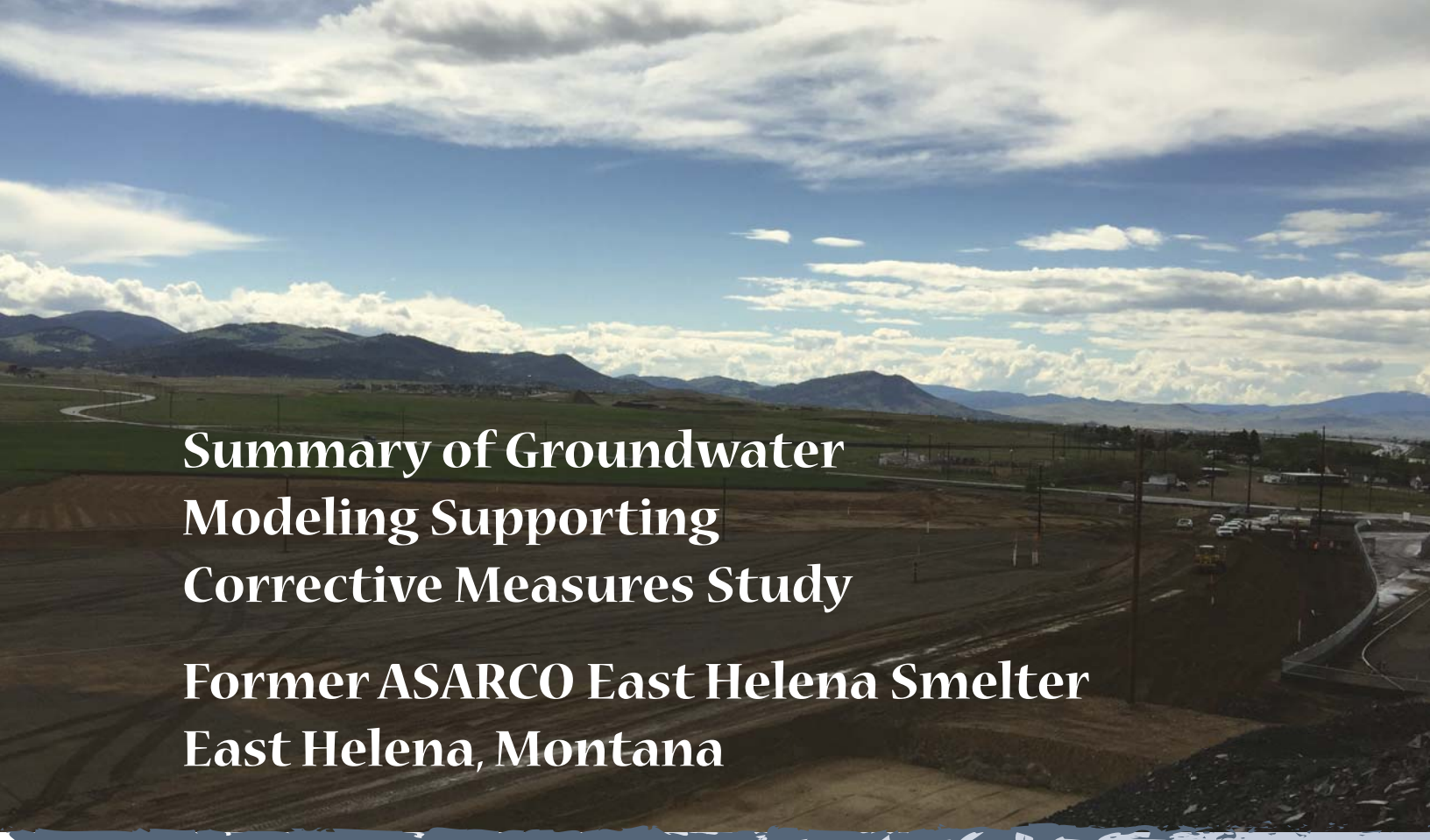

Summary of Groundwater Modeling Supporting Corrective Measures Study

Former ASARCO East Helena Smelter
East Helena, Montana

METG
Montana Environmental Trust Group

November 2017

NewFields

FINAL

Summary of Groundwater Modeling Supporting Corrective Measures Study

Former ASARCO East Helena Smelter
East Helena, Montana

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3D	three-dimensional
AMEC	AMEC Environmental & Infrastructure, Inc.
amsl	above mean sea level
As(III)	arsenite
As(V)	arsenate
Asarco	ASARCO, LLC
ASARCO	ASARCO Consulting, Inc.
CAMU	Corrective Action Management Unit
CGWA	controlled groundwater area
CMS	Corrective Measures Study
COC	contaminant of concern
DEM	digital elevation map
DEQ	Montana Department of Environmental Quality
EPA	Environmental Protection Agency
ET	evapotranspiration
ET Cover System	Evapotranspiration Cover System
FWL4	Fracture Well 4 Package
g/cm^3	grams per cubic centimeter
GHB	General Head Boundary
gpm	gallons per minute
GSI	GSI Water Solutions, Inc.
HDS Plant	High Density Sludge Plant
head	groundwater level
HFB	Horizontal Flow Barrier
IM	Interim Measure
L	representative concentration of SPLP or SBL leachate
M	mass of SPLP/SBL solid
MCL	maximum contaminant level
METG	Montana Environmental Trust Group, LLC
mg/L	milligram per liter
NRDP	Montana Natural Resource Damage Program
ρ	bulk density of SPLP/SBL solids
PRB	permeable reactive barriers
PW	concentration in pore water
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SBL	Sequential Batch Leach
Se(0)	elemental selenium
Se(-II)	selenide
Se(IV)	selenite
Se(VI)	selenite

SPHC	South Plant Hydraulic Control
SPLP	Synthetic Precipitation Leachate Procedure
SY	specific yield
U.S.	United States
USGS	U.S. Geologic Survey
V	volume of SPLP/SBL leachate
WRCC	Western Regional Climate Center

1.0 INTRODUCTION

This report summarizes numerical groundwater flow and contaminant transport modeling activities completed at the former East Helena Smelter site (herein "former Smelter site") located near the City of East Helena, Montana (**Figure 1.1**). Modeling work was completed to support evaluation of potential remedial actions.

The former Smelter site shown in **Figure 1.2** was a custom lead smelter that began operations in 1888 and produced lead bullion from smelting of a variety of metal bearing materials. Operations were suspended in April 2001, and in August of 2005 ASARCO, LLC (Asarco) filed for Chapter 11 bankruptcy. Ownership of the former Smelter site was transferred from Asarco to the Montana Environmental Trust Group, LLC (METG), Trustee of the Montana Environmental Custodial Trust (Custodial Trust) in December 2009 as part of the larger Asarco bankruptcy settlement agreement.

Historical operations at the former Smelter site resulted in release of metals and other contaminants to the environment (GSI, 2014). Investigations have shown that surface and subsurface soils contain elevated concentrations of metals including arsenic and selenium, and groundwater monitoring has delineated areas of elevated arsenic and selenium that extend north and northwestward from the former Smelter site.

In compliance with the Resource Conservation and Recovery Act (RCRA) Corrective Action requirements of the First Modification to the 1998 RCRA Consent Decree (Dreher et al., 2012), the Custodial Trust performed a Corrective Measures Study (CMS) to evaluate potential remedial actions to address contamination in and downgradient of the former Smelter site. As part of the CMS, numerical groundwater flow and contaminant transport modeling was performed to support evaluation of potential remedial actions. In addition, the numerical model has been used to support decision making related to implementation of Interim Measures (IMs), application for a Controlled Groundwater Area, proposed source control measures, multiple site investigations, and construction activities.

This report is included as an appendix to the broader CMS Report for the former Smelter site. The following subsections describe the numerical model background, modeling goals and objectives, the general modeling process, and document organization.

1.1 MODELING BACKGROUND

Groundwater flow and contaminant transport modeling for the former Smelter site were initiated in 2012. AMEC (2012a) prepared a work plan for a phased approach to groundwater modeling designed to meet general modeling objectives listed in the Phase II RCRA Facility Investigation (RFI) Work Plan (Hydrometrics, 2010; see **Section 1.2**). Several phases of groundwater flow modeling and predictive analysis were completed in accordance with AMEC (2012a) and were used to support decision making at the former Smelter site. The modeling performed to support the CMS generally followed the modeling process described in Anderson et al. (2015; **Figure 1.3**).

The numerical groundwater and contaminant transport models were developed based on the conceptual hydrogeologic and contaminant transport models, respectively. Modeling work included initial development of a steady-state groundwater flow model, development of a transient groundwater flow model, and initial development of contaminant transport models for arsenic and selenium. Conceptual models were updated based on additional data collected during routine monitoring, specific site investigations, and construction activities. The numerical models were updated and recalibrated based on the refined conceptual models.

The calibrated models were used to complete predictive analyses, which were used to support decision making regarding cleanup at the former Smelter site. Predictive modeling supported the following activities:

- Interim Measures (IMs) Evaluation: IMs implemented at the former Smelter site include:
    - South Plant Hydraulic Controls (SPHCs) including draining Upper and Lower lakes, dewatering Wilson Ditch, and realigning Prickly Pear Creek, which includes construction of a temporary bypass channel and removal of Smelter Dam;
    - Source Removal including excavation of South Plant and Acid Plant soils; and
    - Evapotranspiration (ET) Cover System including phased implementation of an ET Cover System over the former operating area.
- Tier II Source Control Measures Evaluation: Source control measures included source removal, permeable reactive barriers (PRBs), slurry walls, and focused pump and treat. Tier II source control measures were evaluated based on estimated effectiveness, implementability, and cost (CH2M HILL, 2014).
- Construction Activities: Construction activities completed at the former Smelter site included implementation of IMs, demolition of several structures, source removal, and removal of Upper and Lower lakes.
- Controlled Groundwater Area Petitioning: A petition for a Controlled Groundwater Area downgradient of the former Smelter site was submitted to the Department of Environmental Quality in 2014.
- Slag Pile Remedial Evaluation: Several proposed cover and regrading options for the Slag Pile.

The following documents describe groundwater flow modeling, contaminant transport modeling, and predictive analyses that have been completed for the former Smelter site:

- *AMEC (2012a), Groundwater Flow and Fate and Transport Model Work Plan, East Helena Site:* This work plan describes the technical approach for developing the numerical groundwater flow and contaminant transport models. In addition, it set forth specific modeling objectives that were designed to meet the general modeling objectives listed in the Phase II RFI Site Characterization Work Plan (Hydrometrics, 2010).
- *AMEC (2012b), DRAFT Initial Flow Model Design and Calibration, East Helena Site*: This technical memorandum documents an initial phase of groundwater flow modeling, including the

hydrogeologic conceptual model, code selection, model design, and initial model calibration to 2011 steady-state conditions.

- *NewFields (2014a), Groundwater Flow Model Calibration Refinement, Transient Verification, and Interim Measures Support, East Helena Site:* This technical memorandum documents the second phase of groundwater flow modeling, including refinement of the hydrogeologic conceptual model and corresponding adjustments to the numerical model, recalibration to 2011 steady-state conditions, initial calibration to transient groundwater elevation data measured during the Upper Lake Drawdown Test (Hydrometrics, 2012), and predictive analysis supporting design and implementation of IMs. Results from predictive simulations were used to evaluate changes in groundwater elevations, changes in gain/loss from Prickly Pear Creek, changes in groundwater flux, and changes in groundwater flow directions that would result from implementing the IMs.
- *NewFields (2014b), Revised Work Plan for Solute Transport Model Development Former East Helena Smelter:* This technical memorandum documents the approach to contaminant transport modeling for the former Smelter site. The memorandum describes specific objectives for contaminant transport modeling, the contaminant transport conceptual model, and an approach for developing the numerical contaminant transport model.
- *NewFields (2014c), Advective transport modeling to support petition for a Controlled Groundwater Area Application, East Helena Site:* This technical memorandum documents modeling performed to support a petition for a Controlled Groundwater Area downgradient of the former Smelter site. Particle tracking techniques were used to evaluate flow paths from the former Smelter site and assist in delineation of buffer zones around the existing arsenic and selenium plumes designed to protect human health and the environment.
- *NewFields (2014d), Groundwater Flow Model and Predictive Simulation Update*: This technical memorandum documents updates to the groundwater flow model and predictive analysis described in NewFields (2014a). These updates incorporated new information collected following the Upper Lake Drawdown Test (Hydrometrics, 2012) and during construction of the Prickly Pear Creek bypass channel. A drainage ditch near the gravel pits north of Prickly Pear Creek and a leaking water line at the south end of the Slag Pile were also incorporated into the model. After new information was incorporated, the model was recalibrated to 2011 steady-state conditions and transient conditions between September 2011 and May 2014. Once the model was recalibrated, predictive simulations described in NewFields (2014a) were revised and the new results were evaluated.
- *NewFields (2014e), DRAFT Work Plan Addendum for Fate and Transport Predictive Simulation, Former East Helena Smelter:* This document describes the approach to predictive contaminant transport modeling, including proposed simulations to support evaluation of IMs and Tier II source control measures.
- *NewFields (2015a), FINAL Fate and Transport Model Design and Calibration, East Helena Site*: This technical memorandum describes the design and calibration of the contaminant transport model and refinement of the hydrogeologic conceptual model and groundwater flow model. Refinement of the hydrogeologic conceptual model was based on observed arsenic and selenium concentrations, plume geometry, and the location of potential source areas. The

groundwater flow model was updated, recalibrated, and used as the basis for the contaminant transport model. The memorandum also describes selection of the modeling code and initial source boundary conditions, and calibration of the contaminant transport model, and includes results of sensitivity analysis performed on the calibrated contaminant transport model.

- *NewFields (2015b), FINAL Predictive Fate and Transport Modeling, Interim Measures and Tier II Corrective Actions, East Helena Site:* This technical memorandum describes the methods and results of predictive contaminant transport modeling used to support evaluation of IMs and source control measures for the CMS. In addition, the memorandum includes results of a sensitivity analysis performed on selected input parameters for the predictive simulations.
- *NewFields (2016a) FINAL Groundwater Flow Model, Fate and Transport Model, and Predictive Fate and Transport Simulations Update, East Helena Site:* This technical memorandum describes updates to the hydrogeologic conceptual model, groundwater flow model, contaminant transport model, and predictive analyses performed to support evaluation of IMs and source control measures for the CMS. Updates to the conceptual model were based on source area investigation studies (Hydrometrics, 2015; Hydrometrics, 2016a) and data collected as part of ongoing implementation of IMs. The groundwater flow model was updated based on refinements to the conceptual model and recalibrated to 2011 steady-state data, 2011 to 2015 transient data, and 2014 steady-state data. The contaminant transport model was recalibrated to 2011 and 2014 steady-state arsenic and selenium data. Results of predictive simulations were used to support evaluation of IM implementation and proposed source control measures. The document also includes results of a sensitivity analysis performed on the predictive simulations.
- *NewFields (2016b), Groundwater Modeling Modifications for the Slag Pile and Downgradient Selenium Simulations, East Helena Site:* This presentation describes modifications to the groundwater flow model and contaminant transport model to better reflect the conceptual model for the Slag Pile and measured selenium concentrations in residential and monitoring wells downgradient of the former Smelter site and north of Prickly Pear Creek. Several hydraulic conductivity zones in the Slag Pile area were adjusted allowing groundwater flow directions to match observed flow directions better, while the model remained calibrated. Source areas within the saturated zone Slag Pile area were removed from the transport model and replaced by sources in unsaturated zone. Downgradient of the former Smelter site, hydraulic conductivity and dispersivity values were adjusted. Results of this work, which included a sensitivity analysis on recharge for the Slag Pile, were used to evaluate proposed grading and cover designs for the Slag Pile.

In addition to the work described above, the models were used to guide various construction activities, the installation of additional monitoring wells, and the source area investigations (Hydrometrics, 2015; Hydrometrics, 2016a) at the former Smelter site.

Modeling results were presented to the Groundwater Working Group during regular team meetings. The Groundwater Working Group consisted of members from NewFields, Hydrometrics, CH2M HILL, the Custodial Trust, United States (U.S.) Environmental Protection Agency (EPA), Montana Natural Resource Damage Program (NRDP), Montana Department of Environmental Quality (DEQ), Lewis and Clark County, City of East Helena, and Montana Bureau of Mines and Geology.

1.2 Summary of Goals and Objectives

AMEC (2012a) prepared a work plan for a phased approach to groundwater modeling. This work plan was designed to meet the general modeling objectives listed in the Phase II RFI Work Plan (Hydrometrics, 2010) and provide more detailed groundwater modeling objectives including:

- Supporting preparation of an application for a Controlled Groundwater Area through the Montana Department of Natural Resources and Conservation;
- Assessing the impact of the SPHC project including eliminating Upper Lake and Lower Lake, removing Smelter Dam from Prickly Pear Creek, and constructing a new meandering channel for Prickly Pear Creek on groundwater flow directions and gradients as well as groundwater quality;
- Identifying changes in the groundwater flow regime resulting from onsite remedial actions, such as changes in:
    - Hydraulic gradients and/or groundwater flow rates (e.g., decrease in gradient and flow rate if Lower Lake were removed);
    - Groundwater flow paths (e.g., flow diverted around barrier wall; extraction well capture zones);
    - Groundwater/surface water interactions along Prickly Pear Creek adjacent to the former Smelter site; and
- Supporting refinement of the conceptual model of groundwater flow and groundwater/surface water interaction.

1.3 Document Organization

This report presents and discusses key components of the numerical groundwater and contaminant models, including a hydrogeologic conceptual model, a contaminant transport conceptual model, numerical model design and calibration, and predictive simulations used to support evaluation of IMs, source control measures, application of a Controlled Groundwater Area, and construction activities at the former Smelter site. The remainder of the report is organized into the following sections:

- **Section 2.0** describes the hydrogeologic conceptual model, including background information on the physical, geological, and hydrogeologic settings.
- **Section 3.0** describes the contaminant transport conceptual model, including potential sources and source areas, contaminant geochemistry, groundwater quality, and contaminant transport.
- **Section 4.0** describes groundwater flow model development and calibration.
- **Section 5.0** describes contaminant transport model development and calibration.
- **Section 6.0** describes methods and results from predictive simulations used to support evaluation of IMs, source control measures, construction activities, and application of a Controlled Groundwater Area.
- **Section 7.0** presents results of model sensitivity analysis.

- **Section 8.0** presents a summary and conclusions from the modeling effort.
- **Section 9.0** presents a discussion of model limitations.
- **Section 10.0** lists references cited in this report.

Figures and tables are compiled at the end of the report.

2.0 HYDROGEOLOGIC CONCEPTUAL MODEL

This section summarizes available data on the hydrogeologic setting and describes the current understanding (i.e., conceptual model) of the groundwater flow system in and around the former Smelter site. This conceptual model formed the basis for the design and construction of the numerical groundwater flow model discussed in **Section 4.0**.

GSI (2014) and AMEC (2012b) described the initial hydrogeologic conceptual model used for design of the groundwater flow model. The conceptual model was updated as additional data was collected during IM implementation, source area investigations, and various construction activities at the former Smelter site. In addition, the groundwater flow model was used to evaluate and revise the conceptual model.

The following subsections summarize the physical, geologic, and hydrogeologic setting of the former Smelter site and adjacent areas.

2.1 PHYSICAL SETTING

The former Smelter site is located along the southern margin of the Helena Valley, south of the City of East Helena (**Figure 1.1**). The Helena Valley is located in the Northern Rocky Mountains physiographic province, which is bounded by the Big Belt Mountains on the east and the Garnet Range on the west. The Helena Valley has a semiarid climate that is characterized by cold winters, mild summers, and low precipitation. Average annual precipitation for the valley from 1938 to 2016 was 11.85 inches (WRCC, 2016). Major drainages in the Helena Valley include Tenmile Creek, Sevenmile Creek, and Prickly Pear Creek, which drain to Lake Helena and eventually to the Missouri River.

The former Smelter site encompasses an area of approximately 142 acres and is bounded to the east and northeast by Prickly Pear Creek, to the south by the former Upper Lake, and to the west and southwest by Tertiary-age foothills and uplands. Topographic elevations in the former Smelter site range from approximately 3,875 feet above mean sea level (amsl) at the north end near Prickly Pear Creek to 3,930 feet amsl at the southern end near the former Upper Lake. The Slag Pile, a by-product of the smelting process located in the northern half of the former Smelter site, has an approximate maximum elevation of 3,990 feet amsl.

2.2 GEOLOGY

The following subsections describe the conceptual understanding of the regional and site geologic settings. **Figures 2.1** and **2.2** present bedrock and surface geology maps for the Helena Valley, respectively. **Figures 2.3** and **2.4** present geologic cross-sections through the former Smelter site.

2.2.1 Regional Geology

The former Smelter site is located in the Helena Valley, a fault-bounded valley that is surrounded by uplifted, folded, and fractured sedimentary, metamorphic, and igneous bedrock of Precambrian to Cretaceous Age. The Helena Valley is filled with up to 6,000 feet of Oligocene (Tertiary) tuffaceous and

alluvial strata, younger Tertiary alluvial gravel, and Quaternary alluvium and colluvium. The general sequence of regional stratigraphic units near the former Smelter site consists of, from oldest to youngest: (1) metasedimentary basement rocks of the Middle Proterozoic Belt Super Group (e.g., Spokane Formation); (2) Oligocene tuff, tuffaceous sediments, and intercalated alluvial sand and gravel (OGts/ OGS); (3) younger Tertiary alluvial gravel (older alluvium; Qtg); (4) Quaternary alluvial sand and gravel (Qa/Qal); and, (5) Quaternary mixed alluvium/colluvium (Qac) (Thamke and Reynolds, 2000).

Precambrian metasedimentary rocks, including the Spokane and Greyson formations, and the early Tertiary (Oligocene) clastic alluvial and volcaniclastic sediments together comprise the bedrock formations that bound the southern side of the Helena Valley (**Figure 2.1**; **Table 2.1**). Along stream courses, Quaternary alluvial sediments are composed of coarse sand and gravel mixtures with intercalated fine grained sediments. Poorly sorted, silt-rich colluvium interfingers with alluvial sands and gravels along the basin margins. Toward the center of the valley and away from drainages, the percentage of fines increases.

2.2.2 Site Geology

The former Smelter site is located on the southern margin of the Helena Valley at the transition between bedrock foothills and valley-fill sediments (**Figure 2.2**; **Table 2.2**). Significant features of the local geology include:

- Exposed metasedimentary basement rock northwest of the former Smelter site;
- Alluvium extending along Prickly Pear Creek from south of the former Smelter site northward into the Helena Valley;
- Foothills composed of Tertiary sediments (OgtS and OgS) south, east, and west of the former Smelter site;
- A clayey weathered ash layer at the surface of the Tertiary volcaniclastic sediments beneath and in much of the area surrounding the former Smelter site; and
- Intervening Qac deposits consisting of a mixture of alluvium and Tertiary sediments.

The distribution and nature of each of these units within the project area (**Figures 2.2** through **2.4**; **Table 2.2**) are summarized below.

Alluvium and Mixed Alluvium/Colluvium (Qa/Qac): The former Smelter site is situated on recent unconsolidated alluvial/colluvial sediments that extend northward along Prickly Pear Creek and thicken in a northerly direction from the basin margins into Helena Valley. The alluvium (Qa) represents relatively recent deposition of sediments from Prickly Pear Creek and forms in part the upper primary groundwater-bearing unit at, and north of the former Smelter site. The recent alluvium generally consists of clean sand and gravel, with discontinuous silt/clay layers. Because of the low silt and clay content in the sand and gravel matrix, the recent alluvium generally has relatively high permeability. The thickness of the alluvium typically ranges from 20 feet to more than 50 feet and is overlain by a thin veneer of silt across much of the former Smelter site. Marsh/wetland sediments, composed of 2 to 6 feet of organic-rich silt, are present under the eastern portion of Tito Park (note, Tito Park and

surrounding material was excavated as part of the Source Removal IM) and the southern portion of the Slag Pile.

Onsite and along the foothills surrounding the former Smelter site, a heterogeneous mixture of alluvium and colluvium (Qac) exists and intervenes between early Tertiary volcaniclastic and alluvial sediments (OgtS and OgS) of the surrounding foothills. This transition from alluvium near Prickly Pear Creek to a mixture of alluvium and colluvium in the direction of the foothills is gradual and is characterized as gradational and interfingering, as opposed to an abrupt change. The increase in fine sediment content with distance from the creek is evident from soil samples collected during monitoring well drilling northwest of the former Smelter site, and may influence groundwater flow in this area. This contact is further complicated by at least one fault, which is mapped northwest of the former Smelter site (**Figure 2.2**). The offset along the mapped fault and presence of additional faults is poorly understood.

Quaternary/Tertiary Alluvium (Older Alluvium, Qtg): Older alluvium of early Quaternary and late Tertiary age underlies the more recent unconsolidated sand and gravel sequences. In the former Smelter site, these sediments are weakly consolidated sand, silty sand, and gravel with discontinuous silt layers. The overall thickness of Older Alluvium near the former Smelter site ranges from zero to 30 feet, and increases significantly toward the north to more than 70 feet northwest of the former Smelter site. The unit occupies paleodrainages within older sediments and is more than 100 feet thick west of the former Smelter site. Overall, the unit tends to include layers with a higher percentage of fines than the overlying alluvium.

Tertiary Volcaniclastic and Alluvial Sediments (OGts and OGS): Early Tertiary sediments of Oligocene-age form the uplands and foothills south, east, and west of the former Smelter site and consist of slightly to moderately consolidated volcaniclastic and alluvial sediments deposited by eruptive centers located south of the former Smelter site and ancestral drainages. East and north of the former Smelter site, the sediments are predominantly alluvial with less volcaniclastic-derived materials. South and west of the former Smelter site, the sediments consist of tan, unconsolidated to weakly indurated siltstone and sandstone with varying amounts of volcanic ash and tuff beds partially or completely altered to clay.

The vertical extent of the Oligocene-age sediments near the former Smelter site is not well understood, as only a few well borings fully penetrate it. Limited available information indicates the Oligocene-age sediments are between 40 and 100 feet thick on the north side of the former Smelter site and in the City of East Helena where they are interpreted to directly overlie Spokane Formation bedrock. The thickness of the Oligocene-age sediments exceeds 100 feet in the Seaver Park area and at least 150 feet east of the former Smelter site where borings do not encounter the base.

A clayey weathered ash layer defines the surface of the Oligocene-age sediments beneath and in much of the area surrounding the former Smelter site. This interval appears to be most well developed on strata that consist predominantly of tan silty to sandy sediments with varying amounts of volcanic ash and tuff beds altered to clay. The weathered ash layer is believed to be concentrated in areas that were topographic depressions during the Tertiary, where eroded ash with varying amounts of clastic silt/sand would accumulate. The clayey weathered ash forms a low permeability layer at the top of the Oligocene-age sediments and, where present, generally acts as an aquitard with the exception of the

western edge of the former Smelter site where the clay is intermixed with sand and has relatively higher permeability compared to the rest of the unit. **Figure 2.5** is a map showing contours of the elevation of the upper surface of this unit. There is a distinct paleo-channel eroded into the surface of this unit from the north end of the former Smelter site that extends into the valley. In addition, there is an abrupt change in the surface elevation of the layer adjacent to the West Selenium Area. These features affect groundwater flow and contaminant migration within and north of the former Smelter site.

Although few borings extend very deep into the Oligocene-age sediments, exploration and private wells that penetrate this unit indicate that its characteristics vary vertically and laterally. Beneath the clayey weathered ash surface, borings encounter silt, sand, and gravel with interbedded weathered ash horizons near the former Smelter site. The higher permeability sand and gravel beds appear to have limited connectivity. Some boring logs describe these clastic horizons as loose, saturated, water-producing intervals.

Structure: A normal fault that defines the contact between the Spokane Formation and Helena Valley-fill sediments northwest of the former Smelter site may also define the transition from the volcaniclastic-rich Oligocene-age sediments to alluvium containing a minor component of reworked tuffaceous material observed in borings located northwest of the former Smelter site. The Oligocene-age volcaniclastic-rich sediments may be truncated and down dropped north of the inferred fault in this area, marking a transition north of the fault to younger Tertiary alluvial sediments containing reworked volcaniclastic sediments transported from the adjacent foothill exposures.

2.3 Surface Water

The principle perennial streams in the basin include Sevenmile Creek, Silver Creek, Tenmile Creek, and Prickly Pear Creek. These streams flow into the valley from bedrock highlands and discharge to Lake Helena, which drains into the Missouri River. Other creeks and drainage channels are typically intermittent (having seasonal flow) or ephemeral (flowing only for short periods in response to precipitation and overland runoff). Loss in creek flow to the groundwater system occurs primarily around the basin margins where overall vertical groundwater gradients are downward (see **Section 2.4**). Vertical groundwater gradients transition from downward to upward approaching Lake Helena (Briar and Madison, 1992).

The Helena Valley Irrigation canal runs from east to west, north of the former Smelter site, and where unlined, is a source of groundwater recharge. Additionally, there are approximately 25 miles of irrigation ditches within the model domain that are sources of groundwater recharge.

The primary surface water features at the former Smelter site are Prickly Pear Creek, Upper Lake, Lower Lake, and Wilson Ditch, with the latter three features recently eliminated as part of the SPHC IM. The following list describes these surface water features and significant changes to these surface water features related to implementation of the SPHC IM:

- Prickly Pear Creek flows along the east and northeast boundaries of the former Smelter site from its headwaters in the Elkhorn and Boulder mountains northward to Lake Helena. Historically, a portion of Prickly Pear Creek was diverted into Upper Lake; however, this

diversion has been closed since late 2011 as part of the Upper Lake Drawdown Test (Hydrometrics, 2012) and eventual removal of Upper Lake. Smelter Dam, located on Prickly Pear Creek east of Lower Lake, caused the creek to lose water to the groundwater system upgradient of the dam and gain water from the groundwater system directly downgradient of the dam. As part of the SPHC IM, Prickly Pear Creek was realigned and Smelter Dam was removed. The creek was placed in a temporary bypass channel in October 2013 during construction of the realignment and removal of Smelter Dam, and permanently diverted into the reconstructed creek channel in late 2016. The creek has been impacted by historical mining activities upstream of the former Smelter site, resulting in elevated sediment and concentrations of some metals in stream water (GSI, 2014).

- Wilson Ditch was an agricultural irrigation ditch extending from Upper Lake northwestward towards the Helena Valley. The ditch was decommissioned in October 2011; prior to decommissioning, diversion of surface water from Upper Lake to Wilson Ditch typically began in April and continued through September. While in operation, the ditch would lose water to the groundwater system, which significantly impacted groundwater elevations and flow directions west of the former Smelter site. Water quality in Wilson Ditch prior to decommissioning was similar to Upper Lake and Prickly Pear Creek (Gradient, 2011).
- Upper Lake was located at the southern end of the former Smelter site and prior to November 2011, was fed through diversion of flow from Prickly Pear Creek (Hydrometrics, 2012). Upper Lake seepage discharged via return flow to Prickly Pear Creek, seasonal discharge to Wilson Ditch, evapotranspiration, and leakage to groundwater. In 2012, Hydrometrics performed the Upper Lake Drawdown Test (Hydrometrics, 2012), which significantly reduced the amount of water in the lake, decreased the footprint of the lake, and reduced groundwater elevations northwest of the lake. Upper Lake was permanently eliminated as part of the SPHC IM in 2014. Water quality samples from Upper Lake show relatively good water quality with low total dissolved solids and trace metal concentrations, similar to concentrations in Prickly Pear Creek (GSI, 2014).
- Lower Lake was located north of Upper Lake and south of the Slag Pile, and was a process water pond that received recharge from precipitation, groundwater inflow, and treated effluent from the High Density Sludge (HDS) Plant. Outflow from Lower Lake occurred as leakage to groundwater and evaporation. For the last several decades, Lower Lake was not physically connected to Prickly Pear Creek but was in hydraulic communication with underlying groundwater. The lake was removed as part of the SPHC IM in 2015. Seepage from Lower Lake has been identified as a historical source of metal loading to the groundwater system (GSI, 2014).

2.4 GROUNDWATER

The following subsections describe the physical elements of the groundwater flow system including hydrostratigraphy, recharge and discharge, hydraulic gradients, seasonal fluctuations, hydrogeologic properties, and groundwater/surface water interaction.

2.4.1 Hydrostratigraphy

Based on stratigraphic information described in **Section 2.2.2**, several hydrostratigraphic units have been delineated in the area near the former Smelter site. A hydrostratigraphic unit is one or more stratigraphic units with similar hydrogeologic characteristics allowing for grouping into a single unit for the purposes of describing groundwater occurrence and flow. The hydrostratigraphy forms the physical framework for groundwater flow and contaminant transport. The hydrostratigraphic units at and around the former Smelter site (from top to bottom) are described below and shown on **Figure 2.6**.

Upper Aquifer

The Upper Aquifer hydrostratigraphic unit is composed of unconsolidated granular fill, Quaternary alluvial/colluvial (QA and QAC) sediments and, where present, Quaternary/younger Tertiary alluvial sediments (Qtg) extending from ground surface down to the top of the clayey weathered ash surface of the Oligocene volcaniclastic sediments (see **Section 2.2.2**), where present. Granular fill includes regraded or placed earthen material (sand, gravel) and debris (slag, brick). The fill sits atop alluvial sediments (sand/silt/gravel) across most of the former Smelter site. The Upper Aquifer pinches out in the western part of the former Smelter site where the Oligocene sediment surface daylights and the fill/alluvium ends.

On the east side of the former Smelter site, the bottom of the Upper Aquifer unit is not defined. Alluvial sediments in this area increase in silt content and become denser with depth, signifying a transition to older alluvium. Wells in the Slag Pile area are not deep enough to determine whether the clayey weathered ash surface exists under the Slag Pile. The Upper Aquifer unit extends northward from Upper Lake, through the City of East Helena area and into the Helena Valley. Northwest of the former Smelter site, the Upper Aquifer includes several silt layers at depths of about 30 to 35 feet below ground surface.

Laterally, the Upper Aquifer unit extends to the east of Prickly Pear Creek, although losing reaches of the creek may act as a hydraulic divide in the Upper Aquifer unit north and northeast of the former Smelter site. The western boundary of the Upper Aquifer unit is defined as Oligocene volcaniclastic and alluvial sediments that form the foothills west of the former Smelter site. There is an abrupt change in the surface elevation of the clayey weathered ash surface west of the West Selenium Area that acts as a barrier to westward flow from the former Smelter site.

Aquitard Unit

The clayey weathered ash surface of the Oligocene volcaniclastic sediments underlies the Upper Aquifer. This feature, where present, and the lateral equivalent (fine-grained Tertiary alluvial sediments north of Lamping Field), together form the Aquitard unit. In some locations in the foothills southwest of the former Smelter site, the Aquitard unit consists of tuffaceous sediments partially to completely altered in-place to white clay. Throughout most areas, including beneath the former Smelter site, the Aquitard unit consists of reworked volcanic ash and volcaniclastic sediments, eroded from higher elevation areas and redeposited in low lying areas, including the Prickly Pear Creek drainage bottom. There is evidence in the West Selenium Area that this unit consists of courser material and may allow for some hydraulic communication between the Upper Aquifer and deeper groundwater system (Hydrometrics, 2015; Hydrometrics, 2016a).

The clayey weathered ash has been documented over the western two-thirds of the former Smelter site based on extrapolation of well log data, but its occurrence has not been confirmed on the northeastern portion of the former Smelter site. At the former Smelter site and in portions of the City of East Helena, the Aquitard unit occurs as distinctive white clay with quartz crystals and highly weathered feldspar grains. The Aquitard unit dips to the north and transitions to light brown to tan in color, contains a higher percentage of silt, and becomes less plastic; this south to north change may be the result of the absence of the Oligocene volcaniclastic sediment unit resulting from either truncation or downwarping and transition into Tertiary basin-fill alluvial sediments. Depth to the Aquitard unit increases from about 20 feet below ground surface at the south end of former Smelter site, to 50 feet below ground surface at the north end of the former Smelter site, to 80 feet below ground surface northwest of the former Smelter site.

Deeper Groundwater System

The Deeper Groundwater System hydrostratigraphic unit defines groundwater occurrence within older Tertiary volcaniclastic and alluvial sediments, and alluvial valley-fill sediments beneath the Aquitard unit, where present. As described above, deeper groundwater has been encountered beneath the Aquitard unit where there is a transition from tight clays to coarser-grained sediment intermixed with weathered ash. Coarse-grained Tertiary alluvial valley-fill sediments comprise the Deeper Groundwater System where Oligocene volcaniclastics are not present, northwest of the former Smelter site and the City of East Helena. Unlike the Upper Aquifer, which occurs as one continuous aquifer, deeper groundwater is interpreted to occur within multiple coarser-grained layers interspersed beneath the Aquitard. These deeper water-bearing zones are present within different materials at various depths. The presence and extent of the Deeper Groundwater System is not known because the vast majority of monitoring wells penetrate only the upper few feet of the Aquitard, and the transition to the coarser-grained, water-bearing portion of the Oligocene volcaniclastic unit commonly occurs at least 10 feet or more below the top of the clayey weathered ash. Further, few wells northwest of the former Smelter site are completed in valley-fill sediments below the interpreted aquitard.

2.4.2 Groundwater Flow and Occurrence

Figures 2.7 and **2.8** present potentiometric surface maps for shallow groundwater based on average groundwater elevation data collected in 2011 and 2014, respectively. In general, groundwater flow is from south to north with recharge occurring in the foothills and uplands and discharging to Lake Helena.

Groundwater flow is to the north and northwest from Upper and Lower lakes to the north end of the former Smelter site. After drawdown of Upper Lake, groundwater elevations and gradients decreased in this area as shown by the 3,920 feet amsl potentiometric contour being further to the south in 2014 than in 2011 (**Figure 2.8**). North of the former Smelter site, groundwater flow is generally to the north on the east side of Prickly Pear Creek and to the northwest on the west side of the creek.

The following list summarizes several features near the former Smelter site that influence groundwater flow:

- Low permeability Tertiary sediments with high northeasterly directed gradients bound the west side of the Upper Aquifer;
- Upper and Lower lakes located in the southern part of the former Smelter site lost water to the groundwater system prior to removal;
- Smelter Dam located east of Lower Lake on Prickly Pear Creek influenced groundwater flow prior to removal;
- A northwest oriented buried channel (believed to be an ancestral channel of Prickly Pear Creek) cuts into the clayey weathered ash layer of the Aquitard unit (see **Section 2.2.2**). This erosional feature likely creates a preferential groundwater flow path;
- A gravel seam 80 to 100 feet below ground surface near the Gravel Pits northwest of the former Smelter site may create a preferential flow path for groundwater; and
- A groundwater mound created by leakage from Prickly Pear Creek creates a flow divide as far north as Lamping Field. Additionally, seasonal groundwater mounding near Wilson Ditch affected groundwater flow in the Upper Aquifer unit prior to turning off the ditch in 2011.

2.4.3 Groundwater Recharge and Discharge

Current and historical sources of groundwater recharge include:

- Seepage from Prickly Pear Creek (current);
- Seepage from Upper and Lower lakes (historical);
- Seepage from the Helena Valley Irrigation Canal and other irrigation canals and ditches, seasonally (current);
- Seepage from Wilson Ditch, seasonally (historical);
- Groundwater discharge from Tertiary units that form the foothills on the south, southwest, and east sides of the valley (current);
- Underflow from Precambrian bedrock south of the former Smelter site (current);
- Infiltration of natural precipitation and snowmelt (current);
- Infiltration of irrigation water applied to agricultural lands (current); and
- Minor upward seepage from the deeper groundwater system (current).

The potentiometric surface map presented in **Figure 2.7** shows mounding and discharge to the Upper Aquifer from Upper Lake and Lower Lake. The lakes do not appear to be well-connected to the aquifer on the north side of Lower Lake, evidenced by the steep hydraulic gradient on the north side of Lower Lake and lack of response from water level changes in the lakes (Hydrometrics, 2012).

Losses from Prickly Pear Creek downgradient of the Slag Pile cause groundwater mounding in the Upper Aquifer. This mounding appears to increase in June when higher flows apparently result in greater losses from the creek. When Wilson Ditch was operating, it would lose significant amounts of water to the

shallow groundwater system causing mounding in the Upper Aquifer. This mounding caused changes in groundwater flow directions and hydraulic gradients downgradient of the former Smelter site.

Current areas of groundwater discharge include:

- Pumping from wells (domestic, public water supply, irrigation, etc.);
- Discharge to Prickly Pear Creek and Tenmile Creek;
- Discharge to Lake Helena;
- Discharge to irrigation drains;
- Evaporation from gravel pit ponds north of the former Smelter site; and
- Evapotranspiration from wetlands.

2.4.4 Hydraulic Gradients

Figures 2.7 and **2.8** show potentiometric surfaces for groundwater in the model domain. Where groundwater elevation contours are closer together, horizontal hydraulic gradients are higher; where contours are further apart, gradients are smaller. In general, horizontal hydraulic gradients are higher along the valley margins in the foothills and uplands and smaller near Lake Helena. In the model domain for 2011 data, horizontal hydraulic gradients range from 0.002 feet/foot near Lake Helena to 0.043 feet/foot in the foothills and uplands along the southern margin of the valley. Based on groundwater elevations used to develop the 2014 potentiometric surface (**Figure 2.8**), horizontal hydraulic gradients in and around the former Smelter site range between 0.005 feet/foot west of the Slag Pile near the northern boundary of the former Smelter site to 0.02 feet/foot north of Lower Lake and south of the Slag Pile. Horizontal hydraulic gradients have generally decreased in the former Smelter site between 2011 and 2014 as a result of implementing the SPHC IM.

Vertical hydraulic gradients help identify discharge and recharge areas for the groundwater system. In general, vertical hydraulic gradients are downward along the valley margins indicating recharge to the groundwater system and upward near Lake Helena indicating discharge from groundwater to surface water (Briar and Madison, 1992). Based on groundwater levels measured by Hydrometrics during routine monitoring, there is an upward gradient between the Upper Aquifer (above the ash/clay layer) and the deeper groundwater system (beneath the ash/clay layer) in and around the former Smelter site. Vertical gradients vary for well pairs screened in the Upper Aquifer and there is no overall downward or upward vertical gradient within this hydrostratigraphic unit (**Figure 2.9**). Average vertical gradients in and around the former Smelter site range from -0.172 feet/foot (downward) to 0.111 feet/foot (upward) in 2011 and between -0.062 feet/foot (downward) to 0.078 feet/foot (upward) in 2014 (**Table 2.3**). Average gradients did not change significantly for well pairs between 2011 and 2014.

2.4.5 Seasonal Fluctuations

Groundwater levels have been regularly measured in selected monitoring wells located in and around the former Smelter site for several years. In general, groundwater level fluctuations are smaller for wells completed in the Deeper Groundwater System, whereas wells completed in the Upper Aquifer unit off

site typically exhibit greater fluctuations as the result of the significant, seasonal seepage that occurs from Wilson Ditch (pre-decommissioning) and Prickly Pear Creek. Groundwater elevation data for wells outside the areas directly influenced by stream losses exhibit peak water levels in August, after snowmelt runoff and peak precipitation months of June and July, and during irrigation season. Wells near losing reaches of Prickly Pear Creek exhibit rising water levels beginning in April and peaking in June, coincident with the peak stream flow.

Before Wilson Ditch was turned off in 2011, seasonal fluctuations ranged from 2 to 10 feet (**Figure 2.10**). In general, the seasonal high groundwater level occurred between August and September and the seasonal low occurred between May and June. Water levels in wells near Wilson Ditch responded rapidly to changes in ditch flows.

Elevations and fluctuations of groundwater levels in wells in and downgradient of the former Smelter site have decreased because of IM implementation. Seasonal fluctuations from wells shown on **Figure 2.10** range from less than 1 foot to 2 feet after IM implementation. Decreases in groundwater elevations and fluctuations were caused by the decommissioning of Wilson Ditch and removal of Upper Lake.

2.4.6 Hydrogeologic Properties

Figure 2.11 shows the results of pumping tests and slug tests performed by Hydrometrics or Asarco between 1985 and 2009 on wells located in and around the former Smelter site. Geologically, there is not a significant difference in hydraulic properties between Quaternary alluvial/colluvial sediments (QA and QAC) and Quaternary/younger Tertiary alluvial sediments (Qtg). Geographically however, there do appear to be areas with higher and lower hydraulic conductivity. Within the former Smelter site, there is more permeable material on the west side and less permeable material on the east side and around Lower Lake. Outside of the former Smelter site, there is more permeable material west of East Helena near Wilson Ditch (**Figure 2.11**). In general, wells screened below the Aquitard unit have lower hydraulic conductivity values than wells in the Upper Aquifer.

2.4.7 Groundwater Surface Water Interaction

Major surface water drainages in the Helena Valley include Tenmile Creek and Prickly Pear Creek, which flow into the valley from bedrock highlands and discharge to Lake Helena. Stream losses occur primarily around the outer portion of the basin where overall vertical gradients are downward. Both streams provide recharge to the valley-fill aquifer across losing reaches between the valley margins and Lake Helena. Vertical groundwater gradients transition from downward to upward flow conditions upon approaching Lake Helena (Briar and Madison, 1992) and both streams begin to gain water near the lake.

Prior to removal in 2014, Upper Lake recharged the shallow groundwater system with groundwater flowing from the lake north to Lower Lake, east to Prickly Pear Creek, and northwest through the west side of the former Smelter site (Hydrometrics, 2012). In addition, Lower Lake recharged groundwater to the east and west prior to its removal in 2016. Large horizontal gradients and lack of response to changes in lake levels suggest minimal water entered the groundwater system from the north side of Lower Lake (Hydrometrics, 2012).

Hydrometrics has completed synoptic stream gaging on Prickly Pear Creek as part of ongoing monitoring at the former Smelter site. Results of these synoptic measurements indicate that prior to removal of Upper and Lower lakes and implementation of the Prickly Pear Creek bypass channel, Prickly Pear Creek lost water to the groundwater system south of Upper Lake and the creek switches between gaining and losing water north of, and adjacent to, the Slag Pile (**Figure 2.12**; **Table 2.4**). However, these changes are relatively small (<10 percent) and are generally within the margin of error, suggesting little gain or loss through the former Smelter site. In addition, Prickly Pear Creek gained water below Smelter Dam and in the northern part of the valley as vertical groundwater gradients reverse (**Figure 2.12**; **Table 2.4**). Downgradient of the former Smelter site, losing reaches of Prickly Pear Creek create a groundwater flow divide and divert groundwater in a north and northwesterly direction.

Since the removal of Upper and Lower lakes and implementation of the Prickly Pear Creek bypass channel, Prickly Pear Creek loses slightly less water to the groundwater system east of the former Smelter site (**Table 2.4**). However, the reaches where the creek gains or loses water did not change compared to the 2009 and 2010 synoptic stream gauging results.

3.0 CONTAMINANT TRANSPORT CONCEPTUAL MODEL

This section summarizes the current understanding of contaminant fate and transport, focusing on the primary contaminants of concern (COC): arsenic and selenium. This conceptual model formed the basis for the design and construction of the numerical contaminant transport models, discussed in **Section 5.0**.

GSI (2014) and NewFields (2014b) present the initial contaminant transport conceptual model used for design of the numerical contaminant transport models. The conceptual model was updated as additional data was collected during implementation of IMs, source area investigations, and various construction activities at the former Smelter site. In addition, the numerical groundwater flow and contaminant transport models were used to evaluate and revise the conceptual model.

The following subsections summarize the potential sources and source areas, contaminant geochemistry, contaminant migration in groundwater, and groundwater quality for arsenic and selenium for the former Smelter site and adjacent areas.

3.1 POTENTIAL SOURCES AND SOURCE AREAS

Potential sources of contaminants to groundwater have been evaluated in several previous studies. Hydrometrics (1999) provided a detailed evaluation of potential contaminant sources based on information available at that time. ASARCO (2005) conducted additional source identification and delineation as presented in a RCRA Former Smelter Site Investigation (RFI) report and additional information regarding contaminant sources was obtained through a 2010 Phase II RFI field investigation (GSI, 2014). The most recent information regarding contaminant sources was obtained during a source area inventory (Hydrometrics, 2014) and two source area investigations (Hydrometrics, 2015; Hydrometrics, 2016a).

Figure 3.1 shows the source areas for arsenic and selenium in the former Smelter site identified during the source area inventory (Hydrometrics, 2014). Historically, periodic releases of process water through process circuit leaks or spills are believed to be the primary sources of contaminant loading to soils and groundwater. Plant process water containing high concentrations of arsenic and/or selenium as well as other contaminants were released to the environment on a frequent basis prior to the mid-1990s. Main areas of process water releases include Lower Lake, Acid Plant area, Speiss/Dross area, and Thornock Lake (**Figure 3.1**). Remaining sources of arsenic, selenium, and other contaminants in the former Smelter site are residual deposits in aquifer material and slag.

The following list summarizes the current primary source areas for arsenic and selenium in the former Smelter site:

- *North Plant Site (arsenic):* This area did not contain process water but is currently the primary source of elevated arsenic concentrations in groundwater downgradient of the former Smelter site. This area is located hydraulically downgradient of the Speiss-Dross area and it is believed

that arsenic-rich groundwater from the Speiss-Dross area loaded the saturated soils with arsenic in the North Plant Site area. The arsenic-loaded soils now leach arsenic to groundwater.

- *Acid Plant (arsenic and selenium):* This area is a known source of contaminant loading to groundwater. Historically, the Acid Plant settling pond (**Figure 3.1**) leaked on a regular basis prior to 1992, releasing process water to the subsurface. Process water chemistry indicates that Acid Plant process water contained high concentrations of several constituents including arsenic and selenium. Besides the settling pond, process water releases have been documented during the smelter operational phase at the scrubber blowdown area (**Figure 3.1**). The Acid Plant settling pond was replaced with a tank in 1992 and the settling pond was demolished and excavated in 1993. The remaining highly contaminated soils were removed in 2016 as part of the Source Removal IM.
- *Speiss-Dross (arsenic and selenium):* The Speiss-Dross area included two process water features (speiss pond and speiss granulation pit), as well as nearby Thornock Lake (**Figure 3.1**). These features are known points of historic process water releases. Although these features were removed and surrounding soils excavated in the 1990s, remaining soils are believed to act as ongoing sources of contaminant loading to groundwater. In 2007, a slurry wall was constructed around the Speiss-Dross area to reduce the migration of contaminated groundwater from the area. Based on current groundwater quality, the slurry wall is effective at reducing the downgradient migration of contaminated water from the Speiss-Dross area.
- *West Selenium Area (selenium)*: This area did not contain process water but is currently one of the primary sources of selenium downgradient of the former Smelter site. The West Selenium Area is hydraulically downgradient of the Speiss-Dross area and the Acid Plant area, each of which had process ponds that periodically released process water to the groundwater system. Because of this, the sources of selenium in this area are believed to be from historic loading of selenium onto saturated soils and from leaching of selenium from ore stored in the area.
- *Slag Pile (arsenic and selenium):* The Slag Pile contributes to elevated arsenic and selenium concentrations downgradient of the former Smelter site. The primary source of arsenic and selenium is believed to be unfumed slag that was not processed through the zinc plant (Hydrometrics, 2016b). The zinc plant operated from the 1940's through 1982 and removed zinc from the processed slag to produce a marketable zinc oxide product. Slag that was not processed by the zinc plant contains elevated concentrations of metals including arsenic and selenium that leach to the groundwater through infiltration of precipitation and snow melt (Hydrometrics, 2016b).
- *South Plant Area (arsenic and selenium):* The South Plant Area includes the Acid Plant Sediment Drying Area, the Upper Ore Storage area, Tito Park, and Lower Lake (**Figure 3.1**), and contributes arsenic and selenium to groundwater in the southern part of the former Smelter site. The Acid Plant Sediment Drying Area was located west of Tito Park and was used to store sludge from the Acid Plant Water Treatment Plant. This area was a significant source of arsenic to groundwater and was decommissioned in 1991. In 2006, this area was encapsulated with a slurry wall and temporary cap to isolate groundwater. The Upper Ore Storage area was located west of Upper Lake, contained stockpiles of ore and flux materials, and was a source of arsenic and selenium in

the southern part of the former Smelter site. Tito Park was located in between Upper and Lower lakes and consisted of soil and construction debris stockpiles from historical plant operations. This area was removed as part of the Source Removal IM but has historically been a source of elevated arsenic and selenium concentrations in groundwater. Lower Lake was a former process water pond and a known source of arsenic and selenium groundwater contamination. The lake was the focus of extensive remediation in the mid-1990s, and was removed along with underlying sediment and soils in 2015 and 2016. Arsenic and selenium concentrations in the South Plant area have decreased as a result.

