumping at S2RW-1 also appeared to be effective at reducing the pH in monitoring wells west of the TLC system.

3.1.6.4 Groundwater Sampling

Groundwater sampling was conducted to evaluate hydrologic information as well as water quality as described in Sections 5.2.4 and 5.3.5.1 of the Work Plan (Barr, 2005c). Monitoring wells were developed prior to analytical sampling. Field logs for groundwater sample collection are included as Appendix 3-9. Results of vertical aquifer profiling are presented in Appendix 3-10.

The groundwater samples were sent to the laboratory and analyzed for those parameters as identified in Table 3-3. Water samples collected from all permanent monitoring wells were analyzed according to the "low-level" mercury method, EPA 1631 (mercury analysis)/7471 (all other metals). Also, groundwater samples were collected from the downgradient wells during the first round of groundwater sampling for analyses of VOCs and SVOCs according to U.S. EPA Methods 8260B and 8270C.

Stabilization measurements recorded at the time of groundwater sampling of monitoring wells are summarized on the field logs which are included in Appendix 3-9. The stabilization measurements include the final readings prior to sample collection for water quality parameters collected in the field (dissolved oxygen, temperature, pH, conductivity, ORP, turbidity, physical appearance, and odor) for each groundwater sample, along with the well screen or sampling depth of the sample. Groundwater samples are collected using a QED Micro Purge pump.

Stabilization of the wells was determined based on the following:

Parameter	***Stabilization Criteria (within 3 successive readings 3-5 minutes apart)***
pH	±0.1
Specific Conductance	±3%
Oxidation Reduction Potential (ORP)	±10 mV
Dissolved Oxygen	±10%
Turbidity	±10% or below 20 NTUs

Results of groundwater sampling are discussed in Section 5.5.

3.1.6.5 Hydrogeologic Model

The data gathered during the RI was used to develop a numerical mathematical model of the groundwater flow system at the Site (Barr, 2009a). This model has been designed to help evaluate remedial alternatives at the Site. As discussed in Section 6.1 of the Work Plan, the groundwater flow model is intended to serve multiple purposes, including:

- providing a predictive tool to assist in evaluating the IR components;
- guiding the investigation as it proceeds and helping modify it, if necessary;
- evaluating and analyzing the investigation data to further the understanding of the Site and to refine the conceptual hydrogeologic model;
- providing a predictive tool to assist in evaluating and designing long-term remedial alternatives; and
- providing a tool to organize and synthesize the array of data being collected.

3.1.7 Ecological Investigations

A baseline ecological investigation for benthic organisms and periphyton community for Little Traverse Bay was conducted by CMS as part of the Site characterization. Assessment of bioaccumulation of mercury in mussels was performed according to the U.S. EPA approved work plans. This ecological characterization and mercury assessment work was completed in 2006 and 2007. The objectives of ecological study were to:

- Provide general ecological profile for the study area;
- Document the progress of remediation measures employed; and
- Assess bioaccumulation of mercury using mussels biomass.

3.1.7.1 Methods

The baseline ecological characterization was carried out in two steps. The first step involved a substrate survey of the target areas on January 31, 2006 to ascertain similarity and suitability of natural substrates for sampling and analysis of benthic invertebrates and periphyton communities. Based on the evaluation of the ecologists conducting the survey, sampling of natural substrate for

collecting and enumerating benthic invertebrates would not be feasible to meet the stated objectives. Therefore artificial substrate material (in the form of baskets) was used in the baseline sampling and analysis efforts for benthic invertebrates and periphyton communities.

The second step focused on enumeration of benthic macroinvertebrates and periphytic algae (periphyton) samples collected by deployment of artificial substrates from May through October of 2006. There were six areas and two depths (onshore and offshore) for a total of 12 sampling locations for the benthic and periphyton characterization. Two seasons (Spring and Fall) were used to deploy artificial baskets, collect samples and then enumerate them in the laboratory.

In addition to the baseline ecological characterization, dreissenid (zebra and quagga) mussel tissues were collected and analyzed to assess the potential uptake of mercury. Mussel samples were collected from the same six study areas. The mussel collections were restricted to the fall when mussel biomass and density were likely to be the highest. Sample processing and analysis generally followed U.S. EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition* (U.S. EPA, 2000).

All of the field work and the laboratory work were carried out in accordance with the U.S. EPA approved work plan for the ecological baseline characterization and mercury assessment.

3.1.7.2 Results for Benthic Invertebrates Characterization

The combined quantitative and qualitative sample collections yielded 69 total benthic macroinvertebrate taxa (Appendix 3-11, Table 1). The rock basket samples yielded 50 total taxa while 54 taxa were observed in the qualitative samples. There were 36 taxa common to both types.

In June, based on the combined replicates by location, total richness ranged from 25 taxa at the Seep 2 CKD Area near shore (Appendix 3-11, Table 2) to 10 taxa at East CKD Area offshore (Appendix 3-11, Table 3). In October, based on the combined replicates by location, total richness ranged from 22 taxa at the East Reference Area nearshore (Appendix 3-11, Table 4) to three taxa at Seep 2 CKD Area offshore (Appendix 3-11, Table 5).

Overall, total abundance and total richness were lower in October compared to June while EPT richness in October was equal to or greater than in June. Although these seasonal differences were apparent over the entire study area, they were not always consistent by individual areas or locations.

Based on the 2006 collections, the benthic macroinvertebrate community in the vicinity of Bay Harbor contains several components and taxa common to Lake Michigan and the other Great Lakes. The rock basket results demonstrated that there were no meaningful differences between the near shore locations and offshore locations. These results suggest that proximity to shoreline CKD leachate discharge was inconsequential or was not a factor affecting the benthic macroinvertebrate community during the time period when this study was performed.

3.1.7.3 Results for Periphyton Community Characterization

Total concentrations (NU/sq cm), total Biovolume (um cube/sq cm) and Taxa Richness data were collected for the periphyton community characterization both in June and in October 2006 samples. The resulting data are presented in Tables 6 and 7 of Appendix 3-11 for June and October respectively. Appendix 3-11, Figures 1 and 2 show the bar graphs of taxa richness data with the one standard deviation value also shown on these graphs. Appendix 3-11, Figures 3 and 4 show the bar graphs of total concentrations data with the one standard deviation value also shown on these graphs.

The quantitative samples analyzed yielded a total of 45 taxa for periphyton community. This data can be seen in the tables and figures presented in Appendix 3-11.

Overall, total concentrations were lower in October compared to June. Although these seasonal differences were apparent over the entire study area, they were not always consistent by individual areas or locations.

Based on the 2006 collections, the periphyton community in the vicinity of Bay Harbor contains several components and taxa common to Lake Michigan and the other Great Lakes. The rock basket results demonstrated that there were no meaningful differences between the near shore locations and offshore locations. These results suggest that proximity to shoreline CKD leachate discharge was inconsequential or was not a factor affecting the periphyton community during the 2006 time period.

3.1.7.4 Phase I Survey of Mussels

Prior to submittal of the work plan to the U.S. EPA in September 2006 and due to concerns raised by the U.S. EPA regarding the presence and abundance of zebra mussels in the Little Traverse Bay to assess bioaccumulation of mercury, CMS conducted a field survey of the six areas to determine if sufficient quantity of zebra mussel biomass can be collected to perform the mercury bioaccumulation study. Observations from this survey are reported below.

West Reference Area

Zebra mussels were very abundant throughout the West Reference area except in the "surf-zone" within approximately 10-feet from shore. It appeared that there were at least three and possibly four cohorts (age-classes) observed in the West Reference Area with a length range of approximately 5 to 30-mm. The mussels observed at the West Reference Area seem to prefer the under sides of medium to large rocks (generally >1-ft in diameter). In addition, zebra mussels were abundant on the lower edges of the rocks where they appeared to form the grout in between rocks. Relatively very few mussels were observed on the higher edges or on top of rocks.

West CKD Area

Zebra mussels were numerous in the West CKD Area. The mussels were found in habitats similar to those of the West Reference Area. In addition, where the bedrock was fractured, zebra mussels were fairly abundant on the under sides of large fractured pieces. It appeared that two cohorts (approximately 5 to 15-mm) were present with those in the 5-mm size range being the most abundant.

Seep 2 CKD Area

Zebra mussel size and abundance were indistinguishable compared to the West CKD Area and were found in similar habitats, especially in areas of fractured bedrock. It was observed that rock located beneath, adjacent to, or behind a large boulder seemed to produce high densities of zebra mussels. From this observation as well as those from the other study locations, it seems clear that the zebra mussels along the Site portion of Little Traverse Bay require a fair amount of shelter to become established.

Seep 1 CKD Area

Although zebra mussels at Seep 1 CKD Area were observed in abundance similar to Seep 2 CKD Area and West CKD Area, the mussels at Seep 1 CKD Area were observed to be dominated by the smaller cohort (<10-mm) though some larger individuals were also present.

East CKD Area

Limited zebra mussels were found during the October 2006 Survey in the East CKD Area. This observation is supported by the previous independent observation by U.S. EPA staff.

East Reference Area

Zebra mussels were abundant throughout the East Reference Area. Abundance and size distribution in the East Reference Area were similar to the West Reference area.

As a result of this survey and based on these qualitative observations on the presence and abundance of zebra mussels, it is concluded that replicate samples of more than 10-g of zebra mussels biomass will be feasible from at least five of the six study areas.

3.1.7.5 Phase 2 Sampling and Analysis

Collection of Mussels

Mussel samples were collected from six areas in Little Traverse Bay between October 23 and October 26, 2006. A field duplicate sample was also collected from the West Reference Area. Both zebra and quagga mussels were observed throughout the study area. However, in general, quagga mussels were more abundant. Live mussel specimens of either species were less abundant in the East CKD Area. However, sufficient numbers of mussels were collected to provide the necessary quantity of biomass for the mercury bioaccumulation testing. Altogether, 14 samples were collected in the field for analysis by the laboratory. Duplicate samples from each of the six study areas were collected along with a field duplicate sample from West Reference Area. In addition to the 13 study samples, another sample of transplanted mussels in the East CKD Area was collected for analysis.

Collected specimens at all locations, except from the East CKD Area, were quagga mussels. At the East CKD Area, collected specimens were 50% zebra mussels and 50% quagga mussels.

Shipping and Handling of Collected Samples

The mussel samples were shipped to Columbia Analytical Services in Kelso, WA and arrived at the laboratory on November 1, 2006 in good condition and consistent with the enclosed chain of custody form. The samples were stored by the laboratory at -20° C immediately after they were received.

The laboratory homogenized the whole body samples using a blender. After homogenization a representative aliquot was removed for freeze drying in the Laboratory. Mercury determinations by EPA method 1631 were completed on the freeze dried tissues. Additional milling of the freeze dried tissues was performed to a homogenous meal prior to analysis for mercury. The resulting mercury concentrations data from each area were compared to the reference areas using a single-tailed t-test at 95% confidence level.

Mercury in Mussel Tissues

Appendix 3-11, Table 8 presents the summary of analytical results for the total mercury measured in the 14 mussel tissue samples, the wet weight, the percent dry weight, the mean mercury concentrations, and standard deviations based on two replicates from the six sampling areas.

Appendix 3-11, Figure 5 shows a histogram plot depicting the six mean mercury concentrations and an error bar representing one standard deviations value.

Discussion

Both the East and West Reference Areas have nearly the same average concentrations of mercury (4.4 ng/g for West Reference Area and 4.5 ng/g for East Reference Area) in the mussel tissues and also the same (1.4142 ng/g) standard deviations. The Seep 2 and Seep 1 CKD Areas show the lowest measured mercury concentrations (4.0 ng/g and 3.9 ng/g, respectively). Statistically, the mean mercury concentrations from Seep 2 and Seep 1 CKD Areas are not significantly different from the East and West Reference Areas at the 95% confidence level.

The West CKD Area samples yielded an average mercury concentration of 4.75 ng/g. Statistically, the average mercury concentration in mussel tissues from West CKD Area is not significantly (at 95% confidence level) different from average mercury concentrations in tissue samples from the East and West reference areas.

The mussel samples collected from East CKD Area show an average mercury concentration of 6.4 ng/g. Statistically, this is (at 95% confidence level) higher than the mercury concentrations in tissue samples from the East and West Reference Areas.

Based on the mercury concentrations data and the statistical analyses performed, five of the six areas tested do not show differences in mercury concentrations in mussel tissues whereas the East CKD Area does show elevated mercury concentrations. This is the same area where abundance of the mussels was limited during the Phase 1 survey and also during the Phase 2 sampling effort.

Physicochemical Measurements

During the 2006 ecological surveys, over 850 water quality measurements were recorded between May and October (Appendix 3-11 Table 9). Heavy wave action or meter malfunction occasionally prevented the measurement of some or all of the parameters. Water temperature measurements during the May-June colonization period ranged from 7.88 °C to 20.76 °C while those from the

September-October period were slightly warmer ranging from 8.98 °C to 24.67 °C (Appendix 3-11, Table 9). The observed temperatures varied greatly but largely followed natural diel and seasonal trends. During May-June, mean temperatures were generally warmer near shore compared to offshore with the reverse being true during September-October time period.

Specific conductance exhibited a similar range during both colonization periods from 248 µS/cm to 356 µS/cm and mean values were fairly consistent among areas and locations as well as over time (Appendix 3-11 Table 9).

Like specific conductance, the range of dissolved oxygen (DO) was fairly consistent between the two colonization periods ranging from 8.20 mg/L to 15.55 mg/L (Appendix 3-11 Table 9). However, mean values were slightly higher during May-June compared to September-October.

During the 2006 ecological surveys, no pH measurements were observed above 9.0 in any of the study areas where baskets were installed. Measured pH ranged from 7.25 during May-June to 8.91 during September-October (Appendix 3-11 Table 9). Again the range was similar between colonization periods though slightly higher during the fall.

Turbidity values varied widely during the study. May-June turbidity readings ranged from 0.20 NTU to 6.46 NTU while those from September-October ranged from 0.19 NTU to 3.17 NTU (Appendix 3-11 Table 9). In general, turbidity was slightly higher during May-June compared to September-October and, as would be expected, with rare exception, turbidity was higher near shore compared to offshore. These differences as well as the overall variability are likely a function of algal bloom density and wave action severity

3.1.7.6 Conclusion and Recommendation

Based on this set of data and the statistical evaluation conducted, it is concluded that mercury concentrations in the mussel tissues were statistically the same at the 95% confidence level for Seep 1, Seep 2, West CKD, West Reference and East Reference Areas indicating that there was no additional mercury bioaccumulation associated with the leachate discharge in these areas. In the East CKD Area, mercury concentrations are elevated at 95% confidence level in the mussel tissues collected from East CKD Area compared to the East Reference and West Reference Areas.

3.2 Waste and Leachate Management

3.2.1 Investigation Derived Waste Management

Investigation-Derived Waste (IDW) generated at the Site was managed as per Section 5.2.9 of the Work Plan. IDW generated during RI activities included drill cuttings composed of CKD and CKD mixed with native soils, drilling fluids, and purge water from boreholes and monitoring wells. All IDW was disposed off-site at a receiving site operating in compliance with the requirements of CERCLA Section 121(d)(3), 42 U.S.C. § 9621(d)(3), and 40 CFR § 300.440 as per the AOC.

3.2.2 Interim Response Action Leachate Management

Leachate collected at the Site during the IR was managed as per Section 5.2.9 of the Work Plan. This includes all leachate collected in the ILRS as described in Section 2.2. All leachate was disposed off-site at a receiving site operating in compliance with the requirements of CERCLA Section 121(d)(3), 42 U.S.C. § 9621(d)(3), and 40 CFR § 300.440 as per the AOC. Data pertaining to IDW and leachate disposed of from the Site during RI and RA work activities is available upon request.

3.2.3 Environmental Release Reporting

Releases of regulated materials to the environment that occurred during RI and construction work within the project Site limits were reported to the United States Coast Guard National Response Center (NRC). Reporting was accompanied by an additional notification to the MDEQ. Release reporting included the location of the release, type and quantity of material released, parties responsible for the release, and response actions taken to correct the release. Notification was initiated immediately upon verification of the release. Reporting procedures (e.g., determination of reportable quantities, release type classification, and notification requirements) were performed in accordance with the "Release Notification Requirements in Michigan" table compiled by the Michigan SARA Title III Program in the MDEQ. This table is included in Barr Engineering's Project Health and Safety Plan Revision 5.0 dated May 1, 2006 (Barr, 2005b).

Release response actions were initiated immediately upon discovery of the release. Corrective actions included removal of all impacted soil, rock, and debris from the release area by a waste management contractor. Impacted material identification was performed by field screening and included observance for the presence of sheen, staining, odor, or organic vapor headspace measurements. Additionally corrective actions included the repair or removal of equipment (e.g., drill rig, vacuum truck, etc.) from which the release originated. Released materials included hydraulic oil (< 5

gallons), diesel fuel (<6 gallons), and leachate (~1000 gallons). Reportable incidents that occurred during RI and construction work are not discussed in detail in this section; rather details of all reportable incidents are included in Appendix 3-12a.

Releases of regulated materials that occurred during RI and construction work that were below reportable quantities are not included in Appendix 3-12a; however, these incidents did result in response clean-up actions and are detailed as follows. An incident that occurred on September 9, 2005 during remedial action construction activities resulted in the release of an estimated 42 gallons of leachate to the Seep 2 CKD Area shoreline (CMS letter to U.S. EPA, September 27, 2005). A second release of approximately 24,000 gallons of leachate occurred on December 23, 2006 at the Treatment Plant as a result of vandalism (CMS email to Michigan DEQ, January 10, 2007). These incidents were not reported to the NRC because the released quantities were below the reportable quantities for mercury (1 lb.). A release of approximately 40 gallons of hydraulic oil occurred on December 5, 2005 at the Seep 1 CKD Area approximately 400 feet from the Lake Michigan shoreline. Due to the location of this release it was not reported to the NRC. The December 5, 2005 release was accompanied by analytical sampling to confirm that the release was cleaned up. The associated analytical report can be found in Appendix 3-12b.

4.0 Physical Characteristics of the Study Area

4.1 Surface Features

Surface features at the Site are described in Section 3.1.1.

4.2 Meteorology

Results of weather station and climate data investigation are discussed in Section 3.1.3.

4.3 Surface Water

Results of analysis of surface water drainage and water cycle monitoring are presented in this section. Methods involved in conducting the surface water investigation are presented in Section 3.1.4, Surface Water Investigations.

4.3.1 Surface Water Drainage

Inspection of the quadrangle topographic maps (USGS, 1983a; b; c) indicates that there is a surface water divide located approximately one-half mile south of the Site at an approximate elevation of 790 ft. MSL. Surface water south of this divide flows generally south-southwest toward Walloon Lake, which has a surface elevation of approximately 680 ft. MSL. Surface water north of the divide flows generally north toward Lake Michigan, which has a surface elevation of approximately 578 ft. MSL.

Site drainage conditions at the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area are shown on the figures contain in Appendix 1-2d. Surface water drainage area dimensions are also shown on the tables contained in Appendix 1-2d. Tee boxes, fairways, and greens in each of these areas are maintained with a sprinkler irrigation system. Runoff generally drains to plastic grated inlets located in surface depressions from maintained golf course features (tee boxes, fairways, and greens), native vegetation, and adjacent residential dwellings. Collected runoff is directed through a series of plastic pipes (less than 12 inch diameter) to trunk lines that discharge to drainage swales/creeks that ultimately discharge to Lake Michigan.

The surface area of the West CKD pile is approximately 5.4-acres. Approximately 1.7-acres of tee boxes and fairways are located within the CKD extent. Runoff collected from this area is generally routed east and outfalls into the West-Unnamed Creek.

The surface area of the Seep 2 CKD pile is approximately 34.8-acres. Approximately 8.9-acres of tee boxes, fairways, and greens are located within the CKD extent. Runoff collected from this area is routed south then northwest around the Seep 2 CKD pile, directly north of the pile, or east into the Seep 1 CKD Area. Runoff routed along the west side of the pile outfalls into a drainage swale on the south side of Coastal Drive upgradient from the Pine Court lift station. Runoff routed north of the pile discharges into a drainage swale on the south side of Coastal Drive west of the Guard Rail Seep area or sheet flows off the northern slope of the pile and into roadside drainage swales. A small portion of the eastern Seep 2 CKD Area is routed east across Coastal Drive into the Seep 1 CKD Area surface water drainage network.

The surface area of the Seep 1 CKD pile is approximately 15.5-acres. Approximately 2.68 acres of tee boxes, fairways, and greens are located within the CKD extent. Runoff collected from this area is generally routed east and outfalls into the East-Unnamed Creek #1.

4.3.2 Water Cycle Monitoring

4.3.2.1 Creek Monitoring – Flow and Water Elevation Monitoring

Discharge in the creeks draining the Site was measured on nine occasions in 2006. Measurements were made at three stations per creek. The locations are shown on Figure 3-5a through 3-5c. The sampling events were identified in terms of the conditions prior to the sampling. If no rainfall or snowmelt event preceded the measurements, the event was deemed representative of baseflow conditions. Three baseflow, two snow melt, and four rainfall events were monitored. These events provide an indication of the interaction between the creeks and the groundwater system. In general, the baseflow decreased from spring to summer. Creek flows following snow melt events were variable. Creek flows were monitored within 24 hours of estimated 0.3, 0.8, and 1.2 inch rainfall events in September, May, and August 2006, respectively. Creek flows were also monitored within 48 hours of a 2 inch rain even in August 2006. Creek flow response to rain events was also variable. Creek flow information is summarized in Tables 4-1 for West Unnamed Creek, East Unnamed Creek #1, and East Unnamed Creek #2.

For purposes of comparison between stations, the relative percent difference (RPD) in discharge was calculated as shown in Tables 4-1. This was calculated as the discharge at the downstream station minus the discharge at the upstream station, divided by the average of the two discharge values. Stations with an RPD within the range ±10% are considered within the measurement error. Discussions of the observations along the creeks are presented in the following subsections.

West Unnamed Creek

The West Unnamed Creek runs through the West CKD Area. Measured discharge in this creek ranged from 2.97 cubic feet per second (cfs) to 0.029 cfs (see Table 4-1). During the first baseflow event in late March, this creek gained discharge in the upper reach and was essentially unchanged in the lower reach. During the other two baseflow sampling events, this creek gained discharge in the upper reach and lost discharge in the lower reach. During the first snowmelt event on April 3, 2006 this creek gained discharge in the upper reach and lost discharge in the lower reach. During the second snowmelt event on April 6, 2006 this creek carried less than half the flow rate observed during the first snowmelt event and creek flow was essentially unchanged in the upper reach and gained discharge in the lower reach. In general, this creek lost discharge in the upper reach and gained discharge in the lower reach for all rainfall response monitoring events.

East Unnamed Creek #1

This creek flows onto the Site through a box culvert under Charlevoix Avenue (U.S. Highway 31). East Unnamed Creek #1 showed the greatest range of discharge of the three creeks, ranging from a maximum of 9.67 cfs following a moderate rainfall event in May 2006 to zero cfs. During the first baseflow event measured in March 2006, this creek was observed to lose discharge in the upper reach and gain discharge in the lower reach. During the second baseflow event measured in April 2006, this creek remained relatively unchanged in the upper reach and gained discharge in the lower reach. This creek was dry during the third baseflow event. During the first snowmelt event on April 3, 2006 this creek lost discharge in the upper reach and gained discharge in the lower reach. During the second snowmelt event on April 6, 2006 this creek carried less than two thirds the flow rate observed during the first snowmelt event and was measured to gain discharge in both the upper and lower reaches. This creek gained discharge in both reaches following the May 2006, 0.8 inch rainfall event. Creek flow was generally observed to be dry or immeasurable for all other rainfall response monitoring events.

The flow data collected on these dates indicates that very little to no water flows in this creek during summer months (July through September).

East Unnamed Creek #2

This creek is located along the east side of the ECKD area. Even though this creek is not within the bounds of the Site, as defined for this report, the data are included as they are relevant to the understanding of the Site conceptual model. Measured discharge in this creek ranged from 1.86 cfs to 0.081 cfs. During the first baseflow event in late March, the creek was observed to gain discharge along the entire reach. During the other two baseflow events, this creek lost discharge in the upper reach and gained discharge in the lower reach. During the first snowmelt event on April 3, 2006 this creek lost discharge in the upper reach and gained discharge in the lower reach. During the April 2006 snow melt monitoring events flow in this creek was essentially unchanged in the upper reach and lost discharge in the lower reach. During the first response to rainfall monitoring event, May 2006, flow in this creek was essentially unchanged in the upper reach and gained discharge in the lower reach. Following precipitation events in August and September 2006, this creek was generally observed to gain discharge in the upper reach and loose discharge in the lower reach.

The flow data collected on these dates indicate that, in general, very little water flows in this creek, even during rainfall events that would be expected to generate runoff. This likely reflects that the watershed for East-unnamed creek #2 is relatively small. The data marginally shows an increase in flow from upstream to downstream during baseflow and the moderate rain event indicating that this creek is a gaining creek.

4.3.2.2 Lake Michigan Elevation Monitoring

The Site is bounded on the north by Little Traverse Bay of Lake Michigan. Lake Michigan has a surface elevation of approximately 578 feet MSL (chart datum is 577.5feet [U.S. Army Corps of Engineers, 2005]). The Great Lakes are considered to be essentially non-tidal, but storm surges and seiches create fluctuations of Lake Michigan levels for short periods of time (NOAA, 2006).

Stilling Well

A figure showing a plot of the stilling wells data, the 15-minute elevation summaries, and the raw data files are included in Appendix 4-1a.

Stilling Well Data Comparison

Water level data for Little Traverse Bay does not exist prior to 2006, when a stilling well was installed inside Bay Harbor Lake. In order to appropriately understand the water level for time periods preceding 2006, an analysis was preformed to correlate the known data for Little Traverse Bay with that at other stations along the Lake Michigan coast line.

The water level data for the Site were compared to the NOAA gauging stations at Ludington, MI and Mackinaw, MI. Ludington is located southwest of Traverse City on Michigan's western coast. The gauging station is located within a harbor that is protected by a breakwater system. The Mackinaw, MI gauge is located on the northern coast of Michigan, east of the Mackinac Bridge.

The analysis was completed by looking at data sets, for which there is both NOAA data and Site stilling well data, and comparing them for both long-term change and short, i.e., 5 to 12 hour, changes. Two time series were chosen, June and July 2006, and can be viewed on figures in Appendix 4-1b. The Ludington, MI water elevation is comparable to the stilling well data for long-term averages. However, the short-term oscillations do not match up with that of the Little Traverse Bay data. This can be seen on figures in Appendix 4-1b. Note the small amplitude of oscillations in the Ludington data compared to that of the Little Traverse Bay data. The Mackinaw, MI data shows that the long-term average water level is 0.2 foot less than the Little Traverse Bay data. However, the short-term oscillations closely match those observed in the Little Traverse Bay data. This is shown in all figures with the Mackinaw Data Correction which shows Mackinaw data corrected by adding 0.2 foot to match the Little Traverse Bay data.

The 0.2 foot difference between the water levels observed at Little Traverse Bay and Mackinaw is attributed to the proximity of the Mackinaw station to Lake Huron. The Mackinaw data was compared to other stations located on Lake Huron, and those stations also showed a 0.2-foot difference when compared to Lake Michigan data. Because, both long-term and short-term water level variations are important, it has been determined that the Mackinaw data should be used to develop Little Traverse Bay water levels for time periods in which there is no Site-specific data for Little Traverse Bay.

Ice Cover

Plots of average first ice, last ice, and duration of ice cover for ice concentration at threshold values of 10% and 90% for the Great Lakes for the period 1973 through 2002 are included in Appendix 4-1c. Little Traverse Bay first ice cover is early January for 10% cover and mid-January

for 90% cover; last ice cover is late March/early April for 90% cover and early April for 10% cover. The corresponding duration of ice cover is in the range of 75 to 90 days for 10% ice cover and 60 to 75 days for 90% ice cover. The ice coverage data are based on observed ice concentrations from the grid ice concentration data set described in Assel (Assel, 2003).

4.3.2.3 Infiltration and Evapotranspiration Study

The Penman-Monteith equation (Howell and Evett, 2004) was used to calculate an estimate of the Site specific ET. The equation is made up of an aerodynamic term and an energy balance term.

$$\lambda \mathbf{ET_o} = \{\Delta(R_n\text{-}G) + [86{,}400\rho_a C_p(e_s^o\text{-}e_a)]/r_{av}\}/[\Delta + \gamma(1 + r_s/r_{av})]$$

The energy balance term is $\Delta(R_n\text{-}G)$ and the aerodynamic term is $[86{,}400\rho_a C_p\ (e_s^o\text{-}e_a)]/r_{av}$. The energy balance represents the distribution of the energy emitted by the sun on earth. The aerodynamic term of the ET equation contains the parameters affecting the vegetative surface's ability to evaporate water into the air. This equation is a theoretical potential ET which assumes that unlimited soil moisture is available. Therefore, it will provide a high estimate because soil moisture is not unlimited during dry periods and under frozen conditions.

The calculated cumulative ET from the period of January 1, 2007 to December 31, 2008 at the Bay Harbor weather station was 58.45 inches. The average daily ET was 0.080 in/day or 29.2 in/yr. A table of daily measurements of temperature, wind speed, solar radiation, relative humidity, and calculated potential ET is included in Appendix 3-2a.

