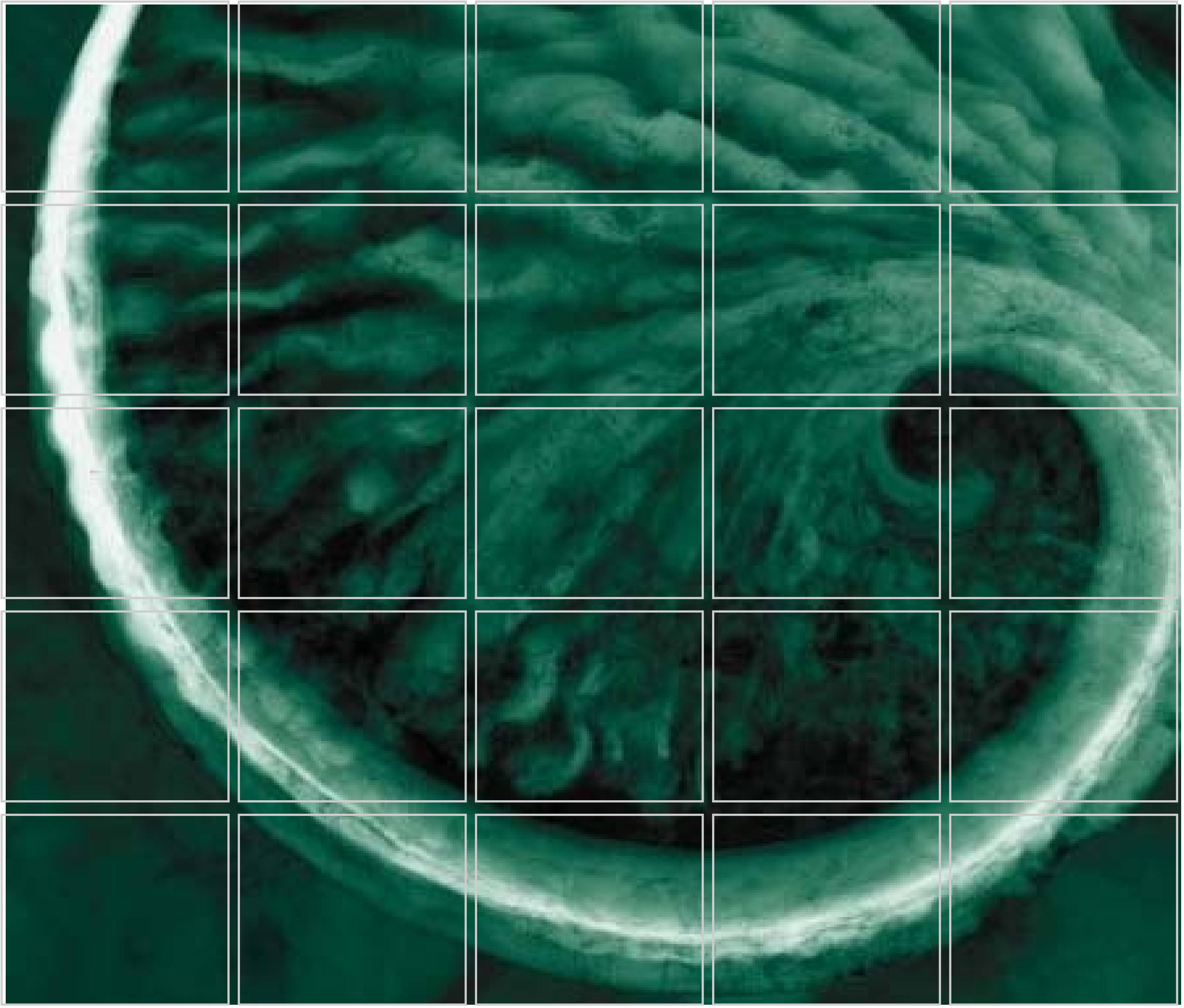


DRAFT Groundwater Modeling Report

Arkema, Inc. Facility
Portland, Oregon

December 2007

Prepared for:
Legacy Site Services LLC

www.erm.com

ERM

Delivering sustainable solutions in a more competitive world

Legacy Site Services LLC

DRAFT Groundwater Modeling Report
Arkema, Inc. Facility
Portland, Oregon

December 2007

Project No. 0057055

Brendan Robinson, E.I.T.
Project Engineer

Erik C. Ipsen, P.E.
Partner

ERM-West, Inc.
915 118th Avenue S.E., Suite 130
Bellevue, Washington 98005
T: 425-462-8591
F: 425-455-3573

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES (*Figures immediately follow the text*)

LIST OF TABLES (Tables immediately follow the figures)

1.0 INTRODUCTION

ERM-West, Inc. (ERM) has prepared this report on behalf of Legacy Site Services LLC (LSS) to present the results of a three-dimensional, numerical groundwater model for the Arkema Inc., (Arkema) site (the "Arkema site") in Portland, Oregon. The model was developed to support the Groundwater Source Control Interim Remedial Measure Focused Feasibility Study for upland groundwater at the Arkema site. The extent of the groundwater model (the "model area") includes portions of upgradient and adjacent properties surrounding the Arkema site. This report describes the design of the groundwater model and the methods that were used to calibrate the model to observed groundwater conditions in the model area.

1.1 MODEL AREA DESCRIPTION

The model area is centered on the Arkema site, located at 6400 N.W. Front Avenue in Portland, Oregon, along the west bank of the Willamette River, at approximately river mile 7.5. The properties within the model area are part of the Guild's Lake Industrial Sanctuary (formerly the Northwest Portland Industrial Sanctuary), zoned and designated "IH" for heavy industrial use (Figure 1-1).

The groundwater model covers an area of 260 acres. The model area is bounded to the west by the West Hills (across Highway 30) and to the east by the Willamette River. The groundwater model extends between approximately 80 and 300 feet (ft) into the Willamette River. The model area slopes gently eastwards to the Willamette River with topographic elevations between 66 and 28 ft relative the North American Vertical Datum of 1988 (NAVD88).

The model area includes portions of the adjacent, crossgradient sites (i.e. the GS Roofing, GATX/Willbridge, City of Portland, and Siltronic sites), as well as upgradient sites, extending to Highway 30. This area includes the ESCO, Gould, Schnitzer, and Metro sites, as well as the former Rhone-Poulenc (RP) manufacturing facility. The model boundaries are presented in Figure 1-2.

1.2 *MODEL AREA HISTORY*

The Arkema site (formerly ATOFINA Chemicals, Inc.) is a former chemical manufacturing plant that began operations at its current location in 1941 as a sodium chlorate plant. For the most part, the plant manufactured chlorine, sodium hydroxide, hydrogen, hydrochloric acid, and sodium chlorate. Other products and processes were added and discontinued over time; including dichlorodiphenyltrichloroethane, ammonia, and ammonium perchlorate. The plant is no longer operating as a manufacturing site, and has been decommissioned and demolished with the exception of the main office building.

The area to the west of the Arkema site has been used for industrial purposes since the 1920s. A portion of this area, the Gould Site, was used for a number of industrial purposes, including disposal of battery recycling wastes (acid and casings). This area was remediated between 1992 and 2000, and included the construction of an engineered landfill and cap.

The former RP pesticide and herbicide manufacturing site, currently owned by Starlink Logistics, Inc. (SLLI), is located on the western portion of the model area. This site is a known source of groundwater contamination of metals, volatile organic compounds, semi-volatile compounds, herbicides, pesticides, dioxin/furans, and chloride. RP contaminants are known to be migrating in groundwater, through downgradient properties (ESCO, Siltronic and Arkema sites) and impacting the Willamette River (ERM 2007, AMEC 2007). Several investigations and evaluations have been implemented at the RP site, including the construction of a groundwater model (AMEC 2005). Hydrogeological information and interpretations (i.e., boring logs and geological cross sections) from these investigations were used in the construction of the Arkema regional groundwater model.

1.3 *REPORT ORGANIZATION*

This report is organized into the following sections.

- Section 2.0 – Summary of major objectives of the groundwater model.
- Section 3.0 - A brief description of the environmental setting of the model area.

- Section 4.0 - Conceptual hydrogeologic model of the model area.
- Section 5.0 - Discusses the selection of the model code that was used to develop the numerical model.
- Section 6.0 - Design of the numerical model.
- Section 7.0 - Summary of model input parameters.
- Section 8.0 - Methods that were used to calibrate the numerical model to groundwater conditions in the model area and the results of the model calibration.
- Section 9.0 - Discussion of uncertainties in the numerical model simulations.

2.0 OBJECTIVES OF GROUNDWATER MODEL

The Arkema groundwater model was developed to more fully characterize the groundwater flow systems in the model area, and determine the fate and transport of constituents of concern in the groundwater. The groundwater model will be used to support the evaluation of containment and extraction alternatives for containing groundwater at the Arkema site in the Focused Feasibility Study, and to develop preliminary design specifications for the selected remedial systems.

3.0 ENVIRONMENTAL SETTING

3.1 GEOGRAPHIC SETTING

The model area lies within the Willamette River Valley province of the Willamette River Basin (Fenneman 1931). The Willamette River Basin is bounded on the west by the Coast Range, on the east by the Cascade Range, on the south by the Calapooya Divide, and on the north by the Columbia River. Elevations range from less than 10 ft above sea level near the Columbia River to about 4,000 ft in the Coast Range and the Calapooya Divide, to more than 10,000 ft in the Cascade Range.

The Willamette River Valley province, generally considered the part of the basin below 500 ft, is about 30 miles wide and 117 miles long and represents about 30 percent of the basin area. Much of the terrain in the Willamette River Valley up to an elevation of about 400 ft is covered by sandy to silty terrace deposits that border existing rivers and form alluvial fans near river mouths (Lee and Risley 2002). These deposits were derived from the surrounding mountains, and they consist of intermingling layers of clay, silt, sand, and gravel.

3.2 CLIMATE

The Portland area climate is relatively mild throughout the year, and is characterized by cool, wet winters and warm, dry summers (Oregon Climate Service 2005). Mean high temperatures range from approximately 80° Fahrenheit (F) in the summer to about 40° F in the coldest months, while average lows are generally around 50° F in the summer and around 30° F in the winter. Monthly average relative humidity ranges from 65 to 84 percent. The average annual lake evaporation is 24 to 26 inches (U.S. Department of Commerce 1968). Winds are generally aligned with the Willamette River Valley.

The 30-year normal precipitation for the Portland area is 37.4 inches (Oregon Climate Service 2005). Most of the precipitation occurs during the winter months with about 50 percent of the annual total occurring from December through February, lesser amounts in the spring and fall, and very little during the summer.

3.3 LAND USE

The properties within the model area have historically been used for industrial purposes. The model area is located within the Guild's Lake Industrial Sanctuary, and is zoned and designated for heavy industrial use. The Guild's Lake Industrial Sanctuary is defined as the area generally bounded by Vaughn Street to the south, St. Johns Bridge to the north, Highway 30 to the west, and the Willamette River to the east. The nearest residential structures are located outside of this industrial area, approximately 0.3 miles west and upgradient of the Arkema site (Figure 1-1). Forest Park, a large, forested park, is located approximately 0.5 miles to the west of the Arkema site. Heavy industrial land use surrounds the Arkema site and isolates it from residential areas and Forest Park.

On 14 December 2001, the Portland City Council voted to adopt the Guild's Lake Industrial Sanctuary Plan (GLISP). The purpose of the GLISP is to maintain and protect the land within the sanctuary boundary as a dedicated area for heavy and general industrial uses. The GLISP became effective on 21 December 2001 (City of Portland 2001). The GLISP's vision statement, policies, and objectives were adopted as part of Portland's Comprehensive Plan and are implemented through amendments to the City's Zoning Code. As a result of the GLISP, the likely future land use of the Arkema site is industrial.

Currently, a significant portion of the model area is paved, gravel covered, or covered with building foundations. The riverbank above the mean high water line of the Willamette River is steeply sloping and covered with large-sized rubble that is used for bank stabilization. A future greenway has been proposed for the area adjacent to the Willamette River. The greenway setback extends 50-ft landward from the top of the riverbank and consists of a 25-foot setback requirement and an additional 25 ft for future landscaping. Due to security concerns, this area will not be accessible from off-site and will be maintained as green space.

3.4 GEOLOGY

The surficial geology in the model area is characterized by fill and alluvial deposits of the Willamette River. Alluvial deposits are underlain by bedrock of the Columbia River Basalt Group. These units are described in detail in the following sections.

3.4.1 *Fill Material*

Fill materials generally occur from the surface to depths of approximately 20 to 30 ft below ground surface (bgs), and consist of clayey silt to silty sand with occasional debris (including wood, brick, concrete, gravel, demolition debris, etc.). Historically, fill materials were used to extend the land surface of the western bank of the Willamette River on the Arkema site. Fill thickness ranges from a few feet in the former manufacturing area to approximately 25 ft along the riverbank.

The source of the fill along the western bank of the Willamette River is generally believed to be river dredge spoils and deposits from on- and off-site excavations. This was common practice for near-shore areas of properties along the Portland Harbor. The shallow, fine-grained soils are the result of dredged material from the Willamette River being placed on the upland portions of the Arkema site. In some areas of the Arkema site, this has resulted in an extension of the ground surface into the river by a distance as much as 300 ft. Areas to the west of the Arkema site, including the former Doane Lake Area have historically been in-filled with sand, clay, organic material and miscellaneous debris. An engineered landfill and cap was also constructed over a large portion of the Gould site.

The fill material is often hard to distinguish from the native material, given that typical sources of the fill were dredge spoils and re-worked native material. Given the similarities between the fill and the shallow alluvial deposits, there is no distinction made between fill and native alluvium for hydrogeologic modeling purposes.

3.4.2 *Alluvial Deposits*

The alluvial deposits typically occur as sand, silty sands, silts and clays. These sands and silts are massive to finely laminated and the contacts between the sand and silt can be gradational.

In general, the alluvium occurs in four alternating sand and silt layers; a sand layer occurs at the ground surface Shallow zone, underlain by a silt layer (Shallow-Intermediate Silt), which is underlain by an additional sand (Intermediate Zone) and a silty sand/sandy silt layer (Deep Zone). The sand and silt layers are continuous over most of the model area. The depth of the alluvium (between 50 and 205 ft bgs) is generally controlled by the topography of the underlying basalt bedrock.

A layer of gravel underlies the deepest sandy silt layer in the western portion of the model area. The gravel consists of subrounded to round colluvial and alluvial gravel. The gravel is typically approximately 10 ft thick.

3.4.3 Bedrock

The Columbia River Basalt Group, which consists of flood basalt that erupted 17 to 6 million years ago, underlies the fill and alluvium throughout the area. These Miocene-age flood basalts are characterized by a thick sequence of dense basalt flows separated by permeable interflow zones. These interflow zones are recognized as productive aquifers. Regionally, the basalt surface dips steeply to the northeast; however, a trough or basin has been identified in the upper basalt surface during other investigations near the Arkema site (Geraghty & Miller 1991; Section 6.3, AMEC 2007).

3.5 SURFACE WATER

The Arkema site is located along the west bank of the Willamette River at approximately river mile 7.5. The daily mean Willamette River discharge in Portland typically ranges from about 8,300 cubic ft per second (cfs) in the summer (August) to 63,000 cfs in the winter (December). The mean daily flow for the period of 1972 to 2006 is 33,000 cfs. The confluence of the Willamette and Columbia Rivers is approximately 7.5 miles northwest of the Arkema site. The Willamette River is not used as a source of drinking water.

The U.S. Geological Survey (USGS) gages the flow and stage elevation of the Willamette River at the Morrison Street Bridge in Portland (Station 14211720) at river mile 12.8, approximately 5 miles upstream of the Arkema site. The datum of the Morrison Street Bridge station is 1.55 ft above the National Geographic Vertical Datum of 1929 (NGVD29). The Willamette River stage data from this station are converted to NAVD88 by adding 5.028 ft.

The minimum monthly river stage along the Willamette River in the Portland Harbor area typically occurs between July and October (U.S. Army Corps of Engineers 2004). Maximum monthly stages usually occur in the winter between December and February, and in the spring between March and June, coincident with flood peaks on the Willamette and Columbia rivers.

The Willamette River stage is influenced by upstream reservoir regulation on both the Willamette and Columbia rivers (up to the Bonneville Dam) and by tidal effects from the Pacific Ocean (U.S. Army Corps of Engineers 2004). Tidal effects are most pronounced (i.e., typically ranging from 2- to 3-ft in amplitude per tidal cycle) when the river stage is less than about 8 ft NGVD29. Tidal influences are more moderate (i.e., less than 2 ft in amplitude) between river stage elevations of 8 to 14 ft NGVD29. Above approximately 14 ft, tidal fluctuations are generally absent in the Portland Harbor. Tidal influences are most pronounced during the summer and fall when river flow and river stage are typically at their lowest.

The area around the Arkema site was once dominated by lakes, including Doane Lake. Much of the original Doane Lake has been filled with hydraulic dredge material as well as rocks, gravel, and sand, up to depths of approximately 40 ft bgs (Groundwater Solutions, 2003). The remnant of Doane Lake was further divided in to two bodies North Doane Lake and West Doane Lake by the placement of fill during the construction of the BNSF rail road. The lakes are underlain by thick lacustrine deposits of silts and clays. The surface water in both lakes is connected to the groundwater (AMEC 2005).

The current surface drainage (storm water runoff) in paved areas of the Arkema site is towards catch basins that contribute to four storm water outfalls, which discharge to the Willamette River. Storm water is allowed to infiltrate in unpaved areas of the Arkema site. Recharge is discussed in detail in Section 7.1.

4.0 CONCEPTUAL GROUNDWATER MODEL

4.1 HYDROSTRATIGRAPHIC UNITS

Groundwater occurs in six distinct water-bearing zones beneath the Arkema site. These water-bearing zones have been designated as the Shallow Zone, Shallow-Intermediate Silt Zone, Intermediate Zone, Deep Zone, Gravel Zone, and Fractured Basalt (Figure 4-1). These water-bearing zones are described in the following sections. The bottom elevation contours of each unit are presented in Section 6.

4.1.1 Shallow Zone

Groundwater in the Shallow Zone is unconfined and occurs at depths of approximately 5 to 25 ft bgs in the uppermost fill and sand alluvium in the model area. In general, the depth to groundwater increases from west to east across the model area (from Highway 30 toward the Willamette River). The saturated thickness of the Shallow Zone is defined as the depth from the top of the water table to the upper surface of the Shallow-Intermediate Silt, and ranges from approximately 2- to 15-ft near the bank of the Willamette River to approximately 15- to 25-ft near Front Avenue. The saturated thickness in areas to the west of Front Avenue ranges between 0 and approximately 15 ft.

4.1.2 Shallow-Intermediate Silt Zone

The Shallow Zone is underlain by the Shallow-Intermediate Silt Zone. This zone comprises of silts, sandy silts, and clays. This layer is approximately 1- to 4-ft thick across the Arkema site and is discontinuous in the southern portion of the Arkema site (i.e. in the former Chlorate Manufacturing Area). The Shallow-Intermediate Silt tends to increase in thickness to the west of the Arkema site, with the thickest portions (up to 45 ft) located in the former Doane Lake Area. This area also corresponds to the thickest silt and clay layers (approximately 47 ft) within the Shallow-Intermediate Silt.

4.1.3 Intermediate Zone

The Intermediate Zone consists of the alluvial sands below the Shallow-Intermediate Silt Zone. The groundwater in the Intermediate Zone is confined or semi-confined and occurs between depths of approximately 36 to 46 ft bgs and a saturated thickness of approximately 5- to 10-ft across the Arkema site. The Intermediate Zone is discontinuous in the northwestern portion of the model area (Doane Lake Area).

4.1.4 Deep Zone

Groundwater in the Deep Zone occurs in the finer-grained deposits below the alluvial sands and above the Columbia River Basalt. Below the sands, at depths from approximately 40 to 60 ft bgs, silt with some clay and fine sand is predominant. The depth and saturated thickness of the Deep Zone (up to approximately 60 ft) is controlled by the topography of the basalt bedrock.

4.1.5 Gravel Zone

In some portions of the model area, alluvial gravel is present between the Deep Zone and the basalt bedrock. The Gravel Zone is typically approximately 10 ft thick, and tends to increase in thickness with proximity to the Willamette River. Consistent with previous modeling efforts for the RP property, highly fractured areas of the underlying basalt bedrock are also included in the Gravel Zone, given the similar high hydraulic conductivities.

The extent of this Gravel Zone throughout the model area is still being investigated. This groundwater model was constructed and calibrated based on information available in June 2007. Additional investigations and interpretations are underway and could lead to some revision of the extent of the Gravel Zone, particularly in the northern portion of the model area. The Gravel Zone has a significantly higher hydraulic conductivity than the overlying Deep Zone, and has been identified as a potential pathway of contaminant migration from the RP site (AMEC 2007).

4.1.6 Fractured Basalt

Basalt-zone groundwater is situated beneath the alluvial deposits at the model area up to the maximum depth explored (approximately 216 ft bgs). Based on information presented in the *Stage 1 Source Control Evaluation* (AMEC 2005) and *Stage 2 Source Control Evaluation* (AMEC 2007), the basalt surface forms a large trough that generally parallels Front Avenue on the Arkema site, and then curves to the northeast extending to the Siltronic property. The Fractured Basalt Zone is characterized by fractured and weathered basalt with a low permeability relative to the Gravel Zone. The Fractured Basalt Zone is underlain by slightly weathered basalt bedrock.

4.2 PROPERTIES OF HYDROGEOLOGIC UNITS

Hydraulic conductivities for the hydrogeologic units in the model area were obtained from slug and pumping tests performed on monitoring wells, and laboratory permeameter tests of selected core samples. These measured hydraulic conductivities are summarized in Table 4-1. Detailed discussions of the slug and pumping tests are provided in the *Elf Atochem Acid Plant Area Remedial Investigation Interim Data Report* (Exponent 1999) and the *Arkema Active Pilot Test Workplan, Appendix B, Hydraulic Testing Summary* (GeoSyntec 2006).

Horizontal hydraulic conductivities in the Shallow Zone from the slug tests range from 5.9 ft/day in MWA-7 to 34 ft/day in MWA-5 (Table 4-1). The slug test data collected from MWA-6 were inconclusive and the low hydraulic conductivity of the Shallow Zone in this monitoring well is not considered representative of the Shallow Zone. Three short-term (4 hour) pumping tests were also performed on the Shallow Zone. The hydraulic conductivities from the pumping tests range from 1.2 ft/day in PT-1 and P-3 to 187 ft/day in PT-2.

Intermediate Zone horizontal hydraulic conductivities range from 0.04 ft/day in MWA-12i to 21 ft/day in MWA-9i based on the slug test results (Table 4-1). The slug test data from MWA-10i showed a rapid water level recovery, indicating that the test only evaluated the annular space surrounding the monitoring well; therefore the measured hydraulic conductivity in this well may not be representative of the Intermediate Zone.

Slug tests were performed only on two monitoring wells screened in the Deep Zone. The horizontal hydraulic conductivities from these slug tests range from 0.04 to 0.3 ft/day (Table 4-1).

There were no hydraulic conductivity tests performed on the Gravel Zone at the Arkema site; however, hydraulic testing was performed on the Gravel Zone in one well on the adjacent RP property by SLLI (AMEC 2005). The hydraulic conductivity from this test was estimated to be greater than 50 ft/day.

A short-term (10-minute) pumping test was performed during sampling of one monitoring well, MW-21b, screened in the Fractured Basalt (Table 4-1). The horizontal hydraulic conductivity of the Fractured Basalt from this test was 0.94 ft/day. Because of well losses during the pumping test, the estimated hydraulic conductivity of the Fractured Basalt in this well is probably inaccurate by an order of magnitude. Hydraulic testing of the Fractured Basalt has also been performed on the adjacent RP property by SLLI (AMEC 2005). Based on these tests, the hydraulic conductivity of the Fractured Basalt ranges from 1.1 to 15 ft/day.

Vertical hydraulic conductivities were measured in three core samples collected from monitoring well MWA-10i, MWA-11i, and MWA-13d. The samples consisted of silt and/or clay and were selected to be representative of the fine-grained units within the groundwater zones. The results of vertical hydraulic conductivity tests are summarized in Table 4-1. The vertical hydraulic conductivities ranged from 0.0007 ft/day (MWA-11i, 39 to 40.25 ft bgs) to 0.0071 ft/day (MWA-13d, 48 to 50 ft bgs).

4.3 GROUNDWATER FLOW

In general, the groundwater flow direction in the model area is toward the Willamette River. The water levels in the groundwater zones fluctuate seasonally, rising during periods of high rainfall in the winter months and falling during periods of low rainfall in mid- to late summer. Shallow groundwater in close proximity to the Willamette River will also rise in direct response to large increases in Willamette River stage (e.g., during a flood). In general, these short-term fluctuations do not affect groundwater flow directions with the exception of short-term groundwater flow reversals in close proximity to the river.

A comprehensive set of groundwater level measurements were collected from monitoring wells in the model area and on adjacent properties on 7 and 8 May 2007 for calibration of the groundwater model (Section 8.0). The contoured groundwater elevations from this water level measurement event are shown in Figures 4-2 to 4-6. The water level data were contoured using a triangulation method with linear interpolation with Surfer 8.0®, a two-dimensional surface modeling computer program (Golden Software, Inc. 2002).

5.0 MODEL SELECTION

The model code that was selected to develop the Arkema groundwater flow model is MODFLOW. MODFLOW was chosen for development of the groundwater flow model to satisfy the following model selection criteria:

- Model code must be capable of simulating a complex, three-dimensional groundwater flow system with heterogeneous hydraulic properties;
- Model code is nonproprietary and well documented;
- Model code has been verified for a wide range of field problems; and
- Model code is widely accepted by the environmental industry, and state and federal regulatory agencies.

MODFLOW is a three-dimensional, finite-difference, groundwater flow model developed by the USGS (McDonald and Harbaugh 1988). MODFLOW is well documented (McDonald and Harbaugh 1988; Harbaugh 2005), and has been verified for a wide range of field problems (United States Environmental Protection Agency [USEPA] 1993). MODFLOW has also been widely accepted by state and federal regulatory agencies, and numerous models based on this code have been published in technical journals (Anderson and Woessner 1992).

6.0 MODEL DESIGN

This section describes the principal design elements of the Arkema groundwater model. These design elements include the major assumptions of the model design, the model grid and layering, the boundary conditions used in the flow model, and the aquifer properties assigned to the model grid.

The Arkema groundwater model was designed, constructed, and calibrated in accordance with the American Society for Testing and Materials (ASTM) guidelines for groundwater modeling (ASTM 1996), USEPA Region 10 guidelines for hydrogeologic modeling (USEPA 1994), and generally accepted industry practice (Anderson and Woessner 1992). The ASTM guidelines were developed as part of a cooperative agreement between the USEPA, the USGS, and the U.S. Navy.

The groundwater model was designed and constructed with Groundwater Vistas™, a computer-aided design program for groundwater modeling (Environmental Simulations Inc. 2004). Groundwater Vistas™ fully supports the model code MODFLOW (McDonald and Harbaugh 1988), which was used to develop the groundwater model.

6.1 ASSUMPTIONS OF MODEL DESIGN

The complex hydrogeologic conditions that control the movement of groundwater in the subsurface are never fully known; therefore, some assumptions and simplifications must be made in the construction of numerical models that simulate groundwater flow. The following simplifying assumptions were made in the design of the Arkema groundwater flow model:

- The shallowest groundwater flow system (Shallow Zone) receives recharge by infiltration of precipitation and surface runoff in unpaved areas;
- The base of the upper portion of the Columbia River Basalt is at an approximate elevation of -200 ft NAVD88;
- Downward groundwater flow between the upper portion of the Columbia River Basalt simulated by the model and the underlying basalt is not significant; and

- The bottom sediments in North Doane Lake and West Doane Lake have a uniform thickness of 1.0 foot.

6.2 MODEL DOMAIN

In order to adequately model the groundwater flow and contaminant flux through the Arkema site, it was necessary to adopt a more regional model extent than the Arkema site alone. The domain of the model was expanded to include portions of the adjacent, cross-gradient sites (e.g., the GS Roofing, Willbridge, City of Portland and Siltronic sites), as well as upgradient sites, extending to Highway 30. The upgradient sites include the ESCO, Gould, Schnitzer, and Metro sites, as well as the former RP manufacturing site (Figure 1-2).

6.3 MODEL GRID

In a numerical groundwater model, the continuous groundwater flow field is approximated by a discretized domain consisting of an array of grid nodes and associated grid blocks. This nodal grid forms the framework of the numerical model. MODFLOW uses a block-centered, finite-difference grid to simulate a continuous groundwater flow field (McDonald and Harbaugh 1988). With this method, the grid blocks are rectangular in shape and the grid nodes are located at the centers of the grid blocks.

The model grid is a seven-layer, uniformly spaced, finite-difference grid. The i-direction of the model grid is oriented approximately north 50 degrees east, approximately parallel to the direction of groundwater flow (Figure 6-1). The row and column spacing of the model grid are a uniform 25 ft.

6.4 MODEL GRID LAYERS

The groundwater flow systems in the model area are simulated in the model by seven layers:

- Layer 1 – Shallow Zone;
- Layer 2 – Shallow-Intermediate Silt Zone;
- Layer 3 – Intermediate Zone;
- Layer 4 – Deep Zone;

- Layer 5 – Gravel Zone
- Layer 6 – Fractured Basalt; and
- Layer 7 – Slightly Weathered Basalt.