3.2 Contaminant Geochemistry

A detailed description of the environmental chemistry of arsenic, metals (cadmium, copper, iron, lead, manganese, and zinc), and petroleum hydrocarbons is presented in Section 8.2 of the CERCLA Comprehensive RI/FS (Hydrometrics, 1990) and in Section 4.5 of the RCRA CC/RA (Hydrometrics, 1999). A discussion of selenium geochemistry is also included in the Phase II RFI Work Plan (Hydrometrics, 2010). It was concluded in these reports that the fate of arsenic and metallic contaminants is determined by their chemical properties and geochemical changes (e.g., pH, redox potential, ionic strength, etc.) that take place in the environment. The discussion below summarizes the environmental chemistry of arsenic and selenium, which were determined to be the primary COCs in groundwater.

3.2.1 Arsenic

Arsenate (HnAsO4n-3) is the most common oxidized aqueous species (+5 oxidation state or As(V)) and arsenite (HnAsO3n-3) is the most common reduced aqueous species (+3 oxidation state or As(III)). The level of protonation of arsenate and arsenite is a function of pH. Additionally, thioarsenic (sulfur-containing As(III) species) may occur under sulfate-reducing conditions with depleted iron concentrations.

As show in **Figure 3.2**, arsenic exists as a mixture of both As(III) and As(V) aqueous species in on-site and off-site groundwater (GSI, 2014). The precipitation of pure phase arsenic minerals is not likely in groundwater systems (EPA, 2007). Arsenic transport in groundwater is typically affected by coprecipitation and adsorption/desorption mechanisms. Coprecipitation of arsenic with oxides and/or sulfides of iron and manganese is a likely sink for arsenic in groundwater in redox transition zones (i.e., where aquifer conditions change from reducing to oxidizing, or vice-versa). Both As(III) and As(V) have been reported to coprecipitate with hydrous iron and manganese oxides. As with other forms of arsenic, the long-term stability of arsenic precipitated minerals will depend on changes in redox, pH, and ionic composition of groundwater following implementation of remedial actions. Arsenic oxide minerals (related to air emission sludges and dusts) and sulfide solid-phases (present in slag and/or ore concentrate) could dissolve over time.

Adsorption of both arsenate and arsenite is pH dependent, and is also influenced by the concentration of other anions in solution that may compete for adsorption sites on aquifer materials. Langmuir et al. (2005) noted that arsenate adsorbed to hydrous ferric oxide is strongly bound at pH values below 8, and desorbed between pH 9 and 11. In natural conditions, As(V) sorbs more strongly than As(III) (Frost and Griffin, 1977). The iron oxides and sulfides noted above that serve as potential coprecipitating minerals

with arsenic are also apparently predominant as adsorptive materials in oxidizing and reducing conditions, respectively (EPA, 2007). Adsorbents such as clays or organic matter may be less important adsorptive controls for anions, such as arsenate and arsenite, due to their negative surface charge under the range of natural pH.

ASARCO (2005) cited three lines of evidence suggesting coprecipitation and/or adsorption of arsenic with iron and manganese oxides is the dominant mechanism for attenuation of arsenic in groundwater including:

- Iron and manganese oxides are abundant in aquifer materials on site;
- Sequential extraction analyses of aquifer materials indicate enrichment of arsenic in iron and manganese mineral phases; and
- Groundwater chemical data suggest removal of iron and manganese from groundwater by oxidation and subsequent precipitation, providing a mechanism for coprecipitation and fresh oxide surfaces for adsorption of arsenic.

Results from subsequent source area investigations have also noted the role of iron and manganese in sequestering arsenic in groundwater, and that significant adsorptive capacity remains in the downgradient aquifer matrix (Hydrometrics, 2016).

3.2.2 Selenium

Selenium may exist in multiple oxidation states in the aqueous phase, including selenide (Se(-II)), selenite (Se(IV)), and selenate (Se(VI)), or solid phases including elemental selenium (Se(0)) and metal selenides (Se(-II)) (EPA, 2007). The Se(IV) and Se(VI) states commonly occur as the oxyanions SeO3-2 (selenite) and SeO4-2 (selenate). Selenium speciation and, consequently, selenium mobility in groundwater is dependent on pH and redox conditions (**Figure 3.3**).

In contrast with arsenic, attenuation of selenium in soils is positively correlated with the formation of reducing conditions in groundwater. Selenite behaves like phosphate and is strongly adsorbed by hydrous ferrous oxides (although sorption decreases significantly above pH values of about 8.5). Selenite may also precipitate with manganese at higher pH if excess manganese is present. According to EPA (2007), selenate (the more oxidized form) is analogous to sulfate, with little adsorption and high mobility.

Elemental selenium (Se(0)) or highly insoluble metal selenides may also precipitate under reducing conditions resulting in very low dissolved selenium concentrations in groundwater. As is discussed by GSI (2014) this is evidenced by the fact that dissolved selenium concentrations at the former Smelter site are very low in areas with low Eh (i.e. area of petroleum impacts). Reoxidation of elemental selenium to more mobile selenite or selenate oxyanions is relatively slow, suggesting that Se(0) phases formed in soil may be important long-term sinks for selenium.

3.3 CONTAMINANT MIGRATION IN GROUNDWATER

As discussed in **Section 3.1**, groundwater contamination originally occurred from historical releases of process water to the groundwater system, and currently occurs from leaching of contaminated soil in the former Smelter site. Both arsenic and selenium can occur in multiple oxidation states and chemical species, and their fate and transport in groundwater systems are closely linked to chemical and physical conditions within the aquifer (GSI, 2014).

Previous investigations identified an area near the Speiss-Dross area with petroleum hydrocarbons in subsurface soil and groundwater that affects groundwater redox conditions (Hydrometrics, 1990; ASARCO, 2005; GSI, 2014). GSI (2014) draws a relationship between groundwater redox and geometry of the arsenic and selenium plumes. High arsenic concentrations occur in the area impacted by petroleum that have very low Eh (approximately -250 mV, based on data from well DH-33), while dissolved selenium concentrations are low in this area. Data indicate that arsenic concentrations are highest (i.e., arsenic is most mobile) under relatively reducing conditions (where iron and manganese oxide minerals available for arsenic adsorption are unstable). Selenium concentrations are lowest under these conditions.

GSI (2014) summarizes contaminant migration for arsenic and selenium in groundwater in and downgradient of the former Smelter site. As discussed in **Section 2.4.2**, the primary source of recharge to the Upper Aquifer prior to 2012 was seepage from Upper Lake. Groundwater flow through the former Smelter site follows two general flow paths: due north from Upper Lake through Lower Lake and beneath the Slag Pile; and, northwestward from Upper Lake through the former Acid Plant and Speiss-Dross areas. These general flow patterns continue north of the former Smelter site as well, with groundwater flow primarily northward on the east side of Prickly Pear Creek and northwestward on the west side of the creek (GSI, 2014).

Figure 3.4 is an arsenic plume map for 2011. Arsenic concentrations were highest within the source areas described in **Section 3.1** (**Figure 3.4**). The extent of arsenic exceeding the groundwater standard (0.010 milligrams per liter [mg/L]) in 2011 encompassed much of the former Smelter site and extended about 2,000 feet northwest of Highway 12 into Lamping Field (GSI, 2014). A lower-concentration lobe of the arsenic plume also extended northerly from the Slag Pile area and underlies a portion of East Helena. The leading edge of the plume was well defined and appeared to be relatively stable.

Figure 3.5 is a selenium plume map for 2011. The selenium plume consists of two lobes, one centered in the West Selenium Area and the other in the Slag Pile area. These two lobes of the selenium plume flank the former Speiss-Dross area and merge into a single narrow plume beneath East Helena. In comparison to arsenic, the extent of selenium concentrations exceeding the groundwater standard (0.050 mg/L) extends much farther to the north through Lamping Field, near Canyon Ferry Road (GSI, 2014).

Figures 3.6 and **3.7** are arsenic and selenium plume maps for 2014, respectively. While in operation, Wilson Ditch created a seasonal groundwater mound west of the former Smelter site that affected groundwater flow directions and gradients (see **Section 2.4**). The ditch was decommissioned in the fall of 2011, eliminating the seasonal groundwater mound in this area and causing the arsenic and selenium plumes to shift to the west (**Figure 3.6** and **3.7**) compared to the 2011 plume maps. In addition, several

IMs were implemented between 2012 and 2014, including removal of Upper Lake and construction of the Prickly Pear Creek bypass channel, that have generally reduced arsenic and selenium concentrations in groundwater beneath the former Smelter site. The downgradient extent of arsenic and selenium exceeding groundwater standards did not change significantly between 2011 and 2014.

3.4 GROUNDWATER QUALITY

In general, groundwater geochemistry beneath the former Smelter site shows a wide range of groundwater compositions and complex geochemistry, resulting from groundwater impacted by historical operations and ongoing releases from site soils. GSI (2014) discusses groundwater quality for the former Smelter site and Hydrometrics (2015 and 2016b) completed specific source area investigations that helped refine the understanding of groundwater quality in and downgradient of the former Smelter site. In addition, Hydrometrics has completed routine groundwater monitoring at wells in and downgradient of the former Smelter site that help identify changes in groundwater quality and distribution of elevated concentrations over time.

Primary conclusions regarding groundwater quality from GSI (2014) include:

- Background shallow alluvial groundwater not impacted by former Smelter site activities, is characterized as a calcium-bicarbonate type with neutral pH.
- Areas of both low pH and high pH persist in groundwater near the former Acid Plant and the Speiss-Dross area, respectively. However, these areas are apparently of limited spatial extent, and the high pH Speiss-Dross influenced groundwater appears to be entirely contained within the Speiss-Dross slurry wall.
- Significant differences in parameter concentrations and groundwater geochemical composition are observed between wells located on the southern end of the Slag Pile and the northern end of the Slag Pile. Groundwater from wells in the south Slag Pile area is characterized by slightly elevated sodium, low sulfate, and reducing conditions. Groundwater from wells in the north Slag Pile area contains elevated potassium, sodium, and sulfate concentrations and more oxidized conditions.
- Wells in the West Selenium Area show elevated chloride concentrations compared with the rest of the former Smelter site. Additionally, sulfate, calcium, and magnesium concentrations are elevated.
- The Speiss-Dross area has elevated sodium and bicarbonate and sulfate concentrations.
- Soil analyses indicate the presence of hydrocarbon contamination in the subsurface throughout the central part of the former Smelter site, from south of the Speiss-Dross slurry wall to north of the main former Smelter site area near the property boundary with American Chemet. Continued degradation of hydrocarbons in this area likely exhibits significant control on groundwater redox conditions, and thus the groundwater fate and transport behavior of arsenic and selenium.

- Downgradient of the former Smelter site, the geochemical impacts of former Smelter site activities are moderated as alluvial groundwater/Prickly Pear Creek water from the east and unimpacted (Tertiary) groundwater from the west mix with the contaminant plume.

4.0 FLOW MODEL DEVELOPMENT AND CALIBRATION

This section summarizes numerical model design elements including the model domain, grid discretization, boundary conditions, and preliminary input parameters, as well as the final model calibration results and final calibrated parameter distribution. The hydrogeologic conceptual model (see **Section 2.0**) served as the basis for the elements of the numerical model.

4.1 MODEL DEVELOPMENT

The following subsections summarize code selection, the model domain and discretization, boundary conditions, and hydraulic properties for the numerical groundwater flow model.

4.1.1 Code Selection

The computer code MODFLOW-NWT (Niswonger et al., 2011) was selected for the project because it has all the required capabilities for the study based on modeling objectives, the size and complexity of the project area, and hydrologic features that affect groundwater within the model domain. MODFLOW-NWT is a standalone program intended for solving groundwater flow equations and is based on the USGS's groundwater modeling software MODFLOW (Harbaugh et al., 2000). The code has been verified and has been used to successfully simulate groundwater flow in similar complex groundwater environments

MODFLOW-NWT flow output can be used by MODPATH (Pollock, 1994) for particle tracking, and by MT3DMS (Zheng and Wang, 1999) for simulating contaminant transport. The graphical-user-interface Groundwater Vistas Version 6 (Rumbaugh and Rumbaugh, 2011) was used for model pre- and post-processing.

4.1.2 Model Domain and Discretization

The active model domain is 45.3 square miles in area inclusive of the former Smelter site (**Figure 4.1**). The margins of the model domain are based on hydraulic and geologic boundaries. The model is bounded to the south by the 3,940 potentiometric contour (**Figure 2.8**), to the west by Tenmile Creek, to the east by the Spokane Bench Fault, and to the north by Lake Helena. The southern boundary deviates from the 3,940 potentiometric contour where the Spokane Formation outcrops in the valley.

The model grid has variable spacing to provide additional detail around the former Smelter site and areas of impacted groundwater north and northwest of the former Smelter site (**Figure 4.1**). Grid spacing ranges from 40 to 312.5 feet and the model contains 596 rows, 473 columns, and 6 layers.

Figures 4.2 through **4.4** show geologic cross-section and cross-sections of the model. The top of Layer 1 represents land surface and was developed using USGS digital elevation map (DEM) data (USGS, 2009). Layer 1 represents unconsolidated fill material found beneath most of the former Smelter site including the Slag Pile in the northeast portion of the former Smelter site. Layer 2 represents a clay layer underlying the Slag Pile, deep fill material beneath the former Smelter site, coarse-grained alluvium

extending from beneath Upper Lake through the western portion of the former Smelter site to Lamping Field, and valley fill north of the former Smelter site. Layer 3 represents the deeper portion of coarse-grained alluvium extending from beneath Upper Lake through the western portion of the former Smelter site to Lamping Field, and valley fill north of the former Smelter site. A gravel seam north of the former Smelter site is between 10 and 20 feet thick and is represented by a relatively high permeability zone in Layer 3. Layers 1, 2, and 3 east and west of the former Smelter site represent undifferentiated Tertiary material, which is generally unsaturated. Layer 4 represents the ash/clay unit beneath the former Smelter site and undifferentiated Tertiary material around the former Smelter site including the Corrective Action Management Unit (CAMU) areas. Layers 5 and 6 represent undifferentiated Tertiary material.

4.1.3 Boundary conditions

Hydrologic boundary conditions are simulated using various MODFLOW-NWT packages. Types and locations of the boundary conditions are shown on **Figure 4.5** and summarized in the following subsections. AMEC (2012b) presents further detail regarding boundary condition development and parameterization.

4.1.3.1 General Head Boundaries

Underflow into and out of the model domain was simulated using MODFLOW's General Head Boundary (GHB) Package (**Figure 4.5**). The GHB Package is a head-dependent boundary commonly used in groundwater modeling to allow groundwater to flow in and out of a model according to a regional gradient. GHB cells are assigned both a head (groundwater level) value and a conductance value that describes how easily groundwater flows in or out of the cell. The flow rate in or out of the model to or from the GHB is then determined by the conductance value and the magnitude of the difference between the head assigned to the GHB and the simulated head in the model cell.

GHB cells representing mountain front recharge entering the model domain as underflow from the south were placed in Layers 1 through 4 along the model domain representing the 3,940-foot potentiometric contour on **Figures 2.7** and **2.8** and in Layer 6 along the fault. To establish a gradient across this boundary, the GHB head was set to 3,960 feet based on an estimated potentiometric contour in this area (AMEC, 2012b), with a distance to the GHB ranging between approximately 800 and 6,000 feet. **Table 4.1** lists initial parameter values assigned to GHB cells in the model. The hydraulic conductivity of GHB cells was set equal to estimates from Waren et al. (2012) for bedrock and based on results of hydraulic testing by Hydrometrics for alluvium. The width of the GHBs was set equal to the cell width. Hydraulic conductivity values of some GHB cells were adjusted during the calibration process (see **Section 4.2**).

GHB cells were placed along the model domain representing under flow into the model domain from the Spokane Bench. The boundary was divided into 19 segments and assigned heads that produced gradients ranging from 0.011 to 0.040 feet/foot. The hydraulic conductivity was set equal to estimates from Waren et al. (2012) for Tertiary material and bedrock and the width of the boundary was set equal to the cell width (**Table 4.1**).

4.1.3.2 Streams and Lake Helena

Tenmile Creek, Prickly Pear Creek, Upper Lake, Lower Lake, and Lake Helena were simulated using MODFLOW's River Package (**Figure 4.5**). The River Package is a head-dependent boundary that simulates flow between groundwater and surface water features. River Package cells simulate interaction between groundwater and surface water based on the surface water stage at the boundary, head in the adjacent aquifer, and conductance of the boundary.

Surface water elevations were assigned based on surveyed ground surface elevations and topographic elevations from USGS topographic quadrangles. River Package conductance is defined by the thickness and hydraulic conductivity of the stream/lake bed and the wetted cross-sectional area of the stream/lake (**Table 4.1**). River Package cells representing Tenmile and Prickly Pear creeks were assigned widths based on measurements from Hydrometrics or estimated from aerial photos. Upper Lake, Lower Lake, and Lake Helena River Package cells were assigned widths based on the cell size and distributed laterally based on aerial photos. Initially, River Package cells were assigned a hydraulic conductivity value of 1 foot/day based on estimated average bed material permeability. Some of these values were later adjusted during the calibration process (see **Section 4.2**).

Between 2011 and 2016, several components of the SPHC IM affecting surface water features were implemented at the former Smelter site including removal of Upper and Lower lakes and construction of the Prickly Pear Creek bypass and realignment channels. The distribution and conductance of River Package cells in simulations that included these IMs were adjusted based on field measurements and observations.

4.1.3.3 Irrigation Ditches and Drains

The Helena Valley is covered by a network of ditches that convey water for irrigation and drain shallow groundwater to allow for farming. Most irrigation ditches have a permeable bed and lose flow to groundwater. The distribution of ditches and drains in the model was established based on information from Waren et al. (2012), with drains occurring primarily in the northern portion of the model domain where the water table nears ground surface.

Leakage from irrigation ditches was simulated with MODFLOW's Well Package (**Figure 4.5**). The Well Package is a specified flux boundary used to simulate constant rates of recharge and discharge from the groundwater system. Each Well Package cell is assigned a specified flux at which it will add or remove water from the groundwater system. Irrigation ditches were simulated using the Well Package and flux rates were assigned based on measured or estimated flux from the groundwater balance (AMEC, 2012b), which was then proportioned based on the length of each ditch in a model boundary cell. Flux rates assigned to Well Package cells ranged from less than 1 foot^3/day to more than 2,000 feet^3/day.

In the fall of 2011, Wilson Ditch, located west of the former Smelter site, was decommissioned. This change was reflected in the model by removing the constant flux boundaries used to simulate seasonal leakage from Wilson Ditch for all simulations representing groundwater flow conditions after 2011.

Drains were simulated with MODFLOW's Drain Package (**Figure 4.5**). The Drain Package is a head-dependent boundary that removes groundwater from the model based on the simulated groundwater

elevation and a user-defined drain elevation and conductance of the drain boundary. Drain boundaries have no effect on the model if simulated groundwater elevations fall below the specified elevation of the drain. Drain Package cells in the model were assigned drain elevation values based on USGS DEM data, an initial hydraulic conductivity of 1 foot/day, and a thickness of 1 foot. The width of each drain boundary cell was set to 5 feet and the length was set equal to the length of the drain in the model cell (**Table 4.1**). Hydraulic conductivity values were adjusted during the calibration process (see **Section 4.2**).

4.1.3.4 Wells

Pumping from four large water supply wells (two industrial and two municipal) were simulated in the model using the Fracture Well 4 (FWL4) Package, with pumping rates set to average rates for 2011 (**Figure 4.5**). The FWL4 Package was selected because of its capabilities to simulate flow in multi-layer wells. Total withdrawal from a well is calculated by the FWL4 Package using modeled transmissivity values for the different model layers containing the screened interval.

Domestic and irrigation wells were not simulated because their consumptive use is a small component of the groundwater balance and it is assumed that most of the water is returned to the groundwater system.

4.1.3.5 Slurry Walls

Slurry walls at the former Smelter site were simulated with MODFLOW's Horizontal Flow Barrier (HFB) Package (Hsieh and Freckleton, 1993). This package implicitly represents a narrow (relative to the width of a model cell) feature in between model cells with a lower hydraulic conductivity than adjacent model cells. The model code calculates the total conductance between the adjacent model cells with the user-specified width and hydraulic conductivity of the barrier feature and the widths and hydraulic conductivities of the adjacent model cells. The slurry walls in the former Smelter site around the Speiss-Dross and the former Acid Plant Sediment Drying Area were simulated using the HFB Package in Layers 1, 2, and 3 (**Figure 4.5**). The boundaries were assigned a thickness of 2 feet and a hydraulic conductivity of 0.01 foot/day, and were adjusted during the calibration process (see **Section 4.2**).

4.1.3.6 Recharge

Aerial recharge from precipitation and percolation from irrigation were simulated using MODFLOW's Recharge Package (**Figure 4.6**). Aerial recharge was simulated based on estimates from METRIC data (Trezza et al., 2011), estimates from ASARCO (2003), HELP modeling performed by Hydrometrics, and PRISM data (PRISM, 2014). Higher recharge to groundwater occurs in the Helena Valley north of the former Smelter site on irrigated lands. In and around the former Smelter site, recharge rates range from 0.009 to 1.0 inch/year. Recharge rates for the model domain range between 0.009 inch/year and 38.9 inches/year and rates were adjusted seasonally for the transient flow calibration based on PRISM data. Recharge rates were adjusted during the calibration process (see **Section 4.2**).

4.1.3.7 Evapotranspiration

Evapotranspiration (ET) from the area of mapped wetlands (U.S. Fish and Wildlife Service, 2009) and ponds associated with a gravel pit north of the former Smelter site were simulated using MODFLOW's ET Package (**Figure 4.7**). The ET Package is used to simulate the effect of plant transpiration and direct

evaporation from groundwater. Each ET Package cell is assigned an ET rate and an extinction depth. The assigned ET rate for wetlands is 23 inches/year based on METRIC data (Trezza et al., 2011) and the extinction depth was set to 2 feet based on the approximate extinction depth of grass in sandy loam soil (Shah et al., 2007). The assigned ET rate for the gravel pit ponds is 35.5 inches/year (WRCC, 2012) and the extinction depth was set to 5 feet. If depth to groundwater becomes greater than the extinction depth, the ET boundary no longer removes groundwater from the system.

4.1.4 Hydraulic Properties

Groundwater flow simulations require assigning horizontal and vertical hydraulic conductivity values to each active model cell. Hydraulic conductivity was assigned using hydrogeologic (or hydraulic conductivity) zones. Hydrogeologic zones are areas where hydraulic parameters are spatially constant. Hydrogeologic zones were developed using information from lithologic logs, aquifer tests, surface geologic maps, and observed groundwater flow patterns. Initially, nine zones were established based on a surficial geologic map (**Figure 2.3**; Reynolds and Brandt, 2005) and hydraulic properties were assigned based on results of pumping and slug tests performed by Hydrometrics (see **Section 2.4.6**). The number, distribution, and hydrogeologic properties of the zones were adjusted during the calibration process to account for heterogeneities in the aquifer (see **Section 4.2**).

For the initial transient simulation, the hydrogeologic zones were assigned storage parameters based on values from Hydrometrics (2010).

4.2 Calibration

Model calibration involves finding a realistic and supportable combination of boundary conditions, input parameters, and stresses that simulate measured groundwater elevation and estimated groundwater flux within a reasonable range throughout the model domain. Model calibration was conducted in general accordance with standard industry practices, such as protocols described in Anderson et al. (2015).

The following subsections describe the calibration process, results, and parameterization.

4.2.1 General Calibration Process

Model calibration refers to demonstrating that the model is capable of reproducing field measured data within reasonable ranges (Anderson et al., 2015). The calibration process requires first establishing a set of calibration targets and goals. Model calibration is then accomplished by adjusting input parameters within reasonable ranges to reduce the difference between field measured data and simulated values until the differences meet the established calibration goals.

The numerical groundwater flow model was calibrated to steady-state and transient data sets to provide a measure of confidence in its ability to simulate groundwater flow accurately and meet project objectives (see **Section 1.2**). Model inputs were adjusted iteratively within the model to achieve a reasonable match between observed and simulated target values. Modifications made in one simulation to steady-state input parameters (e.g., hydraulic conductivity) that improved calibration were

incorporated into the other simulations until calibration goals were met for all data sets. Calibration and verification to several independent sets of both steady-state and transient target data increases confidence in the model's ability to simulate groundwater flow under a variety of aquifer conditions.

The quality of the calibration was judged using both quantitative and qualitative methods. Calibration statistics for groundwater elevation targets were calculated for each model run. These statistics provide a measure of overall match between simulated and observed conditions. The primary input parameters that were varied during calibration of the groundwater flow model included horizontal hydraulic conductivity and streambed hydraulic conductivity in River Package cells representing Prickly Pear Creek.

As new data were collected, the conceptual and numerical models were refined, and the numerical model was recalibrated. Each model update resulted in an improved calibration and reflection of the site conceptual model, which in turn improved confidence in the model's ability to predict changes in groundwater flow.

The following subsections describe target selection and calibration goals.

4.2.1.1 Target selection

Calibration targets were established based on available data and modeling goals and objectives described in **Section 1.2**. Both qualitative and quantitative targets were developed for calibration. Qualitative targets included potentiometric surface maps that were developed based on measured groundwater elevations (**Figures 2.7** and **2.8**) and hydrographs of groundwater elevations in wells over time. Particle tracking was also used periodically throughout the calibration process as a qualitative check for simulated groundwater flow directions. Quantitative targets included measured groundwater elevations and estimated groundwater flux.

Three time periods were used for calibration, which included steady-state simulations for 2011 and 2014, and a transient simulation from September 2011 to June 2015. The following independent steady-state and transient data sets were used to establish calibration targets:

Steady-State:

- Measured 2011 groundwater elevations and estimated groundwater flux.
- Measured 2014 groundwater elevations.

Transient:

- Groundwater elevations measured between September 2011 and June 2015.

The following subsections describe each data set used for calibration.

4.2.1.1.1 Steady-State 2011 Groundwater Elevations and Estimated Groundwater Flux

The 2011 steady-state groundwater flow calibration was evaluated qualitatively using a potentiometric surface (**Figure 2.7**) based on measured 2011 groundwater elevations, and quantitatively using average annual measured groundwater elevations and estimated groundwater flux.

The average groundwater elevation was calculated for each target well using monthly to biweekly measurements collected in 2011, prior to the Upper Lake Drawdown Test (Hydrometrics, 2012). A total of 187 groundwater elevation targets were used for the calibration (**Figure 4.8**). Groundwater elevation targets remained consistent throughout the modeling process.

In addition, estimated groundwater flux values were used as calibration targets (AMEC, 2012b). Including groundwater flux targets in the calibration helps provide insight into different groundwater processes throughout the model domain, and helps evaluate and refine the conceptual model (Anderson et al., 2015). **Table 4.2** contains estimated ranges of flux for different hydraulic features that affect groundwater flow in the model domain (AMEC, 2012b). Groundwater flux was estimated using empirical data collected in the field and literature values as described in **Section 2.0**. Flux targets include gain and loss from Prickly Pear Creek, recharge from aerial precipitation and applied irrigation, loss from Wilson Ditch, loss from Upper and Lower lakes, loss from other irrigation ditches, flux out of the model to irrigation drains, and groundwater flux into and out of the model domain.

4.2.1.1.2 Steady-State 2014 Groundwater Elevations

The 2014 steady-state groundwater flow calibration was evaluated based on average groundwater elevations measured in 2014 at each target location. A total of 203 groundwater elevation targets were used for this evaluation (**Figure 4.9**).

It is important to note that significant changes to the groundwater flow system occurred between 2011 and 2014, including elimination of Upper Lake, decommissioning of Wilson Ditch, installation of the Prickly Pear bypass channel, partial draining of Lower Lake, and the Source Removal IM, all of which contributed to further lowering of groundwater elevations throughout the former Smelter site. These construction related activities created transient groundwater flow direction and elevation changes throughout 2014, which on top of normal seasonal variability, make it especially difficult for a single set of steady-state targets to represent typical conditions.

4.2.1.1.3 Transient Groundwater Flow

The transient groundwater flow calibration encompasses significant hydraulic events, including decommissioning of Wilson Ditch, drawdown and removal of Upper Lake, installation of the Prickly Pear Creek bypass channel, Tito Park source removal, and partial dewatering of Lower Lake.

The transient groundwater flow calibration simulates groundwater flow between September 2011 and June 2015. A total of 219 target wells were used for this evaluation (**Figure 4.10**) with a total of 8,916 individual groundwater elevation measurements.

4.2.1.2 Calibration Goals

Qualitative and quantitative calibration goals were established for each calibration data set (see **Section 4.2.1.1**) to assess groundwater flow model calibration based on the model objectives and intended uses. The calibration goals remained consistent through all phases of modeling and are summarized below.

Steady-State Calibration Goals:

- Residuals (difference between observed and simulated target values) should be less than ±5 feet.
- The residual standard deviation divided by the range in groundwater elevation values should be less than 10 percent.
- The residual mean, defined as the average of all residual values, should be as close to zero as possible.
- Simulated groundwater flux should be within the estimated range of groundwater flux.
- Potentiometric surface contour maps based on simulated and observed groundwater elevations should be similar based on a visual inspection.

Transient Calibration Goals:

- Simulated changes in groundwater elevation in target wells, including timing and magnitude, should be similar to observed changes based on a visual inspection of the data.

4.2.2 Calibration Results

The following subsections present results from the flow model calibration described in NewFields (2016a).

4.2.2.1 2011 Steady-State

Figure 4.11 is a map showing steady-state potentiometric surface contours generated by the calibrated steady-state model and contours interpolated from average field-measured groundwater elevations, pre-Upper Lake Drawdown Test. Comparison of these potentiometric surfaces indicates a good overall visual match between simulated and observed groundwater elevations, flow directions, and gradients. **Figure 4.12** is a series of charts plotting observed versus simulated groundwater elevations from the steady-state calibration. Values appear to be randomly distributed on either side of the regression line, suggesting that the model is not biased toward groundwater elevations that are too high or too low (Anderson et al., 2015).

Table 4.3 presents calibration statistics for the 2011 steady-state calibration residuals. All residuals fall within the established calibration goal of ±5 feet. The calculated mean residual is -0.03 foot, with a standard deviation of 1.57 feet. A mean residual close to zero indicates the model is not biased towards groundwater elevations that are too high or too low (Anderson et al., 2015). The absolute mean residual from the steady-state calibration is 1.24 feet and the scaled standard deviation (residual standard deviation divided by the total change in groundwater elevations across the model domain) is 0.6

percent. Many practitioners believe the scaled standard deviation should be less than 10 percent in a well calibrated model (Anderson et al., 2015). These calibration statistics fall within the established calibration goals (see **Section 4.2.1.2**), and suggest the model is well calibrated to this data set. **Figures 4.13** through **4.17** show the distribution of residuals for Layers 1 through 5 (there are no targets in Layer 6). Positive (blue) residuals plotted on **Figures 4.13** through **4.17** indicate the simulated groundwater elevation is below the observed target value, and negative (red) residuals indicate the simulated groundwater elevation is higher than the observed target value. The fairly random distribution of positive and negative residuals indicates the model exhibits minimal spatial bias (i.e., over- or under-predicts groundwater elevations in any portion of the flow system where target data exist).

Figures 4.18 and **4.19** present simulated and estimated or measured groundwater inflows and outflows, respectively. Simulated inflows are within estimated ranges with the exception of seepage from the Helena Valley Irrigation Canal and upper Tenmile Creek. Simulated outflows are within estimated ranges except for seepage to Tenmile Creek, and evaporation from gravel ponds. Simulated seepage to Lake Helena and seepage from the Helena Valley Irrigation Canal are only slightly (less than 4 percent) outside of the estimated ranges. Seepage from Tenmile Creek and evaporation from gravel ponds are minor components of the groundwater balance, and results indicate that calibration to groundwater elevation and fluxes near the former Smelter site are not sensitive to these flux rates. In addition, there is a considerable degree of uncertainty associated with estimates of inflow from lower Tenmile Creek and evaporation from the gravel ponds (AMEC, 2012b).

4.2.2.2 2014 Steady-State

Figure 4.20 is a map showing the 2014 steady-state potentiometric surface contours generated by the calibrated steady-state model and those interpolated from average 2014 field-measured groundwater elevations. Similar to the 2011 calibration, visual comparison of these potentiometric surfaces indicates a good match between simulated and observed groundwater elevation and flow directions. Observed versus simulated values presented on **Figure 4.21** are randomly distributed on either side of the regression line, suggesting that the model is not biased toward groundwater elevations that are too high or too low (Anderson et al., 2015).

Table 4.4 presents calibration statistics for the 2014 steady-state calibration. All residuals fall within the established calibration goal of ±5 feet and the calculated mean residual is -0.06 foot, with a standard deviation of 1.81 feet. The absolute mean residual is 1.44 feet and the scaled standard deviation is 0.7 percent. These calibration statistics fall within the established calibration goals (see **Section 4.2.1.2**) and suggest the model is well calibrated to average 2014 groundwater elevation measurements.

Figures 4.22 through **4.26** show the distribution of residuals for Layers 1 through 5 (there are no targets in Layer 6). The random distribution of positive and negative residuals indicates the model exhibits minimal spatial bias.

4.2.2.3 2011 through 2015 Transient

The model was calibrated to groundwater elevations measured between September 2011 and June 2015 and results were evaluated qualitatively. Hydrographs showing simulated and field-measured groundwater elevations are displayed on **Figures 4.27** through **4.31** for Layers 1 through 5 (there are no

targets in Layer 6). The degree of fit was assessed qualitatively by visual assessment of the match between simulated and observed data. The magnitude and timing of simulated changes in water levels are similar to observed changes demonstrating that the model is capable of simulating long-term aquifer stresses including decommissioning Wilson Ditch, draining Upper Lake, implementation of the Prickly Pear Creek bypass channel, and seasonality of Prickly Pear Creek.

4.2.3 Parameter Distribution

This section discusses the parameters used for the calibrated model described in NewFields (2016a). **Figure 4.32** is a map showing the distribution of calibrated hydraulic conductivity values in Layers 1 through 4 of the model. In Layers 1, 2, and 3 (Upper Aquifer), horizontal hydraulic conductivity ranges between 0.001 foot/day for Tertiary sediments and low permeability material north of Lower Lake and beneath the Slag Pile and 1,450 feet/day for coarse-grained material northwest of the former Smelter site. Vertical hydraulic conductivity ranges between 1x10-5 foot/day and 100 feet/day. Horizontal hydraulic conductivity in Layer 4 (ash/clay unit and Tertiary sediments) ranges between 0.01 foot/day and 40 feet/day and vertical hydraulic conductivity ranges between 1x10-5 foot/day and 2 feet/day. In Layers 5 and 6 (Deep Groundwater System), horizontal hydraulic conductivity ranges between 0.5 foot/day and 70 feet/day and vertical hydraulic conductivity ranges between 1x10-5 foot/day and 1 foot/day.

Figure 4.33 shows calibrated parameter values for head-dependent boundaries in the model. Conductance for these boundaries ranges between 1x10-3 foot^2/day for General Head Boundaries along the southern and eastern edges of the model and 1.3 x 106 feet^2/day for a reach of Prickly Pear Creek.

4.2.4 2016 Slag Pile Recalibration

One of the final measures being considered in the CMS is capping and regrading of the Slag Pile. NewFields (2016b) updated the groundwater flow and selenium transport models from NewFields (2016a). The objectives of this update were to evaluate elements of the Slag Pile conceptual model, support development of design options for the Slag Pile, and better calibrate the model to selenium concentrations measured north of the Slag Pile and Prickly Pear Creek.

The calibrated contaminant transport model (see **Section 5.2.3**) assumed that the source of selenium in the Slag Pile was in the saturated zone. However, Hydrometrics (2016b) suggested that the majority of selenium in groundwater beneath and downgradient of the Slag Pile comes from leaching in the unsaturated zone. This led to concern that the calibrated selenium transport model may not accurately predict effects of different Slag Pile remedial options.

The flow model was modified and then recalibrated to create downward gradients beneath the Slag Pile. The calibrated flow model (NewFields, 2016a) had upward hydraulic gradients beneath the Slag Pile that made it difficult to match the vertical distribution of observed selenium concentrations in the transport model using sources in the unsaturated zone. The 2011 and 2014 steady-state groundwater elevation targets were used to recalibrate the model. Parameters adjusted in the groundwater flow model included hydraulic conductivity and recharge from aerial precipitation through the Slag Pile.

Figure 4.34 includes maps comparing potentiometric surface contours generated by the recalibrated steady-state model and those interpolated from average field-measured groundwater elevations for 2011 and 2014. Similar to the calibration described in **Sections 4.2.2.1** and **4.2.2.2**, visual comparison of the 2011 and 2014 potentiometric surfaces indicates a good match between simulated and observed groundwater elevation and flow directions. Observed versus simulated values presented on **Figure 4.34** are randomly distributed on either side of the regression line, suggesting that the recalibrated model is not biased toward groundwater elevations that are too high or too low (Anderson et al., 2015).

Table 4.5 includes residual statistics for 2011 and 2014 recalibration simulations. These statistics fall within established calibration goals (see **Section 4.2.1.2**) and are equivalent to those in **Tables 4.3** and **4.4** indicating the quality of the calibration is equivalent to the calibration results discussed in **Section 4.2.2**.

Figure 4.35 shows the updated hydraulic conductivity distribution for the Slag Pile area for model Layers 2 and 3. Layer 1 in this area represents the Slag Pile, Layer 2 represents a fine-grained clay layer beneath the Slag Pile, and Layer 3 represents the sand and gravel alluvial aquifer. The calibrated hydraulic conductivity distribution used in NewFields (2016a) had a low permeability hydraulic conductivity zone in Layer 2 of the model representing the fine-grained clay layer. This zone prevented selenium from unsaturated sources in the Slag Pile from reaching groundwater, thus requiring saturated sources to be used in the model in order to calibrate to observed selenium concentrations in this area. Further evaluation of lithology recorded on well logs for monitoring wells in this area shows less clay and more courser-grained material beneath the north half of the Slag Pile compared to the southern half. Thus, the most significant change in the updated calibration was to add a new hydraulic conductivity zone in Layer 2 in the norther part of the Slag Pile with slightly higher permeability. This change allowed selenium from unsaturated sources to reach groundwater so the selenium transport model could be recalibrated.

Recharge rates were adjusted in the 2016 Slag Pile recalibration for the purposes of matching observed selenium concentrations (see **Section 5.2.4**). **Figure 4.36** shows the updated recharge distribution for the Slag Pile area. The recharge rate was adjusted from approximately 21 percent of annual precipitation to 50 percent of annual precipitation.

5.0 CONTAMINANT TRANSPORT MODEL DEVELOPMENT AND CALIBRATION

This section summarizes the development and calibration of the contaminant transport model including code selection, source boundary conditions, calibration, and parameterization of the calibrated models. The conceptual model of contaminant transport (see **Section 3.0**) and the calibrated groundwater flow model (see **Section 4.0**) served as the basis for the numerical contaminant transport model.

5.1 MODEL DEVELOPMENT

The following subsections describe code selection, source terms, initial source geometry and concentrations, as well as fate and transport parameters for the numerical contaminant transport models.

5.1.1 Code Selection

MT3DMS (Zheng and Wang, 1999) was used to develop the contaminant transport model for the project. MT3DMS is a three-dimensional (3D) transport model capable of simulating advection, dispersion/diffusion, and chemical reaction of contaminants in groundwater flow systems. Contaminants can be added to groundwater from unsaturated and saturated soils and contaminated surface water. The software uses a groundwater flow field generated from a finite-difference model (MODFLOW-NWT was used for this project [see **Section 4.1.1**]) to simulate contaminant movement through a groundwater system. Source mass is input into the model as well as parameters such as effective porosity, retardation, and dispersivity, and contaminant movement is simulated over a specified period of time.

5.1.2 Source Terms

Arsenic and selenium are present in site soils in several areas in both the saturated and unsaturated zones and are sources of ongoing groundwater contamination in and downgradient of the former Smelter site (see **Section 3.1**). Boundary conditions used to simulate arsenic and selenium sources require definition of an initial concentration or mass loading rate and geometry for each source area. Initial concentrations or mass loading rates and geometry were defined based on existing site data including soil and groundwater concentrations and results from Synthetic Precipitation Leachate Procedure (SPLP), Sequential Batch Leach (SBL), Sequential Extraction, and Batch Adsorption tests from samples collected during the Phase II RFI (GSI, 2014). In addition, the hydrogeologic and contaminant transport conceptual models were considered as well as supplemental data from source area investigations completed by Hydrometrics (2015; 2016a).

Unsaturated source areas were simulated using the Recharge Package. Concentrations were assigned to Recharge Package cells in potential source areas and input to the model using the recharge rate. Saturated source areas were simulated using the MT3DMS Mass Loading Package. Source concentrations were multiplied by simulated groundwater flux through source areas to determine mass

loading rates. The calculated mass loading rate was then input using Mass Loading Package cells and distributed based on the estimated source area geometry.

5.1.3 Initial Source Geometry

The initial geometry of saturated and unsaturated source areas was based on historic soil data and a source area inventory (Hydrometrics, 2014). The initial horizontal geometry of saturated source areas for arsenic and selenium corresponded directly to individual potential source areas shown in **Figure 5.1**. The initial vertical geometry of source areas in the saturated zone was based on soil data collected from the former Smelter site. Mass Loading Package cells were placed in model layers corresponding to the elevation of soil samples from the saturated zone that had elevated concentrations of either arsenic or selenium. If soil concentration data were not available for a source area, Mass Loading Package cells were initially placed in model Layers 1 through 3, which represent the Upper Aquifer, above the ash/clay layer. It was assumed that the vertical distribution of source mass in the saturated zone is uniform within each model layer.

The geometry of arsenic source areas in the unsaturated zone was based on site-specific data. Arsenic data for unsaturated soil samples were compiled and used to create a variogram model for the site, which in turn was used to develop an estimated concentration distribution using kriging (NewFields, 2015a).

The initial geometry of selenium source areas in the unsaturated zone was based on the source inventory study. The initial distribution of these boundary conditions corresponded directly to individual potential selenium sources identified in **Figure 5.1**.

The geometry of saturated and unsaturated source areas was adjusted during calibration, along with contaminant retardation and dispersion rates, to better simulate observed plume geometries and concentrations at individual wells (see **Section 5.2**).

5.1.4 Initial Source Concentration

Initial concentrations for source area boundary conditions were calculated using the following equation:

$$PW = L \times (V / M) \times \rho \times SY$$

Where:

PW = concentration in pore water (mass/volume)
L = representative concentration of SPLP or SBL leachate (mass/volume)
V = volume of SPLP/SBL leachate (volume)
M = mass of SPLP/SBL solid (mass)
ρ = bulk density of SPLP/SBL solids (mass/volume)
SY = Specific Yield (unitless)

The concentration in pore water (PW) was used as the initial concentration for source area boundary conditions. SPLP and SBL tests were conducted as part of the Phase II RFI (GSI, 2014) and used to determine leachability of arsenic and selenium under natural conditions for site material.

Representative concentrations of SPLP and SBL leachate (L) were generated for each source area based on site-specific soil, sediment, and slag data. If SPLP or SBL data did not exist for a source area, initial concentrations were estimated based on adjacent source areas with SPLP or SBL data. The ratio of volume of SPLP/SBL leachate (V) to mass of SPLP/SBL solid (M) for the tests was 20:1 (GSI, 2014). Bulk density (ρ) and specific yield (SY) were estimated from literature values and were 1.5 grams per cubic centimeter (g/cm^3; Freeze and Cherry, 1979) and 18 percent (Johnson, 1967), respectively.

The following subsections describe initial concentration calculations for unsaturated and saturated boundary conditions. Boundary condition concentrations were adjusted during calibration to better simulate observed plume geometries and concentrations at individual wells (see **Section 5.2**).

5.1.4.1 Unsaturated Zone Soils

SPLP and SBL extract concentration data were plotted with respect to solid arsenic and selenium concentrations for each unsaturated zone sample (NewFields, 2015a). Based on these plots, there did not appear to be a relationship between solid arsenic or selenium concentrations and SPLP extract concentrations for the samples. Therefore, an equation relating solid and extract concentrations could not be established for calculating source area specific initial concentrations. Instead, source concentrations were estimated based on minimum, maximum, and median concentrations determined for all available SPLP extracts for each source area in the unsaturated zone. These values were used to calculate initial, minimum, and maximum concentrations for unsaturated source boundary conditions. The median SPLP extract concentration (L) was used to calculate the initial concentration for boundary conditions. The minimum and maximum SPLP extract concentrations were used to constrain model input concentrations where data was available for arsenic and selenium during calibration. In areas where SPLP extract data are not available, results from adjacent source areas were used.

5.1.4.2 Saturated Zone Soils

Single-extract SPLP and SBL plots indicated a logarithmic relationship between extract concentrations and solid concentrations in the saturated zone for arsenic in non-petroleum impacted areas and a linear relationship for selenium (NewFields, 2015a). Using equations for these relationships, a representative concentration of SPLP/SBL leachate (L) for saturated zone arsenic and selenium was calculated using source area specific soil samples.

Soil concentration data was compiled for each source area and the average, minimum, and maximum values were calculated. If a source area had less than three soil samples, nearby source area data was used to supplement results. Average soil concentrations were entered into the relationship equations as the solid concentration and the SPLP/SBL extract concentration was calculated. The SPLP/SBL extract concentration was then used to calculate initial source concentrations using the equation presented in **Section 5.1.4**. Minimum and maximum soil concentrations for each source area were used to constrain model input values during calibration.

SBL tests run on subsurface material samples from petroleum hydrocarbon impacted areas did not exhibit a relationship between extract and solid arsenic concentrations (NewFields, 2015a). For this reason, the median SBL concentration for specific source areas was used as the representative concentration for SBL leachate (L) and the minimum and maximum values were used to constrain model

input concentrations during calibration. Based on the contaminant transport conceptual model (see **Section 3.0**), selenium is not mobile where groundwater conditions are reducing due to the presence of petroleum hydrocarbons in subsurface material; therefore, it was assumed there is no selenium source in that portion of the model. In addition, although selenium is present in soil in the Tito Park/Lower Lake and Monier Flue areas, groundwater concentrations in wells downgradient of these areas are low, so selenium sources were not simulated in these areas of the model.

The Mass Loading Package used to simulate saturated zone source areas requires a mass loading rate (unit mass per unit time). The mass loading rate was calculated by multiplying the simulated groundwater flux through saturated source areas by the calculated initial concentration.

5.1.5 Fate and Transport Parameters

In addition to source terms, contaminant transport simulations require estimates of effective porosity, dispersivity coefficients, decay coefficients, and retardation factors. Initial estimates for these parameters are discussed below.

5.1.5.1 Effective Porosity

Initial estimates of effective porosity were based on literature values described in NewFields (2014a) for different zones of predominantly silt, sand, or gravel. These values matched values used in the initial transient flow model calibration and ranged between 0.12 and 0.2. Effective porosity was adjusted during calibration (see **Section 5.2**).

5.1.5.2 Dispersivity Coefficients

Initial estimates of dispersivity coefficients were calculated using the equation developed by Xu and Eckstein (1995). The equation uses a representative travel distance to calculate longitudinal dispersivity and is based on a compilation of dispersivity results from Gelhar et al. (1992). The distance from selenium source areas to the downgradient edge of the selenium plume, defined as the 0.05 mg/L isoconcentration contour line, was used as the representative travel distance to calculate longitudinal dispersivity for the model. This length is approximately 10,000 feet resulting in a longitudinal dispersivity of 55.4 feet.

Bear and Cheng (2010) note that horizontal transverse dispersivity is approximately an order of magnitude less than longitudinal dispersivity, and Gelhar et al. (1992) note that vertical dispersivity is approximately an order of magnitude less than transverse dispersivity. Based on this, the initial transverse dispersivity was set to 5.54 feet and the vertical dispersivity was set to 0.554 feet.

5.1.5.3 Retardation and Decay

Arsenic

There is evidence that mobility of arsenic is controlled by natural attenuation processes including sorption and chemical precipitation, which are in turn controlled by dissolved arsenic concentrations, redox, and pH conditions in the aquifer. The main arsenic plume occurs in a reducing environment downgradient of the Spiess Dross area, where petroleum hydrocarbons are present in aquifer material

(GSI, 2014). Downgradient of the former Smelter site, groundwater becomes more oxidized causing arsenic to become less mobile, resulting in relatively high concentration gradients at the downgradient edge of the plume.

Transport of arsenic in the model was simulated using retardation factors that simulate sorption and decay coefficients (half-lives) that simulate coprecipitation by removing contaminant mass from the model. Retardation factors are a function of bulk soil density, moisture content, chemical adsorption properties, pH, and redox potential (Fetter, 2001).

Dry bulk mass density and volumetric moisture content of soil were estimated from literature values and were 1.5 g/cm^3 (Freeze and Cherry, 1979) and 0.12 to 0.2 (GSI, 2014), respectively. Distribution coefficients for arsenic were developed using adsorption test results, which are representative of aquifer material throughout the former Smelter site (GSI, 2014). Averaged Langmuir parameters were used to create a general Langmuir adsorption isotherm relating the mass of arsenic adsorbed per bulk unit soil to dissolved arsenic concentrations.

NewFields (2014b) presents distribution coefficients and maximum adsorption capacity values derived from the Langmuir isotherm that were incorporated into the model. Retardation factors for arsenic were applied in model layers 1, 2, and 3 in areas with observed arsenic groundwater concentrations.