A long-term Petoskey-area estimate of ET was calculated based on average monthly mean temperature data acquired from http://www.weather.com/weather/wxclimatology/monthly/49770 and a formula developed by Malmstrom (1969, in Dingman, 2002, p. 310). Malmstrom's equation is presented as Equation 1 below.

$$PET_M = 40.9 e_a^*(T_a) \qquad \text{Equation 1}$$

where:

PET_M is potential ET based on Malmstrom's method (mm/month),

$e_a^*(T_a)$ is the saturation vapor pressure (kPa), and

T_a is the mean daily temperature for the given month (^oC)

The saturation vapor pressure is calculated using Equation 2 below (from Dingman, 2002, p. 586).

$$e_a^*(T_a) = 0.611 \exp\left(\frac{17.3T_a}{T_a + 237.3}\right) \qquad \text{Equation 2}$$

Evapotranspiration Estimate for Petoskey, Michigan

Month	Mean Temperature (°F)	Mean Temperature (°C)	Saturation vapor pressure (kPa)	PET_m (mm/month)
JAN	20	-6.7		
FEB	20	-6.7		
MAR	29	-1.7		
APR	40	4.4	0.84	34
MAY	51	11	1.3	53
JUN	61	16	1.8	74
JUL	67	19	2.2	90
AUG	66	19	2.2	90
SEP	59	15	1.7	70
OCT	48	8.9	1.1	45
NOV	36	2.2	0.72	29
DEC	26	-3.3		
Total (mm/yr)				485
Total (in/yr)				19.1

This calculation is only made for months with a mean daily temperature above the freezing point of water because it is assumed that these are the months when vegetation is available for ET and because if water is frozen, it is not available for ET. Based on this method, the annual average rate of ET for Petoskey is 19.1 in/yr. This is believed to be a better estimate because it takes into account long-term seasonality in ET.

Recharge to the water table aquifer/perched groundwater would be expected to vary based on slope, irrigation rates, soil type, cover, ET, and precipitation. The published recharge rate in the general vicinity of the Site ranges from 4 inches/year to 14 inches/year (http://gwmap.rsgis.msu.edu/start.htm). Surface runoff in the Pigeon River watershed at Afton, Michigan approximately 20 miles east of the Site is assumed to be typical of the region. The Pigeon River watershed runoff averages 1.5 in/yr (Holtschlag and Nicholas, 1998, Table 1). Using the average annual precipitation value of 31 in/yr minus the annual average ET for Petoskey (19.1 in/yr),

minus the estimated regional runoff value (1.5 in/yr in the region) yields an estimate of 10.4 in/yr for recharge to the groundwater system, which is within the range of values estimated by the State of Michigan.

4.4 Geology

Results of the investigation of the Site geology are presented in this section, including summaries of the regional and Site geology; followed by discussion field reconnaissance, the drilling program, and surface geophysics. Methods for the geological investigation are discussed in Section 3.1.5, Geological Investigation.

4.4.1 Regional Geology

The native geology at the Site consists of limestone or shaley limestone bedrock overlain by a relatively thin cover of unconsolidated deposits. The uppermost bedrock unit beneath the Site is composed of rocks from the Devonian-age Traverse Group, which is primarily formed from thinly bedded (one to four inches) to very thickly bedded (>three feet) limestone with some shale (Kesling, et al., 1974 and Milstein, 1987). The Traverse Group is part of the Paleozoic-age assemblage of sedimentary rocks comprising the Michigan Basin. The Site is located on the northwest flank of the Michigan Basin. The Traverse Group generally dips gently to the south in the region of the Site, and is gently folded with fold axes trending northwest-southeast. The unconsolidated deposits are either glacial or lacustrine silty clay to sandy gravel materials (Farrand, et al., 1984).

4.4.2 Site Bedrock Geology

The locations of the boreholes are shown on Figures 3-1a, 3-1b, and 3-1c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Are, respectively. Geologic cross section locations are shown on Figure 4-1a, 4-1b, and 4-1c for the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Cross sections of the geology at these three areas are shown on the following figures: Figures 4-2a through 4-2f show West CKD Area cross sections A-A’ through F-F’; Figures 4-3a through 4-3j show Seep 2 CKD Area cross sections A-A’ through J-J’; and Figures 4-4a through 4-4g show Seep 1 CKD Area cross sections A-A’ through G-G’. Boring logs are presented in Appendix 3-4, and surface and downhole geophysical data are presented in Appendix 3-6 and Appendix 4-2, respectively.

Observations of exposed bedrock indicate that the Traverse Group in the vicinity of the Site is comprised primarily of limestone with shale beds. Field reconnaissance was conducted by examining and mapping outcrops, and by measuring orientations of exposed bedrock features. Results of the reconnaissance were incorporated into the geologic discussion below. Groundwater was observed discharging from the exposed wall of the former quarry at Bay Harbor Lake. An intermittent discharge area was reported near the eastern end of the Seep 1 CKD Area. No other indications of conduit flow such as sinkholes, swallow holes in streams, springs, and other karst features have been identified at or near the Site.

Bedrock is present beneath the Site at depths ranging from approximately 0 feet to 60 feet below ground surface. The bedrock topography maps are shown on Figures 4-5, 4-6, and 4-7 for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Based on borehole logging and geophysics data, the Site-specific bedrock geology characteristics at the Site are as follows:

Unit Descriptions

The geophysical logs used to help determine bedrock stratigraphy and differentiate limestone and shaley limestone units were gamma, resistivity, SP and sonic. Gamma logging results indicated that shaley bedrock units at the Site generally have higher concentrations of clay minerals relative to shale formations found in investigation boreholes at the East CKD Area. Sonic logging shows low seismic velocity – high signal time delay – in areas of more highly fractured and weathered bedrock (Appendix 4-2).

Limestone is the predominant bedrock lithology present at the Site. The limestone is normally dark olive-gray to grayish-tan, fine-grained to micritic, fractured, but dense, well indurated, and with high field strength. The limestone is variably fossiliferous with numerous coral, brachiopod, crinoid, and bryozoan fossils or fossil fragments observed throughout rock cores, indicating that the limestone was probably formed in a reef environment. The limestone contains intervals that are massive alternating with intervals that are medium to finely bedded. Fine, wavy laminated limestone intervals were common as well. The fine-grained limestone occasionally breaks conchoidally as well as along apparent bed planes.

Recovered limestone from rotasonic boreholes was typically shattered into angular to platy fractured pieces ¼ inch to two inches in size. Intact core pieces of the limestone were generally less than ¼-foot long. Few intervals of intact core exceeded ½ foot in length.

Calcite-filled solution vugs were sometimes present in the limestone cores. These features were typically 0.2 to 0.8 inch in diameter. Apparent black to dark gray manganese coatings were noted on fracture faces or bed planes in the limestone, typically below elevation of 560 feet MSL. Below this elevation the limestone also frequently exhibited faint irregular gray mottling of the rock matrix. The mottling was typically 0.1 to 0.4 inch in width and irregular to patchy. Very fine to medium grained pyrite crystals imbedded in the rock matrix (at a frequency significantly less than 1% of the rock volume) were sometimes observed in conjunction with the gray irregular mottling. The pyrite and irregular mottling were typically associated with the silty limestone or the micritic limestone lithologies.

Interbedded shaley- or silty-limestone was observed within some boreholes. Some shaley- or silty-limestone intervals were observed to extend laterally between boreholes, but did not extend laterally across the entire Site area. The term “silty-limestone” was used to describe zones which were observed to be rich in apparent silt-sized mud grains, or calcite grains, comprising the majority of the rock matrix. The term “shaley-limestone” was used to describe the limestone when it was observed to contain increased clay-sized particle texture, shaley horizontal cleavage, abundant fine laminations (0.1 inch or less thick), numerous platy core pieces, and/or dark gray to gray-black coloration. Shaley-limestone was observed to be well indurated to soft. Gamma logging was used to help distinguish shale, from shaley limestone, silty limestone, and limestone units.

Shaley- or silty-limestone was typically shattered into rock powder, with angular pieces no greater than one inch in the recovered rotasonic cores. Intervals of shaley-limestone were observed to produce intervals of platy core pieces less than 0.1-foot thick in the rotasonic cores when the interval was well-cemented and/or finely laminated. The mechanical action of the rotasonic core method appeared to produce extensive mechanical breaking of the core material across apparent bed planes when coring silty- or shaley-limestone intervals.

A shale layer with an approximate thickness of 10 feet was penetrated by many of the borings in the drilling program. This ‘marker shale’ was used to help correlate boring logs for cross sections. The upper elevation contours of this shale layer are shown on Figures 4-8a, 4-8b, and 4-8c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. A lower shale layer with an approximate thickness of four feet was also encountered near the northwest corner of the Site and at borings B2026, B3042, and B3017. A shale layer topographically and stratigraphically higher than the marker shale was encountered at B2043 south of the Seep 2 CKD Area near Highway 31. Shale was also observed interbedded within the limestone in a few intervals at the Site, generally in layers

less than three feet thick. Most shale units were not found to be laterally continuous and downhole geophysical investigation identified no intervals with significant clay content. Where visually identified, shale was noted as very dark olive-gray to grayish-black, fine-grained clay-rich, massive to finely laminated shale, sometimes including small concentrations of brachiopod fossil shells or fossil fragments. Apparent shale material in the recovered rock cores was variably intact.

Topography and Features

The bedrock surface has significant topography as shown on the geologic cross sections and bedrock topography maps. Based on geophysical data (Appendix 3-6) and borehole logging, the bedrock surface at the Site is inferred to slope steeply down from the upland located south of the Site. The original bedrock surface likely sloped steeply down to the lakeshore and a bluff face was likely present in this area. Based on the geophysical data, the uppermost portion of the limestone bedrock is interpreted to be weathered (contains low-velocity zones) and thus is more highly fractured at the bedrock surface. The weathered (low-velocity) bedrock zone is likely due to natural weathering processes and anthropogenic effects such as quarrying.

West CKD Area – Bedrock Topography and Features

The bedrock surface at the West CKD Area is inferred to be nearly level, with a gentle slope toward the lakeshore until the vicinity of Quarry Ridge Road as shown on Figure 4-5. In the vicinity of this road, the geophysical profiling suggests that a buried bedrock ravine is present, with a bottom elevation below the current Lake Michigan level. This inferred buried bedrock ravine lines up with a re-entrant feature south of the CKD deposit, shown by the topographic contours on Figure 4-5. This surface drainage feature in turn is aligned with the northern end of Lake Walloon (located 3,500 feet south of Highway 31) (USGS, 1983). At some time in the past a ravine was possibly eroded in the bedrock at this location near the lakeshore. The potential buried bedrock ravine now lies beneath the West CKD Area.

Seep 2 CKD Area and Seep 1 CKD Area – Bedrock Topography and Features

The bedrock surface in the Seep 2 CKD Area (Figure 4-6) and Seep 1 CKD Area (Figure 4-7) is generally higher in elevation south, west, and east of the CKD piles and lower near the beach to the north. The bedrock surface in the southwest portion of the Seep 1 CKD Area is approximately 660 feet MSL. Where exposed along the beach, the bedrock surface forms a wave-cut bench with minor amounts of cobble/sand cover. The bedrock bench along the shoreline is coincident with the Lake Michigan elevation (577.5 feet MSL). Observed bedrock outcrops, measured bedrock

elevations, and interpreted geophysical data indicate that bedrock in the vicinity of the Seep 2 CKD Area and Seep 1 CKD Area does not slope uniformly northward. The data indicate that what appear to be buried bedrock features (e.g., ravine or quarry features) are covered with natural deposits and/or fill beneath the western portion of the Seep 1 CKD Area.

Structure – Folding

Outcrops measured in the vicinity of the East CKD Area have bedding that is generally horizontal to gently dipping (up to about two to three degrees). Between the East CKD area and the Seep 1 and 2 CKD Areas, the limestone beds in an outcrop above the Bay Harbor Lake were seen to dip gently northeastward and southwestward at five to 10 degrees, forming a subtle anticline structure with its fold axis trending northwest to southeast (e.g., Figure 4-4g, Seep 1 G-G' Cross Section or Figure 4-3g, Seep 2 G-G' Cross Section).

Structure – Fracture Density Evaluation Discussion

Geologic mapping indicates that both horizontal/near horizontal fractures along/parallel to bedding planes and high angle fractures (dips of 70° or more) are present in the limestone bedrock. Two main strike orientations were observed for the high angle fractures: approximately 300° and approximately 60°. Spacing of the high angle fractures is generally consistent between outcrops and ranges from approximately one to two feet. In all outcrops observed in the vicinity of the Site, the limestone bedding planes are cross-cut by abundant near-vertical fractures. Fractures observed in outcrop exposures in the vicinity of the Seep 2 CKD Area and Seep 1 CKD Area are generally oriented NW-SE with a secondary set of fractures oriented NE-SW. Fracture spacing is generally consistent from one outcrop to another, ranging from approximately one to two feet.

Polar plots of acoustic televiewer readings in boreholes are shown in Appendix 4-2. The histogram of fracture dips (Figure 4-9) typically show a bimodal distribution of fracture dips: a set of low-angle bedding planes/bedding plane fractures and another set of higher angle fractures. The greatest number of dip measurements occur in the range 5 to 7.5 degrees. These lower-angle fractures (0 to 10 degrees) are inferred to be primarily bedding plane fractures. The higher angle fractures have mean dips ranging from about 53 to 67 degrees. The spread around the higher-dip mode is much greater. This means that horizontal anisotropy is best modeled as spatially variable. Table 4-2 lists the average fracture density for each borehole that was logged. This density ranges from 0.6 to 2.3 fractures per foot. The average among all boreholes is 1.2 fractures per foot.

For a fractured-rock aquifer to be considered porous-medium-equivalent for the purpose of modeling, the distance between fractures should be orders of magnitude smaller than the size of the site under investigation, and the fractures should show appreciable interconnection (ASTM, 2005). The described condition applies to the Site; therefore, the Site can be modeled as an equivalent porous media. Borehole logging provided a measure of the fracture density to the extent that these fractures intersect the vertical boreholes.

Fracture distributions were plotted to determine how the fracture spacing varies with depth. Idealized plots of fractures with depth are shown on Figure 4-10. The x-axis of this figure is depth below ground surface. The y-axis is the fraction of the total number of fractures within the borehole that occur above a specified depth. Four idealized plots are shown on this figure showing different fracture spacing patterns:

- If the fracture density decreases with depth (i.e., spacing between fractures increases with depth), as is typical in many geologic settings, the plot is concave-downward.
- If the fracture density is independent of depth, the data fall on a straight line, the slope of which is the ratio of the number of fractures per unit depth.
- If the fracture density increases with depth (spacing between fractures decreases with depth) the plot if convex-downward. Such fracture distributions might be caused by variations in lithology with depth from a cleaner, more massive limestone to an interbedded limestone with shale having more bedding plane partings.
- The fourth plot on Figure 4-10 shows a plot with overall-uniform spacing with a series of three zones of much greater fracture density. The zones with the overall uniform spacing are linear with a lower slope and are connected by segments with much greater slope. Concentration of flow in the more densely fractured zones could lead to the formation of conduits.

The first three plots on Figure 4-10 are repeated as backdrops in plots of the fractures from the West CKD Area (Figure 4-10a to 4-10c), Seep 2 CKD Area (Figure 4-10d to 4-10f), and Seep 1 CKD Area (Figure 4-10g to 4-10i). In general, the plots suggest uniform fracture density through many of the boreholes. Very few examples of localized zones of greater fracture density are apparent; one example is shown on Figure 4-10i. This zone is in B1018 at an elevation of 542 feet MSL.

4.5 Unconsolidated Materials

Borehole logs are included in Appendix 3-4. The borehole logs are formatted to show the data gathered during direct-push and rotasonic drilling activities. The locations of the boreholes are shown on Figures 3-1a through 3-1c. Figures 4-1a through 4-1c show the locations of the geologic cross sections prepared for the Site. Table 4-3 provides a summary of the unconsolidated units at the Site (e.g., silty sand, clay, sand with gravel) which is intended to provide detail not shown on the geologic cross sections.

Physical (geotechnical) testing performed on samples of CKD and non-CKD unconsolidated material included analysis of vertical and horizontal permeability, UU triaxial compression (non-CKD only), porosity, and grain size distribution. Copies of the Soil Engineering Testing Laboratory reports of physical property testing are included in Appendix 4-3. The physical property testing data are summarized in Table 4-4.

Non-CKD

Results of investigation activities including geophysical investigations and soil borings indicate that topsoil or fill covers the Site; consisting of variable amounts of sand, silt, and gravel in thicknesses ranging from approximately 0 feet to 60 feet (e.g., Figure 4-3f Seep 2 CKD Area Cross Section F-F' and Figure 4-2b West CKD Area Cross Section B-B'). Organic material, roots, and plant detritus are typically present in the topsoil layers. Lesser amounts of clay and sandy clay were observed in some borings, and occasionally in soil directly overlying bedrock. Within the Site boundaries much of the surface cover is non-CKD fill apparently placed during development of the golf course. Along the lakeshore the surface material includes beach cobbles. Non-CKD soils underlying the beach cover at the West CKD Area beach consist of clay to clayey sand with lesser amounts of gravel. Table 4-3 summarizes the unconsolidated borehole data for the Site.

Beneath the CKD in some areas is clean sand that may have been deposited at former beaches. Additionally, clay till was observed in borings drilled in unconsolidated material within the bedrock channel in the West CKD Area.

Non-CKD unconsolidated material vertical permeability ranged from 1.2×10-9 to 5.7×10-2 cm/sec while porosity ranged from 0.20 to 0.39. Median grain sizes of non-CKD samples ranged from 0.006 to 49 millimeters while percent passing the #200 sieve ranged from 0.8 to 95.3%. One sample of unconsolidated soil collected from the West CKD Area was subjected to UU triaxial compression

testing. The testing showed the cohesion for the soil was 1,250 psf occurring at approximately 14% strain. These results were incorporated into a slope stability model to design a safe excavation for the CKD/soil excavation completed in 2008/2009.

CKD

CKD material is present beneath the non-CKD soil cover at thicknesses up to approximately 60 feet (e.g., Figure 4-3b Seep 2 CKD Area Cross Section B-B' and Figure 4-4c Seep 1 CKD Area Cross Section C-C'). The lateral extent of CKD in each area is depicted on Figure 1-2. Bottom of CKD contours for each area are presented on Figures 4-11a, 4-11b, and 4-11c, and top of CKD contours for each area are presented on Figures 4-11d, 4-11e, and 4-11f for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. The saturated lateral extent of CKD is presented on Figure 4-11g for West CKD Area and Figure 4-11h for Seep 1 CKD Area. The Seep 2 CKD Area does not have CKD saturated by the regional groundwater table.

CKD mixed with soil (soil/CKD) was present along the West CKD Area beach as shown on Figure 2-1b. The horizontal and vertical extent of the soil/CKD located on the beach was provided in the West CKD Area Augmentation Design Reports (Barr, 2008a; Barr, 2008d; and Barr, 2008f) and was based on all investigation work completed through summer of 2008. As discussed in Section 2.2.3.1, the soil/CKD was removed in the winter of 2008/2009 as a part of the West CKD Area Augmentation.

CKD vertical permeability ranged from 3.1×10^{-7} to 5.8×10^{-3} cm/sec while porosity ranged from 0.68 to 0.80. Median grain sizes of CKD samples ranged from 0.012 to 11 millimeters while percent passing the #200 sieve ranged from 11.6 to 77.4%. Soil/CKD vertical permeability 1.2×10^{-8} cm/sec. Median grain sizes of soil/CKD samples ranged from 0.25 to 0.74 millimeters while percent passing the #200 sieve ranged from 11.6 to 29.1%.

4.6 Hydrogeology

The hydrogeology at the Site was evaluated using data from several sources, including Site/regional topography information, data from nearby wells, surface water elevation data, geologic data, and data collected from boreholes (e.g., groundwater elevation data, aquifer testing data, and geophysical flow logging data).

The initial working hypothesis for the Site was that groundwater flowed through a limited number of preferential flow paths. These preferential flow paths (i.e. conduits) were hypothesized to be individual fractures in the limestone through which water could flow significant distances. This hypothesis was based on the limestone geologic setting and reported observations of karst-like features in the vicinity of the Site (e.g., Olcott, 1992). The following sections include descriptions of the processes followed to identify "potential conduits". As discussed below, a series of potential conduits were identified, but most are low-angle fractures that are inferred to represent bedding plane partings. Few, if any, of the potential conduits identified are extensive enough to have been encountered in multiple boreholes, particularly in the vicinity of existing and proposed remedial elements. None of the potential conduits identified were indicated by multiple lines of evidence. For example, in some cases what appears to be a conduit based on borehole geophysical logging was proven to not be a conduit because it was shown to be interconnected with surrounding fractures when it was pumped.

Because no actual conduits were identified, it is concluded that the groundwater flow system at the Site consists of a dense, interconnected, fracture system within the bedrock. It can also be concluded that the Site aquifer can be modeled as an equivalent porous medium.

4.6.1 Aquifer Characteristics

The groundwater system at the Site is present within non-CKD soils, CKD, and predominantly limestone bedrock. The aquifer characteristics discussed in this section include flow direction and gradient, geology, perched groundwater, porosity, anisotropy, hydraulic conductivity, heterogeneity, water levels, and temperature.

4.6.1.1 Flow Direction and Gradient

Based on Site/regional topography information and available water well data, the regional horizontal groundwater flow direction in the vicinity of the Site is from south to north toward Lake Michigan, the regional discharge zone for groundwater in the area. The horizontal hydraulic gradient ranges from approximately 0.02 to 0.1 feet/foot. This estimated range is based on groundwater table slopes inferred from adjacent stream profiles, monitoring well data, and the profiles of local drainage pathways within the Site.

While the horizontal groundwater flow direction is generally toward Little Traverse Bay, groundwater elevations measured in monitoring wells at the Site (Table 4-5) indicate that there are

localized seasonal variations in flow direction due to pumping from City of Petoskey municipal wells located south of the Site. This general flow pattern is illustrated by Figures 4-12a to 4-12c through 4-15a to 4-15c which show water table contours for measurements made in the Site monitoring wells in the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area in July 2006, September 2006, January 2007, and March 2007. The groundwater elevation contours indicate that the horizontal flow direction in the West CKD Area and in the southwest portions of the Seep 1 and Seep 2 CKD Area is toward the south or southwest during certain times of the year. The area where flow direction is toward the south expands through the summer months, and has been observed to include all of the West CKD Area by the end of the summer season.

Vertical hydraulic gradients calculated from the groundwater elevations measured in the monitoring well nests at the Site are summarized in Table 4-6a to 4-6c. Since Lake Michigan is the regional discharge zone for groundwater in the vicinity of the Site, it is expected that the groundwater system would show a vertical upward gradient near Lake Michigan. Groundwater elevations measured in monitoring wells at the Site show both vertical downward gradients and vertical upward gradients. This variation is likely due to the superposition of the affects of local infiltration, regional flow/discharge, and the temporal variations in pumping of the nearby Petoskey municipal water supply wells.

The groundwater elevation contours illustrating the hydraulic head distribution with depth for July 2006 are shown in cross section as follows: West CKD Area cross section B-B' on Figure 4-16a, Seep 2 CKD Area cross sections A-A', B-B', and D-D' on Figure 4-17a, Figure 4-17b, and Figure 4-17c, respectively, and Seep 1 CKD Area cross sections A-A', C-C', and D-D' on Figure 4-18a, Figure 4-18b, and Figure 4-18c, respectively. The groundwater elevation contours illustrating the hydraulic head distribution with depth for March 2007 are also shown in cross section as follows: West CKD Area cross section B-B' on Figure 4-19a, Seep 2 CKD Area cross sections A-A', B-B', and D-D' on Figure 4-20a, Figure 4-20b, and Figure 4-20c, respectively, and Seep 1 CKD Area cross sections A-A', C-C', and D-D' on Figure 4-21a, Figure 4-21b, and Figure 4-21c, respectively.

4.6.1.2 Geology

While groundwater appears to flow mainly through fractures in the limestone bedrock at the Site, groundwater flow through the saturated portion of the CKD and other unconsolidated material is through intergranular pore spaces. The porosity of the unconsolidated material would be expected to vary with the grain size of the material, with the finer-grained materials typically having higher

porosity (Fetter, 1980). The grain size for CKD samples analyzed ranges from to 0.12 to 11 mm and the non-CKD samples ranges from 0.006 to 40 mm. The laboratory measurements of porosity in samples of CKD collected at the Site range from 0.68 to 0.80 while the porosity of the non-CKD samples range from 0.20 to 0.39 (Table 4-4).

The affect of fractures on groundwater flow through fractured rock units is somewhat scale-dependent. If fracture densities are low, then on a small scale individual fractures can be significant. On the other hand, if fracture densities are high and the domain of interest is large, then evaluating the system as a porous medium is appropriate (Freeze and Cherry, 1979). Site data indicate that the fracture network is sufficiently dense and interconnected for the hydrogeologic conceptual model of the Site to approximate the groundwater flow system as a heterogeneous, anisotropic porous medium.

No visible indications of large-scale karst features were observed on or near the Site; however, the Site is located in a region known to have karst features (e.g., Olcott, 1992). The results of the geologic mapping and surface and borehole geophysical work all indicate that the bedrock at the Site is fractured. Only small (<0.25 to 1 inch) vugs were noted in borehole logs for borings drilled into the limestone. Typical values of porosity for fractured limestone vary over a wide range from less than 0.01 to as high as 0.30 (e.g., Fetter, 1980; Freeze and Cherry, 1979).

The marker shale layer (defined in Section 4.4.2) present across much of the Site limits vertical flow of water in some areas to the extent that perched groundwater zones are developed on top of it and/or zones of variable saturation are developed below it.

4.6.1.3 Perched Groundwater

Perched water has been observed in wells installed above the marker shale and other shale units. Wells installed in the perched zone within the Seep 2 CKD Area include W2120, W2122, W2125, W2133, W2142, W2242, W2143, W2243, W2144, W2244, W2146, W2156, W2256, W2163, W2164, and W2193. In the West CKD Area, perched groundwater was encountered in W3120 and W3113. The table below summarizes the screened interval for each well where perched groundwater was observed relative to the marker shale. No shale was present in borehole B3013, however, clayey soil is present at an elevation similar to the shale in nearby borings, and may form a continuum with the shale. No wells were installed above the marker shale layer in the Seep 1 CKD Area, but the marker shale was encountered in boreholes B1019, B1020, B1029, and B1030.

Well	Screened Interval Relative to Marker Shale
W2120	Within marker shale
W2122	Within marker shale
W2125	Within marker shale
W2133	Within marker shale
W2142	Within marker shale
W2242	Within marker shale
W2143	Shale above marker shale
W2243	Above marker shale and between two other shale units
W2144	Above marker shale
W2244	Above marker shale
W2146	Within marker shale
W2156	Above marker shale
W2256	Within marker shale
W2163	Within marker shale
W2164	Within marker shale
W2193	Above marker shale
W3120	Above marker shale
W3113	Unconsolidated material above a layer of clayey material

In general, water levels in wells installed in the limestone below the marker shale indicate the limestone directly below the shale is usually unsaturated, except in areas where the shale layer dips to lower elevations, such as in the West CKD Area, the west/southwest portion of Seep 2 CKD Area, and the northeast portion of Seep 2 CKD Area near the monitoring well nests at B2033 and B2046.

4.6.1.4 Porosity – Causes, Extent, and Interconnection

The bedrock at the Site is mantled with granular material with primary porosity. Fill material, including pulverized limestone and CKD has low effective porosity due to the fine-grained nature of the material.

The bedrock beneath the Site has low primary porosity. Fractures within the rock are inferred to have been formed by structural deformation of the rock, loading and unloading during glaciation, unloading due to weathering of the rock, and quarrying of rock in specific areas. These fractures form the vast majority of the void space in the bedrock. Geologic mapping indicates that both horizontal/near horizontal fractures along/parallel to bedding planes and high angle fractures (dips of 70° or more) are present in the limestone bedrock. Spacing of the high angle fractures is generally

consistent between outcrops and ranges from approximately one to two feet. In all outcrops observed in the vicinity of the Site, the limestone bedding planes are cross-cut by abundant near-vertical fractures. Fracture density in the vertical boreholes at the Site ranges from 0.6 to 2.3 fractures per foot. The average among all boreholes is 1.2 fractures per foot.

The factures within the Site bedrock are highly interconnected. This determination is based on observations of exposed bedrock, vertical head differences within well nests, responses to pumping during the packer tests, and evaluation of borehole geophysical data.

4.6.1.5 Aquifer Anisotropy

Fractured rock typically has anisotropic hydraulic properties in three dimensions (ASTM, 2005). Vertical anisotropy was indicated by the packer testing and slug test results and was observed to be highly variable. Evaluation of the available data suggests that there is not significant horizontal anisotropy of hydraulic parameters at the Site. Even though there are abundant high-angle fractures at the Site, they cannot be projected between boreholes. Therefore, the fractures will not exert significant, Site-wide influence on the horizontal flow characteristics of the bedrock and not impart significant horizontal anisotropy.

4.6.1.6 Hydraulic Conductivity / Heterogeneity

Hydraulic conductivity/heterogeneity was evaluated using geophysical tools (caliper, fluid temperature, fluid resistivity, BHTV, and borehole flow logging) and aquifer testing techniques (packer tests, pumping tests, and slug tests).