The model grid layers represent the seven major hydrostratigraphic units identified during the development of the conceptual hydrogeologic model for the model area (Section 4.1). The bottom elevation of the model layers are based on geologic logs of well borings in the model area and on adjacent properties (Tables 6-1 and 6-2). Two-dimensional kriging was used to interpolate the layer bottom elevations between well borings and to the edges of the model grid. A southwest to northeast cross-section along column 120 of the model grid is shown on Figure 6-1.

The bottom elevation of Layer 1, which represents the base of the Shallow Zone, ranges between -8 and 51 ft relative to the North American Vertical Datum of 1988 ([NAVD88], Figure 6-3). The top elevation of this layer, which represents the water table, is calculated by MODFLOW during the model simulation period (McDonald and Harbaugh 1988).

The bottom elevation of Layer 2, which represents the base of the Shallow-Intermediate Silt Zone, ranges between -37 and 46 ft NAVD88 (Figure 6-4). The top elevation of this layer, which represents the base of the Shallow Zone, ranges between -8 and 51 ft NAVD88 (Figure 6-3).

The bottom elevation of Layer 3, which represents the base of the Intermediate Zone, ranges between -41 and 40 ft NAVD88 (Figure 6-5). The top elevation of this layer, which represents the base of the Shallow-Intermediate Silt Zone, ranges between -37 and 46 ft NAVD88 (Figure 6-4).

The bottom elevation of Layer 4, which represents the base of the Deep Zone, ranges between -76 and 29 ft NAVD88 (Figure 6-6). The top elevation of this layer, which represents the base of the Intermediate Zone, ranges between -41 and 40 ft NAVD88 (Figure 6-5).

The bottom elevation of Layer 5, which represents the base of the Gravel Zone, ranges between -78 and 24 ft NAVD88 (Figure 6-7). The top elevation of this layer, which represents the base of the Deep Zone, ranges between -76 and 29 ft NAVD88 (Figure 6-6).

The bottom elevation of Layer 6, which represents the base of the Fractured Basalt, ranges between -78 and 24 ft NAVD88 (Figure 6-8). The top elevation of this layer, which represents the base of the Gravel Zone, ranges between -78 and 24 ft NAVD88 (Figure 6-7).

The bottom elevation of Layer 6, which represents the base of the upper portion of the Columbia River Basalt, was assumed to be a uniform -200 ft NAVD88 as a simplifying assumption in the model design (Section 6.1). The top elevation of this layer, which represents the base of the Fractured Basalt, ranges between -78 and 24 ft NAVD88 (Figure 6-8).

6.5 FLOW CONDITIONS

Flow conditions in Layer 1 (Shallow Zone) are simulated as unconfined (MODFLOW layer type LAYCON=1). The transmissivity of this layer varies during the model simulation period, and is calculated from the saturated thickness and hydraulic conductivity specified for the layer (McDonald and Harbaugh 1988). Flow conditions in the other five model layers are simulated as unconfined/confined (MODFLOW layer type LAYCON=3). The transmissivities of these model layers will vary during the model simulation period, and will be calculated from the saturated thickness and hydraulic conductivity specified for the layers (McDonald and Harbaugh 1988). The storage coefficients specified for these model layers may alternate between confined and unconfined values during the model simulation period.

6.6 FLOW BOUNDARY CONDITIONS

The following flow boundary conditions are used in the Arkema groundwater model:

- Upper boundary of model grid – free-surface (water table) boundary;
- Northwest, southwest, and southeast margins of model grid – constant-head boundaries;
- Lower boundary of model grid– no-flow boundary;
- Willamette River – constant-head boundary; and
- North Doane Lake and West Doane Lake – river (head-dependent-flow) boundaries.

The upper boundary of the model grid is a free-surface boundary. The free-surface boundary simulates the water table in the Shallow Zone. The elevation of this boundary is calculated by MODFLOW during the course of the model simulation (McDonald and Harbaugh 1988).

The lower boundary of the model grid is a no-flow boundary. Downward groundwater flow from the Slightly Weathered Basalt (Layer 7) is assumed to be negligible as a simplifying assumption of the model design.

The northwest, southwest and southeast margins of the model grid are constant-head boundaries (Figures 6-9 to 6-15). These constant-head boundaries simulate the horizontal gradients observed in the groundwater flow systems at the Arkema site.

The Willamette River is represented in the model as a constant-head boundary (Figures 6-9 to 6-14). The Willamette River stage (head) is not affected by groundwater flow into or from the river in the model area because of its size and depth. Therefore, stresses on the groundwater flow system, such as groundwater pumping, are unlikely to significantly impact the river stage.

North Doane Lake and West Doane Lake are represented in the model as river boundaries (Figure 6-9). River boundaries simulate groundwater flow between surface water bodies and underlying groundwater flow systems. Groundwater flow from or to the boundary is dependent on the head gradient between the river boundary and the model layer (McDonald and Harbaugh 1988). When the head in the model layer is higher than the stage elevation of the river boundary, groundwater is discharged into the river boundary. When the stage elevation of the river boundary is higher that the head in the model layer, the model layer receives groundwater recharge from the river boundary. These boundaries simulate the interaction of North Doane Lake and West Doane Lake with the Shallow Zone groundwater.

7.0 MODEL INPUT PARAMETERS

7.1 RECHARGE

Groundwater recharge by infiltration of precipitation and surface runoff in the Portland area is estimated to be approximately 10 inches per year based on precipitation-runoff models of Willamette River Basin (Lee and Risley 2002). Based on this estimate, a uniform recharge rate of 10 inches per year is used in the Arkema groundwater flow model in unpaved areas of the model area (Table 7-1). This recharge rate is approximately 27 percent of the 30-year normal precipitation for the Portland area, which is 37.4 inches (Oregon Climate Service, 2005). In paved and impermeable areas, the recharge rate was assumed to be zero inches per year (Figure 7-1).

7.2 HYDRAULIC CONDUCTIVITY

The values of horizontal hydraulic conductivity that are used in the Arkema groundwater flow model are:

- Layer 1 (Shallow Zone) – 190, 10, 8.0, 5.0, and 2.0 ft/day;
- Layer 2 (Shallow-Intermediate Silt Zone) – 190, 1.0 and 0.01 ft/day;
- Layer 3 (Intermediate Zone) – 20 and 2.0 ft/day;
- Layer 4 (Deep Zone) – 10 and 1.0 ft/day;
- Layer 5 (Gravel Zone) – 150, 10, and 5.0 ft/day;
- Layer 6 (Fractured Basalt) – 10 ft/day; and
- Layer 7 (Slightly Weathered Basalt) – 2.5 ft/day.

Vertical hydraulic conductivity (K_v) values are equal to horizontal hydraulic conductivity (K_h) values (K_h/K_v=1:1) except for two zones in layer 1 (Shallow Zone). The hydraulic conductivities used in the model layers are summarized in Table 7-1. These values of horizontal and vertical hydraulic conductivity were determined by calibration of the flow model to observed groundwater conditions in the model area (Section 8.0) and are within the range of measured conductivity values determined by slug and pumping tests (Section 4.2).

The spatial distribution of the different hydraulic conductivities used in model Layers 1 to 5 are shown in Figures 7-2 to 7-6. In Layer 2 (Shallow-Intermediate Silt Zone), the hydraulic conductivity zone of 0.01 ft/day (Figure 7-3) represents fine-grained sediments that were deposited in Doane Lake, which has largely been filled in as industrial development in the area occurred. In Layer 3 (Intermediate Zone), the 2.0 ft/day conductivity zone (Figure 7-4) represents an area where the Intermediate Zone is absent and clay and silt are present (Figure 6-5). In Layer 4 (Deep Zone) and Layer 5 (Gravel Zone), the conductivity zones of 10 ft/day (Figures 7-5 and 7-6) represent an area where the Deep Zone and Gravel Zone are not present (Figures 6-6 and 6-7).

7.3 CONSTANT-HEAD BOUNDARIES

7.3.1 Willamette River

The Willamette River is represented in the model as constant-head boundaries in Layers 1 to 6 (Figures 6-9 to 6-14). The input parameters for the constant-head boundaries representing the Willamette River in the Arkema groundwater model are summarized in Table 7-2. The elevation of the constant-head boundary is the average stage elevation of the Willamette River in April 2007 measured at the USGS gaging station at the Morrison Street Bridge in Portland, approximately 5 miles upstream of the Arkema site (Appendix A).

7.4 RIVER BOUNDARIES

North Doane Lake and West Doane Lake are represented in the model as river (head-dependent-flow) boundaries in Layer 1 (Shallow Zone). The input parameters for the river boundaries used in the Arkema groundwater model are summarized in Table 7-2. The stage elevations of the river boundaries were set at the water elevations in the lakes, which were estimated from groundwater elevations in adjacent monitoring wells. Water elevations in North Doane Lake and West Doane Lake and adjacent monitoring wells have been measured by SLLI (AMEC 2005). These water level measurements indicate that the water elevation in West Doane Lake is typically about 3 ft lower than the groundwater elevation in monitoring well W-09 and that the water elevation in North Doane Lake is about 1 foot lower than in West Doane Lake. Based on these relationships, and the groundwater elevation in monitoring well W-09 in May 2007 (28.65 ft NAVD88), the water elevations in North Doane Lake and West

Doane Lake were estimated to be 24.65 ft and 25.65 ft NAVD88, respectively.

The bottom elevations of the river boundaries were set at the measured bottom elevations of the lakes, which were measured by SLLI (AMEC 2005). The hydraulic conductance for the river boundary was calculated by the method outlined in McDonald and Harbaugh (1988) using the length and width of the model grid cells (25 ft), an assumed uniform lake bottom sediment thickness of 1.0 ft, and a vertical hydraulic conductivity of 0.00011 ft/day for the sediment in North Doane Lake and 0.00013 for the sediment in West Doane Lake. The vertical hydraulic conductivities of the lake sediments are the average vertical hydraulic conductivities measured at seepage meters installed in the lakes by SLLI (AMEC 2005).

8.0 MODEL CALIBRATION

The Arkema groundwater flow model was calibrated to demonstrate that the model is capable of accurately simulating observed groundwater conditions in the model area. Calibration of the flow model was accomplished by using a model design and input parameters that produced simulated groundwater elevations that reasonably matched field measurements.

8.1 CALIBRATION TARGETS

Groundwater elevations measured at the Arkema site and adjacent properties in May 2007 and in July 2005 were selected as the target water levels for steady-state (head) model calibration. The May 2007 groundwater elevations are currently the most complete set of water level measurements from the Arkema site and adjacent properties, and are considered to be representative of groundwater conditions during periods of high precipitation and high discharge in the Willamette River. The July 2005 groundwater elevations are the most complete set of water level measurements from the Arkema site that are representative of groundwater conditions during periods of low precipitation and low discharge in the Willamette River during the summer months. There were no groundwater level measurements made on the adjacent properties during July 2005.

Only limited pumping test data are available from the Arkema site. Short-term (4-hour), constant-rate pumping tests of three wells, PT-1, PT-2 and PT-3, were performed in April 2006 (GeoSyntec 2006). The groundwater elevation measurements made in the pumping and observation during pumping tests of these wells were used as the target water levels for the transient (flow) calibration of the model.

8.2 CALIBRATION METHOD

Calibration of the flow model was achieved by manual trial-and-error adjustment of model input parameters. The general procedures used in the manual calibration of groundwater flow models are described in Anderson and Woessner (1992). Numerous models based on manual calibration methods have been published in technical journals, and have been accepted by regulatory agencies at the state and federal levels.

8.3 *CALIBRATION PROCEDURE*

The Arkema groundwater flow model was first calibrated to the May 2007 groundwater elevations. The groundwater flow model was calibrated by specifying initial estimates of recharge and hydraulic conductivity, and solving the model for steady-state flow conditions. These estimated input parameters were then varied in successive simulations until the steady-state head solution most closely matched the May 2007 calibration target water levels.

After the model was calibrated to May 2007 water levels, the pumping tests of PT-1, PT-2, and PT-3 were simulated with the model. For the simulation of each pumping test, the model grid spacing was reduced to 1 foot around the pumping and observation wells to more accurately simulate the drawdown measured in the pumping and observation wells during the test. Then a well node was added to Layer 1 (Shallow Zone) of the model grid to represent the pumping well, which is screened across the Shallow Zone. The discharge rate of the well node set at the discharge rate recorded during the pumping test (Table 8-1). The flow model was then calibrated to the pumping water levels by using the estimated input parameters and head solution from the calibrated steady-state model, and solving the model for transient flow conditions with a total simulation time equal to the duration of the pumping test (Table 8-1). The input parameters of the model were then varied in successive simulations until the transient drawdown solutions of the model most closely matched the drawdown in water levels measured in the pumping and observation wells during the pumping tests.

As a further check on model calibration, groundwater conditions during a period of low precipitation and low discharge in the Willamette River in the summer months were simulated with the model and the model head solution was compared to the July 2005 groundwater elevations. For this simulation, the recharge rate was reduced from 10 to 0 inches/year (Table 7-1) and the elevation of the constant-head boundary representing the Willamette River was lowered from 11.65 ft to 9.31 ft NAVD88, the average stage elevation in July 2005 (Appendix A, Table 7-2). The elevation of the constant-head boundaries along the model grid margins was also lowered by 2 ft in Layer 1 (Shallow Zone) and 3 ft in the other model layers to correspond to the average change in water levels in the groundwater zones between May 2007 and July 2005. In addition, the stage elevation of the river boundaries representing North Doane Lake and West Doane Lake was lowered by 1.0 foot to simulate lake levels in the summer months (Table 7-1). The hydraulic gradient across the model domain in the calibrated steady-state model was not changed in this simulation. The change (decrease) in the hydraulic gradient between May 2007 and July 2005 is not known since there were no groundwater level measurements made on the adjacent properties during July 2005 (Section 8.1).

8.4 MODEL SOLUTION CONVERGENCE CRITERIA AND VOLUMETRIC MASS BALANCE

A head convergence (HCLOSE in MODFLOW solver packages) and residual convergence (RCLOSE in MODFLOW solver packages) criteria of 0.001 ft were specified for the model simulations. A head convergence criterion three orders of magnitude smaller than the required accuracy of the model head solutions was used to minimize errors in the model solutions due to floating point truncation and rounding.

The volumetric mass balance (difference between total groundwater inflow and outflow simulated by the model) was monitored during model calibration as a check on the model solutions and to identify errors in the model design. Model solutions with less than one- percent volumetric mass balance error were considered to be acceptable. The volumetric mass balance of the calibrated steady-state model is summarized in Table 8-2.

8.5 CALIBRATION RESULTS

8.5.1 Steady-State Calibration

The results of the steady-state (head) calibration of the Arkema groundwater flow model were evaluated both qualitatively and quantitatively. Model calibration results were evaluated qualitatively by comparing contoured maps of calibration target water levels to the model head solutions. The error in the model head solution was also quantified by determining the mean error, mean absolute error, standard deviation, and sum of squares for the model residuals (target head – model head).

The calibrated steady-state head solution has a residual mean of -0.09 ft, an absolute residual mean of 1.50 ft, a residual standard deviation of 1.88 ft, and a residual sum of squares of 768.72 square ft. A complete listing of the target water levels in the steady-state calibration data set, and the model head solutions, residuals and calibration statistics is given in Appendix B. A comparison of the steady-state head solution and the observed water levels is presented in Figure 8-1. The residual error in the steady-state head solution is shown in Figure 8-2. A comparison of the contoured target water levels and steady-state head solutions for Layer 1 (Shallow Zone), Layer 2 (Shallow-Intermediate Silt Zone), Layer 3 (Intermediate Zone), Layer 4 (Deep Zone), Layer 5 (Gravel Zone), and Layer 6 (Fractured Basalt) are shown in Figures 8-3 to 8-7. The statistical measurements and the contoured water level maps show that the calibrated steady-state head solution reasonably matches the water levels in the target wells.

8.5.2 Transient Calibration

The results of the transient (flow) calibration of the Arkema groundwater flow model to the pumping tests of PT-1, PT-2, and PT-3 were evaluated by graphically comparing the drawdown in water levels measured in the pumping and observation wells during the tests to the model drawdown solutions (Figures 8-8 to 8-10). Only one well, PT-2, had a significant yield during testing (Table 8-1). The model drawdown solutions reasonably match the measured drawdowns during the pumping test of this well (Figure 8-9). The drawdown in the pumping well simulated by the model is somewhat less than the drawdown observed during the test due to well losses that occurred in the pumping well, which are not simulated by the model (Anderson and Woessner, 1992). The other two wells tested, PT-1 and PT-2, had very low yields (Table 8-2). The model drawdown solution reasonably matched the measured drawdown in PT-1 during the pumping test of this well, but not the drawdown in the observation well, MW-33 (Figure 8-8). The large drawdown that was measured in the observation well during the test is inconsistent with the low yield of PT-1 and could not be simulated with the model. The drawdown in water levels in PT-3 during the pumping test of this well fluctuated significantly and only about 0.1 ft of drawdown occurred in the observation well, MWA-19 (Figure 8-10). The model drawdown solution roughly matches the measured drawdowns during the pumping test of this well, but does not match the unusual drawdown curves in the pumping and observation wells.

8.5.3 Calibration of Model to Groundwater Conditions in Summer Months

The steady-state head solution from the simulation of groundwater conditions during a period of low precipitation and low discharge in the Willamette River in the summer months has a residual mean of -0.77 ft, an absolute residual mean of 1.32 ft, a residual standard deviation of 1.67 ft, and a residual sum of squares of 234.02 square ft. A complete listing of the target water levels for this simulation, and the model head solutions, residuals and calibration statistics is given in Appendix B. A comparison of the steady-state head solution and the observed water levels is presented in Figure 8-11. The residual error in the steady-state head solution is shown in Figure 8-12. These statistical measurements show that the model can reasonably simulate periods of low precipitation and low discharge in the Willamette River during the summer months. The residual error in the model head solution is slightly high (Figure 8-12) because the hydraulic gradient across the site was not reduced in this simulation (Section 8.3).

8.6 SENSITIVITY OF MODEL TO INPUT PARAMETERS

The sensitivity of the steady-state model calibration to changes in the values of the input parameters was evaluated for: recharge rate; stage elevation of the constant-head boundaries representing Willamette River; and hydraulic conductivity of each model layer. Each of these key input parameters was changed to a lower and a higher value while all other input parameters were kept at their calibrated value. The recharge rate and the stage elevation of the constant-head boundaries representing Willamette River were decreased and increased by 50 percent (0.5 to 1.5 times the calibrated values). Since the hydraulic conductivities of soil and bedrock typically have a greater degree of variability, the hydraulic conductivities of the model layers were decreased and increased by one order of magnitude (0.1 to 10 times the calibrated values). The impact of the changes in the values of the input parameters on the model calibration was evaluated by recording the change in the sum of squares for the model residuals (target head – model head).

The results of the sensitivity analysis are shown graphically in Figure 8-13. The model calibration is most sensitive to changes in the recharge rate, the stage elevation of the constant-head boundaries representing Willamette River, to a decrease in the values of hydraulic conductivity in Layer 1 (Shallow Zone), and to increases in the values of hydraulic conductivity in model Layers 2 to 6. The recharge rate and stage elevation of the constant-head boundaries representing Willamette River control the overall rate of water inflow to the model as groundwater recharge and water outflow from the model as groundwater discharge to the Willamette River (Table 8-2). The hydraulic conductivities control the elevation of the groundwater levels simulated in the model layers, which represent the major groundwater zones identified in the model area.

9.0 UNCERTAINTY IN MODEL SIMULATIONS

There are uncertainties in the groundwater flow field simulated by a numerical model. These uncertainties are due to the simplifications and assumptions in the design of the model, uncertainty in the boundary conditions and input parameters, and the limited data that is available to calibrate the model to the observed groundwater flow systems at a site.

The uncertainty in the stage elevation of the constant-head boundaries representing the Willamette River in the model is low. The USGS maintains a gaging station approximately 5 miles upstream of the Arkema site that continuously monitors the flow and stage elevation of the Willamette River (Section 3.5). The data from this gaging station were used to set the elevation of the constant-head boundaries representing the Willamette River in the model.

The uncertainty in the elevation of the constant-head boundaries along the northwest, southwest, and southeast margins of model grid is relatively low. The elevations of these constant-head boundaries were set by extrapolating groundwater elevations in nearby monitoring wells to the boundaries. The elevations of the constant-head boundaries in Layer 2 (Shallow-Intermediate Silt Zone) are most uncertain because few monitoring wells are screened in Shallow-Intermediate Silt Zone (Figure 4-3).

The uncertainty in the recharge rate is relatively low. Groundwater recharge rates in the Willamette River Basin have been extensively studied using precipitation-runoff models and are relatively well known (Section 7.1). However, local recharge rates can vary significantly due to variations in topography, vegetation, soil characteristics, and the extent of development of the land surface.

The uncertainty in the hydraulic conductivities in the model is moderate. Only a limited number of aquifer tests have been performed in the model area and on the adjacent properties to measure the hydraulic conductivity of the groundwater zones (Section 4.2).

The uncertainty in the model calibration is low to significant. A comprehensive set of groundwater elevations measurements were made in monitoring wells in the model area and on adjacent properties in May 2007 for the steady-state model calibration (Section 8.1). Therefore, the uncertainty in the groundwater elevations simulated by the model is relatively low, except in areas where there were few water level measurements could be obtained. Data from only three short-term pumping tests of the Shallow Zone in the model area were available for the transient (flow) calibration of the model. Therefore, there is a significant uncertainty in the flow rates simulated by model in the Shallow Zone on the properties adjacent to the Arkema site and in the deeper groundwater zones where pumping test data are not available for calibration of the model.

Groundwater flow in the Columbia River Basalt is very complex. It occurs in fractured zones at the base of individual flows, in scoriaceous and fractured zones at the top of individual flows, and within interflow zones. The groundwater model assumes that groundwater flow in the basalt occurs only as porous media flow and that the hydraulic properties of the basalt are relatively uniform. Therefore, there is a high degree of uncertainty in flow field simulated by the model for the basalt (Layers 6 and 7).

10.0 REFERENCES

AMEC Earth & Environmental, Inc. 2005. *Groundwater Transport Evaluation Report, RP – Portland Site*. AMEC Earth & Environmental, Inc. March 2005.

AMEC Earth & Environmental, Inc. 2006. *Stage 1 Source Control Evaluation Technical Memorandum RP – Portland Site.* AMEC Earth & Environmental, Inc. May 2006.

AMEC Earth & Environmental, Inc. 2007. *Stage 2 Source Control Evaluation Technical Memorandum RP – Portland Site.* AMEC Earth & Environmental, Inc. June 2007.

American Society for Testing and Materials 1996. *ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling* ASTM Publication Number 03-418096-38, 148 pp.

Anderson, Mary P. and W.W. Woessner 1992. *Applied Groundwater Modeling*. Academic Press, Inc., San Diego, CA, 381 pp.

City of Portland 2001. Guild's Lake Industrial Sanctuary Plan. City of Portland, Bureau of Planning. 21 December 2001.

Environmental Simulations, Inc. 2004. *Guide to Using Groundwater Vistas, Version 4.0.* Herndon, VA.

ERM-West, Inc. 2007. *Site Wide Groundwater Monitoring Report – April 2007 Monitoring Event, Arkema, Inc. Facility, Portland, Oregon.* ERM-West, Inc. October 2007.

Exponent 1999. Elf Atochem Acid Plant Area Remedial Investigation Interim Data Report. Exponent, Lake Oswego, Oregon. June 1999.

Fenneman, N.M. 1931. *Physiography of the Western United States*. McGraw-Hill Book Company, Inc., 534 p.

GeoSyntec Consultants 2006. *Arkema Active Pilot Test Workplan*. GeoSyntec Consultants. July 2006

Geraghty & Miller 1991. *Hydrogeological Investigation of the Doane Lake Area, Portland, Oregon.* Geraghty & Miller. February 1991.

Groundwater Solutions, Inc. 2003. *Upland Groundwater Data Review Report Mile 2 – 11 Lower Willamette River.* Groundwater Solutions, Inc., Portland, Oregon 2003.

Golden Software, Inc. 2002. *Surfer 8.0 User's Guide*. Golden, CO.

Harbaugh, A.W. 2005. *MODFLOW 2005, The U.S. Geological Survey Modular Ground-Water Model – the Ground-Water Flow Process*. U.S Geological Survey Techniques and Methods 6-A16.

McDonald, M.G. and A.W. Harbaugh 1988. *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model.* Techniques of Water-Resources Investigations of the United States Geological Survey, Book 6, Chapter A1, 576 pp.

Lee, K.L. and J. C. Risley 2002. *Estimates of Ground-Water Recharge, Base Flow, and Stream Reach Gains and Losses in the Willamette River Basin, Oregon*. U.S. Geological Survey Water Resources Investigation Report 01-4215, 53 pp.

Oregon Climate Service 2005. *Climate of Multnomah County.* www.ocs.oregonstate.edu/county_climate/Multnomah_files/Multnomah.html.

U. S. Army Corps of Engineers 2004. *Portland-Vancouver Harbor Information Package, Reservoir Regulation and Water Quality Section*. November 2004.

U.S. Department of Commerce. 1968. Climatic Atlas of the United States.

U.S. Environmental Protection Agency (USEPA) 1993. *A Manual of Instructional Problems for the U.S.G.S. MODFLOW Model*, USEPA/600/R93/010.

USEPA 1994. *Guidelines for Hydrogeologic Modeling*. United States Environmental Protection Agency Region 10, Environmental Services Division, Seattle, WA. March 1994.