Decay coefficients (half-lives) were used to simulate coprecipitation of arsenic. Decay coefficient values were set sufficiently low (<0.1 days) to simulate high concentration gradients observed at the edge of the arsenic plume.

Selenium

Based on dissolved selenium and physical and chemical data, selenium mobility in groundwater is controlled by redox and pH conditions. Observed selenium speciation from groundwater samples collected on and downgradient of the former Smelter site indicates that selenate is the predominant selenium species where oxidizing conditions exist in the aquifer. Selenate remains soluble (mobile) in groundwater and therefore, was assumed to travel conservatively in the aquifer (i.e., no sorption or precipitation). Detectable selenium in groundwater is not present in areas impacted by petroleum hydrocarbons. These areas are generally characterized by reducing conditions, which causes selenium to become less mobile in groundwater. It was assumed that selenium in areas impacted by petroleum hydrocarbons is in the form of elemental selenium or selenite and selenide precipitates, which become immobile in groundwater.

Decay was used in the transport model to simulate precipitation of selenium in areas with petroleum hydrocarbons. Initial estimates of decay coefficients were based on precipitation rates found in literature (Tokunaga et al., 1994; Zawislanski and Zavarin, 1996; Herbel et al., 2003). Decay was not simulated outside of the area impacted by petroleum hydrocarbons. Within the petroleum hydrocarbon area, a decay coefficient (half-life) was set sufficiently low (<0.1 days) to decrease groundwater selenium concentrations to levels that reasonably match observed concentrations.

5.2 CALIBRATION

Similar to calibration of the groundwater flow model (see **Section 4.2**), calibration of a contaminant transport model involves finding a realistic and supportable combination of boundary conditions, input parameters, and stresses that simulate measured concentrations within a reasonable range throughout the model domain. Model calibration was conducted in general accordance with standard industry practices, such as protocols described in Anderson et al. (2015).

The following subsections describe the calibration process, results, and parameterization.

5.2.1 General Process

The same general calibration process as described for the groundwater flow model (see **Section 4.2.1**) was applied to calibrating the arsenic and selenium contaminant transport models. Calibration targets and goals were established and calibration was then accomplished by adjusting input parameters within reasonable ranges to reduce the difference between field measured data and simulated values.

Steady-state flow fields were generated using the 2011 and 2014 calibrated groundwater flow model. For the 2011 calibration, initial conditions assumed no dissolved arsenic or selenium was present in groundwater. After adding constant source terms, the 2011 transport simulations were run for 20 years to allow concentrations to reach equilibrium within the monitoring well network (i.e., less than 0.1 percent change in concentrations over time). After adjusting source concentrations, the 2014 calibration used 2011 simulated concentrations as initial concentrations and the model was run for 3 years.

The arsenic and selenium contaminant transport models were calibrated to two data sets to provide a measure of confidence in their ability to simulate contaminant transport, and meet project objectives (see **Section 1.2**). Model inputs were adjusted iteratively within the model to achieve a reasonable match between observed and simulated target values. Modifications made in one simulation to non-transient input parameters affecting transport (e.g., effective porosity) that improved the calibration were incorporated into the other simulations until calibration goals were met for all data sets.

The quality of the calibration was judged using both quantitative and qualitative methods. The calibration was evaluated after every model run and input parameters were adjusted in areas that did not meet calibration criteria. The primary input parameters that were varied during calibration of the contaminant transport models included source area distribution, concentrations, and mass loading. Other parameters that were adjusted include effective porosity, dispersivity, decay coefficients, and retardation factors.

The contaminant transport models were updated and recalibrated as new information was collected during annual monitoring and source area investigations. Each model update resulted in an improved calibration and reflection of the site conceptual model, which in turn improved confidence in the model's ability to predict changes in contaminant transport.

The following subsections describe target selection and calibration goals.

5.2.1.1 Target Selection

Calibration targets were established based on available data and modeling goals and objectives described in **Section 1.2**. Both qualitative and quantitative targets were developed for calibration. Qualitative targets included arsenic and selenium plume maps that were developed based on measured concentrations (**Figures 3.4** through **3.7**). Quantitative targets included measured arsenic and selenium concentrations in groundwater.

Two time periods were used for calibration, which included steady-state simulations for 2011 and 2014. Average arsenic and selenium concentrations for 2011 and 2014 were used as calibration targets for the simulations.

The following subsections describe each data set used for calibration.

5.2.1.1.1 2011 Arsenic and Selenium Concentrations

The 2011 contaminant transport calibration was evaluated qualitatively using arsenic and selenium plume geometries, and quantitatively using average measured arsenic and selenium groundwater concentrations. A set of 119 arsenic and 147 selenium targets were selected after reviewing monitoring data collected between January and October 2011 (**Figure 5.2**). Arsenic concentrations related to the west lobe of the arsenic plume (see Figure 1-2 of Hydrometrics [2015]) were not simulated because it is thought that arsenic concentrations in groundwater within this area are within the range of background concentrations derived from groundwater interacting with naturally occurring arsenic-bearing sediments (Hydrometrics, 2015).

Groundwater samples from target wells used for calibration exhibited variability in concentrations primarily due to seasonal changes in groundwater flux and flow directions resulting from operation of Wilson Ditch (GSI, 2014). Due to this variability, targets were evaluated using a range of target values for individual wells in conjunction with calibration criteria described in **Section 5.2.1.2**.

5.2.1.1.2 2014 Arsenic and Selenium Concentrations

The 2014 steady-state contaminant transport calibration was evaluated with the same methods used for the 2011 contaminant transport calibration (see **Section 5.2.1.1.1**). A set of 119 arsenic and 158 selenium targets were selected after reviewing monitoring data collected in 2014 (**Figure 5.3**).

5.2.1.2 Calibration Goals

Qualitative and quantitative calibration goals were established for each calibration data set (see **Section 5.2.1.1**) to assess contaminant transport model calibration based on the model objectives and intended uses. Quantitative evaluation was performed by comparing simulated concentrations to ranges in observed concentration and evaluating residual values. Residual is the difference between simulated and observed target values. Two criteria were used for evaluation: 1) the simulated value relative to the observed range of concentrations; and, 2) the absolute residual value relative to a predetermined calibration goal. The following variables were developed for the second calibration criteria:

R = absolute value of the simulated concentration – observed concentration (mg/L); and

R* = Predetermined calibration goal for the absolute residual value (mg/L).

If the simulated concentration was within the observed range of values or if R was less than R*, the target was considered calibrated. If both calibration criteria were not met, the target was not considered calibrated. The goal was to get greater than 70 percent of simulated concentrations within these calibration criteria.

Table 5.1 presents R* values used for calibration. These values were developed based on the range of concentrations used as target values and are between 25 and 50 percent of the difference between the minimum and maximum values for the range.

5.2.2 Calibration Results

The following subsections present results from the final phase of contaminant transport model calibration described in NewFields (2016a).

5.2.2.1 2011 Simulation

Figures 5.4 and **5.5** are maps of 2011 simulated and observed isoconcentration contours for arsenic and selenium, respectively. These figures include data for June and September 2011, which capture transient effects of seasonal variability on plume geometry. Simulated contours are generated using a steady-state flow field, which is representative of average conditions. For this reason, simulated plume contours were compared to both June and September plumes.

Visual comparison of observed and simulated arsenic and selenium plume maps indicates a reasonable match between simulated and observed plume centerlines, extent, and magnitude. A few areas do not match exactly. For instance, the estimated 0.01 mg/L arsenic isoconcentration contour based on groundwater monitoring results extends north of the Slag Pile approximately 1,900 feet, whereas the simulated 0.01 mg/L contour extends about 350 feet north of the Slag Pile. Uncertainty in three-dimensional groundwater flow, redox boundaries, and source area concentrations make this area difficult to calibrate. However, this area was not the primary focus of the CMS evaluations. In addition, simulated concentrations near the Acid Plant and Speiss-Dross areas are slightly higher than observed concentrations, and the 10 mg/L and 20 mg/L isoconcentration contours extend further northwest from the former Smelter site than the observed contours. However, most calibration targets in this area are considered calibrated based on quantitative evaluation.

For selenium, the observed and simulated isoconcentration contours are generally similar in all areas except at the downgradient end of the plume near Canyon Ferry Road where the simulated 0.05 mg/L isoconcentration contour extends further downgradient than the observed contour. The observed data isoconcentration map was constructed using 53 residential wells in this area that were sampled in 2011. Most of these wells are completed in Layers 1 and 2 and had selenium concentrations less than 0.01 mg/L, suggesting the plume did not extend this far in 2011. Two of these wells are constructed approximately 160 feet below ground surface in Layer 3, and had selenium concentrations greater than 0.01 mg/L. The model is generally able to reproduce observed selenium concentrations in Layer 3 but is less accurate at reproducing concentrations in Layers 1 and 2. NewFields (2016b) addressed this area and the updated calibration is discussed in **Section 5.2.4**.

Based on the quantitative calibration criteria (see **Section 5.2.1.2**), 91 percent of arsenic targets and 86 percent of selenium targets fall within calibration criteria. These percentages exceed the calibration goal of 70 percent.

Figures 5.6 and **5.7** show calibrated and uncalibrated targets for the arsenic and selenium simulations, respectively. Most arsenic concentration targets are calibrated in and downgradient of the former Smelter site. As discussed above, the model is not well calibrated to lower arsenic concentrations in wells north of the Slag Pile. In addition, five wells in the Acid Plant and Speiss-Dross areas have simulated concentrations outside of the calibration criteria. For selenium, the majority of simulated concentrations in selenium source areas are within calibration criteria, including those in the Slag Pile, Acid Plant, and West Selenium Area. Downgradient of the former Smelter site, the model is able to reproduce observed selenium concentrations throughout the selenium plume. Although simulated concentrations for some targets are outside established calibration criteria, simulated concentrations for the majority of targets in the model are within criteria ranges.

5.2.2.2 2014 Simulation

Evaluation of the 2014 arsenic and selenium contaminant transport models was performed using the same methods described for the 2011 contaminant transport calibration (see **Section 5.2.2.1**). **Figures 5.8** and **5.9** show simulated and observed plume maps for the 2014 calibration for arsenic and selenium, respectively. Similar to the 2011 arsenic calibration (see **Section 5.2.2.1**), the 2014 simulated 0.01 mg/L isoconcentration contour does not extend as far north from the Slag Pile as the observed contour. In addition, the 20 mg/L contour does not extend as far north as the observed contour. Uncertainty in these areas is associated with three-dimensional groundwater flow, redox boundaries, and source area concentrations. However, the simulated isoconcentration contours generally match the observed contours where data exist.

For selenium, the model is able to simulate the westward shift in the selenium plume that occurred when Wilson Ditch was decommissioned, and in general, simulated contours are similar to observed contours. There is still uncertainty related to the downgradient extent of the 0.05 mg/L isoconcentration contour. However, the simulated contour extends further downgradient in 2014 than in 2011, which reflects an increase in selenium concentrations observed at two downgradient residential wells.

Based on the quantitative calibration criteria (see **Section 5.2.1.2**), 82 percent of the arsenic targets and 78 percent of the selenium targets are considered calibrated, which exceed the 70 percent goal. **Figures 5.10** and **5.11** present calibrated and uncalibrated targets for arsenic and selenium, respectively. Areas of uncertainty in the 2014 calibration for arsenic include north of the Slag Pile, the Acid Plant, and two wells at the downgradient edge of the arsenic plume. For selenium, several wells in the central portion of the former Smelter site and downgradient of the site near Lamping Field are not calibrated. However, most arsenic and selenium targets are considered calibrated.

5.2.3 Parameter Distribution

This section discusses the parameters used for the calibrated model described in NewFields (2016a). **Figure 5.12** is a map showing the distribution of arsenic and selenium source areas in the unsaturated

zone for the 2011 and 2014 calibration simulations. Arsenic concentrations range from 0.17 to 408 mg/L and selenium concentrations range from 0.54 to 4.24 mg/L for unsaturated boundary conditions.

Figures 5.13 and **5.14** are maps showing the distribution of saturated arsenic and selenium source areas, respectively, for Layers 1, 2, and 3 in the 2011 and 2014 calibration simulations. Arsenic mass loading rates range from less than 1,000 mg/day in the Slag Pile to greater than 1,000,000 mg/day in a small area inside the Speiss-Dross slurry wall. Selenium mass loading rates range from less than 1,000 mg/day in the Acid Plant and Slag Pile areas to greater than 50,000 mg/day in the West Selenium Area.

Figure 5.15 shows the distribution of effective porosity for Layers 1 through 4 in the model. Values range from 1 to 20 percent depending on lithologic material. Effective porosity zones representing sand and gravel material in Layers 1 through 3 with values of 8 percent are near the low end of the range of values expected for alluvial sand and gravel; however, using this value led to the best calibration of the selenium plume downgradient of the former Smelter site. It should be noted that there is considerable uncertainty regarding when leaching began for each source area. The 2011 contaminant transport simulations were run for 20 years but more time may have passed since each source area began impacting groundwater. Effective porosity effects transport velocity and helps deal with uncertainty regarding the time when transport began.

Figures 5.16 and **5.17** show the distribution of retardation and decay coefficients used in the arsenic and selenium simulations, respectively. Decay coefficients for arsenic primarily outline the extent of the observed arsenic plume and were used to simulate high concentration gradients along the outer edge of the plume. Decay coefficients for selenium are generally located in areas with detectable petroleum hydrocarbons in soil.

5.2.4 2016 Selenium Recalibration

As discussed in **Section 4.2.4**, NewFields (2016b) updated the calibrated groundwater flow and selenium contaminant transport models from NewFields (2016a) to reflect the conceptual model for the Slag Pile more accurately. In addition, as part of this update the selenium contaminant transport model was updated to simulate selenium concentrations north of Canyon Ferry Road more accurately.

The calibrated selenium contaminant transport model from NewFields (2016a) used saturated selenium sources in the Slag Pile area to calibrate to observed concentrations (see **Section 5.2.4**). However, the conceptual model for the Slag Pile is that infiltration from precipitation and snowmelt leaches selenium from unsaturated slag that migrates to groundwater. To update the contaminant transport model, the saturated sources were removed, and the unsaturated sources were modified until the model was considered calibrated based on the pre-defined calibration goals (see **Section 5.2.1.2**). The 2011 and 2014 steady-state data sets were used to evaluate model calibration.

Figures 5.18 and **5.19** show simulated and observed plume maps for the 2011 and 2014 selenium calibration, respectively. Similar to the calibration described above, simulated contours are generally similar to observed contours. There is still uncertainty related to simulated selenium concentrations north of Prickly Pear creek in the City of East Helena. However, the area in and downgradient of the Slag Pile is still considered calibrated. Based on the quantitative calibration criteria (see **Section 5.2.1.2**), 84

percent of the 2011 selenium targets, and 71 percent of the 2014 selenium targets are considered calibrated, which exceed the 70 percent goal.

To simulate observed selenium concentrations north of Canyon Ferry Road more accurately, dispersivity was adjusted in the model. Longitudinal dispersivity in the calibrated model described by NewFields (2016a) was set to 50 feet, transverse dispersivity was set to 5 feet, and vertical dispersivity was set to 0.5 feet. Dispersivity was adjusted during this calibration and the final longitudinal dispersivity was set to 25 feet, transverse dispersivity was set to 0.5 feet, and vertical dispersivity was set to 0.08 feet.

Figure 5.20 shows simulated and observed selenium concentrations downgradient of the former Smelter site, north of Canyon Ferry Road. In general, the model accurately simulates the extent of detectable selenium concentrations however, simulated concentrations are slightly higher (1 to 10 micrograms per liter) than observed concentrations.

6.0 PREDICTIVE ANALYSES

This section describes methods and results of the predictive modeling completed at the former Smelter site to support evaluation of IMs, potential source control measures, a Controlled Groundwater Area, regrading and covering of the Slag Pile, and potential changes to groundwater flow directions based on assumed future changes in Prickly Pear Creek flows.

Several phases of predictive modeling were performed in support of the evaluations. In each phase of analysis, the conceptual model was refined based on new information and the numerical models were updated and recalibrated, as summarized in **Section 1.1**.

6.1 INTERIM MEASURES

As discussed above, multiple phases of predictive analyses were completed to support evaluation of IMs. The following subsections summarize the methods and results of these predictive phases of modeling.

6.1.1 Steady-State Flow (NewFields, 2014a; NewFields, 2014d)

NewFields (2014a) describes the initial set up and results for this phase of predictive analyses and NewFields (2014d) describes updates made to the predictive analyses using an updated groundwater flow model. The methods and results described below are from the updated predictive simulations documented in NewFields (2014d).

The SPHC IMs were evaluated for this phase of modeling, which included construction of the Prickly Pear Creek bypass channel, removal of Upper Lake, construction of the Prickly Pear Creek realignment, and removal of Lower Lake and Smelter Dam.

Three transient scenarios were developed for evaluation of SPHC IMs including: 1) current condition; 2) Bypass/Upper Lake; and 3) Realignment/Lower Lake/Smelter Dam. The current conditions scenario simulates predicted groundwater elevations assuming Upper Lake water elevations remain constant after the Upper Lake Drawdown Test (based on projected 2014 steady-state conditions; see NewFields [2014d]). The current conditions scenario and the steady-state 2011 simulation were used as base cases to compare changes in groundwater elevation and flow and gain/loss from Prickly Pear Creek to the other predictive two scenarios. The Bypass/Upper Lake scenario simulated effects of removing Upper Lake and constructing the Prickly Pear Creek bypass channel. The Realignment/Lower Lake/Smelter Dam scenario simulated effects of removing Lower Lake and Smelter Dam and realigning Prickly Pear Creek. Each simulation was run until it reached equilibrium (i.e., groundwater elevations only vary seasonally); equilibrium was typically reached in one year, and therefore results from the second year of the simulation were used for evaluation.

The following is a summary of key findings from this predictive analysis:

- The Prickly Pear Creek bypass channel was predicted to gain water in the southern portion of the model and lose water in reaches east of Upper and Lower lakes (**Figure 6.1**). The model

predicted groundwater elevations in wells northwest of Upper Lake would drop between 4 and 7 feet after completion of the bypass as compared to the current conditions scenario. This change is attributable to further lowering of Upper Lake water levels and is consistent with groundwater levels measured after Prickly Pear Creek was diverted into the bypass channel. The model predicted that groundwater elevations northwest of Upper Lake would decrease between 3 and 8 feet following construction of the realignment (**Figure 6.2**), or a total of 7 to 15 feet as compared to the 2014 current conditions simulation.

- The model predicted that following implementation of the Prickly Pear Creek realignment, groundwater elevations would decrease more on the west side of the former Smelter site than on the east side, with the exception of wells around Lower Lake and Smelter Dam (**Figure 6.3**). **Figure 6.3** shows predicted changes in groundwater elevations between the steady-state 2011 simulation and the Realignment/Lower Lake/Smelter Dam scenario. Groundwater elevations were predicted to decrease by as much as 8 feet in the western half of the site near the former Acid Plant after completion of the realignment and in general, average declines ranged between 2 and 6 feet in the area. The maximum decrease in groundwater elevation was predicted to occur in Tito Park between Upper and Lower lakes, as a result of removing the lakes and Smelter Dam. Groundwater elevations in the Slag Pile area were predicted to decline between 1.5 and 3 feet.
- The model predicted that groundwater flux through contaminated zones would decrease by an average of 47 percent as a result of implementation of the SPHC IMs (**Table 6.1** and **Figure 6.4**). The model predicted that source material in Tito Park and the Acid Plant Sediment Drying Area in Layers 1 and 2 would be desaturated; groundwater flux in Layer 2 in the Acid Plant, Speiss-Dross, and Thornock Lake areas would decrease significantly; and, groundwater flux beneath the Slag Pile would not change appreciably as a result of implementation of the SPHC IMs. The model predicted that after Upper and Lower lakes are removed, hydraulic gradients, groundwater elevations, and fluxes would decrease in contaminated areas, resulting in less contaminated soil in contact with groundwater.
- **Figure 6.5** through **6.9** present particle tracking results for different source areas. After bypass construction and removal of Upper Lake, the model predicted that Tito Park would be desaturated resulting in no active particles (**Figure 6.5**). Particle tracks from the Speiss-Dross (**Figure 6.6**) and Acid Plant (**Figure 6.9**) areas did not travel as far for the Bypass/Upper Lake and Realignment/Lower Lake/Smelter Dam simulations compared to the steady-state 2011 simulation. Particles in the Slag Pile area were not significantly affected by the SPHC IMs (**Figure 6.7**). In the simulations, particles representing contamination from Lower Lake sediment did not travel as far once the lake was removed during construction of realigned creek (**Figure 6.8**).

6.1.2 Steady- State Flow and Transient Transport (NewFields, 2015b)

NewFields (2015b) used the calibrated groundwater flow and contaminant transport models to develop predictive simulations to support evaluation of completed or planned implementation of SPHC IMs. Predictive simulations included the construction of the Prickly Pear Creek bypass channel and realignment.

The model set up included steady-state flow field with transient contaminant transport (NewFields, 2015b). This setup caused rapid changes in concentrations that are not representative of the time it would take concentrations to actually change. Predictive results presented below show changes in concentration that could be expected if an IM were operational until concentrations reached equilibrium. In addition, equilibrium results are appropriate for evaluating IMs on a comparative basis.

The following is a summary of key findings from this predictive analysis:

- This analysis predicted that implementation of SPHC IMs would improve groundwater quality downgradient of the former Smelter site. The lateral and vertical extent and volume of groundwater with arsenic concentrations above the MCL were not predicted to be affected greatly by the SPHC IMs (**Figure 6.10**); however, the total mass of arsenic was predicted to decrease from the 2011 baseline simulation. The extent of the downgradient selenium plume (**Figure 6.11**), volume of groundwater with concentrations above the selenium MCL, and the total mass of selenium in groundwater were predicted to decrease as a result of IM implementation.
- This simulation predicted that the volume of groundwater with arsenic concentrations above the MCL would not change appreciably with implementation of the SPHC IMs (**Figure 6.12**; **Table 6.2a**). Both the conceptual and numerical models assume that northward migration of arsenic is limited by changing redox conditions that creates high concentration gradients. The area of high concentration gradients is simulated with a decay coefficient, which removes mass and thus does not allow arsenic to migrate farther northward (see **Section 5.1.5**).
- This simulation predicted that implementation of the SPHC IMs would result in a greater than 50 percent reduction of the total mass of arsenic in groundwater downgradient of the former Smelter site (**Figure 6.12**; **Table 6.2b**). Based on these results, the model predicted that implementation of SPHC IMs would have the greatest reduction in downgradient arsenic concentrations compared to partial implementation of the SPHC IMs (bypass simulation) and the 2011 calibration.
- This simulation predicted that implementation of SPHC IMs would decrease the volume of groundwater with selenium concentrations above the MCL by 42 percent (**Figure 6.13**; **Table 6.3a**) and the mass of selenium by 39 percent (**Figure 6.13**; **Table 6.3b**) downgradient of the former Smelter site compared to the 2011 calibration.

6.1.3 Transient Flow and Transport (NewFields, 2016a)

NewFields (2016a) updated the models and used them to develop a transient flow field for predictive analysis to support continued evaluation of IMs, including SPHCs, construction of an ET cover system, and source removal in the Acid Plant and Tito Park areas. This setup allowed the model to more accurately predict change in concentration over time compared to results using a steady-state flow field (see **Section 6.1.2**) because it takes into account the time required for changes in groundwater flow to develop in response to IM implementation.

The following is a summary of key findings from this predictive analysis:

- This analysis predicted that implementation of the three IMs would improve groundwater quality for arsenic (**Figure 6.14**) and selenium (**Figure 6.15**) downgradient of the former Smelter site. The extent and volume of groundwater with arsenic concentrations above the MCL were not predicted to be affected greatly by IMs; however, the total mass of arsenic was predicted to decrease from the 2011 calibration. The extent of the downgradient selenium plume and volume of groundwater with concentrations above the selenium MCL were predicted to decrease because of IM implementation.
- Implementation of IMs were predicted to reduce the total mass of arsenic in groundwater (**Figure 6.16**; **Table 6.4b**) but not greatly change the total volume of groundwater with arsenic concentrations above the MCL (**Figure 6.16**; **Table 6.4a**). These simulations predicted that IM implementation would result in a 66 percent decrease in the amount of arsenic moving across the former Smelter site boundary compared to the 2011 calibration (**Figure 6.17**; **Table 6.4c**).
- These simulations predicted that implementation of IMs would decrease the volume of groundwater above the selenium MCL by 82 percent (**Figure 6.18**; **Table 6.5a**) and increase the mass of selenium by 42 percent (**Figure 6.18**; **Table 6.5b**) downgradient of the former Smelter site compared to the 2011 calibration. Predicted increases in the mass of selenium in groundwater are a result of assumptions used to simulate selenium. It was assumed that selenium behaves conservatively (i.e., selenium is not adsorbed or precipitated), with the exception of precipitation used to simulate a low redox area in the Speiss-Dross and North Plant Site areas. Thus, selenium is not removed from the model until it reaches the northern extent of the model domain near Lake Helena. Consequently, mass is continually added to the model domain through source areas but is not removed from the model, which causes predicted increases in total mass of selenium dissolved in groundwater. It is important to note that while the total mass of selenium in groundwater is predicted to increase, the volume of groundwater with selenium concentrations above the MCL is predicted to decrease.
- Selenium mass flux in groundwater across the former Smelter site boundary was predicted to decrease by 68 percent after IM implementation (**Figure 6.19**; **Table 6.5c**).

6.2 Tier II Evaluation

Two phases of predictive analyses were completed to support evaluation of proposed Tier II source control measures. The following subsections summarize the methods and results of these predictive phases of modeling.

6.2.1 Steady-State Flow and Transient Transport (NewFields, 2015b)

NewFields (2015b) developed predictive simulations to support evaluation of proposed Tier II source control measures, including source removal, a PRB, slurry walls, and focused pump and treat. For the first Tier II evaluation phase, the predictive simulation of SPHCs IMs (see **Section 6.1.2**) was used as the basis for predictive Tier II source control simulations (source removal and ET cap IMs were included in the second phase).

The following is a summary of key findings from this predictive analysis:

- The model predicted that construction of a PRB downgradient of the North Plant Site arsenic source would not result in a substantial decrease in the extent of the arsenic plume (**Figure 6.20**). However, predicted concentrations within the plume downgradient of the site are lower for the three predictive simulations. Note, a half-life of 0.001 days was assigned to the PRB to simulate 100 percent arsenic removal. To evaluate a range of potential effectiveness, additional simulations were run using half-lives of approximately 6.6 and 3.8 days to simulate 43 and 55 percent arsenic mass removal, respectively. Half-lives were determined based on estimated residence time in the PRB from the groundwater flow model. All other arsenic transport inputs remained consistent with the IM realignment simulation.

  The volume of groundwater containing arsenic above the MCL was predicted to increase between 2 and 3 percent after implementation of the PRB compared to the SPHC IM simulation (**Figure 6.21**; **Table 6.6a**). The predicted increase in volume of groundwater above the MCL is likely the result of small increases in saturated thickness behind the PRB. The total mass of arsenic in groundwater was predicted to decrease between 15 and 37 percent relative to the SPHC IM simulation depending on PRB effectiveness (**Figure 6.21**; **Table 6.6b**). The mass of arsenic in groundwater downgradient of the former Smelter site was predicted to decrease between 26 and 58 percent compared to the SPHC IM simulation.

- A slurry wall encompassing the North Plant Site arsenic source area was predicted to have little effect on the overall extent of the arsenic plume (**Figure 6.22**). However, similar to the PRB simulations, the model predicted that construction of a slurry wall would result in decreased concentrations within the plume. The model predicted that slurry wall construction would result in a 3 percent increase in the volume of groundwater above the MCL compared to the IM implementation alone, which is likely related to changes in saturated thickness around the slurry wall (**Figure 6.21**; **Table 6.6a**). Similar to the PRB simulations, the model predicted that high concentration zones in the North Plant Site area would shrink and the total mass of arsenic in groundwater would decrease between 40 and 47 percent after implementation of the slurry wall compared to the SPHC IM simulation (**Figure 6.21**; **Table 6.6b**). The mass of arsenic in groundwater downgradient of the former Smelter site was predicted to decrease between 43 and 53 percent compared to SPHC IM implementation alone.

- The model predicted that a slurry wall would cause groundwater elevations to increase south and southeast of the wall up to 3 feet, with the largest increases occurring directly upgradient of the wall (**Figure 6.23**). Directly downgradient of the wall groundwater elevations would decrease by up to 0.75 feet. Particle tracking indicates that the direction of groundwater flow would shift to the west, towards the West Selenium Area source after construction of a slurry wall in the North Plant Site area (**Figure 6.24**).

- The model predicted that removal of saturated source material would result in a reduction of the downgradient extent of the selenium plume and selenium concentrations at individual monitoring wells. **Figure 6.25** compares predicted plumes for the SPHC IM and West Selenium Area source removal simulations with concentrations at individual wells. Source removal was predicted to reduce the total volume of groundwater with selenium concentrations above the MCL between 33 and 75 percent (**Figure 6.26**; **Table 6.7a**) and the total mass of selenium in groundwater between 24 and 55 percent (**Figure 6.26**; **Table 6.7b**). Downgradient of the former

Smelter site, the volume of groundwater above the MCL is predicted to decrease between 38 and 84 percent (**Figure 6.26**; **Table 6.7a**) and the mass of selenium is predicted to decrease between 37 and 54 percent (**Figure 6.26**; **Table 6.7b**) compared to SPHC IM implementation alone.

- Similar to source removal simulations, implementation of a PRB downgradient of the West Selenium Area is predicted to reduce the downgradient extent of the selenium plume, the volume of groundwater above the MCL, and the total mass of selenium in groundwater. **Figure 6.27** shows predicted changes in plume geometry and concentrations at individual wells after PRB implementation. As PRB effectiveness increases, the extent of downgradient selenium contamination is reduced. In addition, the total volume of groundwater above the MCL is predicted to decrease between 58 and 74 percent (**Figure 6.26**; **Table 6.7a**) and the total mass of selenium in groundwater is predicted to decrease between 35 and 52 percent depending on PRB effectiveness (**Figure 6.26**; **Table 6.7b**). The volume of groundwater above the MCL downgradient of the former Smelter site is predicted to decrease between 66 and 84 percent (**Figure 6.26**; **Table 6.7a**) and the mass of selenium downgradient of the former Smelter site is predicted to decrease between 37 and 54 percent (**Figure 6.26**; **Table 6.7b**) compared to SPHC IM implementation alone.
- **Figure 6.28** shows predicted plume geometry and concentrations at individual wells for West Selenium Area slurry wall simulations. Implementation of the slurry wall reduces the downgradient extent of the selenium plume. The volume of groundwater with selenium concentrations above the MCL is predicted to be reduced between 38 and 74 percent (**Figure 6.26**; **Table 6.7a**) and the total mass of selenium in groundwater is predicted to be reduced between 18 and 44 percent depending on slurry wall permeability (**Figure 6.26**; **Table 6.7b**). Downgradient of the former Smelter site, the volume of groundwater above the MCL is predicted to decrease between 43 and 84 percent (**Figure 6.26**; **Table 6.7a**) and the mass of selenium in groundwater is predicted to decrease between 19 and 45 percent (**Figure 6.26**; **Table 6.7b**) compared to SPHC IM implementation alone.
- Groundwater elevations are predicted to increase south and southwest of the West Selenium Area slurry wall by up to 2.36 feet, with the largest increases occurring directly upgradient of the slurry wall (**Figure 6.29**). Downgradient of the slurry wall, groundwater elevations are predicted to change less than 0.5 feet. Implementation of the slurry wall results in a westward shift in groundwater flow directions around the slurry wall (**Figure 6.30**).
- Focused pump and treat was evaluated using pumping rates ranging from 11.5 to 14.5 gallons per minute (gpm) per well for the West Selenium Area (**Figure 6.31**). Plume geometry and volume of groundwater above the MCL do not vary appreciably for the three simulations. The model predicted that focused pump and treat downgradient of the West Selenium Area would reduce the total volume of groundwater above the MCL between 74 and 79 percent (**Figure 6.26**; **Table 6.7a**) and the total mass of selenium in groundwater between 38 and 56 percent (**Figure 6.26**; **Table 6.7b**). The volume of groundwater above the MCL downgradient of the former Smelter site is predicted to decrease between 85 and 89 percent (**Figure 6.26**; **Table 6.7a**) and the mass of selenium is predicted to decrease between 40 and 58 percent (**Figure 6.26**; **Table 6.7b**).

6.2.2 Transient Flow and Transport (NewFields, 2016a)

NewFields (2016a) used the updated models to develop predictive simulations supporting the second phase of evaluation for additional Tier II source control measures including source removal in the Acid Plant, North Plant Site arsenic area, and West Selenium Area. In addition, a simulation was developed to evaluate a decreasing source term in the West Selenium Area.

As discussed in **Section 6.1.3**, NewFields (2016a) developed a transient groundwater flow model for predictive simulations. The transient flow simulation allows for gradual implementation of source control measures, and more accurately predicts the time it may take for concentrations in groundwater to change because of source control measures.

The following is a summary of key findings from this predictive analysis:

- **Figures 6.32** and **6.33** show simulated plumes for the Acid Plant and North Plant Site removal simulations, respectively. Results show that additional source control measures would have little additional effect on the plume extent compared to IM implementation (see **Section 6.1.3**).
- Implementation of additional source control measures including removal of the Acid Plant and North Plant Site Arsenic areas did not greatly reduce the volume of groundwater with arsenic concentrations above the MCL. However, 70 percent removal of the North Plant Site Arsenic area is predicted to decrease the arsenic mass flux by an additional 17 percent compared to IM implementation alone.
- **Figure 6.34** and **Tables 6.8a** and **6.8b** present predicted changes in the volume of groundwater above the arsenic MCL and total mass of arsenic in groundwater for the 2011 and 2014 calibration, and the predictive simulations. The model predicted that implementation of the IMs would result in a greater than 50 percent reduction of the total mass of arsenic in groundwater downgradient of the former Smelter site. **Figure 6.34** illustrates that the volume of groundwater above the MCL does not change appreciably with implementation of additional source control measures.
- **Figure 6.35** and **Table 6.8c** present predicted changes in the mass flux of arsenic in groundwater across the former Smelter site boundary for the 2011 and 2014 calibration, and the predictive simulations. Removing 70 percent of the North Plant Site Arsenic area would result in an additional 17 percent reduction in mass flux beyond the IM implementation reductions alone.
- **Figures 6.36** and **6.37** show predicted results for the West Selenium Area declining source and West Selenium Area source removal simulations, respectively. Both simulations show that there is little additional effect on the extent of the downgradient selenium plume compared to IM implementation (see **Section 6.2.3**).
- **Figure 6.38** and **Tables 6.9a** and **6.9b** present predicted changes in the volume of groundwater above the selenium MCL and total mass of selenium in groundwater for the 2011 and 2014 calibration, and source control predictive simulations. The total volume of groundwater with selenium above the MCL is predicted to decrease by approximately 82 percent and the total mass of selenium dissolved in groundwater is predicted to increase by approximately 42 percent

as a result of removing the West Selenium Area source. Similar to results discussed in **Section 6.1.3**, the increase in mass is a result of assumptions used to simulate selenium. It was assumed that selenium behaves conservatively (i.e., selenium is not adsorbed or precipitated), with the exception of precipitation used to simulate a low redox area in the Speiss-Dross and North Plant Site areas. Thus, selenium is not removed from the model until it reaches the northern extent of the model domain near Lake Helena. Consequently, mass is continually added to the model domain through source areas but is not removed from the model, which causes predicted increases in total mass of selenium dissolved in groundwater. It is important to note that while the total mass of selenium in groundwater is predicted to increase, the volume of groundwater with selenium concentrations above the MCL is predicted to decrease.

- The mass flux of selenium in groundwater across the former Smelter site boundary is predicted to decrease by approximately 69 percent (**Figure 6.39**; **Table 5.2c**) compared to the 2011 calibration.
- The volume of groundwater above the selenium MCL is predicted to decrease by approximately 82 percent (**Figure 6.38**; **Table 6.9a**) and the total mass of selenium dissolved in groundwater is predicted in increase by approximately 41 percent (**Figure 6.38**; **Table 6.9b**) for the declining source in the West Selenium Area simulation compared to the 2011 calibration. Mass flux of selenium across the former Smelter site boundary is predicted to decrease by approximately 68 percent compared to the 2011 calibration, but only 1 percent compared to IM implementation (**Figure 6.39**; **Table 6.9c**).

6.3 Controlled Groundwater Area

NewFields (2014c) developed three steady-state groundwater flow simulations and a transient predictive simulation to support application of a Controlled Groundwater Area. The following is a summary of key findings from this predictive analysis:

- Model results indicated that most groundwater in wells west of the former Smelter site originates from Tertiary foothills southwest and west of the former Smelter site and not from contaminant source areas at the former Smelter site (**Figures 6.40** through **6.42**).
- Model results suggested that concentrations of selenium in groundwater originating from the former Smelter site may decrease below approximately 180 feet below ground surface north of Lamping Field. Particle tracks used to evaluate groundwater flow directions are present in Layers 2 and 3 of the model with most particle tracks in Layer 3 (**Figures 6.43** through **6.45**) and there are no particle tracks in Layers 1, 4, 5, and 6. Results from the 2011 and 2013 simulations were similar, suggesting leakage from Wilson Ditch did not have an appreciable effect on vertical plume migration.
- Model results used to evaluate the effects of Wilson Ditch showed that groundwater flow paths in the 2013 simulation are shifted about 500 feet west compared to those from the 2011 simulation, when Wilson Ditch was not operating (**Figure 6.46**). These results were consistent with observed changes in concentration in wells in the Lamping Field area, and indicated that buffer zones considered for the Controlled Groundwater Area should be large enough to

encompass this westward shift in groundwater flow/contaminants. In addition, results indicated that groundwater flow paths northwest of the former Smelter site in Lamping Field shift to the west approximately 800 to 900 feet. Further north, near Prickly Pear Creek, groundwater flow paths shift to the west approximately 1,500 feet (**Figure 6.46**).

- Model results were used to delineate a buffer zone around the existing extent of the selenium plume such that any new wells (domestic or production) would not impact the plume. **Figures 6.47** and **6.48** show the placement of hypothetical domestic and productions wells, respectively, resulting from this analysis. These results suggested that new domestic wells should be installed at least 250 feet away from the estimated extent of the selenium plume in the upgradient direction of groundwater flow and 500 feet away in the downgradient direction. New production wells should be installed at least 700 feet away from the extent of the selenium plume. **Figures 6.49** and **6.50** show recommended buffer zones for domestic and production wells, respectively. Based on results of the analysis, if a new well is completed within the buffer zones, it may be impacted by the selenium or arsenic plumes; if a new well is completed outside of the buffer zones, it likely will not be impacted by the plumes.

6.4 Slag Pile

NewFields (2016b) used the updated groundwater flow model and selenium contaminant transport model to evaluate proposed regrading and capping designs for the Slag Pile. Simulated selenium concentrations from the 10 percent recharge simulation described in **Section 7.4** were used to evaluate a minimum, intermediate, and maximum regrading and capping design developed by CH2M HILL for the Slag Pile.

Figure 6.51 shows simulated isoconcentration contours for the updated 2014 calibration and the 10 percent Slag Pile recharge simulation. The model predicted that reducing recharge in the Slag Pile from the model estimated rate of 50 percent of annual precipitation to 10 percent would eliminate selenium concentrations in groundwater above the MCL downgradient of the Slag Pile.

Hydrometrics used results from the target 10 percent recharge simulation to calculate expected changes in selenium concentrations in groundwater at wells downgradient of the former Smelter site for the regrading and capping alternatives. The results from the 10 percent recharge simulation were adjusted based on the estimated distribution of selenium concentrations in the fumed versus unfumed slag, the proposed regrading plans, and the estimated cover areas and effectiveness of proposed soil and ET caps on the Slag Pile.

Figure 6.52 shows estimated changes in selenium concentrations in groundwater based on the 10 percent recharge simulation and Hydrometrics calculations. The minimum and intermediate regrading and capping alternatives were predicted to reduce selenium concentrations in groundwater in the Slag Pile by approximately 73 percent and 76 percent, respectively. The maximum regrading and capping alternative was estimated to reduce selenium concentrations in groundwater by approximately 94 percent. Further downgradient of the Slag Pile, the estimated reduction in selenium concentrations in groundwater was less than estimated for the Slag Pile (due to other sources) although concentrations are predicted to decrease between approximately 35 and 58 percent. Estimated reductions in selenium

concentrations decrease downgradient of the Slag Pile because of increased influence from selenium coming from the West Selenium Area source.

6.5 Prickly Pear Creek

The calibrated groundwater flow and advective transport models were used to evaluate potential changes to groundwater flow directions if Prickly Pear Creek returned to pre-instream leasing program flow conditions.

Figure 6.53 presents particle tracking results for the 2014 calibrated simulation and the Prickly Pear Creek predictive simulation. Results indicated that there would be no appreciable effect on groundwater flow directions if Prickly Pear Creek returned to pre-instream leasing flow conditions and went dry downgradient of the second irrigation ditch. Results showed that there is a slight shift to the west in groundwater flow directions for the Prickly Pear Creek predictive simulation as compared to the 2014 calibration north of the Helena Valley Irrigation Canal.

Table 6.10 presents predicted groundwater elevations in monitoring wells near Prickly Pear Creek between the two irrigation ditches for the 2014 calibration and the Prickly Pear Creek predictive simulation. Model results show that reducing flow in Prickly Pear Creek between the two irrigation ditches would reduce groundwater elevations between approximately 7 and 15 feet in the adjacent aquifer.

Table 6.11 presents predicted groundwater elevations in monitoring wells near Prickly Pear Creek between the two irrigation ditches for the IM predictive simulation and the Prickly Pear Creek predictive simulation. Model results show that Prickly Pear Creek returning to pre-instream leasing flow conditions would reduce groundwater elevations between approximately 4 and 20 feet for the monitoring wells presented in **Table 6.11**.

7.0 SENSITIVITY ANALYSES

A degree of uncertainty is inherent to any modeling effort. The purpose of sensitivity analysis is to quantify uncertainty in model simulations caused by uncertainty in estimates of model parameters (Anderson et al., 2015). During sensitivity analysis, model input parameters are systematically changed one at a time within reasonable ranges to determine the effect on model results of changing model input parameters.

The following subsections describe the results of four phases of sensitivity analyses that were performed on the calibrated and predictive contaminant transport models.

7.1 PHASE 1 (NEWFIELDS, 2015A)

NewFields (2015a) performed a sensitivity analysis on the calibrated contaminant transport model by systematically adjusting effective porosity, mass loading rates, selenium sorption, and the lateral distribution of saturated source terms. The following list summarizes key results from this analysis:

- Effective porosity values were increased and decreased by 50 percent. **Figures 7.1** and **7.2** show changes in plume geometry for arsenic and selenium, respectively. Changes in effective porosity result in nearly identical arsenic plume geometry (**Figure 7.1**). For selenium simulations, reducing effective porosity slightly increased the downgradient extent of the 0.05 mg/L isoconcentration contour and the distance downgradient where the east and west lobes of the selenium plume merge (**Figure 7.2**).
- Saturated arsenic and selenium mass loading rates were increased and decreased by 50 percent. In addition, a simulation was run with the West Selenium Area mass loading rate adjusted to reflect a mass loading rate that was estimated using analytic methods. **Figures 7.3** and **7.4** show changes in plume geometry for arsenic and selenium, respectively. Adjusting mass loading rates did not significantly affect the downgradient extent of the arsenic plume; however, changing the mass loading rate did affect on-site plume geometry and concentrations within the plume (**Figure 7.3**). The downgradient extent of the selenium plume is sensitive to the mass loading rate. As mass loading rates are increased, the downgradient extent of the selenium plume increases (**Figure 7.4**).
- Although the conceptual model assumes sorption of selenium to aquifer material will not occur in areas with oxidizing conditions, a simulation was performed to evaluate sensitivity of model results to this assumption. Factors including a distribution coefficient (K_d) and bulk density described in NewFields (2015b), along with porosity were used in the model that resulted in a retardation factors ranging from 39 to 62, which were used for this sensitivity analysis. Results of this simulation indicated that adsorption of selenium at the estimated levels would significantly reduce the downgradient extent of the plume and concentrations within the plume (**Figure 7.5**). This simulation supports the assumption that little or no sorption of selenium occurs in oxidized portions of the aquifer downgradient of the former Smelter site.
- Sensitivity of the distribution and lateral extent of saturated source areas was evaluated by adjusting the location and size of boundary conditions representing the West Selenium Area and

North Plant Site sources. In general, the overall extent of the arsenic plume was not sensitive to the location or size of the North Plant Site source area (**Figure 7.6**) and most simulated concentrations at individual wells were close to observed concentrations. Results suggested that the model calibration was sensitive to the location of the West Selenium Area source (**Figure 7.7**). However, adjusting the source area did not produce plume geometries and concentrations at individual wells that reasonably matched observed geometries and concentrations for selenium.

7.2 PHASE 2 (NEWFIELDS, 2015B)

NewFields (2015b) performed a sensitivity analysis on the calibrated contaminant transport model and predictive simulations by adjusting Prickly Pear Creek bypass and realignment streambed conductance, unsaturated source terms, effective porosity, and arsenic attenuation parameters. The following list summarizes key results from this analysis:

- Streambed conductance was increased and decreased 50 percent by adjusting hydraulic conductivity. In general, predicted transport of arsenic and selenium is not sensitive to changes in conductance for the bypass or realignment.
    - **Figures 7.8** and **7.9** show predicted arsenic plume geometry for the bypass and realignment simulations, respectively. The overall extent of the arsenic plume did not vary significantly with changes to streambed conductance. In addition, the volume of groundwater above the arsenic MCL and the total mass of arsenic in groundwater changed less than 5 percent as a result of the sensitivity analysis (**Tables 7.1a** and **7.1b**).
    - **Figures 7.10** and **7.11** show predicted selenium plume geometry for the bypass and realignment simulations, respectively. There was no appreciable difference in plume geometry because of adjusting bypass or realignment conductance. In addition, the volume of groundwater above the selenium MCL and the total mass of selenium in groundwater changed less than 5 percent (**Tables 7.2a** and **7.2b**).
- The IM realignment predictive simulation was used to evaluate sensitivity of model predictions to unsaturated selenium source terms. **Figure 7.12** shows changes in plume geometry for the unsaturated source sensitivity simulations. Increasing unsaturated source concentrations increased concentrations in groundwater in the Slag Pile area but had little effect on concentrations in the West Selenium Area and downgradient of the former Smelter site. The volume of groundwater above the selenium MCL and the total mass of selenium in groundwater increased for both sensitivity simulations (**Tables 7.2a** and **7.2b**).
- Temporal sensitivity of effective porosity was evaluated by increasing and decreasing effective porosity by 50 percent. **Figure 7.13** shows predicted changes in arsenic and selenium concentrations for wells downgradient of the former Smelter site. In general, as effective porosity is increased, the time it takes to reach equilibrium concentrations increases.
- The sensitivity of arsenic concentrations to retardation and decay coefficients used to simulate sorption and precipitation, respectively, was evaluated. Decay coefficients were replaced with retardation coefficients to test key assumptions in the model. **Figure 7.14** shows results of the

attenuation sensitivity simulation. The downgradient extent of the arsenic plume increases by approximately 350 feet and the lateral extent increases by approximately 100 feet. These results suggest that the arsenic plume could migrate further downgradient if the primary attenuation factor is sorption instead of precipitation, although movement would be relatively slow compared to selenium transport.

7.3 Phase 3 (NewFields, 2016a)

NewFields (2016a) used the predictive contaminant transport model to evaluate uncertainty in retardation parameters used to simulate adsorption of arsenic in groundwater. The parameters evaluated included the Langmuir coefficient and the adsorption capacity.

In general, predicted transport of arsenic was not sensitive to changes in retardation parameters within the range of empirically determined values. **Figure 7.15** shows predicted arsenic plume geometry for the Acid Plant removal simulation and sensitivity simulations. There was no appreciable difference in arsenic plume geometry caused by adjusting retardation parameters, with the exception of the 0.01 and 0.1 mg/L isoconcentration contours north of the Slag Pile.

Changes in arsenic concentrations at wells downgradient of the North Plant Site Arsenic area were not sensitive to changes in retardation parameters with the exception of the arsenic concentration in well EH-111 with low retardation parameters. Decreasing the retardation parameters results in decreased seasonal variability of the arsenic concentration in this well (**Figure 7.15**).

The volume of groundwater above the arsenic MCL was predicted to increase by approximately 22 percent as a result of using low retardation parameters and was relatively unchanged using high retardation parameters (**Table 7.3a**). The increase in the volume of groundwater with arsenic above the MCL with low retardation parameters was a result of arsenic migrating further north from the Slag Pile. The total mass of arsenic in groundwater was not sensitive to changes in retardation parameters (**Table 7.3b**).

7.4 Phase 4 (NewFields, 2016b)

NewFields (2016b) used the calibrated 2014 groundwater flow model and the selenium contaminant transport model to evaluate the uncertainty in simulated recharge from precipitation and snowmelt on the Slag Pile. The calibrated recharge rate for the Slag Pile was 50 percent of annual precipitation. This rate was adjusted to 10, 25, and 75 percent of annual precipitation for this sensitivity analysis.

Figure 7.16 shows simulated plume maps for the 2014 calibration and the sensitivity simulations. The downgradient extent of the selenium plume and selenium concentrations in the Slag Pile were predicted to decrease as recharge is decreased.

The volume of groundwater above the selenium MCL was predicted to increase by approximately 38 percent as a result of increasing the recharge rate in the Slag Pile (**Figure 7.17**; **Table 7.4a**). The volume of groundwater above the selenium MCL was predicted to decrease by approximately 79 and 56 percent

if recharge was reduced to 10 and 25 percent of annual precipitation, respectively (**Figure 7.17**; **Table 7.4a**).

The total mass flux of selenium across the former Smelter site boundary was predicted to decrease by 52 and 39 percent for the 10 and 25 percent recharge simulations, respectively, compared to the 2014 calibration (**Figure 7.18**; **Table 7.4b**). Increasing recharge to 75 percent of annual precipitation was predicted to increase mass flux across the former Smelter site boundary by approximately 3 percent compared to the 2014 calibration (**Figure 7.18**; **Table 7.4b**).

8.0 SUMMARY AND CONCLUSIONS

The groundwater flow and contaminant transport modeling summarized above met all modeling objectives established by AMEC (2012a) and Hydrometrics (2010; see **Section 1.2**). The initial modeling work plan (AMEC, 2012a) guided the general modeling effort, and the contaminant transport modeling work plans (NewFields, 2014b; NewFields, 2014e) guided the development of the contaminant transport models and contaminant transport predictive simulations.

The model was calibrated during each modeling phase to independent steady-state and transient data sets for groundwater flow and arsenic and selenium concentrations. Each phase of calibration demonstrated that the model was capable of reproducing field-measured groundwater elevations and arsenic and selenium concentrations, as well as estimated groundwater flux and arsenic and selenium plume geometries within pre-defined calibration criteria.