Hydraulic conductivity differences of several orders of magnitude can occur over very short horizontal and vertical distances in fractured-rock and karst aquifers (ASTM, 2005). Heterogeneity within the aquifer was observed through comparison of hydraulic conductivity estimates based on packer tests and borehole flow testing at similar elevations in adjacent boreholes (Figures 4-22a to 4-22c). Hydraulic conductivity measured at the Site ranges from approximately 0.004 to 450 feet/day as shown in Table 4-7a, Table 4-7b, and 4-7c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. The hydraulic conductivity distributions are shown on Figure 4-23a, Figure 4-23b, and Figure 4-23c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. As shown on Figure 4-24, hydraulic conductivity measurements from the Site are approximately log-normally distributed. ASTM Standard D5717-95e1 notes that “in porous-medium-

equivalent settings, the distribution of hydraulic conductivity … tends to be approximately log-normal."

4.6.1.7 Water Level and Temperature Monitoring

Water levels were measured manually in all Site wells approximately monthly. Water levels were also measured automatically at 5-minute intervals in selected wells using MiniTroll® data loggers. The MiniTroll® data loggers also monitored groundwater temperature. Water level and temperature data were analyzed for responses to seasonal variation in groundwater withdrawal from wells, rainfall/snowfall events, ET, and lake stage. These data are summarized in Appendix 4-4a and described in detail below.

Water Level Data Trends

Examples of the correlation of groundwater level changes with rainfall/snowfall events are shown on Figures 4-25a and 4-25b. The upper traces on these plots are cumulative rainfall/snowfall beginning when the weather station was installed, and difference between rainfall/snowfall and estimated potential ET. The vertical tie lines indicate relatively large rainfall/snowfall events. Reversals of the water level trends in the two shallower wells in the well nest at the borehole B1022 well nest correlate with these rainfall/snowfall events (Figure 4-25a). The water level in the deepest well in the nest, W1422, did not respond to the first three events, but the rise starting in mid-October correlates with the last highlighted event. The responses in wells W1122 and W1222 are examples of what are termed "lagged" responses to rainfall/snowfall events in Table 4-8.

The rise in water level in response to rainfall/snowfall events was more marked in wells W2150 and W2350 than in the well nest at borehole B1022 (Figure 4-25b). The responses in wells W2150 and W2350 are examples of what are termed "flashy" responses to rainfall/snowfall events in Table 4-8. Implications of these observations are described below in Section 4.6.4.1.

Water Temperature Data Trends

Groundwater temperatures are influenced by a number of factors, including:

- Heat flux between the atmosphere and the shallow groundwater system.
- Influx of heat with surface water in recharge zones. Recharge zones for the groundwater system at the Site include the upland areas and, seasonally, some reaches of the shoreline of Lake Michigan.

- Heat flow within the crust which causes geothermal gradients of approximately 1°C per 40 meters of depth in stable cratonic settings. In general, the borings at the Site are too shallow for the influence of the geothermal gradient on groundwater temperature to be evident.

Surface water temperatures can be influenced by groundwater in groundwater discharge zones. Appendix 3-1 contains a memorandum that presents and discusses an aerial thermometry survey that was conducted at the Site. The survey showed background offshore Lake Michigan temperatures of 2°-4°C and nearshore zones of temperatures as high as 9°C. Temperatures of 6°-7°C were present near the shores of the West, Seep 2, and Seep 1 CKD Areas. The higher temperatures near the shore are likely the result of subsurface water discharge to Lake Michigan. However, the subsurface discharge locations were not associated solely with areas with >9 pH.

Groundwater temperatures were monitored automatically using MiniTroll® data loggers in approximately 50 wells across the Site and measured manually at all wells during groundwater sampling events. The location of the MiniTroll® and when they were in use is summarized in Table 3-4. Temperature trends observed in the wells monitored with MiniTrolls® are summarized in Table 4-8. Groundwater temperatures in many wells show little temperature variation (i.e., less than about 1°C) whereas in other wells, the variations were much larger. Surface water temperatures in Bay Harbor Lake were measured automatically at 5-minute intervals using a MiniTroll® data logger. The Bay Harbor Lake temperature ranged from approximately 4.5^{o}C to 25°C during the monitoring period.

The relationship between groundwater levels and groundwater temperatures near Lake Michigan and the lake stage varied from location to location. Measurements at specific well nests are described below to provide examples of the interaction between the groundwater and Lake Michigan.

At the well nest installed at borehole B1017, water levels in all three wells in the nest monitored automatically were above lake stage throughout the monitoring period, suggesting that this is a groundwater discharge zone (see Figure 4-26a). The groundwater temperatures measured in the wells were very stable. This would be expected for groundwater in the bedrock in an area that is not recharged by Lake Michigan. The water level in Well W1117 is far enough below ground surface (greater than 20 feet) that fluctuations in air temperature do not affect the groundwater temperature.

At the well nest at borehole B2038, the shallow groundwater elevation is above the lake stage and the temperature rises gradually through the summer into the fall and then begins dropping in the late fall (Figure 4-26b). This is believed to be caused by fluctuations in air temperature causing a similar trend in temperature of water recharging the shallow groundwater zone. The water level in well W2138 is approximately 11 feet below ground surface. Wells exhibiting similar temperature variations are labeled "Recharge affect" in Table 4-8. During the monitoring period, the deepest well in the nest (W2438) had water levels above the lake stage in early summer, falling below lake stage in mid-summer and remaining below lake stage until early fall. This trend is believed to have been caused by the reduction in net recharge to the groundwater system and higher rates of regional groundwater withdrawal during the summers. The water temperature in well W2438 exhibited a much smaller, but continuous rise in water temperature over the course of the monitoring period compared to well W2138. Groundwater temperature increases in this well reflect the influence of infiltration of warmer water as recharge from Lake Michigan during the summer. This temperature trend reversed over the winter as the deeper groundwater system discharged toward Lake Michigan during this time.

The shallow groundwater system at the well nest at borehole B3016 is not perched and is more proximal to Lake Michigan in elevation than at the borehole B2038 well nest (see Figure 4-26c). Water level trends in wells W3116 and W3416 were similar to that described above for well W2438. This suggests that Lake Michigan recharged the aquifer system during the summer and the groundwater system discharged to Lake Michigan after approximately mid-September. The observed trend in groundwater temperature is consistent with this hypothesis – with temperatures rising during the period when the Lake Michigan temperature was rising and Lake Michigan is inferred to have recharged the aquifer and falling during the period when the groundwater system is inferred to discharge to Lake Michigan. Additional water level summaries are included in Appendix 4-4.

The recharge affect described above tends to produce a smooth variation in temperature that coincides with seasonal air temperature variations or is offset in time relative to the air temperature. An example of rapid infiltration of recharge affecting groundwater temperatures after individual storm events is shown for well W2150 on Figure 4-27. The top of the screen in well W2150 is approximately five feet below the top of bedrock and approximately 22 feet below ground surface. The response observed in well W2150 is an indication of localized recharge. The rapid recharge may be attributed to more highly fractured bedrock in this area that resulted from historic quarrying operations (Section 1.3.3.2).

Groundwater temperatures in wells with static water levels within the frost zone were observed to drop to very low values during the winter (e.g., well nest at borehole B1014 shown on Figure 4-26d). This is likely caused by sinking of water cooled at the top of well to the bottom of the well where the transducer is located. This is a function of the position of the static water level in the well, not the screened interval, and does not provide information about the groundwater flow system.

4.6.2 Borehole Flow Logging

Flow logging was performed in 63 boreholes. In all cases, the ambient (unpumped) flow within the borehole was measured at a series of stations chosen based on the geophysical logging. Additionally, in 17 boreholes a pump was placed just below static water level in the borehole and the flow logging repeated as the borehole was pumped. The borehole flow data were used in conjunction with the geophysical logging to identify permeable zones within the boreholes and to differentiate zones with possible conduit flow from those with diffuse flow. An illustrative example of the data analysis is shown in Table 4-9 and described below. Data analysis summaries for the additional boreholes are presented in Appendix 4-5.

The instrument used in the flow logging in 2005 and 2006 was rated to 0.013 gpm. The instrument used for flow logging in 2007 was rated to 0.2 gpm. The flow rates differ because two different contractors performed the work. Both pieces of equipment met calibration criteria as discussed in Section 3.1.5.3. Flow values and differences between stations below this threshold were considered indicative of no flow or no net change in discharge, respectively. By convention, positive values indicate flow up the borehole and negative values represent flow down the borehole.

In many boreholes, flow was in one direction at all of the monitoring stations. The flow was presumably induced by differences in pressure (hydraulic head) between zones that were temporarily connected by the borehole. In some cases flow direction in the borehole changed at one or more elevations. A station with upward flow above a station with downward flow represents net inflow from the aquifer into the borehole in the interval between the stations. Such an interval is referred to as a divergence zone.

A station with downward flow above a station with upward flow represents net outflow from the borehole to the aquifer in the interval between the stations. Such an interval is referred to as a convergence zone. Convergence and divergence zones were identified as locations of possible conduits.

Two additional flow logging stations were assumed in the analysis:

- A station representing the static water level or bottom of the casing in the borehole, whichever was lower. This station represents the top of the saturated rock exposed in the borehole. For boreholes with the water level in the open-rock section, the water level is lowered by pumping. However, this drawdown caused by pumping was typically small in these tests due to the relatively low pumping rates.

- A station representing the bottom of borehole, labeled "TD" for total depth.

The analysis includes the following assumptions about the flow at these stations:

- The discharge was assumed to be zero at the top of the saturated rock exposed in the borehole for the ambient tests, and assumed equal to the pumping rate for the pumped flow logging.

- The discharge was assumed to be zero at the bottom of the borehole in both cases.

A flow budget calculation was then done for each pair of stations working down the borehole. The 6th column of Table 4-9 contains the flow budget calculation for the ambient test (no pumping from the borehole). The values in this column total to zero, indicating mass balance. Figures 4-28a, 4-28c, and 4-28e illustrate the ambient flow gains and losses for the boreholes in the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. The borehole traces on these figures are divided into the intervals between the discharge measurement stations. Gaps in the plot of borehole intervals indicate areas of potential conduit flow inferred from the geophysical logs. The gap represents less permeable rock surrounding the more permeable zones. By convention, the potential conduit(s) would be located in the filled rectangles that are surrounded above and below with gaps.

The 4th column in Table 4-9 is the flow gain or loss between stations during pumping. These differences add up to the discharge rate of the pump. Positive values indicate a section of the borehole that had a net gain in discharge. Negative values indicate a section of the borehole that had a net loss of discharge. Figures 4-28b, 4-28d, and 4-28f show the flow gains and losses for the boreholes in the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively that were pumped. In these figures, gaining intervals are differentiated into those that had a gain in discharge greater than 25% of the pumping rate and those that had gains less than or equal to 25% of the pumping rate. Most of the gain occurred in the interval between the pumping water level/bottom of the casing and the uppermost discharge measurement station.

The 7th column of Table 4-9 is the change between columns 4 and 6, which was caused by the pumping. This column also adds up to the pumping rate and indicates where the water came from that was removed by the pump. Figures 4-29a through 4-29c show the change in flow gains and losses caused by pumping for the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively.

Specific capacity of a well or borehole is defined as the pumping rate divided by drawdown caused by the pumping. Aquifer transmissivity can be estimated based on an empirical relationship between specific capacity and transmissivity shown in Equation A (from Driscoll, 1986).

$$T = C\frac{Q}{s} \qquad \text{Equation A}$$

where:

- T is the aquifer transmissivity in gallons per day per foot (gpd/ft),
- C is an empirical constant that equals 1500 for unconfined aquifers and 2000 for confined aquifers,
- Q is the pumping rate in gallons per minute (gpm), and
- s is the drawdown caused by pumping in feet.

For a borehole that intersects a series of transmissive zones, the fraction of the transmissivity of each zone can be estimated as the amount of inflow into that zone divided by the total inflow into all of the zones in the borehole (Paillet and Reese, 2000).

$$T_i = C\frac{Q_i}{s} \qquad \text{Equation B}$$

Hydraulic conductivity values were estimated for each interval of the borehole that exhibited a positive change in flow rate due to pumping based on Equations B and C.

$$K_i = \frac{T_i}{b_i} \qquad \text{Equation C}$$

where:

- T_i is the transmissivity of an interval within the borehole,

Q_i is the net gain in discharge of the interval caused by pumping,

K_i is the effective hydraulic conductivity of the interval, and

b_i is the effective saturated thickness of the interval.

Estimated hydraulic conductivity values from borehole flow sampling are compared with values from aquifer testing on Figures 4-22a through 4-22c. Aquifer test results and test intervals are plotted directly above the borehole traces in these figures and borehole flow test results are plotted to the right of the borehole traces. In general, there is good agreement between the two methods for estimating hydraulic conductivity. On a plot such as this, potential conduits would show up as relatively large hydraulic conductivity values estimated for intervals picked as conduits (i.e., intervals surrounded by gaps on the plot). Examples of higher conductivity occur at an elevation of approximately 585 feet MSL in B3014 and 535 feet MSL in borehole B3019. The latter example is somewhat lacking in that the hydraulic conductivity value is not among the largest measured and flow from the interval was not induced when the borehole was pumped. Examples with low conductivity based on the packer testing are plotted for boreholes B3015, B3016, and B3020.

4.6.3 Aquifer Testing

Aquifer testing data was collected from 171 borehole packer tests and 24 slug tests prior to 2009 and 302 additional slug tests completed in 2009. In addition, small-scale pumping tests were conducted at the borehole B1034, B2042 and B2044 well nests. The aquifer testing data and the flow logging data were used to determine the aquifer characteristics and illustrate the variations in the hydraulic conductivity across the Site. Aquifer test data (drawdown and recovery) were analyzed to determine the hydraulic conductivity (K) and other aquifer parameters using AQTESOLV. The printouts from AQTESOLV as well as the aquifer test analysis methods are included in Appendix 4-6.

4.6.3.1 Packer Testing

Data collected from packer tests were analyzed in part to determine the hydraulic conductivity of the pumped zones. The AQTESOLV printouts from packer testing are included in Appendix 4-6b.

Responses in the intervals below and/or above the packed interval were noted in many of the tests as illustrated on Figures 4-30a to 4-30c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. On these figures the packer test interval(s) within each borehole are represented by a vertical line connecting to a horizontal line to the left indicating the bottom of the interval and to a

horizontal line on the right indicating the top of the interval. Vertical rectangles with white fill represent the portion of the borehole in which response to the pumping was measured. Two examples are labeled on the figure – one in which neither interval above or below the packer responded to the pumping and one in which both intervals responded. The response in intervals above and/or below the pumped interval is either an indication of failure of the packer to seal or of cross-connection of the fractures beyond the limit of the boreholes. In the few cases when intervals above and/or below the pumped interval responded to pumping, the data was taken as indicative of fractures cross-connecting the intervals unless other data (e.g. caliper log) suggested that the packer did not seal. Table 4-10 summarizes the evaluation of flow regime indicated by the packer test responses. Most of the packer test data strongly suggest diffuse flow in those boreholes. Some of the individual tests suggest conduit flow; however, other hydrogeologic data do not support the conclusion that conduit flow is occurring.

All of the packer test data were merged with the borehole flow logging data (Section 4.6.2, Borehole Flow Logging) and slug testing data (Section 4.6.3.2, Slug Testing) and their base-10 logarithms were plotted as a histogram on Figure 4-24. Although the distribution does not monotonically decrease away from the mode, no separate peaks occur. The data approximate a log-normal distribution, demonstrating that an assumption of porous-medium-equivalence is warranted (ASTM, 2005).

If a series of perfectly efficient boreholes were pumped at such rates that the same amount of drawdown occurred in each borehole, the pumping rates from the boreholes would likewise follow a log-normal distribution in porous-medium-equivalent settings. A histogram of pumping rates from the packer tests is shown on Figure 4-31. As expected, the distribution is not log-normal. Some reasons the distribution is not log-normal are listed below.

- The boreholes were not pumped such that drawdown was the same in each (instead, the pumping rate was maximized).
- The boreholes likely have borehole skin effects (e.g., Kaehler and Hsieh, 1994). Positive borehole skin effects are caused by increased resistance to flow near the borehole compared to the adjacent aquifer material due, for example, to clogging of the porosity with cuttings. Negative borehole skin effects are caused by decreased resistance to flow near the borehole compared to the adjacent aquifer material due, for example, to washout of material pulverized by drilling.

4.6.3.2 Slug Testing

Slug tests were performed in temporary wells placed in unconsolidated material in direct-push boreholes, in select permanent monitoring wells in bedrock placed in boreholes or intervals that were not packer tested, and the 2009 investigation wells to determine the hydraulic conductivity of the aquifer material in those areas. Slug test results are presented in Tables 4-7a through 4-7c for the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Slug tests were conducted in three wells screened through CKD material yielding hydraulic conductivity values ranging from 1.19 to 30.4 feet per day. Four of the tested wells were screened in unconsolidated material of clay, silt, sand, and/or gravel. Hydraulic conductivity values for the unconsolidated material ranged from 5.14 to 108.9 feet per day. The majority of the slug tests were conducted in wells screened in bedrock. Due to the fractured nature of the bedrock aquifer, hydraulic conductivity values for these wells ranged from 0.0013 to 299.1 feet per day. The AQTESOLV printouts from slug testing are included in Appendix 4-6c.

4.6.3.3 Vertical Pumping Tests at Well Nests

Short duration pumping tests were performed at the monitoring well nests installed at borehole B1034/B1031, B2042, and B2044 to evaluate vertical hydraulic connection and hydraulic conductivity. Pumping test results are presented in Table 4-7a, Table 4-7b, and 4-7c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Printouts of the analyses of the pumping test data in AQTESOLV are included in Appendix 4-6d.

Water levels in wells W1334, W1431, and W1331 were observably drawn down in response to pumping in W1434, indicating that the wells are hydraulically well-connected to W1434 and each other. The lack of response in wells W1131, W1231, W1134, and W1234 indicates that the hydraulic connection between these wells and W1434 – and presumably with wells W1331, W1431, and W1334 – is relatively limited or W1434 was not pumped hard enough or long enough to see a response. Analysis of the pumping test data for all wells with observable drawdown yielded a vertical-to-horizontal hydraulic conductivity anisotropy ratio (Kz/Kr) of about 43.5.

Pumping in W2442 produced observable drawdown in W2342, indicating that the wells are hydraulically well-connected. There was no apparent response in the water levels of the upper two wells of the nest, which are completed within and above the shale unit – W2242 and W2142, respectively. The lack of response in the upper two wells of the nest lends weight to the hypothesis

that the shale unit acts as a barrier to vertical groundwater flow. Analysis of the pumping test data for wells W2442 and W2342 yielded a Kz/Kr of about 0.35.

Pumping in W2444 had no observable effect on water levels in any of the other nested monitoring wells in B2044, suggesting that the hydraulic connection between the wells is limited. Analysis of the drawdown data of W2444 revealed that the hydraulic conductivity anisotropy ratio (Kz/Kr) is not a sensitive parameter for the analytical solution and, consequently, a unique value of Kz/Kr could not be determined.

4.6.4 Mechanisms of Flow

It was initially assumed, as a working hypothesis, that groundwater at the Site flowed through preferential flow paths (i.e. conduits). This hypothesis was based on the limestone geologic setting and reported observations of karst-like features in the vicinity of the Site. Sections 4.6.1 to 4.6.3 summarized the processes followed to identify "potential conduits". Because no actual conduits were identified, it is concluded that the groundwater flow system at the Site is predominantly through a dense interconnected fracture system within the bedrock. It can also be concluded that the Site aquifer can be modeled as an equivalent porous medium.

4.6.4.1 Recharge to the Aquifer System

In granular aquifers and fractured rock aquifers with a thick mantle of unconsolidated material, the aquifer's response to recharge events tends to be damped and delayed due to the time required for the recharge to percolate through the unsaturated zone. Water level fluctuations caused by recharge events rarely exceed a few meters. Karst and fractured-rock aquifers with thin mantles of unconsolidated material tend to have rapid recharge in which water levels rise within minutes of the start of a storm and water-table fluctuations may be tens of meters (ASTM, 2005).

Sufficient data are available from 34 wells to assess the response to rainfall/snowfall events. Of these wells, only seven have flashy responses to rainfall/snowfall events that suggest potential conduits (see Table 4-8). However, other data from these boreholes/wells do not support the presence of conduits. Examples of hydrographs exhibiting a flashy response are shown on Figure 4-25b. A close-up of the response to the rainfall event on August 25, 2006 is shown on Figure 4-32. The response in the deeper well (W2350) is more rapid than in the shallow well, suggesting that the recharge occurs along a pathway that is not as well connected to the shallower well (W2150).

All ILRS flows show a seasonal trend of the highest flows in the spring, while decreasing throughout the summer finishing with fall increases. Flow correlates directly with rainfall/snowmelt and the regional groundwater elevation. All drains exhibited a flow increase response as a result of snowmelt and rainfall. The greatest and least responsive in terms of rate of flow increase due to rainfall/snowmelt were the Pine Court Seep area and the Edge Drain, respectively.

4.6.4.2 Response to the City of Petoskey Well Pumping

Many of the deep and intermediate depth wells in the well nests at the Site show the affects of cycling of the pumps in the City of Petoskey Municipal Wells. An example is shown on Figure 4-33a in which hydrographs for four days in late December 2006 to early January 2007 are plotted for the well nest installed at borehole B1030, the closest wells to Petoskey Well 3. The inset figure on Figure 4-33a shows the locations of the well screens in the borehole B1030 well nest relative to the open interval of Petoskey Well 3. The screens of the two deepest wells in the nest overlap the open interval of Petoskey Well 3. The bottom of the screen in well W1230 is just over four feet above the top of the open rock section of Petoskey Well 3. The magnitude of the response in well W1430 is somewhat larger than that of well W1330, suggesting that Petoskey Well 3 does not draw water at a uniform rate throughout its open section.

A relatively significant resistance to vertical flow exists in the rock between the screens of W1330 and W1230 as the pumping signal is greatly reduced in magnitude and offset in time. The dashed tie lines show peaks in the hydrographs that are inferred to be related to the same pumping event in Petoskey Well 3. A significant resistance to vertical flow also exists in the rock between the screens of wells W1230 and W1130 as no response to the pumping can be seen in the hydrograph from well W1130.

Hydrographs for late December 2006 to early January 2007 from the well nest closest to Petoskey Well 5 (the B2044 well nest) are shown on Figure 4-33b. The overall trend for wells W2144 and W2244 during this period was falling water levels, presumably due to the reduction in recharge to the water table due to the formation of frost. The overall trend for wells W2344 and W2444 is rising water levels, presumably due to reduced overall groundwater withdrawal in the winter time. The screens in the well nest at B2044 are all above the open rock interval of Petoskey Well 5. The hydrograph from well W2444 shows relatively long periods with a recovery signature followed by a pair of drawdown spikes that suggest the pump in Petoskey Well 5 is turned on only for brief periods

of time. The hydrograph for well W2344 follows a similar overall trend, but has a much smaller magnitude response to the pumping.

The hydrographs for wells W2144 and W2244 are plotted on a separate, much larger scale in order to show the response to pumping in these wells. The screens of these wells are above the marker shale and the low vertical hydraulic conductivity of this shale is the likely cause of the large difference in hydraulic head between wells W2144 and W2244 and the deeper wells in the nest. The periods of recovering water level in well W2444 do not correlate with any portion of the W2144 or W2244 hydrographs. The periods of rapid drawdown do have correlating responses in wells W2144 and W2244. However, these responses are much smaller in magnitude and of the opposite sense from that of well W2444. The mechanism believed to be causing this response is known as the Noordbergum effect in unconsolidated materials (Hsieh, 1996) and is referred to as poroelasticity in fractured rock (e.g., Long et al., 1996). The Noordbergum or poroelastic effect can consist of an induced increase in hydraulic head (pore pressure) in an aquitard or an unpumped layer above an aquitard as the aquitard deforms due to lowering of pore pressure in an underlying, pumped aquifer.

A zone of variable saturation has developed beneath the marker shale at the B2044 well nest. Static water levels in well W2444 range from four to more than 44 feet below the base of the shale throughout the period of record. Well W2344 was dry on many occasions during the period of higher pumping in 2006.

Responses in the bedrock wells to pumping of the City wells vary with distance from the wells and distance to the lakeshore, which acts as a recharge boundary, reducing the amount of drawdown and recovery caused by cycling of the City wells.

4.6.4.3 Response to the Lake Stage Changes

In many cases, water level trends in wells close to Lake Michigan correlate with lake stage variations. This is an indication of the hydraulic connection between the aquifer system and Lake Michigan. The stage in Lake Michigan fluctuated through a range of 1.87 feet from mid-April to late-October 2006.

The distance landward of the lakeshore that a perceptible pressure pulse caused by lake stage variation would be propagated depends on the diffusivity of the aquifer (hydraulic conductivity divided by specific storage). Theoretically, the pressure pulse caused by a recharge boundary would be measurable great distances landward into a granular or porous-medium-equivalent aquifer relative

to the dimensions of the site. However, other influences on groundwater levels, such as recharge and regional pumping, cause much larger variations than those predicted for lake stage changes in wells located more than a few tens of feet from the lakeshore.

Since tidal effects in Lake Michigan are minimal, it is unlikely that static groundwater elevations and, hence, flow directions are significantly affected by tidal fluctuations of Lake Michigan.

4.6.4.4 Borehole Interval Classification

Each borehole log was reviewed and the intervals identified via the evaluation of the borehole flow logging results were classified as one of the following types of flow zones using information from the geophysical logging. The basis for the classification is also listed.

- Zone of diffuse flow with potentially low hydraulic conductivity. None of the logs (with the possible exception of the caliper log) suggest flow to or from the aquifer in this interval. Fluid temperature and fluid resistivity remain uniform through the interval. The net change in flow in borehole over these intervals was typically very small (i.e., < 0.013 gpm or <0.2 gpm, depending on the instrument used).

- Zone of diffuse flow with potentially high hydraulic conductivity. One or more of the logs indicate flow to or from the aquifer throughout the interval. Examples include intervals in which the fluid temperature or fluid resistivity fluctuated up and down or began changing abruptly at one end or the other. The caliper logs and BHTV log typically indicated fractures in these intervals. The net change in flow in borehole over these intervals was typically much larger than the noise level on the borehole flow measurement (i.e., 0.013 gpm or 0.2 gpm, depending upon the instrument used).

- Zone with mixed high and low hydraulic conductivity. One or more of the logs suggest an isolated zone or zones with flow to or from the borehole within an overall zone with little or no flow to or from the aquifer. These were identified as potential conduits.

- Zones of convergence or divergence of flow within the borehole.

- Zones from which relatively large quantities of water can be produced by pumping from the borehole. These zones were identified during packer testing as intervals that required a higher pumping rate.

4.6.4.5 Fracture Projection

Each fracture identified in the BHTV logs was projected to the positions of all adjacent boreholes. The borehole from which the fracture was projected was called the source and the borehole to which the projection was made was called the target. This yielded an elevation in the target borehole near which to look for a fracture with a similar attitude (dip and azimuth). Tolerances of ± 2.5 feet for elevation and ± 2.5 degrees for dip and azimuth were defined and the attitude of each fracture within this elevation range in the target borehole was compared with that of the fracture from the source borehole.

Fractures with dips and azimuths within the specified tolerance were identified as potential matches for the fracture in the source borehole. Thousands of possible matches were identified, most of which are likely coincidental, particularly for bedding plane fractures projected across changes in the bedrock structure. The possible matching fractures were further screened as described below.

Matching pairs of fractures between boreholes were screened to identify those for which both fractures are located within 2.5 feet of a zone identified in the following list. If the fractures at both ends of the projection met the criteria on the list below, the projected conduit was identified as a potentially extensive conduit. A conservative methodology was because potential conduits identified based on only one line of evidence were not eliminated from consideration.

- Potential conduits based on the data from the borehole flow logging and geophysical logs.
- Zones of flow convergence or divergence based on the borehole flow logging.
- Zones from which relatively large quantities of water were produced by pumping from the borehole.
- Zones with high hydraulic conductivity as identified from the packer tests during which adjacent intervals did not respond to the pumping.
- Zones with packer test responses suggesting linear or bilinear fracture flow.

Figures 4-34a through 4-34c show the distribution of potential conduits identified in the boreholes from the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Based on their proximity to fractures that were successfully projected from one borehole to another, potential

conduits were identified as potentially extensive conduits on Figures 4-35a through 4-35c and Table 4-11.

No conduits with medium to high dip angles were successfully projected between boreholes. Eleven potential conduits were projected between boreholes in the Seep 1 CKD Area using the methods described above. The dips of these features range from 0 to 13 degrees (Table 4-11). These potential conduits are parallel to sub-parallel to the bedding. Twenty-five potential conduits were projected between boreholes in the Seep 2 CKD Area using the methods described above. The dips of these features range from 0 to 6 degrees (Table 4-11). These potential conduits are parallel to sub-parallel to the bedding. Six potential conduits were projected between boreholes in the West CKD Area. The tolerance for distance from a projected fracture to a potential conduit was expanded from ±2.5 feet to ±5 feet for the West CKD Area as no matches were identified using the tighter tolerance. The dips of these features range from 0 to 2 degrees (Table 4-11). These potential conduits are parallel to sub-parallel to the bedding.