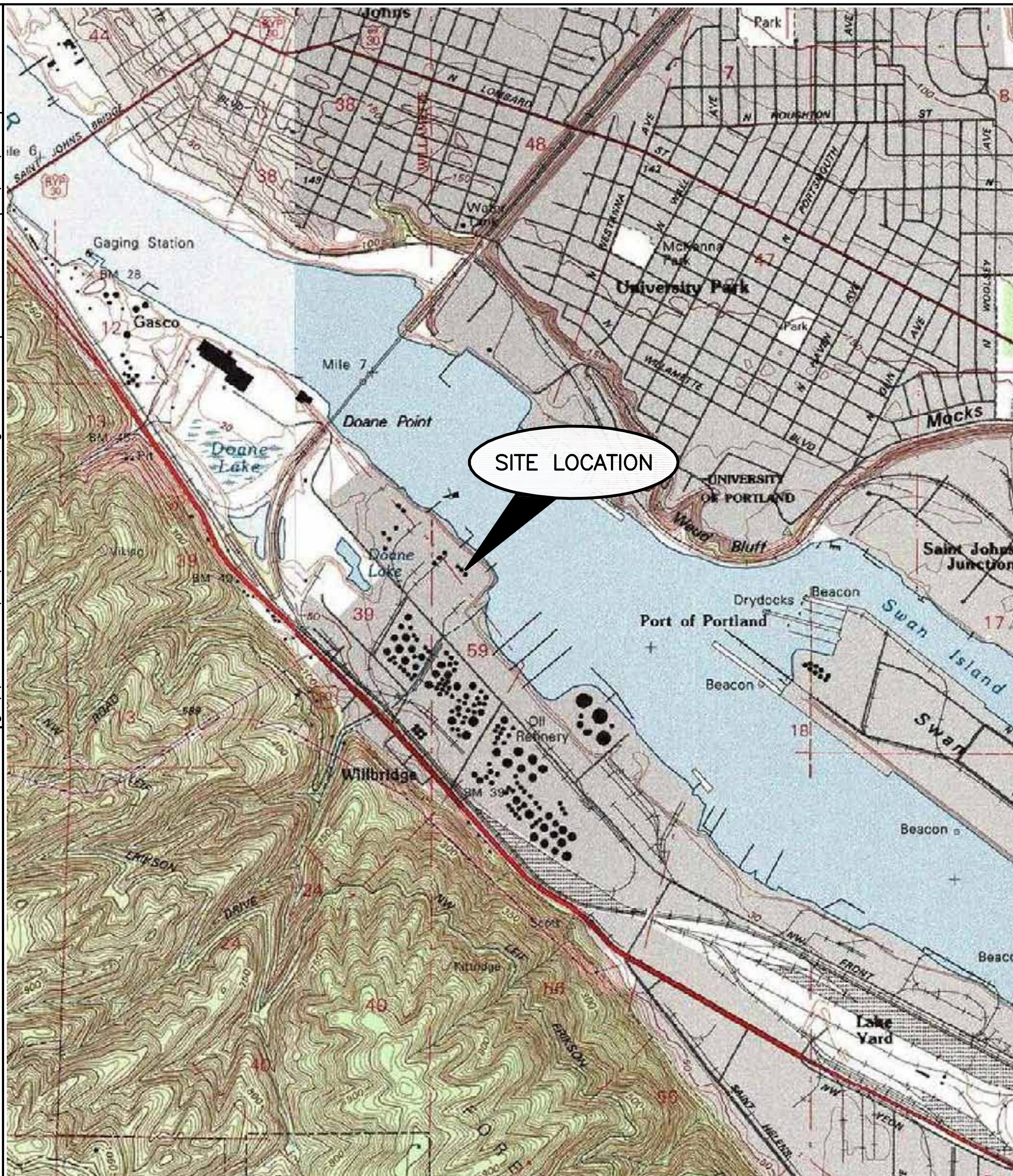
Figures

CAD File: g:\\0057055\30\site location.dwg

Drawn By: R. Olson

Date: 11/01/07

Project No. 0057055.30



SCALE 1:24,000

1 — 1/2 — 0 — 1 MILE

1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET

1 — .5 — 0 — 1 KILOMETER

N

References:
TOPO!® Software
U.S.G.S. 7.5 Minute Series (Topographic) Quadrangle,
Linnton, OR Version: 1990; Current: 1990
Portland, OR WA Version: 1990; Current: 1990

Figure 1-1

Site Location Map
Arkema, Inc.
Portland, Oregon

ERM 11/07

Aerial Photography - July, 2005

True North
Plant North

0 400 800
Feet

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Figure 1-2
Site Layout
Arkema, Inc.
Portland, Oregon

ERM 10/07

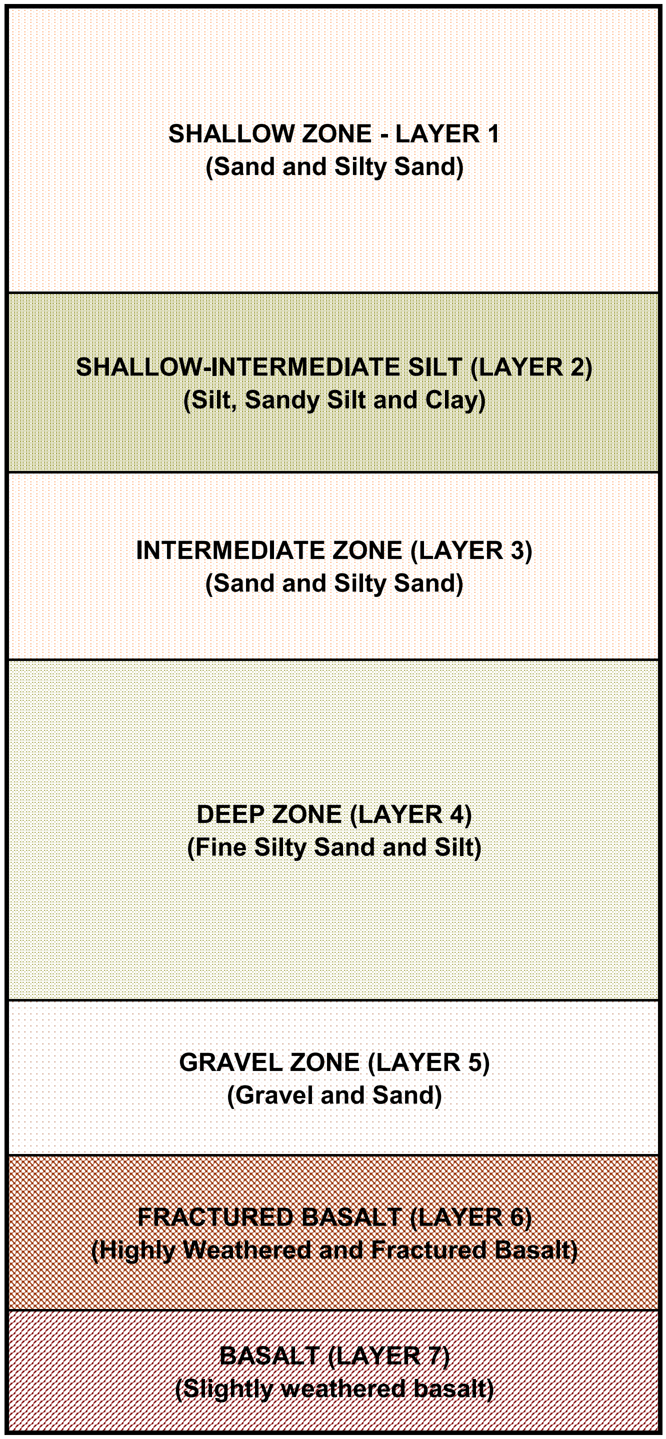


Figure 4-1
Hydrostratigraphic Units
Arkema, Inc.
Portland, Oregon
ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Groundwater Elevation Contour (ft NAVD88)

Shallow Zone Monitoring Well

Monitoring Well Not Used for Contouring

True North

Plant North

0 400 800

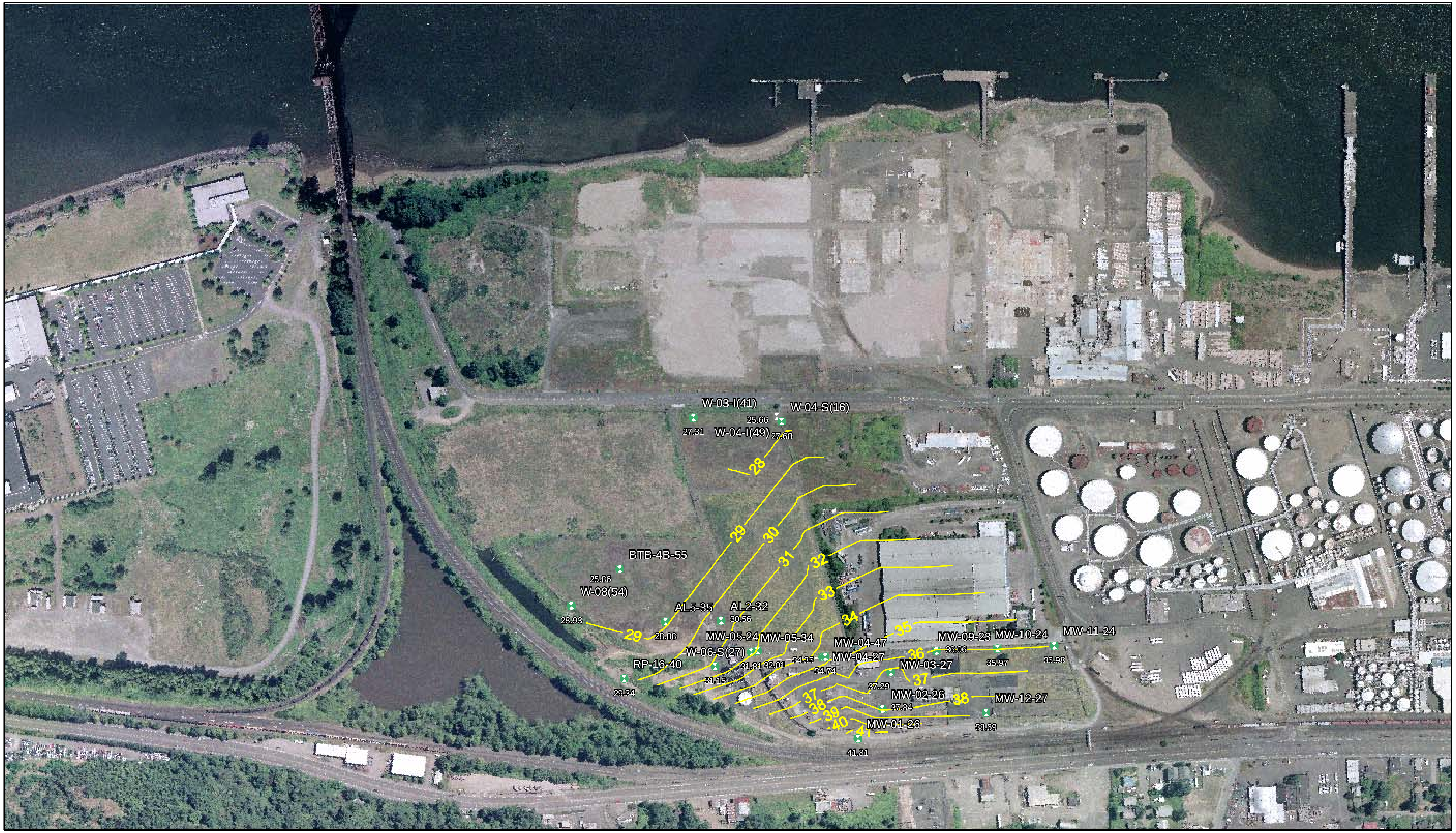
Feet

Figure 4-2

Shallow Zone Groundwater Elevations
May 2007
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND

- Groundwater Elevation Contour (ft NAVD88)
- Shallow-Intermeidate Silt Zone Monitoring Well
- Monitoring Well Not Used for Contouring

N True North

N Plant North

0 400 800

Feet

Figure 4-3

Shallow-Intermediate Silt Zone Groundwater Elevations
May 2007
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No.
0057055
Date:
10/03/07
Drawn By:
T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Groundwater Elevation Contour (ft NAVD88)

Intermediate Zone Monitoring Well

Monitoring Well Not Used for Contouring

True North

Plant North

0 400 800

Feet

Figure 4-4

Intermediate Zone Groundwater Elevations
May 2007
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Groundwater Elevation Contour (ft NAVD88)

Deep/Gravel Zone Monitoring Well

Monitoring Well Not Used for Contouring

True North

Plant North

0 400 800

Feet

Figure 4-5

Deep/Gravel Zone Groundwater Elevations
May 2007
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Groundwater Elevation Contour (ft NAVD88)

Fractured Basalt Monitoring Well

Monitoring Well Not Used for Contouring

True North

Plant North

0 400 800

Feet

Figure 4-6

Fractured Basalt Groundwater Elevations
May 2007
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

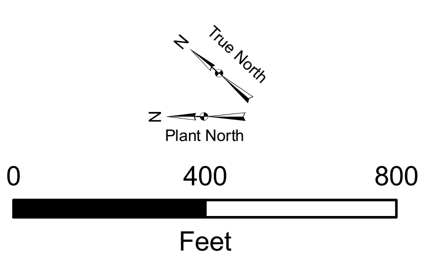


Figure 6-1

Finite-Difference Model Grid
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

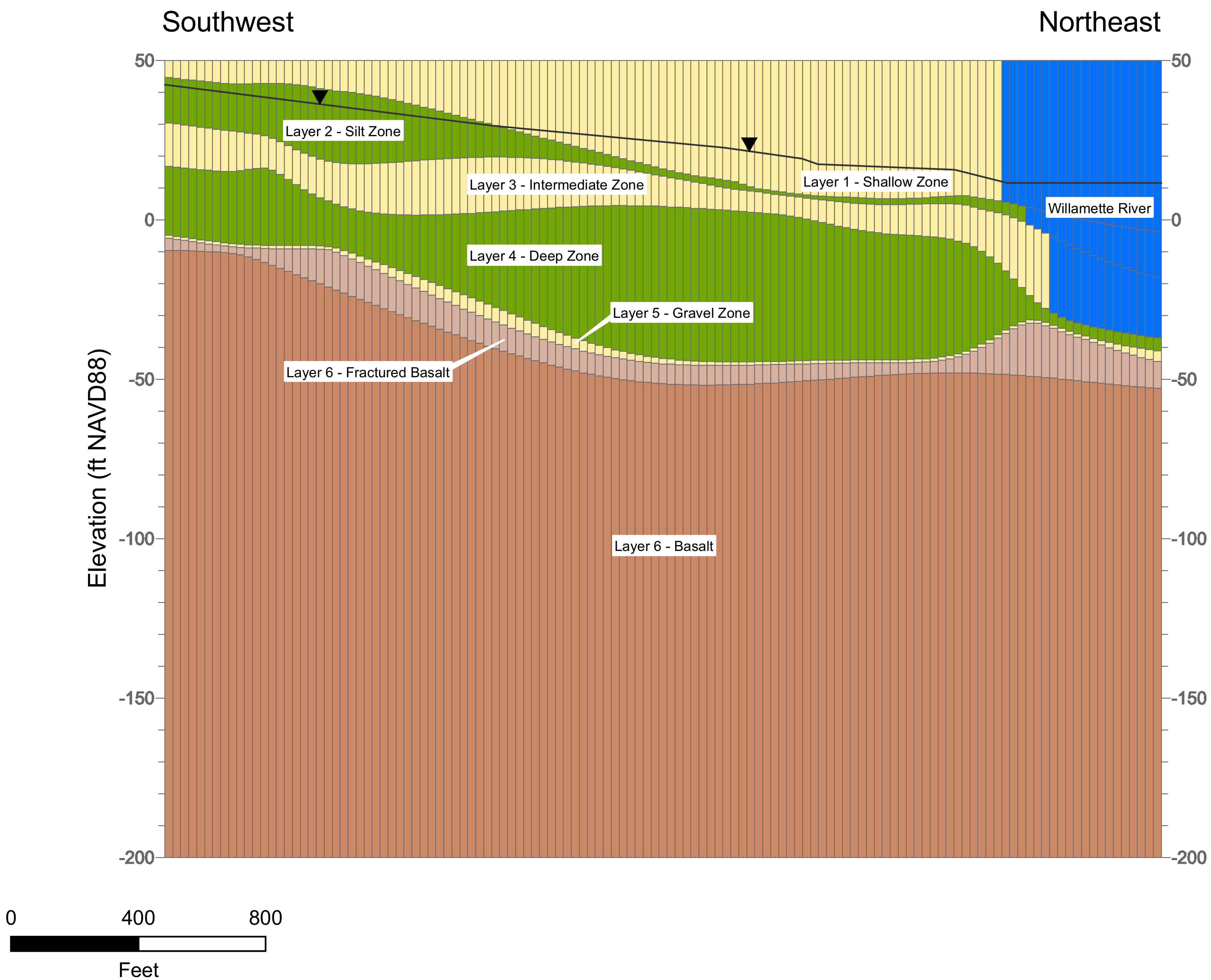


Figure 6-2

Model Grid Layers
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No. 0057055

Date: 10/07/07

Drawn By: T. Cota

GIS File:

Aerial Photography - July, 2005

LEGEND

Elevation Contour (ft NAVD88)

MWA-5 Monitoring Well/Transition Zone Boring

True North

N

Plant North

0 400 800

Feet

Figure 6-3

Bottom Elevation of Shallow Zone (Layer 1)

Arkema, Inc.

Portland, Oregon

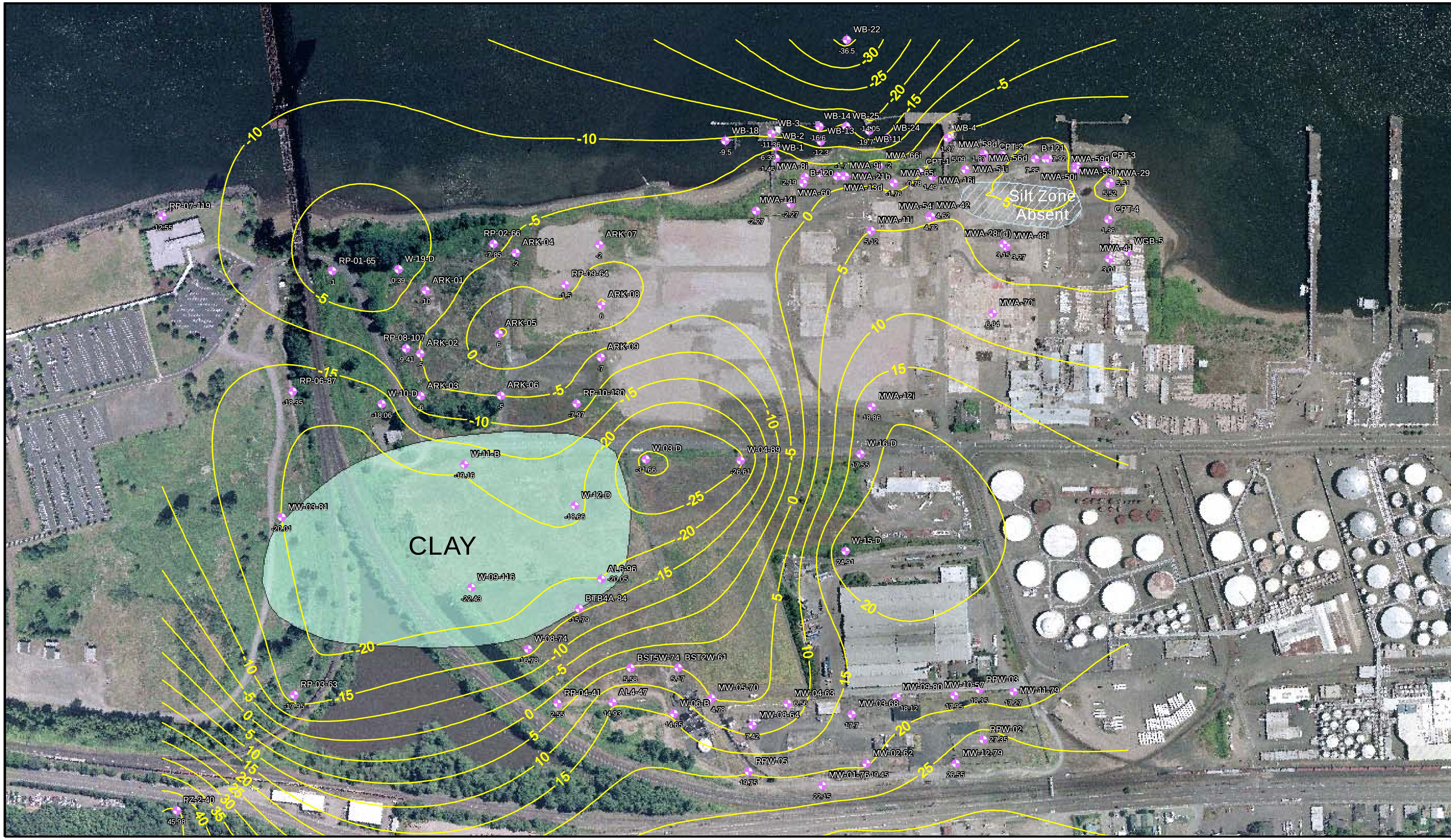
ERM 10/07

Project No. 0057055

Date: 10/07/07

Drawn By: T. Cota

GIS File:



Aerial Photography - July, 2005

LEGEND

Elevation Contour (ft NAVD88)

MWA-8i Monitoring Well/Transition Zone Boring

True North

Plant North

0 400 800

Feet

Figure 6-4

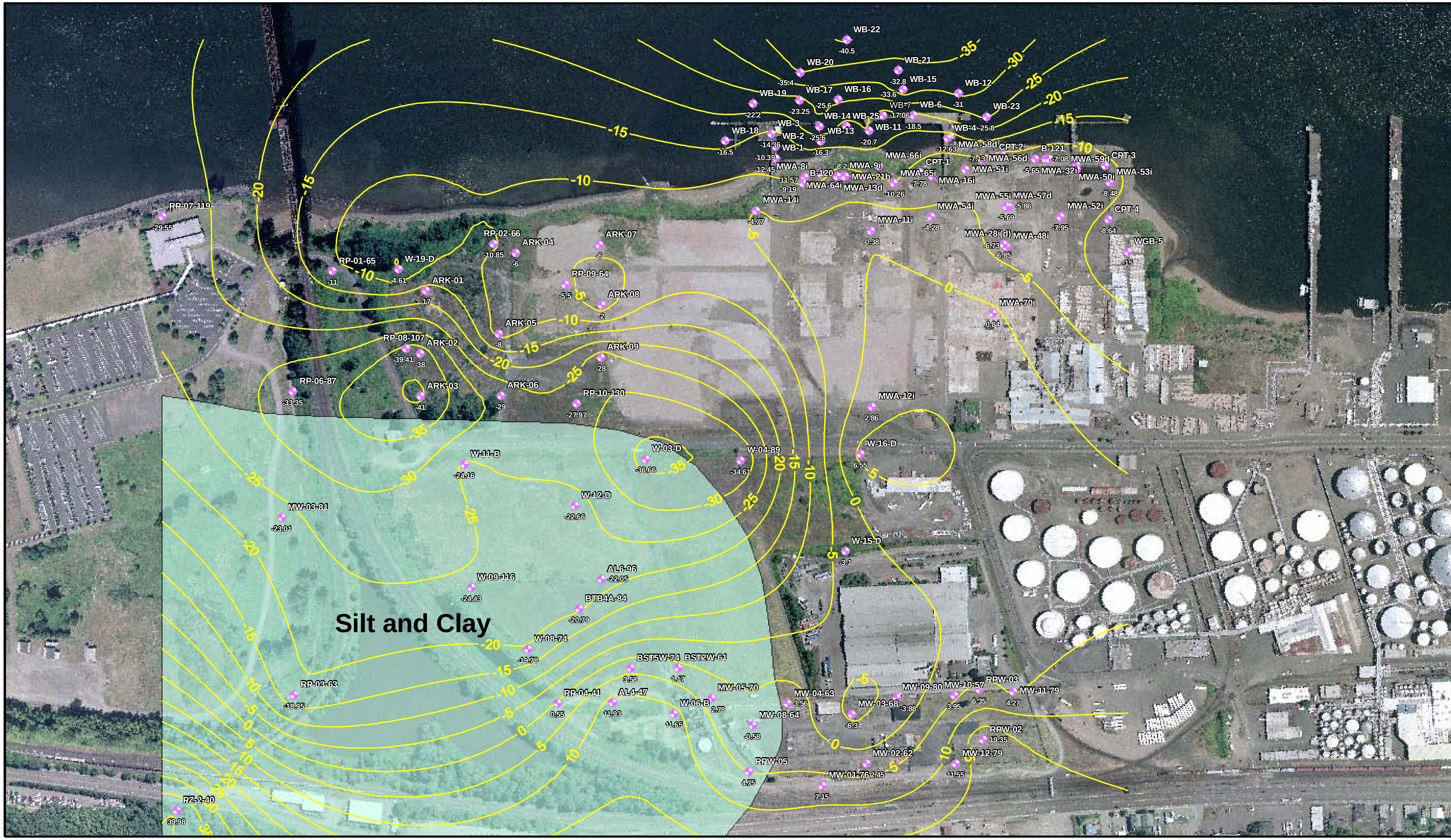
Bottom Elevation of Shallow-Intermediate Silt Zone (Layer 2)

Arkema, Inc.

Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/07/07
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND

Elevation Contour (ft NAVD88)

MWA-8i Monitoring Well/Transition Zone Boring

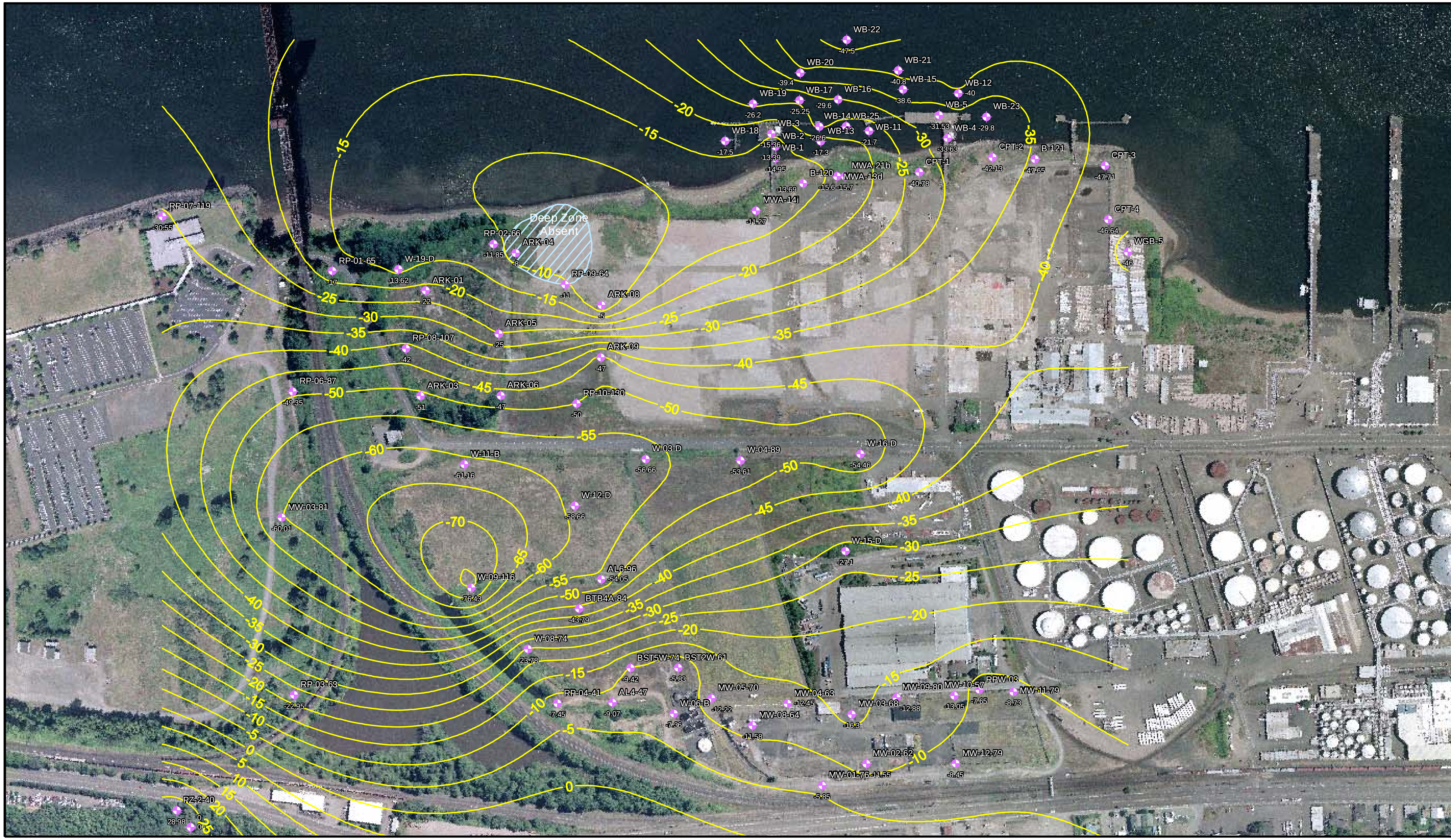
True North
Plant North

0 400 800
Feet

Figure 6-5
Bottom Elevation of Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No.	Date:	Drawn By:	GIS File:
0057055	03/14/07	T. Cota	



Aerial Photography - July, 2005

LEGEND

Elevation Contour (ft NAVD88)

MWA-13d Monitoring Well/Transition Zone Boring

N True North

N Plant North

0 400 800

Feet

Figure 6-6

Bottom Elevation of Deep Zone (Layer 4)
Arkema, Inc.
Portland, Oregon

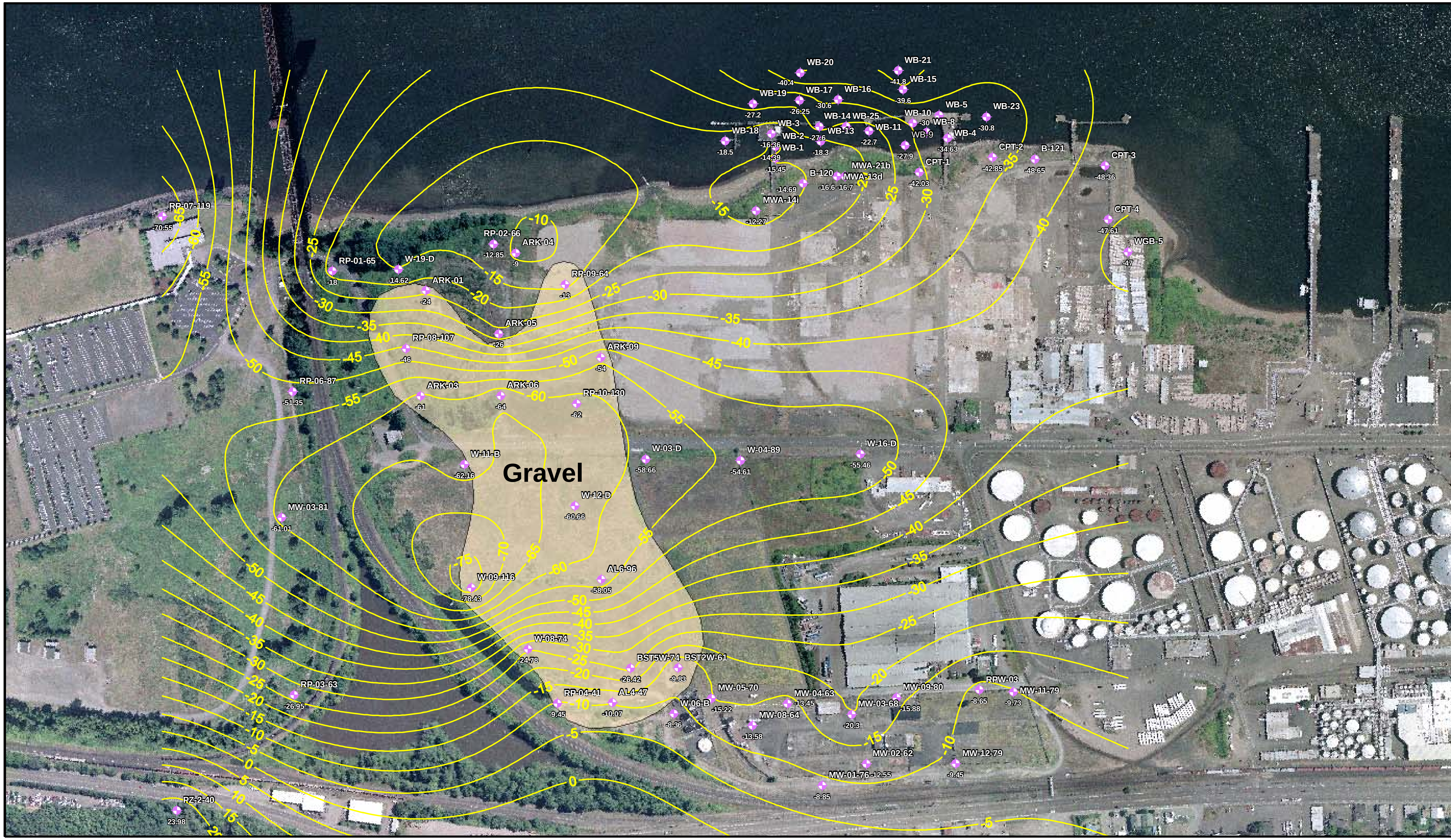
ERM 03/07

Project No. 0057055

Date: 03/14/07

Drawn By: T. Cota

GIS File:



Aerial Photography - July, 2005

LEGEND

Elevation Contour (ft NAVD88)

MWA-13d Monitoring Well/Transition Zone Boring

True North

Plant North

0 400 800

Feet

Figure 6-7

Bottom Elevation of Gravel Zone (Layer 5)

Arkema, Inc.