The calibrated models were appropriate for use in evaluating elements of the conceptual model and the potential effects of IMs and proposed source control measures on groundwater flow and contaminant transport in and downgradient of the former Smelter site. The calibrated models were used to develop predictive simulations used to support decision making related to IM implementation, application for a Controlled Groundwater Area, proposed source control measures, multiple site investigations, and site construction activities.

The following provides a summary of conclusions from each predictive modeling phase:

NewFields (2014a), Groundwater Flow Model Calibration Refinement, Transient Verification, and Interim Measures Support, East Helena Site:

The updated calibration demonstrated that the model was capable of reproducing groundwater elevations measured in the field and estimated fluxes within pre-defined calibration criteria. In addition, the model was capable of simulating the effects of long-term aquifer stresses in and around the former Smelter site.

The model predicted that implementation of IMs including removing Upper Lake, Lower Lake, and the Smelter Dam would result in a decrease in groundwater elevations, flux, and horizontal gradients at the former Smelter site. Reduction in groundwater flux through source areas should result in decreases in contaminant mass flux in groundwater as well as decreases in contaminant concentrations in groundwater.

NewFields (2014c), Advective Transport Modeling to Support Petition for a Controlled Groundwater Area Application, East Helena Site:

The groundwater flow model was used to support a petition for a Controlled Groundwater Area downgradient of the former Smelter site. Particle tracking techniques were used to evaluate flow paths from the former Smelter site and assist in delineation of buffer zones around the existing arsenic and selenium plumes that may be necessary to protect human health and the environment.

Key findings of the analysis are summarized below:

- Most groundwater intercepted by wells west of the former Smelter site originates from Tertiary material/bedrock southwest and west of the former Smelter site.
- The model predicted that selenium contamination is not present below approximately 180 feet below ground surface north of Lamping Field. This result reflected the current conceptual model upon which the numerical model is based.
- Model results suggested that the selenium plume may shift up to 500 feet to the west if Wilson Ditch is not operated in the future.
- New domestic wells should not be installed within 250 feet of the current extent of the selenium plume and new production wells should not be installed within 700 feet of the current extent of the selenium plume.

NewFields (2014d), Groundwater Flow Model and Predictive Simulation Update:

The model predicted that implementation of IMs including removing Upper Lake, Lower Lake, and the Smelter Dam would result in a decrease in groundwater elevations, flux, and horizontal gradients at the former Smelter site. Reduction in groundwater flux through source areas should result in decreases in contaminant mass flux in groundwater as well as decreases in contaminant concentrations in groundwater. These conclusions are similar to predictive modeling completed by NewFields (2014a) and generally consistent with field measurements taken after completion of the Prickly Pear Creek bypass.

NewFields (2015b), FINAL Predictive Fate and Transport Modeling, Interim Measures and Tier II Corrective Actions, East Helena Site:

The model predicted that the planned IMs and potential source control measures would improve groundwater quality for arsenic and selenium downgradient of the former Smelter site. The overall extent of groundwater with arsenic concentrations above the MCL was not predicted to be significantly affected by IMs or source control measures; however, the total mass of arsenic was predicted to decrease from baseline conditions in all predictive simulations. The downgradient extent of the selenium plume, volume of groundwater with concentrations above the selenium MCL, and the total mass of selenium in groundwater were predicted to decrease because of the IMs and source control measures. Differences in results for arsenic and selenium reflect differences in chemical behavior in groundwater.

NewFields (2016a) FINAL Groundwater Flow Model, Fate and Transport Model, and Predictive Fate and Transport Simulations Update, East Helena Site:

Predictive results indicated that complete implementation of the planned IMs would improve groundwater quality relative to arsenic and selenium downgradient of the former Smelter site. The overall extent of groundwater with arsenic concentrations above the MCL was not predicted to be affected to a major degree by IMs; however, the total mass of arsenic and the mass flux of arsenic across the former Smelter site boundary was predicted to decrease in all predictive simulations. The extent of the downgradient selenium plume, volume of groundwater with concentrations above the selenium MCL, and the mass flux of selenium across the former Smelter site boundary was predicted to decrease because of the IMs.

NewFields (2016b), Groundwater Modeling Slag Pile and Downgradient Modifications, East Helena:

Predictive results showed that reducing recharge in the Slag Pile from 50 percent of annual precipitation to 10 percent would eliminate selenium concentrations in groundwater above the MCL downgradient of the Slag Pile. The minimum and intermediate alternatives were predicted to reduce selenium concentrations in groundwater in the Slag Pile by approximately 73 percent and 76 percent, respectively. The maximum alternative was estimated to reduce selenium concentrations in groundwater by approximately 94 percent. Further downgradient of the Slag Pile, the estimated reduction in selenium concentrations in groundwater was less than estimated for the Slag Pile although concentrations are predicted to decrease between approximately 35 and 58 percent.

Prickly Pear Creek Analysis, East Helena Site:

Predictive results indicated that there would be no appreciable effect on groundwater flow directions if Prickly Pear Creek were to go dry downgradient of the second irrigation ditch. However, the model did predict that groundwater elevations would decrease between 7 and 15 feet compared to the 2014 calibration and between 4 and 20 feet compared to the IM predictive simulation if Prickly Pear Creek returned to historical flow conditions.

9.0 MODEL LIMITATIONS

Models are simplifications of complex systems, and in all modeling exercises, some model parameters are not well quantified due to a lack of data, which ultimately leads to uncertainty in model predictions. The primary objective of modeling completed for this project was to develop a numerical tool to support the CMS. This work included refining the conceptual model, supporting construction activities and petition for a Controlled Groundwater Area, as well as evaluating the impact of IM and Tier II source control measures.

Calibration results demonstrated that the model was capable of simulating groundwater flow within the model area under steady-state and transient conditions, and was capable of simulating fate and transport of arsenic and selenium within most of the model area under steady-state conditions. It should be noted that achieving calibration does not guarantee the set of input parameters selected is unique and that other plausible inputs would not achieve similar calibration results. However, calibration and verification to several independent sets of both steady-state and transient target data increases confidence in the model's capability to simulate groundwater flow under a variety of aquifer conditions.

The following provides a summary of model limitations for the work described in this report:

- The ability of the model to predict changes in groundwater flow and concentrations over short distances at the scale of tens of feet or less may be limited, especially in areas with complex flow dynamics and geochemistry.
- Groundwater elevation targets are concentrated in and around the former Smelter site, and scarcity of data outside this area leads to increasing model uncertainty. Where data were not available or insufficient to characterize variability in the system, conservative assumptions were made in developing model inputs based on literature values.
- Variability in concentrations over time and uncertainty in some aspects the conceptual model affect the ability of the model to predict steady-state concentrations at a few specific wells accurately. However, the model was still an appropriate tool for evaluating IMs and source control measures on a comparative basis.
- Lack of site-specific data related to transport parameters such as dispersivity, effective porosity, and decay creates some uncertainty in predictive results. Where data were not available or insufficient to characterize variability in the system, conservative assumptions were made to develop model inputs based on literature values.
- There is uncertainty associated with assumptions used for the development of predictive simulations including parameterization of the Prickly Pear Creek bypass and realignment, placement and parameterization of source control measures, and location and mass loading rates/concentrations of source terms. Where data were not available or insufficient to characterize these inputs, conservative assumptions were made to develop model inputs based on literature values.

The numerical model described above met all modeling objectives (see **Section 1.2**) and was an appropriate tool for predicting flow and contaminant transport in and downgradient of the former Smelter site at an intermediate scale. Model results are appropriate for comparative analysis of remedial measures. The model results supported refinement of the conceptual model, site construction activities, and petitioning for a Controlled Groundwater Area, as well as evaluating the impact of IM and Tier II source control measures.

10.0 REFERENCES

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FIGURES

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F1.1 Location Map.mxd

Source: NAIP, 2015; GSI, 2014

0 Feet 6,000

NewFields

- Fault
- Lamping Field
- Former Smelter Site Boundary
- Model Domain

Location Map
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 1.1

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\FI.2 Site Map.mxd

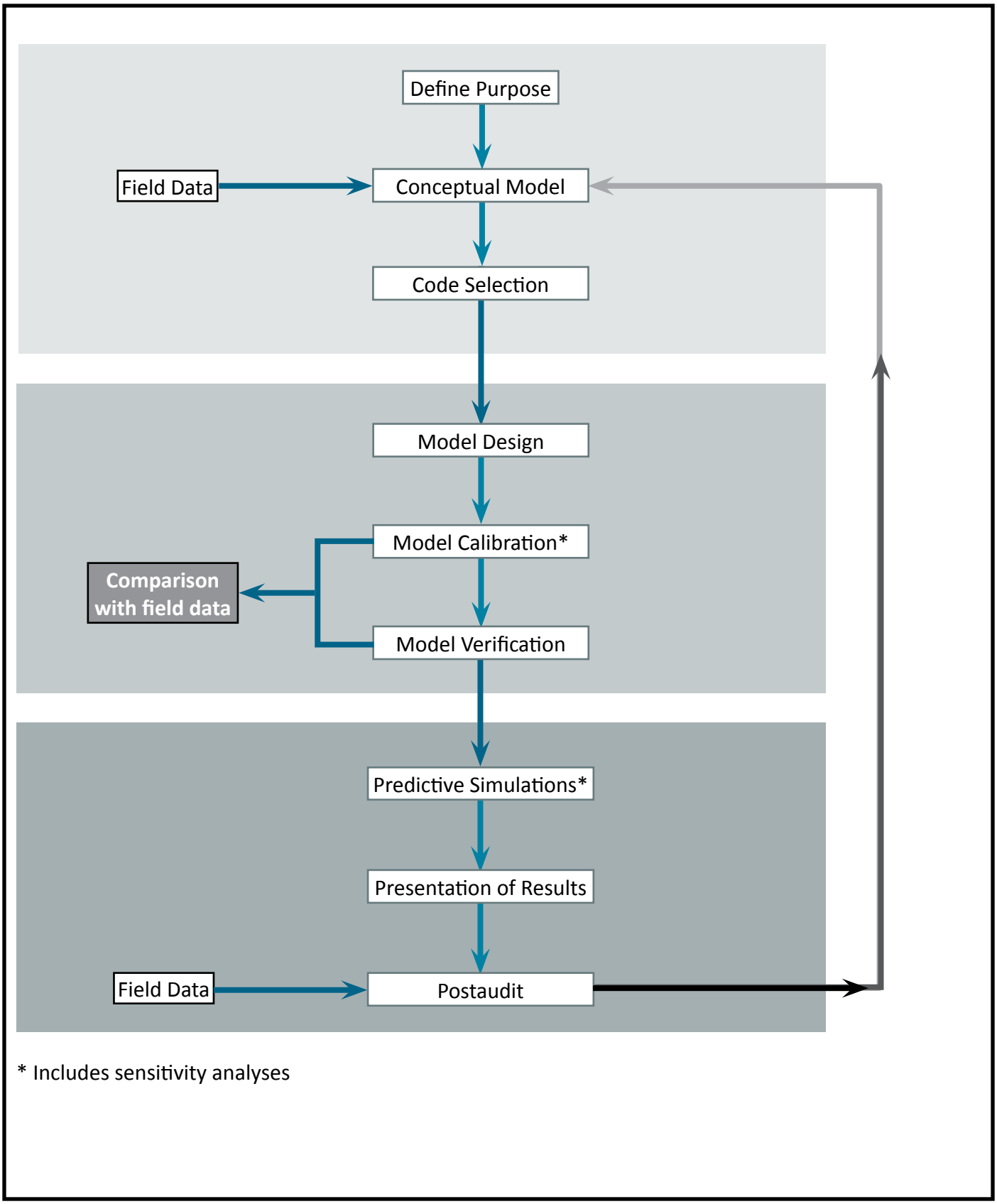
Source: NAIP, 2011; GSI, 2014

0 Feet 800

Former Smelter Site Boundary

NewFields

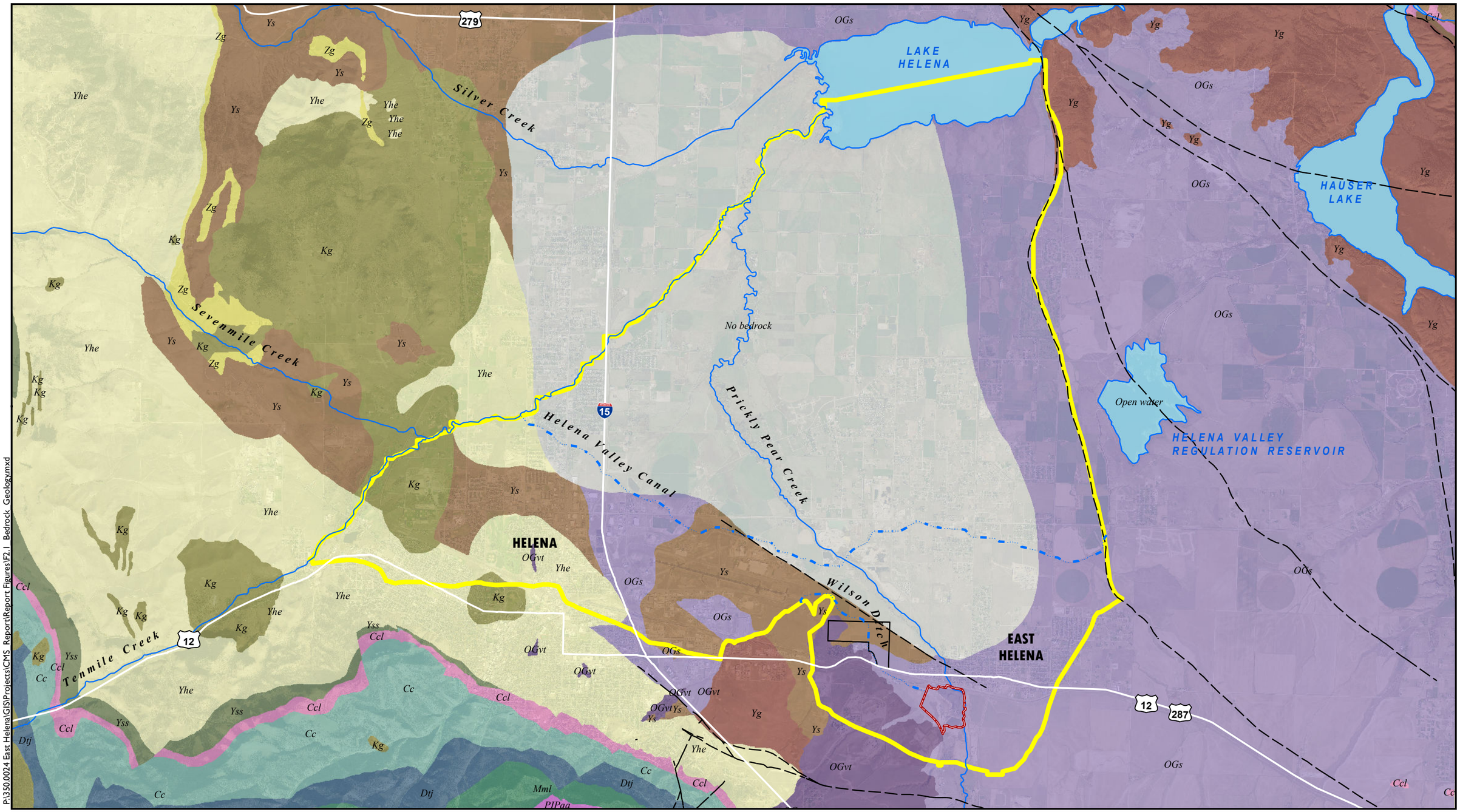
Former Smelter Site Features
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 1.2



* Includes sensitivity analyses

NewFields

General Modeling Process
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 1.3



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.1 Bedrock Geology.mxd

Source: NAIP, 2015; GSI, 2014

0 Feet 6,000

NewFields

Notes;
1) See Table 2.1 for description of geology.

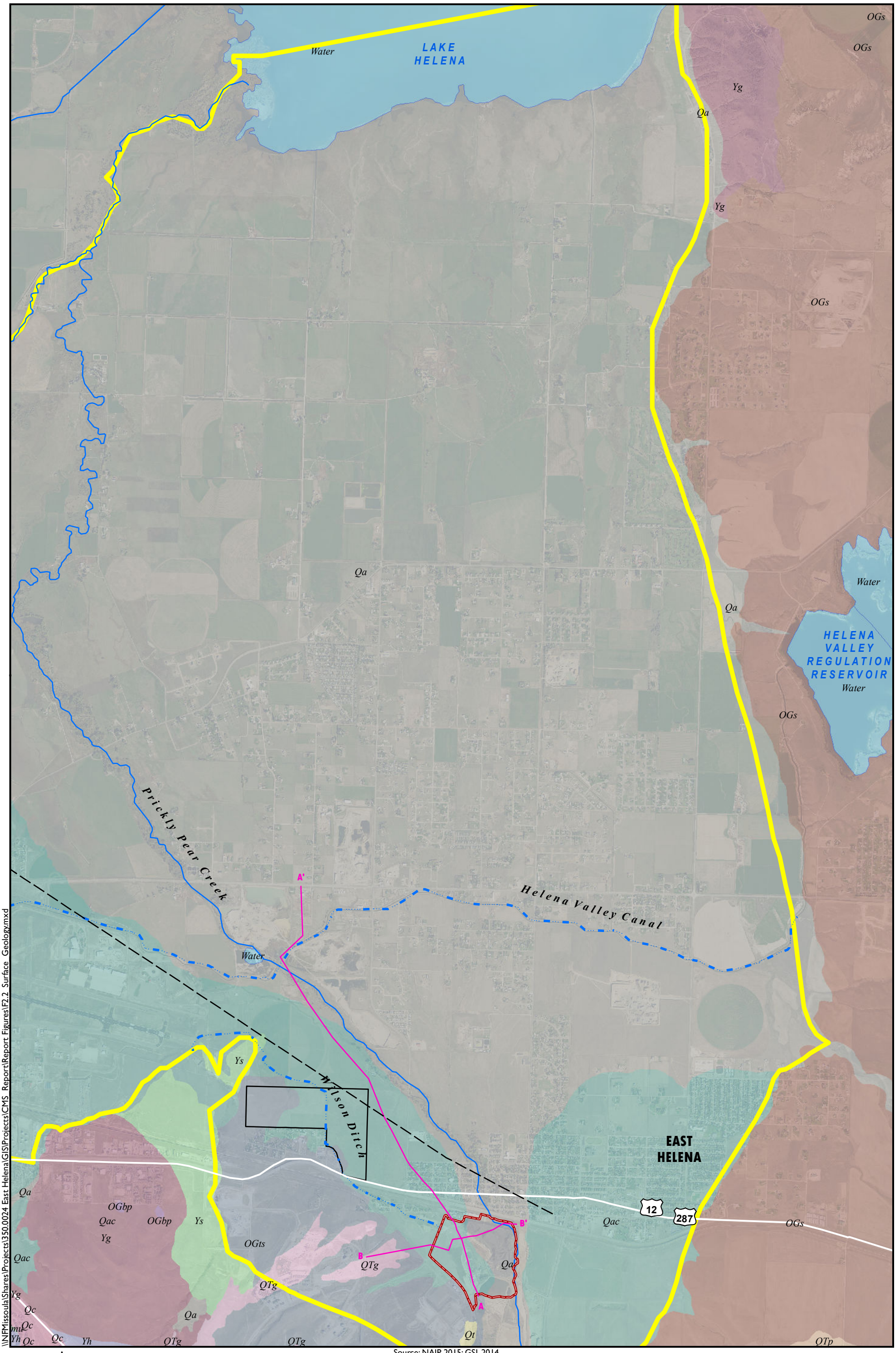
2) Geology Map Source:Thamke and Reynolds, 2000.

Fault
Former Smelter Site Boundary
Lamping Field
Model Domain

Geology

Cc, Ccl, Dtj, Jme, Kg, Mml, No bedrock, OGs, OGvt, Open water, PlPqa, Yg, Yhe, Ys, Yss, Zg

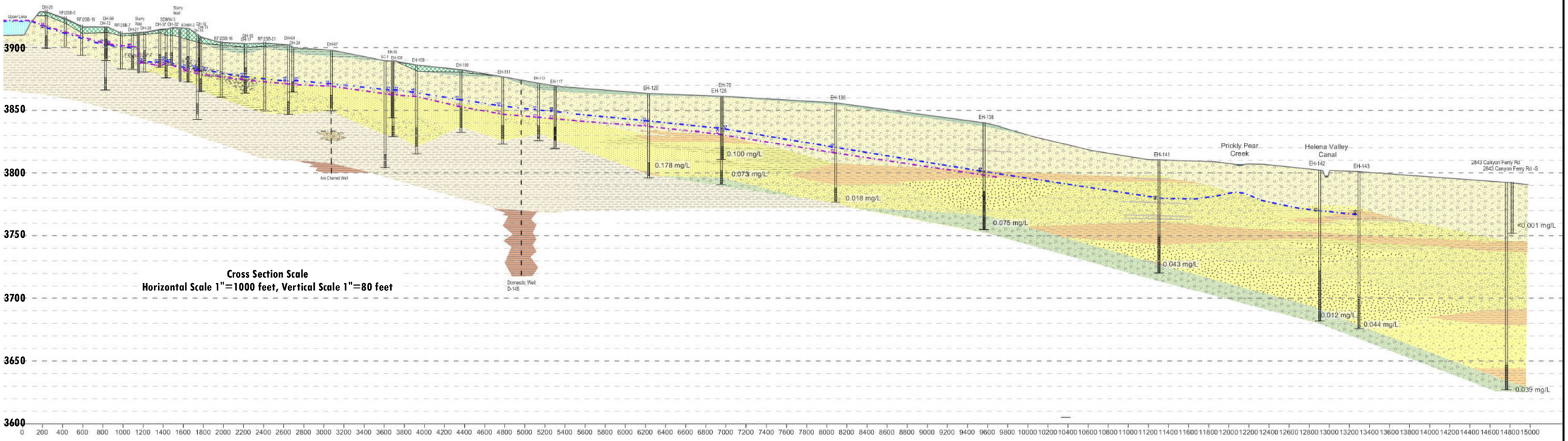
Bedrock Geology
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.1



Surface Geology
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.2

A

A'



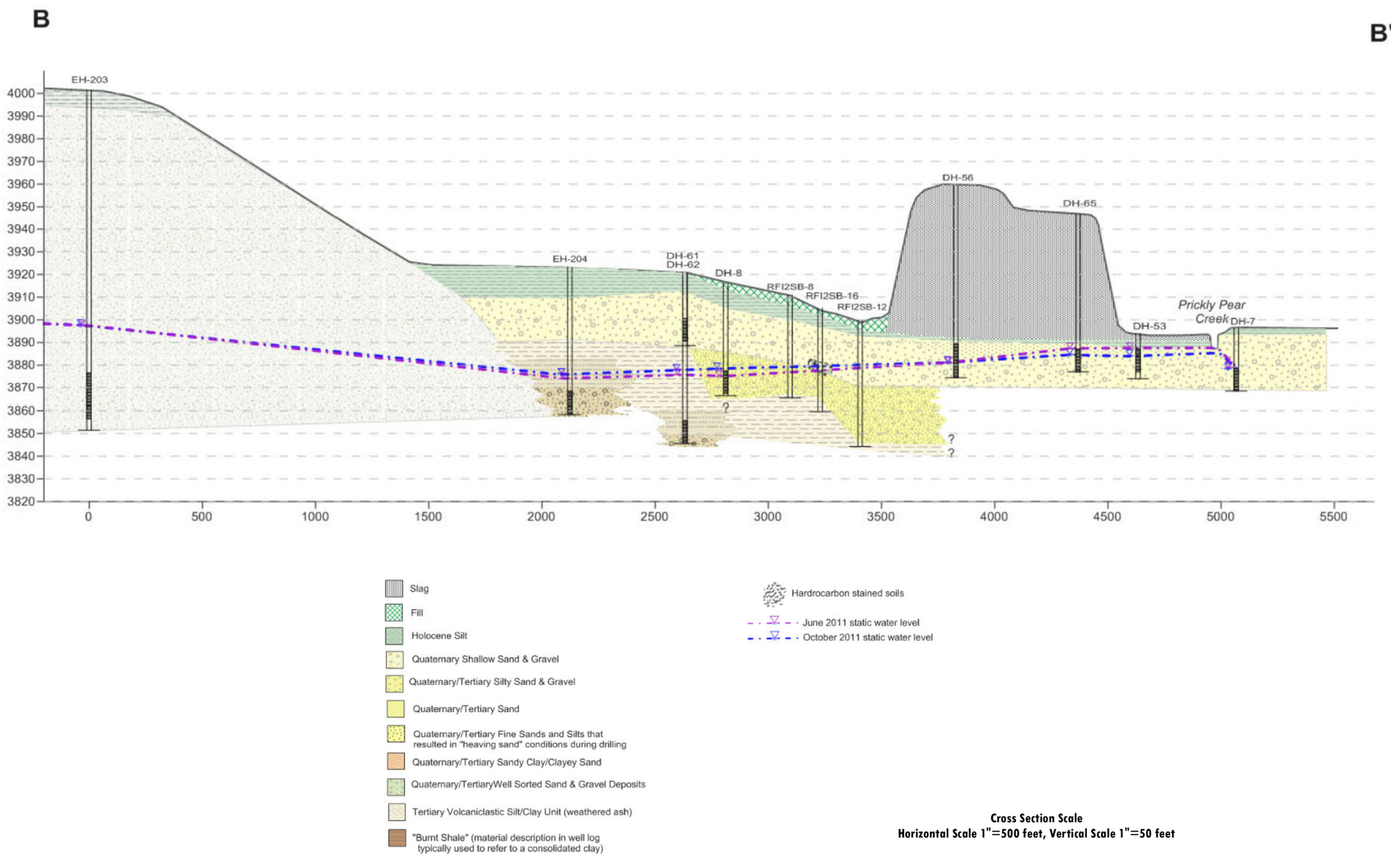
P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.3 Cross Section A.mxd

Source: Provided by Hydrometrics

Note: Location of cross-section shown on Figure 2.2.

NewFields

Cross Section A-A'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.3



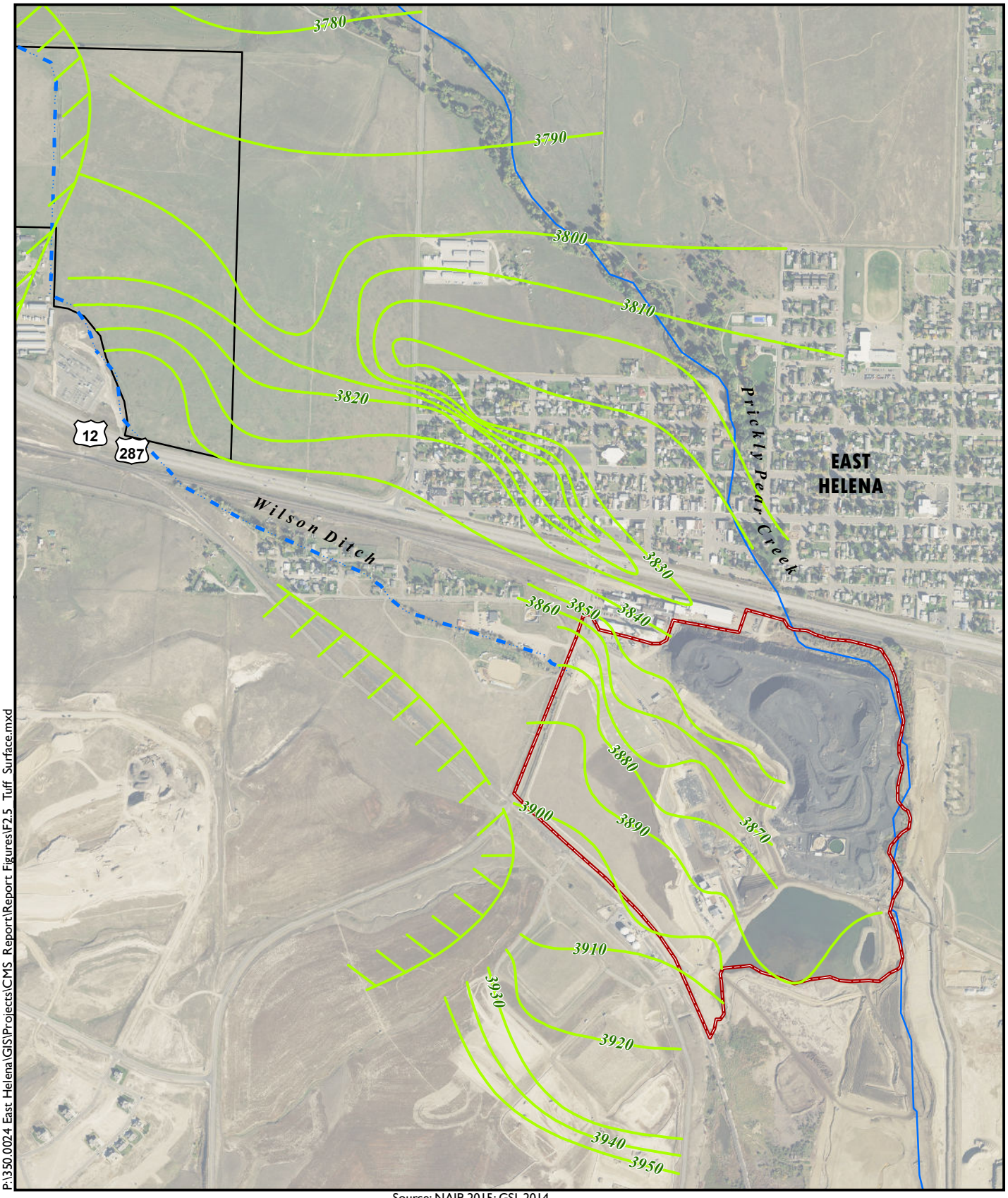
P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F2.4_Cross Section B.mxd

Source: Provided by Hydrometrics

Note: Location of cross-section shown on Figure 2.2.

NewFields

Cross Section B-B'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.4



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.5 Tuff Surface.mxd

Source: NAIP, 2015; GSI, 2014

Weathered Tuffaceous Sediment Elevation Contour (feet) (GSI, 2014)

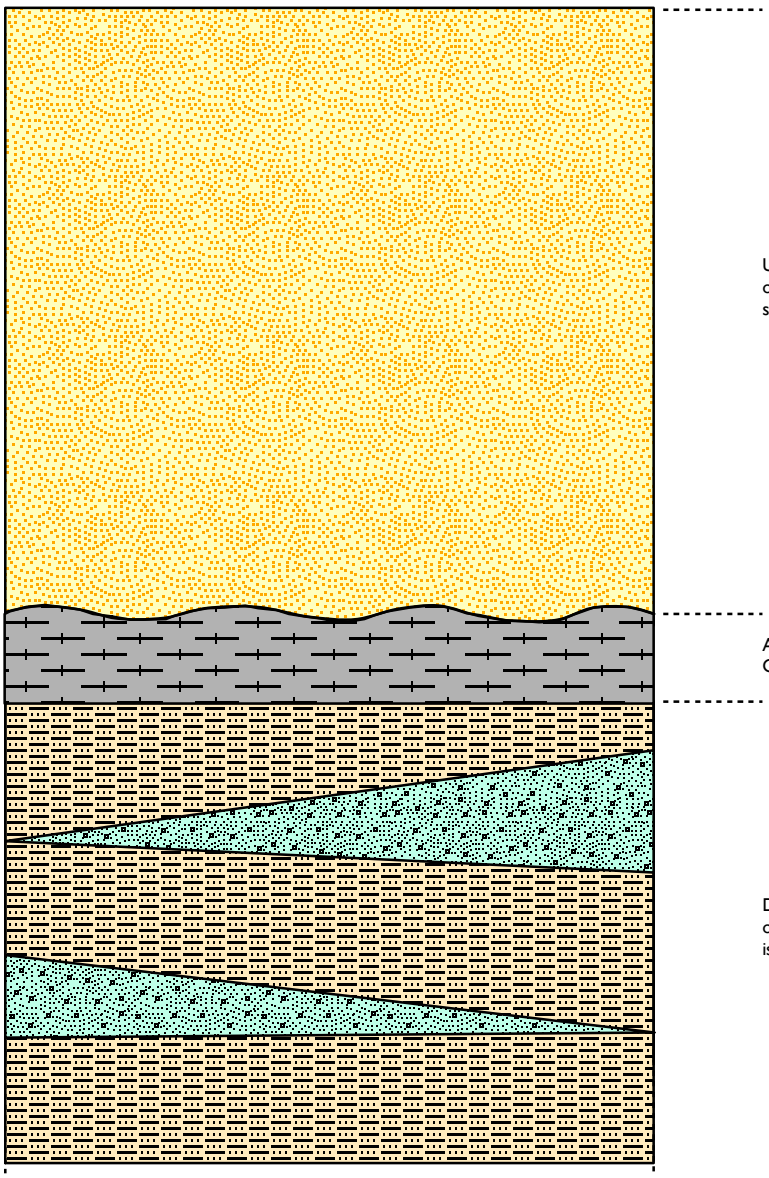
Former Smelter Site Boundary

Lamping Field

0 Feet 1,000

NewFields

Weathered Tuffaceous Sediment Surface
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.5



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.6 Hydrostratigraphic Column.mxd

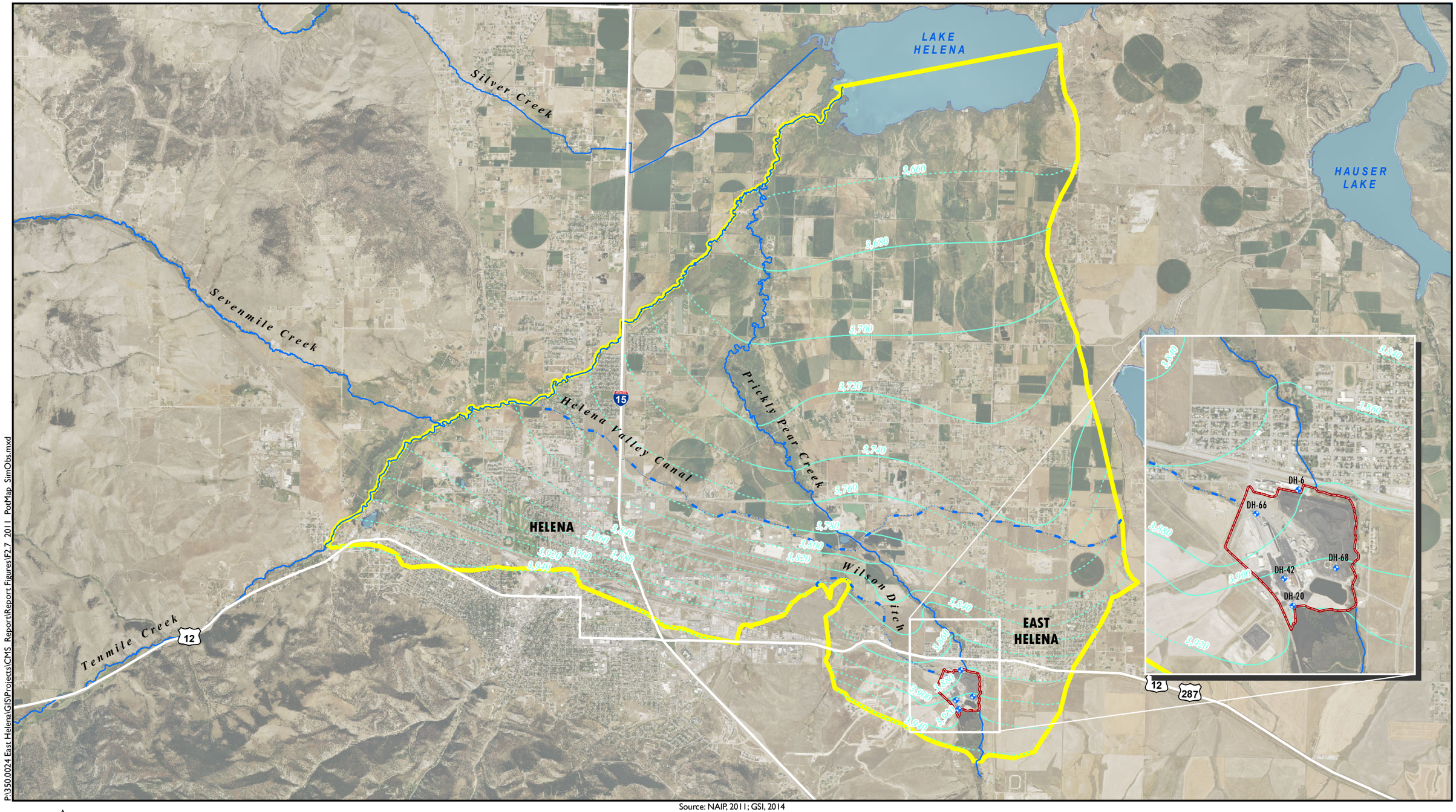
Upper Aquifer

Aquitard Unit

Deep Groundwater System

NewFields

Conceptual Hydrostratigraphic Column
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.6



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.7 2011 PotMap SimObs.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 6,000

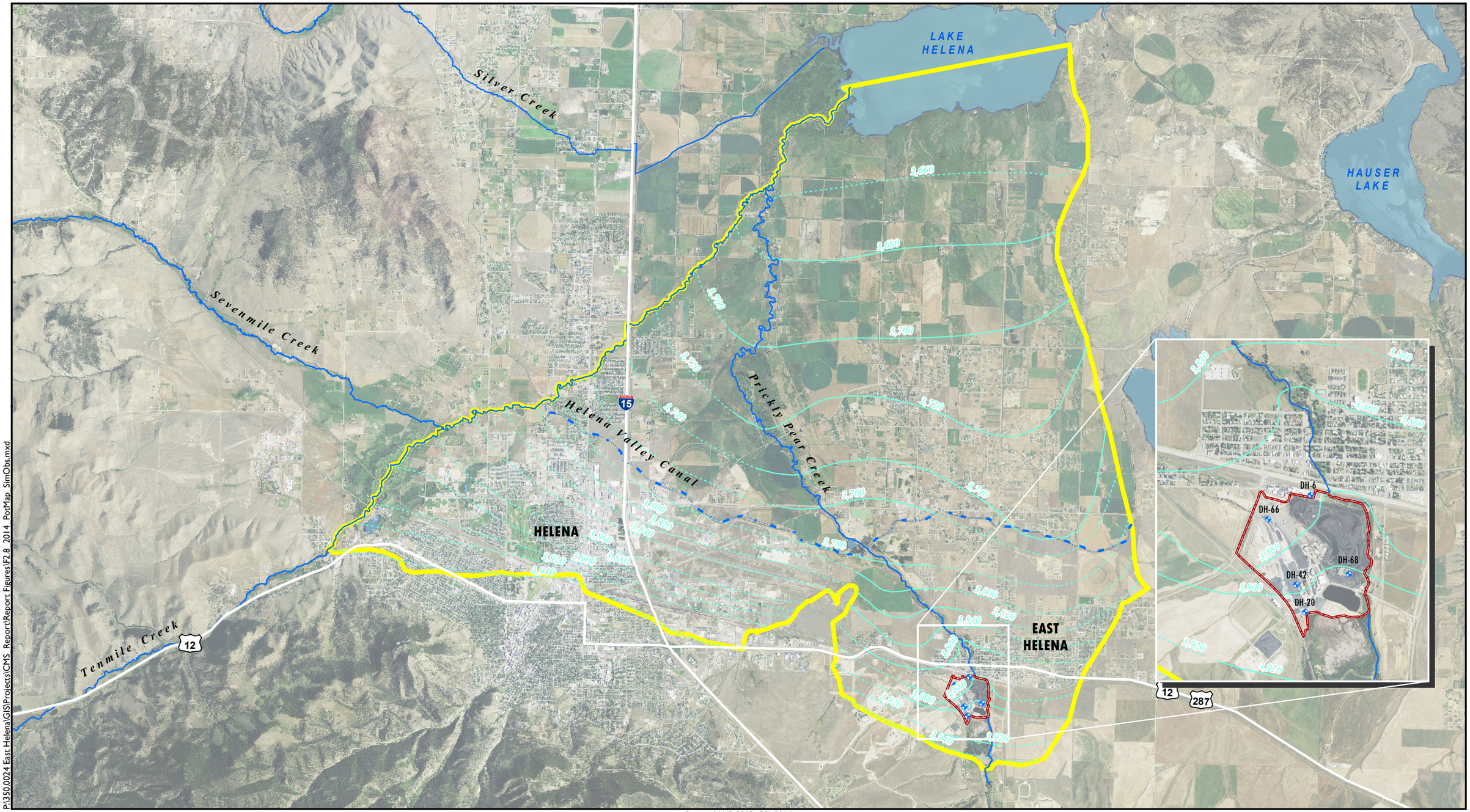
NewFields

Notes:
1) Observed potentiometric surface was developed using average 2011 groundwater elevations, pre-Upper Lake Drawdown Test.

2) Hydrographs for wells are shown on Figure 2.10.

- Monitoring Well
- Potentiometric contour (feet above mean sea level)
- Inferred potentiometric contour
- Former Smelter Site Boundary
- Model Domain

Potentiometric Surface (Average 2011)
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.7



P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F2.8_2014_PotMap_SimObs.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 6,000

NewFields

Monitoring Well

Potentiometric contour (feet above mean sea level)

Inferred potentiometric contour

Former Smelter Site Boundary

Model Domain

Notes:
1) Observed potentiometric surface was developed using average 2014 groundwater elevations.

2) Hydrographs for wells are shown on Figure 2.10.

Potentiometric Surface (Average 2014)
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.8

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.9 Vertical Gradients.mxd

Source: NAIP, 2015; GSI, 2014

0 1,000 Feet

Note:Table 2.3 presents vertical gradient values.

Lamping Field

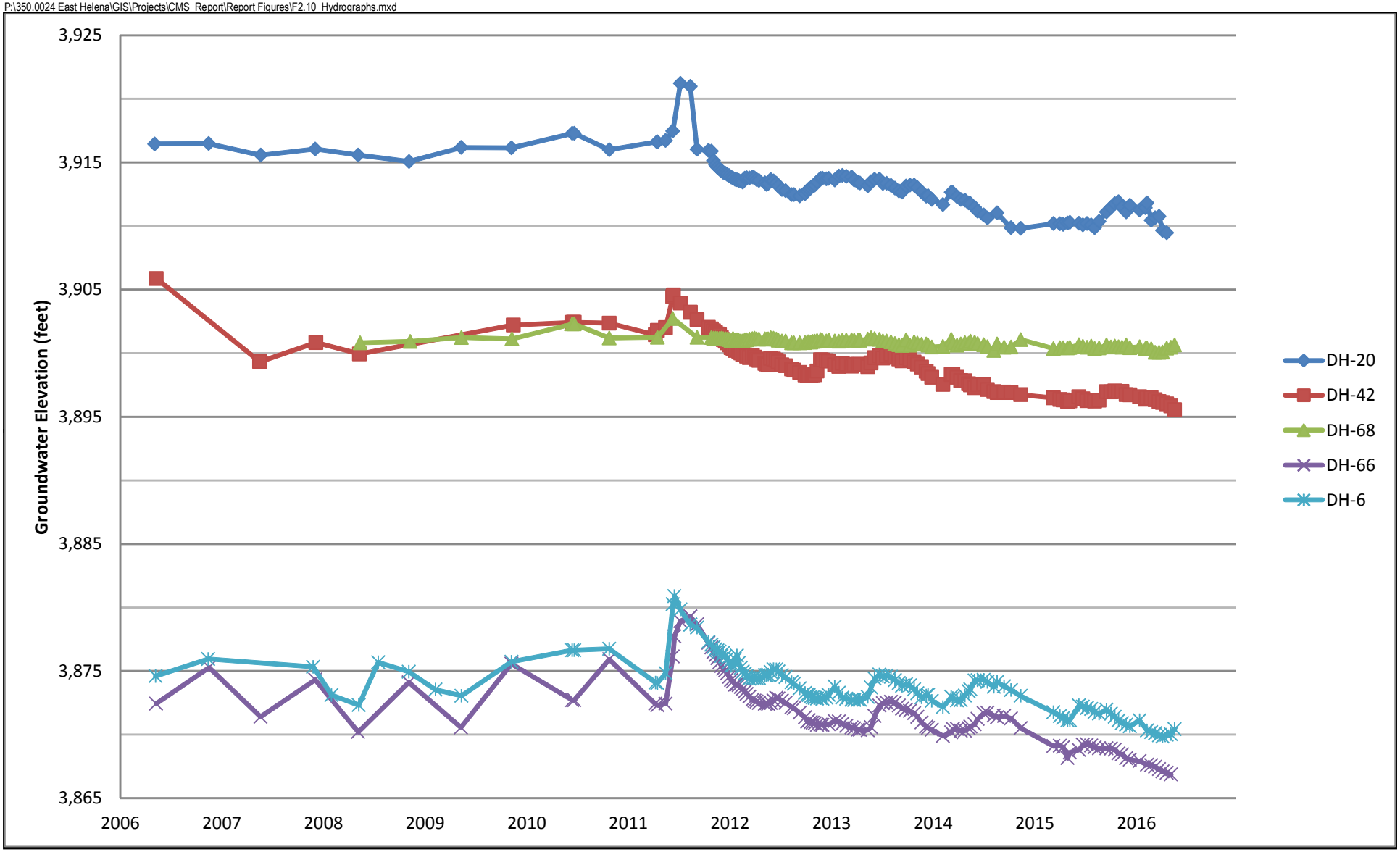
Former Smelter Site Boundary

Model Domain

NewFields

Vertical Gradients
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.9

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F2.10_Hydrographs.mxd

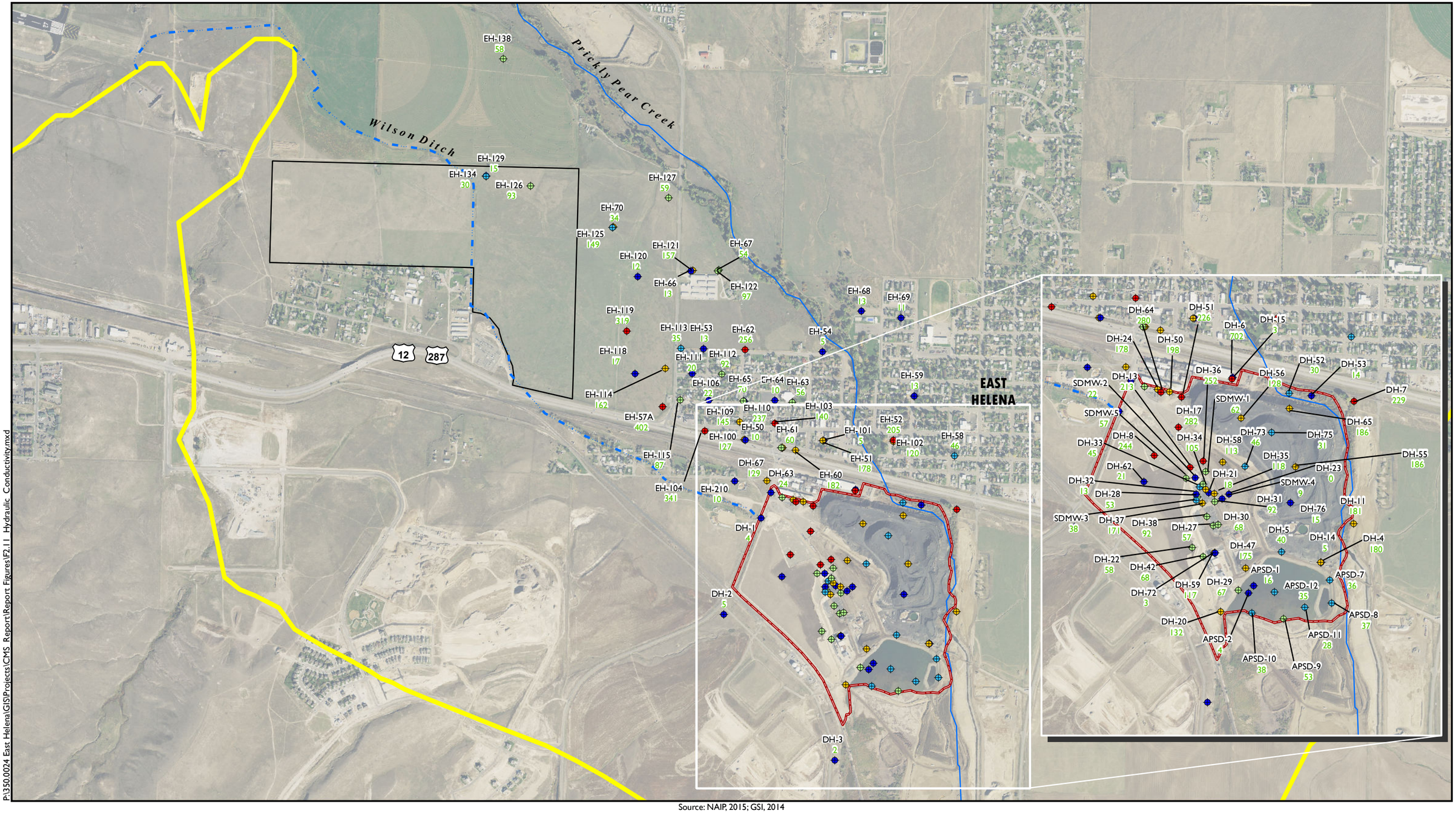


NewFields

Notes:
1) Groundwater elevation data was collected by Hydrometrics during routine monitoring.

2) Well locations are shown on Figures 2.7 and 2.8.