Even though potential conduits that project between boreholes were identified by this technique of data evaluation, none of the potential conduits identified were indicated by multiple lines of evidence. Therefore, groundwater flow in bedrock is predominantly through the dense fracture system (i.e., flow is not through individual large conduits).

4.7 Demography and Land Use

Petoskey is the county seat of Emmet County. The 2007 population estimate for Petoskey is 6,017 (US Census Bureau, 2007 Population Estimates). The total population of Emmet County is 33,535 (U.S. Census Bureau, 2008 Population Estimates). The Little Traverse Bay Bands of Odawa Indians currently has approximately 4000 members with a large number living within Charlevoix and Emmet Counties (LTTB, http://www.ltbbodawa-nsn.gov/TribalHistory.html).

Emmet County is both a summer and winter vacation destination for vacationers from Michigan and the Midwest. Seasonal surges in population, not included in the above census figures, can reach 25,000 during peak days. During the winter, approximately 225,000 skiers visit the area (Petoskey Regional Chamber of Commerce).

In the City of Petoskey, the median resident age was 38.7 in 2000, and the median household income was $33,657. The population consisted of 94.2 percent white, 0.3 percent Black or African American,

3.2 percent American Indian and Alaska Native, 0.8 percent Asian, 0.2 percent some other race, and 1.3 percent two or more races. (US Census Bureau, Census 2000).

Per the 2000 census, the educational and employment demographics for the population 25 years and older in the City of Petoskey are summarized as follows:

- High school or higher: 87.1 percent
- Bachelor's degree or higher: 31.0 percent

The retail and service industries are the largest employment type in Emmet County. The following table summarizes the distribution of jobs in Emmet County by industry:

Emmet County Employment by Industry – 2005

Industry	Number of Jobs
Private	21,213
Forestry, fishing, related activities, and other	61
Mining	69
Utilities	83
Construction	2,362
Manufacturing	1,653
Wholesale trade	417
Retail trade	3,331
Transportation and warehousing	289
Finance and insurance	550
Real estate and rental and leasing	1,329
Government and Government Enterprises	2,892
Federal, civilian	116
Military	62
State and local	2,714

Source: U.S. Department of Commerce- Economics and Statistics Administration-Bureau of Economic Analysis, Issued May 2007.

Land uses directly adjacent to the Site are a mixture of undeveloped, residential, and commercial properties. The West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area are owned by the Bay Harbor Golf Club, Inc (which owns and operates a golf course on the Site) private property owners, CMS, and Bay Harbor Company. A golf course fairway and rough areas were constructed over each

of the CKD piles. The West CKD Area is bounded by Lake Michigan and undeveloped residential lots on the north, developed and undeveloped residential properties to the west and south, and the golf course club house to the east. The Seep 2 CKD Area is bounded by Lake Michigan developed and undeveloped lots on the north, developed and undeveloped residential properties to the west, east, and south, and Coastal Ridge Drive and the Seep 1 CKD Area to the east. The Seep 1 CKD Area is bounded by Lake Michigan on the north and by developed and undeveloped residential properties to the west, east, and south. Directly east of the Seep 1 CKD Area is Bay Harbor Lake, which includes the Bay Harbor Yacht Club. East of Bay Harbor Lake is Village Harbor, a marina for private use of Village Harbor development residents.

5.0 Nature and Extent of Contamination

5.1 Data Evaluation

Analytical data for Site samples were evaluated against applicable criteria to identify potential Site COCs. Data for groundwater and unconsolidated material samples (non-CKD and CKD) were compared to Part 201 Generic Cleanup Criteria.

Analytical data for surface water samples were compared to potentially applicable Part 31 surface water criteria. Site analytical data are summarized in Tables 5-1a, 5-1b, 5-1c, 5-2, 5-3, 5-4a, 5-4b, 5-4c, 5-5a, 5-5b, 5-5c, 5-6a, 5-6b, and 5-6c. Copies of the analytical data reports are included as Appendix 5-1.

5.2 Contamination Source

The source of high-pH leachate impacts at the Site are three CKD piles placed at the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area. The locations and extents of the CKD piles are shown on Figure 1-2.

5.3 Surface Water

5.3.1 Lake/Pool Surface Water Sampling

Surface water analytical samples for the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area were collected between August 18, 2005 and April 29, 2007 in accordance with the Work Plan (Barr, 2005d) and were compared to Michigan Part 31 criteria. In a letter dated January 31, 2007 CMS requested that the surface water sampling requirements pursuant to Section 4.2.5.2 of the Work Plan be eliminated. Data collected prior to January 2007 sporadically and inconsistently exceeded potentially applicable Part 31 criteria and these data could not be correlated to the seep areas. For example, all pH levels measured in the Seep 2 CKD Area were below 9.0 after the ILRS installation while approximately half of the surface water criteria exceedances at the Seep 2 CKD Area occurred after the ILRS was operating. The U.S. EPA approved this request in an email dated May 11, 2007.

No additional surface water analytical samples were collected from these areas after receipt of U.S EPA approval to cease sampling. Surface water laboratory analytical results are shown in Tables 5-1a, 5-1b, and 5-1c. Pool sampling at the West CKD Area, Seep 2 CKD Area, and Seep 1

CKD Area was also conducted in accordance with the Work Plan and these data are also included in Tables 5-1a to 5-1c; however, since pools are not hydraulically connected to Lake Michigan their analytical data are not used to assess surface water quality.

5.3.1.1 West CKD Area Surface Water Quality

Thirty-seven surface water samples (excluding pool samples and duplicates) were collected at the West CKD Area between May 23, 2006 and April 29, 2007. Results are shown in Table 5-1a. Criteria were not exceeded for phosphorous, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, nickel, silver, thallium, and zinc. Sample concentrations exceeded criteria for the following parameters:

Criteria Exceedances in Surface Water at West CKD

Parameter	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	# of Samples Exceeding Criteria	Surface Water Criteria Exceeded
Chloride	10,000	200,000	4	Part 4 Water Quality Standards
Total Dissolved Solids	110,000	3,720,000	9	Part 4 Water Quality Standards
pH (pH units)	7.2	10.3	7	Part 4 Water Quality Standards
Antimony	ND	2.4	3	Human Noncancer Value Drinking Water
Mercury	ND	0.0322	11	Wildlife Value Human Noncancer Value Drinking Water Human Noncancer Value Non-Drinking Water
Selenium	ND	5	1	Final Chronic Value
Vanadium	ND	13	1	Final Chronic Value

ND = Not detected

5.3.1.2 Seep 2 CKD Area Surface Water Quality

Eighty-nine surface water samples (excluding pool samples and duplicates) were collected at the Seep 2 CKD Area between August 25, 2005 and April 22, 2007. Results are shown in Table 5-1b. Criteria were not exceeded for phosphorous, arsenic, barium, beryllium, cadmium, chromium, iron, lead, manganese, nickel, silver, and thallium. Sample concentrations exceeded criteria for the following parameters:

Criteria Exceedances in Surface Water at Seep 2 CKD

Parameter	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	Number of Samples Exceeding Criteria	Criteria Exceeded
Chloride	10,000	220,000	7	Part 4 Water Quality Standards
Total Dissolved Solids	112,000	2,830,000	15	Part 4 Water Quality Standards
pH (pH units)	7.2	9.7	7	Part 4 Water Quality Standards
Antimony	ND	5.3	4	Human Noncancer Value Drinking Water
Copper	ND	19	5	Final Chronic Value Aquatic Maximum Value
Mercury	ND	0.066	3	Aquatic Maximum Value Human Noncancer Value Non-Drinking Water Human Noncancer Value Drinking Water
Selenium	ND	6.6	1	Final Chronic Value
Vanadium	ND	23	2	Final Chronic Value
Zinc	ND	260	1	Final Chronic Value

ND = Not detected

5.3.1.3 Seep 1 CKD Area Surface Water Quality

Sixty-five surface water samples (excluding pool samples and duplicates) were collected at the Seep 1 CKD Area between August 18, 2005 and April 21, 2007. Results are shown in Table 5-1c. Criteria were not exceeded for phosphorous, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, nickel, selenium, thallium, and zinc. Sample concentrations exceeded criteria for the following parameters:

Criteria Exceedances in Surface Water at Seep 1 CKD

Parameter	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	Number of Samples Exceeding Criteria	Criteria Exceeded
Chloride	10,000	97,000	2	Part 4 Water Quality Standards
Total Dissolved Solids	122,000	1,010,000	4	Part 4 Water Quality Standards
pH (pH units)	7.22	9.6	4	Part 4 Water Quality Standards
Antimony	ND	2.9	5	Human Noncancer Value Drinking Water
Mercury	ND	0.0215	16	Aquatic Maximum Value Human Noncancer Value Drinking Water Human Noncancer Value Non-Drinking Water
Silver	ND	0.27	2	Final Chronic Value
Vanadium	ND	12	1	Final Chronic Value

ND = Not detected

5.3.2 Creek Sampling

Monitoring and analytical data have been collected from the West Unnamed Creek and East Unnamed Creek #1 as part of the U.S. EPA approved Surface Water/Water Cycle Monitoring Work Plan Revision 1 (Barr, 2006a). Table 5-2 summarizes the range of data for pH, specific conductance, and temperature for both West Unnamed Creek and East Unnamed Creek #1. A complete data set for each monitoring event is included in Appendix 5-2. The approximate locations where the pH data points were recorded are also included on Figures 3-5a and 3-5b. Analytical data are summarized in Table 5-3. Analytical laboratory reports are included in Appendix 5-1a.

5.3.2.1 West Unnamed Creek

West Unnamed Creek flows from U.S. Highway 31 north through a constructed pond (Pond #1) on the south side of the West CKD Area, along the east side of the West CKD Area, and into Lake Michigan. The pH was measured in the West Unnamed Creek during seven events between April 2006 and September 2006. The pH was measured at approximately 25-foot intervals along the creek from the outfall at Lake Michigan to Quarry Ridge Road. The pH measurements ranged from 7.06 to 8.46 in the West Unnamed Creek water during the seven monitoring events. Although surface water

criteria were occasionally exceeded for chloride, total dissolved solids, antimony, and mercury, the analytical data indicate that the creek is not impacted by the CKD because samples collected from upstream of the Site exceeded for these parameters.

5.3.2.2 East Unnamed Creek #1

East Unnamed Creek #1 borders the Seep 1 CKD Area on the east. The creek falls from an elevation of approximately 645 feet MSL at its intersection with U.S. Highway 31 south of the Site to approximately 578 feet MSL at its discharge point into Lake Michigan over a distance of approximately 1,900 feet. The pH was measured in the East Unnamed Creek #1 during five events between April 2006 and September 2006. The pH was measured at approximately 25-foot intervals along the creek from the outfall at Lake Michigan to U.S. Highway 31. The pH measurements ranged from 7.2 to 8.49 in the East Unnamed Creek #1 water during the five monitoring events. Although surface water criteria were occasionally exceeded for chloride, total dissolved solids, and mercury, the analytical data indicate that the creek is not impacted by the CKD because samples collected from upstream of the Site exceeded for these parameters .

Monitoring and analytical data have been collected from the West Unnamed Creek and East Unnamed Creek #1 as part of the U.S. EPA approved Surface Water/Water Cycle Monitoring Work Plan Revision 1 (Barr, 2006a). Table 5-2 summarizes the range of data for pH, specific conductance, and temperature for both West Unnamed Creek and East Unnamed Creek #1. A complete data set for each monitoring event is included in Appendix 5-2. The approximate locations where the pH data points were recorded are also included on Figures 3-5a and 3-5b. Analytical data are summarized in Table 5-3. Analytical laboratory reports are included in Appendix 5-1a.

West Unnamed Creek flows from U.S. Highway 31 north through a constructed pond (Pond #1) on the south side of the West CKD Area, along the east side of the West CKD Area, and into Lake Michigan. The pH was measured in the West Unnamed Creek during seven events between April 2006 and September 2006. The pH was measured at approximately 25-foot intervals along the creek from the outfall at Lake Michigan to Quarry Ridge Road. The pH measurements ranged from 7.06 to 8.46 in the West Unnamed Creek water during the seven monitoring events. Analytical data indicate that the creek is not impacted by the CKD.

East Unnamed Creek #1 borders the Seep 1 CKD Area on the east. The creek falls from an elevation of approximately 645 feet MSL at its intersection with U.S. Highway 31 south of the Site to approximately 578 feet MSL at its discharge point into Lake Michigan over a distance of

approximately 1,900 feet. The pH was measured in the East Un-named Creek #1 during five events between April 2006 and September 2006. The pH was measured at approximately 25-foot intervals along the creek from the outfall at Lake Michigan to U.S. Highway 31. The pH measurements ranged from 7.2 to 8.49 in the East Un-named Creek #1 water during the five monitoring events. Analytical data indicate that the creek is not impacted by the CKD.

5.4 Soils

Representative samples of non-CKD (soil) and CKD unconsolidated materials were collected and analyzed for both chemical and physical properties. The chemical analytical data are summarized in Table 5-4a, Table 5-4b, and Table 5-4c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. As indicated on these tables, data for unconsolidated samples were compared to all Part 201 Generic Soil Cleanup Criteria. It is noted in Table 5-4a through Table 5-4c which unconsolidated materials are CKD and which are non-CKD.

The following criteria were not exceeded: Groundwater Contact Protection, Soil Volatilization to Indoor Air Inhalation Criteria, Infinite Source Volatile Soil Inhalation Criteria, Particulate Soil Inhalation Criteria, and Soil Saturation Concentration Screening Levels.

Only those criteria with exceedances (i.e., Residential/Commercial I Drinking Water Protection (DW Protection) criteria, Groundwater Surface Interface (GSI) Protection criteria, and Residential/Commercial I Direct Contact (Direct Contact) criteria) are listed on the tables. Only samples collected from borings located on the beach were compared to GSI Protection criteria. Qualifiers presented in Table 5-4a, Table 5-4b, and Table 5-4c are defined either in the legend of the table or on the “footnotes” insert. Chemical analytical data reports for these unconsolidated materials are included in Appendix 5-1d.

The analytical data results for all unconsolidated materials (both non-CKD and CKD) were compared to the potentially applicable Part 201 Generic Cleanup Criteria and Screening Levels. These criteria were selected because the potential exposure scenarios for non-CKD and CKD are identical and because Part 201 has been used to resolve contaminant issues at other Michigan CKD sites.

West CKD Area

Three non-CKD samples and one CKD sample exceeded the DW Protection criteria for the sum of potential nitrogen sources: B3012 at 1.7-6.4 ft., B3014 at 15-17 ft., B3017 at 7-8 ft. and B3025 at

0-4 ft.. The sums of potential nitrogen sources that exceeded the criteria ranged from 240,000 to 710,000 µg/kg. Two CKD samples exceeded the DW Protection criteria for sulfate: B3004 (10-15 ft.) and B3006 (8-10 ft.). The concentrations were 6,400,000 and 17,000,000 µg/kg, respectively. Nine (out of 18) CKD samples exceeded the DW Protection criteria for aluminum. The aluminum concentrations ranged from 9,200,000 to 14,000,000 µg/kg. Two CKD samples exceeded the DW Protection criteria for arsenic, B3007 at 10-12 ft. and B3015 at 13-15 ft., with concentrations of 5,800 and 6,700 µg/kg. One sample collected at B3004 at 10-15 ft. exceeded the DW Protection criteria for chromium VI with a total chromium concentration of 53,000 µg/kg. One non-CKD sample (B3018 at 10-14 ft.) exceeded the DW Protection criteria for iron with a concentration of 19,000,000 µg/kg. Thirty-eight (out of 47 total samples collected at the West CKD Area) exceeded the DW Protection criteria for magnesium. The concentrations that exceeded the magnesium criteria ranged from 8,200,000 to 110,000,000 µg/kg. One sample collected from B3018 at 10-14 ft. exceeded the DW Protection criteria for manganese with a concentration of 450,000 µg/kg. One CKD sample, B3006 at 8-10 ft., exceeded the DW Protection criteria for sodium with a concentration of 2,800,000 µg/kg and one CKD sample, B3015 at 13-15 ft., exceeded the DW Protection criteria for thallium.

Nineteen samples collected from beach borings exceeded the GSI Protection criteria for chromium VI. The total chromium concentrations ranged from 3,400 to 12000 µg/kg. One CKD sample collected at B3025 exceeded the GSI Protection criteria for selenium with a concentration of 770 µg/kg.

One non-CKD (B3014 at 15-17 ft.) and two CKD samples (B3006 at 8-10 ft. and B3007 at 10-12 ft.) exceeded the Direct Contact criteria for chloride with concentrations ranging from 660,000 to 4,700,000 µg/kg.

Seep 2 CKD Area

Six non-CKD samples and one CKD sample exceeded the DW Protection criteria for the sum of potential nitrogen sources: B2002 at 12-15 ft., B2027 at 0-1 ft., B2029 at 15-17 ft., B2030 at 1.5-4 ft., B2035 at 5.5-6.5 ft., B2037 at 10-10.5 ft., and B2038 at 2-3 ft. with concentrations ranging from 210,000 to 780,000 µg/kg. Five CKD samples exceeded the DW Protection criteria for sulfate with concentrations ranging from 5,000,000 to 13,000,000 µg/kg. Sixteen (out of 16) CKD samples and one non-CKD sample exceeded the DW Protection criteria for aluminum. Eight CKD samples exceeded the DW Protection criteria for arsenic with concentrations ranging from 6,500 to

11,000 µg/kg. Twenty-one samples (out of 45 total samples collected) exceeded the DW Protection criteria for magnesium. The concentrations that exceeded the magnesium criteria ranged from 8,200,000 to 17,000,000 µg/kg. Two CKD samples (B2011 at 15-20 ft. and B2012 at 22-25 ft.) exceeded the DW Protection criteria for sodium with concentrations of 8,700,000 and 4,000,000 µg/kg, respectively. Three CKD samples (B2014 at 8-10 ft., B2025 at 10-11 ft., and B2025 at 35-36 ft.) exceeded the DW Protection criteria for thallium with concentrations ranging from 2,300 to 2,500 µg/kg.

Six CKD and three non-CKD samples exceeded the Direct Contact criteria for chloride with concentrations ranging from 600,000 to 4,100,000 µg/kg. Three CKD samples (B2003 at 22-24 ft., B2004 at 30-35 ft., and B2022 42-47.5 ft.) exceeded the Direct Contact criteria for arsenic with concentrations of 10,000, 11,000, and 8,100 µg/kg, respectively.

Seep 1 CKD Area

Five non-CKD samples exceeded the DW Protection criteria for the sum of potential nitrogen sources: B1017 (0.5-1.5 ft.), B1018 (0.5-1.2 ft.), B1021 (45.5-47.5), B1029 (0.5-1.5 ft.), and B1033 (10-12 ft.). The sums of potential nitrogen sources ranged from 302,400 to 753,000 µg/kg. Two non-CKD samples exceeded the DW Protection criteria for sulfate: B1017 (0.5-1.5 ft.) and B1017 (26-27 ft.). The concentrations were 37,000,000 and 17,000,000 µg/kg, respectively. One CKD sample collected from B1018 (10-10.5 ft.) exceeded the DW Protection criteria for total phosphorus with a concentration of 1,300,000 µg/kg. Eleven (out of 12) CKD samples exceeded the DW Protection criteria for aluminum. Five CKD samples exceeded the DW Protection criteria for arsenic: B1001 (5-9 ft.), B1005 (13-15 ft.), B1017 (13-14 ft.), B1018 (10-10.5 ft.), and B1021 (10-15 ft.). The arsenic concentration for these samples ranged from 6,000 to 10,000 µg/kg. One CKD sample exceeded the DW Protection criteria for chromium VI: B1003 (29-31 ft.). The total chromium reported for this sample was 40,000 µg/kg. One non-CKD sample (B1029 at 0.5-1.5 ft.) exceeded the DW Protection criteria for iron with a concentration of 14,000,000 µg/kg. Eleven (out of 12) CKD samples and eight of the non-CKD samples exceeded the DW Protection criteria for magnesium. The concentrations that exceeded the magnesium criteria ranged from 8,400,000 to 100,000,000 µg/kg. Two non-CKD samples (B1012 at 15-18 ft. and B1029 at 0.5-1.5 ft.) exceeded the DW Protection criteria for manganese with concentrations of 510,000 and 450,000 µg/kg, respectively. One CKD sample collected from B1010 at 10-12.5 ft. exceeded the DW Protection criteria for thallium and lead with a concentration of 3,100 µg/kg.

One non-CKD sample collected from B1021 (45.5-47.5 ft.) exceeded the Direct Contact criteria for chloride with a concentration of 700,000 µg/kg. Two CKD samples collected from B1001 (5-9 ft.) and B1005 (13-15 ft.) exceeded the Direct Contact criteria for arsenic with concentrations of 9,900 and 10,000 µg/kg, respectively.

5.5 Groundwater

5.5.1 Groundwater Quality – Borehole Water

Analytical sampling of CKD leachate was conducted during the 2005 and 2006 borehole program in accordance with the Work Plan (Barr, 2005c). Samples collected from the boreholes in 2005 and 2006 were found to be of lower quality than samples collected from completed monitoring wells. Specifically borehole leachate analytical results from borings B1021, B1024, B2020, B2032, B3013, and B3014 show elevated concentrations of total suspended solids and select metals compared to their respective monitoring well analytical data. The difference in analytical results is attributed to the higher level of accuracy afforded by monitoring wells as compared to borehole samples (i.e., monitoring wells are properly developed and all drilling residue is removed which is not possible during packer testing in boreholes). CKD leachate analytical samples were not collected from boreholes during the Supplemental Investigation in 2007 because samples collected from the boreholes in 2005 and 2006 were found to be of lower quality than samples collected from completed monitoring wells.

The analytical data collected from the boreholes during borehole packer testing were not compared to the potentially applicable Part 201 Generic Criteria due to the poor quality of the samples. Results of the groundwater and leachate samples collected during the borehole packer testing are summarized in Table 5-5a, Table 5-5b, and Table 5-5c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Copies of the analytical data reports for these samples are included in Appendix 5-1c. The pH and specific conductivity measurements from the vertical profiling conducted as the rotasonic boreholes were advanced are presented in Appendix 3-10.

5.5.2 Groundwater Quality – Monitoring Wells

Groundwater samples were collected from each of the monitoring wells approximately quarterly as described in Sections 5.2.4 and 5.3.5.1 of the Work Plan (Barr, 2005c). Monitoring well analytical water quality data are summarized in Table 5-6a, Table 5-6b and Table 5-6c for West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area, respectively. Figures 5-1a to 5-1c through Figure 5-18a to 5-18c

graphically show the distribution of the exceedances of select parameters at the Site. Field logs for the groundwater sample collection are included as Appendix 3-9. Copies of the analytical data reports for these samples are included in Appendix 5-1b.

Groundwater samples were collected and analyzed following the procedures described in the QAPP (Barr, 2005d). Groundwater samples were analyzed for the parameters listed in Table 3-3. Samples from monitoring wells were analyzed according to the “low-level” mercury method, EPA 1631 (mercury analysis)/7471 (all other metals). Groundwater samples were collected from Site monitoring wells for the analyses of SVOC and VOCs according to U.S. EPA methods 8270C and 8260B, respectively.

The analytical and field data were reviewed and validated following the procedures indicated in Section D of the QAPP (Barr, 2005d). The analytical laboratory provided Barr with a full analytical data package including a data summary, a Quality Assurance (QA) summary and all analytical raw data. Upon receipt from the laboratory, the data were loaded electronically into Barr's Laboratory Information Management System (LIMS). All electronic data were verified using the original laboratory hardcopy report. Data qualifiers were added as necessary and data summary tables were created. Data validation was conducted following U.S. EPA Contract Laboratory Program (CLP) procedures as indicated in Section D of the QAPP (Barr, 2005d) for data reports validated prior to June 4, 2007. After this date 10% of the data was validated and 100% of the data was reviewed as per the U.S. EPA letter dated June 4, 2007 (Appendix 1-1). Copies of the QA summaries are included in Appendix 5-1b.

The analytical data collected from the monitoring wells as part of the RI were compared to the potentially applicable Part 201 Generic Criteria. The following criteria were not exceeded: Residential/Commercial I Groundwater Volatilization to Indoor Air, Industrial/Commercial II III IV Groundwater Volatilization to Indoor Air, Groundwater Contact Criteria, Water Solubility, Flammability and Explosivity Screening Levels, and Acute Inhalation Screening Levels. The parameters that exceeded generic criteria are highlighted on the data summary tables (Table 5-6a, Table 5-6b and Table 5-6c). As noted on the tables, the data were compared to all criteria, but only those criteria that were exceeded are listed on the tables. Qualifiers presented in Table 5-6a, Table 5-6b and Table 5-6c are defined either in the legend of the table or on the “footnotes” insert. Only groundwater sample results from beach wells are compared to GSI criteria.

5.5.2.1 West CKD Area

No samples collected at the West CKD Area exceeded generic criteria for antimony, barium, beryllium, cadmium, magnesium, thallium, phosphorus, VOCs, or SVOCs.

Chloride

Groundwater samples collected from each of the beach monitoring well nests at the West CKD Area exceeded the GSI criteria for chloride. Only samples collected from W3114, W3214, W3119, W3219, W3319, and W3419 exceeded the DW criteria for chloride. The ubiquitous nature of the chloride combined with the elevated concentration in some areas suggests that chloride is present due to both CKD and non-CKD sources (e.g., road salt).

Sum of Potential Nitrogen Sources

Groundwater samples collected from W3114 and W3214 exceeded the DW criteria for "sum of potential nitrogen sources." Each of the samples exceeded for the water table well (W3114) and only the July 31, 2007 sample exceeded for the W3214 well. The deeper wells in this nest did not exceed the DW criteria nor did the monitoring well nest downgradient of these wells indicating that the exceedance is isolated at the B3014 well nest.

Ammonia That Will Become NH_3 in Surface Water

Samples collected from W3116, W3119, W3219, W3319, and W3419 exceeded the GSI criteria for ammonia that will become NH_3 in surface water. The calculated ammonia criterion is 29 µg/L, which is 3.8% of total ammonia.

Total Dissolved Solids (TDS)

Samples collected from W3113, W3213, W3114, W3214, W3314, W3414, W3116, W3118, W3119, W3219, W3319, W3419, W3220, W3142, W3242, and W3342 exceeded the aesthetic DW criteria for TDS. Samples collected from W3116, W3118, W3119, W3219, W3319, and W3419 exceeded the GSI criteria for TDS.

Sulfate

Samples collected from W3114, W3214, W3314, W3116, W3118, W3119, W3219, W3319, and W3419 exceeded the DW criteria for sulfate. There is no GSI criterion for sulfate.

pH

Samples collected from each of the nested wells at the B3014 location (W3114, W3214, W3314, and W3414) and the B3019 location (W3119, W3219, W3319, and W3419), W3116, W3174, W3274, W3474, and W3242 exceed the generic DW criteria for pH. The sample collected from W3320 exceeded the DW criteria of 6.5 with a pH measurement of 5.58. Naturally occurring low pH is observed in deeper groundwater at the Site. The low pH is likely caused by the degradation of organic matter under anaerobic conditions. Samples collected from the B3019 wells (W3119, W3219, W3319, and W3419), W3116, W3174, W3274, and W3474 exceed the generic GSI criterion of 9.0 for pH.

Aluminum

The majority of the groundwater samples collected at the West CKD Area exceeded the DW criteria for aluminum, including those collected from the upgradient monitoring well nest (W3220, W3320, and W3420). However, the concentrations of aluminum are elevated in locations with other indicators of leachate impacts (e.g., W3114). The ubiquitous nature of the aluminum combined with the elevated concentration in some areas suggests that aluminum is both naturally occurring and associated with the CKD.

Arsenic

Each of the samples collected from W3114 and the July 31, 2006 and October 24, 2006 samples from W3214 exceeded the DW criteria for arsenic (concentrations ranged from 11 to 37 µg/L); however, samples from the deeper wells in this nest did not exceed criteria. Arsenic concentrations from each well at the W3119/W3219/W3319/W3419 nest exceeded DW criteria and samples from W3219 and W3319 exceeded the GSI criteria for arsenic.

Chromium

The reported concentration of total chromium in samples from W3119, W3219, W3319, and W3419 monitoring wells exceeded the GSI criterion for chromium VI. The reported total chromium concentrations ranged from 11 to 23 µg/L which are just over the criterion for chromium VI. It is unlikely that all of the reported chromium is chromium VI; however speciation analysis was not conducted.

Copper

Each of the samples collected from W3119; the Summer 2006 samples from W3416 and W3319; the Fall 2006 samples from W3219, W3319, and W3419; the Fall 2007 sample from W3116, and the Winter 2007 sample from W3318 exceeded the GSI criteria for copper (concentrations ranged from 12 to 31 µg/L).

Iron

The majority of the groundwater samples collected at the West CKD Area exceeded the aesthetic DW criteria for iron, including those collected from the upgradient monitoring well nest (W3120, W3220, W3320, and W3420). The ubiquitous nature of the iron and the high concentrations in upgradient wells suggests that this metal is naturally occurring and not associated with the CKD.