Portland, Oregon

ERM 03/07

Project No.
0057055

Date:
10/07/07

Drawn By:
T. Cota

GIS File:

Aerial Photography - July, 2005

LEGEND

Elevation Contour (ft NAVD88)

MWA-21b
Monitoring Well

N True North

N Plant North

0 400 800

Feet

Figure 6-8

Bottom Elevation of Fractured Basalt (Layer 6)

Arkema, Inc.

Portland, Oregon

ERM *10/07*

Project No.
0057055
Date:
10/03/07
Drawn By:
T. Cota
GIS File:

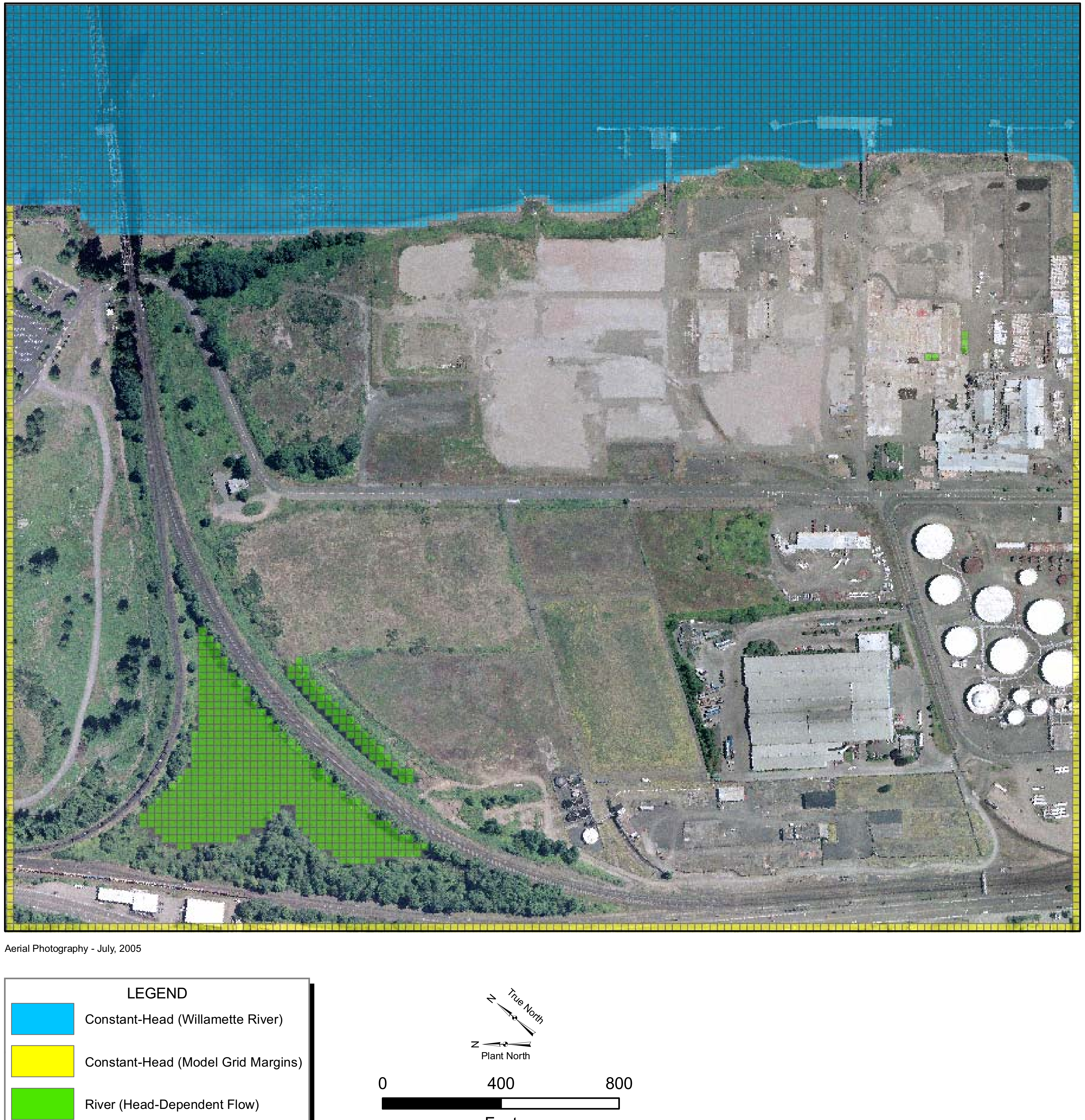


Figure 6-9
Flow Boundary Conditions
Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No.
0057055

Date:
10/03/07

Drawn By:
T. Cota

GIS File:

Aerial Photography - July, 2005

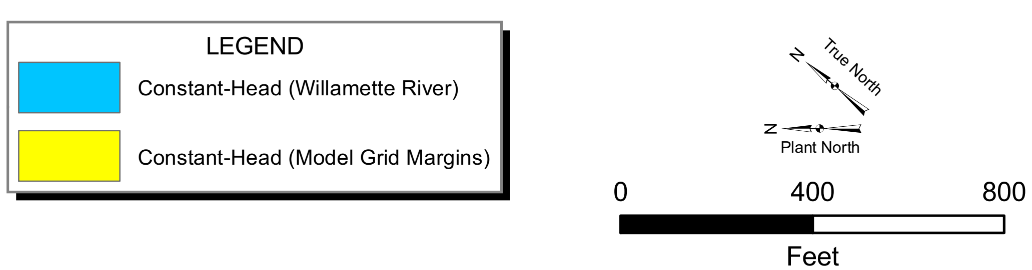


Figure 6-10
Flow Boundary Conditions
Shallow-Intermediate Silt Zone (Layer 2)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Constant-Head (Willamette River)

Constant-Head (Model Grid Margins)

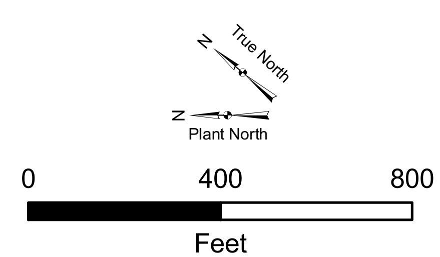


Figure 6-11

Flow Boundary Conditions
Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No.: 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

- Constant-Head (Willamette River)
- Constant-Head (Model Grid Margins)

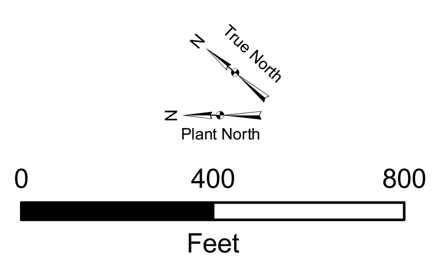


Figure 6-12
Flow Boundary Conditions
Deep Zone (Layer 4)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No.
0057055
Date:
10/03/07
Drawn By:
T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Constant-Head (Willamette River)

Constant-Head (Model Grid Margins)

N True North

N Plant North

0 400 800

Feet

Figure 6-13

Flow Boundary Conditions
Gravel Zone (Layer 5)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Aerial Photography - July, 2005

LEGEND

Constant-Head (Willamette River)

Constant-Head (Model Grid Margins)

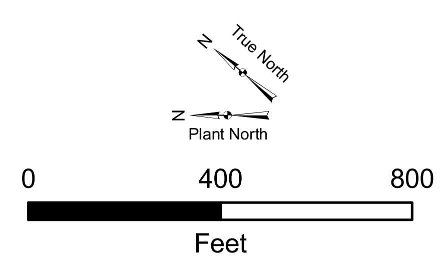


Figure 6-14

Flow Boundary Conditions
Fractured Basalt (Layer 6)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Constant-Head (Willamette River)

Constant-Head (Model Grid Margins)

True North
N

N
Plant North

0 400 800

Feet

Figure 6-15

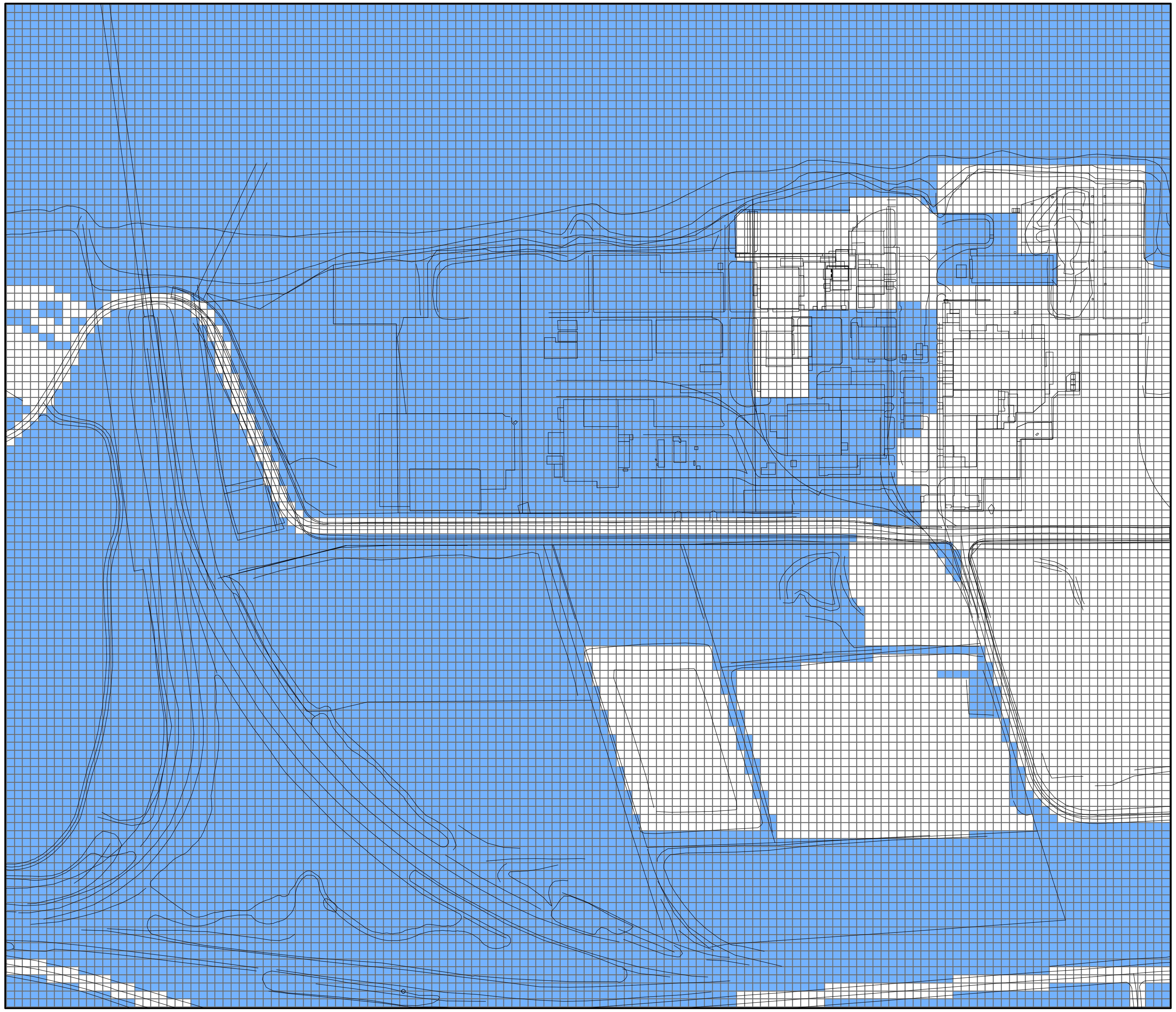
Flow Boundary Conditions

Basalt (Layer 7)

Arkema, Inc.

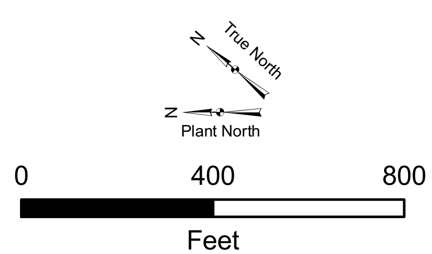
Portland, Oregon

ERM *10/07*



Aerial Photography - July, 2005

LEGEND
Recharge Rate
10.0 in/yr
0.0 in/yr



Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Figure 7-1
Recharge Zonation
Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

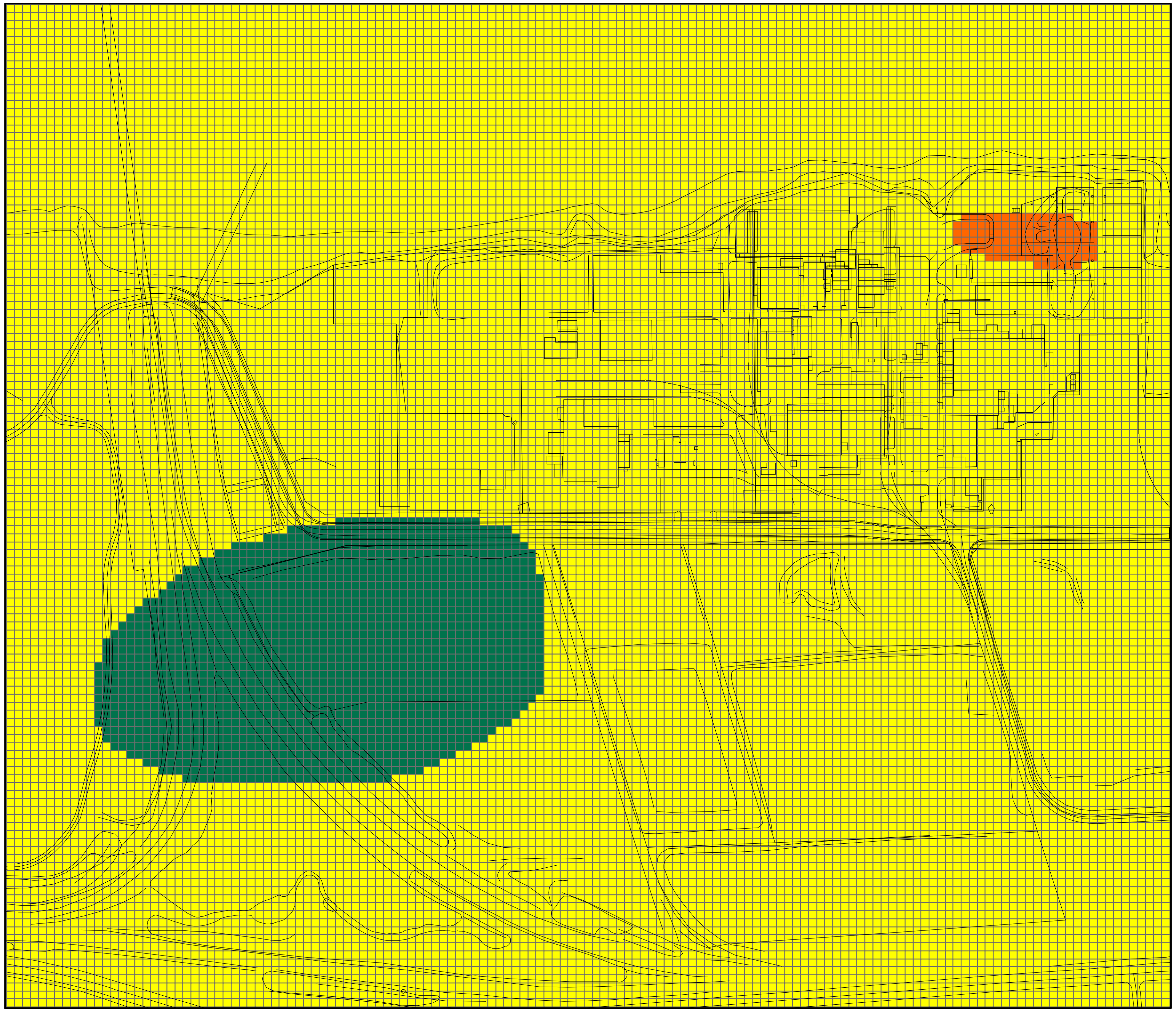
ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Figure 7-2
Hydraulic Conductivity Zonation
Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND
Hydraulic Conductivity

Orange	190 ft/day
Yellow	1.0 ft/day
Green	0.01 ft/day

N True North
N Plant North

0 400 800
Feet

Figure 7-3
Hydraulic Conductivity Zonation
Shallow-Intermediate Silt Zone (Layer 2)
Arkema, Inc.
Portland, Oregon

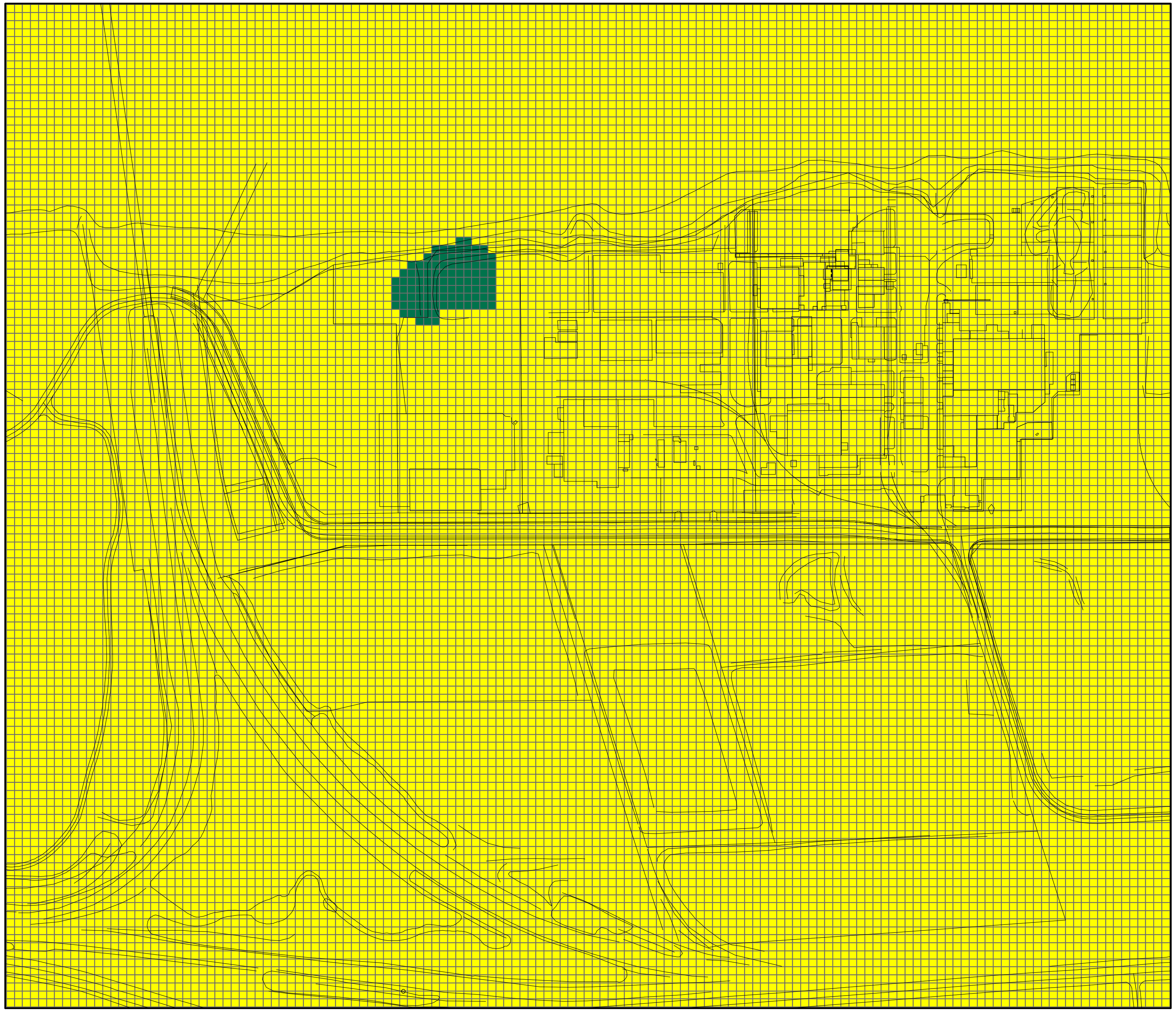
ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Figure 7-4
Hydraulic Conductivity Zonation
Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND
Hydraulic Conductivity
10 ft/day
1.0 ft/day

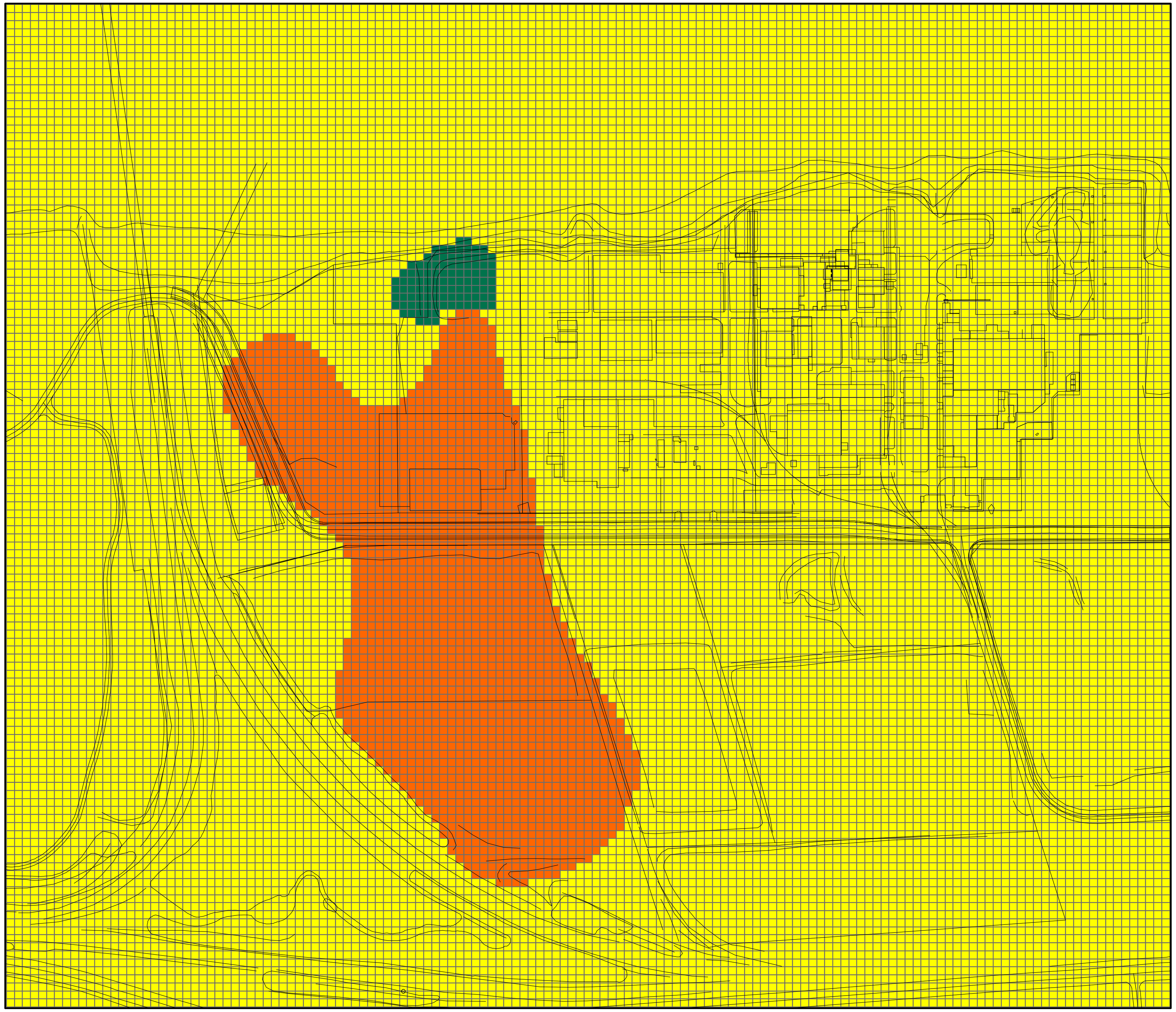
N True North
N Plant North

0 400 800
Feet

Figure 7-5
Hydraulic Conductivity Zonation
Deep Zone (Layer 4)
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

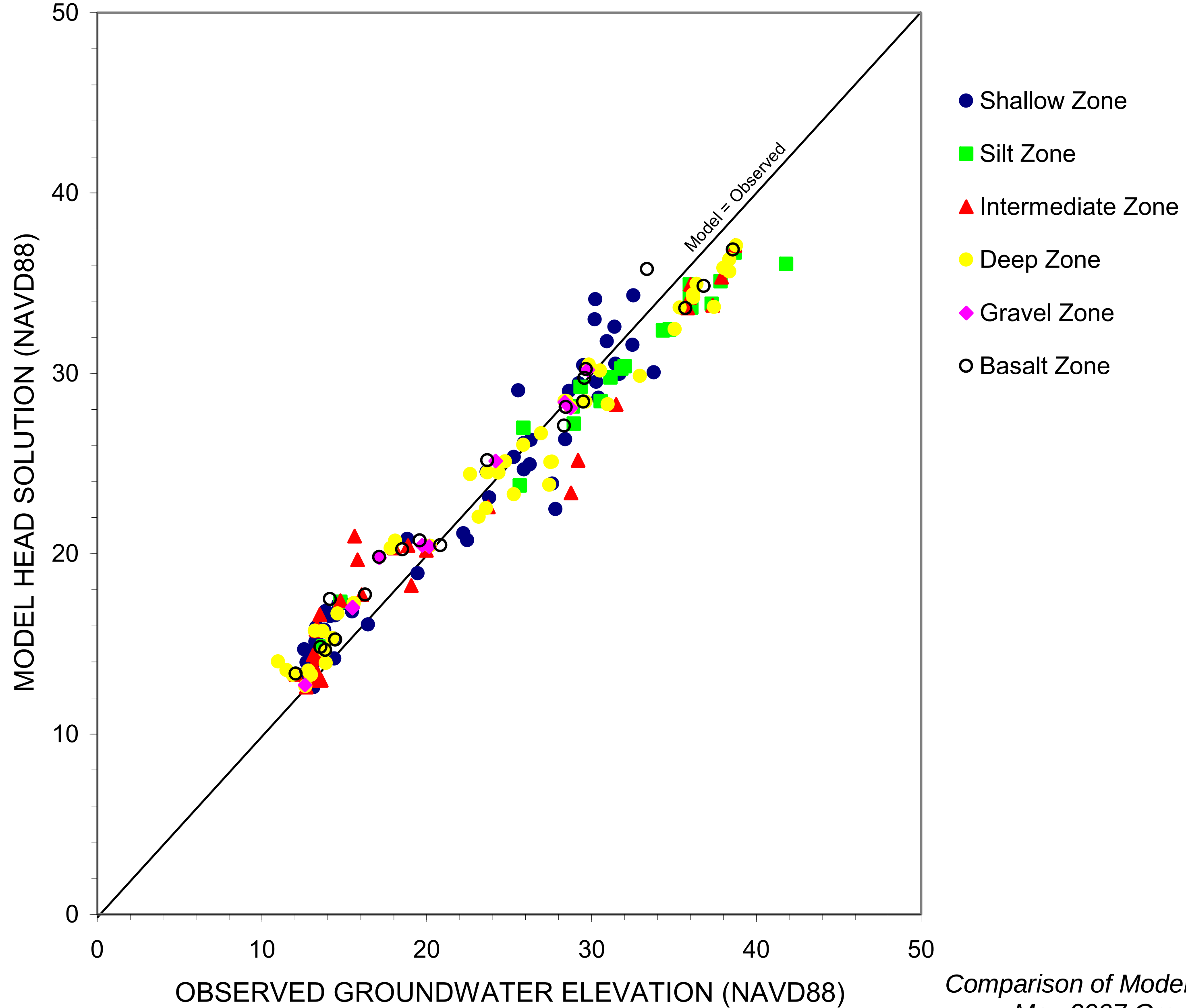
LEGEND
Hydraulic Conductivity
150 ft/day
10 ft/day
5.0 ft/day

True North
Plant North

0 400 800
Feet

Figure 7-6
Hydraulic Conductivity Zonation
Gravel Zone (Layer 5)
Arkema, Inc.
Portland, Oregon