Hydrographs for Selected Wells
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.10



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.11 Hydraulic Conductivity.mxd

Source: NAIP, 2015; GSI, 2014

0 Feet 1,200

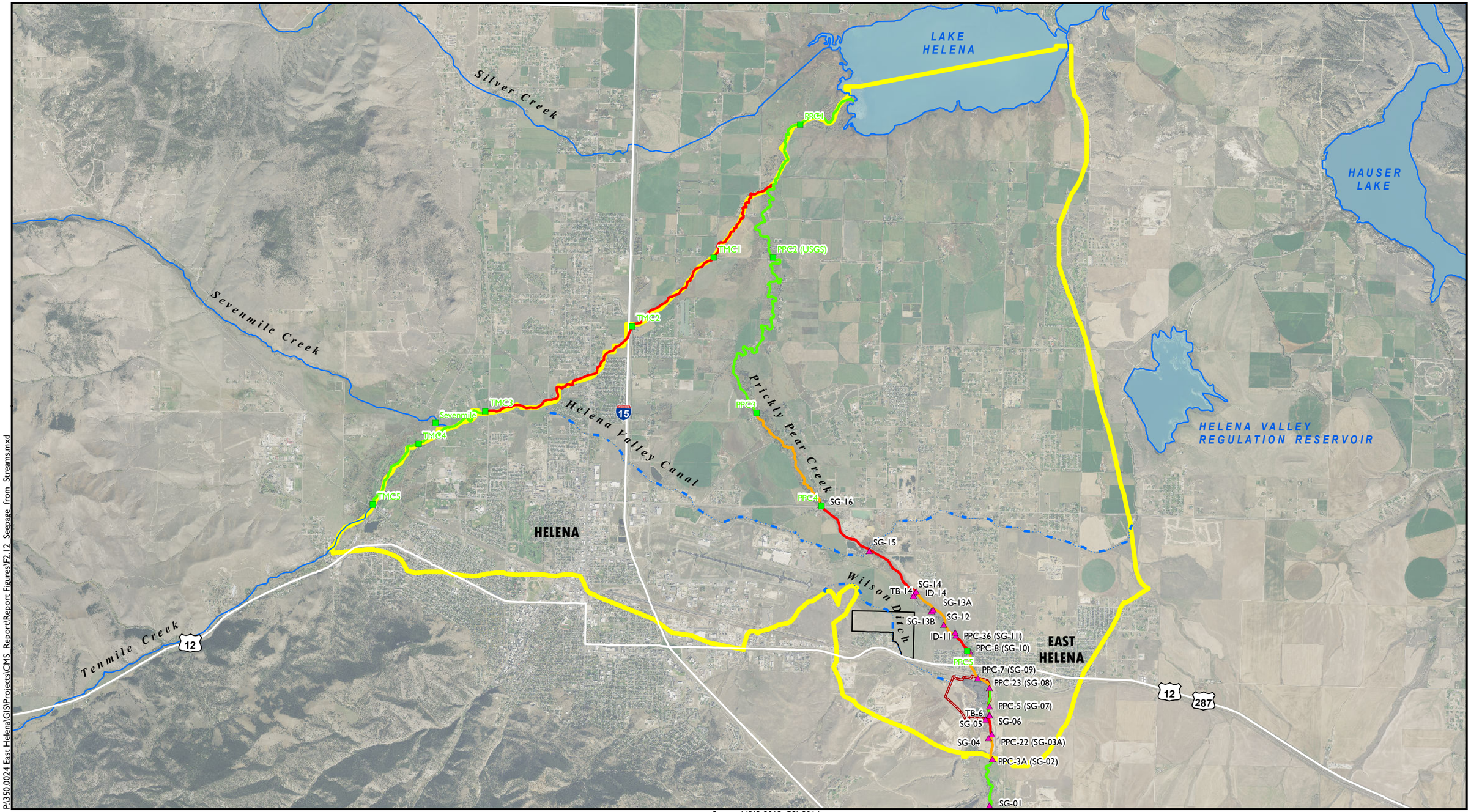
NewFields

Well with Estimated Hydraulic Conductivity (feet/day)

- <25
- 25 - 50
- 50 - 100
- 100 - 200
- >200

- Lamping Field
- Former Smelter Site Boundary
- Model Domain

Plotted Hydraulic Conductivity Based on Aquifer Tests
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.11



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F2.12 Seepage from Streams.mxd

Source: NRIS, 2015; GSI, 2014

0 Feet 6,000

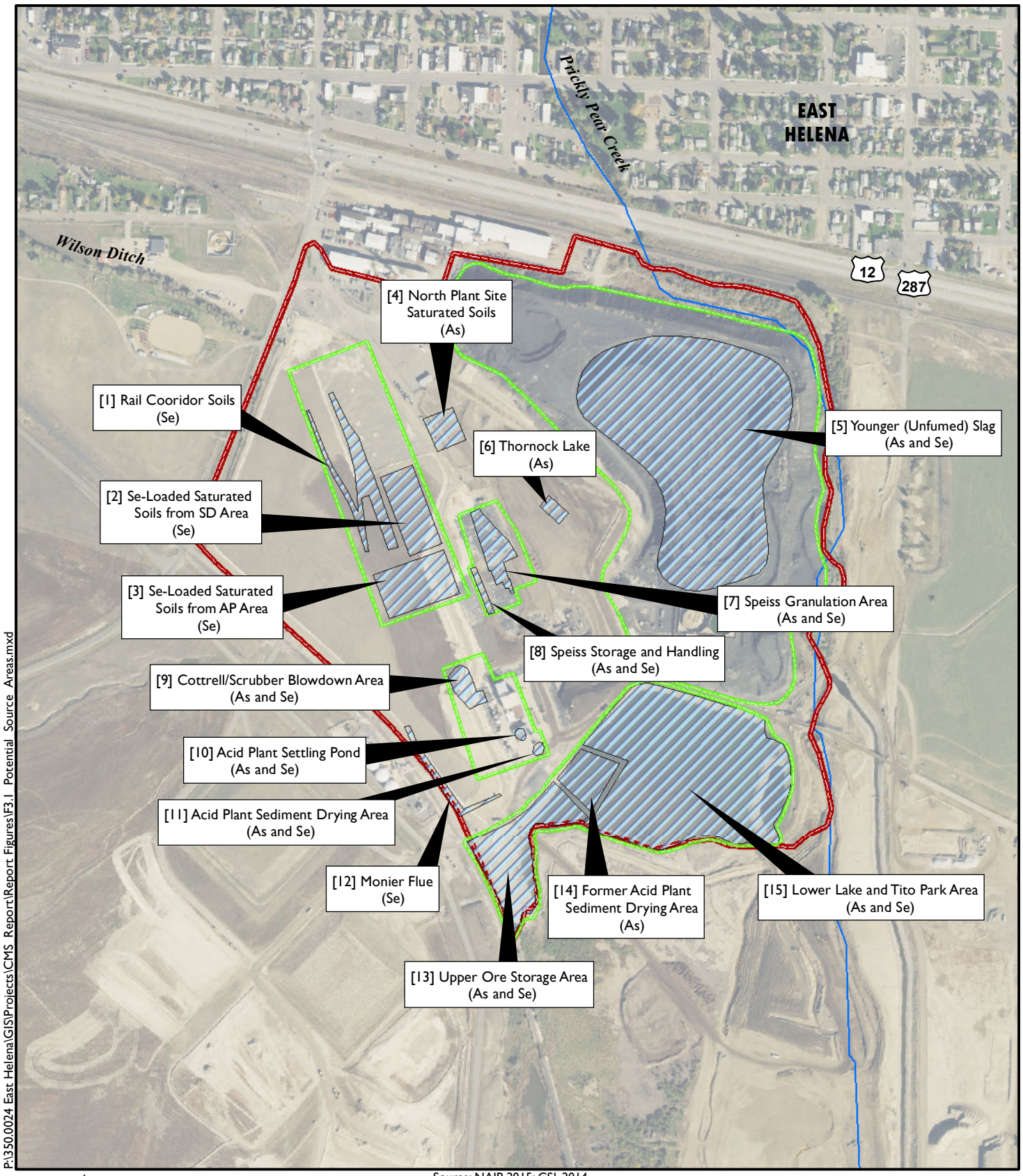
NewFields

Notes:
1) Synoptic stream gaging for Prickly Pear Creek conducted by Hydrometrics in December 2009, August 2010, and June and October 2014.

2) Table 2.4 presents synoptic flow measurements for Prickly Pear Creek.

- Synoptic Site (Briar and Madison, 1992)
- Synoptic Site (Hydrometrics)
- Gain
- Loss
- Switches between gain/loss
- Former Smelter Site Boundary
- Lamping Field
- Model Domain

Seepage from Streams
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 2.12



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F3.1 Potential Source Areas.mxd

Source: NAIP, 2015; GSI, 2014

N

0 Feet 600

Former Smelter Site Boundary

General Source Area (Hydrometrics, 2015)

Individual Source Area (Hydrometrics, 2015)

Note: As = Arsenic; Se = Selenium.

NewFields

Potential Source Areas
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.1

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F3.2_Arsenic_EhpH.mxd

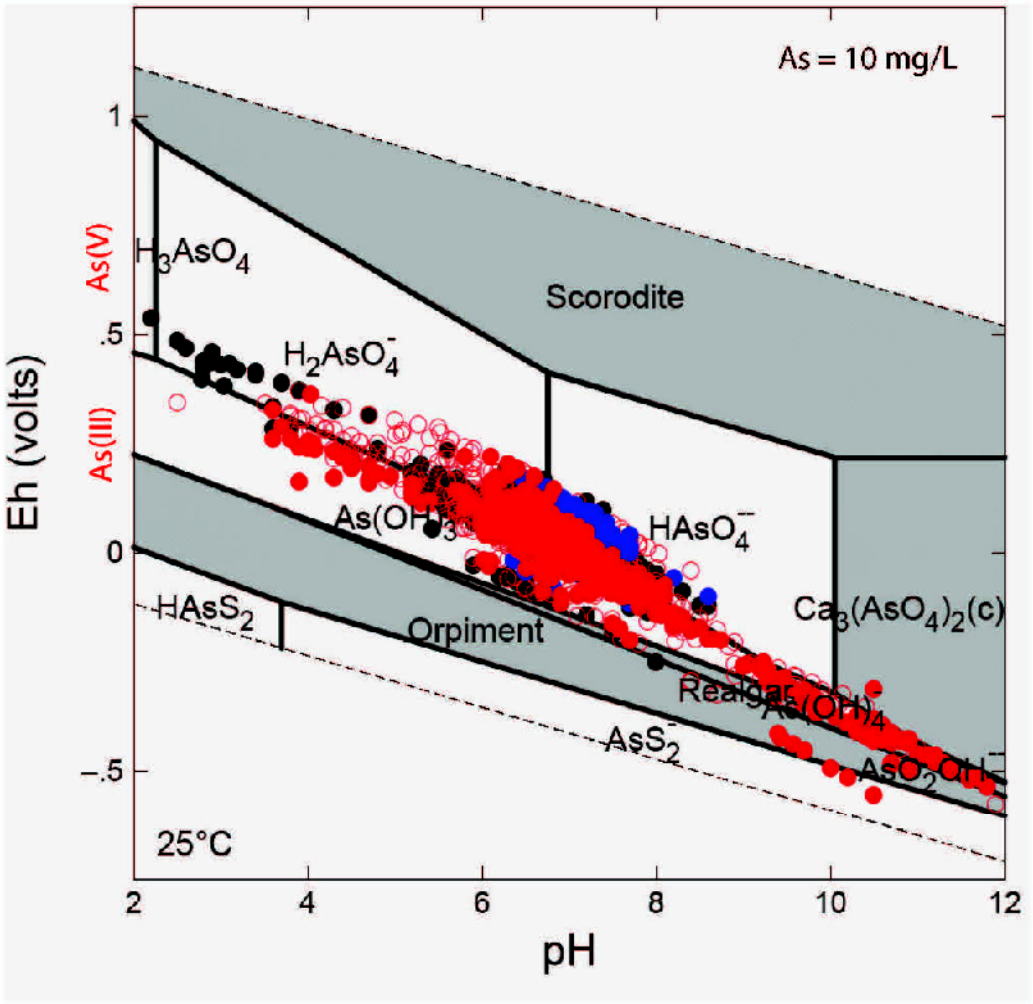


FIGURE 11-5

Site Groundwater Plotted on Eh-pH Diagram for Arsenic
Phase II RFI Report
East Helena Facility

LEGEND
- Site Source Areas
- Other Onsite
- Slag Area
- Offsite

GSI Water Solutions, Inc.

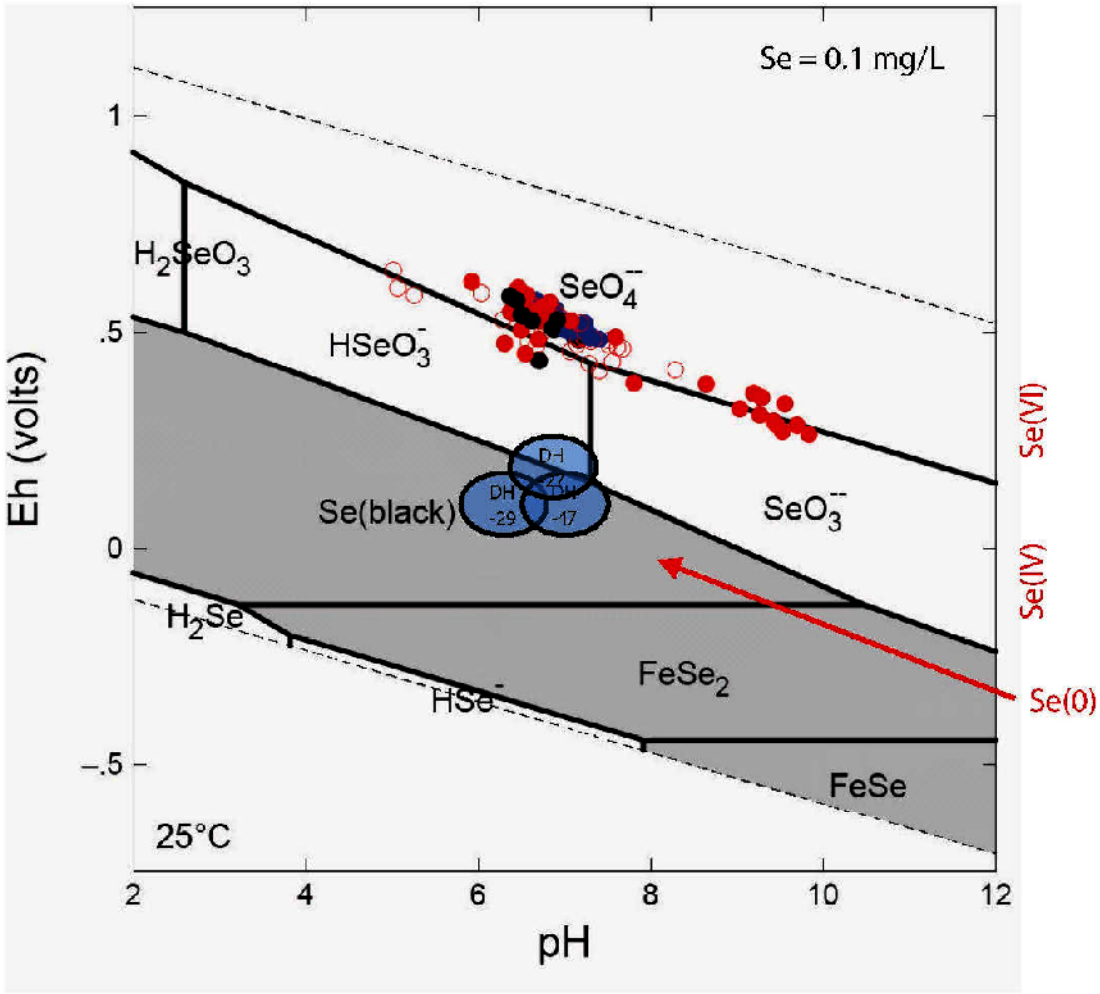
P:\Portland\394-MT_Environmental_Trust_Group\001_MT_Environ_Asarco\Figures

Source: GSI (2014)

NewFields

Arsenic Eh/pH Diagram
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.2

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F3.3_Selenium_EhpH.mxd



P:\Portland\391-MT Environmental Trust Group\001 MT Environ Asarco\Figures

FIGURE 11-6

Site Groundwater Plotted on Eh-pH Diagram for Selenium
Phase II RFI Report
East Helena Facility

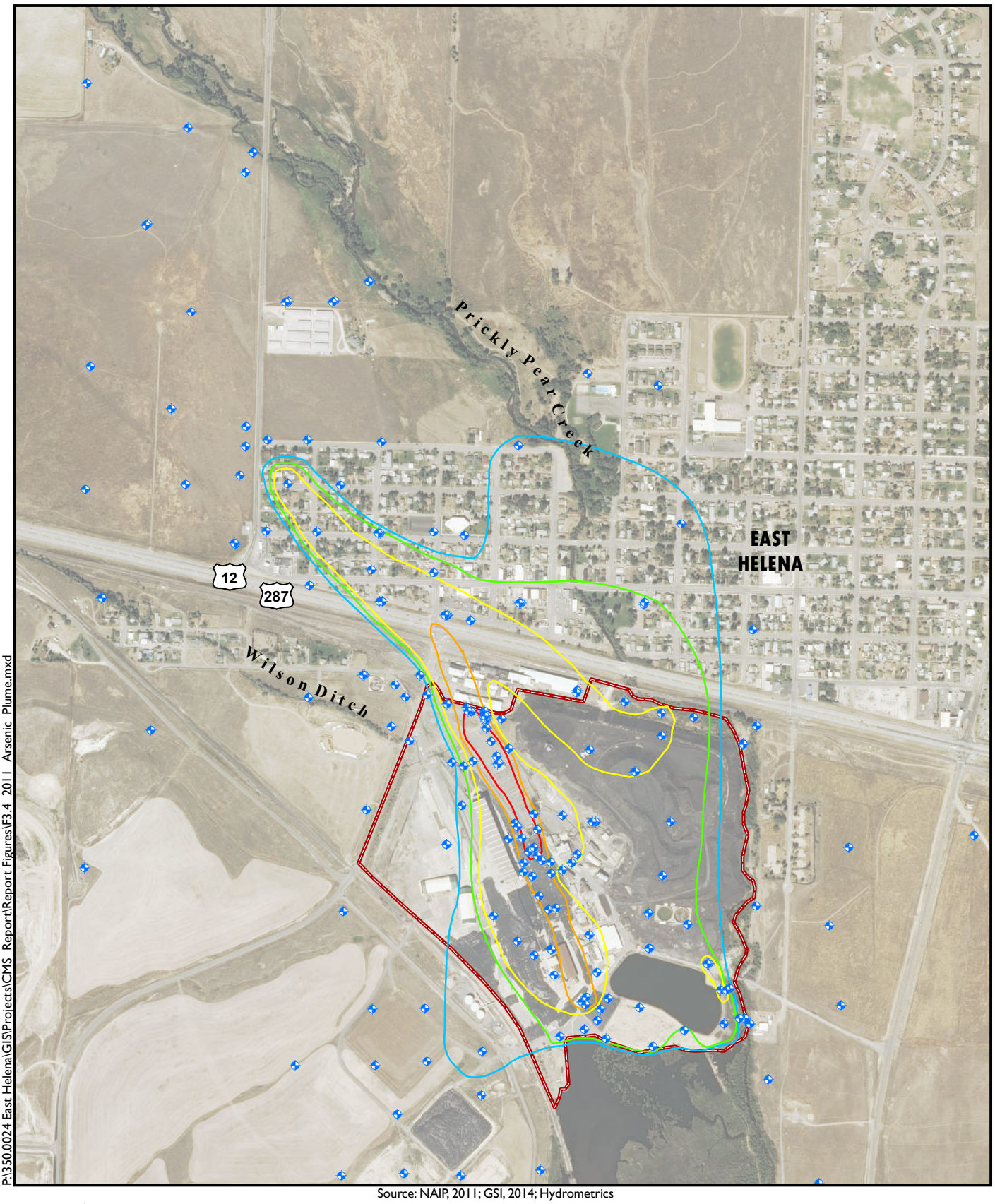
LEGEND
- Site Source Areas
- Other Onsite
- Slag Area
- Offsite

GSI Water Solutions, Inc.

Source: GSI (2014)

NewFields

Selenium Eh/pH Diagram
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.3



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F3.4 2011 Arsenic Plume.mxd

Source: NAIP, 2011; GSI, 2014; Hydrometrics

Isoconcentration Contour (mg/L)

0.01 | 10 | 0.1 | > 20 | 1

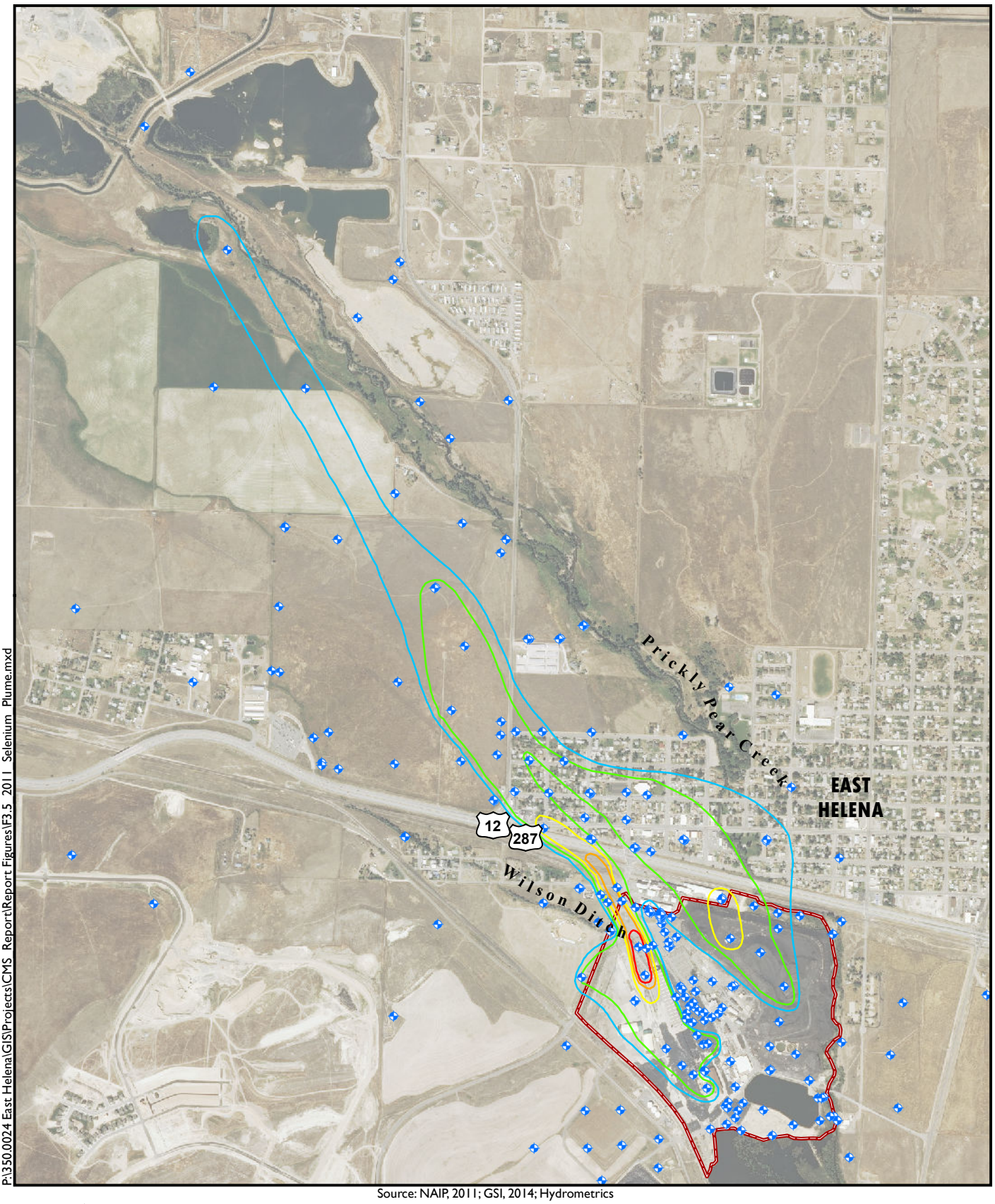
Monitoring Well

Former Smelter Site Boundary

0 Feet 1,000

NewFields

Observed Arsenic Plume (2011)
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.4



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F3.5 2011 Selenium Plume.mxd

Source: NAIP, 2011; GSI, 2014; Hydrometrics

Isoconcentration Contour (mg/L)

0.05 — 1 — 0.1 — > 3 — 0.5

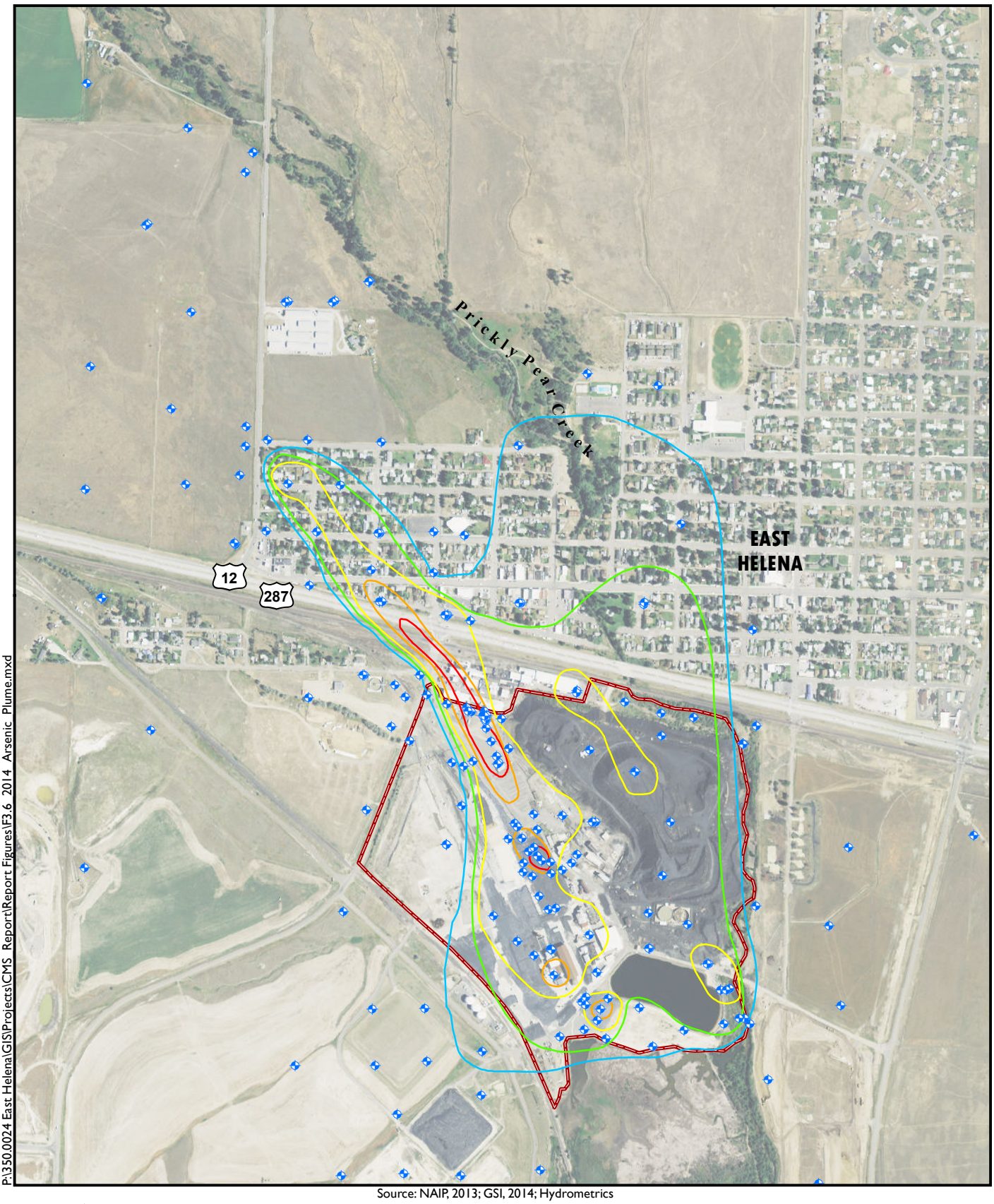
Monitoring Well

Former Smelter Site Boundary

0 Feet 1,500

NewFields

Observed Selenium Plume (2011)
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.5



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F3.6 2014 Arsenic Plume.mxd

Source: NAIP, 2013; GSI, 2014; Hydrometrics

Isoconcentration Contour (mg/L)

0.01 — 10

0.1 — > 20

1

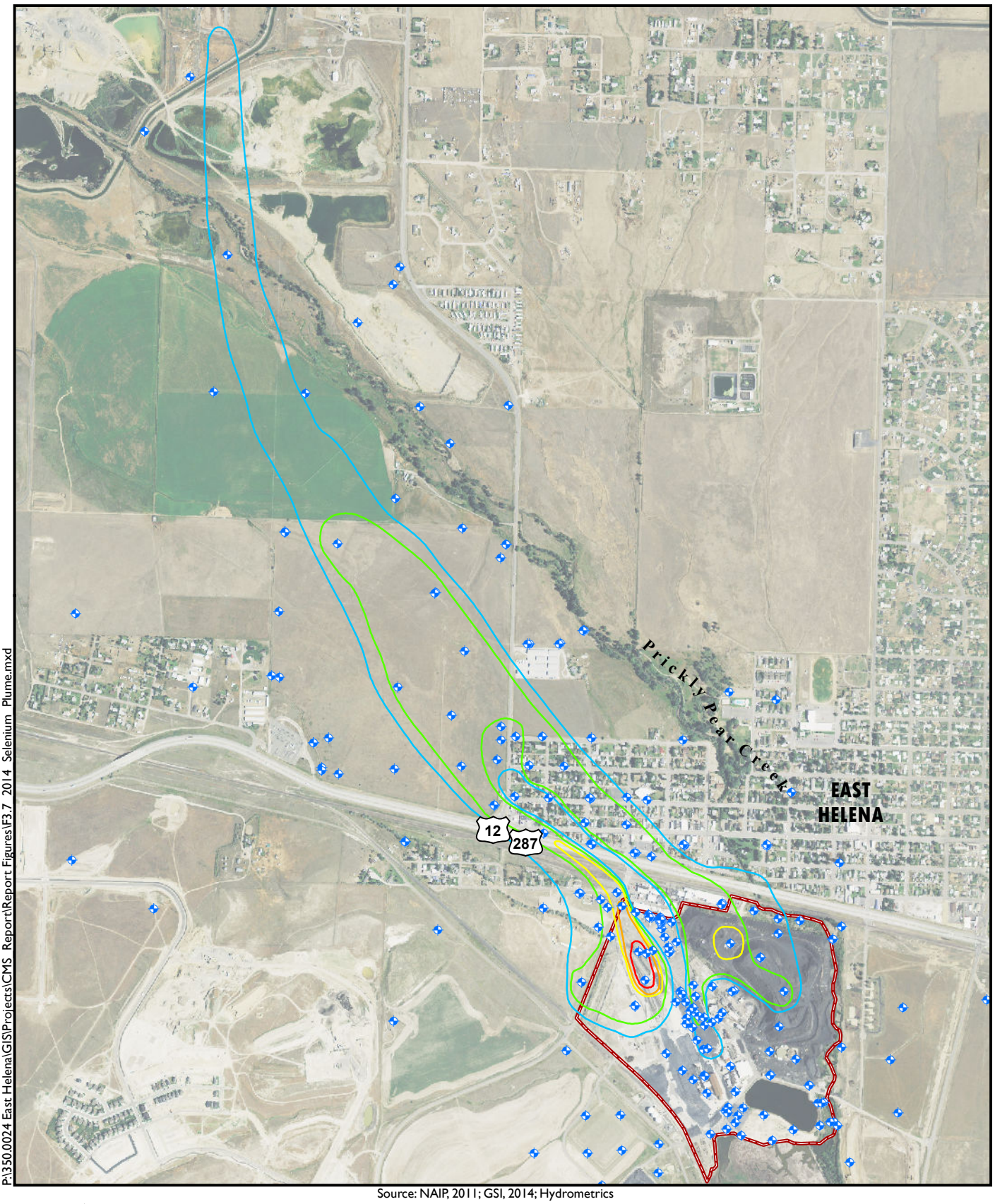
Monitoring Well

Former Smelter Site Boundary

0 Feet 1,000

NewFields

Observed Arsenic Plume (2014)
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.6



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F3.7 2014 Selenium Plume.mxd

Source: NAIP, 2011; GSI, 2014; Hydrometrics

Isoconcentration Contour (mg/L)

0.05 — 1 — Monitoring Well

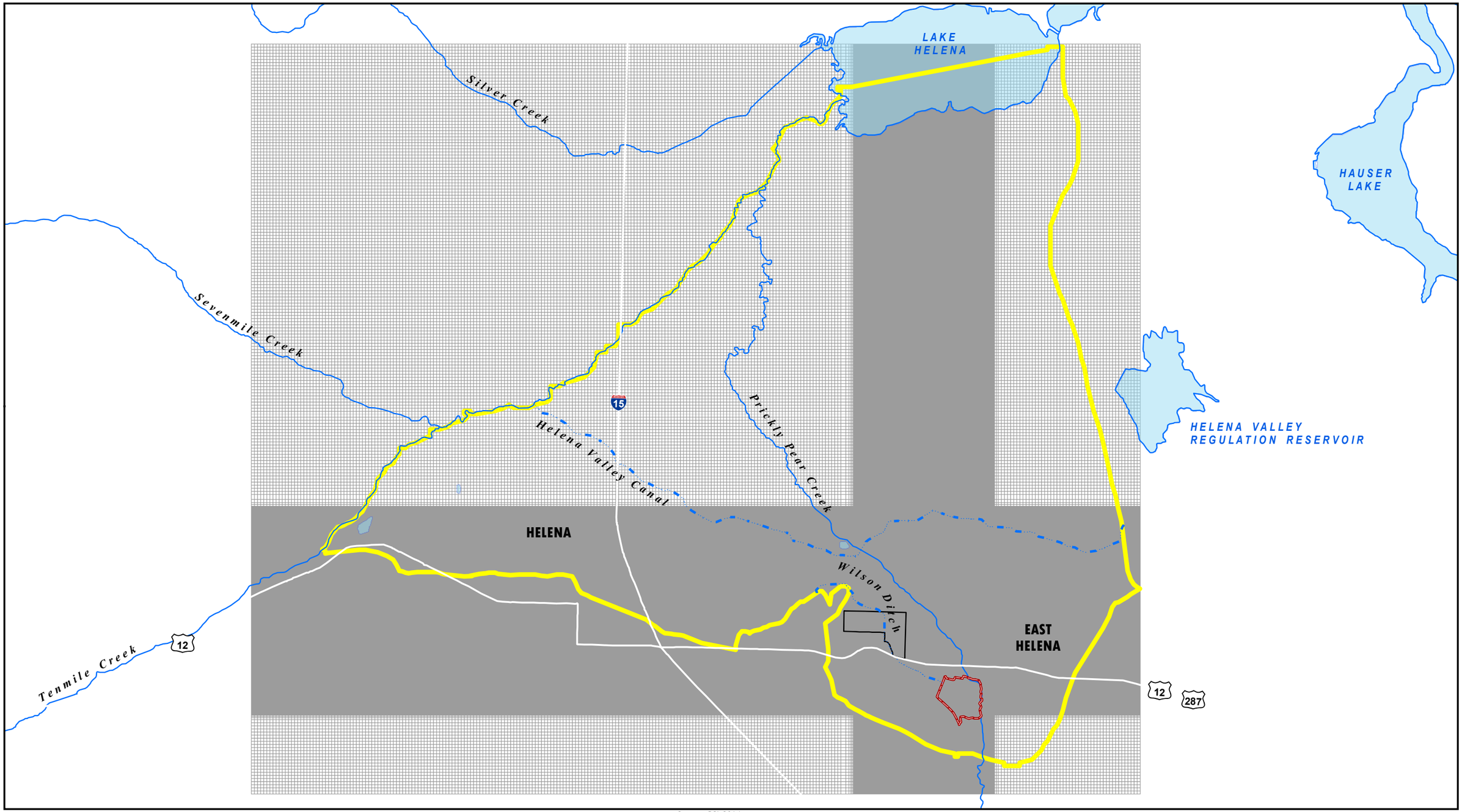
0.1 — > 3 — Former Smelter Site Boundary

0.5

0 Feet 1,500

NewFields

Observed Selenium Plume (2014)
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 3.7



Source: GSI, 2014

N

0 Feet 6,000

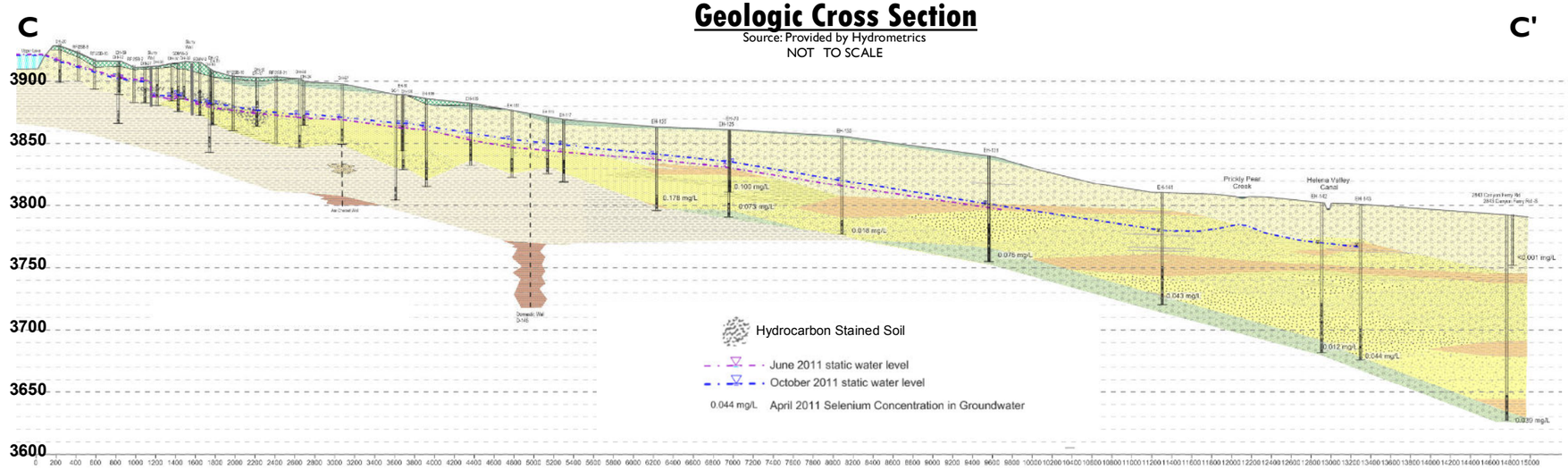
NewFields

- Grid
- Lamping Field
- Former Smelter Site Boundary
- Model Domain

Model Domain and Grid
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.1

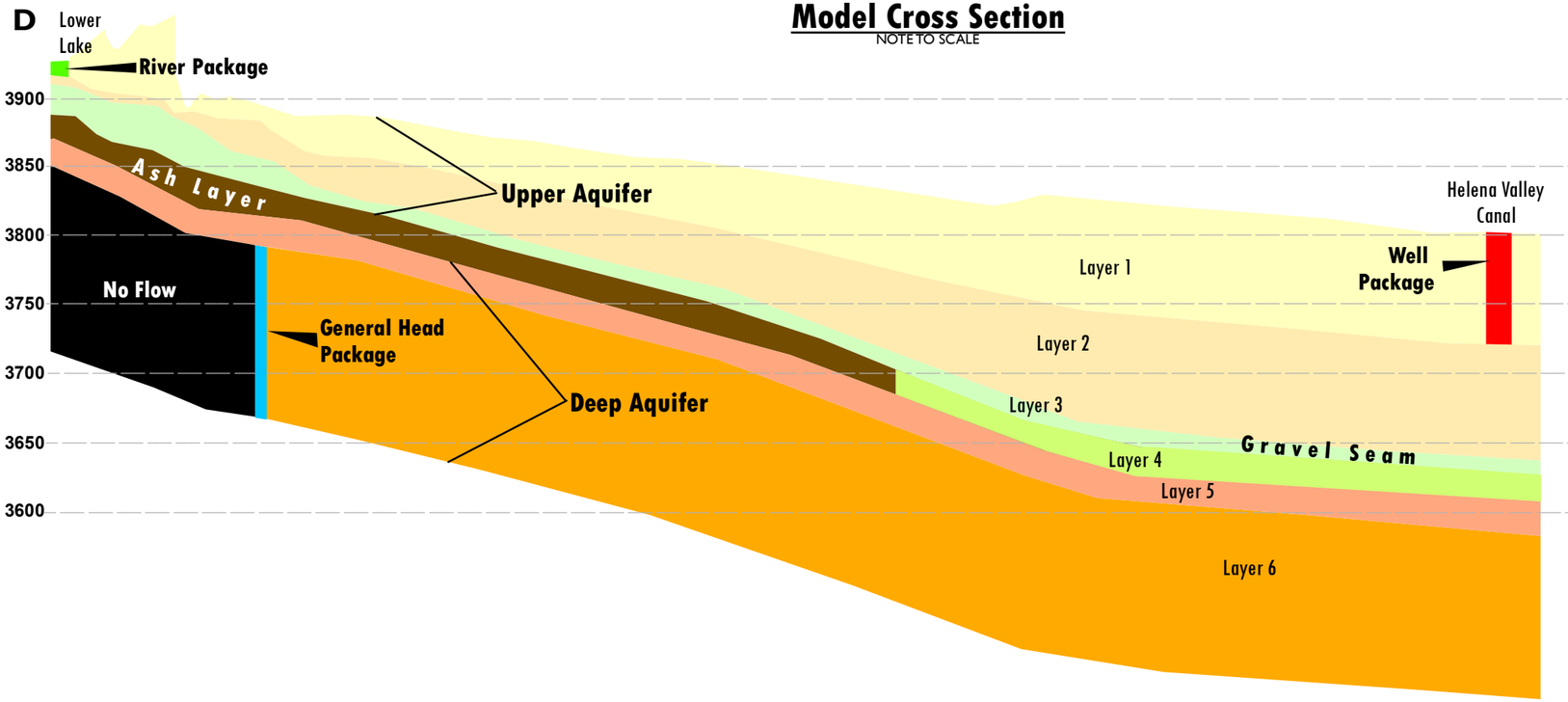
Geologic Cross Section

Source: Provided by Hydrometrics
NOT TO SCALE



Model Cross Section

NOTE TO SCALE



Note: Location of cross-section shown on Figure 4.5.

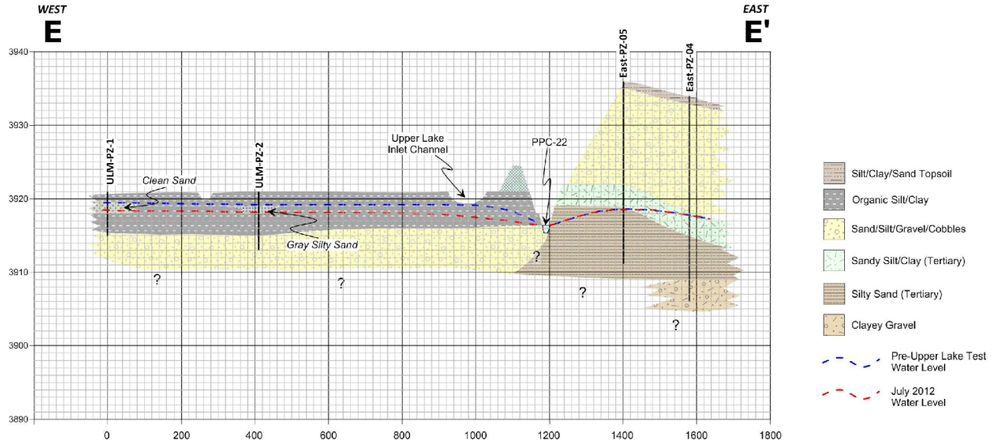
NewFields

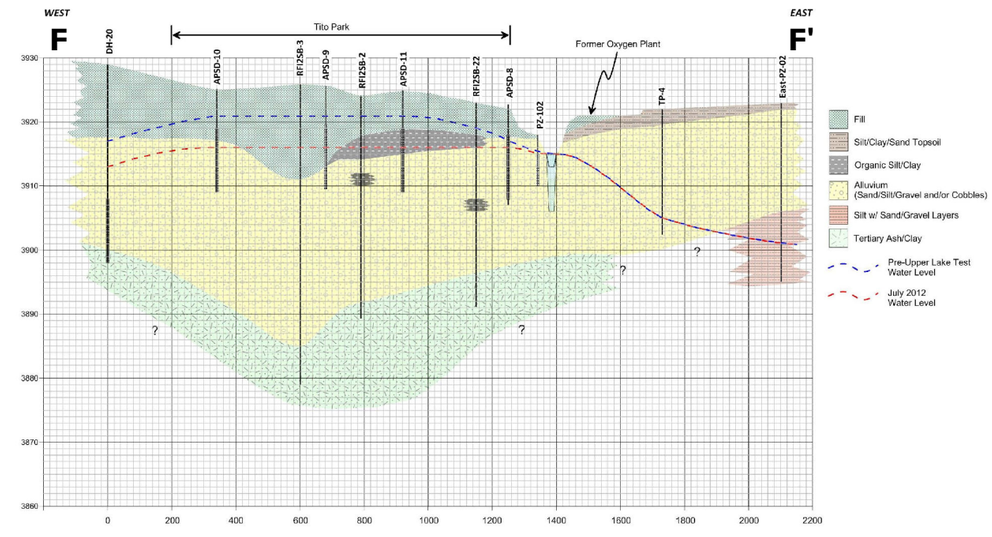
Cross Sections C-C' and D-D'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.2

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F4.2_Cross_SectionC-C,D-D.mxd

Geologic Cross Section

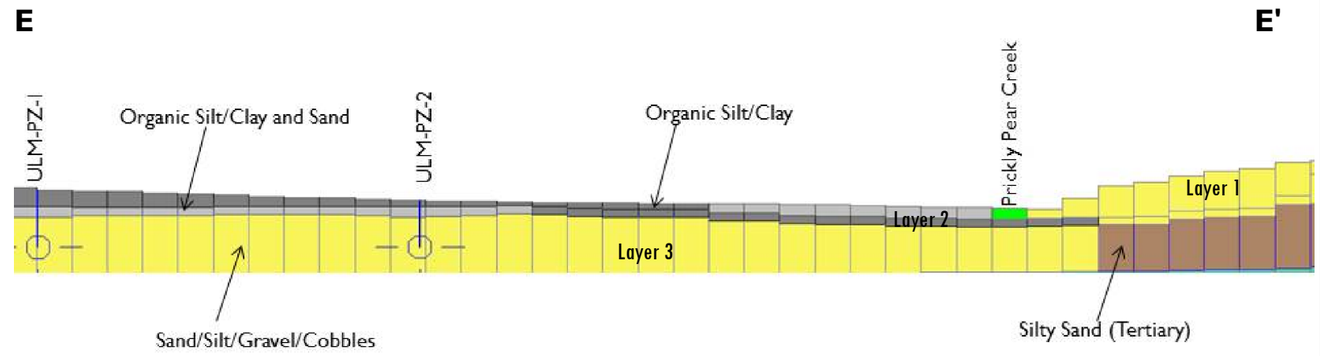
Source: Provided by Hydrometrics
NOT TO SCALE

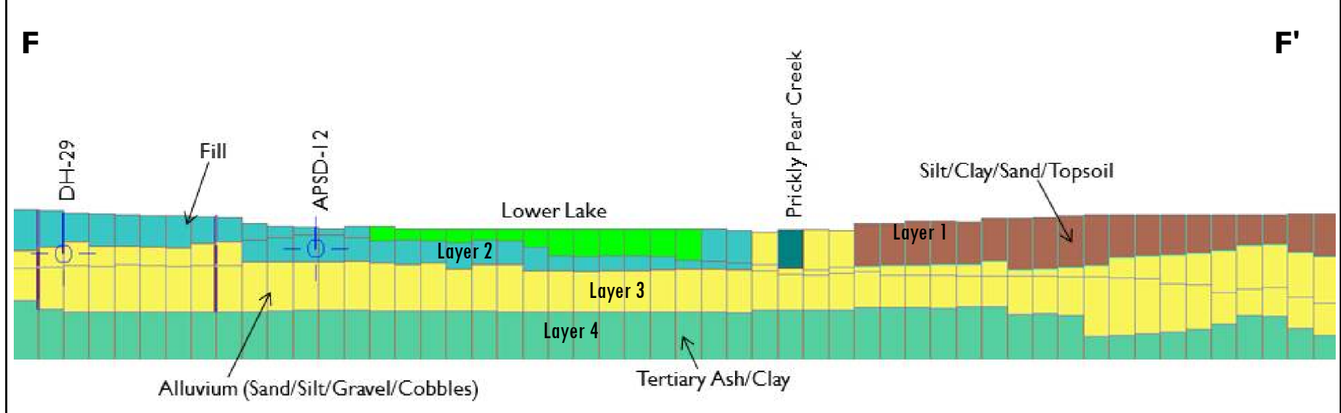




Model Cross Section

NOT TO SCALE





Note: Location of cross-sections shown on Figure 4.5.