Lead

Groundwater samples collected from W3114, W3214, W3314, W3116, W3417, W3318, W3119, W3219, W3319, and W3419 exceeded the DW criteria for lead. One sample from W3119 and from W3219 equaled or slightly exceeded the GSI criteria for lead.

Manganese

Approximately half of the groundwater samples collected at the West CKD Area exceeded the aesthetic DW criteria for manganese, including samples from the upgradient well W3420. The ubiquitous nature and the elevated concentrations in upgradient wells of the manganese suggest that manganese is naturally occurring.

Mercury

Groundwater samples collected from the West CKD Area exceeded GSI criteria for mercury at W3116, W3216, W3416, W3118, W3318, W3418, W3119, W3219, W3319, W3419, W3174, W3274, and W3474.

Nickel

Samples collected from W3114 and the July 31, 2006 sample from W3214 exceeded the DW criteria for nickel (concentrations ranged from 120 to 160 µg/L); however, samples from the deeper wells in this nest did not exceed the nickel criterion, indicating that the exceedance is isolated. The September 21, 2006 nickel concentration in the sample from W3219 was slightly over the GSI criteria with a concentration of 67 µg/L.

Selenium

The shallow well W3116 and each of the wells at the B3019 location (W3119, W3219, W3319, and W3419) exceeded the GSI criteria for selenium. Concentrations of selenium ranged from 5.1 to 15 µg/L.

Silver

The shallow well at W3119 exceeded the GSI criteria for silver on July 13, 2006 and January 2, 2007 with concentrations that were at or slightly above the criteria. The concentrations of silver in the September 21-26, 2006 samples from W3219, W3319, and W3419 were just over the GSI criteria; however, these wells did not exceed criteria for subsequent sampling dates.

Sodium

The concentration of sodium in monitoring wells W3114 and W3214 ranged from 120,000 to 150,000 µg/L and these concentrations were just over the DW criteria of 120,000 µg/L. The deeper wells in this nest did not exceed generic criteria. Samples from each of the wells in the B3019 monitoring well nest exceeded the DW criteria for sodium and the concentrations ranged from 150,000 to 270,000.

Vanadium

Most of the samples collected from the nested wells at the B3014 location (W3114, W3214, W3314, and W3414) and B3019 location (W3119, W3219, W3319, and W3419), the shallow wells W3116 and W3118, and the medium depth well W3318 exceeded the DW criteria for vanadium. Samples collected from W3116, W3318, W3119, W3219, W3319, and W3419 exceeded the GSI criteria for vanadium.

Zinc

Only the sample collected at W3318 on January 3, 2007 exceeded the GSI criteria for zinc with a concentration of 170 µg/L which is just over the GSI criteria of 150 µg/L. This isolated exceedance suggests that zinc may not be associated with the CKD.

5.5.2.2 Seep 2 CKD Area

No samples collected at the Seep 2 CKD Area exceeded generic criteria for phosphorus, nitrates, barium, beryllium, cadmium, magnesium, thallium, zinc, or VOCs.

Chloride

Groundwater samples collected from each of the beach monitoring well nests at the Seep 2 CKD Area sampled and analyzed for chloride exceeded the GSI criteria for that parameter. Only samples collected from W2420, W2122/W2222/W2322/W2422/W2522/W2622, W2125/W2225/W2325/W2425, W2130/W2230, W2133/W2233/W2333, W2135, W2138, W2338, W2226, W2326, W2145, W2146/W2246/W2446, W2148, W2149, W2150, W2151, W2153/W2253/W2353, W2154, W2155/W2255, W2256/W2356, W2158, W2159, W2262/W2362, W2163/W2263/W2363, W2264, and W2166/W2266 exceeded the DW criteria for chloride. The ubiquitous nature of the chloride, combined with the elevated concentration in some areas, suggest that chloride is present due to both CKD and non-CKD sources (e.g., road salt).

Sum of Potential Nitrogen Sources

Groundwater samples collected from the W2122/W2222/W2322/W2422/2522, W2125/W2225/W2325, W2130/W2230 and W2233/W2333 monitoring well nests, and from W2420, W2158, W2146, W2356, and W2163 were the only samples collected at the Seep 2 CKD Area that exceeded the DW criteria for "sum of potential nitrogen sources."

Ammonia

Only samples collected from W2122/W2222/W2322/W2422/W2522, W2125/W2225/W2325, W2233, W2333, W2146, W2356, and W2163 exceeded the DW criteria for ammonia.

Ammonia That Will Become NH_3 in Surface Water

Groundwater samples collected from W2153/W2253/W2353/W2453, W2154, and W2155/W2255 exceeded the GSI criteria for ammonia that will become NH_3 in surface water. The calculated ammonia criterion is 29 µg/L, which is 3.8% of total ammonia.

Total Dissolved Solids (TDS)

The majority of the samples collected from the Seep 2 CKD Area, including the upgradient well W2243, exceeded the aesthetic DW criteria for TDS. Samples collected from W2141, W2241, W2341, W2441, W2153, W2253, W2353, W2453, W2154, W2254, W2155, and W2255 exceed the GSI criteria for TDS.

Sulfate

Samples collected from the majority of the wells at the Seep 2 CKD Area exceeded the DW criteria for sulfate. There is no GSI criterion for sulfate.

pH

Groundwater samples collected from W2319, W2420, W2122, W2322, W2422, W2522, W2125, W2225, W2325, W2226, W2326, W2130, W2230, W2233, W2333, W2138, W2146, W2246, W2250, W2153, W2253, W2353, W2453, W2154, W2155, W2256, W2356, W2158, W2262, W2362, W2462, W2163, W2263, W2363, W2264, W2166, W2266, W2196, W2296, W2396, W2298, and W2398 exceeded the DW criteria of 8.5 for pH.

Samples collected from W2119, W2320, W2425, W2126, W2426, W2135, W2235, W2335, W2238, W2142, W2342, W2442, W2443, W2144, W2148, W2354, W2355, and W2293 exceeded the DW criteria because the pH was less than 6.5. The low pH is likely caused by the degradation of organic matter under anaerobic conditions.

Groundwater samples collected from the following beach wells exceeded the GSI criteria of 9.0: W2153, W2253, W2353, W2154, W2155, W2196, W2296, W2396, W2298 and W2398. Two wells exceeded the GSI criteria by being below the criteria of 6.5 (W2354 and W2355).

Aluminum

The majority of the groundwater samples collected at the Seep 2 CKD Area exceeded the DW criteria for aluminum, including those collected from the upgradient monitoring well nest (W2143, W2243, W2343, and W2443). However, the concentrations of aluminum are elevated in locations with other indicators of leachate impacts (e.g., W2163). The ubiquitous nature of the aluminum, combined with the elevated concentration in some areas, suggest that aluminum is both naturally occurring and associated with the CKD.

Antimony

The DW criterion for antimony was not exceeded by any samples collected at the Seep 2 CKD Area. One sample collected from W2155 (3.2 µg/L, September 20, 2007) exceeded the GSI criteria for antimony. The single exceedance suggests that antimony is not associated with the CKD and is not a chemical of concern.

Arsenic

Groundwater samples collected from W2319, W2420, W2122/W2322/W2422/W2522, W2125/W2225/W2325, W2226, W2130/W2230, W2133/W2233/W2333, W2135, W2138, W2146/W2246, W2153/W2253, W2154, W2356, W2158, W2159, W2262/W2362, W2163/W2263/W2363, W2264, W2166 exceeded the DW criteria for arsenic. The GSI criterion of 50 µg/L was not exceeded at wells on the beach.

Chromium

The reported concentration of total chromium in samples from monitoring wells W2241 and W2441 exceeded the GSI criteria for chromium VI. The reported total chromium concentrations ranged from 11 to 13 µg/L which are just over the criteria for chromium VI. It is unlikely that all of the reported chromium is chromium VI; however speciation analysis was not conducted.

Copper

The DW criterion for copper was not exceeded by samples collected at the Seep 2 CKD Area. Single samples collected from W2241, W2441, W2453, and W2154 exceeded the GSI criteria of 11 µg/L. Multiple samples from W2155, W2153, W2253, and W2353 exceeded the GSI criteria for copper.

Iron

The majority of the groundwater samples collected at the Seep 2 CKD Area exceeded the aesthetic DW criteria for iron, including those collected from the upgradient monitoring well nest (W2243, W2343, and W2443). The ubiquitous nature of the iron and the high concentrations in upgradient wells suggests that this metal is naturally occurring and not associated with the CKD.

Lead

Groundwater samples collected from W2318, W2119, W2420, W2122/W2522, W2325/W2425, W2126/W2226, W2330, W2133, W2135, W2138, W2141/W2241/W2441, W2153, W2158, and W2262 exceeded the DW criteria for lead.

Manganese

Approximately half of the groundwater samples collected at the Seep 2 CKD Area exceeded the aesthetic DW criteria for manganese, including samples from the upgradient well W2243. The ubiquitous nature of the manganese and the high concentration in the upgradient well suggests that manganese is naturally occurring.

Mercury

Groundwater samples collected from the following beach monitoring wells exceeded the GSI criteria for mercury: W2141/W2241/W2341/W2441, W2153/W2253/W2353/W2453, W2154/W2254, W2155, W2195/W2295, W2196/W2296/W2396, W2197/W2297 and W2298/W2398. One sample collected from W2225 exceeded the DW criteria for mercury.

Nickel

Each of the samples collected from the shallow wells W2146 and W2163 exceeded the DW criteria for nickel while deeper wells in these nests did not exceed. Most of the samples collected from W2122/W2322/W2422/W2522, W2125/W2225/W2325, and W2130 monitoring wells exceeded the DW criteria for nickel; however samples from the deepest wells in these nests did not exceed. Single samples from W2420, W2153, W2253, and W2353 exceeded the DW and/or GSI criteria for nickel; however samples from the deepest well in this nest did not exceed. Single samples from W2356 and W2263 exceeded the DW criteria while wells below these wells did not exceed.

Selenium

One beach monitoring well sample collected from W2153 and W2155 exceeded the GSI criteria for selenium. Samples collected from W2322, W2125, W2130, W2146, W2163, and W2263 also exceeded the DW criteria of 50 µg/L.

Silver

Samples collected from W2441 and W2153 exceeded the GSI criteria for silver.

Sodium

Groundwater samples collected from the following monitoring wells exceeded the DW criteria for sodium: W2420, W2122/W2222/W2322/W2422/W2522/W2622, W2125/W2225/W2325/W2425, W2126/W2226/W2326, W2130/W2230, W2133/W2233/W2333, W2135, W2138, W2141, W2145, W2146/W2246/W2346/W2446, W2148, W2149, W2150/W2250, W2151, W2153/W2253/W2353, W2155/W2255, W2256/W2356/W2456, W2158, W2159, W2262/W2362, W2163/W2263/W2363, W2264, W2166/W2266. There is no GSI criterion for sodium.

Vanadium

Samples collected from W2318, W2319, W2420, W2122/W2222/W2322/W2422/W2522, W2125/W2225/W2325/W2425, W2126/W2226/W2326/W2426, W2130/W2230/W2330,

W2133/W2233/W2333, W2135, W2138/W2338, W2141/W2241/W2341/W2441, W2146/W2246, W2149, W2250/W2350, W2153/W2253/W2353/W2453, W2154, W2155, W2256/W2356/W2456, W2158, W2159, W2162/W2262/W2362/W2462, W2163/W2263/W2363, W2264, and W2166 exceeded the DW criteria for vanadium. Samples collected from W2441, W2153, W2253, W2353, W2453, and W2154 exceeded the GSI criteria for vanadium.

SVOCs

One sample collected from W2227 on May 23, 2006 slightly exceeded the DW criteria for bis(2-ethylhexyl)phthalate. This occurrence is the sole exceedance of an organic compound at the Seep 2 CKD Area and is not likely associated with the CKD. Bis(2-ethylhexyl)phthalate is a common laboratory contaminant.

5.5.2.3 Seep 1 CKD Area

No samples collected at the Seep 1 CKD Area exceeded generic criteria for nitrates, phosphorus, antimony, cadmium, or VOCs.

Chloride

Groundwater samples collected from the beach wells W1113, W1213, W1313, W1114, W1131, W1231, W1331, W1132, W1232, W1134, W1234, W1135, W1235, W1136, W1145, W1245, and W1345 exceeded the GSI criteria for chloride. Only samples collected from W1113/1213/W1313, W1114, W1117/W1217/W1317/W1417, W1118/W1218/W1318/W1418, W1219/W1319/W1419, W1121/W1221/W1321, W1122, W1124, W1131/W1231, W1132, W1134/W1234, W1135, and W1145/W1245/W1345 exceeded the DW criteria for chloride. The ubiquitous nature of the chloride combined with the elevated concentration in some areas suggests that chloride is present due to both CKD and non-CKD sources (e.g., road salt).

Sum of Potential Nitrogen Sources

Groundwater samples collected from the W1117/W1217/W1317, W1219/W1319, W1121/W1221, W1124, and W1134/W1234 monitoring wells were the only samples collected at the Seep 1 CKD Area that exceeded the DW criteria for “sum of potential nitrogen sources.” The deeper wells in these nests did not exceed the DW criteria.

Ammonia

Only samples collected from W1117/W1317 and W1124 exceeded the DW criteria for ammonia.

Ammonia That Will Become NH_3 in Surface Water

Groundwater samples collected from W1113/W1213, W1114, W1131/W1231, W1134/W1234, W1135, and W1145/W1245/W1345 exceeded the GSI criteria for ammonia that will become NH_3 in surface water. The calculated ammonia criterion is 29 µg/L, which is 3.8% of total ammonia.

Total Dissolved Solids (TDS)

The majority of the samples collected from the uppermost well in each monitoring well nest exceeded the aesthetic DW criteria for TDS. Samples collected from the beach wells W1113, W1213, W1313, W1114, W1131, W1231, W1331, W1132, W1134, W1234, W1135, W1235, W1136, and W1145/W1245/W1345 exceeded the GSI criterion for TDS.

Sulfate

Groundwater samples collected from the following wells exceeded the DW criteria for sulfate: W1113/W1213/W1313, W1114, W1117/W1217/W1317/W1417, W1118/W1218/W1318/W1418, W1119/W1219/W1319/W1419, W1121/W1221/W1321/W1421, W1122/W1222/W1322, W1124, W1131/W1231/W1331, W1132, W1134/W1234, and W1135

pH

The measured pH in monitoring wells W1213, W1117/W1217/W1317/W1417, W1118/W1218/W1318/W1418, W1119/W1219/W1319/W1419, W1121/W1221, W1122/W1322, W1124, W1131/W1231, W1134/W1234, W1135, W1143/W1243, and W1145/W1245/W1345 exceeded the DW criteria for pH. Several samples also exceeded the pH DW criteria by having too low of pH: W1218, W1321, W1222, W1422, and W1330. The low pH is likely caused by the degradation of organic matter under anaerobic conditions. Samples collected from the following beach wells exceeded the GSI criteria for pH: W1131/W1231, W1134/W1234, W1135, W1143/W1243, and W1145/W1245/W1345.

Aluminum

The majority of the groundwater samples collected at the Seep 1 CKD Area exceeded the DW criteria for aluminum, including those collected from the upgradient monitoring well nests (W1130/W1230/W1330/W1430 and W1133/W1233/W1333). However, the concentrations of aluminum are elevated in locations with other indicators of leachate impacts (e.g., W1117). The ubiquitous nature of the aluminum combined with the elevated concentration in some areas suggests that aluminum is both naturally occurring and associated with the CKD.

Arsenic

Groundwater samples collected from W1213, W1117/W1217/W1317/W1417, W1118/W1318/W1418, W1219/W1319/W1419, W1121/W1221, W1122, W1124, W1225, W1127, W1131/W1231, W1134/W1234, W1135, and W1145/W1245/W1345 exceeded the DW criteria for arsenic. Only samples from W1134 and W1234 exceeded the GSI criteria.

Barium

Groundwater samples collected from W1127 on June 7, 2006 and August 24, 2006 are the only samples from the Site that exceed the DW criteria for barium. These exceedances are isolated and sporadic and are not likely associated with CKD, therefore barium is not a Site COC.

Beryllium

One sample collected from W1225 on August 9, 2006 and one sample collected from W1127 on June 7, 2006 slightly exceeded the DW criteria for beryllium. These occurrences are the only exceedances for this parameter. They are isolated and sporadic and, therefore, not likely associated with the CKD and beryllim is not a Site COC.

Chromium

Two samples collected from W1134 contained a total chromium concentration that exceeded the GSI criterion for chromium VI. The samples collected from W1118, W1225, and W1127 contained total chromium concentrations that exceeded the DW criteria for chromium VI. It is unlikely that all of the reported chromium is chromium VI; however speciation analysis was not conducted.

Copper

Samples collected from W1131, W1134, W1234, W1135, W1235, W1245, and W1345 exceeded the GSI criteria for copper. No samples exceeded the DW criteria.

Iron

The majority of the groundwater samples collected at the Seep 1 CKD Area exceeded the aesthetic DW criteria for iron, including those collected from the upgradient monitoring well nests (W1130/W1230/W1330/W1430 and W1133/W1233/W1333). The ubiquitous nature of the iron suggests that this metal is naturally occurring and not associated with the CKD. Samples collected from W1225 and W1127 were elevated in iron relative to the rest of the Site; however the pH is low

in these wells (indicating that they are not leachate impacted). The elevated iron does not appear to be associated with CKD.

Lead

Samples from W1117/W1317/W1417, W1318, W1419, W1222, W1124, W1225/W1425, W1127, W1234, and W1235 exceeded the DW criteria for lead.

Magnesium

One sample collected from W1225 on August 9, 2006 slightly exceeded the DW criteria for magnesium. Subsequent samples from this well did not exceed the criterion. This occurrence is the only exceedances for this parameter at the Site. It is isolated and singular and, therefore, not likely associated with the CKD and magnesium is not a Site COC.

Manganese

Samples collected from W1113, W1114, W1117/W1217/W1317/W1417, W1218/W1418, W1119/W1219/W1319/W1419, W1121/W1221/W1321/W1421, W1222/W1322/W1422, W1124/W1224/W1324, W1225/W1425, W1127/W1327, W1130/W1330/W1430, W1231/W1331, W1132, W1133/W1233, W1134/W1234/W1334, W1235, and W1436 exceeded the DW criteria for manganese. Monitoring wells W1130/W1330/W1430 and W1133/W1233 are upgradient wells. The manganese DW criteria exceedances upgradient of the Site indicate that manganese is naturally occurring.

Mercury

Groundwater samples collected from W1113, W1213, W1114, W1414, W1131, W1231, W1331, W1431, W1132, W1134, W1234, W1334, W1434, W1135, W1235, W1436, W1143, W1243, W1145, W1245, and W1345 exceeded the GSI criteria for mercury. One sample collected from W1217 on July 17, 2006 exceeded the DW criteria for mercury.

Nickel

Groundwater samples collected from W1117/W1217/W1317, W1418, W1219/W1319/W1419, W1121/W1221, W1225, and W1127 exceeded the DW criteria for nickel. Only samples from W1134, W1234, and W1345 exceeded the GSI criteria for nickel.

Selenium

Groundwater samples collected from beach wells W1114, W1131, W1231, W1134, W1234, W1135, W1145, W1245, and W1345 exceeded the GSI for selenium. Only samples from W1117, W1217, and W1317 exceeded the DW criteria for selenium.

Silver

Groundwater samples collected from W1114 and W1334 exceeded the GSI criteria for silver.

Sodium

Samples collected from W1113/W1213, W1114, W1117/W1217/W1317/W1417, W1118/W1218/W1318/W1418, W1219/W1319/W1419, W1121/W1221/W1321, W1122, W1124, W1127, W1131, W1132, W1233, W1134/W1234, W1135, and W1145/W1245/W1345 exceeded the DW criteria for sodium. There is no GSI criterion for sodium.

Thallium

One sample collected from W1225 on August 9, 2006 and one sample collected from W1127 on June 7, 2006 slightly exceeded the DW criteria for thallium. These occurrences are the only exceedances for this parameter. They are isolated and sporadic and, therefore, not likely associated with the CKD and thallium is not a COC.

Vanadium

Samples from W1213, W1117/W1217/W1317/W1417, W1118/W1218/W1318/W1418, W1119/W1219/W1319/W1419, W1121/W1221/W1321, W1122/W1222, W1124, W1225, W1127/W1327, W1430, W1131/W1231/W1331, W1134/W1234, W1135/W1235, W1436, and W1145/W1245/W1345 exceeded the DW criteria for vanadium. Samples collected from beach wells W1131, W1231, W1134, W1234, W1135, W1235, W1145, W1245, and W1345 also exceeded the GSI criteria.

Zinc

The sample collected at W1331 on July 2, 2007 is the only sample that exceeded the GSI criteria for zinc. The DW criterion for zinc was not exceeded. The zinc exceedance is isolated and singular and, therefore, not likely associated with the CKD and zinc is not a COC.

SVOCs

One sample collected from W1225 on August 9, 2006 and one sample collected from W1127 on June 7, 2006 slightly exceeded the DW criteria for bis(2-ethylhexyl)phthalate. These occurrences are the sole exceedances of organic compounds at the Seep 1 CKD Area and are not likely associated with the CKD. Bis(2-ethylhexyl)phthalate is a common laboratory contaminant.

6.0 Cement Kiln Dust Characteristics and Leachate Chemistry

6.1 Cement Kiln Dust Characteristics

CKD is a by-product of Portland cement production. In the United States, the manufacture of Portland cement typically involves roasting a finely ground proportional mix of raw materials in a rotary kiln (U.S. Dept. of the Interior, 2004).

The specific chemical, mineralogical, and physical characteristics of CKD vary from plant to plant due to differences in raw feed materials, type of kiln operation, dust collection systems, and fuel used in operating the kiln. In general, CKDs are particulate mixtures of partially calcined and unreacted raw limestone feed, clinker dust, and fuel ash, enriched with alkali sulfates, halides, and other volatile inorganic materials (Portland Cement Association, 2003). These particulates and combustion gas precipitates are collectively referred to as CKD. The following sections discuss the physical and chemical properties of CKD.

6.1.1 Physical Properties

CKD is a fine, powdery material of relatively uniform size. A publication by the Portland Cement Association (PCA) conducted on three samples of CKD reported the physical properties listed below (Todres et al., 1992a):

Property	Value/Range
% Passing 0.075 mm (No. 200 sieve)	> 90%
Median Grain Size	0.003 to 0.022 mm

Compared to the published results, CKD samples from the Site were coarser grained with median grain sizes ranging from 0.012 to 11 millimeters while percent passing the #200 sieve ranged from 11.6 to 77.4%.

U.S. EPA has estimated the permeability of CKD ranging from 1 x 10^{-6} to 1 x 10^{-3} cm/sec, which is similar to fly ash when placed under similar conditions (U.S. EPA, 1997). It is likely that

permeability will vary greatly, depending on density of the material when placed and at present, and moisture content both when placed and at present. It would appear that CKD placed in an uncontrolled fill would likely have a permeability of at least 1 x 10^{-5} cm/sec.

EPA published permeability values are similar to results from physical testing conducted on CKD samples from the Site which ranged from 3.1×10^{-7} to 5.8×10^{-3} cm/sec.

A study by the PCA reported field dry densities ranging from 71.9 lb/ft^3 to 90.2 lb/ft^3 (Todres et al., 1992b). Density testing conducted at the East CKD Area portion of the LTB CKD Release Site have shown similar results to the PCA study with CKD field dry densities ranging from approximately 75 lb/ft^3 to 100 lb/ft^3.

6.1.2 Chemical Properties

CKD shares many common characteristics with Portland cement as CKD is a byproduct of the Portland cement manufacturing process. However, there are some important differences between CKD and Portland cement. These differences arise from the way in which CKD is collected from the production process. Because CKD is collected as a dust from the exhaust stream of the cement kiln, it also contains components derived from the kiln fuel, as well as elements that condense within the collected CKD as exhaust gases cool.

The major elemental constituents of CKD are summarized below. Like Portland cement, CKD contains free lime, calcium silicates, calcium aluminates, and calcium aluminoferrites. Unlike Portland cement, CKD contains a large amount of alkali (potassium and sodium) and sulfate. This difference arises because, at operating temperatures in the kiln, potassium, sodium, and sulfate volatilize from the raw material and then, as exhaust gases cool, condense and partition into the CKD. Portland cement specifications usually limit the amounts of sodium and potassium allowed in the final product. Because bypass CKD contains a large quantity of these minerals, CKD is usually removed from the process. Typical mineral composition of CKD is listed below (Portland Cement Association, 1996):

Typical CKD Composition

Constituent	% By Weight	Constituent	% By Weight
CaCO3	55.5	Fe2O3	2.1
SiO2	13.6	KCl	1.4
CaO	8.1	MgO	1.3
K2SO4	5.9	Na2SO4	1.3
CaSO4	5.2	KF	0.4
Al2O3	4.5	Others	0.7

Typical chemical elements found in CKD (> 0.05% by weight) include aluminum, calcium, iron, magnesium, potassium, and sodium (U.S. EPA, 1997). Listed below are the range, arithmetic mean, and median concentrations of these common elements found in CKD. These values, which were based on 113 CKD samples, were provided by Haynes and Kramer (1982).

Typical Concentrations of Elements Found in CKD

Element	Range (ug/kg)	Mean (ug/kg)	Median (ug/kg)
Aluminum	9,900,000 – 50,200,000	23,200,000	23,100,000
Calcium	106,000,000 – 367,000,000	295,000,000	305,000,000
Iron	1,000,000 – 44,400,000	14,700,000	14,100,000
Potassium	3,400,000 – 232,000,000	36,600,000	26,800,000
Magnesium	1,980,000 – 19,100,000	7,820,000	6,820,000
Sodium	495,000 – 27,700,000	4,700,000	3,190,000

Representative samples of non-CKD (soil) and CKD materials were collected from the Site and analyzed for chemical properties. The chemical analytical data for both CKD and non-CKD samples are summarized in Tables 5-4a to 5-4c. The Site CKD analytical data were compared to the concentrations of the common elements found in CKD listed above. The table below summarizes the concentrations of the elements listed above for the CKD samples collected at the Site.

Element Concentrations Found in CKD Samples Collected On-site[1,2]

Element	Range (ug/kg)	Mean (ug/kg)[3]	Median (ug/kg)[3]
Aluminum	4,700,000 – 17,000,000	10,457,500	10,500,000
Calcium	82,000,000 – 310,000,000	220,725,000	235,000,000
Iron	4,500,000 – 10,000,000	7,080,000	6,900,000
Potassium	1,100,000 – 53,000,000	8,090,000	3,100,000
Magnesium	4,800,000 – 16,000,000	10,520,000	10,500,000
Sodium	<50,000 – 8,700,000	737,250	260,000

[1]Values based on concentrations in CKD samples included in Table 5-4a, Table 5-4b, and Table 5-4c.

2 Analytical samples from West CKD Area beach were not included because those samples contained a mixture of CKD and soil.

[3]A value of ½ the detection limit was arbitrarily used to calculate the mean and median for those elements having concentrations both above and below the detection limit.

The typical CKD concentrations are similar to element concentrations of the CKD samples from the Site. Typically, the arithmetic mean and median of the concentrations from the Site CKD analytical data fall within the ranges of the typical element concentrations of CKD provided by Haynes and Kramer, with the exception of the median of the potassium and sodium concentration. The Site CKD concentrations of potassium and sodium are lower than the published concentrations. In addition, some Site CKD samples have concentrations that fall outside of the typical concentration ranges provided by Haynes and Kramer (1982) for the other elements listed above. These include 18 out of 40 Site CKD samples had concentrations less than the typical aluminum range, and two out of the 40 Site CKD samples had concentrations less than the typical calcium range. These variations in concentrations are likely due to the composition of CKD being dependent on how it was generated and the degree of weathering. CKD weathering is further described in Section 6.1.3.

The element concentrations in the CKD and non-CKD analytical data from the Site were evaluated to determine if CKD samples could be distinguished from non-CKD samples. The tables below summarize the concentrations of the non-CKD samples collected at the Site.

Element Concentrations Found in Non-CKD Samples Collected On-site[1,2]

Element	Range (ug/kg)	Mean (ug/kg)[3]	Median (ug/kg)[3]
Aluminum	310,000 – 7,900,000	1,615,246	1,300,000
Calcium	200,000 – 1,600,000,000	92,467,049	19,000,000
Iron	910,000 – 14,000,000	3,471,311	2,700,000
Potassium	83,000 – 9,200,000	1,148,016	450,000
Magnesium	76,000 – 100,000,000	8,963,557	2,900,000
Sodium	<50,000 – 1,200,000	127,033	<50,000

[1]*Values based on concentrations in CKD samples included in Table 4-6a, Table 4-6b, and Table 4-6c.*

2 Analytical samples from West CKD Area beach were not included because those samples contained a mixture of CKD and soil.

[3]*A value of ½ the detection limit was arbitrarily used to calculate the mean and median for those elements having concentrations both above and below the detection limit.*

Based on the tables above, the concentrations from the CKD analytical data are typically greater for these elements than the concentrations from the non-CKD analytical data.

The CKD and non-CKD analytical data were also evaluated for patterns and inter-element correlations that may distinguish CKD samples from non-CKD samples. The only parameters observed to exhibit any trends were aluminum and iron. Iron concentrations and aluminum concentrations were plotted for the CKD and non-CKD samples from the Site. The ratio of iron to aluminum in CKD samples is much lower than in non-CKD samples.