ERM 10/07

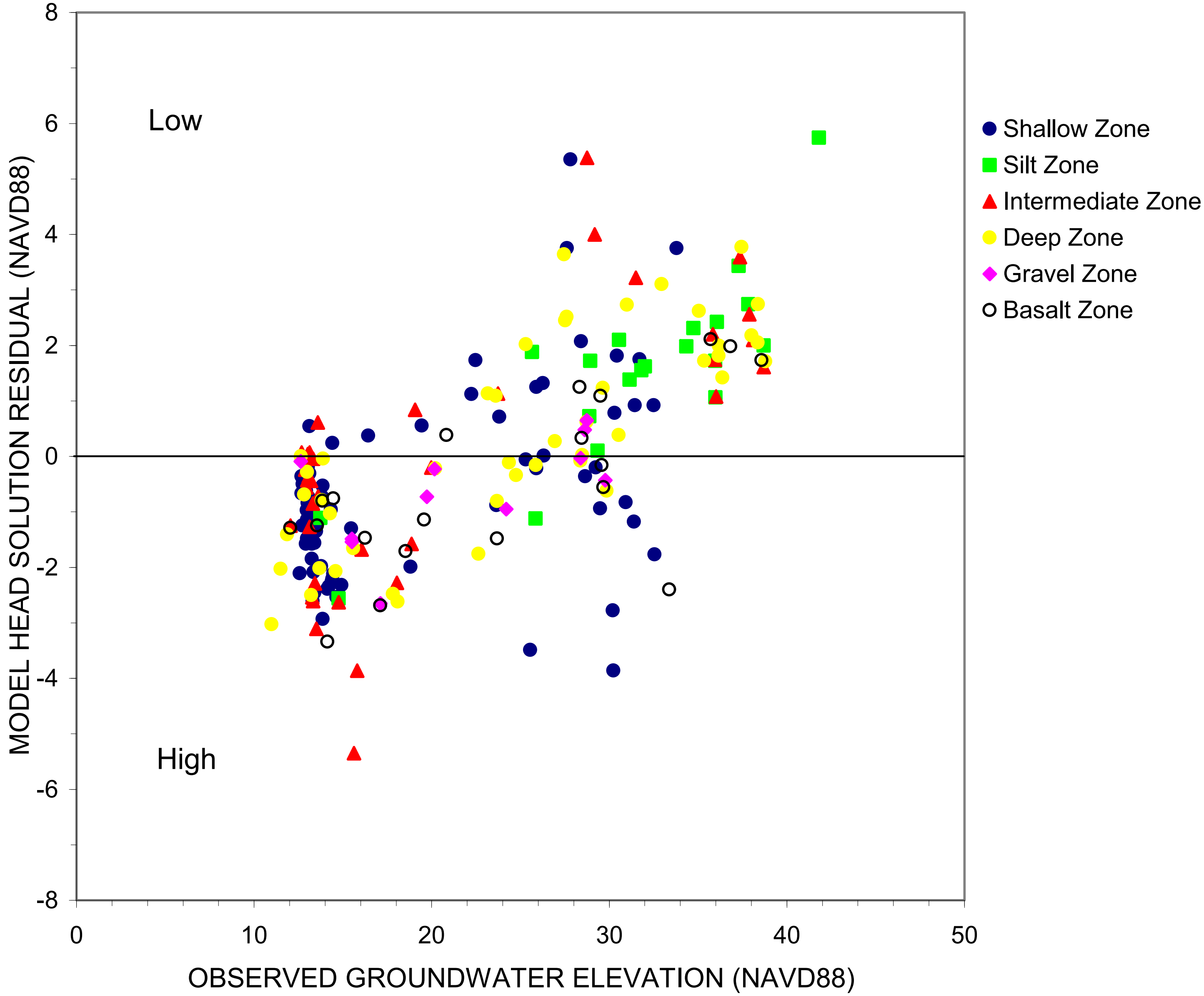


Project No. 0057055
Drawn By: T. Cota
Date: 10/03/07
GIS File:

Figure 8-1

Comparison of Model Head Solution and May 2007 Groundwater Elevations
Arkema, Inc.
Portland, Oregon

ERM 10/07



Project No. 0057055

Drawn By: T. Cota

Date: 10/03/07

GIS File:

Figure 8-2

Comparison of Model Head Solution Residuals and May 2007 Groundwater Elevations
Arkema, Inc.
Portland, Oregon

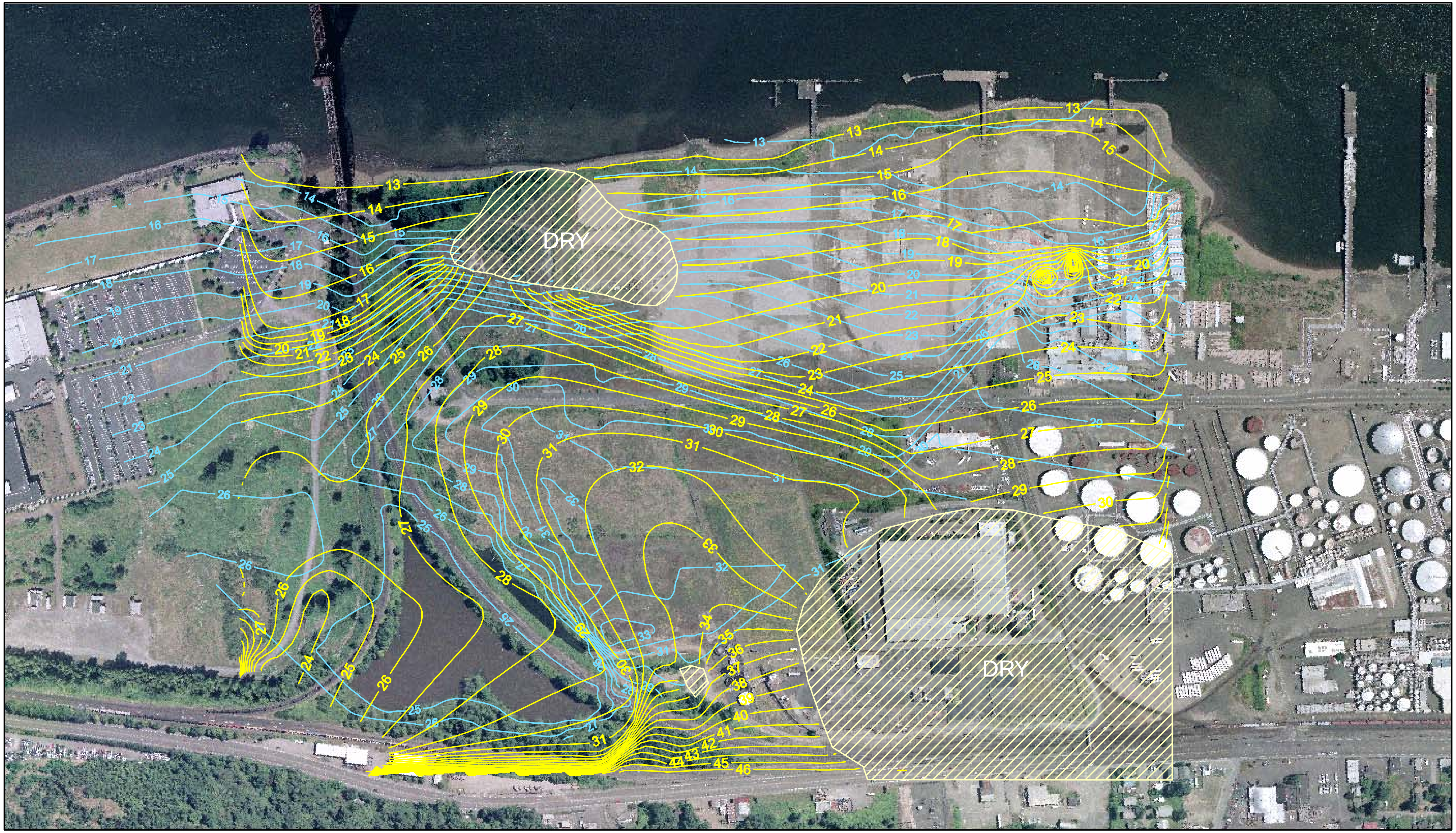
ERM 10/07

Project No. 0057055

Date: 10/03/07

Drawn By: T. Cota

GIS File:



Aerial Photography - July, 2005

LEGEND

- Model Head Solution (ft NAVD88)
- Dry Areas
- May 2007 Groundwater Elevations (ft NAVD88)

N True North

N Plant North

0 400 800

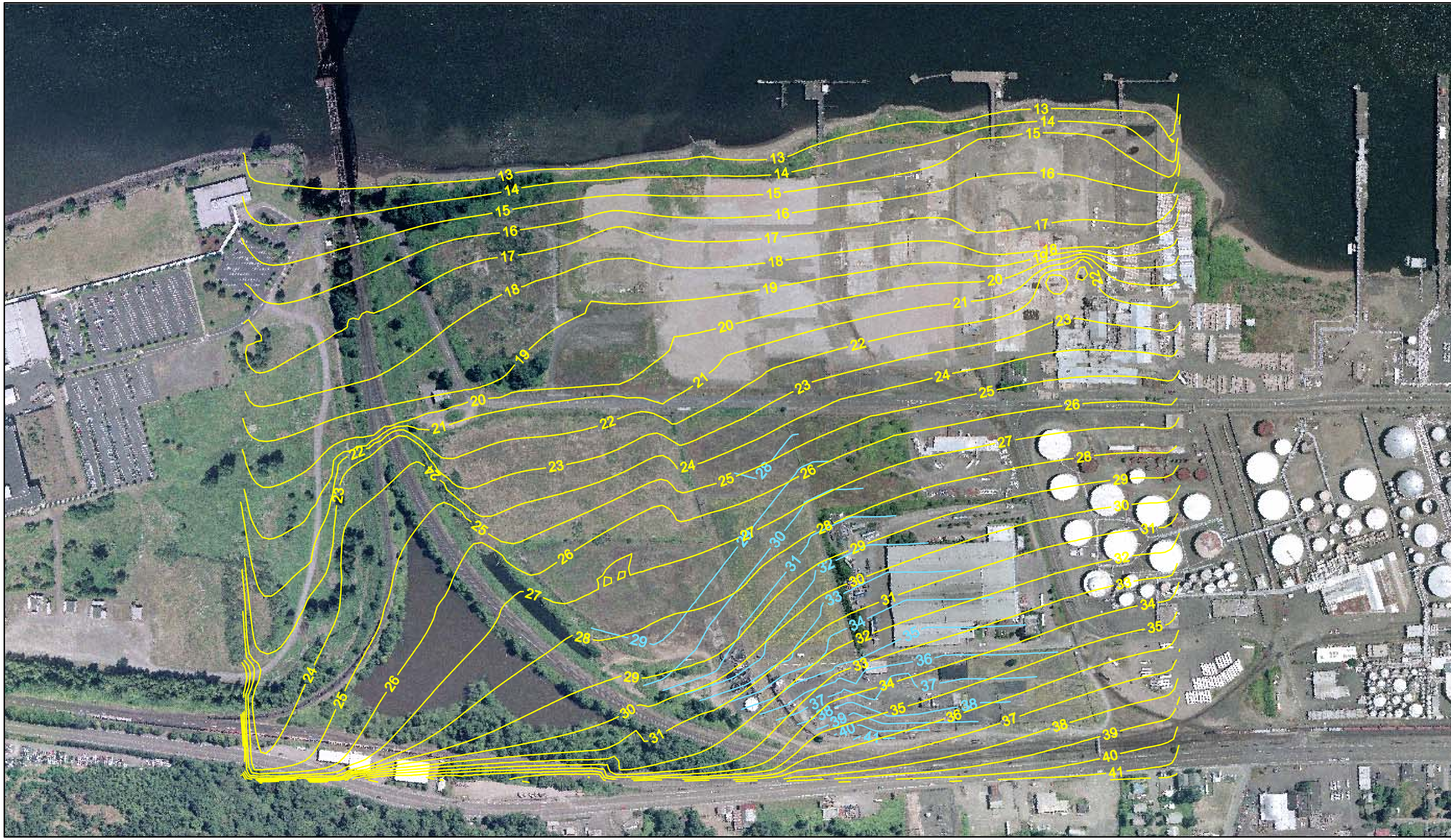
Feet

Figure 8-3

Model Head Solution and May 2007 Groundwater Elevations
Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND

- Model Head Solution (ft NAVD88)
- May 2007 Groundwater Elevations (ft NAVD88)

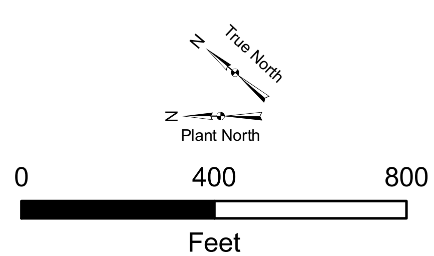


Figure 8-4

Model Head Solution and May 2007 Groundwater Elevations
Shallow-Intermediate Silt Zone (Layer 2)
Arkema, Inc.
Portland, Oregon

ERM *10/07*

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

- Model Head Solution (ft NAVD88)
- May 2007 Groundwater Elevations (ft NAVD88)

N True North
N Plant North

0 400 800
Feet

Figure 8-5

Model Head Solution and May 2007 Groundwater Elevations
Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND

Model Head Solution (ft NAVD88)

May 2007 Groundwater Elevations (ft NAVD88)

True North
Plant North

0 400 800
Feet

Figure 8-6

Model Head Solution and May 2007 Groundwater Elevations
Deep/Gravel Zone (Layers 4/5)
Arkema, Inc.
Portland, Oregon

ERM 10/07

Project No. 0057055
Date: 10/03/07
Drawn By: T. Cota
GIS File:

Aerial Photography - July, 2005

LEGEND
Model Head Solution (ft NAVD88)
May 2007 Groundwater Elevations (ft NAVD88)

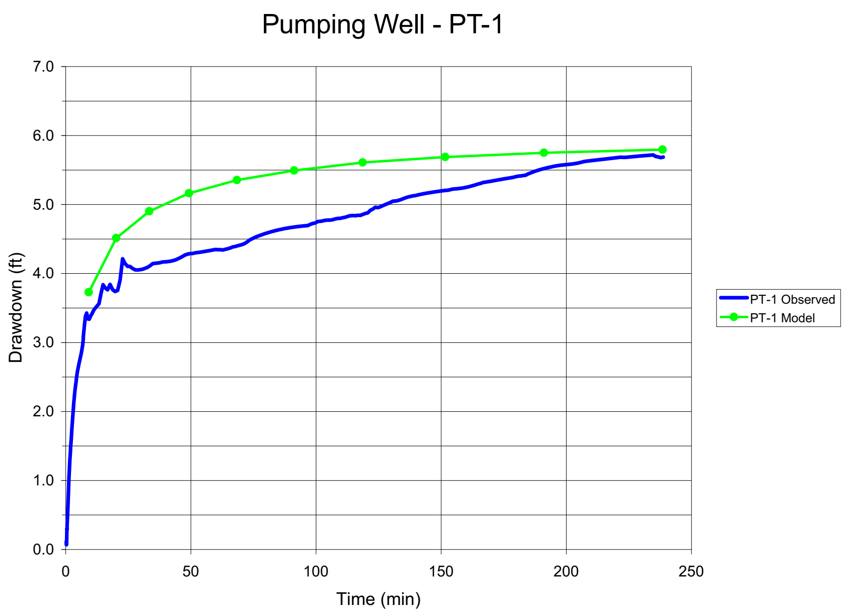
True North
Plant North

0 400 800
Feet

Figure 8-7

Model Head Solution and May 2007 Groundwater Elevations
Fractured Basalt (Layer 6)
Arkema, Inc.
Portland, Oregon

ERM 10/07



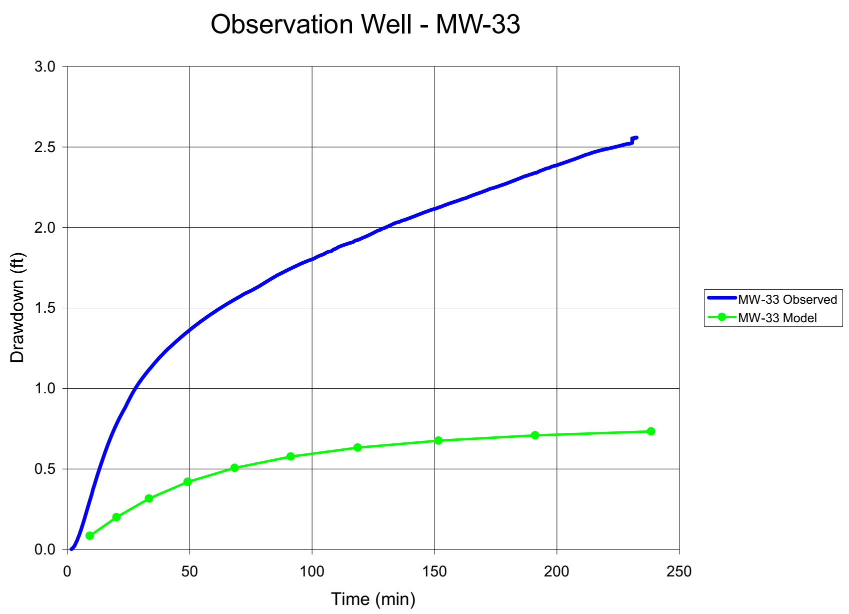


Figure 8-8
Comparison of Model Drawdown Solution and Observed Drawdown
PT-1 Pumping Test
Arkema, Inc.
Portland, Oregon

ERM 10/07

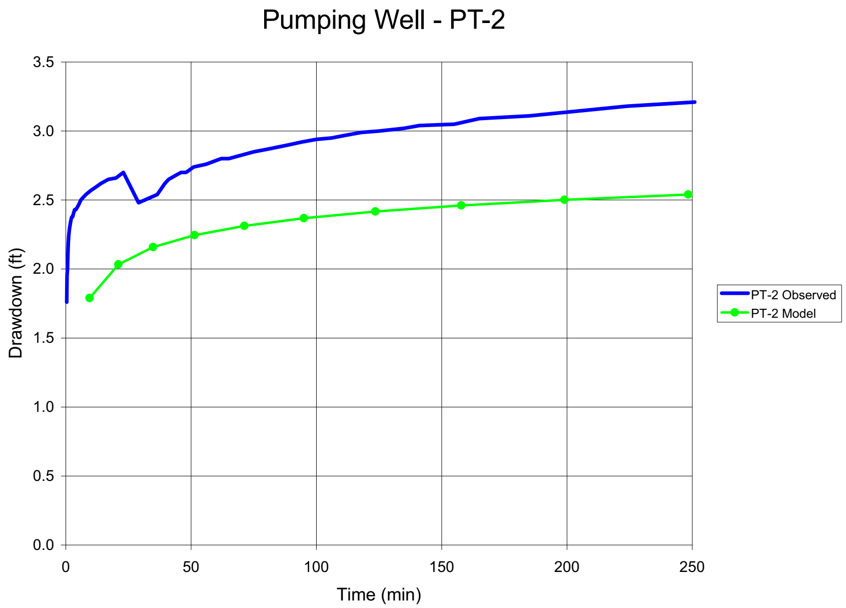
Project No. 0057055
Drawn By: T. Cota
Date: 10/03/07
GIS File:

Project No. 0057055

Drawn By: T. Cota

Date: 10/03/07

GIS File:



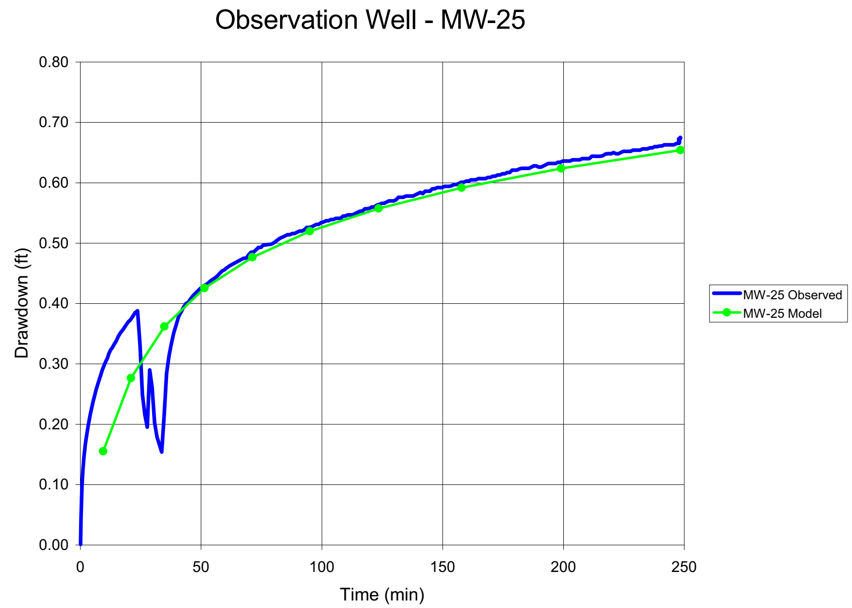


Figure 8-9
Comparison of Model Drawdown Solution
and Observed Drawdown
PT-2 Pumping Test
Arkema, Inc.
Portland, Oregon

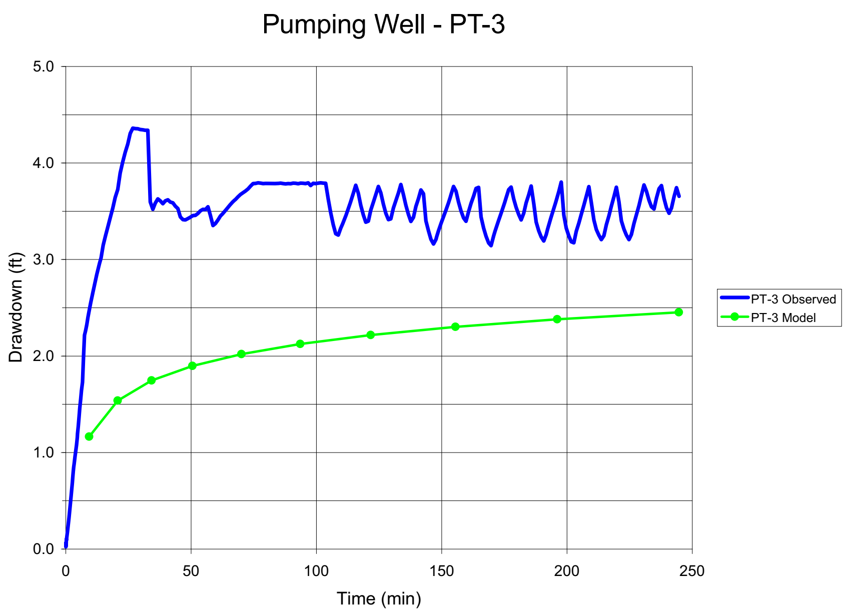
ERM 10/07

Project No. 0057055

Drawn By: T. Cota

Date: 10/03/07

GIS File:



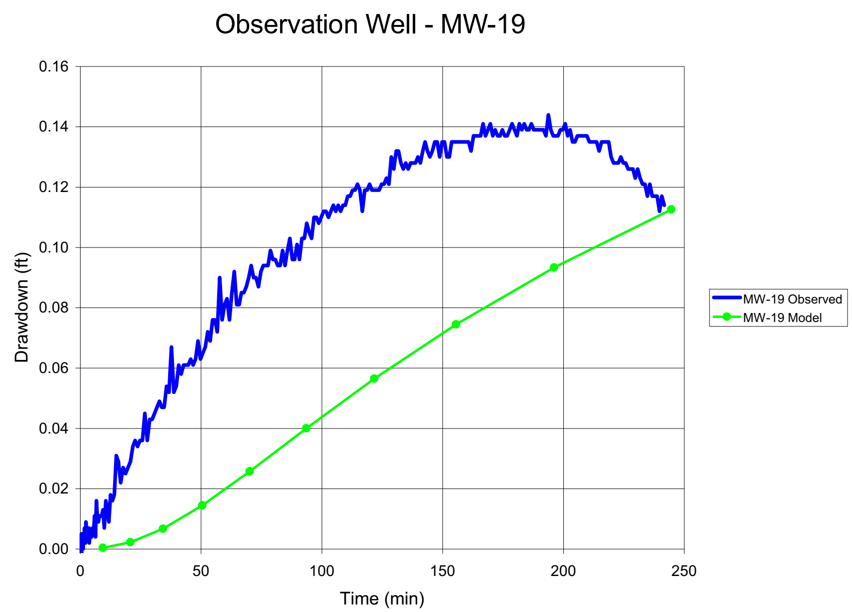


Figure 8-10

Comparison of Model Drawdown Solution and Observed Drawdown

PT-3 Pumping Test

Arkema, Inc.

Portland, Oregon

ERM 10/07

Project No.	0057055
Drawn By:	T. Cota
Date:	10/03/07
GIS File:	

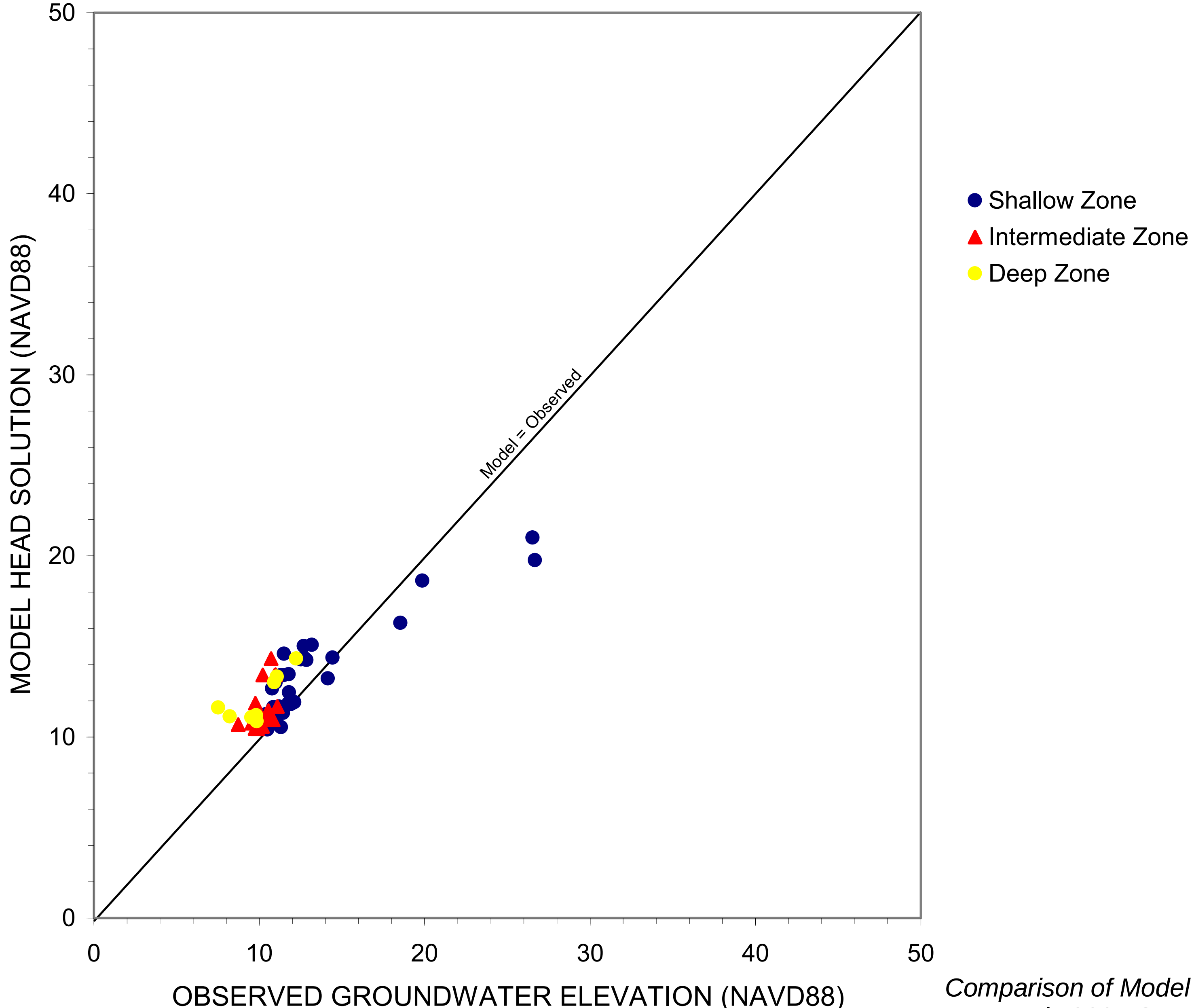


Figure 8-11

Comparison of Model Head Solution and
July 2005 Groundwater Elevations
Arkema, Inc.
Portland, Oregon

ERM 10/07

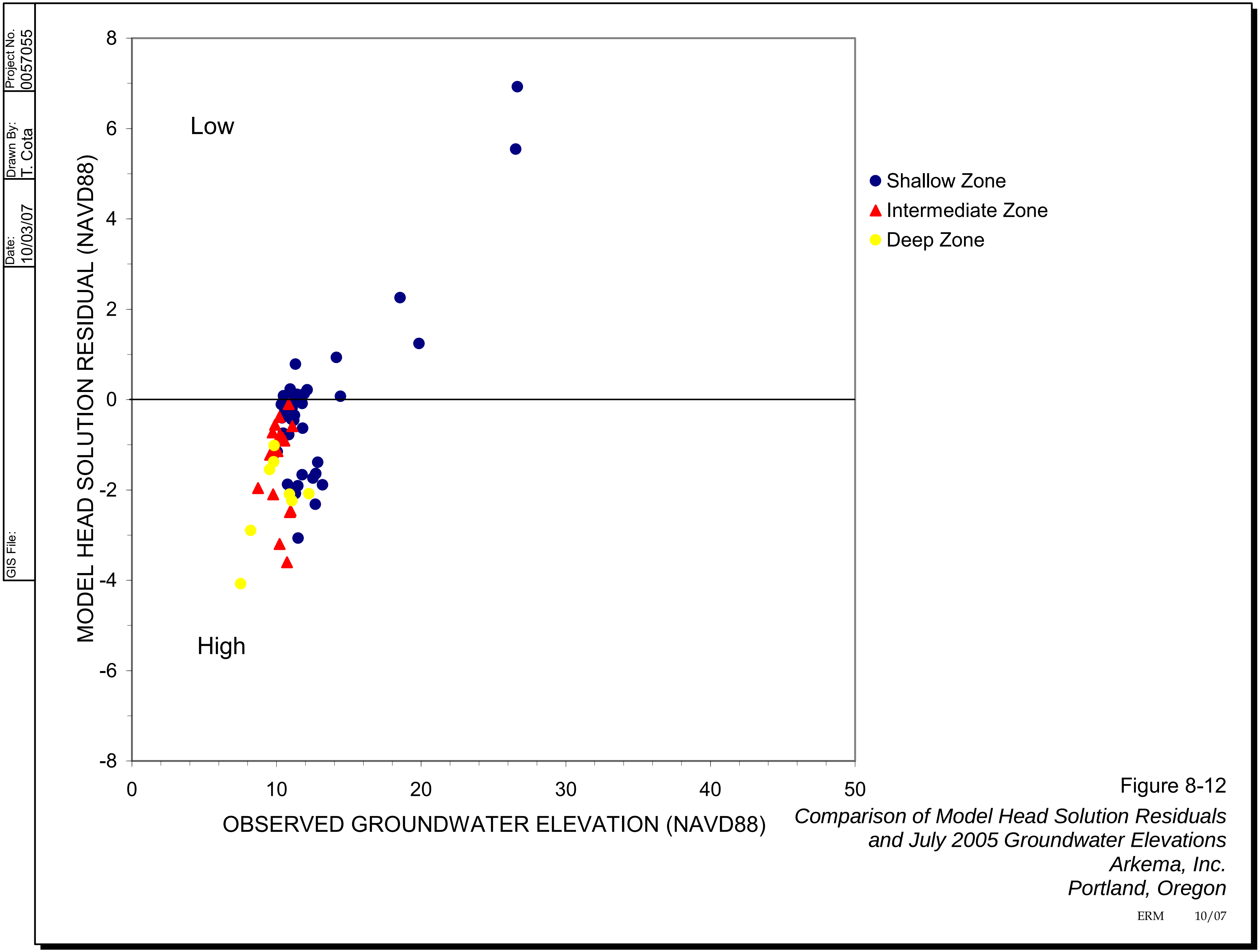


Figure 8-12

Comparison of Model Head Solution Residuals and July 2005 Groundwater Elevations

Arkema, Inc.