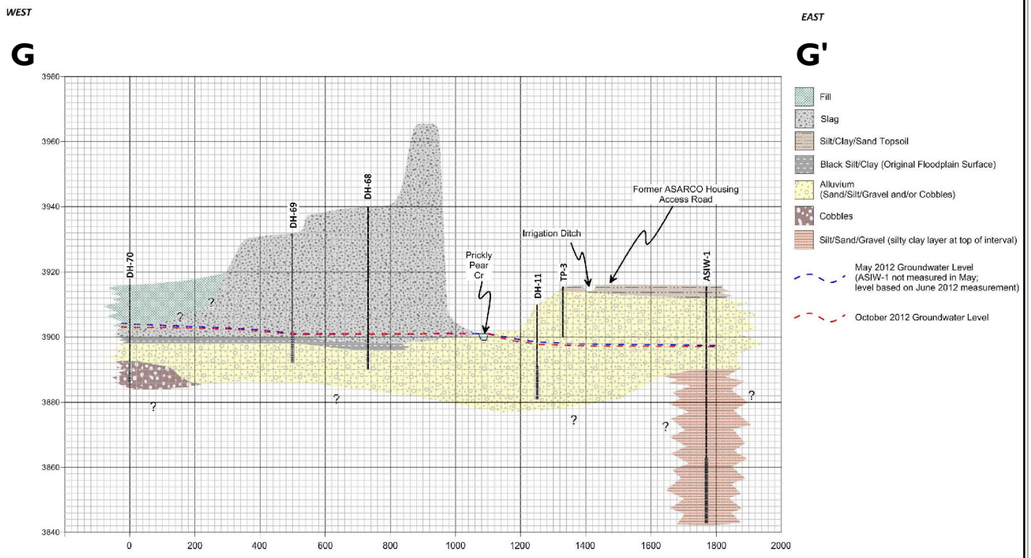
NewFields

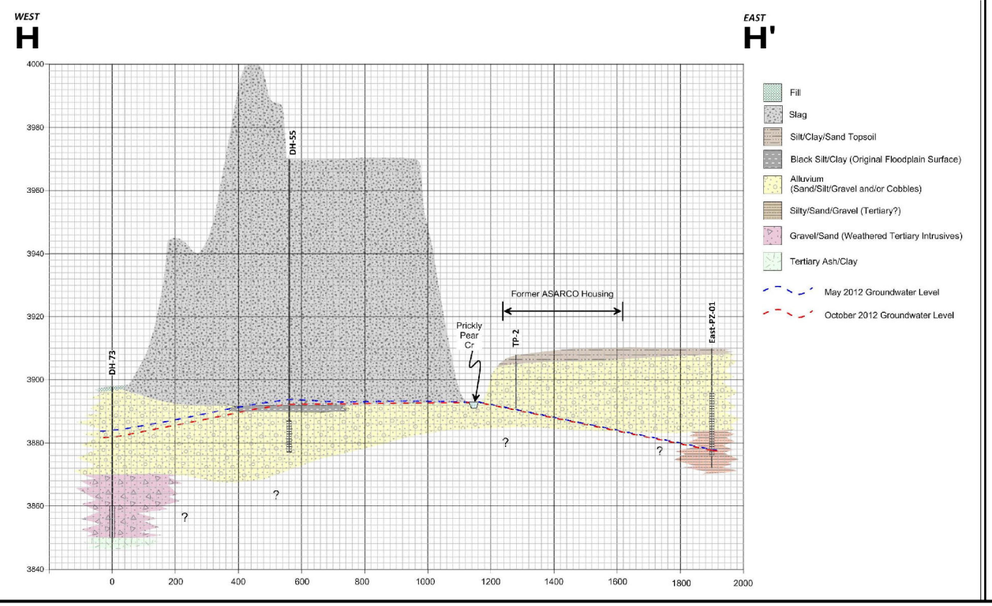
Cross Sections E-E' and F-F'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.3

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.3 Cross Section E-E, F-F.mxd

Geologic Cross Section

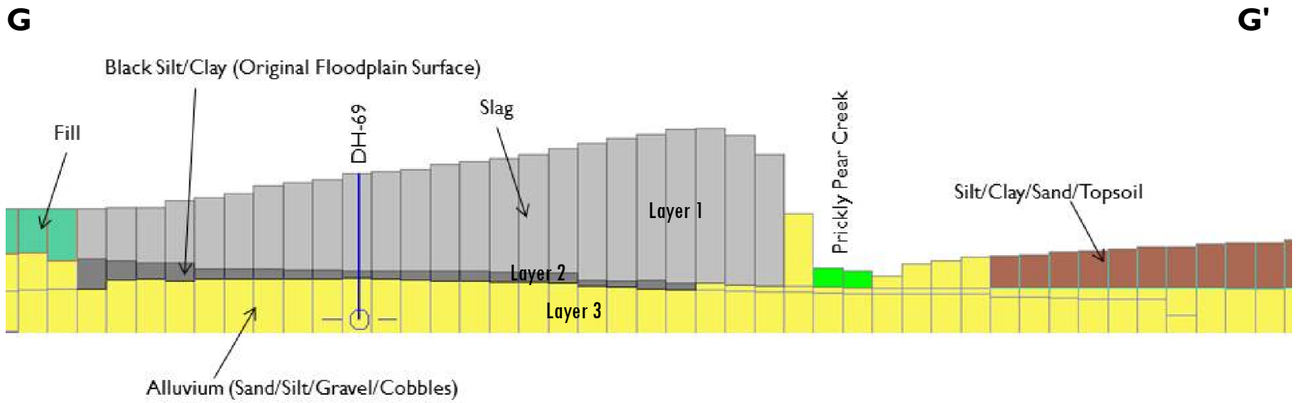
Source: Provided by Hydrometrics
NOT TO SCALE

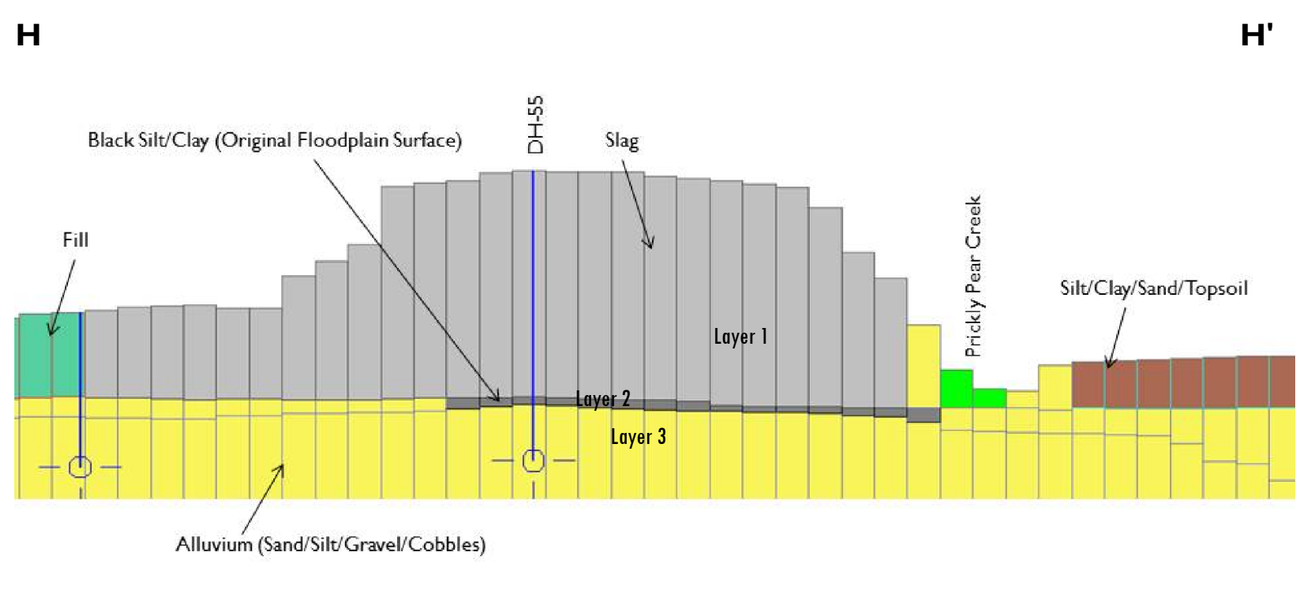




Model Cross Section

NOT TO SCALE





Note: Location of cross-sections shown on Figure 4.5.

NewFields

Cross Sections G-G' and H-H'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.4

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F4.4_Cross_SectionG-G-H-H.mxd

LAKE HELENA

HAUSER LAKE

HELENA VALLEY REGULATION RESERVOIR

Silver Creek

Sevenmile Creek

Tenmile Creek

Helena Valley Canal

Prickly Pear Creek

Spokane Bench Fault

Wilson Ditch

HELENA

EAST HELENA

15

12

287

12

Wilson Ditch

Prickly Pear Creek

Lower Lake

Upper Lake

H H'

G G'

F F'

E E'

D D'

C C'

B B'

A A'

Source: NAIP, 2011; GSI, 2014

Boundary Condition

- Pumping Well
- Horizontal Flow Barrier
- Well Package Cell
- River Package Cell
- Drain Package Cell
- General Head Package Cell
- Former Smelter Site Boundary
- Hydrometrics Cross-section
- Model Cross-section

N

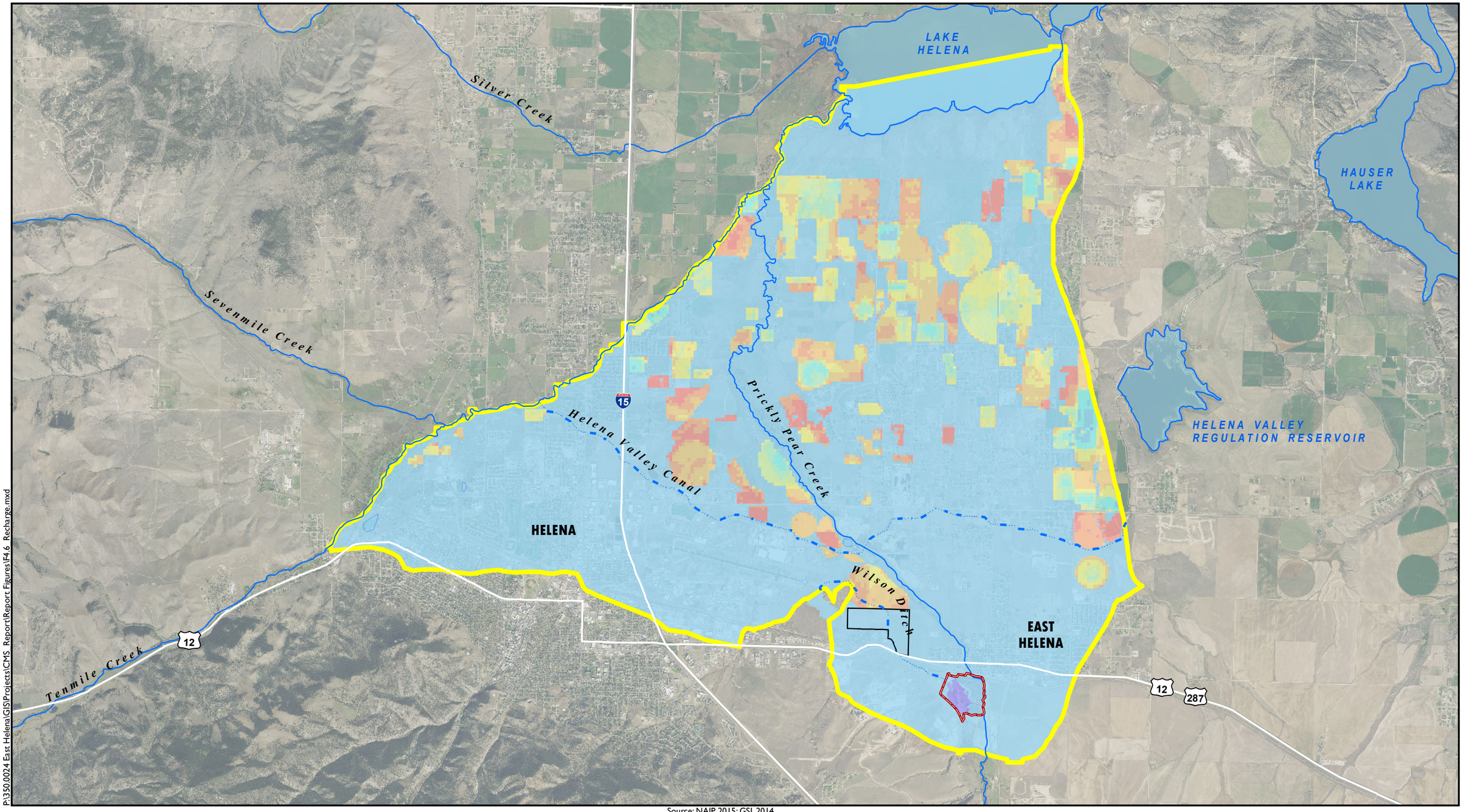
0 Feet 6,000

NewFields

Note: Corss-sectnions are presented on Figures 4.2, 4.3, and 4.4.

Model Boundary Conditions
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.5

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.5 Model Boundary Conditions.mxd



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.6 Recharge.mxd

Source: NAIP, 2015; GSI, 2014

Recharge (inches/year)

<0.01	5.0 - 7.5	20.0 - 25.0
0.01 - 1.0	7.5 - 10.0	>25.0
1.0 - 2.5	10.0 - 15.0	
2.5 - 5.0	15.0 - 20.0	

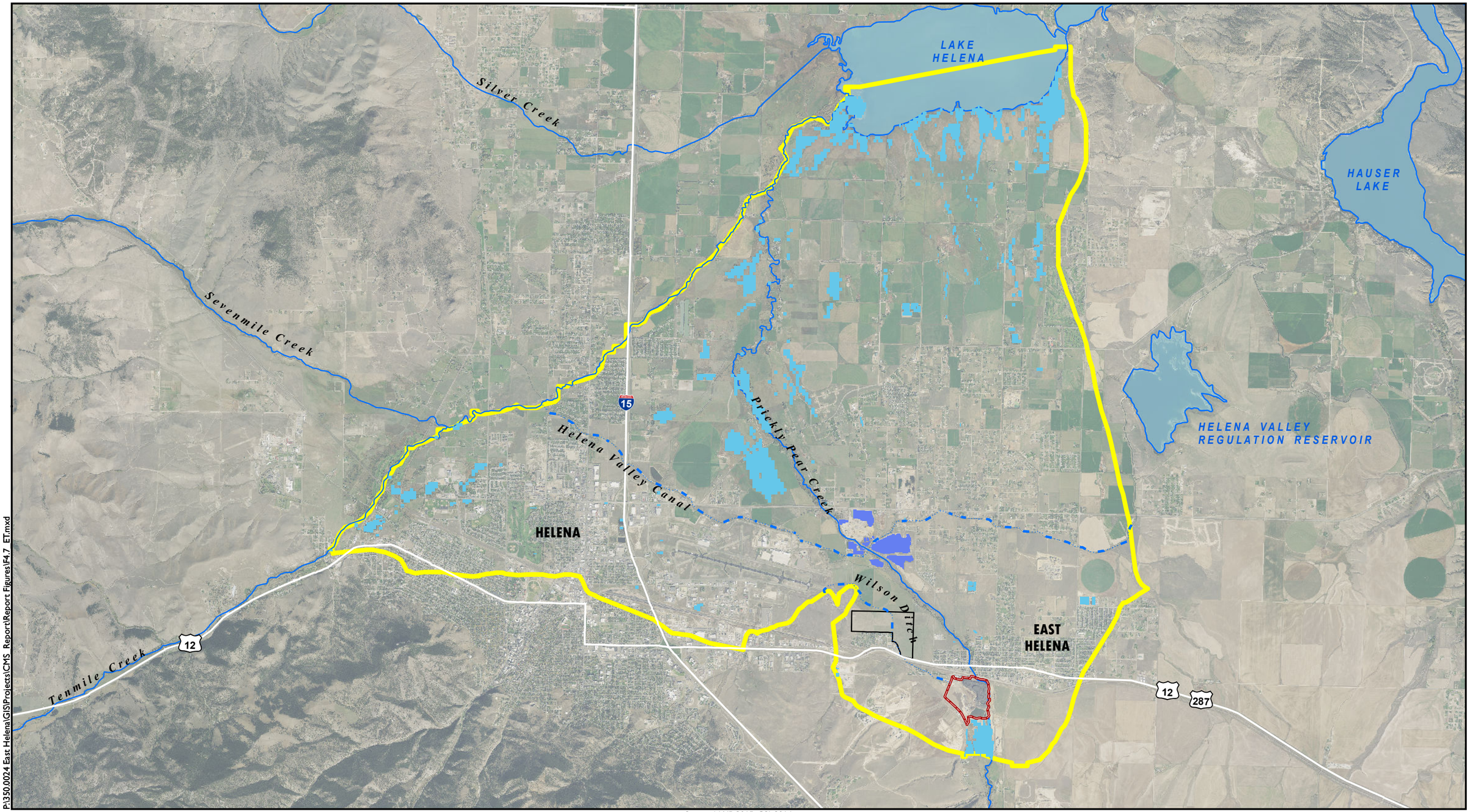
- Former Smelter Site Boundary
- Lamping Field
- Model Domain

0 Feet 6,000

Source for rechage rates: PRISM (2014).

NewFields

Aerial Recharge
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.6



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.7 ET.mxd

Source: NAIP, 2015; GSI, 2014

0 Feet 6,000

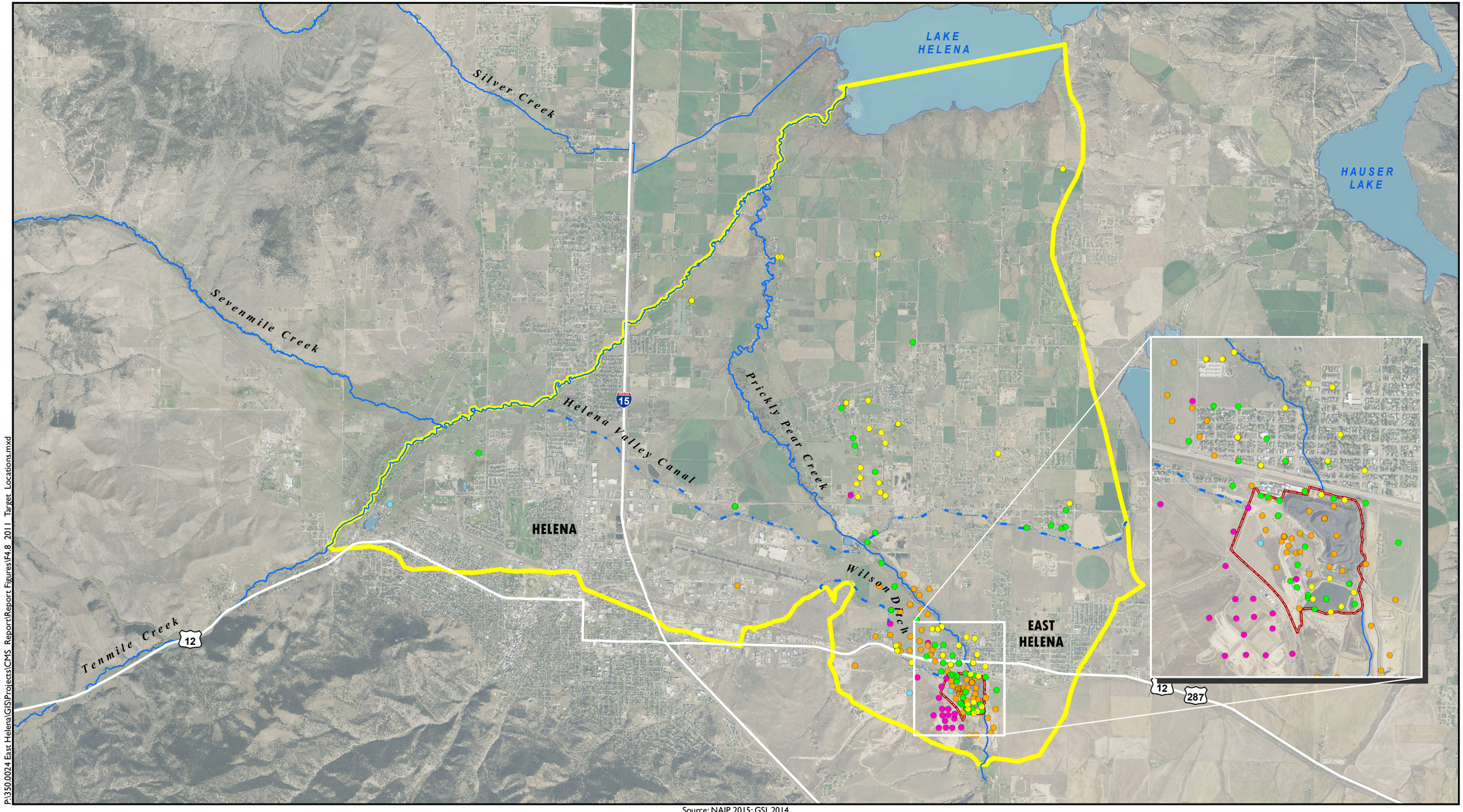
NewFields

Evapotranspiration Rate (inches/year)

- 23 (Trezza et al., 2011)
- 35.5 (WRCCb, 2012)

- Former Smelter Site Boundary
- Lamping Field
- Model Domain

Evapotranspiration
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.7



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.8 2011 Target Locations.mxd

Source: NAIP, 2015; GSI, 2014

Groundwater Elevation Target

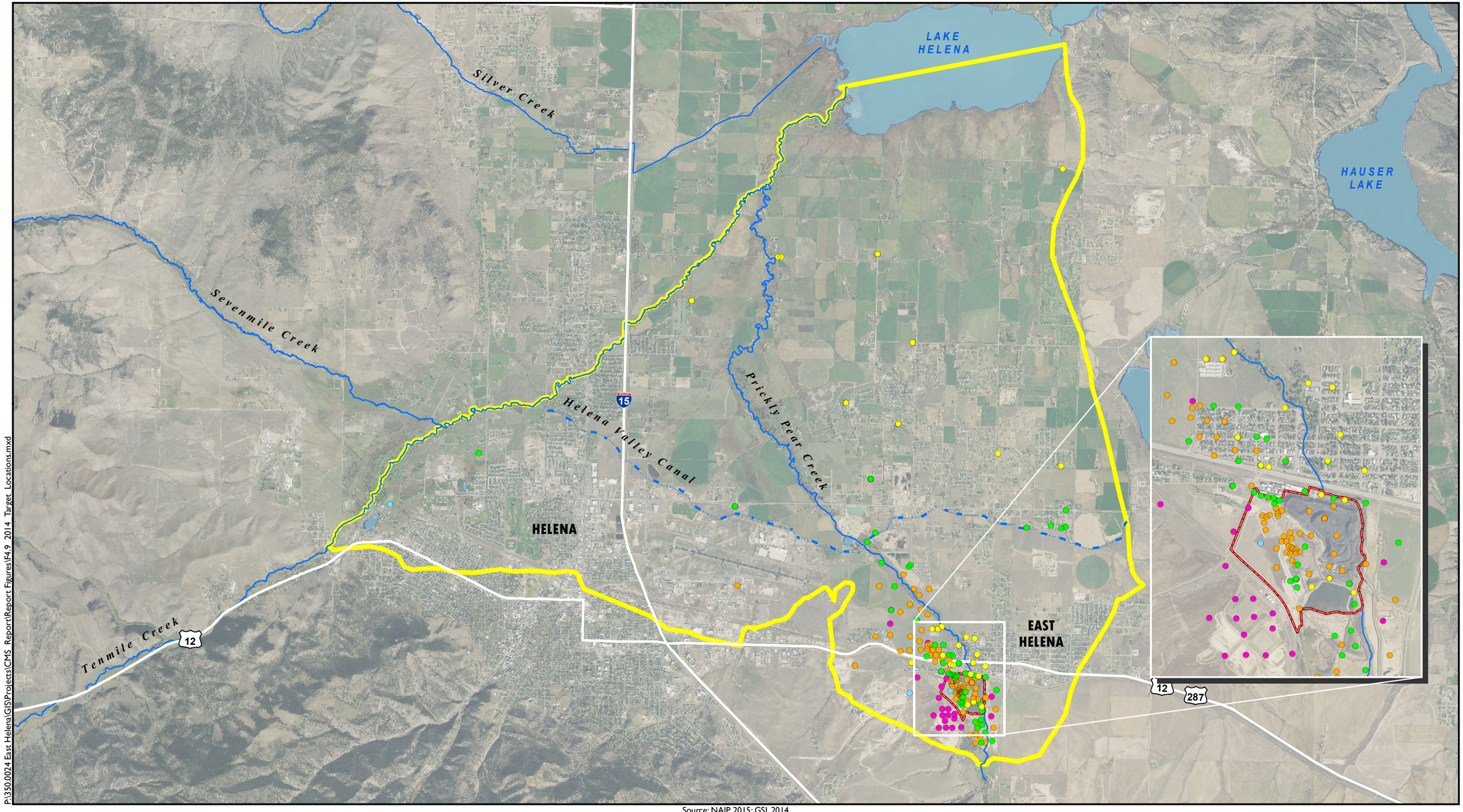
- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

- Former Smelter Site Boundary
- Model Domain

0 Feet 6,000

NewFields

2011 Steady-State Groundwater Elevation Target Locations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.8



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.9 2014 Target Locations.mxd

Source: NAIP, 2015; GSI, 2014

Groundwater Elevation Target

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

- Former Smelter Site Boundary
- Model Domain

0 Feet 6,000

NewFields

2014 Steady-State Groundwater Elevation Target Locations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.9

LAKE HELENA

HAUSER LAKE

Silver Creek

Sevenmile Creek

Helena Valley Canal

Prickly Pear Creek

Wilson Ditch

Tenmile Creek

HELENA

EAST HELENA

15

12

287

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.10 Transient Target Locations.mxd

Source: NAIP, 2015; GSI, 2014

Groundwater Elevation Target

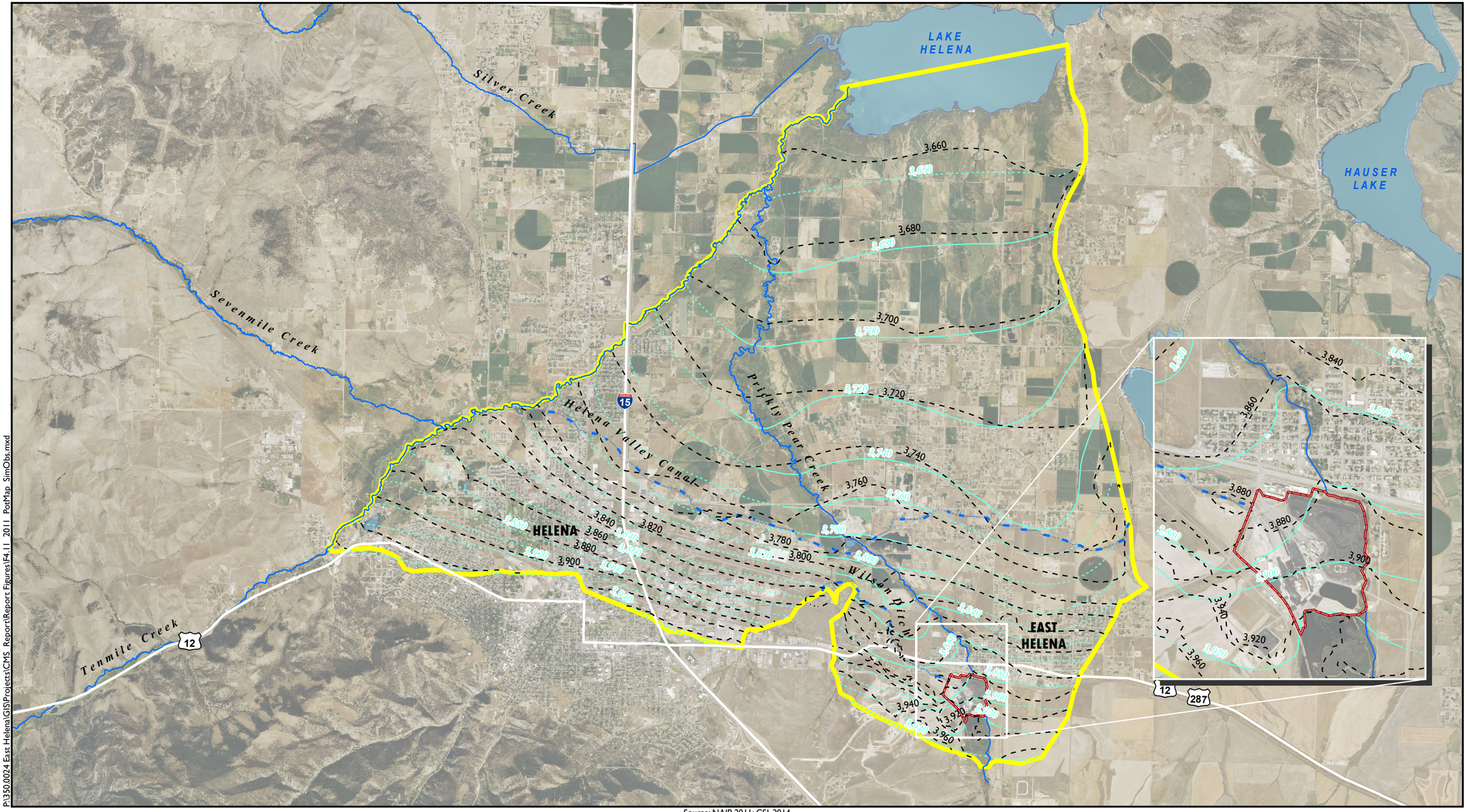
- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

- Former Smelter Site Boundary
- Model Domain

0 Feet 6,000

NewFields

Transient Groundwater Elevation Target Locations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.10



Source: NAIP, 2011; GSI, 2014

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.11 2011 PotMap SimObs.mxd

0 Feet 6,000

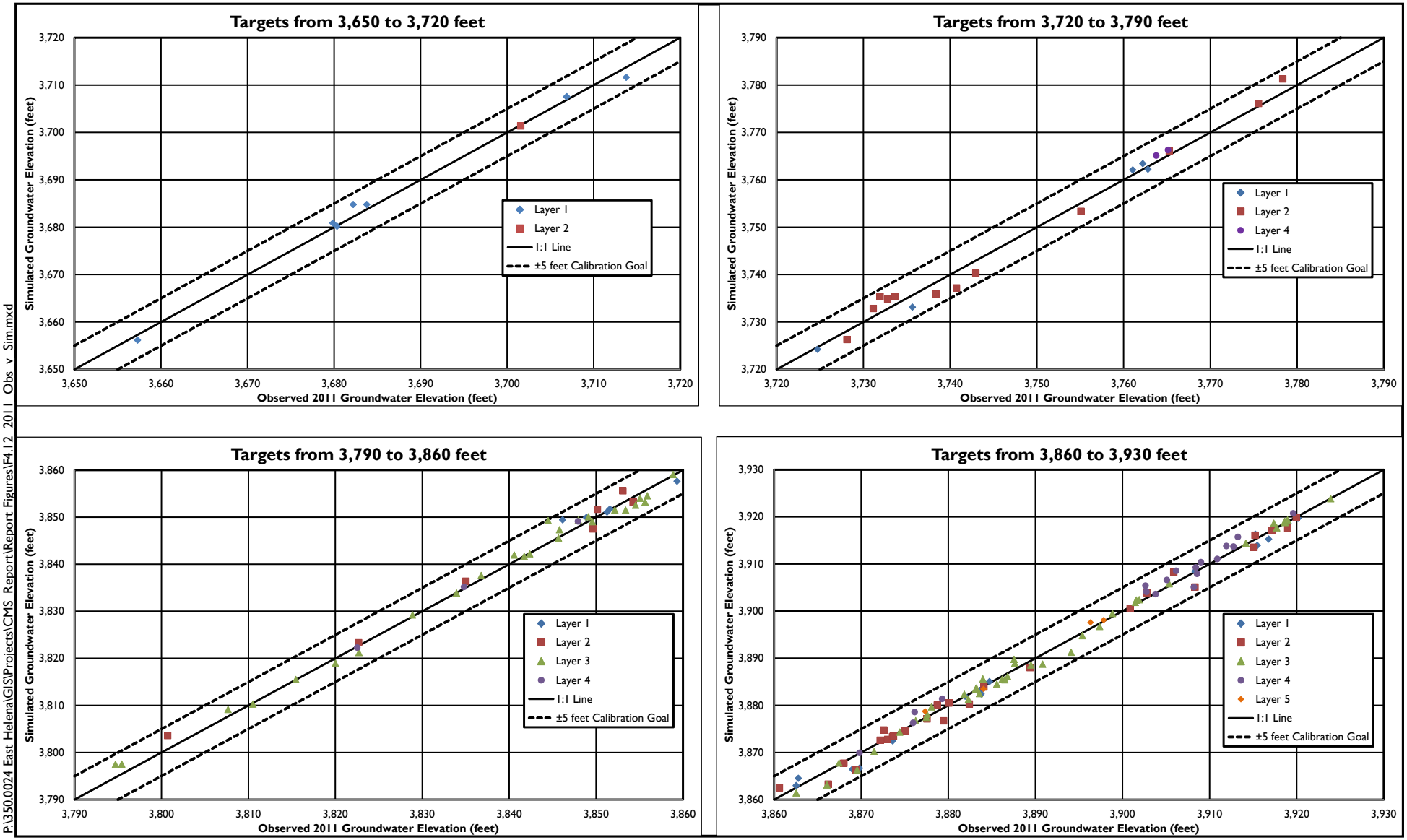
NewFields

Notes:
1) Observed potentiometric surface was developed using average 2011 groundwater elevations, pre-Upper Lake Drawdown Test.

2) Results are from NewFields (2016a).

- Simulated potentiometric contour (feet above mean sea level)
- Potentiometric contour (feet above mean sea level)
- Inferred potentiometric contour
- Former Smelter Site Boundary
- Model Domain

2011 Simulated Steady-State and Observed Potentiometric Surfaces
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.11

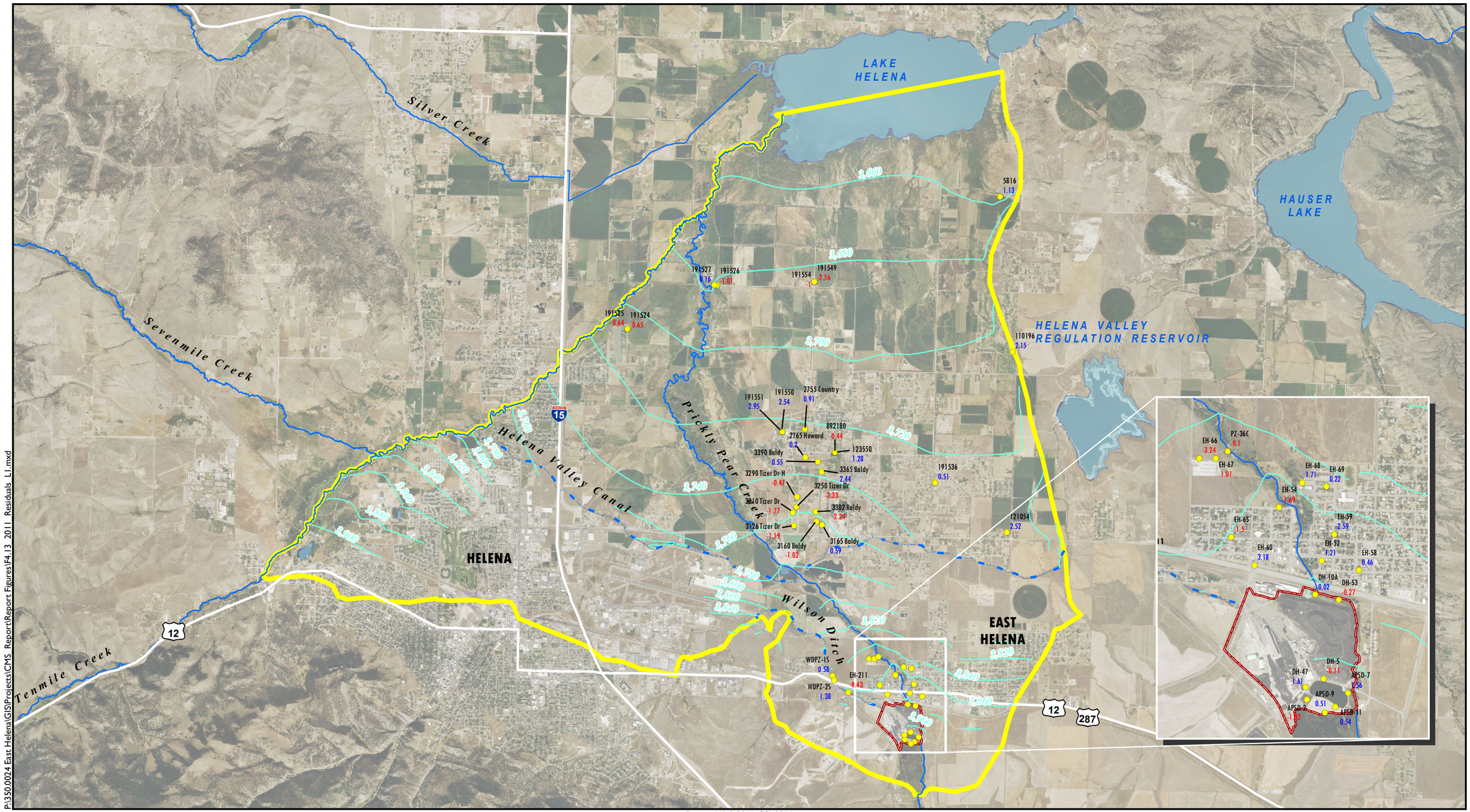


P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.12 2011 Obs v Sim.mxd

Note: Results are from NewFields (2016a).

NewFields

2011 Observed versus Simulated Steady-State Groundwater Elevations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.12



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.13 2011 Residuals LI.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a)

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2011 Steady-State Residuals and Potentiometric Surface - Layer 1
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.13

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.14 2011 Residuals L2.mxd

LAKE HELENA

HAUSER LAKE

HELENA VALLEY REGULATION RESERVOIR

Silver Creek

Sevenmile Creek

Tenmile Creek

Helena Valley Canal

Prickly Pear Creek

Wilson Ditch

HELENA

EAST HELENA

3,660

3,680

3,700

3,720

3,740

3,760

3,780

3,800

3,820

3,840

3,860

3,880

3,900

3,920

3,940

88213 0.22

191539 2.16

193012 -0.79

2640 Old York-H 1.83

2690 Matyas 3.57

3400 Tizer Dr 2.71

3290 Rogan Rd 1.73

EH-143 -0.56

EH-142 -2.92

EH-141 -2.44

EH-138 -2.88

EH-134 -0.63

238204 2.46

60826 -1.7

60803 -3.37

182549 -2.02

238195 -1.77

East-PZ 1 -0.43

EH-70 -1.34

WDPZ-1D 2.15

WDPZ-2D -2.17

EH-53 -1.51

EH-62 -2.53

EH-57A 1.08

EH-63 -1.89

EH-50 2.94

EH-61 3.15

EH-51 0.29

EH-102 -0.4

EH-205 0.23

DH-49 0.88

DH-24 -0.3

DH-51 0.45

DH-6 0.44

DH-52 0.22

DH-7 -1.3

DH-16 2.76

DH-57 1.4

DH-30 0.35

DH-42 -1.01

APSD-16 1.58

APSD-12 1.4

DH-4 3.25

DH-19R -2.33

APSD-10 0.19

APSD-8 2.05

DH-29 -0.87

Source: NAIP, 2011; GSI, 2014

0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

Groundwater Elevation Target

3.28 Positive Residual (feet under predicted)

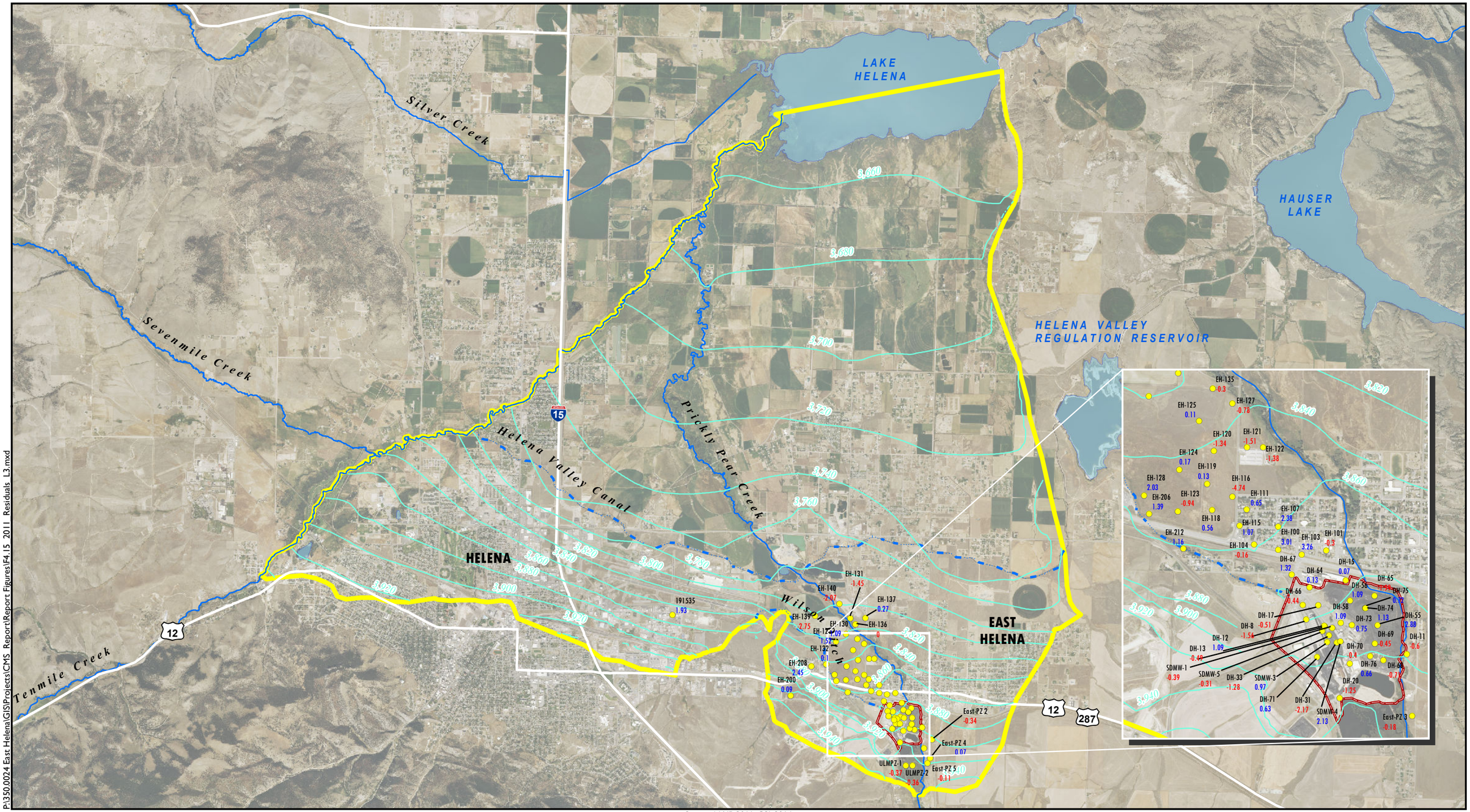
-1.89 Negative Residual (feet over predicted)

Simulated Potentiometric Contour (feet)

Former Smelter Site Boundary

Model Domain

Spatial Distribution of 2011 Steady-State Residuals and Potentiometric Surface - Layer 2
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.14



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.15 2011 Residuals L3.mxd

Source: NAIP, 2011; GSI, 2014

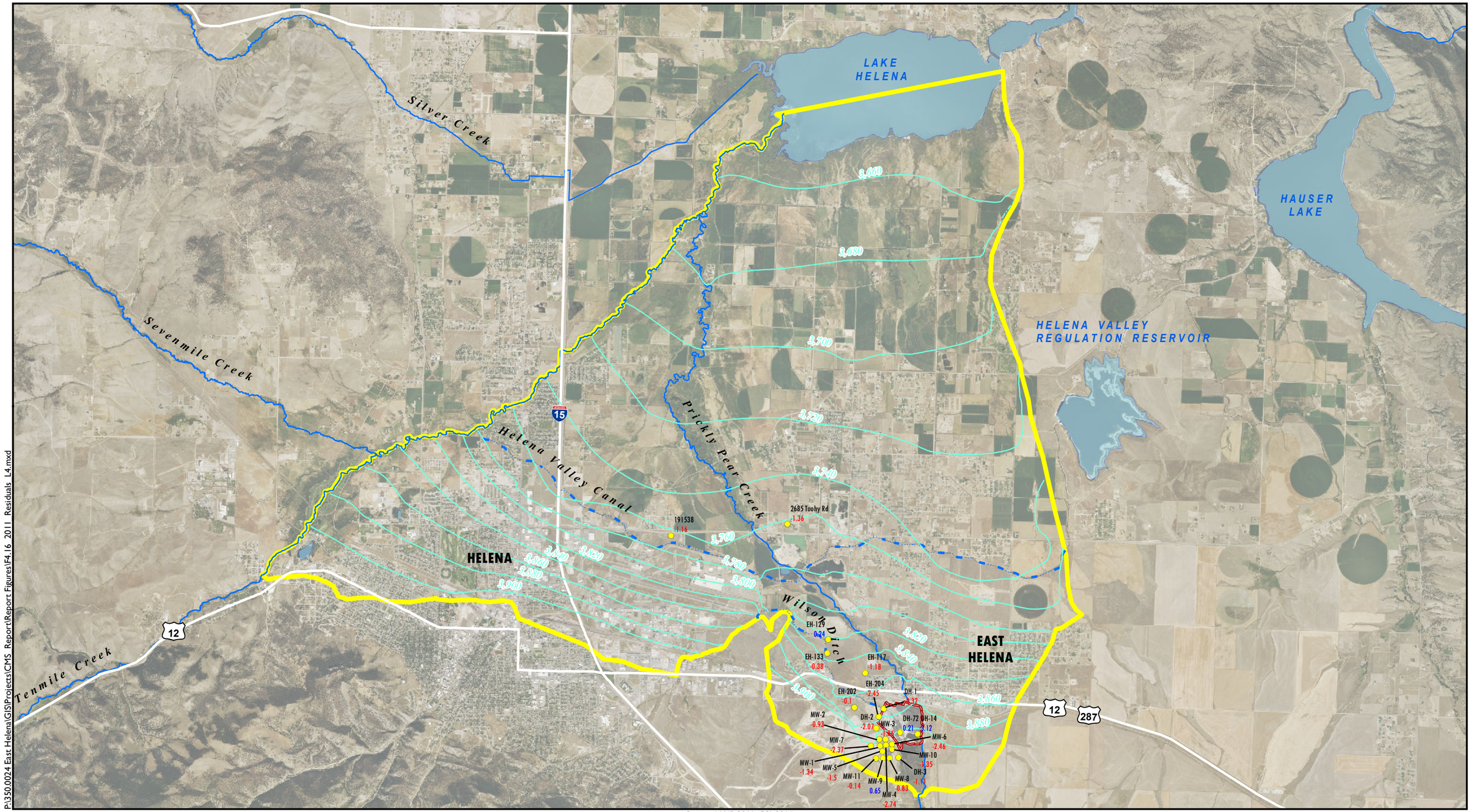
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2011 Steady-State Residuals and Potentiometric Surface - Layer 3
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.15



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.16 2011 Residuals L4.mxd

Source: NAIP, 2011; GSI, 2014

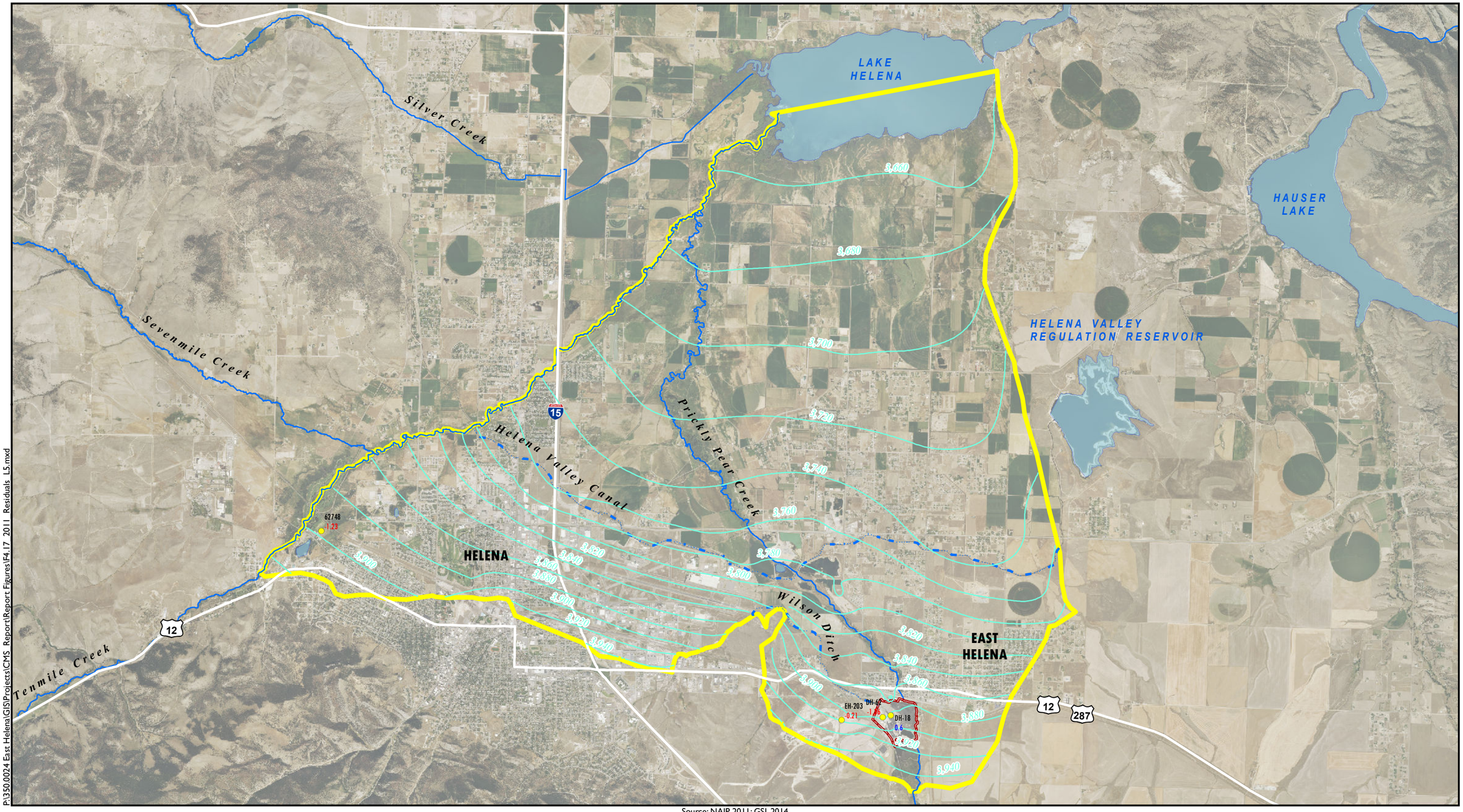
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2011 Steady-State Residuals and Potentiometric Surface - Layer 4
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.16



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.17 2011 Residuals L5.mxd

Source: NAIP, 2011; GSI, 2014

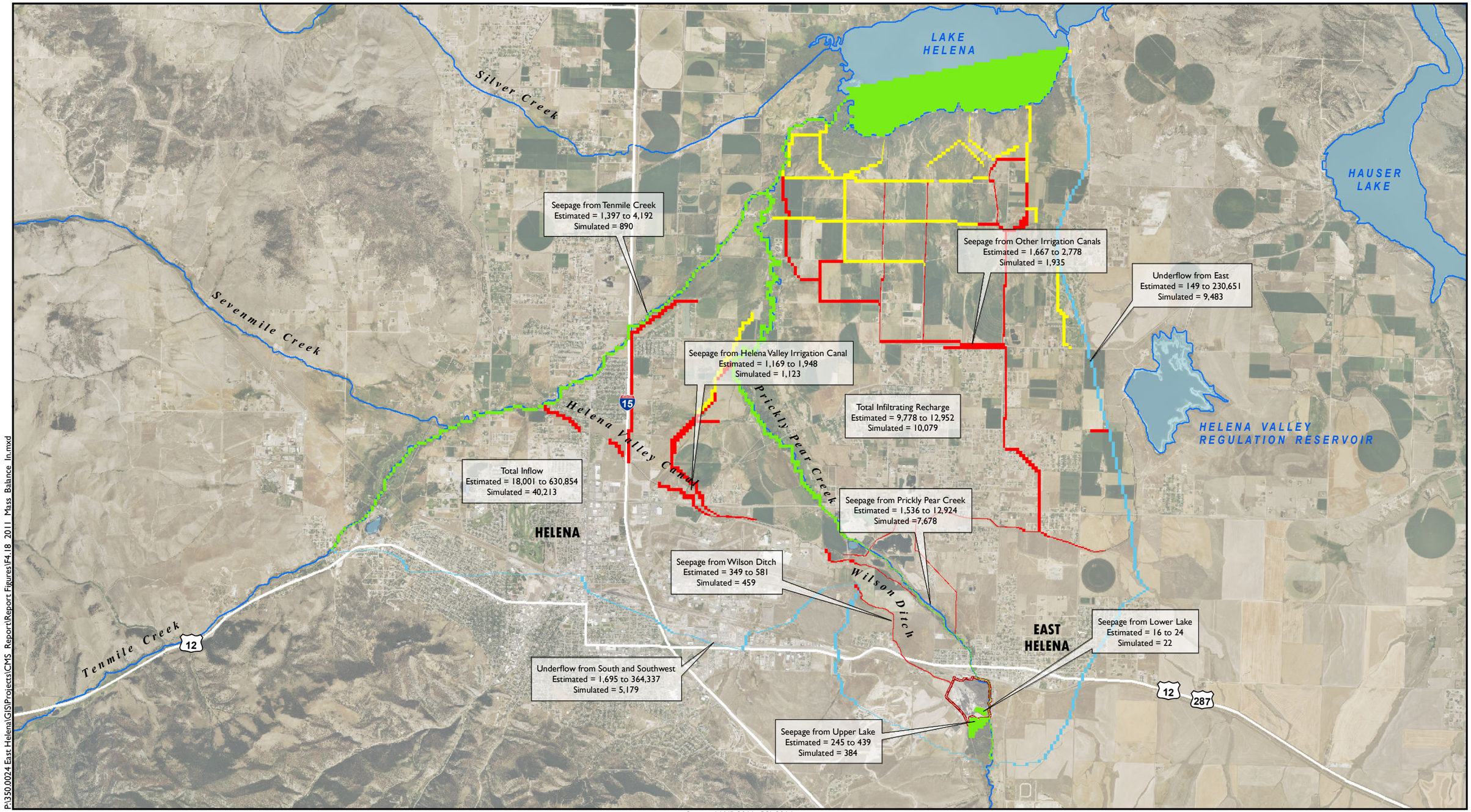
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2011 Steady-State Residuals and Potentiometric Surface - Layer 5
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.17



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.18 2011 Mass Balance In.mxd

Source: NAIP, 2011; GSI, 2014

Boundary Condition

- Well Package Cell
- River Package Cell
- General Head Package Cell
- Drain Package Cell
- Former Smelter Site Boundary

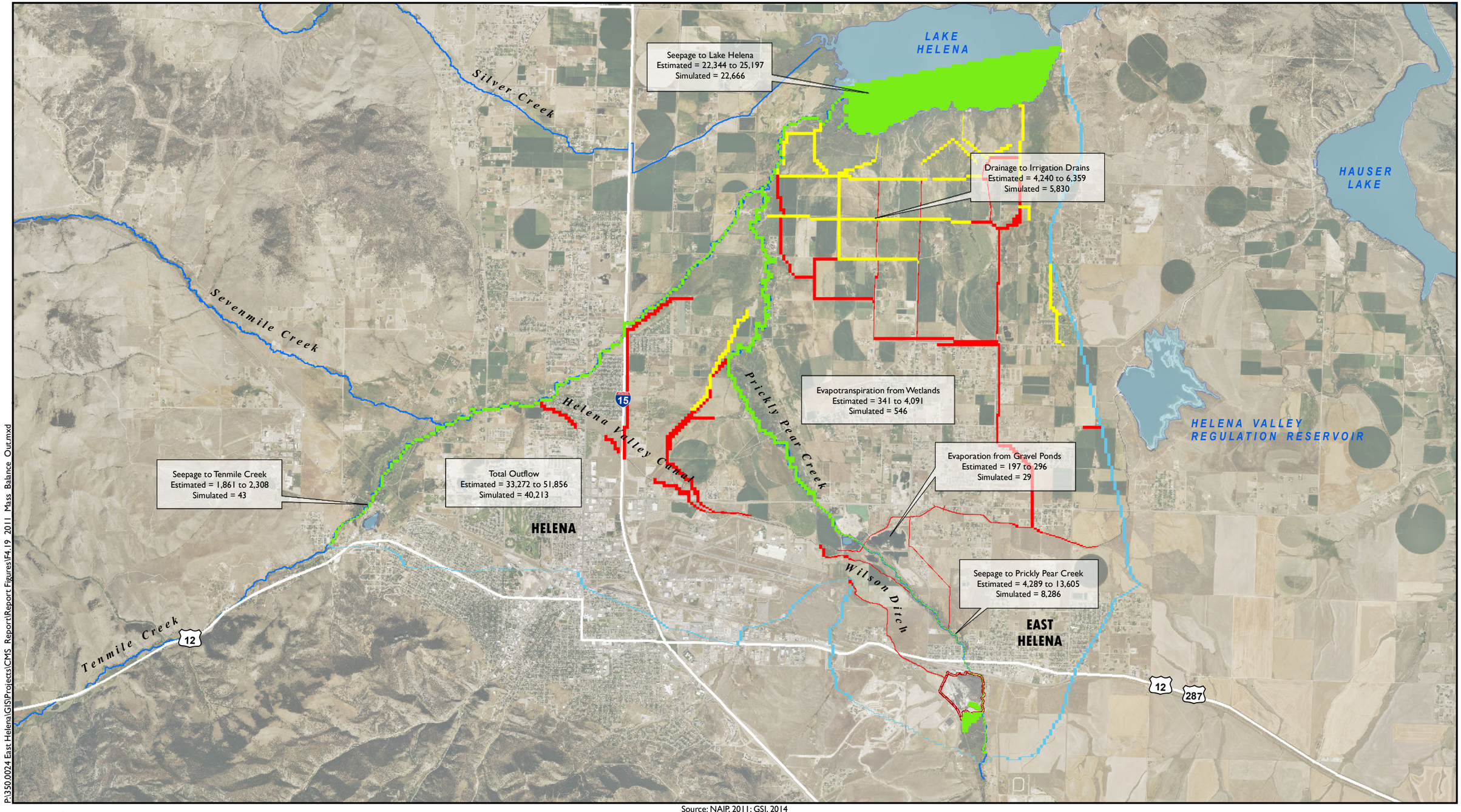
Notes:
1) All values are in acre-feet per year.