6.1.3 CKD Weathering

Upon contact of CKD with water, various chemical reactions take place resulting in physical and chemical changes in the CKD. Because CKD shares many similarities with Portland cement, CKD weathering follows many of the same pathways as cement hydration. An important aspect of cement and CKD hydration is that a relatively large amount of water is consumed in the reactions. Reactions involved in the CKD hydration are discussed further in Section 6.2.2. The reactions involved in cement hydration (in order of relative reaction speed) are:

- Dissolution of sulfate and chloride salts of potassium and sodium
- Hydration of free lime and alkali oxides
- Hydration of calcium silicates
- Hydration of calcium aluminates
- Hydration of calcium aluminoferrites

There are, however, some key differences between CKD weathering and Portland cement hydration:

- CKD contains more alkali and sulfate than Portland cement, thus the hydration rates of aluminate and aluminoferrite mineral phases may be retarded in CKD relative to Portland cement.
- In Portland cement applications, the water:cement ratio is maintained in a specific range. In a CKD pile, environmental inputs of water may occur in amounts much greater or much less than what is required to complete the hydration reactions. Thus, CKD weathering could result in the formation of some minerals in the pile that would not form in Portland cement, and/or the leaching of some constituents from the pile that would be retained in Portland cement.
- In Portland cement applications, air content is maintained in a specific range. In a CKD pile, the air content varies depending on the degree of saturation in the pile. A greater degree of air content in the pile increases the potential for partitioning of atmospheric CO_2 into the alkaline porewater. This could result in a higher porewater carbonate concentrations and a greater degree of carbonate precipitation in CKD than in Portland cement.

Thus, CKD weathering is the cement hydration process as modified by moisture conditions within the pile. The following sections discuss CKD weathering under variably-saturated and continuously-saturated moisture conditions.

6.1.3.1 CKD Weathering in the Saturated Zone

Under saturated conditions, water would be supplied in excess of the CKD hydration demand. Additionally, a saturated CKD pile can be treated as a closed system with respect to carbonate, since there are no unsaturated pores for gas transfer. Under these conditions, the hydration reactions described above can proceed to completion. Compounds potentially leached from the pile under these conditions include (in order of leaching):

- potassium, sodium, sulfate, chloride, calcium, and hydroxide alkalinity
- small amounts of aluminum
- small amounts of iron

The soluble potassium and sodium salts would leach out of the pile rapidly. Calcium concentrations in the porewater would be near the portlandite solubility limit. The porewater would be devoid of carbonate alkalinity due to calcite precipitation within the pile. Once much of the sulfate had leached out of the pile, calcium aluminate and calcium aluminoferrite hydration would proceed, leaching small amounts of aluminum and iron from the pile. Aluminate hydration is more rapid than aluminoferrite hydration; the relative amounts of aluminum to iron in the CKD would decrease as weathering progressed. Thus, the ratio of iron to aluminum should increase as weathering progresses, perhaps approaching a value similar to non-CKD material. Therefore, the ratio of iron to aluminum is an indicator of the degree of weathering of the CKD.

6.1.3.2 CKD Weathering in the Unsaturated Zone

Under variably-saturated conditions, water would be supplied in amounts less than the hydration demand in some portions of the pile, and in amounts greater than the hydration demand in other parts of the pile. Additionally, the CKD pile would be treated as an open system with respect to carbonate, since air would be drawn into the pore spaces as water percolates down through the pile. Hydration reactions would proceed to completion in portions of the pile where sufficient water is present, and would proceed to the exhaustion of the water supply elsewhere.

Compounds potentially leached from the pile under these conditions include (in order of leaching):

- Potassium, sodium, sulfate, and chloride
- Hydroxide alkalinity and carbonate alkalinity
- Calcium in low concentrations
- Small amounts of aluminum
- Small amounts of iron

A likely scenario is that sufficient hydration water is present in the upper portion of the pile, but conditions become water-limited deeper in the pile, as water is consumed by hydration reactions along the infiltration path. As water is consumed deeper in the pile, the salts leached from above are concentrated and, ultimately, re-precipitated in a more concentrated form deeper in the pile. Upon re-wetting of the pile, these salts are readily re-dissolved. The additional input of CO_2 with the infiltration water results in conversion of hydroxide alkalinity to carbonate alkalinity in the porewater, and subsequent precipitation of carbonates. Over many wetting and drying cycles,

carbonate may build up in the porewater, and calcium concentrations may become limited by carbonate solubility.

6.2 Leachate Chemistry Discussion

When water comes in contact with reactive CKD, it reacts with solid-phase minerals in the CKD. While many different reactions take place upon wetting reactive CKD, the net effect of all these reactions is to convert unimpacted water into leachate by imparting some specific chemical characteristics to the water.

The chemical characteristics imparted to the water by the reactive CKD affect the behavior of the leachate in both natural and engineered systems. It is therefore important to understand how water is converted to leachate by contact with reactive CKD, and how the chemical characteristics of leachate affect its interaction with environmental media.

The following sections describe the chemistry involved in the conversion of water to leachate, as well as the chemistry behind interactions between leachate and environmental media.

6.2.1 Interactions between CKD and Water

The end result of the Portland cement manufacturing process is the production of a reactive powder that, when mixed with water in specific proportions, will be converted into a strong crystalline structure. Like Portland cement, CKD is also a reactive powder. Some of the same reactions occur in both CKD and Portland cement. However, due to the differences described above, some reactions occur in CKD that do not occur in Portland cement.

Portland cement is typically combined with water in specific proportions, such that the reactive minerals are uniformly hydrated and all the added water is ultimately incorporated into the hydrated crystalline matrix. A CKD pile exposed to variable moisture conditions would not likely be uniformly hydrated, and, at times, contains moisture in excess of the hydration requirement, which may exit the pile as leachate. Portland cement pastes also typically contain a specific amount of entrained air, whereas a CKD pile is largely open to gas exchange with the atmosphere.

The following sections describe reactions that occur during hydration of CKD.

6.2.1.1 Reactions Common to Portland Cement and CKD

As described above, both Portland cement and CKD contain free lime, calcium silicates, calcium aluminates, and calcium aluminoferrites. Therefore, the hydration reactions for these minerals are shared by Portland cement and CKD.

As many of the reactions presented in this Section were obtained from Portland cement literature, they are written such that a stoichiometrically balanced amount of water is supplied and, subsequently, incorporated into the resultant hydrated solid phases. If water is supplied in a lesser amount, the reaction would not proceed to completion. If water is supplied in a greater amount, then the reaction may release some elements into solution, in accordance with the solubility products of the hydrated minerals.

Free Lime

Free lime reacts rapidly with water according to the following reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2(s) \qquad \text{Equation 1}$$

Any water supplied in excess of the stoichiometric requirement for the above reaction would be expected to contain calcium and hydroxide in accordance with the solubility product of portlandite ($Ca(OH)_2$). However, any carbonate present in the water will also precipitate with calcium via the following reaction:

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(s) \qquad \text{Equation 2}$$

In typical Portland cement applications, the degree to which reaction 2 occurs is limited by the air content of the paste. In the case of a CKD pile, however, variable wetting conditions (and air content) likely results in a greater input of carbonate to the system, allowing reaction 2 to occur to a greater extent. Calcium is therefore largely retained in the CKD pile as precipitated calcite.

The net result of free lime hydration in CKD is to contribute hydroxide alkalinity to the leachate and remove calcium and magnesium from the leachate.

Calcium Silicates

Calcium silicate minerals react with water according to the following reactions:

$$2Ca_2SiO_4 + 5H_2O \rightarrow (CaO)_3 \cdot (SiO_2)_2 \cdot 4H_2O(s) + Ca(OH)_2(s) \qquad \text{Equation 3}$$

Hydration of silicates results in the release of hydroxide alkalinity into solution, as well as the incorporation of water into the hydrated crystalline matrix.

Silicate hydration reactions are typically rapid, being responsible for much of the early strength of concrete. The net effect of silicate hydration in CKD is to consume some water and contribute hydroxide alkalinity, as well as small amounts of calcium and silicon to leachate.

Calcium Aluminates

Calcium aluminate minerals react with water according to the following reactions:

$$2(CaO)_2 Al_2O_3 + 21H_2O \rightarrow (CaO)_4(Al_2O_3) \cdot 13H_2O(s) + (CaO)_2 \cdot Al_2O_3 \cdot 8H_2O(s) \qquad \text{Equation 4}$$

Hydration results in the release of hydroxide alkalinity into solution, as well as the incorporation of water into the hydrated crystalline matrix.

Aluminate hydration can be rapid under certain conditions, leading to “flash set” in concrete applications. Gypsum is typically added to the concrete mix in order to retard hydration of aluminate minerals, allowing the concrete to be placed before hydration begins. Specifically, sulfate from the added gypsum allows formation of a mineral coating (ettringite) on the aluminate mineral surface, retarding hydration. Slow hydration of aluminate minerals is largely responsible for late concrete strength.

The net effect of aluminate hydration in CKD is to consume some water and contribute hydroxide alkalinity, as well as small amounts of calcium and aluminum to leachate. The fact that a large amount of sulfate is present in the CKD may lead to significant retardation of aluminate hydration reactions, until much of the sulfate is leached out.

Calcium Aluminoferrites

Hydration of calcium aluminoferrite minerals is analogous to aluminate hydration (reaction 4), except aluminoferrite hydration proceeds more slowly. Hydration results in the release of hydroxide alkalinity into solution, as well as the incorporation of water into the hydrated crystalline matrix.

The net effect of aluminoferrite hydration in CKD is to consume some water and contribute hydroxide alkalinity, as well as small amounts of calcium, aluminum, and iron to the leachate. Like aluminate hydration, aluminoferrite hydration may be significantly retarded by sulfate in the CKD.

6.2.1.2 Reactions Specific to CKD

As described above, CKD contains some elements that are absent from Portland cement. These elements impart characteristics to the leachate that make it different from Portland cement porewater.

Alkali Reactions

Reactions of alkali oxides in CKD with water are rapid and proceed as follows:

$$K_2O + H_2O \rightarrow 2K^+ + 2OH^- \qquad \text{Equation 5}$$

Because of the high solubility of alkali in water, these reactions can raise the pH to very high values (>13).

Also, sulfate salts of potassium and sodium dissolve readily in water, contributing high concentrations of dissolved solids to the leachate:

$$K_2SO_4 + H_2O \rightarrow 2K^+ + SO_4^{2-} + H_2O \qquad \text{Equation 6}$$

As discussed above, the presence of large amount of sulfate in leachate will retard hydration to a greater degree than observed in cement porewater.

Organic Reactions

Unlike Portland cement, CKD contains organic matter (on the order of 1% by weight) imparted by the kiln fuel. When the CKD is wetted, high pH conditions can act upon the organic matter, dissolving it via a process known as saponification. Saponification is the base-catalyzed hydrolysis of organic matter, and results in the production of fatty acid surfactant molecules, having a hydrophilic head and hydrophobic tail (Figure 6-1).

The fatty acid surfactants produced are soluble in the presence of monovalent cations, such as sodium and potassium. However, in the presence of sufficient amounts of hardness, the sodium or potassium can be exchanged for calcium or magnesium, and the surfactant precipitates. Also, some fatty acid surfactants are soluble at alkaline pH, but insoluble at acidic pH. Fatty acid surfactants also reduce the surface tension of the leachate, making it a better wetting agent.

Site analytical data indicates a correlation between mercury and total organic carbon concentrations within leachate. This correlation is the result of mercury binding to the fatty acid surfactant molecules. This trend has important implications on the transport of mercury within the Site and the precipitation of mercury as the leachate mixes with calcium-rich groundwater.

6.2.2 Properties Imparted to Leachate by CKD Hydration

The net effect of the reactions described above is to impart some specific properties to leachate:

- Relative to natural waters, leachate is enriched in sodium and potassium, but depleted in calcium and magnesium.
- Leachate has a high pH.
- Leachate has high concentrations of sulfate and total dissolved solids.
- Leachate will have varying concentrations of aluminum and iron, depending on the degree to which sulfate has leached out of the CKD. Aluminum will elute from a CKD pile earlier in the weathering process than iron, due to differences in hydration rates.
- Fatty acid surfactants impart total organic carbon to the leachate, as well as a lower surface tension relative to water.
- Leachate has elevated concentrations of mercury.

6.2.3 Interactions between Leachate and Environmental Media

The chemical properties imparted to leachate by the CKD affect the way in which it interacts with various environmental media.

In contact with solid media, the low surface tension of leachate allows it to penetrate cracks and pores that natural water cannot. If solid media contains exchangeable cations, they can be displaced by the sodium and potassium in the leachate.

Leachate reacts with groundwater to produce both mineral and organic precipitates. The high pH of the leachate causes calcite to precipitate from the groundwater. Hardness in the groundwater also causes the fatty acid surfactants in the leachate to precipitate. These reactions are well-demonstrated in the collection trenches, where collected leachate mixes with groundwater, resulting in fouling of the trench with precipitate (refer to Appendix 2-6).

Alkalinity in the leachate is also neutralized by acidity in the groundwater, attenuating the high pH.

6.2.4 Description of Site Data Using Stiff Diagrams

As leachate mixes with groundwater, its chemical properties change. These changes can be illustrated using Stiff diagrams, which are graphical representations of the aqueous ion balance. Cations are plotted on the left side of the diagram, while anions are plotted on the right. The resulting shape of the diagram is analogous to a “fingerprint” for the sample.

Some example Stiff diagrams are shown on Figure 6-2. These diagrams illustrate the blending of leachate into groundwater. The uppermost diagram is for a leachate sample, coded yellow. It can be seen that the sample is rich in sodium and potassium, but poor in calcium and magnesium. The sample also contains a large amount of sulfate, and carbonate alkalinity. Aluminum is also present in the sample, though its concentration is small relative to other cations.

The bottom most diagram is a groundwater sample, coded blue. Overall, the small size of the diagram relative to the leachate sample indicates a lower concentration of dissolved solids. It can be seen that the groundwater is rich in calcium and magnesium, but poor in sodium and potassium. The sulfate concentration is low, and carbonate is present in roughly stoichiometric balance to calcium and magnesium.

The green diagrams on Figure 6-2 represent mixtures of leachate and groundwater. These samples contain varying amounts of calcium, magnesium, sodium, and potassium. Samples with relatively more sodium and potassium relative to calcium and magnesium represent mixtures that are relatively more leachate than groundwater. Sulfate concentrations decrease as the leachate mixes with groundwater, and the amount of carbonate alkalinity also decreases due to precipitation of calcite.

It can be seen from Figure 6-2 that the ratio of divalent cations to monovalent cations (Ca+Mg : Na+K) can be used as an indicator of the degree to which leachate has blended with groundwater. As

leachate mixes with groundwater, its constituents of concern are also attenuated. Thus, the ratio of divalent:monovalent cations can be used as an indicator of leachate attenuation.

As shown on Figure 6-3, Site samples fall into a wide-ranging continuum with respect to the ratio of divalent:monovalent cations (Ca+Mg : Na+K). As expected, pH is attenuated as the ratio of divalent:monovalent cations increases, due to dilution, precipitation of carbonate alkalinity, and neutralization with groundwater acidity. As shown on Figure 6-4, mercury is also attenuated as the ratio of divalent:monovalent cations increases, due to dilution as well as precipitation of the mercury-bearing fatty acid surfactants.

Also included on Figures 6-3 and 6-4 is chloride concentration. The change in chloride concentration as leachate mixes with groundwater is a reasonable measure of the degree of dilution that occurs. It can be seen that, as the leachate is mixed with sufficient groundwater to affect its chemical properties, trends in pH and mercury concentration begin to diverge from the trend in chloride concentration. This suggests attenuation by the reaction mechanisms previously discussed, in addition to dilution.

In general, samples with a ratio of divalent:monovalent cations below 0.07 (eq:eq) were considered unattenuated leachate, as this is the approximate point of divergence between trends in pH and chloride. Samples with a ratio of divalent:monovalent cations between 0.07 and 2.0 were considered a mixture of leachate and groundwater. Samples with a ratio of >2.0 were considered unimpacted groundwater, as this is the point where the pH trend flattens.

Stiff diagrams for groundwater samples collected in the development are in Appendix 6-1. The diagrams are color-coded, with yellow denoting leachate, green denoting a mixture of leachate and groundwater, and blue denoting groundwater. The color codes (i.e., yellow, green, and blue) are also presented on the water quality cross sections, along with a summary of the monitoring well pH and mercury data. Figures 6-5a, 6-5b, 6-5c, and 6-5d show data from the West CKD Area, Figure 6-6a, 6-6b, 6-6c, 6-6d, 6-6e, 6-6f, 6-6g and 6-6h show data from the Seep 2 CKD Area, and Figures 6-7a, 6-7b, 6-7c, 6-7d, and 6-7e present the data from the Seep 1 CKD Area.

7.0 Contaminant Fate and Transport

7.1 Potential Site COCs

The following criteria were exceeded by potential Site COCs in groundwater, surface water, and/or unconsolidated materials (including non-CKD and CKD). The locations of the exceedances in groundwater monitoring well samples are shown on Figures 5-1a to 5-1c through Figures 5-18a to 5-18c. The "a" figures show the data from the West CKD Area, the "b" figures show the data from the Seep 2 CKD Area, and the "c" figures show the data from the Seep 1 CKD Area.

Groundwater (monitoring well samples):

Residential Drinking Water Criteria	chloride, sum of potential nitrogen sources, ammonia nitrogen as N, TDS, sulfate, pH, aluminum, arsenic, barium, beryllium, chromium, iron, lead, magnesium, manganese, mercury, nickel, selenium, sodium, thallium, vanadium, bis(2-ethylhexyl)phthalate
Groundwater Surface Water Interface Criteria	chloride, % ammonia that will become NH_3 in surface water, TDS, pH, antimony, arsenic, chromium, copper, lead, mercury, nickel, selenium, silver, vanadium, zinc

Unconsolidated Materials (non-CKD and CKD):

Drinking Water Protection Criteria	sum of potential nitrogen sources, total phosphorus, sulfate, aluminum, arsenic, chromium, iron, lead, magnesium, manganese, sodium, thallium
Groundwater Surface Water Interface Protection Criteria	chromium, selenium, manganese
Direct Contact Criteria	chloride, arsenic

Surface Water:

Surface Water Human Non-Cancer Drinking and Non-Drinking Water Criteria	antimony, mercury, lead, arsenic
Final Chronic and Acute, Aquatic Maximum and Wildlife Values	copper, mercury, lead, nickel, selenium, silver, vanadium, zinc
MI Part 4 Water Quality Standards – Rules 50, 51, 53, and 60	chloride, pH, TDS

The following narrative is based on the groundwater monitoring well, unconsolidated material sampling results, and surface water analytical data. This section outlines the prevalence of potential

COCs, their characteristics, distribution at the Site, and the potential attenuation processes which will control their concentrations along a groundwater flow path.

Chloride

Unconsolidated material analytical samples collected from Site boreholes have chloride concentrations exceeding Direct Contact criteria. CKD samples typically have chloride concentrations equal to or somewhat greater than non-CKD samples.

Groundwater chloride concentrations exceeding criteria at the Site are shown on Figures 5-1a, 5-1b, and 5-1c. Monitoring wells within the CKD limits show increased chloride concentrations compared to upgradient wells. Downgradient monitoring wells show chloride exceedances and a decrease in chloride concentrations in deeper wells.

Lake Michigan surface water samples show a reduction in chloride concentrations compared to groundwater within the CKD area and are similar to chloride concentrations within upgradient monitoring wells. Three of the 18 surface water samples collected from West Unnamed Creek and three of the 12 surface water samples collected from East Unnamed Creek #1 have chloride concentrations that exceed criteria; however, these samples' chloride concentrations are similar to chloride concentrations within upgradient monitoring wells.

Chloride is generally considered a conservative parameter that will only be attenuated during dilution. Evidence of dilution at the Site is apparent in the reduction of chloride concentrations in surface water compared to chloride concentrations in groundwater within the CKD limits. Additionally, dilution of chloride is evident in the reduction of chloride concentrations in deep monitoring wells compared to shallow monitoring wells.

Sum of potential nitrogen sources and nitrogen-nitrate

Unconsolidated material analytical samples collected from the Site exceeded DW Protection criteria for the sum of potential nitrogen sources. In general, the non-CKD samples contained higher concentrations of nitrogen than CKD. No unconsolidated samples exceeded criteria for nitrogen-nitrate. Groundwater samples collected from 15 Site monitoring well nests exceeded DW criteria for potential nitrogen sources. The criterion for nitrogen-nitrate was not exceeded.

Site data indicate that nitrogen sources are not prevalent at the Site, impacts generally are at depth, and Little Traverse Bay is not being impacted by the Site.

Ammonia that will become NH_3 in surface water and Ammonia

No unconsolidated material samples from the Site exceeded criteria for ammonia as nitrogen or for percent ammonia that will become NH_3 in surface water.

Groundwater ammonia concentrations exceeding criteria at the Site are shown on Figures 5-2a, 5-2b, and 5-2c. Groundwater samples collected from 11 Site monitoring well nests exceeded GSI criteria for percent ammonia that will become NH_3 in surface water. Only eight monitoring well nests exceeded DW criteria for ammonia as nitrogen. Site surface water samples show NH_3 concentrations less than groundwater NH_3 concentrations, showing evidence of attenuation.

Total Dissolved Solids (TDS)

Groundwater TDS concentrations exceeding criteria at the Site are shown on Figures 5-3a, 5-3b, and 5-3c. Many of the Site monitoring wells exceeded GSI and the aesthetic DW criteria for total dissolved solids (TDS). Monitoring wells located within the CKD pile limits show increased TDS concentrations compared to upgradient wells. Downgradient monitoring wells show TDS exceedances with some evidence of decreased concentrations in deeper wells.

Most Lake Michigan samples show a reduction in TDS concentrations compared to groundwater within the CKD pile limits. Additionally, lake surface water TDS concentrations are similar to or below TDS concentrations within monitoring wells located upgradient of the CKD pile limits. Three creek surface water samples show exceedances of TDS; however, these concentrations are similar to TDS concentrations within upgradient monitoring wells.

TDS is an operationally defined parameter that includes a variety of dissolved cations and anions. TDS can be attenuated by dilution, and its constituents can be attenuated by a variety of means (adsorption, etc.). Evidence of dilution at the Site is apparent in the reduction of TDS concentrations in surface water compared to concentrations in groundwater from within the CKD pile limits. Additionally, dilution of TDS is evident in the reduction of TDS concentrations in deep monitoring wells compared to shallow monitoring wells.

Sulfate

Seven CKD and two non-CKD unconsolidated samples collected at Site boreholes exceeded the DW Protection criteria for sulfate. These samples represent less than 8% of the total samples.

Groundwater sulfate concentrations exceeding criteria at the Site are shown on Figures 5-4a, 5-4b, and 5-4c. Sulfate concentrations in monitoring wells located within the CKD limits generally exceed DW criteria. Sulfate concentrations in monitoring wells located downgradient of the CKD limits also exceed DW criteria; however, downgradient monitoring wells show an overall reduction of sulfate concentrations with depth. No surface water samples exceed criteria for sulfate. This includes both creek samples and Lake Michigan surface water samples.

Sulfate concentrations exceed criteria within the CKD limits. Sulfate is an anion that is not attenuated significantly in groundwater; however, the lack of exceedances within surface water samples and the reduction of groundwater concentrations with depth show that sulfate is subject to dilution.

pH

Laboratory pH results of groundwater samples are typically not representative of actual groundwater quality due to attenuation during sample hold times; therefore, field measurements are used to assess groundwater pH. Some monitoring well pH measurements less than 6.5 were recorded during the Site investigation. Although these pH measurements are below the lower limits of DW and GSI criteria their occurrences are naturally occurring, likely due to the degradation of organic material under anaerobic conditions, and not associated with Site CKD impacts; therefore, pH measurements of below 6.5 are not included in this discussion.

Groundwater pH concentrations exceeding criteria at the Site are shown on Figures 5-5a, 5-5b, and 5-5c. Generally, the shallowest wells located within the CKD pile limits had pH measurements in exceedance of DW criteria and, generally, the shallowest wells downgradient of the CKD piles also had pH measurements that exceed criteria.

Overall, groundwater shows a reduction of pH with depth in downgradient monitoring wells as evident on the geologic cross section figures with water quality data (Figures 6-5a to 6-5d through Figures 6-7a to 6-7e). This reduction of pH with depth is evidence that leachate is subject to dilution. Additionally, reduction of pH with depth in downgradient monitoring wells suggests that deep leachate from within the CKD pile limits is influenced by an upward hydraulic gradient.

Surface water monitoring conducted at the West Unnamed Creek and East Unnamed Creek #1 has shown no exceedances of pH. As discussed in Section 2.2.6, effectiveness monitoring has been

conducted at the Site to assess the effectiveness of the ILRS. Collected data demonstrate that the existing ILRS is very effective at controlling pH in Lake Michigan.

Phosphorus

Only one single CKD sample from the Site exceeded DW Protection criteria for total phosphorus. No groundwater samples exceeded criteria for this parameter. No Lake Michigan surface water or creek samples from the Site exceeded criteria for total phosphorous.

In the environment, phosphorous exists as the weak acid anion phosphate. Phosphate is an essential nutrient that is often the limiting nutrient for algal growth in lakes. Phosphate has been shown to be attenuated by adsorption. Additionally, it is likely that phosphorous within Site groundwater is subject to dilution. Evidence of this is apparent in that no exceedances of total phosphorous exist within surface water samples.

Aluminum

The majority of the CKD samples and one of the non-CKD samples from the Site exceeded the DW Protection criteria for aluminum.

Groundwater aluminum concentrations exceeding criteria at the Site are shown on Figures 5-7a, 5-7b, and 5-7c. The majority of the groundwater samples collected at the Site exceeded the DW criteria for aluminum, including those collected from the upgradient monitoring well nests.

Aluminum did not exceed Michigan Part 201 Generic Cleanup Criteria surface water quality standards in surface water samples collected at the Site.

Aluminum is the most common metal in the earth's crust, comprising about 8% of it (U.S.EPA 2003). Aluminum is also found in CKD, commonly comprising 4.5% by weight as Al_2O_3 (Section 6.1). Aluminum may complex with hydroxides at high pH. At neutral pH aluminum concentrations in solution are often limited by the precipitation of aluminum hydroxide. The ubiquitous nature of the aluminum combined with the elevated concentration in some areas suggests that aluminum is both naturally occurring and associated with the CKD. Although relatively high concentrations of aluminum are found in the CKD piles, lower concentrations are found in groundwater, and no exceedances were found in surface water.

Antimony

Unconsolidated material analytical samples collected from the Site did not exceed criteria for antimony (Tables 5-4a to 5-4c).

Groundwater analytical data are summarized in Tables 5-6a to 5-6c. One Seep 2 CKD Area monitoring well contained antimony concentrations above GSI criteria. The deeper wells within this well nest have lower antimony concentrations and do not exceed criteria.

Fourteen Lake Michigan surface water samples from the Site contained antimony concentrations exceeding Human Non-Cancer Drinking Water criteria as shown in Tables 5-1a to 5-1c. In addition, one upgradient creek sample from East un-named creek #1 contained antimony concentrations exceeding the Human Non-Cancer Drinking Water criteria (Table 5-3).

The absence of exceedances within the unconsolidated material samples and the sporadic and inconsistent exceedances in the water samples suggest that antimony is not associated with the CKD and is not a COC.

Arsenic

Unconsolidated material analytical sample data are summarized in Tables 5-4a to 5-4c. CKD samples collected from each of the CKD Areas have arsenic concentrations that exceed DW Protection criteria. Samples of the CKD from the Seep 2 and Seep 1 CKD Areas also contained arsenic concentrations that exceeded the Direct Contact criterion.

Groundwater analytical data are summarized in Tables 5-6a to 5-6c. Groundwater arsenic concentrations that exceed criteria are shown on Figures 5-8a to 5-8c. One well nest (B3014) in the northeast portion of the West CKD Area contains arsenic concentrations above DW criteria in the two shallowest wells. The deeper wells within this well nest did not exceed criteria. The well nest downgradient (B3019) of the B3014 nest contains arsenic concentrations above DW and GSI criteria. Seep 2 CKD Area and Seep 1 CKD Area monitoring wells within the CKD limits contain arsenic concentrations above DW criteria. Two samples in the Seep 1 CKD area (W1134 and W1234) exceed GSI criteria. Some downgradient monitoring wells show arsenic exceedances in the shallow wells. The deep downgradient wells have decreased arsenic concentrations and do not exceed criteria.

There were no exceedances of arsenic concentrations in the surface water samples collected at the Site (Tables 5-1a to 5-1c and 5-3).

Arsenic can exist in both the arsenate and arsenite forms in the environment and is attenuated through adsorption.

Barium, Beryllium, Cadmium, Thallium

Unconsolidated material analytical samples collected from boreholes at the Site did not have barium, beryllium, or cadmium concentrations in exceedance of criteria. Five unconsolidated material analytical samples collected at the Site exceeded the DW Protection criteria for thallium (Tables 5-4a to 5-4c).