Portland, Oregon

ERM 10/07

Project No. 0057055
Drawn By: T. Cota
Date: 10/03/07
GIS File:

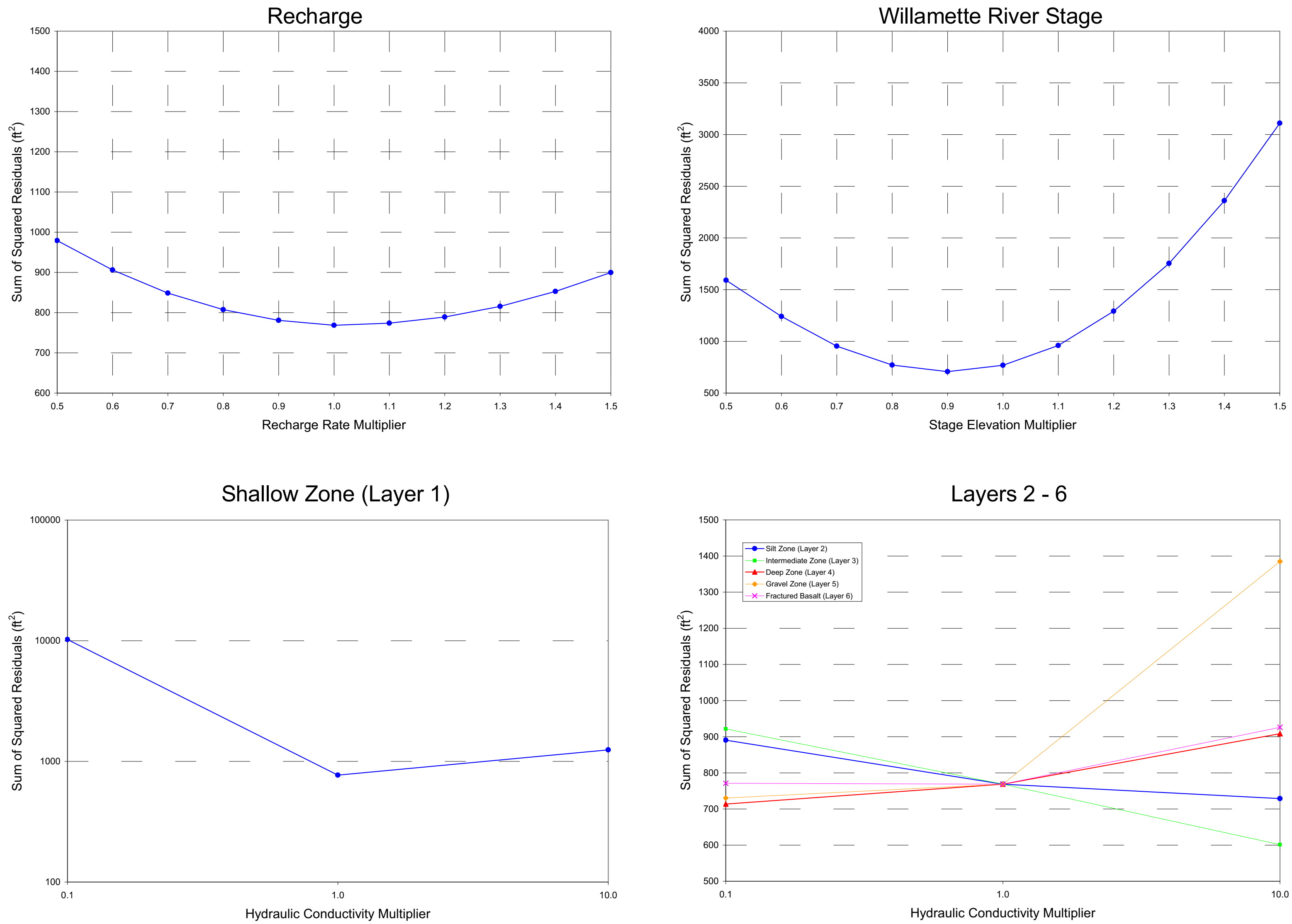


Figure 8-13
Sum of Squared Residuals
Model Calibration Parameter Sensitivity
Arkema, Inc.
Portland, Oregon

ERM 10/07

Tables

Table 4-1
Aquifer Test Results
Arkema, Inc.
Portland, Oregon

Well Number	Groundwater Zone	Type of Test	Method of Analysis	Horizontal Hydraulic Conductivity (cm/sec)	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (cm/sec)	Vertical Hydraulic Conductivity (ft/day)
MWA-1	Shallow	Slug Test	Bower and Rice	0.0023	6.50	--	--
MWA-3	Shallow	Slug Test	Bower and Rice	0.0078	22.00	--	--
MWA-5	Shallow	Slug Test	Bower and Rice	0.0120	34.00	--	--
MWA-6	Shallow	Slug Test	Bower and Rice	0.0000	0.03	--	--
MWA-7	Shallow	Slug Test	Bower and Rice	0.0021	5.90	--	--
PT-1	Shallow	Pumping Test	Neuman - Unconfined	0.0004	1.20	--	--
PT-2	Shallow	Pumping Test	Moench - Unconfined, Partial Penetration	0.0660	187.00	--	--
PT-3	Shallow	Pumping Test	Moench - Unconfined, Theis Recovery	0.0004 - 0.0016	1.20 - 4.50	--	--
MWA-8i	Intermediate	Slug Test	Bower and Rice	0.0007	1.90	--	--
MWA-9i	Intermediate	Slug Test	Bower and Rice	0.0074	21.00	--	--
MWA-10i	Intermediate	Slug Test	Bower and Rice	0.0099	28.00	--	--
MWA-10i	Intermediate	Permeameter	--	--		0.000001	0.0028
MWA-11i	Intermediate	Slug Test	Bower and Rice	0.0007	1.90	--	--
MWA-11i	Intermediate	Permeameter	--	--		0.0000002	0.0007
MWA-14i	Intermediate	Slug Test	Bower and Rice	0.0014	4.10	--	--
MWA-12i(d)	Deep	Slug Test	Bower and Rice	0.00001	0.04	--	--
MWA-13d	Deep	Slug Test	Bower and Rice	0.0001	0.30	--	--
MWA-13d	Deep	Permeameter	--	--		0.000003	0.0071
MWA-21b	Basalt	Pumping Test	Hantush-Jacob	0.0003	0.94	--	--

Table 6-1
Bottom Elevation of Model Layers
Arkema Facility
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Measuring Point Elevation [a] (ft)	Ground Surface Elevation [a] (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
MWA-2	Shallow	32.3	38.46	35.22												
MWA-3	Shallow	32.1	39.44	36.38												
MWA-4	Shallow	32.0	38.44	35.57												
MWA-5	Shallow	39.0	39.06	36.81	38						-1.19					
MWA-6	Shallow	36.0	36.22	36.75												
MWA-6r	Shallow	34.0	36.46	36.75												
MWA-15r	Shallow	32.5	36.06	36.39												
MWA-18	Shallow	29.5	39.43	36.44	29						7.44					
MWA-19	Shallow	35.5	39.90	37.42												
MWA-20	Shallow	35.5	40.95	38.46												
MWA-22	Shallow	36.0	36.59	36.91	34.5						2.41					
MWA-23	Shallow	26.0	36.81	37.10	25.5						11.60					
MWA-24	Shallow	36.0	37.58	37.94	29						8.94					
MWA-25	Shallow	34.0	37.67	38.07												
MWA-26	Shallow	31.5	37.68	38.03	31						7.03					
MWA-27	Shallow	36.0	36.86	37.29												
MWA-29	Shallow	35.2	37.23	37.51	31	32					6.51	5.51				
MWA-30	Shallow	30.0	38.34	38.75	29						9.75					
MWA-33	Shallow	30.0	37.26	37.75	30						7.75					
MWA-35	Shallow	35.0	37.97	37.97												
MWA-36	Shallow	34.0	37.34	37.34												
MWA-37	Shallow	33.5	37.56	37.56												
MWA-38	Shallow	32.0	37.55	37.55												
MWA-39	Shallow	26.5	37.06	37.23	25						12.23					
MWA-40	Shallow	31.0	36.96	37.18	29						8.18					
MWA-41	Shallow	35.0	37.77	38.01	33	34					5.01	4.01				
MWA-42	Shallow	33.5	37.24	37.62	32	33					5.62	4.62				
MWA-43	Shallow	35.0	37.22	37.46												
MWA-44	Shallow	35.5	37.34	37.66												
MWA-45	Shallow	35.0	38.22	38.67												
MWA-46	Shallow	30.5	36.67	36.68	30						6.68					
MWA-47	Shallow	35.0	38.69	38.99												
MWA-60	Shallow	38.0	35.59	35.73	37	38					-1.27	-2.27				
MWA-61	Shallow	33.5	36.21	36.15												
MWA-62	Shallow	30.5	36.28	36.06												
MWA-63	Shallow	30.5	36.29	36.38												
MWA-69	Shallow	30.0	33.69	33.65												
NMP-1D	Shallow	36.0	35.82	36.18	36						0.18					
NMP-2D	Shallow	37.0	35.56	35.97	36.5						-0.53					
NMP-3D	Shallow	37.0	35.76	35.91	36.5						-0.59					
NMP-4D	Shallow	36.0	35.63	35.91	36						-0.09					
NMP-5D	Shallow	35.5	35.38	35.84	35						0.84					
NMP-6D	Shallow	36.0	36.08	36.27	35.5						0.77					
NMP-1S	Shallow	30.5	35.90	36.11												
NMP-2S	Shallow	30.5	35.75	35.88												
NMP-3S	Shallow	30.5	35.68	36.02												
NMP-4S	Shallow	30.5	35.67	35.89												

Table 6-1
Bottom Elevation of Model Layers
Arkema Facility
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Measuring Point Elevation [a] (ft)	Ground Surface Elevation [a] (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
NMP-5S	Shallow	30.5	35.57	35.55												
NMP-6S	Shallow	30.5	35.94	36.23												
PMP-1	Shallow	35.0	36.36	36.35	34.5						1.85					
PMP-2	Shallow	35.0	36.36	36.32	34.5						1.82					
PMP-3	Shallow	35.0	36.17	36.14												
PMP-4	Shallow	33.5	35.90	35.90												
PMP-5	Shallow	34.0	36.04	35.96												
PMP-6	Shallow	36.5	35.83	35.77												
PT-1	Shallow	31.0	37.59	37.86	30						7.86					
PT-2	Shallow	34.5	37.78	38.12												
PT-3	Shallow	29.5	37.02	37.37	29						8.37					
MWA-17si	Shallow	35.3	39.15	36.53												
MWA-67si	Shallow	38.0	36.34	36.14												
MWA-68si	Shallow	34.0	33.77	33.65	34						-0.35					
MWA-7	Intermediate	33.0	36.24	36.24	15						21.24					
MWA-8i	Intermediate	47.3	38.09	35.43	36	37.5	47				-0.57	-2.07	-11.57			
MWA-9i	Intermediate	48.0	38.80	36.44	37	38	44.5				-0.56	-1.56	-8.06			
MWA-10i	Intermediate	46.8	37.89	35.40	36	37	45				-0.60	-1.60	-9.60			
MWA-11i	Intermediate	51.0	36.49	36.62	30	31.5	37				6.62	5.12	-0.38			
MWA-14i	Intermediate	49.3	39.41	36.73	38	39	41.5	48	49		-1.27	-2.27	-4.77	-11.27	-12.27	
MWA-16i	Intermediate	45.3	36.72	36.99	34.5	35.5	44				2.49	1.49	-7.01			
MWA-32i	Intermediate	44.0	38.70	38.92	29	31	46				9.92	7.92	-7.08			
MWA-34i	Intermediate	38.0	39.92	37.33	30	33					7.33	4.33				
MWA-48i	Intermediate	47.5	37.47	37.77	33	34.5	44.5				4.77	3.27	-6.73			
MWA-49i	Intermediate	44.0	36.68	36.84	30	34					6.84	2.84				
MWA-50i	Intermediate	47.0	38.80	39.03	33	35	46				6.03	4.03	-6.97			
MWA-51i	Intermediate	44.0	36.33	36.59	29	31.5	44				7.59	5.09	-7.41			
MWA-52i	Intermediate	44.5	35.65	36.05			44						-7.95			
MWA-53i	Intermediate	44.5	37.27	37.52	31	32	46				6.52	5.52	-8.48			
MWA-54i	Intermediate	41.5	37.31	37.72	32	33	42				5.72	4.72	-4.28			
MWA-55i	Intermediate	44.0	38.12	38.14			44						-5.86			
MWA-64i	Intermediate	49.0	35.84	36.17	37.5	39	48				-1.33	-2.83	-11.83			
MWA-65i	Intermediate	47.0	35.45	35.74	36	37.5	46				-0.26	-1.76	-10.26			
MWA-66i	Intermediate	49.0	33.10	33.50	34	35.5	45				-0.50	-2.00	-11.50			
MWA-70i	Intermediate	46.5	37.62	37.84	30	31	37				7.84	6.84	0.84			
MWA-12i	Deep	52.0	35.86	35.86	15	17	33				20.86	18.86	2.86			
MWA-13d	Deep	53.8	39.07	36.40	37	38	44.5	52	53		-0.60	-1.60	-8.10	-15.60	-16.60	
MWA-28i(d)	Deep	59.2	37.84	38.15	33.5	35	45				4.65	3.15	-6.85			
MWA-31i(d)	Deep	60.0	38.36	38.74	29	31	46				9.74	7.74	-7.26			
MWA-56d	Deep	61.0	36.68	36.82	30	34	46				6.82	2.82	-9.18			
MWA-57d	Deep	66.0	38.11	38.31			44						-5.69			
MWA-58d	Deep	63.0	37.07	37.19	30	33	46				7.19	4.19	-8.81			
MWA-59d	Deep	61.0	38.87	39.01	33	35	46				6.01	4.01	-6.99			
MWA-21b	Basalt	76.0	38.83	36.30	37	38	44.5	52	53	70	-0.70	-1.70	-8.20	-15.70	-16.70	-33.70
B-70b		36.0		38.49	33						5.49					
B-73		32.0		38.03	31.5						6.53					

Table 6-1
Bottom Elevation of Model Layers
Arkema Facility
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Measuring Point Elevation [a] (ft)	Ground Surface Elevation [a] (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
B-77		32.0		37.82	31						6.82					
B-84		32.0		37.85	31.5						6.35					
B-87		32.0		36.96	27						9.96					
B-88		32.0		37.17	28						9.17					
B-90		32.0		37.63	29						8.63					
GP-7		35.0		35.91	34.6						1.31					
GP-8		34.5		36.11	34.2						1.91					
GP-9		34.0		36.15	33.7						2.45					
GP-10		35.0		36.01	34.4						1.61					
GP-11		33.0		36.20	32						4.20					
GP-12		29.5		36.99	29.3						7.69					
GP-13		33.5		36.27	32.6						3.67					
GP-14		35.0		36.64	34.9						1.74					
GP-15		29.5		36.10	28.8						7.30					
GP-16		30.5		36.45	29.9						6.55					
GP-17		35.0		35.98	34						1.98					
GP-18		30.0		35.93	29.8						6.13					
GP-19		31.8		36.26	31.5						4.76					
GP-20		35.0		36.23	33.7						2.53					
GP-21		34.8		36.35	34.5						1.85					
GP-22		36.5		36.18	36.4						-0.22					
GP-23		33.0		36.60	32						4.60					
GP-24		30.0		36.72	27.8						8.92					
GP-25		40.5		40.12	38						2.12					
GP-26		35.0		36.53	34.5						2.03					
GP-27		32.5		36.78	31.6						5.18					
GP-28		30.0		36.56	27.4						9.16					
GP-30		29.5		37.10	27.5						9.60					
GP-31		33.0		37.10	28.2						8.90					
GP-32		31.0		36.13	26.8						9.33					
GP-33		35.0		36.37	34.5						1.87					
GP-34		34.0		36.40	33.6						2.80					
GP-35		40.0		36.08	35.9						0.18					
GP-36		37.0		35.81	36.2						-0.39					
GP-37		37.0		36.34	36.1						0.24					
GP-38		38.0		36.01	36.4						-0.39					
GP-39		38.0		35.82	36.2						-0.38					
GP-40		38.0		35.96	36.7						-0.74					
GP-41		39.0		36.05	36.1						-0.05					
GP-42		38.5		35.72	36.9						-1.18					
GP-43		38.0		35.93	36.2						-0.27					
GP-44		38.0		35.93	36.6						-0.67					
GP-45		39.0		35.79	36.5						-0.71					
GP-46		38.0		35.98	36.5						-0.52					
GP-47		38.0		35.96	36.2						-0.24					
GP-48		38.0		35.85	35.9						-0.05					
GP-49		38.0		35.84	36.9						-1.06					
GP-50		38.0		35.96	36.9						-0.94					
GP-51		38.0		36.32	37.2						-0.88					
GP-52		38.5		35.81	37						-1.19					
GP-53		38.0		35.98	37.1						-1.12					
GP-54		38.0		36.16	36.8						-0.64					
GP-55		38.0		36.03	36.4						-0.37					
GP-56		38.8		35.57	36.1						-0.53					
GP-57		38.0		35.40	36.4						-1.00					
GP-58		40.0		36.04	36.7						-0.66					

Table 6-1
Bottom Elevation of Model Layers
Arkema Facility
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Measuring Point Elevation [a] (ft)	Ground Surface Elevation [a] (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
GP-59		38.5		36.36	36.7						-0.34					
GP-60		40.0		36.14	37.4						-1.26					
GP-61		38.5		36.11	38						-1.89					
GP-62		38.0		36.16	37.3						-1.14					
GP-63		38.0		35.66	35.7						-0.04					
GP-64		38.0		35.61	36.5						-0.89					
GP-65		38.0		35.86	35.1						0.76					
WB-1		56.0		38.55	34	40	51	53.5	54		4.55	-1.45	-12.45	-14.95	-15.45	
WB-2		51.0		38.61	35	45	50	52	53		3.61	-6.39	-11.39	-13.39	-14.39	
WB-3		54.5		38.64	40	50	53	54	55		-1.36	-11.36	-14.36	-15.36	-16.36	
WB-4		72.5		38.37	34	37	51	72	73		4.37	1.37	-12.63	-33.63	-34.63	
WB-5		70.2		38.47				70	71					-31.53	-32.53	
WB-6		67.0		38.50			57						-18.50			
WB-7		65.0		38.94			56						-17.06			
WB-8		43.8		10.60	11	16	19	42	44		-0.40	-5.40	-8.40	-31.40	-33.40	
WB-9		40.2		12.10	15	23	27	39	40		-2.90	-10.90	-14.90	-26.90	-27.90	
WB-10		42.7		12.00					42						-30.00	
WB-11		34.0		11.30	12	31	32	33	34		-0.70	-19.70	-20.70	-21.70	-22.70	
WB-12		52.2		12.00			43	52					-31.00	-40.00		
WB-13		28.5		10.70	11	23	27	28	29		-0.30	-12.30	-16.30	-17.30	-18.30	
WB-14		37.0		10.40		27	36	37	38			-16.60	-25.60	-26.60	-27.60	
WB-15		50.0		10.40			44	49	50				-33.60	-38.60	-39.60	
WB-16		43.3		13.40			39	43	44				-25.60	-29.60	-30.60	
WB-17		36.2		10.75			34	36	37				-23.25	-25.25	-26.25	
WB-18		29.7		11.50	10	21	28	29	30		1.50	-9.50	-16.50	-17.50	-18.50	
WB-19		38.1		11.80			34	38	39				-22.20	-26.20	-27.20	
WB-20		51.8		11.60			47	51	52				-35.40	-39.40	-40.40	
WB-21		53.4		12.20			45	53	54				-32.80	-40.80	-41.80	
WB-22		62.5		13.50		50	54	61				-36.50	-40.50	-47.50		
WB-23		42.4		12.20			38	42	43				-25.80	-29.80	-30.80	
WB-24		32.0		11.95	20	26					-8.05	-14.05				
WB-25		36.0		11.90	19	26	30	35	36		-7.10	-14.10	-18.10	-23.10	-24.10	
WGB-5	Basalt	104.0		33.00	27	29	48	79	80	90	6.00	4.00	-15.00	-46.00	-47.00	-57.00

[a] Vertical survey data from Hydrogeolical Investigation of the Doane Lake Area (G&M, 1991). Datum used is NAVD29, converted to NAVD88 (added 3.325 ft)
NAVD29 to City of Portland = + 1.375
City of Portland to NAVD88 = +1.95
NAVD29 to NAVD 88 = +3.325
WB surface elevation is drilling platform elevation. Depths are measured from the dock or barge deck

Table 6-2
Bottom Elevation of Model Layers
Rhone-Poulenc Portland Plant
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Top of Casing Elevation* (ft)	Ground Surface Elevation* (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
ARK-01		62.0		35.00	15	45	52	57	59	62	20.00	-10.00	-17.00	-22.00	-24.00	-27.00
ARK-02		80.0		42.00	25	47	80				17.00	-5.00	-38.00			
ARK-03		102.5		39.00	26	45	80	90	100	103	13.00	-6.00	-41.00	-51.00	-61.00	-64.00
ARK-04		47.0		38.00	17	40	44	46	47		21.00	-2.00	-6.00	-8.00	-9.00	
ARK-05		67.5		40.00	22	34	48	65	66	68	18.00	6.00	-8.00	-25.00	-26.00	-28.00
ARK-06		107.5		41.00	27	46	70	88	105	107	14.00	-5.00	-29.00	-47.00	-64.00	-66.00
ARK-07		45.0		38.00	24	40	44				14.00	-2.00	-6.00			
ARK-08		43.5		38.00	15	32	40	43			23.00	6.00	-2.00	-5.00		
ARK-09		84.0		38.00	20	45	66	85	92	95	18.00	-7.00	-28.00	-47.00	-54.00	-57.00
RP-01-31	Shallow	31.5		34.00												
RP-01-51	Deep	51.0		34.00												
RP-01-65	Basalt	66.0		34.00	30	35	45	51	52	66	4.00	-1.00	-11.00	-17.00	-18.00	-32.00
RP-02-31	Shallow	31.0	42.07	39.57												
RP-02-49	Intermediate	49.7	41.78	39.28												
RP-02-66	Basalt	66.5	41.65	39.15	20	47	50	51	52	60	19.15	-7.85	-10.85	-11.85	-12.85	-20.85
RP-03-30R	Shallow		38.56	36.06												
RP-03-52R	Deep		38.55	36.05												
RP-03-26	Shallow	26.5		36.05												
RP-03-63	Gravel	64.0		36.05	25	54	55	59	63	64	11.05	-17.95	-18.95	-22.95	-26.95	-27.95
RP-04-16	Shallow	16.5	35.61	33.11												
RP-04-41	Deep	42.0	36.05	33.55	18	31	33	41	43		15.55	2.55	0.55	-7.45	-9.45	
RP-05-16	Shallow	16.5	42.49	39.99												
RP-06-30	Shallow	31.5	39.05	36.55												
RP-06-87	Deep	88.0	39.15	36.65	28	55	70	86	88	90	8.65	-18.35	-33.35	-49.35	-51.35	-53.35
RP-07-30	Shallow			37.45												
RP-07-55	Intermediate			37.45												
RP-07-84	Gravel	114.0		37.45												
RP-07-119	Basalt	119.4		37.45	35	50	67	68	108	112	2.45	-12.55	-29.55	-30.55	-70.55	-74.55
RP-08-23	Shallow	27.0		42.00												
RP-08-80	Intermediate	83.0		42.00												
RP-08-107	Basalt	107.5		42.00	25	48	78	84	88	97	17.00	-6.00	-36.00	-42.00	-46.00	-55.00
RP-09-35	Shallow	35.0		38.00												
RP-09-47	Intermediate	49.0		38.00												
RP-09-64	Basalt	66.0		38.00	20	40	44	49	51	60	18.00	-2.00	-6.00	-11.00	-13.00	-22.00
RP-10-30	Shallow	30.0		38.00												
RP-10-60	Intermediate	62.0		38.00												
RP-10-97	Gravel	106.0		38.00												
RP-10-130	Basalt	139.0		38.00	27	45	65	88	100	125	11.00	-7.00	-27.00	-50.00	-62.00	-87.00
W-03-S	Intermediate	40.0	36.32	33.95												
W-03-I	Deep	54.0	35.05	33.25												
W-03-D	Deep	94.4	34.51	33.35	18	65	70	90	92	95	15.35	-31.66	-36.66	-56.66	-58.66	-61.66
W-04-S	SI Silt	40.0	34.65	32.65												
W-04-I	SI Silt	50.0	34.60	32.65												
W-04-89	Deep	90.2		35.39	20	62	70	89	90	95	15.39	-26.61	-34.61	-53.61	-54.61	-59.61
W-06-S	SI Silt	28.0	41.49	39.85												
W-06-D	Deep	51.5	43.05	41.05												
W-06-B	Basalt	67.9	41.90	39.65	5	25	28	47	48	70	34.65	14.65	11.65	-7.36	-8.36	-30.36
W-08-I			37.86	37.06												
W-08-D	SI Silt	55.5	37.82	36.57												
W-08-26	Shallow	26.5	40.61	38.11												
W-08-74	Basalt	74.5	40.72	38.22	30	55	58	62	63	74.5	8.22	-16.78	-19.78	-23.78	-24.78	-36.28
W-09-I			36.85	35.66												
W-09	Shallow	40.0	36.83	35.83												

Table 6-2
Bottom Elevation of Model Layers
Rhone-Poulenc Portland Plant
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Top of Casing Elevation* (ft)	Ground Surface Elevation* (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
W-09-86	Deep	86.5	40.49	37.99												
W-09-116	Deep	116.5	40.07	37.57	30	60	62	114	116	117	7.57	-22.43	-24.43	-76.43	-78.43	-79.43
W-10-D	Intermediate	71.5	33.94	34.18	24	50					10.18	-15.82				
W-11-S	Shallow	23.5	42.84	40.85												
W-11-I	Intermediate	60.0	42.17	40.75												
W-11-D	Deep	97.8	42.15	40.75												
W-11-B	Basalt	121.9	43.28	40.85	28	60	65	102	103	122	12.85	-19.16	-24.16	-61.16	-62.16	-81.16
W-12-S	Shallow	20.0	43.37	41.25												
W-12-I	Intermediate	61.0	43.65	41.35												
W-12-D	Deep	104.5	43.63	41.35	32	60	64	100	102	105	9.35	-18.66	-22.66	-58.66	-60.66	-63.66
W-15-S	Shallow	15.0	44.03	42.25												
W-15-I	Intermediate	40.0	44.48	41.91												
W-15-D	Deep	70.0	44.53	41.91	15	17	45	69	70		26.91	24.91	-3.10	-27.10		
W-16-31	Intermediate	31.5	35.65	33.70												
W-16-S	Shallow	14.0	37.09	34.65												
W-16-I	Deep	53.0	37.39	34.55												
W-16-D	Deep	90.3	37.41	34.55	14	17	28	89	90		20.55	17.55	6.55	-54.46	-55.46	
W-18-S	Intermediate	30.0	57.20	56.22												
W-18-I	Deep	56.0	56.71	56.11												
W-18-D	Basalt	64.0	57.66	56.46	10	24	40	58	59		46.46	32.46	16.46	-1.54	-2.54	
W-19-S	Shallow	25.0	37.17	35.54												
W-19-I	Deep	50.0	37.31	35.76												
W-19-D	Basalt	68.0	37.08	35.39	28	35	40	49	50	65	7.39	0.39	-4.61	-13.62	-14.62	-29.62
MW-01-26	SI Silt		51.84	49.34												
MW-01-41	Intermediate		51.48	48.98												
MW-01-56	Deep		51.65	49.15												
MW-01-76	Basalt	76.6	49.65	47.15	5	25	40	53	56	68	42.15	22.15	7.15	-5.85	-8.85	-20.85
MW-02-46	Intermediate		49.86	47.36												
MW-02-62	Deep	65.1	49.95	47.45	5	28	45	59	60	64	42.45	19.45	2.45	-11.55	-12.55	-16.55
MW-03-27	SI Silt		50.24	47.74												
MW-03-49	Intermediate		50.23	47.73												
MW-03-68	Deep	69.0	50.20	47.70	5	30	54	64	68	70	42.70	17.70	-6.30	-16.30	-20.30	-22.30
MW-04-27	SI Silt		49.50	48.19												
MW-04-47	SI Silt		49.61	48.23												
MW-04-63	Deep	68.1	49.97	48.56	5	42	45	61	62	64	43.56	6.56	3.56	-12.45	-13.45	-15.45
MW-05-24	SI Silt		39.78	37.28												
MW-05-34	SI Silt		39.78	37.28												
MW-05-52	Deep	52.2	39.65	37.15												
MW-05-70	Basalt	71.0	40.28	37.78	10	33	35	50	53	65	27.78	4.78	2.78	-12.22	-15.22	-27.22
MW-08-27	SI Silt		50.18	47.68												
MW-08-46	SI Silt		50.06	47.56												
MW-08-64	Deep	65.1	49.92	47.42	15	40	48	59	61	62	32.42	7.42	-0.58	-11.58	-13.58	-14.58
MW-09-23	SI Silt		48.98	46.48												
MW-09-42	Intermediate		49.59	47.09												
MW-09-58	Deep		48.16	45.66												
MW-09-80	Basalt	80.5	48.62	46.12	5	28	50	59	62	75	41.12	18.12	-3.88	-12.88	-15.88	-28.88
MW-10-24	SI Silt	25.0	48.16	45.76												
MW-10-44	Intermediate	44.0	48.49	45.88												
MW-10-57	Deep	58.0	48.61	45.95	4	28	42	59			41.95	17.95	3.95	-13.05		
MW-11-24	SI Silt	24.0	46.09	44.27												
MW-11-37	Intermediate	37.0	45.75	45.26												
MW-11-56	Deep	56.0	45.58	45.89												
MW-11-79	Basalt	79.5	46.09	47.27	3	30	43	56	57	65	44.27	17.27	4.27	-8.73	-9.73	-17.73