2) Results are from NewFields (2016a).

0 Feet 6,000

NewFields

2011 Steady-State Mass Balance Inflow
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.18



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.19 2011 Mass Balance Out.mxd

Source: NAIP, 2011; GSI, 2014

Boundary Condition

- Well Package Cell
- River Package Cell
- General Head Package Cell
- Drain Package Cell
- Former Smelter Site Boundary

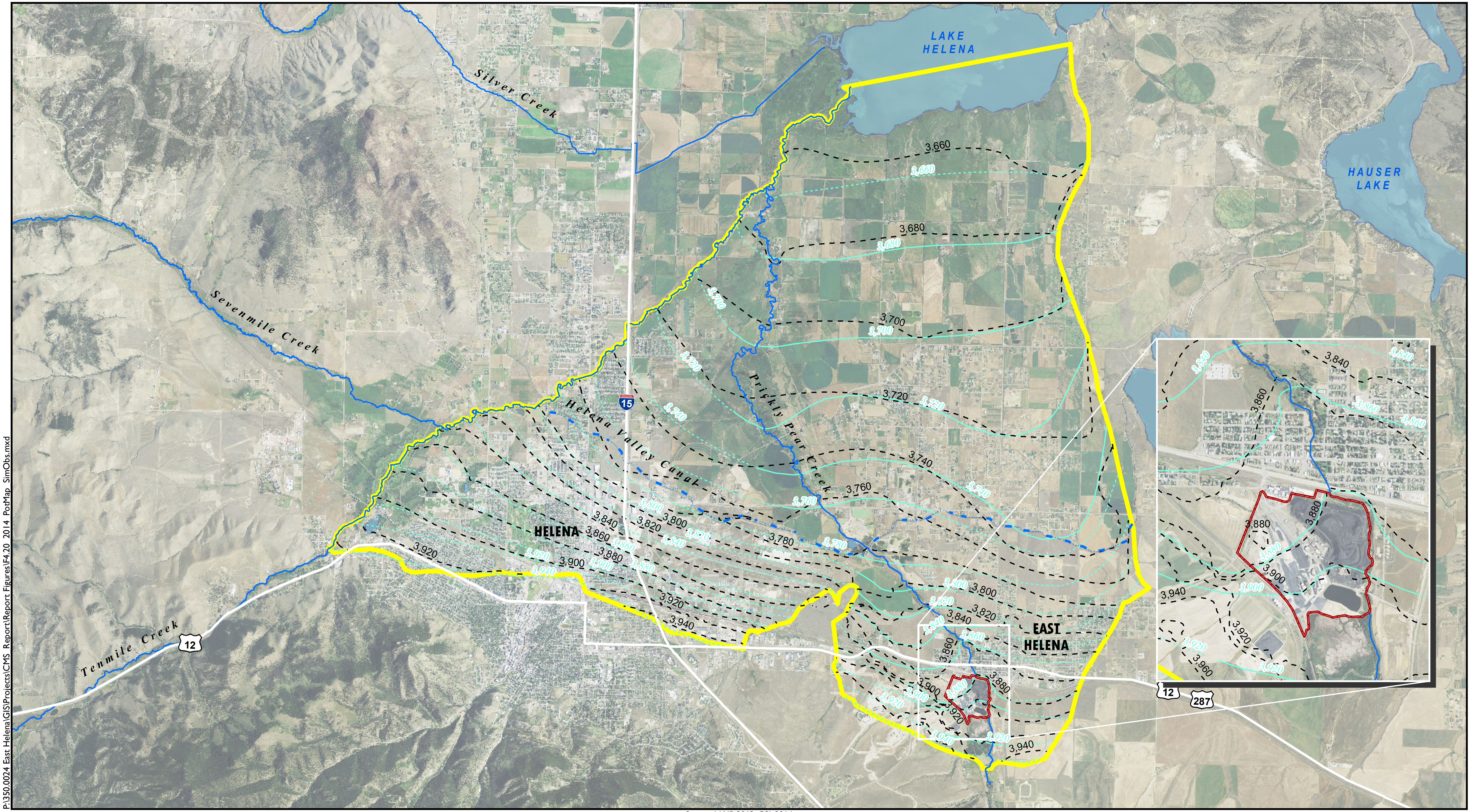
0 Feet 6,000

NewFields

Notes:
1) All values are in acre-feet per year.

2) Results are from NewFields (2016a).

2011 Steady-State Mass Balance Outflow
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.19



Source: NAIP, 2013; GSI, 2014

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.20 2014 PotMap SimObs.mxd

0 Feet 6,000

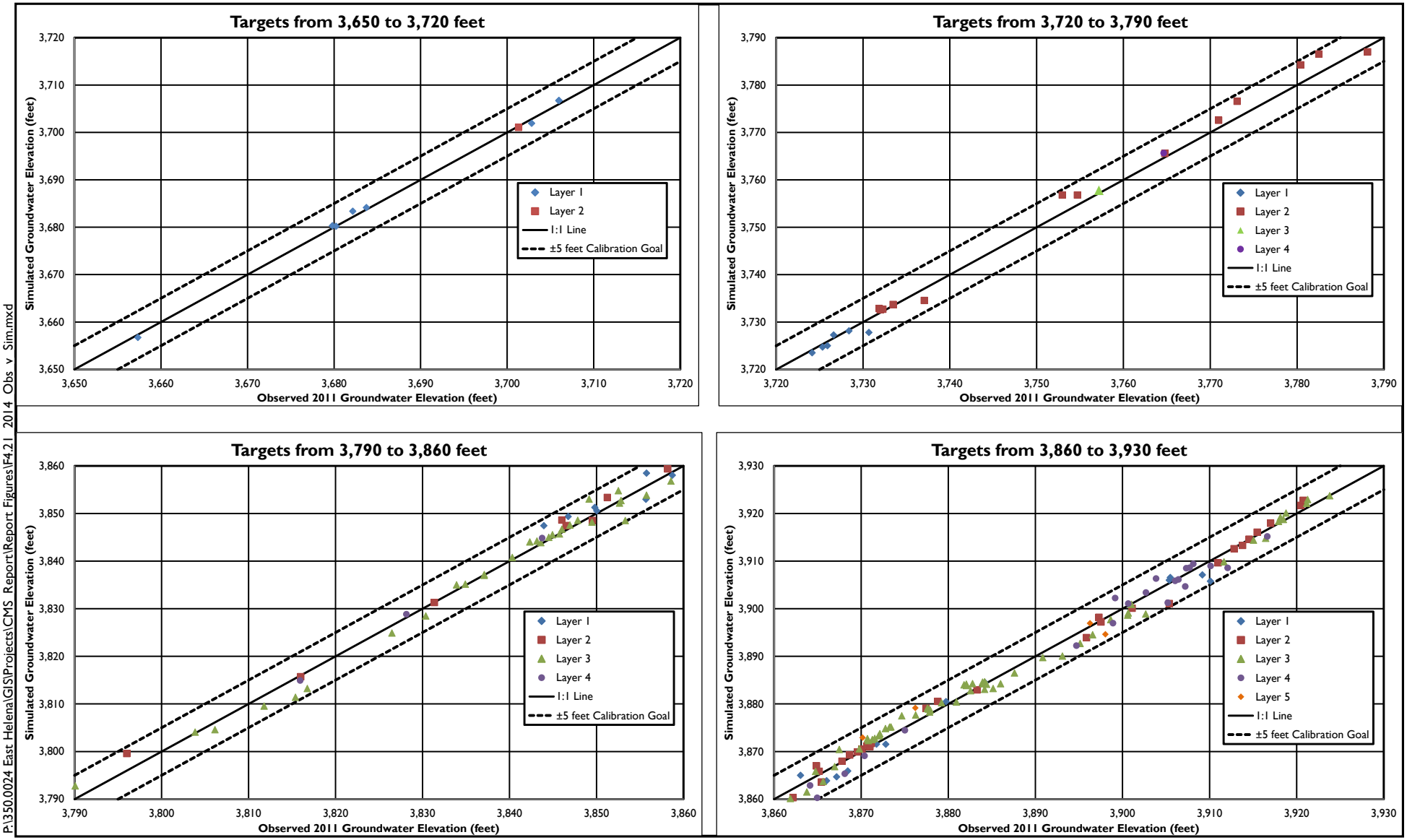
NewFields

Notes:
1) Observed potentiometric surface was developed using average 2014 groundwater elevations.

2) Results are from NewFields (2016a).

- Simulated potentiometric contour (feet above mean sea level)
- Potentiometric contour (feet above mean sea level)
- Inferred potentiometric contour
- Former Smelter Site Boundary
- Model Domain

2014 Simulated Steady-State and Observed Potentiometric Surfaces
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.20

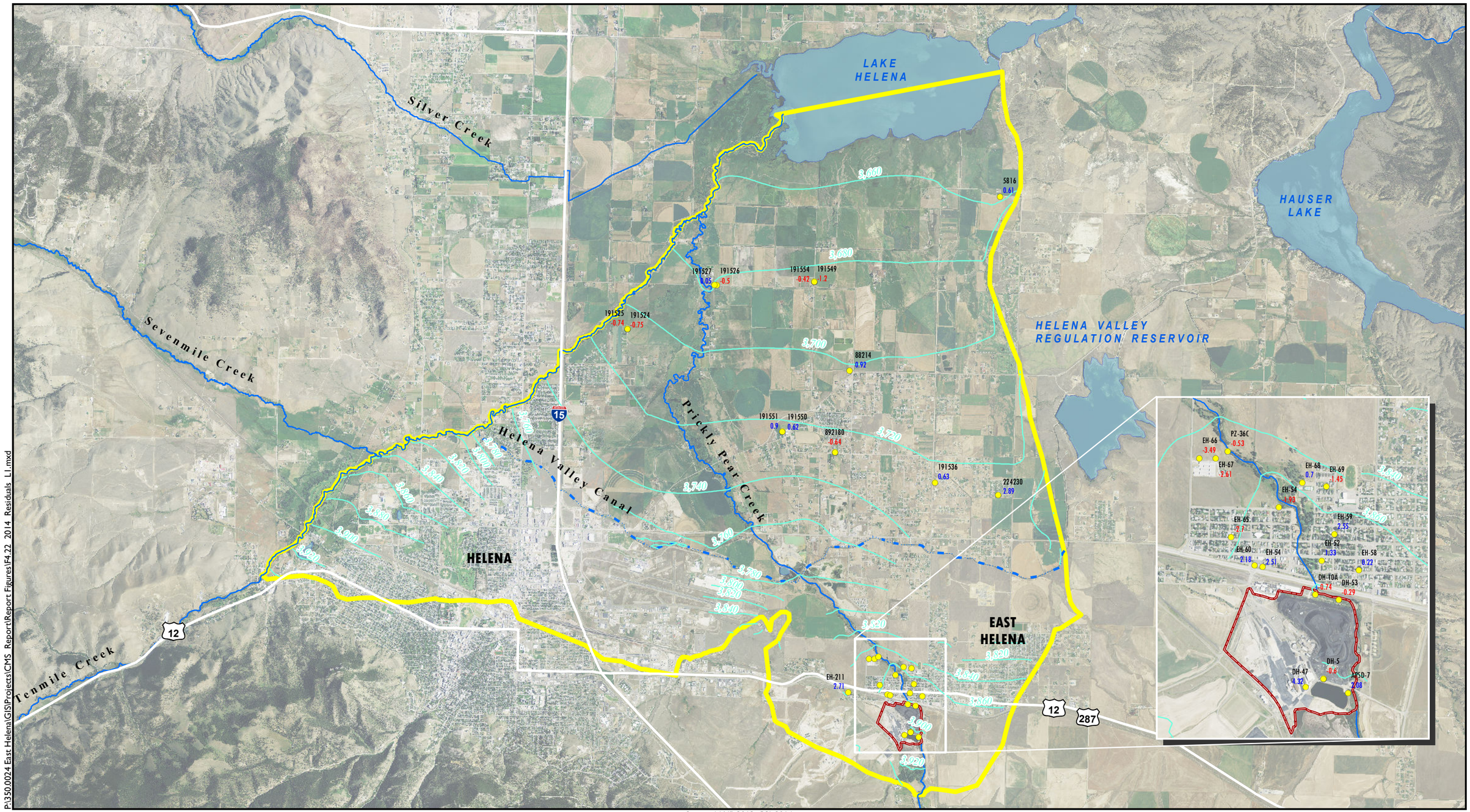


P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.21 2014 Obs v Sim.mxd

NewFields

Note: Results are from NewFields (2016a).

2014 Observed versus Simulated Steady-State Groundwater Elevations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.21



Source: NAIP, 2013; GSI, 2014

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.22 2014 Residuals LI.mxd

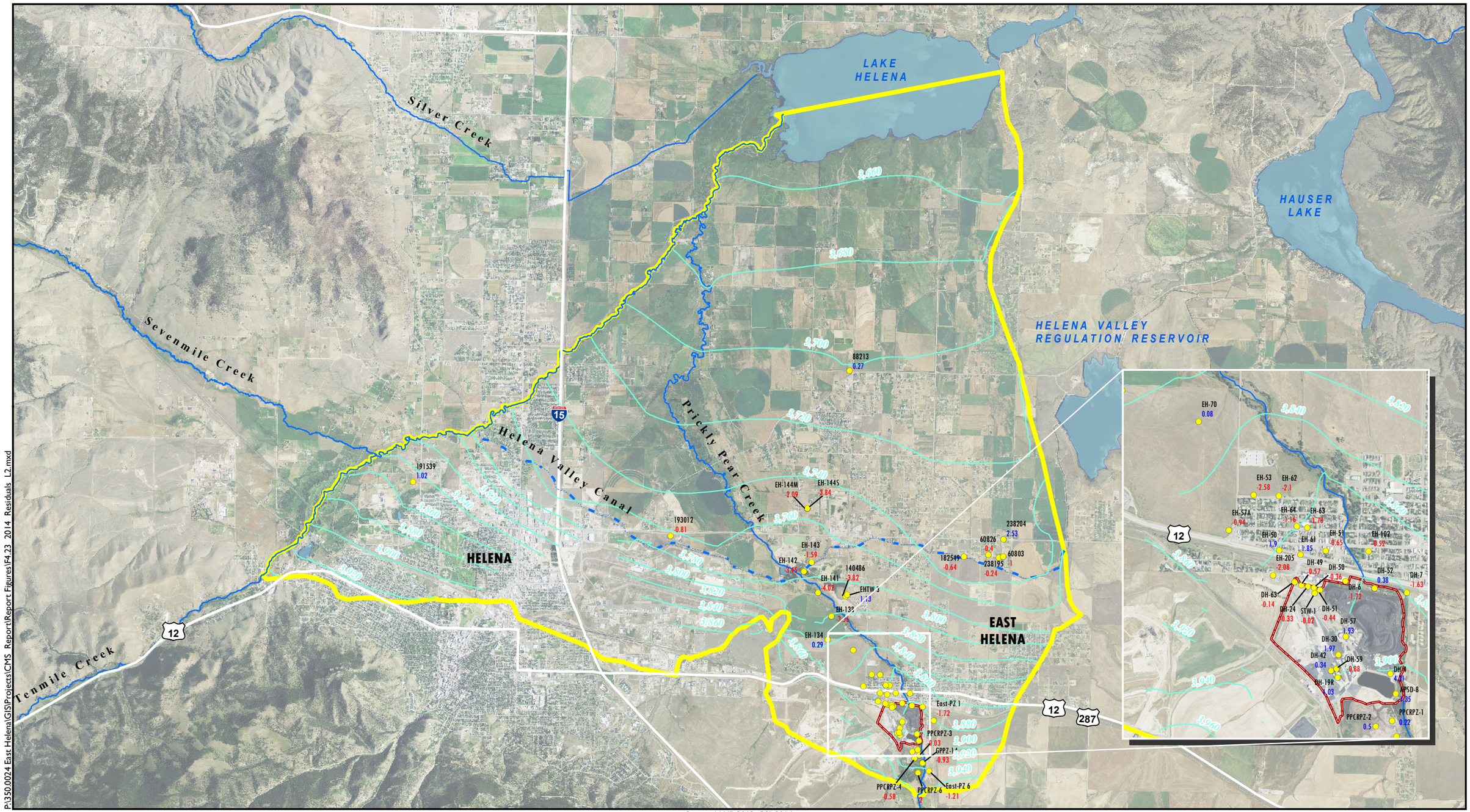
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2014 Steady-State Residuals and Potentiometric Surface - Layer 1
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.22



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.23 2014 Residuals L2.mxd

Source: NAIP, 2013; GSI, 2014

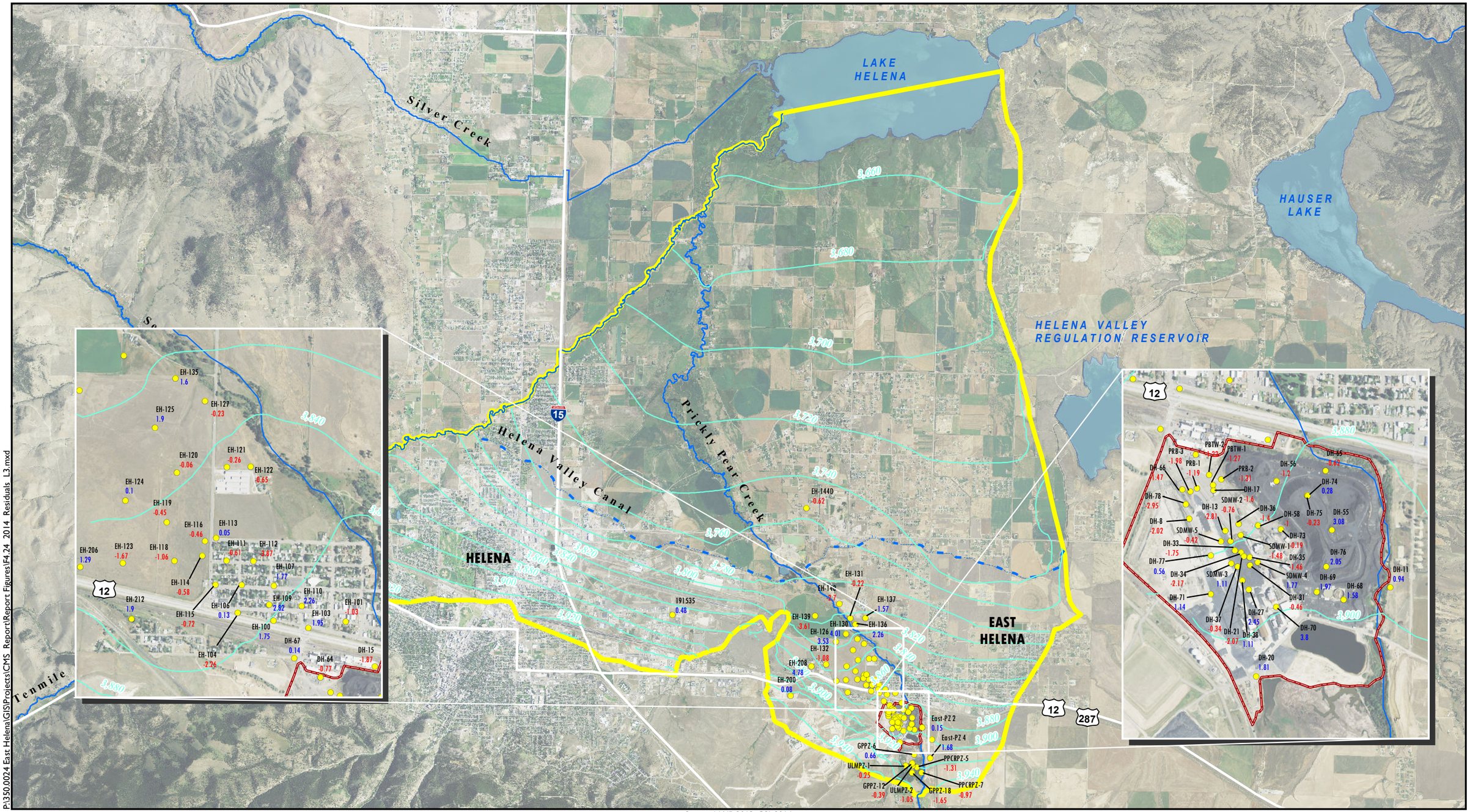
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2014 Steady-State Residuals and Potentiometric Surface - Layer 2
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.23



Source: NAIP, 2013; GSI, 2014

P:\350\0024 East Helena\GIS\Projects\CMS Report\Report Figures\f4.24 2014 Residuals L3.mxd

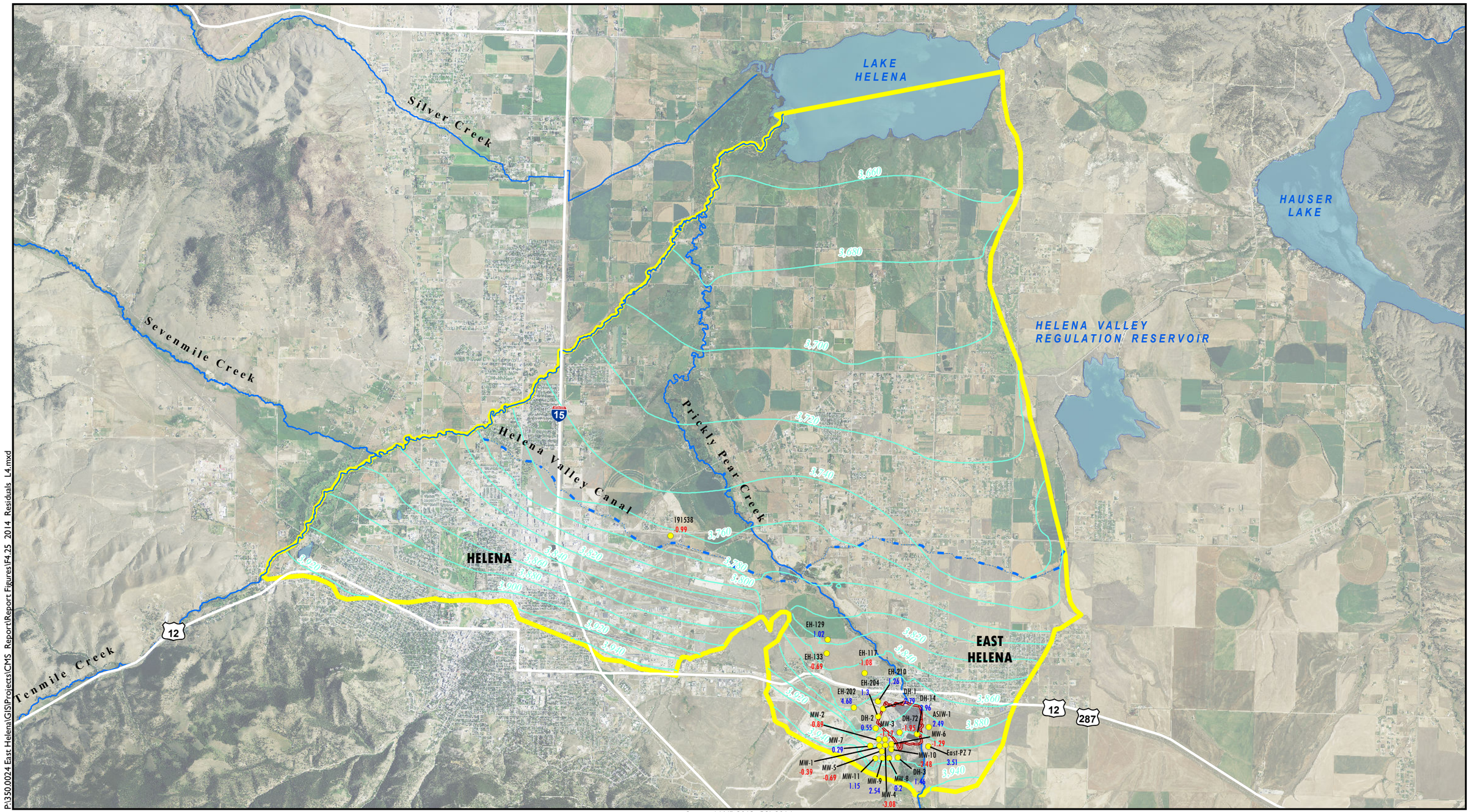
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2014 Steady-State Residuals and Potentiometric Surface - Layer 3
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.24



Source: NAIP, 2013; GSI, 2014

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.25 2014 Residuals L4.mxd

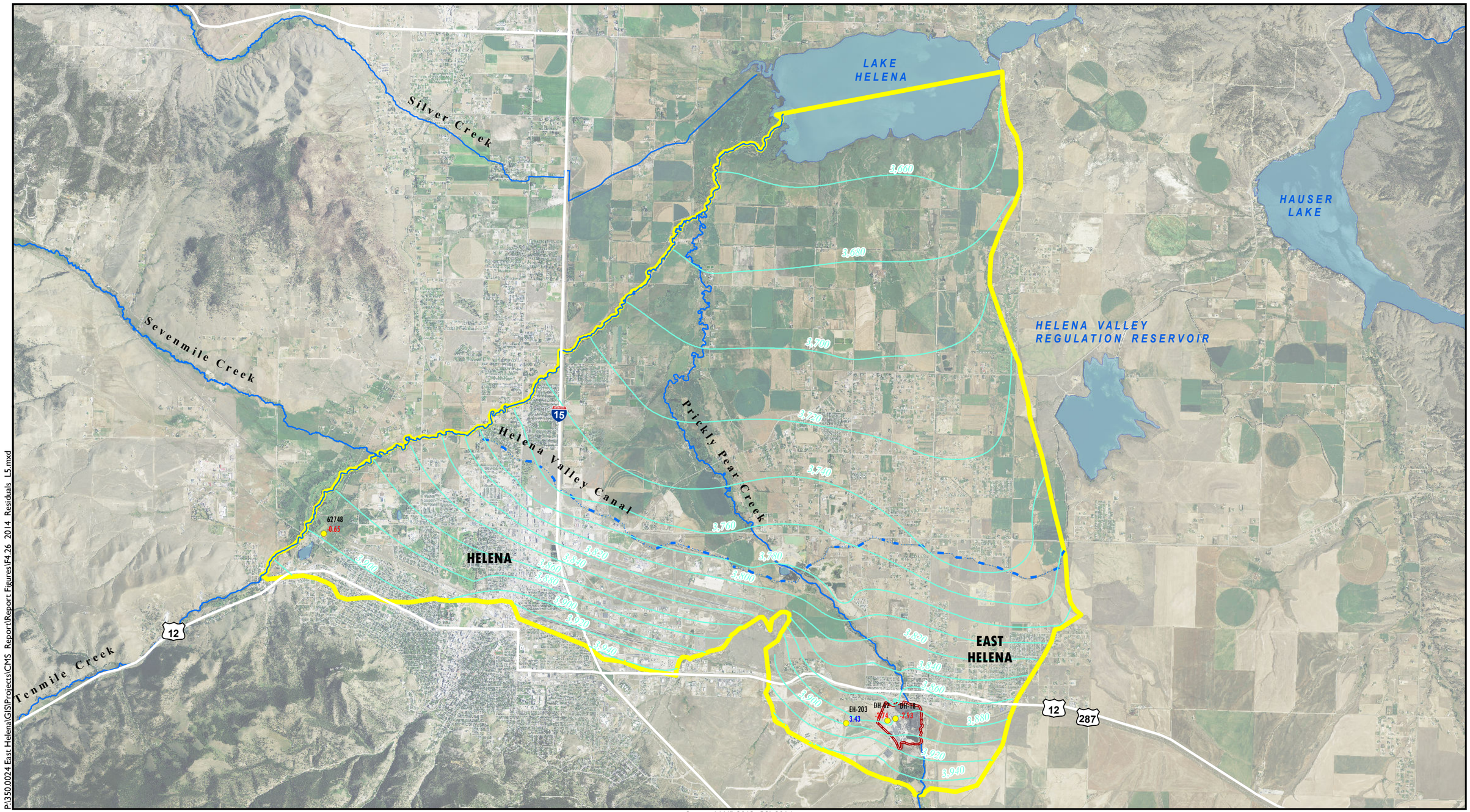
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2014 Steady-State Residuals and Potentiometric Surface - Layer 4
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.25



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.26 2014 Residuals L5.mxd

Source: NAIP, 2013; GSI, 2014

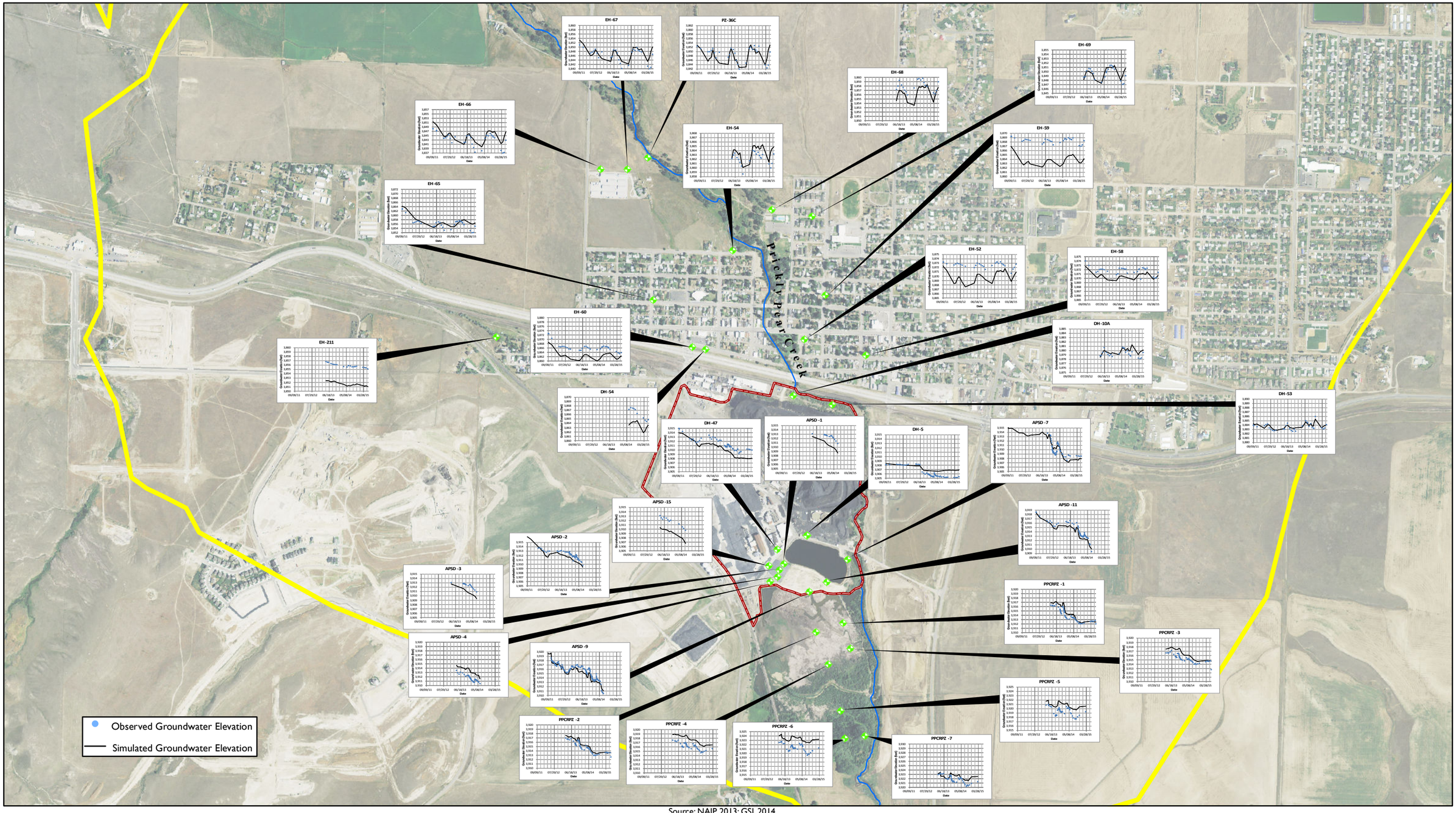
0 Feet 6,000

NewFields

Note: Results are from NewFields (2016a).

- Groundwater Elevation Target
- 3.28 Positive Residual (feet under predicted)
- -1.89 Negative Residual (feet over predicted)
- Simulated Potentiometric Contour (feet)
- Former Smelter Site Boundary
- Model Domain

Spatial Distribution of 2014 Steady-State Residuals and Potentiometric Surface - Layer 5
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.26



Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

NewFields

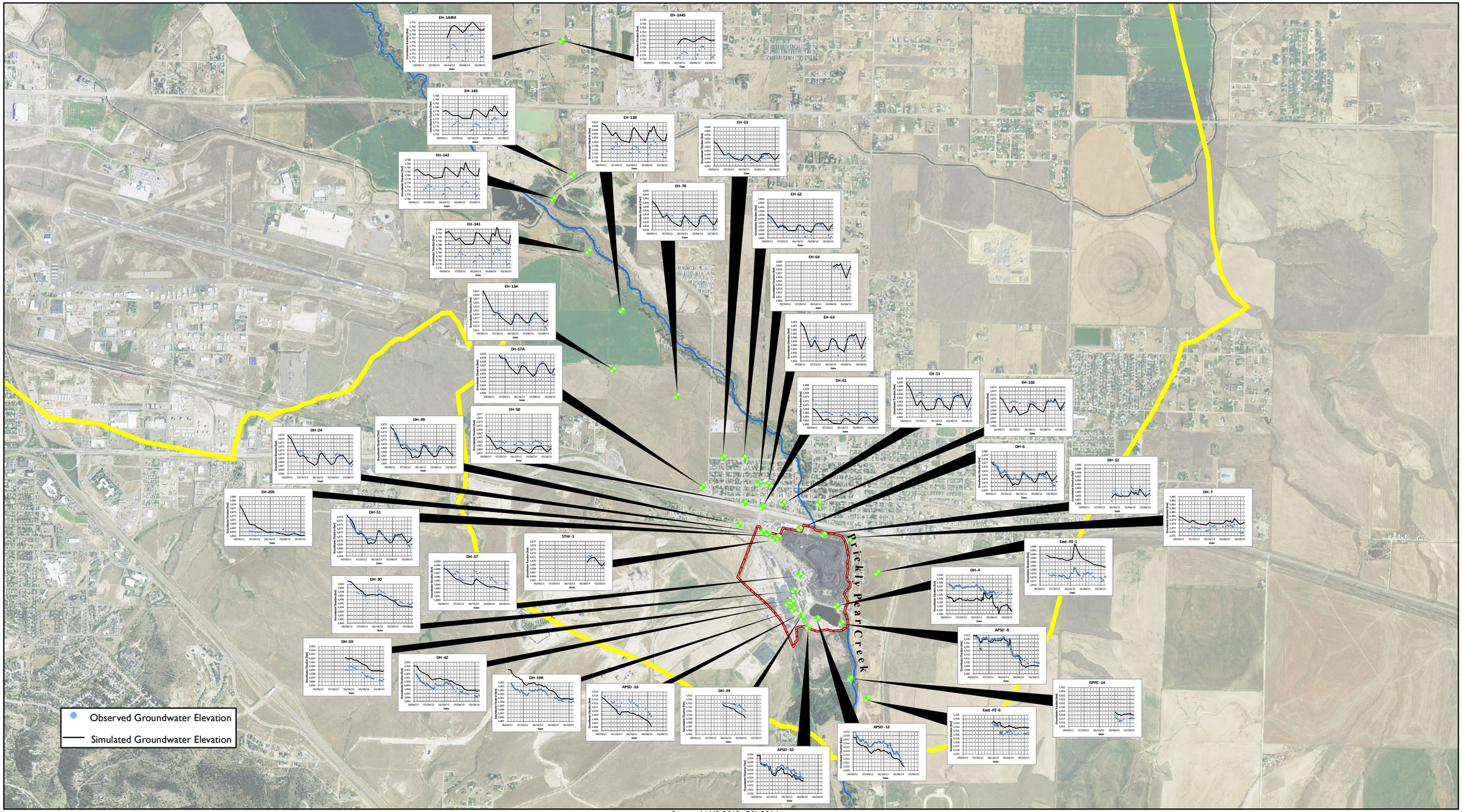
Transient Groundwater Elevation Target

Former Smelter Site Boundary

Model Domain

Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 1
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.27



Source: NAIP, 2013; GSI, 2014

0 Feet 2,400

NewFields

Transient Head Target

Former Smelter Site Boundary

Model Domain

Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 2
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.28

Prickly Pear Creek

EH-144D

EH-140

EH-136

EH-137

EH-130

EH-131

EH-135

EH-127

EH-139

EH-125

EH-121

EH-126

EH-122

EH-120

EH-116

EH-124

EH-132

EH-113

EH-128

EH-114

EH-111

EH-200

EH-123

EH-119

EH-118

EH-115

EH-110

EH-107

Observed Groundwater Elevation

Simulated Groundwater Elevation

Source: NAIP, 2013; GSI, 2014

0 Feet 1,600

NewFields

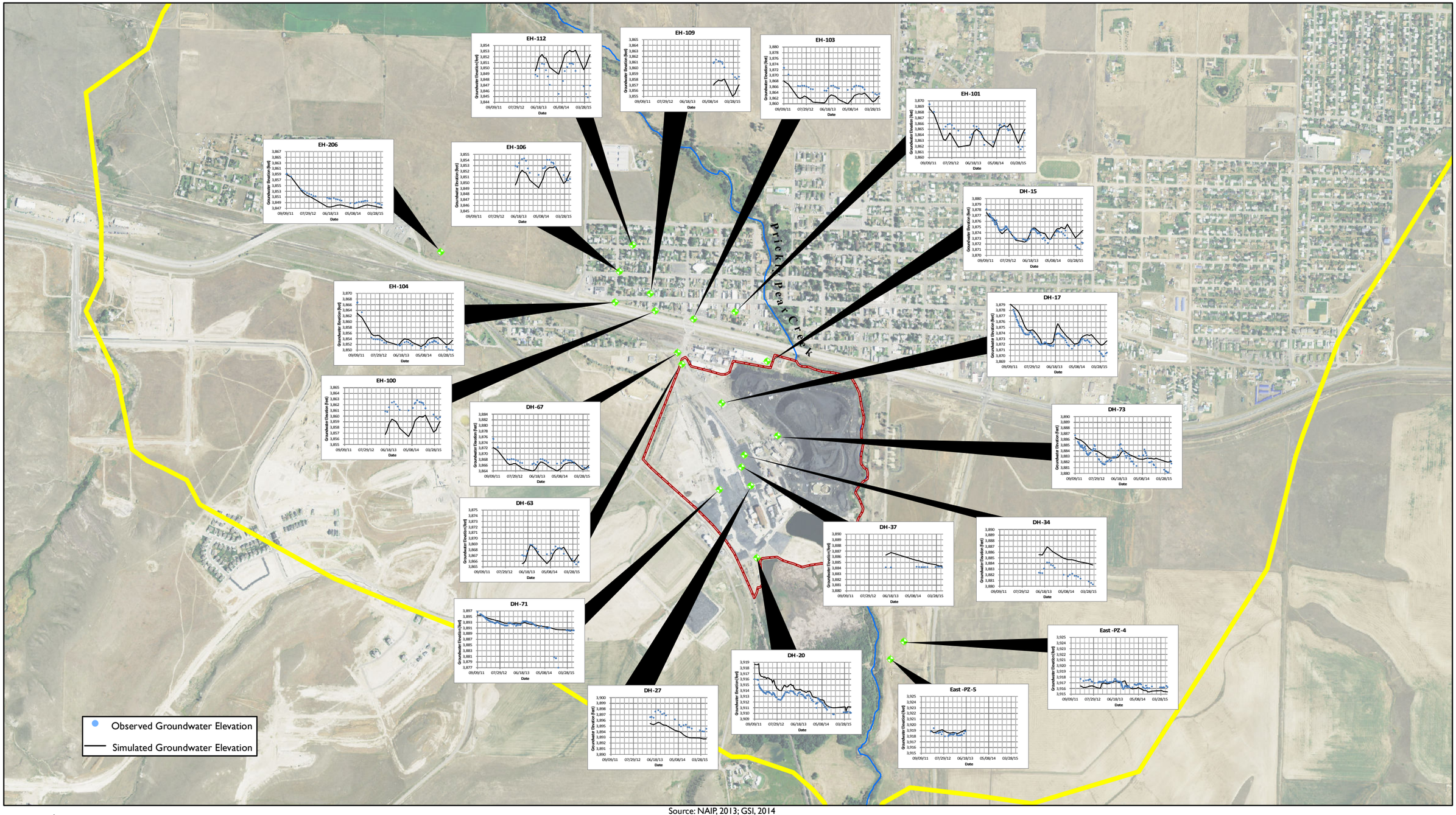
Transient Groundwater Elevation Target

Former Smelter Site Boundary

Model Domain

Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 3
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.29a



Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

NewFields

Transient Groundwater Elevation Target

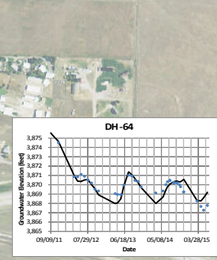
Former Smelter Site Boundary

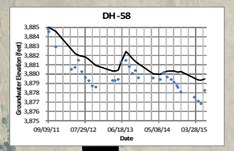
Model Domain

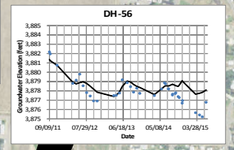
Note: Results are from NewFields (2016a).