Groundwater barium concentrations exceeded DW Criteria only at well W1127. Groundwater beryllium and thallium concentrations exceeded DW Criteria at wells W1127 and W1225. These wells are located at the southern edge of the Seep 1 CKD Area extent. No other exceedances of barium, beryllium, cadmium, or thallium concentrations occurred downgradient of these locations or elsewhere at the Site (Tables 5-6a to 5-6c). There is evidence that solids were in the total metals samples collected at W1127 and W1225. The stiff diagram (Appendix 6-1) shows an inordinate amount of calcium in the total metals sample, with no anions to balance it on the other side. This suggests that solids in the sample, when exposed to the nitric acid preservative, dissolved and liberated normally insoluble metals into the liquid phase, resulting in detections that were biased high. Because the general chemistry sample was unpreserved, the companion anions for these metals were not detected. The solids were flushed from the well in time and later samples were more consistent with surrounding wells.

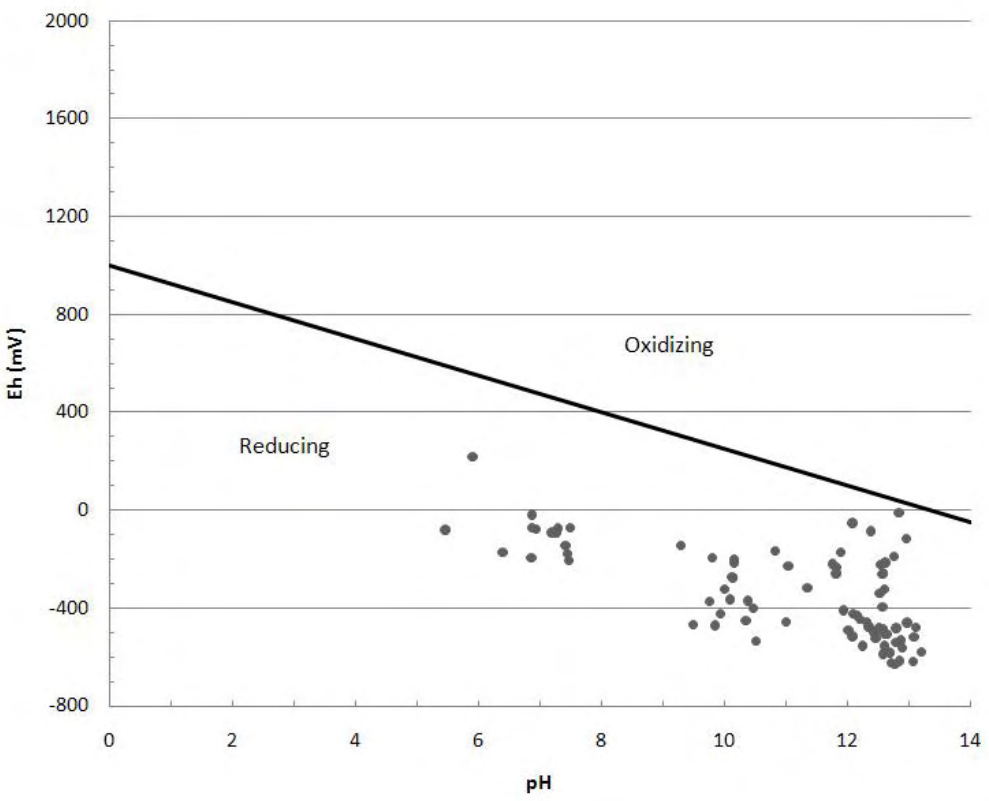
Surface water samples collected throughout the Site did not have barium, beryllium, cadmium, or thallium concentrations in exceedance of criteria as shown in Tables 5-1a to 5-1c and 5-3.

The only exceedances for these metals are due to samples that contained solids. Therefore, barium, beryllium, cadmium, and thallium are not COCs.

Chromium

Since chromium speciation was not performed for these samples, the analytical results were compared to chromium VI criteria. This is a very conservative approach as chromium VI is generally not expected to be present at the redox conditions found at the Site. Field redox measurements taken at the Site indicate a strongly reduced environment in the subsurface. The inserted chart is a plot of Eh (mV) and pH for all groundwater samples collected at the Site for which there is also chromium data. The solid line delineates oxidizing and reducing conditions as per Kostecki, Paul T. Chromium

in Soil - Perspectives in Chemistry, Health, and Environmental Regulation (Journal of Soil Contamination,). CRC, 1998. – add to references



Therefore, any chromium detected in Site samples is expected to be in the reduced chromium III form, rather than the oxidized chromium VI form.

Nineteen of the unconsolidated material analytical samples collected at the Site contained total chromium concentrations that exceeded the GSI Protection criteria for chromium VI. Two samples contained total chromium concentrations that exceeded the DW Protection criteria for chromium VI. The majority of the samples classified as CKD show increased total chromium concentrations compared to the non-CKD samples.

Groundwater total chromium concentrations that exceed criteria for chromium VI are shown on Figures 5-9a to 5-9c. Chromium concentrations generally decrease in deeper wells.

Chromium was not detected in any of the surface water samples collected at the Site and therefore did not exceed Michigan Part 201 Surface Water Criteria as shown in Tables 5-1a to 5-1c, and 5-3.

It is highly unlikely that chromium VI is present at the Site at concentrations that exceed criteria due to the redox conditions at the Site. Therefore, chromium is not a COC.

Copper

Unconsolidated material analytical samples collected from the Site boreholes did not exceed the Michigan Part 201 Soil Residential/Commercial I Criteria for copper (Tables 5-4a to 5-4c). Groundwater copper concentrations exceeding criteria in samples collected at the Site are summarized in Tables 5-6a to 5-6c. Beach monitoring wells at each of the areas contain copper concentrations above GSI criteria. There were no exceedances of copper in the surface water samples collected at the West CKD Area and Seep 1 CKD Area (Tables 5-1a and 5-1c). Four surface water samples in the Pine Court Seep area had copper concentrations exceeding the Final Chronic Value criteria. Two of these samples also had copper exceedances for the Aquatic Maximum Value criteria (Table 5-1b).

Iron

One non-CKD analytical sample collected from the West CKD Area and one non-CKD sample from the Seep 1 CKD Area contained iron concentrations that exceeded the DW Protection criteria (Table 5-4a and 5-4c). Groundwater iron concentrations that exceed criteria are shown on Figures 5-10a to 5-10c. Groundwater samples collected from most of the Site wells, including upgradient wells, contained iron concentrations that exceeded the aesthetic DW criteria.

Surface water samples collected at the Site did not exceed criteria for iron (Tables 5-1a to 5-1c and 5-3).

Iron is naturally occurring at the Site. In the environment iron typically exists in either the Fe^{2+} or Fe^{3+} oxidation state depending on the redox conditions. Fe^{3+} will precipitate as iron hydroxide at near neutral pH. Iron will also be attenuated through adsorption.

Lead

Unconsolidated material analytical samples collected from boreholes in the central and eastern portions of the West CKD Area had lead concentrations that exceeded the DW Protection criteria (Table 5-4a). The sample in the central portion of the CKD pile was classified as CKD, while the sample in the eastern portion of the CKD pile was non-CKD. Unconsolidated samples collected from Seep 2 CKD Area boreholes did not exceed criteria (Table 5-4b). One CKD sample collected from

the center of the Seep 1 CKD Area had lead concentrations that exceeded DW Protection criteria (Table 5-4c).

Groundwater lead concentrations that exceed criteria are shown on Figures 5-11a to 5-11c. Lead concentrations exceeded DW and GSI criteria in the West CKD Area and DW criteria at the Seep 2 and Seep 1 CKD Areas.

Surface water samples collected at the Site did not exceed criteria (Table 5-1a to 5-1c and 5-3).

Lead is a cation that is readily attenuated through adsorption.

Magnesium

Unconsolidated material analytical samples collected throughout the Site exceeded DW Protection criteria (Tables 5-4a to 5-4c). In general, the samples classified as CKD did not differ significantly in magnesium concentrations compared to the samples classified as non-CKD.

Groundwater samples collected at the West CKD Area and Seep 2 CKD Area did not exceed criteria for magnesium (Table 5-6a and 5-6b). The sample collected from monitoring well W1225 on August 9, 2006 in the Seep 1 CKD Area exceeded the DW criteria for magnesium (Table 5-6c). As discussed previously, solids in this well likely produced anomalous data. Subsequent samples, after the solids were flushed from the well, are similar to surrounding wells.

Surface water samples collected at the Site did not exceed criteria (Table 5-1a to 5-1c and 5-3).

Even though magnesium is present in the unconsolidated materials at the Site, it is not leaching to the groundwater and/or surface water; therefore, magnesium is not a COC.

Manganese

Unconsolidated material analytical samples collected from the Seep 2 CKD Area did not exceed criteria for manganese (Table 5-4b). One non-CKD sample collected from the West CKD Area exceeded the DW Protection criteria for manganese (Table 5-4a). Two non-CKD samples collected outside of the CKD limits at the Seep 1 CKD Area exceeded the DW Protection criteria for manganese (Table 5-4c).

Groundwater manganese concentrations that exceed criteria are shown on Figures 5-12a to 5-12c. These data are also summarized in Tables 5-6a to 5-6c. Monitoring wells across the Site, including upgradient wells, exceed the DW criteria for manganese.

Surface water samples collected at the Site did not exceed criteria for manganese (Table 5-1a to 5-1c and 5-3).

Mercury

Mercury did not exceed criteria in unconsolidated material samples collected at the Site.

Groundwater mercury concentrations that exceed criteria are shown on Figures 5-13a to 5-13c. Samples collected from beach monitoring wells exceeded the GSI criteria in some locations. It was noted that several of the upgradient monitoring wells also contained mercury at concentrations greater than the GSI criteria. Two groundwater samples collected from within the CKD limits exceeded the DW criteria for mercury. Generally, the mercury concentrations are highest in or immediately below the CKD and the concentrations decrease towards Little Traverse Bay, indicating mercury attenuation.

Surface water samples collected from Little Traverse Bay and the creeks at the Site exceeded generic surface water criteria for mercury. Mercury concentrations in Little Traverse Bay were often higher than those in the creeks, but lower than in groundwater. Mercury concentrations in the creeks were consistent between the creeks and in the upstream, middle, and downstream sampling locations indicated that the source of mercury in the creeks is likely upgradient of the Site. Since other parameters do not indicate that water in the creeks is impacted by CKD, the source of mercury in samples collected from the creeks is likely from non-CKD sources.

Given the oxidative conditions that the CKD was produced under and the elevated pH, it is unlikely that the mercury is present in the reduced metallic (Hg^0) mercury form. The fact that the mercury is likely in an inorganic form is significant to its attenuation. As discussed in Section 6.2.1.2 mercury concentrations are correlated with organic content of groundwater.

Nickel

Unconsolidated material analytical samples collected at the Site did not exceed criteria (Table 5-4a to 5-4c) for nickel.

Groundwater nickel concentrations that exceed criteria are shown on Figures 5-14a to 5-14c. Groundwater nickel concentrations at each of the areas exceed DW and GSI criteria.

One surface water sample collected near Pine Court Seep area exceeded the Final Chronic Value criteria for nickel (Table 5-1b). No other samples exceeded surface water criteria for nickel.

Selenium

One CKD sample collected from the Site contained selenium at a concentration that exceeded the GSI protection criteria (Tables 5-4a to 5-4c).

Groundwater selenium concentrations that exceed criteria are shown on Figures 5-15a to 5-15c. Groundwater data are summarized in Tables 5-6a to 5-6c. Groundwater selenium concentrations at each of the areas exceed DW and GSI criteria.

One surface water sample collected at the Seep 2 CKD Area exceeded the Final Chronic Value criteria for selenium (Table 5-1b). No other surface water samples had selenium concentrations in exceedance of criteria (Table 5-1a, Table 5-1c, Table 5-3).

Silver

Unconsolidated material analytical samples collected from Site boreholes did not exceed criteria for silver (Tables 5-4a to 5-4c).

Groundwater silver concentrations that exceed criteria are shown on Figures 5-16a to 5-16c. Groundwater data are summarized in Tables 5-6a to 5-6c. Groundwater samples collected at each of the areas exceed the GSI criterion for silver.

Surface water samples collected from the West CKD Area and Seep 2 CKD Area had no silver concentrations that exceeded criteria (Tables 5-1a and 5-1b). Two surface water samples collected at the Seep 1 CKD Area had silver concentrations in exceedance of Final Chronic Value criteria (Table 5-1c). These two samples were collected in September 2005, prior to the drain line installation on October 10, 2005. Subsequent samples at these locations did not have silver concentrations in exceedance of surface water criteria.

Sodium

Two unconsolidated material analytical samples collected from the Seep 2 CKD Area boreholes exceeded the DW Protection criteria for sodium (Table 5-4b). One sample collected at the West CKD

Area exceeded the DW Protection criteria. No other samples exceeded criteria (Tables 5-4a and 5-4c).

Groundwater sodium concentrations that exceed criteria are shown on Figures 5-17a to 5-17c. Groundwater data are summarized in Tables 5-6a to 5-6c. Sodium concentrations exceed DW criteria at each area within the Site.

Surface water samples collected at the Site did not exceed criteria (Table 5-1a to 5-1c and 5-3).

Vanadium

Unconsolidated material analytical samples collected from Site boreholes did not exceed criteria for vanadium (Tables 5-4a to 5-4c).

Groundwater vanadium concentrations that exceed criteria are shown on Figures 5-18a to 5-18c. At all areas, groundwater vanadium concentrations exceeded DW criteria within the CKD extent and downgradient of the CKD piles. Vanadium exceeded the GSI criteria in beach wells at each of the areas. Vanadium concentrations were found to generally decrease in deeper wells.

Two surface water samples collected in the Seep 2 CKD Area and one from the Seep 1 CKD Area contained vanadium concentrations that exceeded the Final Chronic Value criteria (Table 5-1b and 5-1c).

Zinc

Unconsolidated material analytical samples collected from Site boreholes did not exceed criteria for zinc (Tables 5-4a to 5-4c).

Only two beach wells exceeded the GSI criteria for zinc (Table 5-6a and 5-6b). As discussed previously, there is evidence that solids in these wells caused erroneous data for the initial samples from these wells.

One surface water sample collected from the Seep 2 CKD Area exceeded the Final Chronic Value criteria for zinc (Table 5-1b). No other surface water samples collected at the Site exceeded criteria for zinc (Table 5-1a, Table 5-1c, Table 5-3).

VOCs and SVOCs

There were no exceedances of criteria for VOCs at the Site. The only exceedances of SVOCs at the Site were at the Seep 2 CKD Area and Seep 1 CKD Area. The bis(2-ethylhexyl)phthalate concentrations measured at W2227, W1225, and W1127 sporadically exceeded the DW criteria as shown in Tables 5-6b and 5-6c. Bis (2-ethylhexyl)phthalate is a common laboratory contaminant. These sporadic and isolated exceedances indicate the bis(2-ethylhexyl)phthalate is not a COC.

7.2 Potential Routes of Migration

Potential COCs may be released from the CKD piles through leaching by infiltration or groundwater, or from a breach of cover soils. The COCs can move along potential exposure pathways with groundwater (i.e., water in the saturated zone); leachate (water reaching the surface through the unsaturated zone); or as particulates carried along as a solid (as in a slope failure), as suspended sediment in runoff, or as an airborne particulate. These pathways can then manifest themselves in a variety of migration routes that eventually reach potential receptors.

7.2.1 Air

None of the COCs would develop significant emissions due to volatilization, and the CKD piles at the Site are currently covered by a MDEQ approved soil cover, which limits the potential for airborne suspension of particulates. Based on this information, air is not considered a significant route of migration for the COCs at the Site under current conditions. CMS acknowledges that if the CKD is exposed by erosion or weathering, air could become a relevant pathway. However, inspection of the Site did not reveal exposed CKD at the Site suggesting that the soil barrier placed over the CKD during golf course development is effectively mitigating this potential route of migration.

7.2.2 Surface Water

Because groundwater impacted by potential Site COCs flows from the Site to Little Traverse Bay, the surface water receiving the potential Site COCs could potentially be a migration pathway. However, analytical data collected adjacent to the Site indicate that potential Site COCs have been greatly attenuated between the source material (CKD) and Little Traverse Bay indicating that the surface water has not been and is not currently a source of significant exposure to potential COCs other than pH. The ILRS installed as part of the removal action at the Site collects leachate prior to discharge to Little Traverse Bay. The ILRS is very effective at controlling the pH at the beach and in Little Traverse Bay.

Monitoring and analytical data collected in East-unnamed creek #1 and West-unnamed creek show that the creeks have not been impacted by the Site. Therefore, the creeks are not migration pathways.

7.2.3 Unconsolidated Material (Non-CKD and CKD)

Unconsolidated materials containing CKD at the Site are covered by a MDEQ approved soil barrier. Inspection of the cover has not revealed breaches of the cover due to erosion or slope failure. Therefore, there is no reason to believe that particulates carried along as solids, suspended sediment in runoff, or airborne particulates are applicable routes of migration. All potential final remedies will include maintaining existing cover to minimize contact with the CKD and to ensure that slope failure or erosion of the CKD is not a migration route in the future.

7.2.4 Groundwater/Leachate

The presence of COCs in groundwater samples in excess of Part 201 criteria was used as an indicator that the COC could potentially migrate in the groundwater. The impacts of the various mechanisms of attenuation need to be considered in evaluating which parameters pose a risk and the magnitude of the risk.

7.3 Contaminant Persistence

All of the potential Site COCs identified are inorganic and are not subject to biodegradation with the possible exception of ammonia. Many of the COCs are subject to changes in oxidative states or may react in precipitation or adsorption reactions.

As shown on Figure 6-3, Site samples fall into a wide-ranging continuum with respect to the ratio of divalent:monovalent cations (Ca+Mg : Na+K). As expected, pH is attenuated as the ratio of divalent:monovalent cations increases, due to dilution, precipitation of carbonate alkalinity, and neutralization with groundwater acidity. As shown on Figure 6-4, mercury is also attenuated as the ratio of divalent:monovalent cations increases, due to dilution as well as precipitation of the mercury-bearing fatty acid surfactants.

Also included on Figures 6-3 and 6-4 is chloride concentration. The change in chloride concentration as leachate mixes with groundwater is a reasonable measure of the degree of dilution that occurs. It can be seen that, as the leachate is mixed with sufficient groundwater to affect its chemical properties, trends in pH and mercury concentration begin to diverge from the trend in chloride

concentration. This suggests attenuation by the reaction mechanisms previously discussed, in addition to dilution.

7.4 Contaminant Migration

The data gathered during the RI was sufficient to provide an understanding of groundwater flow at the Site. As discussed previously, the migration of the potential Site COCs is controlled by a number of factors. Movement (advection) of leachate/groundwater is likely the predominant migration mechanism, but will only be significant in areas of downward or lateral gradients (i.e., when the gradient is "flat", the flux of contaminants to Little Traverse Bay will be minimal). Lake Michigan is the regional groundwater discharge area for the aquifer beneath the Site.

This section discusses mechanisms for generation of CKD leachate, the flow mechanisms, and migration of the leachate to groundwater and surface water at each area of the Site.

7.4.1 Leachate Generation

Elevated pH levels in groundwater and at the beach are generally caused by leachate generated from within the CKD piles. Leachate can be generated by infiltration of rainfall/snowfall or irrigation water into the CKD piles or through contact with groundwater within the CKD piles. Groundwater that may contact the CKD could be: regional groundwater, perched groundwater, or interflow above the bedrock. These methods of generation can occur alone or in combination within a given CKD pile.

As discussed in Section 3.1.3, average annual rainfall/snowfall is 31 inches in the area of the Site (period of record 1971 to 2000). In addition to the natural rainfall, the golf course is well irrigated. An unknown amount of water is sprayed onto the golf course tee boxes, fairways, and greens in each area. Surface runoff generally drains to grated inlets located in surface depressions from maintained golf course features (tee boxes, fairways, and greens). Collected runoff is directed through flexible corrugated drain piping and plastic storm drain piping or drainage swales/creeks that ultimately discharge to Lake Michigan. The golf course areas above the CKD piles are also drained by a sand fill base.

Rainfall/snowfall or irrigation that does not runoff or evapotranspirate will infiltrate into the covered CKD pile. When infiltrated water reaches the soil/CKD boundary, a portion of it may enter the CKD

pile, or it may flow along the top of the pile as interflow, interacting with the top of the CKD pile, and generating leachate.

Seasonal rising and falling of the regional groundwater table and seasonal perched groundwater result in seasonal saturation of the CKD. Leachate is only generated when the CKD is wet. The population of the region increases during the summer tourism season in the area (Section 4.7 Demographics), and more groundwater gets pumped from the municipal wells which causes drawdown of the regional groundwater table in the vicinity of the municipal wells. This raising and lowering of the regional groundwater table can have several potential effects:

- Lowering the groundwater table can temporarily decrease the CKD/groundwater contact and reduce the leachate generated.
- Lowering the groundwater table can decrease the hydraulic gradient, slowing down the rate of groundwater/leachate travel.
- Repeated changes of hydraulic gradient can also change the direction of leachate plume migration, serving to spread out and dilute leachate plumes.
- Raising the groundwater table can temporarily increase the CKD/groundwater contact and increase the leachate generated.

Leachate may also be generated by groundwater interflow above the limestone bedrock intersecting CKD that may be resting on bedrock.

7.4.2 Flow Mechanisms

As discussed in Section 4.6, Hydrogeology, the groundwater flow system in the bedrock is predominantly through a dense fracture system. No indications of large-scale karst features were observed on or near the Site. Potential conduits were identified; however, subsequent data analysis determined that none of the potential conduits were confirmed by multiple lines of evidence. Most of the potential conduits were determined to be low-angle fractures that are inferred to represent bedding plane partings. Few, if any, of the potential conduits were extensive enough to have been encountered in multiple boreholes, particularly in the vicinity of existing and likely remedial elements. This suggests that interconnection of the water-transmitting fractures is sufficient enough that an equivalent porous medium approach is generally appropriate for the Site groundwater model.

As discussed in Section 4.6.1.6, Hydraulic Conductivity / Heterogeneity, hydraulic conductivity differences of several orders of magnitude occur in tests conducted in Site boreholes; therefore, varied groundwater flow velocities are present at the Site. For example, the bedrock is generally more permeable than the CKD so under similar hydraulic conditions it can be expected to transmit proportionately more groundwater than the CKD. This additional flow will provide dilution water for attenuation of the COCs.

Other flow/migration mechanisms are related to the high-concentration leachate formed in the CKD. The leachate can reach TDS concentrations that have higher densities than groundwater and the potential for vertically downward movement of the denser water. The density of leachate within a CKD pile at the East CKD Area portion of the LTB CKD Release Area Site was found to be 1.03, which is approximately equal to the density of sea water. This density is great enough to induce a density driven plume. However, this density-driven migration is counteracted by dilution as the density plume mixes with clean groundwater. The observed density in groundwater samples collected immediately below the CKD at the East CKD Area is only 1.01, which suggests that the total dissolved solids are rapidly diluted as they travel vertically beneath the CKD. In other words, the leachate will sink vertically for a short distance until it hits the water table where it mixes and the resulting density quickly becomes approximately 1.01 and thus loses its driving force for vertical movement. After mixing, lateral plume movement is the predominant flow.

The relatively high concentrations in the CKD piles can also create chemical gradients that will drive diffusion. The mechanism is also quickly countered by dilution. Both density-driven migration and diffusion will be countered by the vertically upward groundwater flows indicated by the upward gradients. Groundwater elevations measured in monitoring wells at the Site indicate that both upward and downward vertical hydraulic gradients are present, including in wells installed at the beach. This variation is likely due to the superposition of the affects of local infiltration, regional flow/discharge, and the temporal variations in pumping of the nearby Petoskey municipal water supply wells.

7.5 CKD Area Summary and COC Determination

7.5.1 West CKD Area

The West CKD pile is generally prism-shaped with a near-horizontal upper surface, and a lower surface that deepens northward, toward an escarpment at the beach. The surface area of the West CKD pile is approximately 5.4-acres. Approximately 1.7-acres of tee boxes and fairways are located

above the CKD extent. CKD mixed with soil was present on the West CKD Area beach, possibly as a result of West CKD pile sloughing. The mixed soil/CKD on the beach was removed in 2008/2009.

The West CKD Area can be divided into four subparts, namely, the western, central, eastern, and beach. The majority of the West CKD pile is located above the regional groundwater table. The exception is the northern toe of the central portion of the CKD pile which is seasonally saturated by the regional groundwater table.

The western portion (west of B3003) of the West CKD Area pile rests on limestone bedrock, and the central and eastern portions are on native soil above limestone bedrock. The western portion of the West CKD pile does not produce much leachate likely because less of the CKD is saturated. In addition, this area includes relatively longer migration routes, minimal irrigated areas, and steep slopes with primarily tall grass vegetation.

The leachate observed at the beach from the West CKD pile is generated in the center and eastern portions of the pile. The clay layer beneath the central portion of the CKD pile (Figure 4-16a) perches water above allowing it to contact CKD and generate leachate. This clay layer also retards downward movement of leachate deeper into the buried bedrock valley (Figure 4-5). Interflow may also be occurring along the top of the West CKD pile, producing leachate that emerges near the bottom of the escarpment where it is collected in the drain.

In addition to interflow generating leachate in the central and eastern portions of the pile, leachate migrates downward in the southeastern portion of the West CKD Area pile. The clayey soil is notably absent in the vicinity of borehole B3014 which is in this area. The monitoring well nest installed at B3014 typically contains the highest concentrations of potential COCs. This well nest is also located upgradient of the highest potential COC concentrations on the West CKD Area beach.

The marker shale is only present near the southern edge of the West CKD pile (Figure 4-8a) and is generally not considered to be a major factor in influencing the generation or flow of leachate in the West CKD Area.

Groundwater elevations in the bedrock at the West CKD Area are influenced by the pumping of the City of Petoskey wells, specifically Petoskey Well 4 and 5. Regional groundwater at the West CKD Area generally flows towards Lake Michigan; however, seasonal fluctuations within monitoring wells suggest that regional groundwater is influenced by pumping of the City of Petoskey Well 5 in particular. Evidence of this is visible in groundwater elevation trends in the monitoring well nests

installed at B3013, B3014, and B3020. These well nests, specifically in the deeper wells, show groundwater elevations that fall to near or below average lake level during the summer months corresponding to peak municipal water usage. It is important to note that seasonal groundwater fluctuations are not evident in monitoring wells W3113 and W3120; such a trend indicates that a low permeability barrier (i.e. the clay discussed previously or marker shale) restricts groundwater flow between the shallow wells and the deeper wells in these well nests..

The hydraulic gradient of the regional groundwater seasonally reverses during times of high pumping of Petoskey Well 5 (Figure 4-12a). Perched groundwater is not affected by gradient reversals. Perched water will eventually flow to the north and merge with the regional groundwater table near the base of the West CKD Area pile northern escarpment. Even though the gradient temporarily reverses during times of high groundwater usage, leachate does not impact the municipal wells. This statement is supported by the upgradient well nests installed at boreholes B3013 and B3020 for which no exceedances of pH have been observed.

The soil/CKD removed from the beach was typically saturated and was not likely affected by changes in hydraulic gradient. Leachate generation on the beach was primarily associated with surface disturbances. As discussed in Section 2.2.7.1, Effectiveness Monitoring, the observed pH in Lake Michigan prior to the West CKD Area augmentation was less than 9.0 at the West CKD Area except immediately after times of surface disturbances (e.g., cleaning/jetting vehicles on the beach).

The majority of high pH measurements from the spring 2005 and fall 2005 targeted shoreline survey are downgradient of the central and eastern portions of the West CKD pile. The highest concentrations of potential Site COCs on the beach are located in the monitoring well nest installed at B3019, further evidence that the leachate penetrates the limestone on the eastern portion for the pile. Monitoring well data from W3116 supports the conclusion that shallow interflow is generated in the central West CKD Area.

Surface runoff from the West CKD Area is collected by the under drain system and routed east, out falling to West-Unnamed Creek. Neither analyte exceedances nor occurrences of elevated pH have been observed in the creek, demonstrating that the creek is not impacted by CKD. However, at the mouth of the stream elevated pH data points were measured on occasion, which have been attributed to algae blooms from golf course fertilizer runoff.

The identified COCs for the West CKD Area are summarized in Table 7-1a (for soil) and Table 7-1b (for groundwater).

Chloride, ammonia, sulfate, pH, and TDS are general parameters that are associated with CKD, exceed generic Part 201 criteria, and have the demonstrated ability to migrate from the West CKD Area pile to a potential point of exposure. Aluminum, arsenic, copper, lead, iron, mercury, nickel, selenium, silver, and vanadium are metals that are associated with CKD, exceed generic Part 201 criteria, and have the demonstrated ability to migrate from the West CKD Area to a potential point of exposure.

7.5.2 Seep 2 CKD Area

The Seep 2 CKD Area pile is situated parallel to Lake Michigan, with its long axis having an east-west orientation (Figure 3-1b). The surface area of the Seep 2 CKD Area pile is approximately 34.8 acres. Approximately 8.9-acres of tee boxes, fairways, and greens are located within the CKD extent.

The entire Seep 2 CKD Area is underlain by limestone, with a “marker” shale layer approximately 30 feet beneath the limestone surface. The marker shale extent is shown on Figure 4-8b. The shale layer has an asymmetric anticline shape with an east-west trending fold axis, and acts as a leaky aquitard. The shale generally dips to the south under the western side of the pile and to the north under the eastern side of the pile. All of the CKD at the Seep 2 CKD Area lies above the regional groundwater table.