Table 6-2
Bottom Elevation of Model Layers
Rhone-Poulenc Portland Plant
Portland, Oregon

Well Number	Groundwater Zone	Depth Drilled (ft)	Top of Casing Elevation* (ft)	Ground Surface Elevation* (ft)	Depth of Shallow Aquifer (Layer 1)	Depth of SI Silt (Layer 2)	Depth of Intermediate Aquifer (Layer 3)	Depth of Deep Zone (Layer 4)	Depth of Gravel Zone (Layer 5)	Depth of Fractured Basalt (Layer 6)	Elev of Shallow Aquifer (Layer 1)	Elev of SI Silt (Layer 2)	Elev of Intermediate Aquifer (Layer 3)	Elev of Deep Zone (Layer 4)	Elev of Gravel Zone (Layer 5)	Elev of Fractured Basalt (Layer 6)
MW-12-27	SI Silt	26.5	52.17	49.67												
MW-12-41	Intermediate	41.0	52.03	49.44												
MW-12-59	Deep	59.5	51.53	49.09												
MW-12-79	Basalt	85.0	52.03	49.55	8	23	38	58	59	60	41.55	26.55	11.55	-8.45	-9.45	-10.45
RPW-02	Deep	40.0	48.35	47.35	4	20	28				43.35	27.35	19.35			
RPW-03	Deep	54.0	45.35	44.35	4	26	38	52	53		40.35	18.35	6.35	-7.65	-8.65	
RPW-05	Intermediate	42.0	51.50	49.75	12	30	45				37.75	19.75	4.75			
BTB4B-55	Shallow	55.0	41.76	39.26												
BTB4A-84	Deep	84.0	41.71	39.21	26	55	60	83			13.21	-15.79	-20.79	-43.79		
AL2-17	Shallow	17.5	43.72	41.03												
AL2-32	SI Silt	33.0	43.36	41.04												
AL2-46	Deep	46.5	43.72	41.09												
BST2W-61	Basalt	61.5	43.13	41.17	17	36	40	47	51	59	24.17	5.17	1.17	-5.83	-9.83	-17.83
AL4-47	Deep	49.6	42.21	39.93	9	25	28	49	50		30.93	14.93	11.93	-9.07	-10.07	
AL5-19	Shallow	19.5	42.02	39.92												
AL5-35	SI Silt	35.8	41.49	39.35												
AL5-62	Gravel	62.5	41.54	39.21												
BST5W-74	Basalt	74.5	41.82	39.58	16	34	36	49	66	70	23.58	5.58	3.58	-9.42	-26.42	-30.42
AL6-96	Deep	107.5		37.95	27	58	60	92	96	100	10.95	-20.05	-22.05	-54.05	-58.05	-62.05
PZ-2-40	Deep	40.3	66.48	63.98	12	18	24	35	40		51.98	45.98	39.98	28.98	23.98	
MW-01-S	Shallow	31.5	38.21	36.15	25						11.15					
MW-02-S	Shallow	31.5	36.74	35.15	21						14.15					
MW-03-S	Shallow	32.0	38.22	36.72												
MW-03-I	Intermediate	61.5	38.44	36.77												
MW-03-81	Deep	91.5	37.49	34.99	30	55	58	95	96		4.99	-20.01	-23.01	-60.01	-61.01	
MW-05-S	Shallow	31.5		37.50	25						12.50					
MW-06-S	Shallow	31.5	38.38	37.15	22						15.15					
MW-07-S	Shallow	41.5	39.32	38.15	22						16.15					
B-120		50.5		35.81	37	38	45	49.5	50.5		-1.19	-2.19	-9.19	-13.69	-14.69	
B-121		87.0		38.35	29	31	44	86	87		9.35	7.35	-5.65	-47.65	-48.65	
CPT-1		78.3		36.22	36	37	44	77	78.25		0.22	-0.78	-7.78	-40.78	-42.03	
CPT-2		79.7		36.87	31	35	44	79	79.72		5.87	1.87	-7.13	-42.13	-42.85	
CPT-3		84.7		36.29	30	31	43	84	84.65		6.29	5.29	-6.71	-47.71	-48.36	
CPT-4		85.0		37.36	35	36	46	84	84.97		2.36	1.36	-8.64	-46.64	-47.61	

[a] Vertical survey data from Hydrogeolical Investigation of the Doane Lake Area (G&M, 1991). Datum used is NAVD29, converted to NAVD88 (added 3.325 ft) , unless noted
NAVD29 to City of Portland = + 1.375
City of Portland to NAVD88 = +1.95
NAVD29 to NAVD 88 = +3.325

Table 7-1
Flow Model Input Parameters
Arkema, Inc.
Portland, Oregon

Model Parameter	Value				Source
Recharge					
Spring - May 2007 Calibration	10 in/yr				Lee and Risley (2002)[1]
Summer - July 2005 Calibration	0 in/yr				Estimated
Hydraulic Conductivity	Lithology	K_h	K_v		
Layer 1 (Shallow Zone)	Sand	190 ft/day	190 ft/day		Model Calibration GeoSyntec (2006)[2]
	Silty Sand	10 ft/day	10 ft/day		
	Silty Sand	5 ft/day	5 ft/day		
	Silty Sand	2 ft/day	2 ft/day		
	Silty Sand	8 ft/day	0.008 ft/day		
	Silty Sand	2 ft/day	0.002 ft/day		
Layer 2 (Shallow-Intermediate Silt Zone)	Silt/Sandy Silt	1.0 ft/day	1.0 ft/day		Model Calibration
	Clay	0.01 ft/day	0.01 ft/day		
	Sand	190 ft/day	190 ft/day		
Layer 3 (Intermediate Zone)	Sand/Silty Sand	20 ft/day	20 ft/day		Model Calibration
	Clay/Silt	2 ft/day	2 ft/day		
Layer 4 (Deep Zone)	Silty Sand/Silt	1.0 ft/day	1.0 ft/day		Model Calibration
	Fractured Basalt	10 ft/day	10 ft/day		
Layer 5 (Gravel Zone)	Gravel	150 ft/day	150 ft/day		Model Calibration
	Silty Sand	5 ft/day	5 ft/day		
	Fractured Basalt	10 ft/day	10 ft/day		
Layer 6 (Fractured Basalt)	Fractured Basalt	10 ft/day	10 ft/day		Model Calibration
Layer 7 (Basalt)	Weathered Basalt	2.5 ft/day	2.5 ft/day		Model Calibration

Notes:
K_h - horizontal hydraulic conductivity
K_v - vertical hydraulic conductivity
[1]Lee, K.K., and J.C. Risley, 2002, "Estimates of Ground-Water Recharge, Base Flow, and Stream Reach Gains and Losses in the Wilamette River Basin, Oregon," U.S. Geological Survey Water-Resources Investigations Report 01-4215.
[2]GeoSyntec Consultants, 2006, "Hydraulic Testing Summary," Arkema Active Pilot Test Workplan, Appendix B, Arkema Facility, Portland, Oregon

Table 7-2
Flow Model Boundary Condition Parameters
Arkema, Inc.
Portland, Oregon

Boundary Condition	Parameter				Source
Constant-Head Boundary - Willamette River					
	Stage				
Spring - May 2007 Calibration	11.65 ft NAVD88				USGS Gage at Morrison Bridge[1]
Summer - July 2005 Calibration	9.31 ft NAVD88				USGS Gage at Morrison Bridge[1]
River- Boundary - North Doane Lake					
	Stage	Bottom	K_v	Thickness	
Spring - May 2007 Calibration	24.65 ft NAVD88	21.36 ft NAVD88	0.00011 ft/day	1.0 ft	AMEC (2005)[2], Stage Estimated
Summer - July 2005 Calibration	23.65 ft NAVD88	21.36 ft NAVD88	0.00011 ft/day	1.0 ft	AMEC (2005)[2], Stage Estimated
River- Boundary - West Doane Lake					
	Stage	Bottom	K_v	Thickness	
Spring - May 2007 Calibration	25.65 ft NAVD88	24.35 ft NAVD88	0.00013 ft/day	1.0 ft	AMEC (2005)[2], Stage Estimated
Summer - July 2005 Calibration	24.65 ft NAVD88	21.36 ft NAVD88	0.00013 ft/day	1.0 ft	AMEC (2005)[2], Stage Estimated
River- Boundary - Chlorate Cell Room Sumps					
	Stage	Bottom	K_v	Thickness	
Spring - May 2007 Calibration	32 ft NAVD88	28 ft NAVD88	1.0 ft/day	1.0 ft	Estimated
Summer - July 2005 Calibration	32 ft NAVD88	28 ft NAVD88	1.0 ft/day	1.0 ft	Estimated

Notes:
K_v - vertical hydraulic conductivity
[1]USGS Gaging Station 14211720 Willamette River at Portland, Oregon.
[2]AMEC Earth & Environmental, Inc., 2005, "Groundwater Transport Evaluation Report, RP Portland Site," prepared for SLLI, Morrisville, North Carolina.

Table 8-1
Constant-Rate Pumping Tests
Arkema, Inc.
Portland, Oregon

Pumping Well					Observation Well				Aquifer Properties		
Well Name	Screened Interval (ft bgs)	Hydrostratigrahic Unit	Discharge Rate (gpm)	Test Duration (min)	Well Name	Screened Interval (ft bgs)	Hydrostratigrahic Unit	Radial Distance (ft)	Hydraulic Conductivity (ft/day)	Storativity (unitless)	Specific Yield (unitless)
PT-1	19.9 - 29.1	Shallow Zone	0.9	238.49	MWA-33	20-30	Shallow Zone	10.35	1.2	0.002	0.05
PT-2	24.4 - 33.5	Shallow Zone	27.6	248.46	MWA-25	24.4 - 33.5	Shallow Zone	12.91	187	0.009	0.03
PT-3	19.5 - 28.7	Shallow Zone	0.75; 0.5	244.7	MW-19	19.2 - 20.2	Shallow Zone	11.00	1.2 - 4.5	0.003	0.05

Table 8-2
Volumetric Mass Balance
Arkema, Inc.
Portland, Oregon

Model Boundary	Inflows ft^3/day	Outflows ft^3/day	Volumetric Mass Balance
Constant Head	105948.57	125795.95	
River Leakage	5637.58	85.30	
Recharge	14295.06	0.00	
Totals	125881.20	125881.25	
Inflow - Outflow (ft^3/day)			-0.04
Percent Discrepency			0.00

Appendix A
Willamette River Stage Elevation Measurements

Appendix A-1
Arkema, Inc.
Portland Oregon
Willamette River Stage Elevations - 2007

Date	Morrison Bridge Gage Height		Columbia Slough Gage Height		Stage Difference
	(ft)	(ft NAVD88)	(ft)	(ft NAVD88)	(ft)
1/1/2007	6.19	11.22	6.14	11.06	0.16
1/2/2007	6.41	11.44	6.44	11.36	0.08
1/3/2007	7.71	12.74	7.70	12.62	0.12
1/4/2007	9.63	14.66	9.65	14.57	0.09
1/5/2007	9.64	14.67	9.67	14.59	0.08
1/6/2007	10.13	15.16	10.18	15.10	0.06
1/7/2007	9.16	14.19	9.20	14.12	0.07
1/8/2007	8.74	13.77	8.77	13.69	0.08
1/9/2007	8.26	13.29	8.29	13.21	0.08
1/10/2007	7.98	13.01	7.97	12.89	0.12
1/11/2007	7.26	12.29	7.23	12.15	0.14
1/12/2007	6.98	12.01	6.93	11.85	0.16
1/13/2007	6.83	11.86	6.80	11.72	0.14
1/14/2007	6.54	11.57	6.51	11.43	0.14
1/15/2007	6.41	11.44	6.45	11.37	0.07
1/16/2007	6.75	11.78	6.79	11.71	0.07
1/17/2007	6.68	11.71	6.74	11.66	0.05
1/18/2007	6.46	11.49	6.51	11.43	0.06
1/19/2007	6.46	11.49	6.53	11.45	0.04
1/20/2007	6.39	11.42	6.46	11.38	0.04
1/21/2007	5.70	10.73	5.75	10.67	0.06
1/22/2007	5.27	10.30	5.31	10.23	0.07
1/23/2007	5.53	10.56	5.56	10.48	0.08
1/24/2007	5.29	10.32	5.32	10.24	0.08
1/25/2007	5.14	10.17	5.17	10.09	0.08
1/26/2007	5.19	10.22	5.23	10.15	0.07
1/27/2007	4.97	10.00	5.02	9.94	0.06
1/28/2007	4.63	9.66	4.68	9.60	0.06
1/29/2007	4.07	9.10	4.10	9.02	0.08
1/30/2007	4.46	9.49	4.49	9.41	0.08
1/31/2007	4.37	9.40	4.41	9.33	0.07
2/1/2007	4.49	9.52	4.50	9.42	0.10
2/2/2007	4.68	9.71	4.70	9.62	0.09
2/3/2007	4.47	9.50	4.51	9.43	0.07
2/4/2007	4.32	9.35			
2/5/2007	4.10	9.13			
2/6/2007	4.03	9.06	4.07	8.99	0.07
2/7/2007	3.97	9.00	4.02	8.94	0.06
2/8/2007	3.81	8.84	3.84	8.76	0.08
2/9/2007	3.62	8.65	3.67	8.59	0.06
2/10/2007	3.48	8.51	3.52	8.44	0.07
2/11/2007	3.69	8.72	3.75	8.67	0.05
2/12/2007	3.68	8.71	3.70	8.62	0.09
2/13/2007	3.73	8.76	3.74	8.66	0.10
2/14/2007	3.74	8.77	3.80	8.72	0.05
2/15/2007	4.59	9.62	4.65	9.57	0.05
2/16/2007	6.19	11.22	6.23	11.15	0.07
2/17/2007	6.77	11.80	6.78	11.70	0.10
2/18/2007	6.90	11.93	6.92	11.84	0.09
2/19/2007	6.45	11.48	6.51	11.43	0.05
2/20/2007	6.95	11.98	7.03	11.95	0.03
2/21/2007	6.95	11.98	7.01	11.93	0.05
2/22/2007	6.42	11.45	6.46	11.38	0.07
2/23/2007	5.56	10.59	5.58	10.50	0.09
2/24/2007	5.13	10.16	5.16	10.08	0.08
2/25/2007	5.52	10.55	5.54	10.46	0.09
2/26/2007	5.68	10.71	5.66	10.58	0.13
2/27/2007	5.59	10.62	5.61	10.53	0.09
2/28/2007	5.90	10.93	5.90	10.82	0.11

3/1/2007	5.93	10.96	5.95	10.87	0.09
3/2/2007	6.22	11.25	6.29	11.21	0.04
3/3/2007	6.18	11.21	6.21	11.13	0.08
3/4/2007	5.92	10.95	5.95	10.87	0.08
3/5/2007	5.70	10.73	5.73	10.65	0.08
3/6/2007	5.47	10.50	5.50	10.42	0.08
3/7/2007	5.39	10.42	5.42	10.34	0.08
3/8/2007	5.49	10.52	5.52	10.44	0.08
3/9/2007	5.95	10.98	6.03	10.95	0.03
3/10/2007	5.58	10.61	5.66	10.58	0.03
3/11/2007	4.91	9.94	4.95	9.87	0.07
3/12/2007	4.93	9.96	4.93	9.85	0.11
3/13/2007	5.85	10.88	5.87	10.79	0.09
3/14/2007	6.25	11.28	6.29	11.21	0.07
3/15/2007	6.55	11.58	6.60	11.52	0.06
3/16/2007	6.82	11.85	6.90	11.82	0.03
3/17/2007	6.78	11.81	6.88	11.80	0.01
3/18/2007	6.88	11.91	6.99	11.91	0.00
3/19/2007	6.92	11.95	7.04	11.96	-0.01
3/20/2007		5.03	7.74	12.66	-7.63
3/21/2007	8.18	13.21	8.30	13.22	-0.01
3/22/2007	8.57	13.60	8.71	13.63	-0.03
3/23/2007	7.52	12.55	7.65	12.57	-0.02
3/24/2007	6.76	11.79	6.90	11.82	-0.03
3/25/2007	7.82	12.85	7.93	12.85	0.00
3/26/2007	8.37	13.40	8.50	13.42	-0.02
3/27/2007	8.74	13.77	8.87	13.79	-0.02
3/28/2007	7.78	12.81	7.88	12.80	0.01
3/29/2007	7.43	12.46	7.54	12.46	0.00
3/30/2007	7.95	12.98	8.07	12.99	-0.01
3/31/2007	8.14	13.17	8.29	13.21	-0.04
4/1/2007	8.46	13.49	8.57	13.49	0.00
4/2/2007	7.96	12.99	8.05	12.97	0.02
4/3/2007	7.47	12.50	7.57	12.49	0.01
4/4/2007	7.49	12.52	7.61	12.53	-0.01
4/5/2007	7.58	12.61			
4/6/2007	7.47	12.50			
4/7/2007	6.63	11.66			
4/8/2007	6.14	11.17			
4/9/2007	5.96	10.99	6.02	10.94	0.05
4/10/2007	5.91	10.94	5.96	10.88	0.06
4/11/2007	6.27	11.30	6.35	11.27	0.03
4/12/2007	5.92	10.95	5.99	10.91	0.04
4/13/2007	6.17	11.20	6.26	11.18	0.02
4/14/2007	6.67	11.70	6.76	11.68	0.02
4/15/2007	6.87	11.90	6.93	11.85	0.05
4/16/2007	6.69	11.72	6.80	11.72	0.00
4/17/2007	7.10	12.13	7.21	12.13	0.00
4/18/2007	7.48	12.51	7.60	12.52	-0.01
4/19/2007	6.93	11.96	6.99	11.91	0.05
4/20/2007	7.15	12.18	7.23	12.15	0.03
4/21/2007	6.88	11.91	7.00	11.92	-0.01
4/22/2007	6.76	11.79	6.86	11.78	0.01
4/23/2007	6.46	11.49	6.52	11.44	0.05
4/24/2007	5.96	10.99	6.04	10.96	0.03
4/25/2007	5.33	10.36	5.37	10.29	0.07
4/26/2007	5.54	10.57	5.58	10.50	0.07
4/27/2007	5.61	10.64	5.66	10.58	0.06
4/28/2007	5.82	10.85	5.84	10.76	0.09
4/29/2007	6.03	11.06	6.06	10.98	0.08
4/30/2007	6.09	11.12	6.13	11.05	0.07
5/1/2007	6.60	11.63	6.67	11.59	0.04
5/2/2007	7.33	12.36	7.46	12.38	-0.02
5/3/2007	7.42	12.45	7.53	12.45	0.00
5/4/2007	7.76	12.79	7.88	12.80	-0.01
5/5/2007	7.98	13.01	8.05	12.97	0.04
5/6/2007	7.80	12.83	7.91	12.83	0.00
5/7/2007	7.07	12.10	7.16	12.08	0.02

5/8/2007	6.55	11.58	6.60	11.52	0.06
5/9/2007	6.81	11.84	6.88	11.80	0.04
5/10/2007	6.90	11.93	6.97	11.89	0.04
5/11/2007	6.98	12.01	7.04	11.96	0.05
5/12/2007	7.31	12.34	7.40	12.32	0.02
5/13/2007	6.90	11.93	6.94	11.86	0.07
5/14/2007	7.28	12.31	7.37	12.29	0.02
5/15/2007	8.06	13.09	8.17	13.09	0.00
5/16/2007	8.19	13.22	8.28	13.20	0.02
5/17/2007	7.73	12.76	7.82	12.74	0.02
5/18/2007	7.64	12.67	7.74	12.66	0.01
5/19/2007	7.60	12.63	7.70	12.62	0.01
5/20/2007	7.62	12.65	7.74	12.66	-0.01
5/21/2007	6.92	11.95	7.02	11.94	0.01
5/22/2007	6.95	11.98	7.01	11.93	0.05
5/23/2007	6.54	11.57	6.62	11.54	0.03
5/24/2007	6.26	11.29	6.31	11.23	0.06
5/25/2007	6.62	11.65	6.67	11.59	0.06
5/26/2007	6.31	11.34	6.36	11.28	0.06
5/27/2007	5.91	10.94	5.94	10.86	0.08
5/28/2007	5.67	10.70	5.68	10.60	0.10
5/29/2007	6.26	11.29	6.30	11.22	0.07
5/30/2007	6.14	11.17	6.18	11.10	0.07
5/31/2007	6.17	11.20			
6/1/2007	6.19	11.22			
6/2/2007	6.09	11.12			
6/3/2007	5.79	10.82			
6/4/2007	5.71	10.74			
6/5/2007	5.96	10.99			
6/6/2007		5.03	5.75	10.67	-5.64
6/7/2007	5.91	10.94	5.96	10.88	0.06
6/8/2007	5.59	10.62	5.62	10.54	0.08
6/9/2007	6.30	11.33	6.42	11.34	-0.01
6/10/2007	6.90	11.93	6.98	11.90	0.03
6/11/2007		5.03	6.52	11.44	-6.41
6/12/2007	6.70	11.73	6.76	11.68	0.05
6/13/2007	6.58	11.61	6.65	11.57	0.04
6/14/2007	6.50	11.53	6.54	11.46	0.07
6/15/2007	6.52	11.55	6.58	11.50	0.05
6/16/2007	6.39	11.42	6.45	11.37	0.05
6/17/2007	5.39	10.42	5.44	10.36	0.06
6/18/2007	4.88	9.91	4.86	9.78	0.13
6/19/2007	5.40	10.43	5.42	10.34	0.09
6/20/2007	5.16	10.19	5.16	10.08	0.11
6/21/2007	4.35	9.38	4.34	9.26	0.12
6/22/2007	4.32	9.35	4.29	9.21	0.14
6/23/2007	4.34	9.37	4.32	9.24	0.13
6/24/2007	4.04	9.07	4.02	8.94	0.13
6/25/2007	3.32	8.35	3.27	8.19	0.16
6/26/2007	3.50	8.53	3.46	8.38	0.15
6/27/2007	3.88	8.91	3.83	8.75	0.16
6/28/2007	3.90	8.93	3.92	8.84	0.09
6/29/2007	4.14	9.17	4.17	9.09	0.08
6/30/2007	4.80	9.83	4.80	9.72	0.11
7/1/2007	4.75	9.78	4.75	9.67	0.11
7/2/2007	3.82	8.85	3.81	8.73	0.12
7/3/2007	3.80	8.83	3.79	8.71	0.12
7/4/2007	4.04	9.07	4.04	8.96	0.11
7/5/2007	3.64	8.67	3.62	8.54	0.13
7/6/2007	3.99	9.02	3.95	8.87	0.15
7/7/2007	3.65	8.68	3.62	8.54	0.14
7/8/2007	3.45	8.48	3.41	8.33	0.15
7/9/2007	3.69	8.72	3.67	8.59	0.13
7/10/2007	4.15	9.18			
7/11/2007	4.44	9.47	4.43	9.35	0.12
7/12/2007	4.94	9.97	4.94	9.86	0.11
7/13/2007	5.30	10.33	5.30	10.22	0.11
7/14/2007	5.43	10.46	5.47	10.39	0.07

7/15/2007	5.48	10.51	5.54	10.46	0.05
7/16/2007	5.52	10.55	5.54	10.46	0.09
7/17/2007	5.50	10.53	5.58	10.50	0.03
7/18/2007	4.70	9.73	4.76	9.68	0.05
7/19/2007		5.03	4.18	9.10	-4.07
7/20/2007		5.03			
7/21/2007	3.70	8.73			
7/22/2007	3.61	8.64	3.64	8.56	0.08
7/23/2007	3.80	8.83	3.85	8.77	0.06
7/24/2007	3.54	8.57	3.51	8.43	0.14
7/25/2007	3.22	8.25	3.19	8.11	0.14
7/26/2007	3.31	8.34	3.28	8.20	0.14
7/27/2007	3.77	8.80	3.76	8.68	0.12
7/28/2007	4.23	9.26	4.24	9.16	0.10
7/29/2007	4.16	9.19	4.17	9.09	0.10
7/30/2007	4.11	9.14			
7/31/2007	4.41	9.44			

Appendix A-2
Arkema, Inc.
Portland Oregon
Willamette River Stage Elevations - 2005

Date	Morrison Bridge	
	Gage Height	
	(ft)	(ft NAVD88)
1/1/2005	4.30	9.33
1/2/2005	3.77	8.80
1/3/2005	3.64	8.67
1/4/2005	4.04	9.07
1/5/2005	4.02	9.05
1/6/2005	4.43	9.46
1/7/2005	4.95	9.98
1/8/2005	5.61	10.64
1/9/2005	5.50	10.53
1/10/2005	4.97	10.00
1/11/2005	5.31	10.34
1/12/2005	5.07	10.10
1/13/2005	4.56	9.59
1/14/2005		
1/15/2005		
1/16/2005		
1/17/2005	3.59	8.62
1/18/2005		
1/19/2005	5.06	10.09
1/20/2005	5.12	10.15
1/21/2005	4.87	9.90
1/22/2005	4.81	9.84
1/23/2005	4.62	9.65
1/24/2005	4.61	9.64
1/25/2005	4.63	9.66
1/26/2005	4.76	9.79
1/27/2005	5.14	10.17
1/28/2005	5.06	10.09
1/29/2005	4.64	9.67
1/30/2005	4.05	9.08
1/31/2005	3.64	8.67
2/1/2005	3.41	8.44
2/2/2005	3.39	8.42
2/3/2005	3.50	8.53
2/4/2005	3.86	8.89
2/5/2005	4.15	9.18
2/6/2005	4.70	9.73
2/7/2005	4.77	9.80
2/8/2005	4.82	9.85
2/9/2005	4.72	9.75
2/10/2005	4.80	9.83
2/11/2005	4.93	9.96
2/12/2005	4.95	9.98
2/13/2005	4.33	9.36
2/14/2005	3.54	8.57

2/15/2005	3.48	8.51
2/16/2005	3.35	8.38
2/17/2005	3.32	8.35
2/18/2005	3.59	8.62
2/19/2005	3.72	8.75
2/20/2005	3.84	8.87
2/21/2005	3.47	8.50
2/22/2005	3.48	8.51
2/23/2005	3.49	8.52
2/24/2005	3.75	8.78
2/25/2005	3.80	8.83
2/26/2005	3.77	8.80
2/27/2005	3.77	8.80
2/28/2005	3.77	8.80
3/1/2005	3.84	8.87
3/2/2005		
3/3/2005	3.41	8.44
3/4/2005	3.43	8.46
3/5/2005	3.45	8.48
3/6/2005	3.14	8.17
3/7/2005	3.29	8.32
3/8/2005	3.40	8.43
3/9/2005		
3/10/2005	3.73	8.76
3/11/2005	4.24	9.27
3/12/2005	4.08	9.11
3/13/2005	3.55	8.58
3/14/2005	3.51	8.54
3/15/2005	3.26	8.29
3/16/2005	3.17	8.20
3/17/2005	2.89	7.92
3/18/2005	2.59	7.62
3/19/2005	2.83	7.86
3/20/2005	3.51	8.54
3/21/2005	3.51	8.54
3/22/2005	3.59	8.62
3/23/2005		
3/24/2005	3.97	9.00
3/25/2005	3.67	8.70
3/26/2005	3.94	8.97
3/27/2005	5.27	10.30
3/28/2005	6.69	11.72
3/29/2005	7.31	12.34
3/30/2005	7.05	12.08
3/31/2005	6.37	11.40
4/1/2005	6.17	11.20
4/2/2005	5.35	10.38
4/3/2005	4.88	9.91
4/4/2005	4.47	9.50
4/5/2005	4.37	9.40
4/6/2005		
4/7/2005	5.84	10.87
4/8/2005	5.11	10.14
4/9/2005	5.04	10.07