Regional groundwater flow is seasonally variable due to the City of Petoskey groundwater pumping. Groundwater generally flows north in this area; however, the hydraulic gradient seasonally reverses during times of high usage (e.g., on Figure 4-12b). Even though the gradient temporarily reverses during times of high usage, leachate does not impact the municipal wells. This statement is supported by the upgradient well nests installed at boreholes B2042, B2044, and B2093 for which no exceedances of pH have been observed.

Leachate has historically been observed at three beach locations within the Seep 2 CKD Area: the original Seep 2 location north of the east side of the CKD pile, Guard Rail Seep area, and the Pine Court Seep area. The Edge Drain and the ILRS installed in the Guard Rail Seep area and original Seep 2 location have been proven to be effective at controlling pH in Lake Michigan.

The primary mechanism for leachate production at the Seep 2 CKD Area (including the Guard Rail Seep area) is perched groundwater interacting with the CKD pile with subsequent leachate migration northward to the beach. Leachate at the Seep 2 CKD Area typically follows an indirect path on its way north. The geometry of the marker shale has a direct impact on leachate movement. For example, the shale retains leachate in a bowled structure in the vicinity of borehole B2063. The shale is not a perfect aquitard as evidenced by leachate observed below the shale at W2522 and W2325. It is also likely that lesser amounts of leachate are produced by interflow occurring along the top of the CKD pile, producing leachate that emerges near the bottom of the escarpment.

The mechanisms of leachate generation at Pine Court are a combination of interflow occurring along the top of the CKD pile, and along the limestone surface (where CKD rests on the limestone), and saturation of CKD via perched groundwater. The leachate generated by perched groundwater is generated continuously in the vicinity of borehole B2025 and intermittently elsewhere across the western portion of the Seep 2 CKD pile. The northern edge marker shale layer rises in elevation in the western portion of the Seep 2 CKD Area and perches groundwater until it flows off the northern edge. The geometry of the marker shale drives groundwater toward the Pine Court area. Once the leachate flows off the northern edge of the shale, it mixes with the regional groundwater and flows toward the beach seasonally. At the Pine Court Seep area, pH levels at the beach generally range from <9.0 to 10, indicating that leachate produced within the nearby CKD pile is diluted by groundwater to a significant degree.

Perched groundwater is not affected by gradient reversals. Perched water will eventually flow to the north and merge with the regional groundwater table. An additional factor in regional groundwater flow is the influence of an upward hydraulic gradient. Groundwater contours on Figures 4-17a to 4-17c and Figures 4-20a to 4-20c show that deep regional groundwater migrating towards Lake Michigan has an upward trend and releases within close proximity of the beach. The lack of pH exceedances in deep monitoring wells located adjacent to the Lake Michigan shoreline (e.g., W2335 and W2354) show additional evidence of an upward gradient.

Surface runoff collected from the Seep 2 CKD Area is routed south then northwest around the Seep 2 CKD pile, directly north of the pile, or east into the Seep 1 CKD Area. Surface runoff routed around the west side of the pile outfalls into a drainage swale on the south side of Coastal Drive upgradient from the Pine Court lift station. Surface runoff routed north of the pile discharges into a drainage swale on the south side of Coastal Drive west of the Guard Rail Seep area or sheet flows off the

northern slope of the pile and into roadside drainage swales. A small portion of the eastern Seep 2 CKD Area is routed east across Coastal Drive into the Seep 1 CKD Area collection drain network.

The identified COCs for the Seep 2 CKD Area are summarized in Table 7-2a (for soil) and Table 7-2b (for groundwater).

Chloride, ammonia, sulfate, pH, and TDS are general parameters that are associated with CKD, exceed generic Part 201 criteria, and have the demonstrated ability to migrate from the Seep 2 CKD Area pile to a potential point of exposure. Aluminum, copper, iron, mercury, nickel, selenium, silver, and vanadium are metals that are associated with CKD, exceed generic Part 201 criteria, and have the demonstrated ability to migrate from the Seep 2 CKD Area to a potential point of exposure.

7.5.3 Seep 1 CKD Area

The Seep 1 CKD Area consists of one CKD pile situated parallel to Little Traverse Bay, with its long axis having an east-west orientation (Figure 3-1c). The surface area of the Seep 1 CKD pile is approximately 15.5-acres. Approximately 2.68-acres of tee boxes, fairways, and greens are located within the CKD extent.

The western and central portion of the Seep 1 CKD pile lies on limestone bedrock at its southern half, and soil at its northern half. The eastern side of the pile lies on soil above limestone bedrock. The western side of the Seep 1 CKD pile is thicker than the eastern side. Two bedrock depressions at the center of the pile near boreholes B1022 and B1023 contain CKD saturated by the regional groundwater table (Figure 4-11h). As shown on Figure 4-8c, except at the western end of the pile, the marker shale is largely absent in the Seep 1 CKD Area. Hence, the shale is not a significant factor in leachate flow. Although the shale at the western end of the pile may potentially perch groundwater up into the overlying CKD, it likely acts as a leaky aquitard, as evidenced by leachate concentrations measured in groundwater samples collected beneath the shale (Figure 6-7a).

The Seep 1 CKD Area groundwater table shows only minor seasonal variation; however, a groundwater divide is evident on the south side of the Seep 1 CKD Area outside of the CKD limits (Figures 4-12c through 4-15c). The groundwater divide is due to pumping of Petoskey City Wells 3 and 5 located to the south and southwest of the Seep 1 CKD Area, respectively. Leachate generated within the Seep 1 CKD pile does not migrate towards the municipal wells. This statement is supported by the upgradient well nests installed at boreholes B1025, B1027, B1030, and B1033 for which no exceedances of pH have been observed.

The primary mechanisms for leachate production at the Seep 1 CKD Area are: CKD saturated by the regional groundwater table and interflow. Site data show that regional groundwater contacts the CKD pile in an isolated area near boreholes B1022 and B1023. This isolated area represents less than an estimated 1% of the Seep 1 CKD (Figure 4-11h). This small area of saturated CKD is located upgradient of a channelized section of the beach with approximately six feet of silt, sand, and gravel filling the bedrock channel (Figure 4-7). This bedrock channel is located between boreholes B1034 and B1031. The location of the saturated CKD coupled with the unconsolidated silt, sand, and, gravel overlying the bedrock supports the conclusion that a preferential flow path for leachate exists within this portion of the Seep 1 CKD Area.

In addition to the contribution from saturated CKD, leachate is also generated by interflow along the top of the CKD pile or by interflow on top of the limestone bedrock where CKD is in contact with the bedrock. The significance of interflow at the Seep 1 CKD Area is evidenced by the “road seep” discussed in Section 2.1.5 and the shallow nature of the initial Seep 1 shoreline impacts.

Shallow leachate migrates towards Little Traverse Bay through the CKD pile and underlying soil as evident in pH exceedances in shallow monitoring wells (e.g., W1117 and W1118). Shallow leachate also migrates downward through the CKD and underlying soil to the regional groundwater table as evident in pH exceedances in deep monitoring wells (e.g., W1417 and W1418). Monitoring well data show that regional groundwater within the Seep 1 CKD Area is under the influence of an upward hydraulic gradient. Groundwater contours on Figures 4-21a and 4-21b show that deep regional groundwater migrating towards Lake Michigan has an upward trend and releases within close proximity of the shoreline. Additionally, groundwater pH exceedances are not evident in deep monitoring wells located adjacent to the Lake Michigan shoreline (e.g., W1332 and W1414). These trends indicate that leachate produced in the Seep 1 CKD Area does infiltrate deep regional groundwater, but is contained and diluted by the regional groundwater via the upward vertical hydraulic gradient.

Surface runoff collected from this area is generally routed east and outfalls into the East-Unnamed Creek #1. As discussed in Section 3.1.4.5, based on the results of the Bay Harbor Lake assessment, there are no signs that CKD or CKD leachate is present in or is currently impacting Bay Harbor Lake.

The identified COCs for the Seep 1 CKD Area are summarized in Table 7-3a (for soil) and Table 7-3b (for groundwater).

Chloride, ammonia, sulfate, pH, and TDS are general parameters that are associated with CKD, exceed generic Part 201 criteria, and have the demonstrated ability to migrate from the Seep 1 CKD Area pile to a potential point of exposure. Aluminum, arsenic, copper, iron, mercury, nickel, selenium, silver, and vanadium are metals that are associated with CKD, exceed generic Part 201 criteria, and have the demonstrated ability to migrate from the Seep 1 CKD Area to a potential point of exposure.

8.0 Summary and Conclusions

8.1 Summary

This RI Report has been prepared on behalf of CMS Land Company and CMS Capital, LLC to describe the investigation activities conducted at the portions of the LTB CKD Release Site identified as the West CKD Area, Seep 2 CKD Area, and Seep 1 CKD Area.

The Site RI activities were planned to generate the data necessary to complete the Site characterization and evaluate final remedy alternatives for addressing current and potential threats to public health, welfare and the environment from CKD waste material. The RI activities at the Site built upon the results of previous investigations, and focused on data collection via borehole and well placement, down-hole geophysical methods, and aquifer and surface water testing, sampling, and analysis.

8.1.1 Interim Response and Effectiveness of ILRS

Recommended expedited removal actions and IR activities for the Site were presented in the Work Plan. An ILRS was designed and constructed, and is in operation at the Site as required by the AOC. Collection trenches have been installed in the West CKD, Pine Court, Guard Rail, Seep 2 CKD, and Seep 1 CKD Areas.

Effectiveness monitoring of surface water at the seep areas has been conducted in accordance with the Work Plan. In response to effectiveness monitoring conducted at the Site, augmentation has been implemented by CMS at all seep areas. Augmentation refers to activities to improve ILRS performance following construction. Augmentation has consisted of the following activities:

Area	Augmentation Activities
West CKD Area	• expanding the WILRS • removal of the downgradient soil and CKD mixture (soil/CKD) • reconstruction of the WILRS • installation of a low permeability MFZ • installation of a GCL cover system

Area	Augmentation Activities
Seep 2 CKD Area/Pine Court Area	• design, installation, operation, and modification of a pilot carbon dioxide injection system • installation of a targeted leachate collection system (TLC) • replacement of weir gates with stand pipes (except for Pine Court ILRS) • installing a temporary forcemain and frac tanks for collection of leachate
Seep 1 CKD Area	• additional monitoring • sampling and analysis • cleaning • increased collection • installation of low permeability barrier wall • installation of a GCL cover system

Effectiveness monitoring data summaries and figures for both lakeshore and pools pH are presented in Appendix 2-8. Tables are included which show the dates of effectiveness monitoring events, total number of Lake Michigan samples, and summary of pH measurement ranges. Most of the data points collected show the continued effectiveness of the ILRS. The occasional and low-level exceedances do not pose any threat to public health and safety or the environment. As the recently augmented areas of the ILRS continue to operate, CMS expects to see a continued decline in the number of pH exceedances.

8.1.2 Nature and Extent of Contamination

The extent of CKD at the Site and the extent of CKD leachate impacts in Little Traverse Bay have been defined as a result of the RI.

The source of high-pH leachate impacts at the Site are three CKD piles placed at the West CKD Area (approximately 5.4 acres and 100,000 cubic yards of CKD), Seep 2 CKD Area (approximately 34.8 acres and 1.1 million cubic yards of CKD), and Seep 1 CKD Area (approximately 15.5 acres and 550,000 cubic yards of CKD). The locations and extents of the CKD piles are shown on Figure 1-2.

The analytical data collected from monitoring wells as part of the RI were compared to the potentially applicable Part 201 Generic Criteria. The following criteria were not exceeded: residential/commercial I groundwater volatilization to indoor air, industrial/commercial II III IV

groundwater volatilization to indoor air, groundwater contact criteria, water solubility, flammability and explosivity screening levels, and acute inhalation screening levels. The parameters that exceeded generic criteria are highlighted on the data summary tables (Table 5-6a to 5-6c). As noted on the tables, the data were compared to all criteria, but only those criteria that were exceeded are listed on the tables. Only groundwater sample results from beach wells are compared to GSI criteria.

The following criteria were exceeded by potential Site COCs in groundwater. The locations of the exceedances in groundwater monitoring well samples are shown on the "a", "b", and "c" versions of Figures 5-1 through 5-18. The "a" figures show the data from the West CKD Area, the "b" figures show the data from the Seep 2 CKD Area, and the "c" figures show the data from the Seep 1 CKD Area.

Groundwater (monitoring well samples):

Residential Drinking Water Criteria	chloride, sum of potential nitrogen sources, ammonia nitrogen as N, TDS, sulfate, pH, aluminum, arsenic, barium, beryllium, chromium, iron, lead, magnesium, manganese, mercury, nickel, selenium, sodium, thallium, vanadium, bis(2-ethylhexyl)phthalate
Groundwater Surface Water Interface Criteria	chloride, % ammonia that will become NH_3 in surface water, TDS, pH, antimony, arsenic, chromium, copper, lead, mercury, nickel, selenium, silver, vanadium, zinc

8.1.3 Fate and Transport

Analysis of data from the RI indicates that the predominant migration mechanism is the movement (advection) of leachate/groundwater in areas of downward or lateral gradients. Elevated pH levels in groundwater and at the Lake Michigan beach at the Site are caused by leachate generated from within the CKD piles. Leachate can be generated by infiltration of rainfall/snowfall or irrigation water into the CKD piles or through contact with groundwater within the CKD piles. CKD piles are located on top of differing configurations of soil, limestone, and/or shale bedrock. There are variations in perched and regional water table elevations. There are several different possible migration pathways for leachate to follow to the beach. Migration may occur through interflow, and/or migration through perched or unperched groundwater through CKD, soil, or bedrock. Both density-driven migration and diffusion will be countered by dilution and upward groundwater flows.

Particulates carried along as solids, suspended sediment in runoff, or airborne particulates are not considered a significant route of migration for the potential COCs under current Site conditions as the CKD is being effectively isolated by the MDEQ approved soil barrier that was placed over it during development at the Site. Surface water investigations at Lake Michigan indicate that surface water is not a source of significant exposure to potential COCs other than pH. The results of remedial investigations for the two creeks within the Site indicate that they are not impacted by the CKD.

All of the potential Site COCs identified are inorganic and are not subject to biodegradation with the possible exception of ammonia. Many of the COCs are subject to changes in oxidative states or may react in precipitation or adsorption reactions. Results of chemical analysis suggest that leachate is variously attenuated by dilution, precipitation, adsorption, and neutralization by groundwater acidity.

Site analytical data indicate a correlation between mercury and total organic carbon concentrations within leachate.

8.2 Conclusions

The extent of CKD at the Site and the extent of CKD leachate impacts in Little Traverse Bay have been defined as a result of the RI. The mechanisms of migration from the CKD Area to Little Traverse Bay have also been defined allowing CMS to evaluate and select appropriate remedies for the Site. The data collected has allowed CMS to identify preferential groundwater pathways and to determine aquifer characteristics in order to evaluate the feasibility of alternative final remedial systems, and compare their expected performance to support final remedy selection. This evaluation is included in the Alternatives Evaluation Report.

9.0 References

Administrative Agreement and Covenant Not to Sue (AA/CNTS) (July 11, 1994). AA/CNTS between Bay Harbor Company, CMS Land Company, Boyne USA, Inc., JAKS, Inc., CMS Capital Corp., and the Michigan DNR.

Assel, Raymond A., National Oceanic and Atmospheric Administration (NOAA), 2003. Great Lakes Ice Cover, First Ice, Last Ice, and Ice Duration: Winters 1973-2002. NOAA Technical Memorandum GLERL-125.

ASTM, 2005. International Standard Guide for Design of Groundwater Monitoring Systems in Karst and Fractured-Rock Aquifers (D-5717-95e1).

ASTM D6032, 2006. Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core. 2006.

ASTM D4044-96, 2002. Standard Test Method (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers.

Barr Engineering Co., 2003. Quality Management Plan for Data Collection and Management of Contaminated Site Assessment and Remediation Projects - Revision 1.0 (October 3, 2003).

Barr Engineering Company, 2005a. Site Control and Access Management Plan – Revision 1.0, Little Traverse Bay CKD Release Site, Emmet County , Michigan, prepared for CMS Land Company (April 4, 2005).

Barr Engineering Company, 2005b. Project Health and Safety Plan – Revision 4.0 (August 31, 2005), and Revision 5.0 (May 1, 2006) as amended, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company.

Barr Engineering Company, 2005c. Final Approved Removal Action Work Plan, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (July 28, 2005).

Barr Engineering Co., 2005d. Quality Assurance Project Plan - Revision 1.0 (April 26, 2005) and Addendum 1.0 (August 5, 2005) – Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company.

Barr Engineering Company, 2005e. Contingent Isolation/Containment System Alternative Design Report, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (September 29, 2005).

Barr Engineering Company, 2005f. West CKD Beach Area Delineation and Characterization Plan, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (December 16, 2005).

Barr Engineering Company, 2006a. Surface Water/Water Cycle Monitoring Work Plan - Revision 1, Little Traverse Bay CKD Release Site, Emmet County, Michigan (March 31, 2006).

Barr Engineering Company, 2006b. Pine Ridge Court Interim Leachate Collection System Pilot Carbon Dioxide Augmentation Plan, Little Traverse Bay CKD Release Site, Emmet County, Michigan (May 5, 2006).

Barr Engineering Company, 2007a. Supplemental Investigation Activities document, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (April 5, 2007).

Barr Engineering Company, 2007b. Interim Leachate Recovery System Operation and Maintenance (O&M) Plan (December 14, 2007).

Barr Engineering Company, 2008a. Seep 2 CKD Area Augmentation Pilot System Design Report Targeted Leachate Collection, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (April 29, 2008).

Barr Engineering Company, 2008b. Seep 1 CKD Area Augmentation Conceptual Design Report Barrier System, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (May 1, 2008).

Barr Engineering Company, 2008c. West CKD Area Augmentation Conceptual Design Report – Downgradient Soil/CKD Removal, Little Traverse Bay CKD Release Site, Emmet Count, Michigan, prepared for CMS Land Company and CMS Capital, LLC (May 1, 2008).

Barr Engineering Company, 2008d. Seep 1 CKD Area Augmentation Plan – Preliminary Design, Little Traverse Bay CKD Release Site, Emmet Count, Michigan, prepared for CMS Land Company and CMS Capital, LLC (June 2008).

Barr Engineering Company, 2008e. Removal Action Investigation/Remedial Investigation Report East CKD Area Revision 2.0, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (June 4, 2008).

Barr Engineering Company, 2008f. Seep 1 Augmentation Plan – Final Design, Little Traverse Bay CKD Release Site, Emmet Count, Michigan, prepared for CMS Land Company (July 2008).

Barr Engineering Company, 2008g. West CKD Area Augmentation Preliminary Design Report – Downgradient Soil/CKD Removal, Little Traverse Bay CKD Release Site, Emmet Count, Michigan, prepared for CMS Land Company and CMS Capital, LLC (July 1, 2008).

Barr Engineering Company, 2008h. Seep 2 CKD Area Augmentation Pilot System Installation, Data Collection, and Proposed Enhanced Monitoring Report – Targeted Leachate Collection (August 28, 2008).

Barr Engineering Company, 2008i. West CKD Area Augmentation Final Design, Little Traverse Bay CKD Release Site, Emmet County , Michigan, prepared for CMS Land Company (September 15, 2008).

Barr Engineering Company, 2008j. Seep 2 CKD Area Augmentation Targeted Leachate Collection Phase 5 Final Design Report – Pilot System Installation, Data Collection, and Future Operation Recommendations (December 15, 2008).

Barr Engineering Company, 2009a. Seep 2 CKD Area Augmentation – Targeted Leachate Collection Modification Work Plan (April 2, 2009).

Barr Engineering Company, 2009b. Pine Court Area Augmentation – ILRS Modification Work Plan, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company (April 10, 2009).

Barr Engineering Company, 2009c. Groundwater Modeling Report – West, Seep 2 and Seep 1 CKD Areas, Little Traverse Bay CKD Release Site, Emmet County, Michigan, prepared for CMS Land Company, Revision 0.0 (July 31, 2009).

Boyne Golf/Bay Harbor Golf Club, 2004. Brochure.

Butler, J.J., Jr., 1997. The Design, Performance, and Analysis of Slug Tests, Lewis Publishers, Boca Raton, Florida, 252 p.

Dingman, S.L, 2002. Physical Hydrology, 2nd edition. Prentice-Hall, Inc., Upper Saddle River, New Jersey. 646 p.

Driscoll, F.G., 1986. Groundwater and Wells, 2nd edition. Johnson Filtration Systems, Inc., St. Paul, MN.

Duffield, 2003. Aqtesolv® for Windows® Professional – Version 3.5.

ETL 1110-2-282, 1983. "Engineering and Design Rock Mass Classification Data Requirements for Rippability." June 30, 1983.

Environmental Data Resources, Inc. (EDR, 2004a), October 7, 2004. Aerial Photos, 3600 Village Harbor Drive, Bay Harbor, MI 49779. Years of Coverage: 1938, 1952, 1965, 1973, 1981, & 1992.

Environmental Data Resources, Inc. (EDR, 2004b), October 7, 2004. Sanborn Map Report, 3600 Village Harbor Drive, Bay Harbor, MI 49779. Years of Coverage: 1913, 1919, 1929, 1950 & 1955.

Environmental Resources, Inc. (ERI), 2005. Historical aerial photographs. Years of Coverage: 1938, 1952, 1973, 1974, and 1993.

Farrand et. al., 1984. Quaternary Geologic Map of the Lake Superior 4^0 x 6^0 Quadrangle, United States and Canada: Quaternary Geologic Atlas of the United States. Map I-1420 (NL-16). Edited by Richmond and Fullerton, Dept. of the Interior, US Geological Survey.

Fetter, C.W., Jr., 1980. Applied Hydrogeology, Charles E. Merrill Publishing Co., Columbus, Ohio, 488 p.

Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Hanson Engineering P.C., 2003. Report of Geotechnical Investigation and Slope Evaluation, The Links Golf Course Hole No. 7, Bay Harbor Resort, Bay Harbor, Michigan, prepared for Plunkett & Cooney, March 3, 2003.

Haynes, B.W. and G.W. Kramer, 1982. Characterization of U.S. Cement Kiln Dust. U.S. Bureau of Mines, Dept. of the Interior, Information Circular 8885.

Heath, 1987. Basic Groundwater Hydrology. US Geological Survey, Denver, Colorado. Water Supply Paper 2220.

Holtschlag, D.J., and Nicholas, J.R., 1998, Indirect ground-water discharge to the Great Lakes: U.S. Geological Survey Open-File Report 98-579, 25 p.

Howell, T., and Evett, S., 2004. The Penman-Monteith Method. United States Department of Agriculture – Agricultural Research Service, Conservation and Production Research Laboratory. Bushland, Texas. http://www.cprl.ars.usda.gov/wmru/pdfs/PM%20COLO%20Bar%202004%20corrected%209apr04.pdf.

Hsieh, P.A., 1996. Deformation-induced changes in hydraulic head during ground-water withdrawal, Ground Water, vol. 34, no. 6, pp. 1082-1089.

Johnson, Johnson & Roy, June 8, 1988. Environmental Assessment, Bay Resort Properties, LTD. Resort Township, Michigan.

Kaehler, C.A. and P.A. Hsieh, 1994. Hydraulic Properties of a Fractured-Rock Aquifer, Lee Valley, San Diego County, California. U.S. Geological Survey Water-Supply Paper 2394. 64 p.

Kesling, et. al., 1974. Devonian Strata of Emmet and Charlevoix Counties, Michigan. Museum of Paleontology. Papers on Paleontology No. 7, University of Michigan.

LTTB, 2008. A Tribal History of The Little Traverse Bay Bands of Odawa Indians. http://www.ltbbodawa-nsn.gov/TribalHistory.html.

Long, J.C.S, and others, 1996. Rock Fractures and Fluid Flow – Contemporary Understanding and Applications. Committee on Fracture Characterization and Fluid Flow, U.S. National Committee for Rock Mechanics. National Academy Press, Washington, D.C. 551 p.

Michigan State Climatologist, 2005. Temperature and Climate Data for Petoskey, Michigan weather station. http://climate.geo.msu.edu/.

Midwest Regional Climate Center (MRCC), 2008. http://mcc.sws.uiuc.edu/

Milstein, R., 1987. Bedrock Geology of Southern Michigan. State of Michigan Dept. of Natural Resources, Geological Survey.

National Geodetic Survey (NGS), 2007. Datasheet by Station Name. http://www.ngs.noaa.gov/cgi-bin/ds_desig.

National Oceanic and Atmospheric Administration (NOAA), 2005. Precipitation data for Southern Michigan. http://www.ncdc.noaa.gov/oa/climateresearch.html.

National Oceanic and Atmospheric Administration (NOAA), 2006. Revised 10/05/2006 Tide Predictions and Data Frequently Asked Questions. http://tidesandcurrents.noaa.gov/faq2.html#17

NEPI. 2000. Assessing the Bioavailability of Metals in Soil for Use in Human Health Risk Assessments. Bioavailability Policy Report Phase II: Metals Task Force Report. National Environmental Policy Institute (NEPI). Summer, 2000.

NTH Consultants, Ltd. (NTH), 1994. Environmental Data Report, Former Penn-Dixie Cement Plant, Resort Township, Emmet County, Michigan, May 1994.

NTH Consultants, Ltd. (NTH), 1995. Report on: Hydrogeologic Investigation, Bay Harbor Development, Petoskey, Michigan, July 31, 1995. Prepared for Bay Harbor Company, Southfield, Michigan.

Olcott, 1992, Ground water atlas of the United States—segment 9, Iowa, Michigan, Minnesota, and Wisconsin: U.S. Geological Survey Hydrologic Investigations Atlas 730-J, accessed July 13, 2005 at http://pubs.er.usgs.gov/pubs/ha/ha730J.

Paillet, F.L. and R.S. Reese, 2000. Integrating Borehole Logs and Aquifer Tests in Aquifer Characterization. Ground Water, V. 38, No. 5, p. 713-725.

Petoskey Regional Chamber of Commerce, 2008. http://www.petoskey.com/chamber/our-people/.

Portland Cement Association, 2003. Cement Kiln Dust Production, Management, and Disposal, PCA R&D Serial No. 2737.

Portland Cement Association, 1996. Use of Cement Kiln Dust in Stabilizing Clay Soils. Skokie, IL.

Roadcap et. al., 2005. Geochemistry of Extremely Alkaline (pH>12) Ground Water in Slag-Fill Aquifers, Groundwater, November-December 2005, Vol. 43, No. 6, pages 806-816.

Snyder, R.L., and Eching, S., 2006. Penman-Monteith Daily (24-hour) Reference Evapotranspiration Equations for Estimating ETo, ETr, and HS ETo with Daily Data. http://biomet.ucdavis.edu/evapotranspiration/PMdayXLS/PMday.htm.

Todres, et al., 1992a. Cement Kiln Dust Management: Permeability, Research and Development Bulletin RD 103T. Portland Cement Association, Skokie, IL.

Todres, H.A., 1992b. Cement Kiln Dust: Field Compaction and Resulting Permeability, Research and Development Bulletin RD 106T. Portland Cement Association, Skokie, IL.

U.S. Army Corps of Engineers, 2005. Detroit District publishes information regarding Lakes Michigan and Huron lake levels at: http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/waterlevelforecasts/weeklygreatlakeswaterlevels/.

U.S. Department of The Interior, 2004. U.S. Geological Survey, Lime Kiln Dust as a Potential Raw Material in Portland Cement Manufacturing, Open-File Report 2004-1336.

U.S. Environmental Protection Agency, 1988. Office of Emergency and Remedial Response, Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final.

U.S. Environmental Protection Agency, 1997. Office of Solid Waste, Technical Background Document on the Efficiency and Effectiveness of CKD Landfill Design Elements, Draft.

U.S. Environmental Protection Agency, 1998. *Draft technical background document on groundwater controls at CKD landfills*. Office of Solid Waste, U.S. EPA, June 1998.

U.S. Environmental Protection Agency, 2003. *Ecological Soil Screening for Aluminum, Interim Final.* OSWER Directive 9285.7-60.

U.S. Environmental Protection Agency Region 5, 2005. Administrative Order on Consent for Removal Action, Little Traverse Bay CKD Release Site, Emmet County, Michigan, Docket No. VW-05-C-810, February 22, 2005.

U.S. Environmental Protection Agency, 2000. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition.*

U.S. Geological Survey (USGS), 1958. Bay Shore 7.5' Quadrangle Map.

U.S. Geological Survey (USGS), 1983a. Bay Shore, Michigan 7.5' Quadrangle, Provisional Edition, 45085-C1-TM-025.

U.S. Geological Survey (USGS), 1983b. Petoskey, Michigan 7.5' Quadrangle, Provisional Edition, 45084-C8-TM-025.

U.S. Geological Survey (USGS), 1983c. Harbor Springs, Michigan 7.5' Quadrangle, Provisional Edition, 45084-D8-TM-025.

U. S. Department of Transportation, 2005. Federal Highway Administration. Turner-Fairbank Research Center, Web page, http://www.tfhrc.gov/hnr20/recycle/waste/kd1.htm

Weston Solutions, Inc., 2007. *Assessment Report for Bay Harbor Lake*, June 2007.