4/10/2005	4.47	9.50
4/11/2005	4.90	9.93
4/12/2005	4.72	9.75
4/13/2005	4.70	9.73
4/14/2005	4.06	9.09
4/15/2005	3.69	8.72
4/16/2005	3.78	8.81
4/17/2005	3.59	8.62
4/18/2005	3.41	8.44
4/19/2005	3.52	8.55
4/20/2005	3.64	8.67
4/21/2005	3.54	8.57
4/22/2005	4.13	9.16
4/23/2005	4.66	9.69
4/24/2005	4.87	9.90
4/25/2005		
4/26/2005	4.99	10.02
4/27/2005	5.69	10.72
4/28/2005	5.88	10.91
4/29/2005	5.42	10.45
4/30/2005	4.69	9.72
5/1/2005	4.33	9.36
5/2/2005	4.56	9.59
5/3/2005	4.73	9.76
5/4/2005		
5/5/2005	5.24	10.27
5/6/2005	5.72	10.75
5/7/2005	6.03	11.06
5/8/2005	6.38	11.41
5/9/2005	6.81	11.84
5/10/2005	7.23	12.26
5/11/2005	7.55	12.58
5/12/2005	8.45	13.48
5/13/2005	7.96	12.99
5/14/2005	7.16	12.19
5/15/2005	6.86	11.89
5/16/2005	6.83	11.86
5/17/2005	6.42	11.45
5/18/2005	7.88	12.91
5/19/2005	8.97	14.00
5/20/2005	9.01	14.04
5/21/2005	8.93	13.96
5/22/2005	9.22	14.25
5/23/2005	9.06	14.09
5/24/2005	8.71	13.74
5/25/2005	8.36	13.39
5/26/2005	7.51	12.54
5/27/2005	7.47	12.50
5/28/2005	7.62	12.65
5/29/2005	7.13	12.16
5/30/2005	6.14	11.17
5/31/2005	5.02	10.05
6/1/2005	5.33	10.36
6/2/2005	6.11	11.14

6/3/2005	6.16	11.19
6/4/2005	5.59	10.62
6/5/2005	5.75	10.78
6/6/2005	5.33	10.36
6/7/2005	5.49	10.52
6/8/2005	5.28	10.31
6/9/2005	5.29	10.32
6/10/2005	5.52	10.55
6/11/2005	5.07	10.10
6/12/2005	4.64	9.67
6/13/2005	3.95	8.98
6/14/2005	3.92	8.95
6/15/2005	3.59	8.62
6/16/2005	3.88	8.91
6/17/2005	4.54	9.57
6/18/2005	4.92	9.95
6/19/2005	4.82	9.85
6/20/2005	4.96	9.99
6/21/2005	5.76	10.79
6/22/2005	5.70	10.73
6/23/2005	6.05	11.08
6/24/2005	6.10	11.13
6/25/2005	5.78	10.81
6/26/2005	5.54	10.57
6/27/2005	5.24	10.27
6/28/2005	5.13	10.16
6/29/2005	4.54	9.57
6/30/2005	4.66	9.69
7/1/2005	4.94	9.97
7/2/2005	5.17	10.20
7/3/2005	4.60	9.63
7/4/2005	4.23	9.26
7/5/2005	3.79	8.82
7/6/2005	4.64	9.67
7/7/2005	4.03	9.06
7/8/2005	4.65	9.68
7/9/2005	4.73	9.76
7/10/2005	4.31	9.34
7/11/2005	4.18	9.21
7/12/2005	4.00	9.03
7/13/2005	3.70	8.73
7/14/2005	3.77	8.80
7/15/2005	4.14	9.17
7/16/2005	4.38	9.41
7/17/2005	4.41	9.44
7/18/2005		
7/19/2005		
7/20/2005		
7/21/2005		
7/22/2005	5.33	10.36
7/23/2005	5.01	10.04
7/24/2005	4.52	9.55
7/25/2005	3.93	8.96
7/26/2005	4.24	9.27

7/27/2005	4.14	9.17
7/28/2005	3.62	8.65
7/29/2005	3.54	8.57
7/30/2005	3.78	8.81
7/31/2005	3.91	8.94
8/1/2005	4.23	9.26
8/2/2005	3.95	8.98
8/3/2005	3.68	8.71
8/4/2005	3.24	8.27
8/5/2005	3.44	8.47
8/6/2005	3.71	8.74
8/7/2005	3.60	8.63
8/8/2005	3.43	8.46
8/9/2005	3.44	8.47
8/10/2005	3.10	8.13
8/11/2005	3.08	8.11
8/12/2005	3.17	8.20
8/13/2005	2.64	7.67
8/14/2005	2.55	7.58
8/15/2005	2.60	7.63
8/16/2005	2.98	8.01
8/17/2005	3.21	8.24
8/18/2005	4.14	9.17
8/19/2005	4.25	9.28
8/20/2005	4.18	9.21
8/21/2005	3.96	8.99
8/22/2005	3.57	8.60
8/23/2005	3.64	8.67
8/24/2005	3.69	8.72
8/25/2005	3.18	8.21
8/26/2005	2.62	7.65
8/27/2005	2.30	7.33
8/28/2005	2.54	7.57
8/29/2005	2.47	7.50
8/30/2005	2.52	7.55
8/31/2005	2.83	7.86
9/1/2005	2.70	7.73
9/2/2005	2.67	7.70
9/3/2005	2.49	7.52
9/4/2005	2.54	7.57
9/5/2005	2.37	7.40
9/6/2005	2.30	7.33
9/7/2005	2.22	7.25
9/8/2005	2.16	7.19
9/9/2005	2.33	7.36
9/10/2005	2.23	7.26
9/11/2005	1.61	6.64
9/12/2005	1.64	6.67
9/13/2005	1.90	6.93
9/14/2005	2.24	7.27
9/15/2005	2.22	7.25
9/16/2005	2.57	7.60
9/17/2005	2.66	7.69
9/18/2005	2.95	7.98

9/19/2005	2.60	7.63
9/20/2005	2.50	7.53
9/21/2005	2.73	7.76
9/22/2005	2.71	7.74
9/23/2005	2.43	7.46
9/24/2005	1.98	7.01
9/25/2005	1.45	6.48
9/26/2005	1.16	6.19
9/27/2005	1.56	6.59
9/28/2005	1.39	6.42
9/29/2005	1.71	6.74
9/30/2005	2.76	7.79
10/1/2005	3.00	8.03
10/2/2005	2.53	7.56
10/3/2005	2.54	7.57
10/4/2005	2.85	7.88
10/5/2005	3.29	8.32
10/6/2005	3.27	8.30
10/7/2005	3.34	8.37
10/8/2005	3.29	8.32
10/9/2005	2.77	7.80
10/10/2005	2.41	7.44
10/11/2005	2.34	7.37
10/12/2005	2.28	7.31
10/13/2005	2.54	7.57
10/14/2005	2.94	7.97
10/15/2005	3.49	8.52
10/16/2005	3.15	8.18
10/17/2005	3.10	8.13
10/18/2005	3.38	8.41
10/19/2005	3.97	9.00
10/20/2005	3.70	8.73
10/21/2005	3.26	8.29
10/22/2005	3.08	8.11
10/23/2005	2.50	7.53
10/24/2005	2.12	7.15
10/25/2005	2.36	7.39
10/26/2005	2.39	7.42
10/27/2005	2.37	7.40
10/28/2005	2.87	7.90
10/29/2005	2.89	7.92
10/30/2005	2.62	7.65
10/31/2005	3.09	8.12
11/1/2005	4.44	9.47
11/2/2005	4.67	9.70
11/3/2005	4.96	9.99
11/4/2005	5.28	10.31
11/5/2005	5.16	10.19
11/6/2005	5.26	10.29
11/7/2005	4.89	9.92
11/8/2005	4.51	9.54
11/9/2005	3.93	8.96
11/10/2005	3.45	8.48
11/11/2005	3.73	8.76

11/12/2005	4.08	9.11
11/13/2005	4.55	9.58
11/14/2005	4.80	9.83
11/15/2005	4.54	9.57
11/16/2005	4.53	9.56
11/17/2005	4.25	9.28
11/18/2005	4.13	9.16
11/19/2005	3.89	8.92
11/20/2005	3.58	8.61
11/21/2005	3.18	8.21
11/22/2005	3.01	8.04
11/23/2005	2.66	7.69
11/24/2005	2.61	7.64
11/25/2005	3.07	8.10
11/26/2005	3.51	8.54
11/27/2005	3.50	8.53
11/28/2005	3.48	8.51
11/29/2005	4.23	9.26
11/30/2005	4.31	9.34
12/1/2005	5.05	10.08
12/2/2005	5.21	10.24
12/3/2005	5.42	10.45
12/4/2005	4.74	9.77
12/5/2005	4.49	9.52
12/6/2005	4.36	9.39
12/7/2005	4.01	9.04
12/8/2005	3.47	8.50
12/9/2005	3.41	8.44
12/10/2005	3.24	8.27
12/11/2005	3.62	8.65
12/12/2005	3.74	8.77
12/13/2005	3.70	8.73
12/14/2005	3.72	8.75
12/15/2005	3.88	8.91
12/16/2005	4.31	9.34
12/17/2005	4.12	9.15
12/18/2005	3.71	8.74
12/19/2005	3.67	8.70
12/20/2005	3.67	8.70
12/21/2005	4.10	9.13
12/22/2005	5.02	10.05
12/23/2005	5.81	10.84
12/24/2005	5.83	10.86
12/25/2005	5.83	10.86
12/26/2005	5.95	10.98
12/27/2005	6.12	11.15
12/28/2005	8.01	13.04
12/29/2005	10.01	15.04
12/30/2005	11.02	16.05
12/31/2005	12.77	17.80

Appendix B
Steady-State Calibration Results

MODSTATS Version 1.5 - GROUND WATER MODEL CALIBRATION SUMMARY
ERM - Rocky Mountain
Ground Water Modeling
Denver, Colorado

Simulation: ARK015
Comments: Calibrated Steady-State Model
Flow Conditions: Steady-State Flow

Calibration Target	Layer Number	Target Head	Model Head	Model Residual
MWA-2	1	12.86	12.94	-0.08
MWA-3	1	13.00	13.27	-0.27
MWA-4	1	13.08	13.41	-0.33
MWA-5	1	12.72	13.97	-1.25
MWA-6r	1	13.11	14.00	-0.89
MWA-15r	1	13.26	15.11	-1.85
MWA-17si	1	12.97	13.34	-0.37
MWA-18	1	12.99	14.13	-1.14
MWA-19	1	12.68	13.35	-0.67
MWA-20	1	13.40	15.86	-2.46
MWA-22	1	16.44	16.07	0.37
MWA-23	1	27.63	23.88	3.75
MWA-24	1	15.48	16.78	-1.30
MWA-25	1	14.21	16.56	-2.35
MWA-26	1	14.65	17.19	-2.54
MWA-27	1	13.79	15.77	-1.98
MWA-29	1	12.99	13.49	-0.50
MWA-30	1	13.13	13.44	-0.31
MWA-33	1	18.82	20.81	-1.99
MWA-35	1	14.46	16.58	-2.12
MWA-36	1	14.41	16.62	-2.21
MWA-37	1	14.38	16.64	-2.26
MWA-38	1	14.93	17.25	-2.32
MWA-39	1	27.82	22.47	5.35
MWA-40	1	19.45	18.90	0.55
MWA-41	1	13.87	16.80	-2.93
MWA-42	1	13.31	15.92	-2.61
MWA-43	1	13.26	14.84	-1.58
MWA-44	1	13.12	14.28	-1.16
MWA-45	1	13.35	15.44	-2.09
MWA-46	1	12.74	13.24	-0.50
MWA-47	1	13.04	13.23	-0.19
MWA-60	1	12.97	13.94	-0.97
MWA-61	1	12.88	12.96	-0.08
MWA-62	1	13.87	14.40	-0.53
MWA-63	1	14.41	14.17	0.24
MWA-67si	1	12.86	12.96	-0.10
MWA-68si	1	12.93	13.01	-0.08
MWA-69	1	12.67	13.03	-0.36
NMP-1D	1	12.58	14.69	-2.11
NMP-2D	1	13.00	14.48	-1.48
NMP-3D	1	13.22	14.27	-1.05
NMP-4D	1	13.03	14.56	-1.53
NMP-5D	1	12.93	14.51	-1.58
NMP-6D	1	13.17	14.32	-1.15
PMP-1	1	13.41	14.97	-1.56
PMP-2	1	13.51	14.86	-1.35
PMP-3	1	13.55	14.73	-1.18
PMP-4	1	13.08	14.26	-1.18
PMP-5	1	13.03	13.87	-0.84
PMP-6	1	13.08	13.82	-0.74
PT-1	1	22.47	20.74	1.73
PT-2	1	14.13	16.52	-2.39

PT-3	1	12.95	13.57	-0.62
AL2-17	1	32.55	34.32	-1.77
AL5-19	1	30.20	32.98	-2.78
BTB-4B-25	1	31.40	32.58	-1.18
MW-03-S(27)	1	25.91	26.13	-0.22
MW-06-S(31)	1	26.32	26.31	0.01
MW-07-S(41)	1	25.30	25.36	-0.06
RP-01-31	1	13.84	14.57	-0.73
RP-03-30R	1	23.65	24.53	-0.88
RP-04-16	1	25.56	29.05	-3.49
RP-05-16	1	30.24	34.10	-3.86
RP-06-30	1	22.24	21.12	1.12
RP-08-23	1	25.91	24.66	1.25
RP-10-30	1	28.41	26.34	2.07
RP-15-25	1	33.79	30.04	3.75
RP-16-25	1	29.24	29.44	-0.20
RP-17-25	1	32.50	31.58	0.92
RP-18-30	1	30.44	28.63	1.81
RP-19-25	1	29.50	30.44	-0.94
RP-24-30	1	13.13	12.59	0.54
W-03-S(17)	1	29.92	29.26	0.66
W-08-26	1	30.30	29.52	0.78
W-09(38)	1	28.65	29.01	-0.36
W-11-S(21)	1	31.71	29.96	1.75
W-12-S(20)	1	30.94	31.77	-0.83
W-15-S(14)	1	31.45	30.53	0.92
W-19-S(25)	1	14.33	15.29	-0.96
MW-1	1	26.27	24.95	1.32
MW-11	1	23.81	23.10	0.71
BTB-4B-55	2	25.86	26.98	-1.12
AL2-32	2	30.56	28.46	2.10
AL5-35	2	28.88	28.16	0.72
MW-01-26	2	41.81	36.07	5.74
MW-02-26	2	37.84	35.10	2.74
MW-03-27	2	37.29	33.86	3.43
MW-04-27	2	34.35	32.37	1.98
MW-04-47	2	34.74	32.43	2.31
MW-05-24	2	32.01	30.39	1.62
MW-05-34	2	31.81	30.26	1.55
MW-09-23	2	36.06	33.64	2.42
MW-10-24	2	35.97	34.25	1.72
MW-11-24	2	35.98	34.92	1.06
MW-12-27	2	38.69	36.69	2.00
RP-02-31	2	13.74	14.85	-1.11
RP-09-35	2	14.77	17.33	-2.56
RP-16-40	2	29.34	29.24	0.10
W-03-I(41)	2	27.31	22.32	4.99
W-04-I(49)	2	25.66	23.78	1.88
W-06-S(27)	2	31.15	29.77	1.38
W-08(54)	2	28.93	27.21	1.72
MWA-7(i)	3	28.75	23.37	5.38
MWA-8i	3	13.59	12.98	0.61
MWA-9i	3	12.05	13.30	-1.25
MWA-10i	3	13.08	13.44	-0.36
MWA-16i	3	13.12	14.39	-1.27
MWA-32i	3	13.00	13.43	-0.43
MWA-34i	3	13.32	13.36	-0.04
MWA-48i	3	13.51	16.62	-3.11
MWA-49i	3	12.87	13.11	-0.24
MWA-50i	3	13.21	13.65	-0.44
MWA-51i	3	13.31	14.16	-0.85
MWA-52i	3	13.43	15.72	-2.29
MWA-53i	3	12.95	13.51	-0.56
MWA-54i	3	13.32	15.93	-2.61
MWA-55i	3	13.27	15.81	-2.54
MWA-64i	3	13.02	12.98	0.04
MWA-66i	3	13.13	13.06	0.07

MWA-70i	3	15.62	20.97	-5.35
MW-01-41	3	38.10	36.00	2.10
MW-02-46	3	37.89	35.33	2.56
MW-03-49	3	37.36	33.77	3.59
MW-03-I(60)	3	19.98	20.18	-0.20
MW-09-42	3	35.83	33.63	2.20
MW-10-44	3	35.95	34.21	1.74
MW-11-37	3	36.01	34.93	1.08
MW-12-41	3	38.69	37.08	1.61
RP-02-49	3	13.60	14.32	-0.72
RP-08-80	3	16.05	17.73	-1.68
RP-09-47	3	14.76	17.39	-2.63
RP-10-60	3	15.80	19.66	-3.86
RP-18-70	3	18.87	20.45	-1.58
RP-24-60	3	12.68	12.61	0.07
W-10(71)	3	19.07	18.23	0.84
W-11-I(60)	3	18.04	20.32	-2.28
W-12-I(58)	3	23.73	22.60	1.13
W-15-I(38)	3	31.50	28.28	3.22
W-16-31	3	29.18	25.18	4.00
MWA-11i	4	13.69	15.71	-2.02
MWA-14i	4	13.89	13.93	-0.04
RPW-02(38)	4	38.37	36.32	2.05
RP-04-48	4	28.38	28.46	-0.08
RP-19-90	4	18.09	20.71	-2.62
MWA-12i(d)	4	25.30	23.28	2.02
MWA-13d	4	12.99	13.27	-0.28
MWA-28i(d)	4	14.60	16.67	-2.07
MWA-31i(d)	4	11.51	13.54	-2.03
MWA-56d	4	12.82	13.51	-0.69
MWA-57d	4	13.22	15.72	-2.50
MWA-58d	4	11.87	13.28	-1.41
MWA-59d	4	10.99	14.02	-3.03
AL2-46	4	29.65	28.42	1.23
AL6-96	4	25.87	26.03	-0.16
BTB-4A-84	4	26.94	26.67	0.27
MW-01-56	4	38.02	35.84	2.18
MW-02-62	4	38.38	35.64	2.74
MW-03-68	4	37.45	33.68	3.77
MW-03-81	4	20.21	20.43	-0.22
MW-04-63	4	35.06	32.44	2.62
MW-05-52	4	29.85	30.47	-0.62
MW-09-58	4	35.36	33.64	1.72
MW-10-57	4	36.18	34.19	1.99
MW-11-56	4	36.38	34.96	1.42
MW-12-59	4	38.79	37.08	1.71
RP-01-51	4	13.82	14.61	-0.79
RP-03-52R	4	22.64	24.40	-1.76
RP-04-41	4	28.48	28.46	0.02
RP-05-47	4	30.53	30.15	0.38
RP-06-87	4	15.59	17.25	-1.66
RP-15-53	4	28.73	28.11	0.62
RP-17-95	4	24.76	25.10	-0.34
RP-24-73	4	12.65	12.65	0.00
RPW-03(53)	4	36.17	34.36	1.81
W-03-D(89)	4	23.17	22.04	1.13
W-04-89	4	27.45	23.81	3.64
W-06-D(49)	4	32.95	29.85	3.10
W-09-116	4	24.37	24.48	-0.11
W-09-86	4	23.69	24.50	-0.81
W-11-D(91)	4	17.82	20.30	-2.48
W-12-D(100)	4	23.61	22.52	1.09
W-15-D(62)	4	31.00	28.27	2.73
W-16-D(85)	4	27.52	25.07	2.45
W-16-I(50)	4	27.60	25.09	2.51
W-19-I(49)	4	14.28	15.31	-1.03
AL5-62	5	28.73	28.08	0.65

RP-10-97	5	17.12	19.77	-2.65
RP-15-65	5	28.62	28.14	0.48
RP-17-119	5	24.19	25.14	-0.95
RP-24-85	5	12.62	12.71	-0.09
MW-03-137	5	20.16	20.39	-0.23
RP-04-56	5	28.38	28.41	-0.03
RP-05-65	5	29.77	30.20	-0.43
RP-06-105	5	15.50	17.04	-1.54
RP-06-95	5	15.50	16.99	-1.49
RP-18-111	5	19.73	20.46	-0.73
MWA-21b	6	12.05	13.34	-1.29
BST2W-61	6	29.51	28.42	1.09
BST5W-74	6	28.45	28.12	0.33
MW-01-76	6	33.38	35.78	-2.40
MW-05-70	6	29.67	30.23	-0.56
MW-09-80	6	35.71	33.60	2.11
MW-11-79	6	36.82	34.84	1.98
MW-12-79	6	38.58	36.85	1.73
RP-01-65	6	13.85	14.65	-0.80
RP-02-66	6	13.56	14.81	-1.25
RP-08-107	6	16.26	17.73	-1.47
RP-09-64	6	14.14	17.48	-3.34
RP-10-130	6	17.12	19.81	-2.69
RP-17-145	6	23.69	25.17	-1.48
RP-18-125	6	20.84	20.46	0.38
RP-19-129	6	19.58	20.72	-1.14
W-06-B(67)	6	29.58	29.74	-0.16
W-08-74	6	28.34	27.09	1.25
W-11-B(122)	6	18.53	20.24	-1.71
W-19-D(68)	6	14.46	15.22	-0.76

----------- Calibration Statistics for Entire Model -----------

Number of Targets: 217

Minimum Residual: -5.35
Maximum Residual: 5.74

Residual Mean: -0.09
Absolute Residual Mean: 1.50

Sum of Squared Residuals: 768.72
Root Mean Squared Error: 1.88
Residual Standard Dev.: 1.88

Range In Target Head: 30.82
Residual Std. Dev./Range: 0.061

------------- Calibration Statistics for Layer 1 ------------

Number of Targets: 82

Minimum Residual: -3.86
Maximum Residual: 5.35

Residual Mean: -0.61
Absolute Residual Mean: 1.33

Sum of Squared Residuals: 231.57
Root Mean Squared Error: 1.68
Residual Standard Dev.: 1.57

Range In Target Head: 21.21
Residual Std. Dev./Range: 0.074

------------- Calibration Statistics for Layer 2 ------------

```
Number of Targets:         21

Minimum Residual:         -2.56
Maximum Residual:          5.74

Residual Mean:             1.65
Absolute Residual Mean:    2.11

Sum of Squared Residuals:  127.71
Root Mean Squared Error:   2.47
Residual Standard Dev.:    1.83

Range In Target Head:      28.07
Residual Std. Dev./Range:  0.065


------------- Calibration Statistics for Layer  3  ------------
Number of Targets:         37

Minimum Residual:         -5.35
Maximum Residual:          5.38

Residual Mean:            -0.11
Absolute Residual Mean:    1.74

Sum of Squared Residuals:  187.47
Root Mean Squared Error:   2.25
Residual Standard Dev.:    2.25

Range In Target Head:      26.64
Residual Std. Dev./Range:  0.084


------------- Calibration Statistics for Layer  4  ------------
Number of Targets:         46

Minimum Residual:         -3.03
Maximum Residual:          3.77

Residual Mean:             0.36
Absolute Residual Mean:    1.52

Sum of Squared Residuals:  156.19
Root Mean Squared Error:   1.84
Residual Standard Dev.:    1.81

Range In Target Head:      27.80
Residual Std. Dev./Range:  0.065


------------- Calibration Statistics for Layer  5  ------------
Number of Targets:         11

Minimum Residual:         -2.65
Maximum Residual:          0.65

Residual Mean:            -0.64
Absolute Residual Mean:    0.84

Sum of Squared Residuals:  13.93
Root Mean Squared Error:   1.13
Residual Standard Dev.:    0.93

Range In Target Head:      17.15
Residual Std. Dev./Range:  0.054
```

```
------------- Calibration Statistics for Layer  6  ------------
Number of Targets:         20

Minimum Residual:         -3.34
Maximum Residual:          2.11

Residual Mean:            -0.51
Absolute Residual Mean:    1.40

Sum of Squared Residuals:  51.86
Root Mean Squared Error:   1.61
Residual Standard Dev.:    1.53

Range In Target Head:      26.53
Residual Std. Dev./Range:  0.058
```

MODSTATS Version 1.5 - GROUND WATER MODEL CALIBRATION SUMMARY
ERM - Rocky Mountain
Ground Water Modeling
Denver, Colorado

Simulation: ARKLW015
Comments: Steady-State Calibration Simulation - July 2005 Water Levels
Flow Conditions: Steady-State Flow

Calibration Target	Layer Number	Target Head	Model Head	Model Residual
MWA-2	1	10.49	10.41	0.08
MWA-3	1	10.96	10.73	0.23
MWA-4	1	11.04	10.89	0.15
MWA-5	1	10.06	11.22	-1.16
MWA-6r	1	11.06	11.50	-0.44
MWA-15r	1	11.81	12.45	-0.64
MWA-17si	1	10.90	10.79	0.11
MWA-18	1	10.86	11.64	-0.78
MWA-19	1	10.65	10.92	-0.27
MWA-20	1	11.32	13.40	-2.08
MWA-22	1	14.15	13.22	0.93
MWA-23	1	26.54	21.00	5.54
MWA-24	1	14.44	14.37	0.07
MWA-25	1	12.53	14.27	-1.74
MWA-26	1	12.70	15.02	-2.32
MWA-27	1	11.78	13.45	-1.67
MWA-29	1	10.47	11.22	-0.75
MWA-30	1	10.69	11.04	-0.35
MWA-33	1	19.86	18.62	1.24
MWA-35	1	12.86	14.25	-1.39
MWA-36	1	12.72	14.36	-1.64
MWA-37	1	12.71	14.36	-1.65
MWA-38	1	13.19	15.08	-1.89
MWA-39	1	26.67	19.75	6.92
MWA-40	1	18.55	16.30	2.25
MWA-41	1	11.51	14.58	-3.07
MWA-42	1	11.49	13.40	-1.91
MWA-43	1	10.78	12.66	-1.88
MWA-44	1	11.94	11.81	0.13
MWA-45	1	11.00	13.00	-2.00
MWA-46	1	10.40	10.81	-0.41
MWA-47	1	10.60	10.85	-0.25
MWA-60	1	10.44	11.26	-0.82
MWA-61	1	10.51	10.45	0.06
MWA-62	1	11.78	11.87	-0.09
MWA-63	1	11.44	11.33	0.11
MWA-67si	1	10.34	10.45	-0.11
MWA-68si	1	11.32	10.54	0.78
MWA-69	1	10.49	10.56	-0.07
NMP-3D	1	11.21	11.67	-0.46
NMP-4D	1	12.13	11.92	0.21
PMP-4	1	11.25	11.60	-0.35
PMP-5	1	11.09	11.28	-0.19
PMP-6	1	11.18	11.25	-0.07
MWA-8i	3	9.89	10.45	-0.56
MWA-9i	3	9.55	10.77	-1.22
MWA-10i	3	9.74	10.92	-1.18
MWA-16i	3	9.77	11.87	-2.10
MWA-32i	3	10.25	11.03	-0.78
MWA-34i	3	10.84	10.94	-0.10
MWA-48i	3	10.72	14.32	-3.60
MWA-49i	3	8.73	10.69	-1.96
MWA-50i	3	10.43	11.28	-0.85

MWA-51i	3	11.09	11.68	-0.59
MWA-52i	3	10.98	13.44	-2.46
MWA-53i	3	10.06	11.20	-1.14
MWA-54i	3	10.92	13.41	-2.49
MWA-55i	3	10.22	13.42	-3.20
MWA-64i	3	9.74	10.47	-0.73
MWA-65i	3	10.55	11.46	-0.91
MWA-66i	3	10.20	10.59	-0.39
MWA-11i(d)	4	10.91	13.01	-2.10
MWA-14i(d)	4	9.81	11.19	-1.38
MWA-28i(d)	4	12.24	14.33	-2.09
MWA-31i(d)	4	8.23	11.13	-2.90
MWA-56d	4	9.53	11.08	-1.55
MWA-57d	4	11.08	13.32	-2.24
MWA-58d	4	9.85	10.87	-1.02
MWA-59d	4	7.53	11.61	-4.08

----------- Calibration Statistics for Entire Model -----------
Number of Targets: 69

Minimum Residual: -4.08
Maximum Residual: 6.92

Residual Mean: -0.77
Absolute Residual Mean: 1.32

Sum of Squared Residuals: 234.02
Root Mean Squared Error: 1.84
Residual Standard Dev.: 1.67

Range In Target Head: 19.14
Residual Std. Dev./Range: 0.087

------------- Calibration Statistics for Layer 1 ------------
Number of Targets: 44

Minimum Residual: -3.07
Maximum Residual: 6.92

Residual Mean: -0.26
Absolute Residual Mean: 1.12

Sum of Squared Residuals: 138.49
Root Mean Squared Error: 1.77
Residual Standard Dev.: 1.75

Range In Target Head: 16.61
Residual Std. Dev./Range: 0.106

------------- Calibration Statistics for Layer 3 ------------
Number of Targets: 17

Minimum Residual: -3.60
Maximum Residual: -0.10

Residual Mean: -1.43
Absolute Residual Mean: 1.43

Sum of Squared Residuals: 51.38
Root Mean Squared Error: 1.74
Residual Standard Dev.: 0.99

Range In Target Head: 2.36
Residual Std. Dev./Range: 0.421

```
------------- Calibration Statistics for Layer  4  ------------
Number of Targets:          8

Minimum Residual:          -4.08
Maximum Residual:          -1.02

Residual Mean:             -2.17
Absolute Residual Mean:     2.17

Sum of Squared Residuals:  44.16
Root Mean Squared Error:   2.35
Residual Standard Dev.:    0.90

Range In Target Head:      4.71
Residual Std. Dev./Range:  0.192
```

Appendix C
Groundwater Flow Model Files

INCLUDED ON CD-ROM IN APPENDIX C