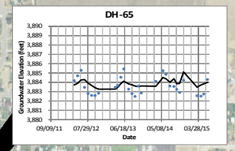
Transient Calibration Hydrographs - Layer 3
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.29b

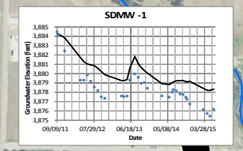
Prickly Pear Creek

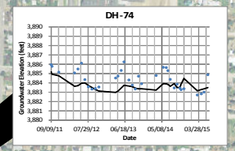


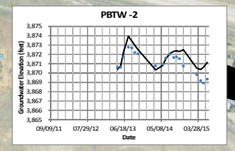


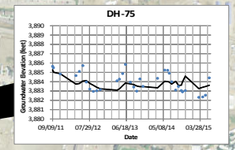


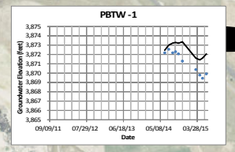


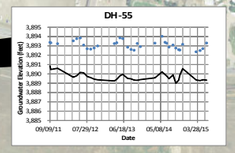


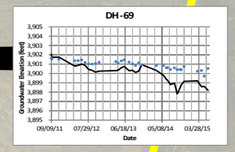


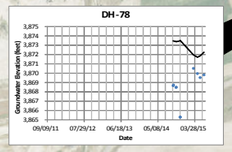


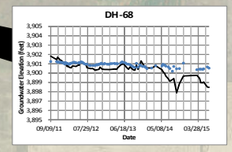


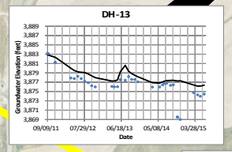


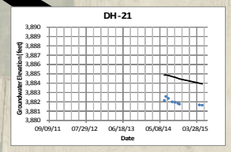


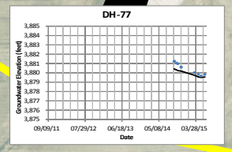


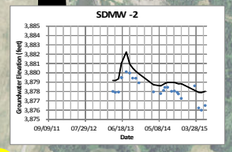


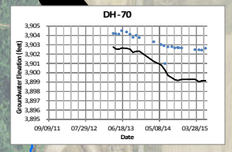












Observed Groundwater Elevation

Simulated Groundwater Elevation

Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

NewFields

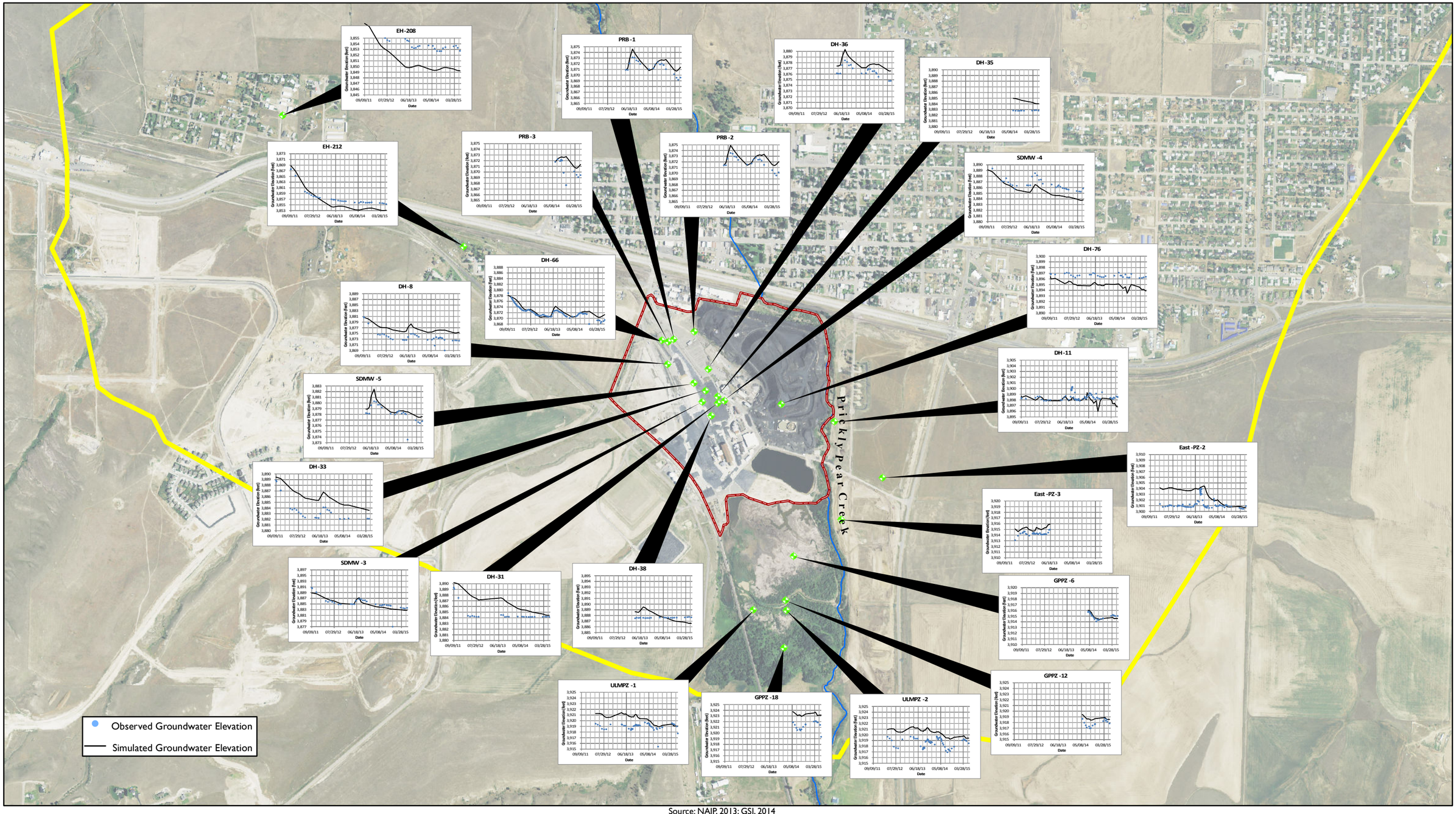
Transient Groundwater Elevation Target

Former Smelter Site Boundary

Model Domain

Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 3
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.29c



Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

NewFields

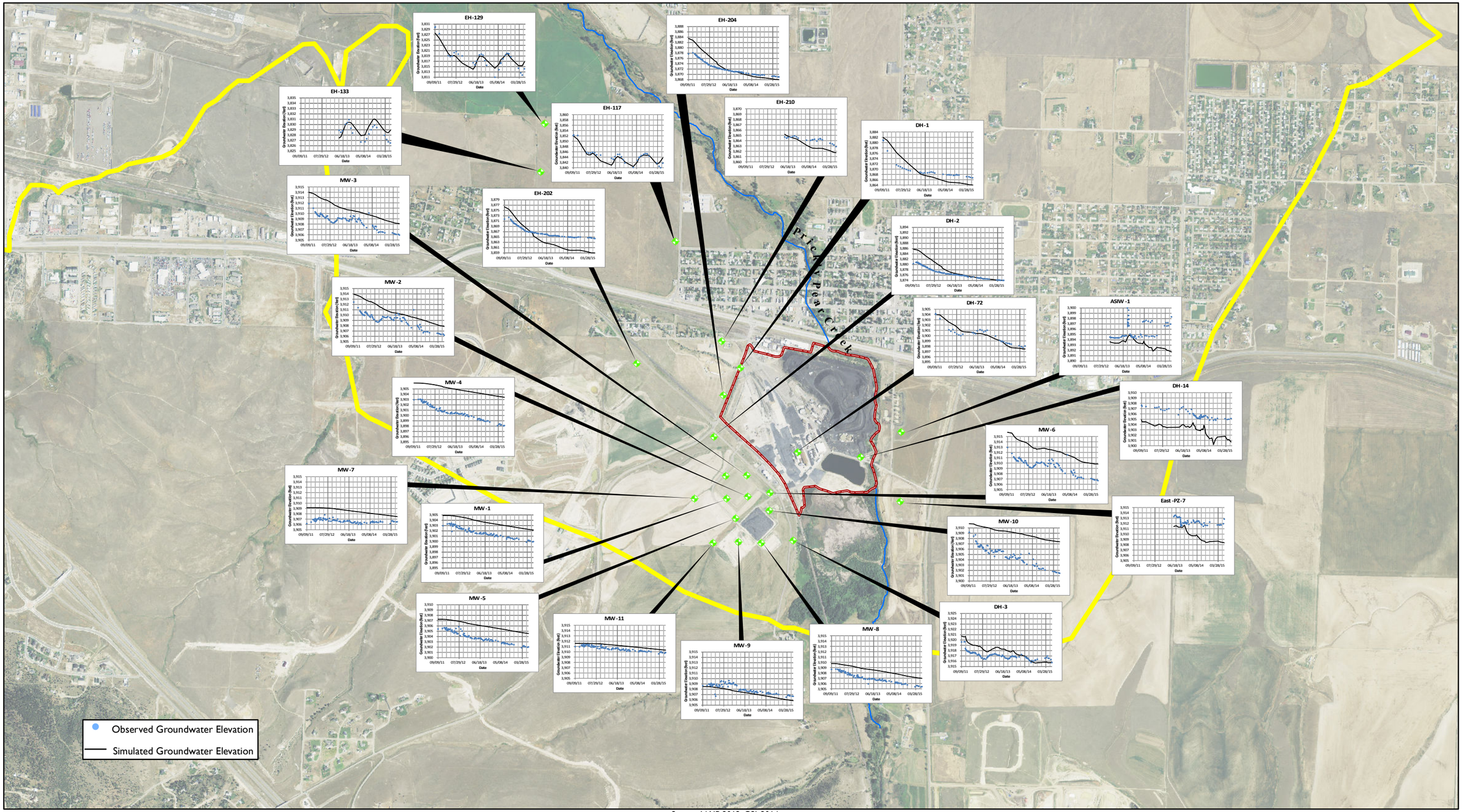
Transient Groundwater Elevation Target

Former Smelter Site Boundary

Model Domain

Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 3
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.29d



Source: NAIP, 2013; GSI, 2014

0 Feet 1,700

NewFields

Transient Groundwater Elevation Target

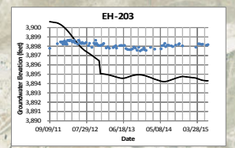
Former Smelter Site Boundary

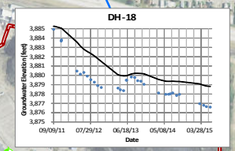
Model Domain

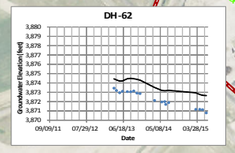
Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 4
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.30

Prickly Pear Creek







Observed Groundwater Elevation
Simulated Groundwater Elevation

Source: NAIP, 2013; GSI, 2014

N

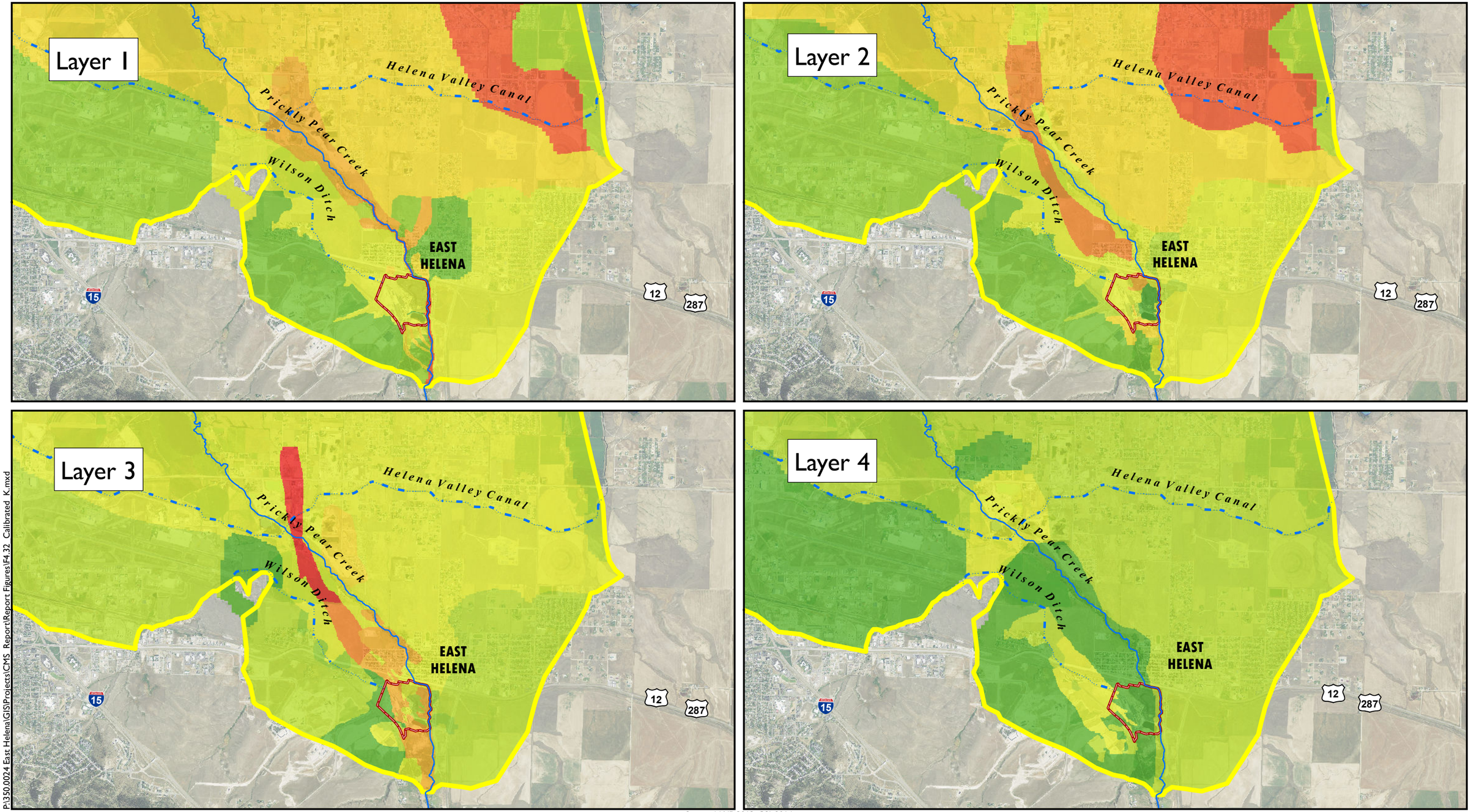
0 Feet 1,200

NewFields

Transient Groundwater Elevation Target
Former Smelter Site Boundary
Model Domain

Note: Results are from NewFields (2016a).

Transient Calibration Hydrographs - Layer 5
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.31

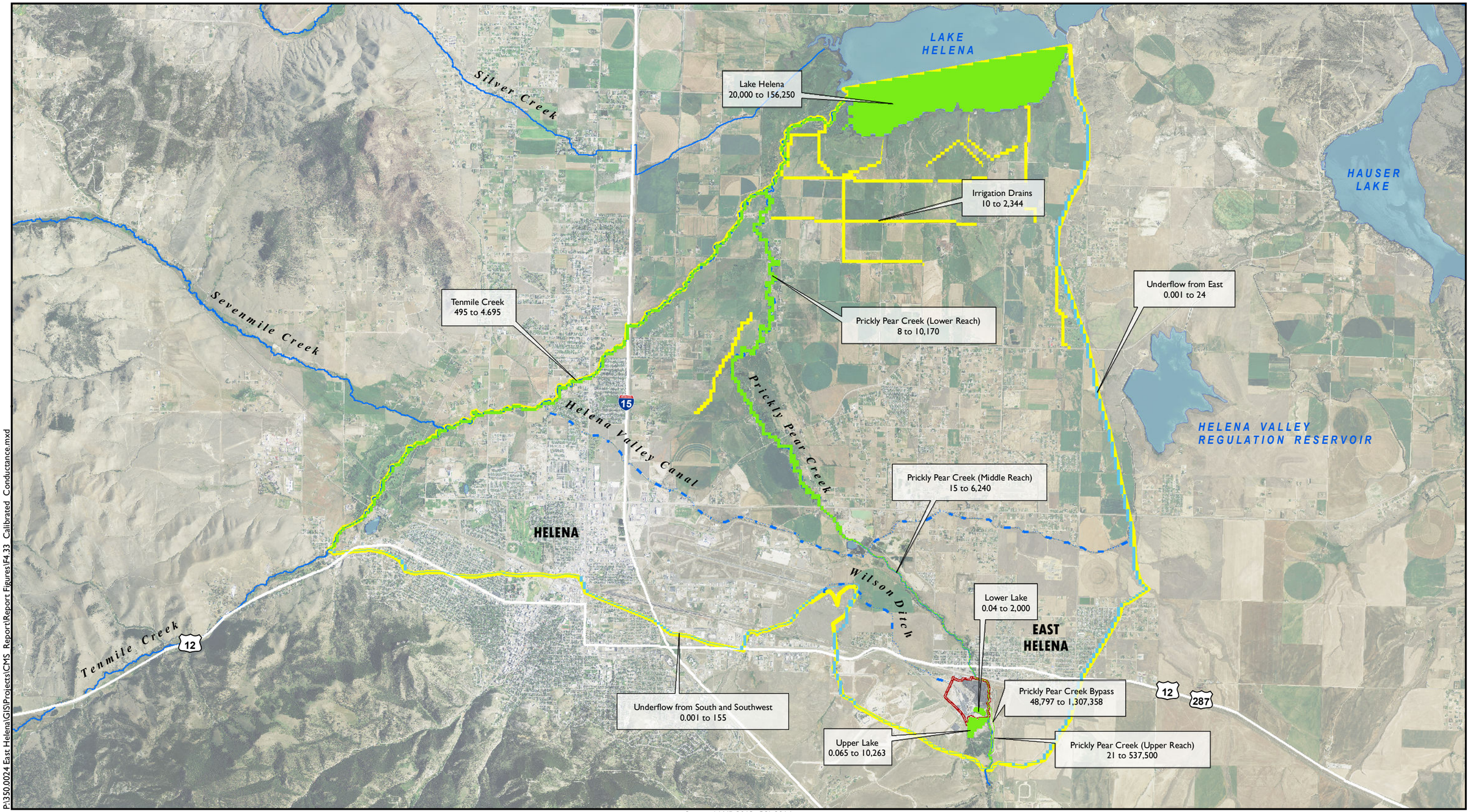


P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.32 Calibrated K.mxd

Source: NAIP, 2013; GSI, 2014

Note: Results are from NewFields (2016a).

Calibrated Hydraulic Conductivity
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.32



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.33 Calibrated Conductance.mxd

Source: NAIP, 2013; GSI, 2014

Boundary Condition

- River Package Cell
- General Head Package Cell
- Drain Package Cell
- Former Smelter Site Boundary
- Model Domain

Notes:
1) Conductance values are in feet² per day.

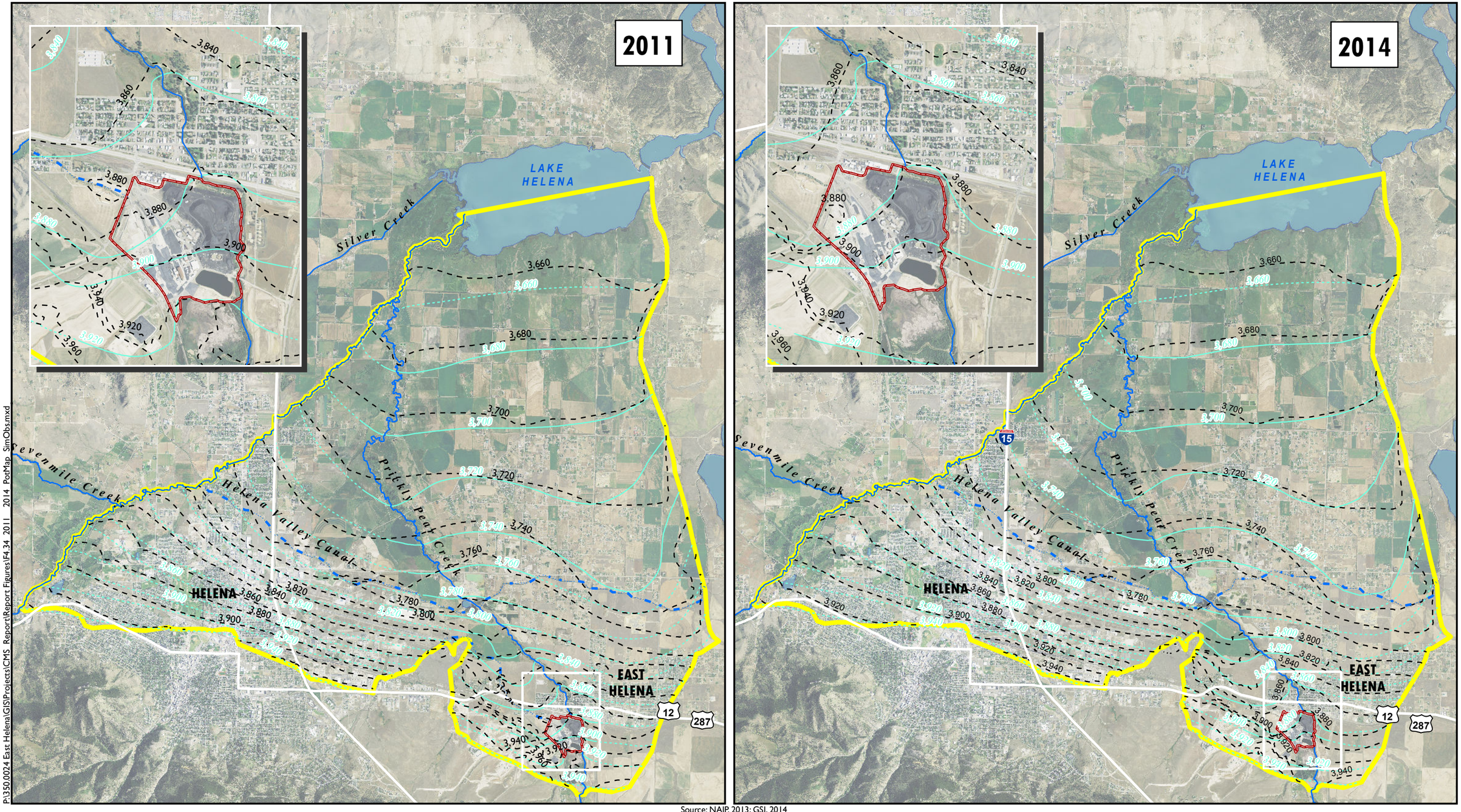
2) Results are from NewFields (2016a).

0 Feet 6,000

NewFields

Calibrated Conductance for Head-Dependant Boundaries
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.33

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.34 2011 2014 PotMap SimObs.mxd



Source: NAIP, 2013; GSI, 2014

0 Feet 7,000

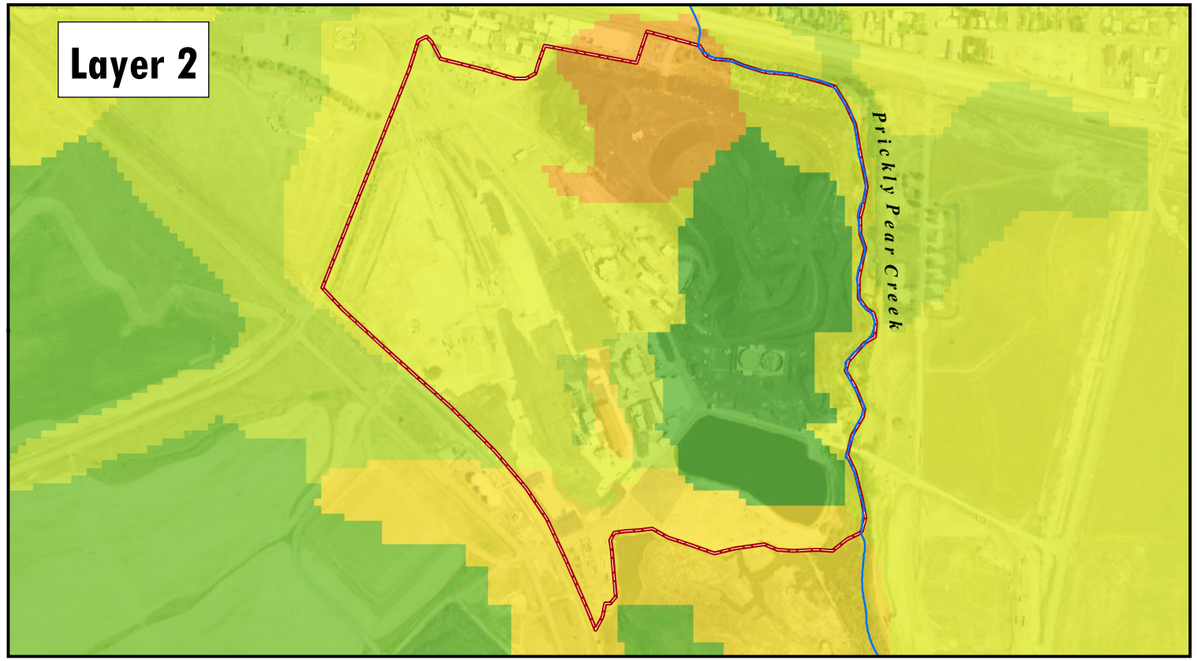
NewFields

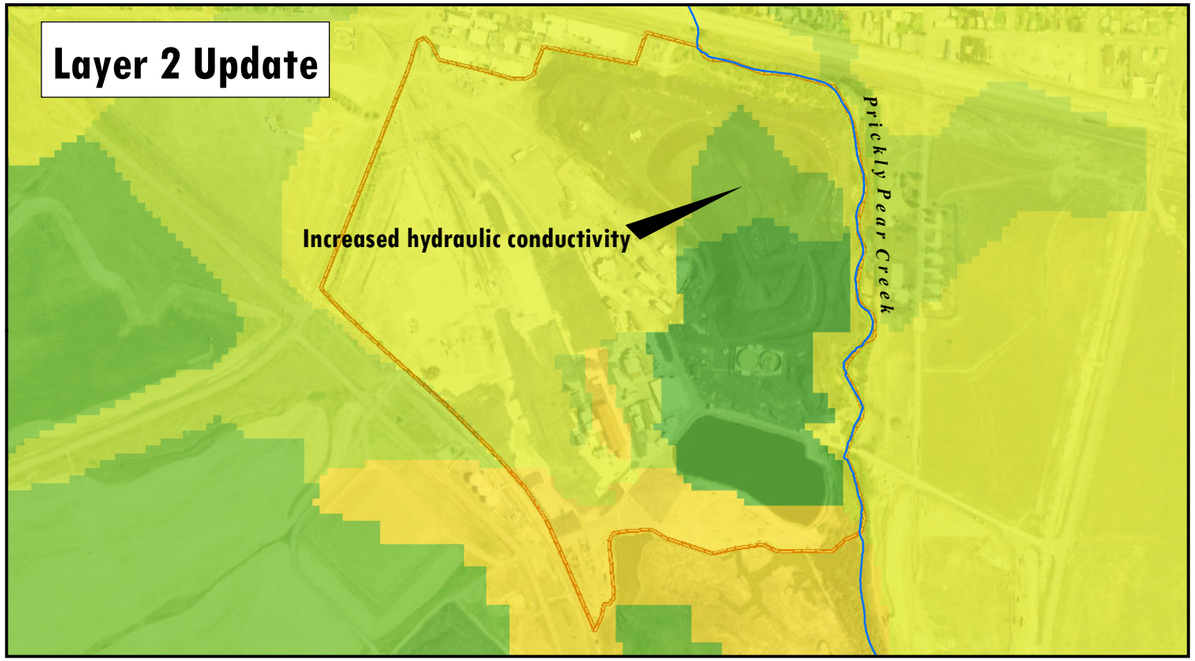
Notes:
1) Observed potentiometric surface was developed using average 2011 and 2014 groundwater elevations.

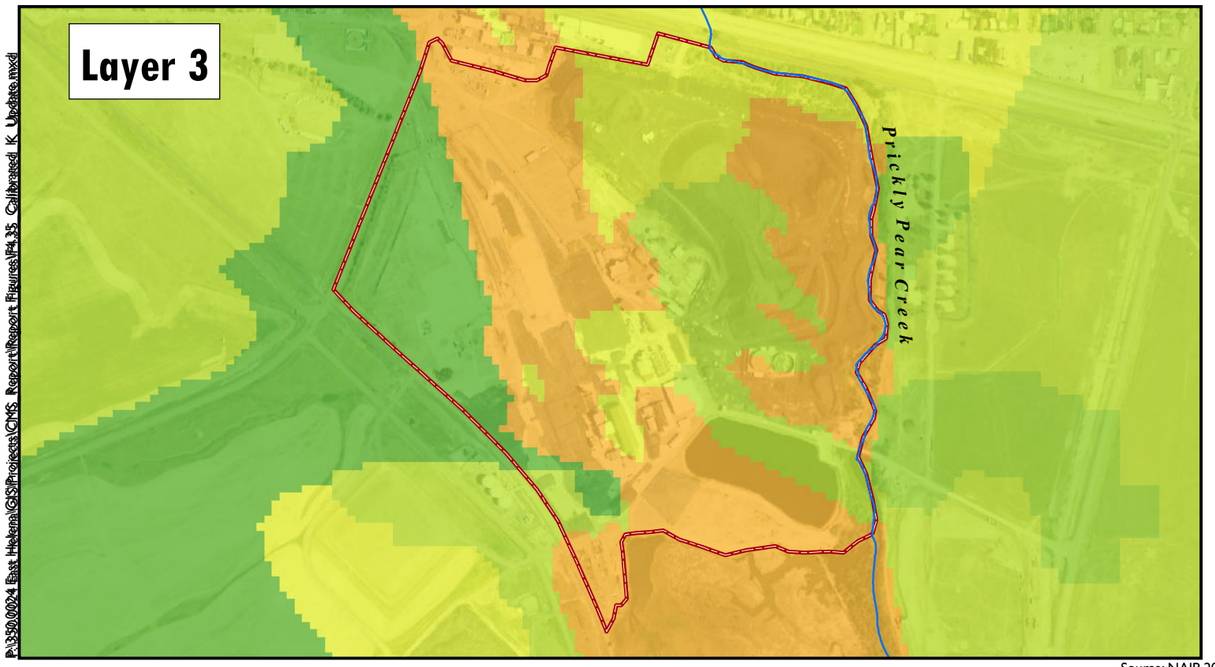
2) Results are from NewFields (2016b).

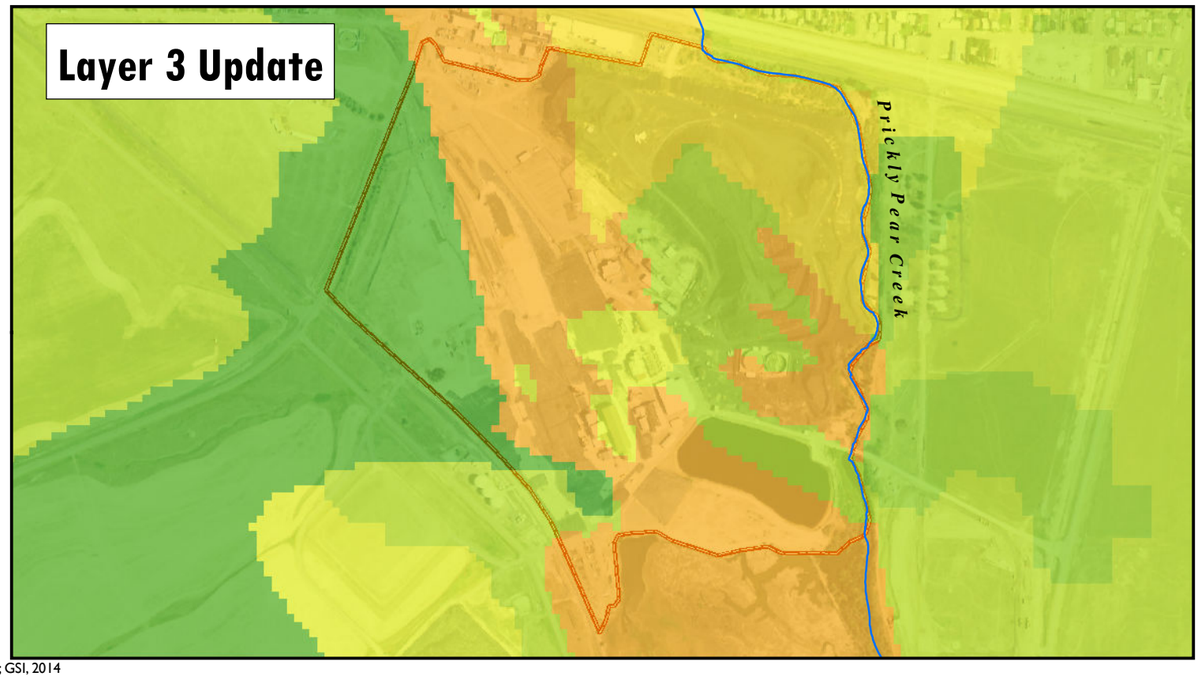
- Simulated potentiometric contour (feet above mean sea level)
- Potentiometric contour (feet above mean sea level)
- Inferred potentiometric contour
- Former Smelter Site Boundary
- Model Domain

2011 and 2014 Simulated and Observed Potentiometric Surfaces
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.34









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\Fig 4.35 Calibrated K Updates.mxd

Source: NAIP, 2013; GSI, 2014

N

0 Feet 800

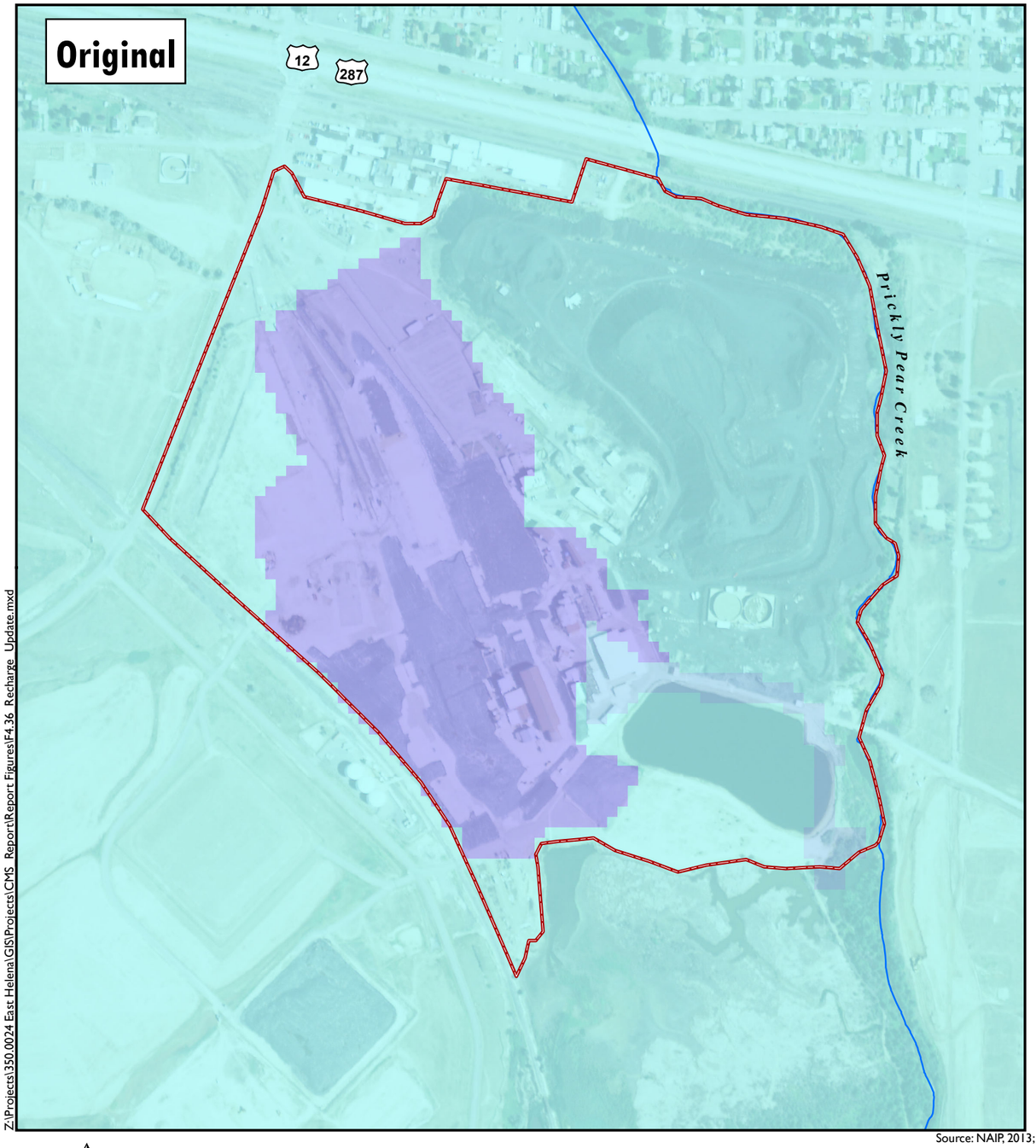
NewFields

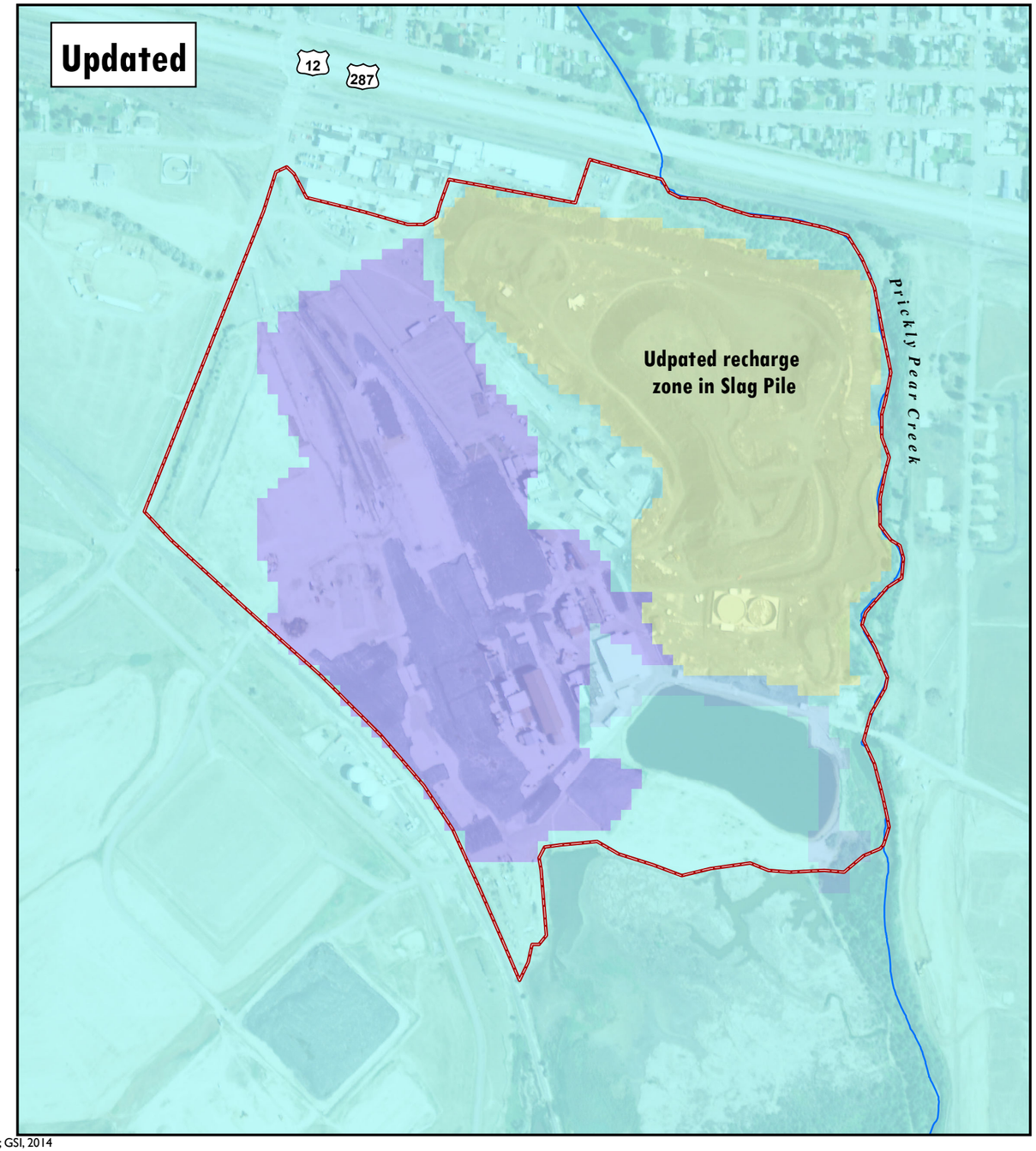
Note: Results are from NewFields (2016b).

Hydraulic Conductivity

- < 0.1
- 0.1 - 0.5
- 0.5 - 1.0
- 1.0 - 10
- 10 - 50
- 50 - 100
- 100 - 250
- 250 - 500
- 500 - 1,000
- > 1,000
- Former Smelter Site Boundary

Updated Hydraulic Conductivity Distribution
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.35





Z:\Projects\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F4.36 Recharge Update.mxd

Source: NAIP, 2013; GSI, 2014

Recharge (inches/year)

<0.01	5.0 - 7.5	20.0 - 25.0
0.01 - 1.0	7.5 - 10.0	>25.0
1.0 - 2.5	10.0 - 15.0	
2.5 - 5.0	15.0 - 20.0	

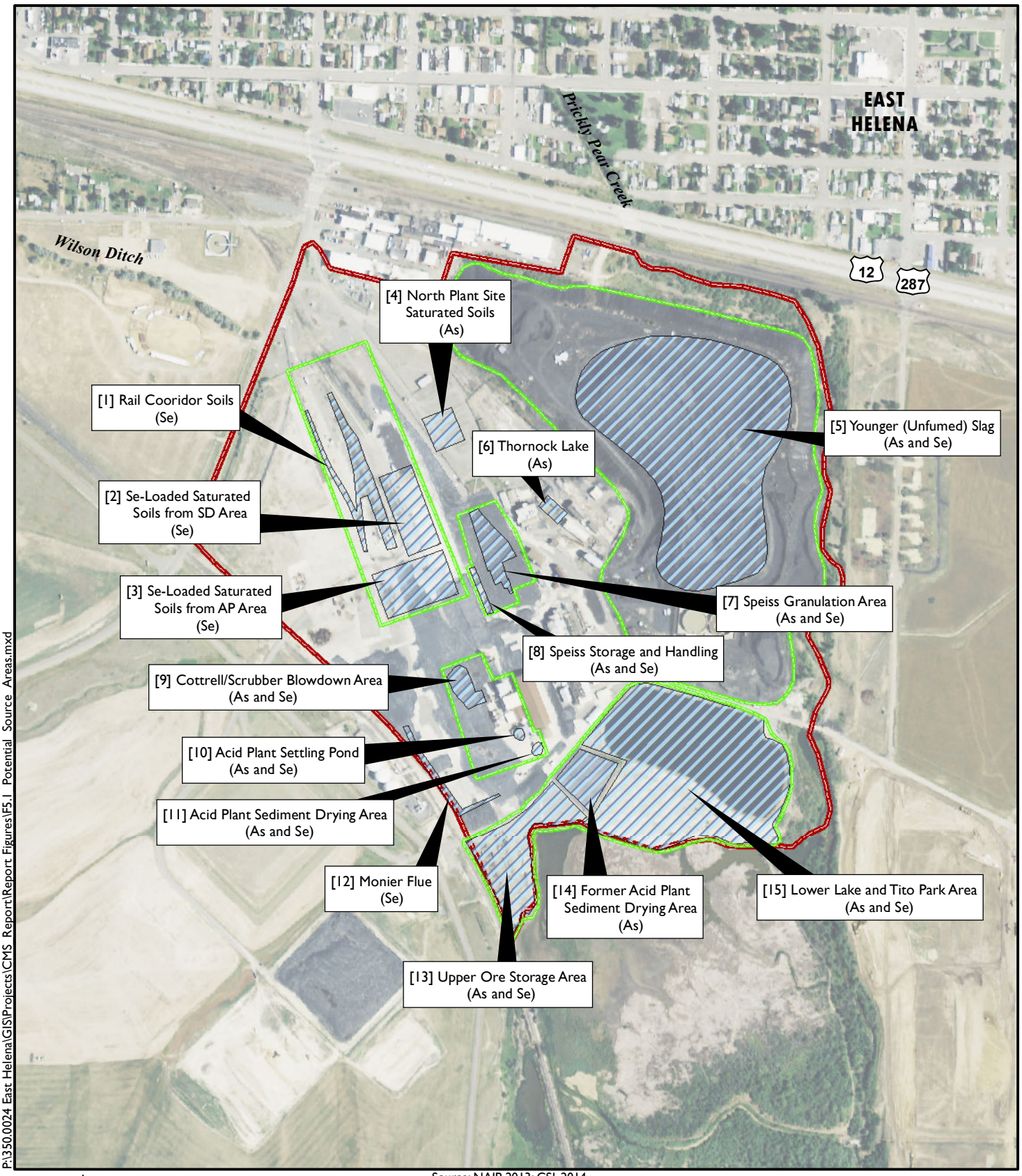
Former Smelter Site Boundary

0 Feet 500

NewFields

Note: Results are from NewFields (2016b).

Updated Recharge Distribution
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 4.36



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.1 Potential Source Areas.mxd

Source: NAIP, 2013; GSI, 2014

N

0 600
Feet

NewFields

Former Smelter Site Boundary

General Source Area (Hydrometrics, 2015)

Individual Source Area (Hydrometrics, 2015)

Note: As = Arsenic; Se = Selenium.

Potential Source Areas
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.1

LAKE HELENA

HAUSER LAKE

Silver Creek

Sevenmile Creek

Helena Valley Canal

Prickly Pear Creek

Wilson Ditch

Tenmile Creek

HELENA

EAST HELENA

15

12

287

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.2 2011 FT Target Locations.mxd

Source: NAIP, 2011; GSI, 2014

Concentration Target

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

Former Smelter Site Boundary

Model Domain

0 Feet 6,000

NewFields

2011 Arsenic and Selenium Concentration Target Locations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.2

LAKE HELENA

HAUSER LAKE

Silver Creek

Sevenmile Creek

Helena Valley Canal

Prickly Pear Creek

Tenmile Creek

HELENA

EAST HELENA

15

12

287

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.3 2014 FT Target Locations.mxd

Source: NAIP, 2013; GSI, 2014

Concentration Target

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

Former Smelter Site Boundary

Model Domain

0 Feet 6,000

NewFields

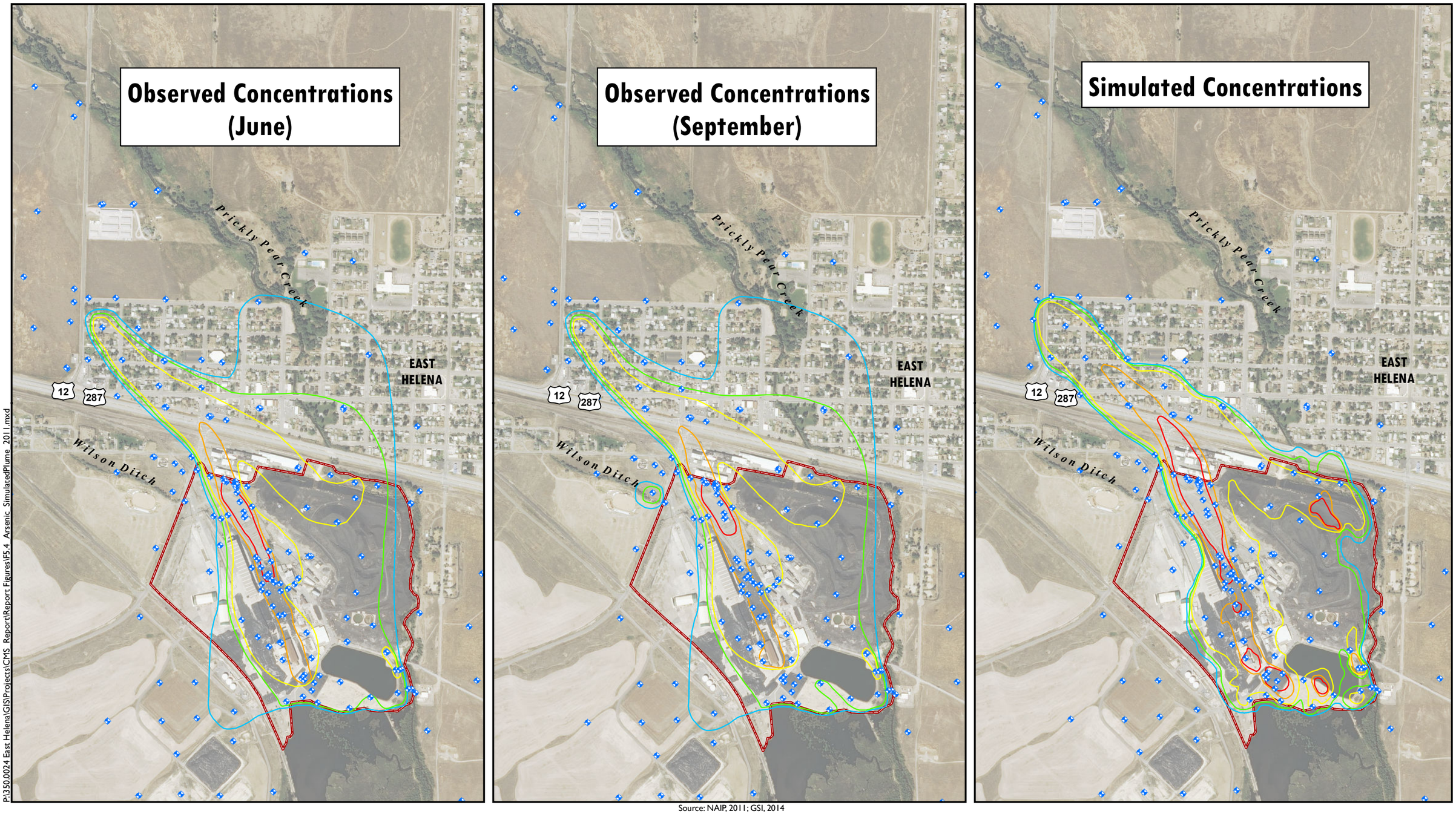
2014 Arsenic and Selenium Concentration Target Locations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.3

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.4 Arsenic SimulatedPlume 2011.mxd

Observed Concentrations (June)

Observed Concentrations (September)

Simulated Concentrations



Source: NAIP, 2011; GSI, 2014

Isoconcentration Contour (mg/L)

- 0.01
- 0.1
- 1
- 10
- > 20
- Monitoring Well
- Former Smelter Site Boundary

0 Feet 1,000

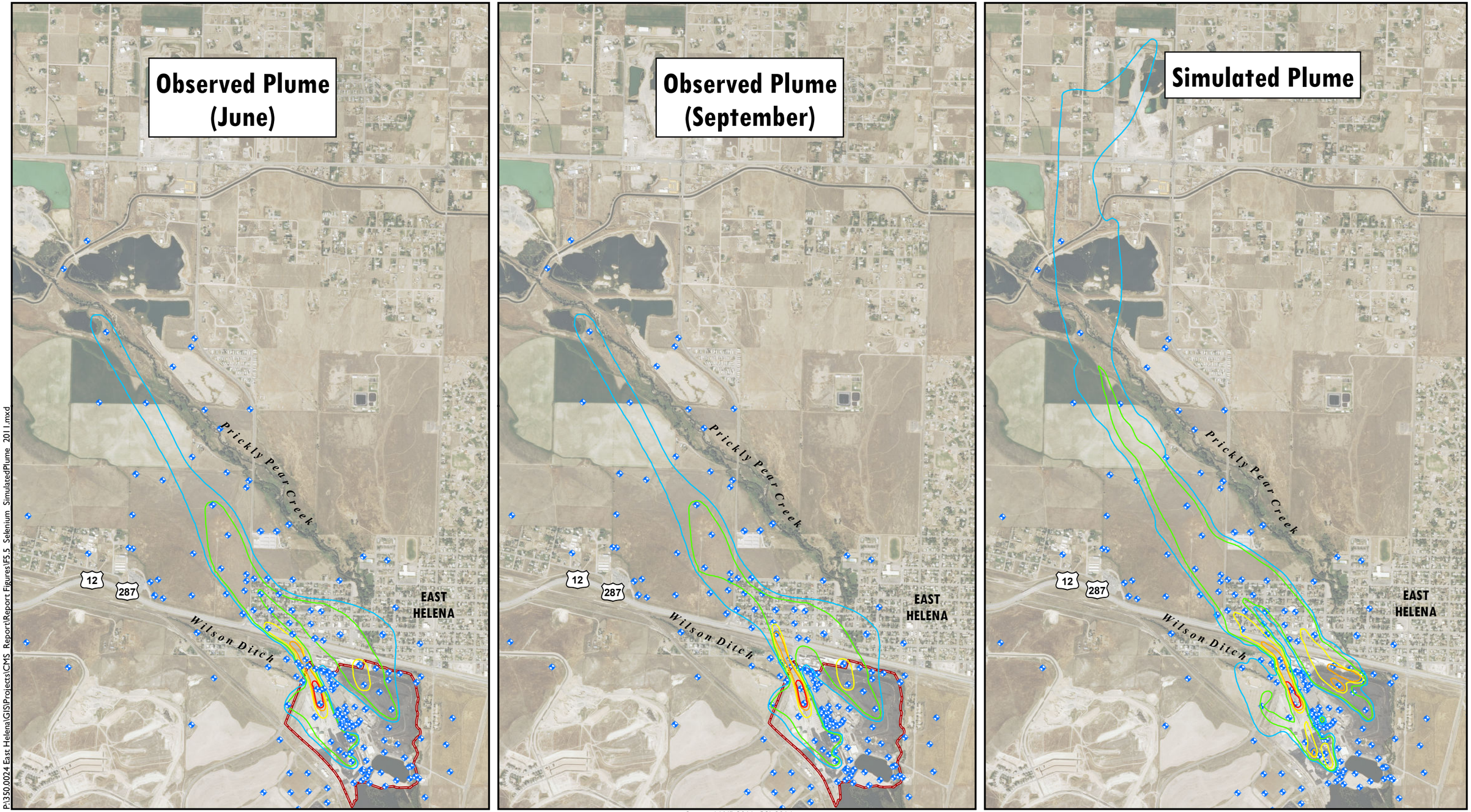
NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2106a).

2011 Observed and Simulated Arsenic Isoconcentration Contours
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.4

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F5.5_Selenium_SimulatedPlume_2011.mxd



Source: NAIP, 2011; GSI, 2014

0 Feet 2,000

Isoconcentration Contour (mg/L)

0.05 | 0.1 | 0.5 | 1 | > 3

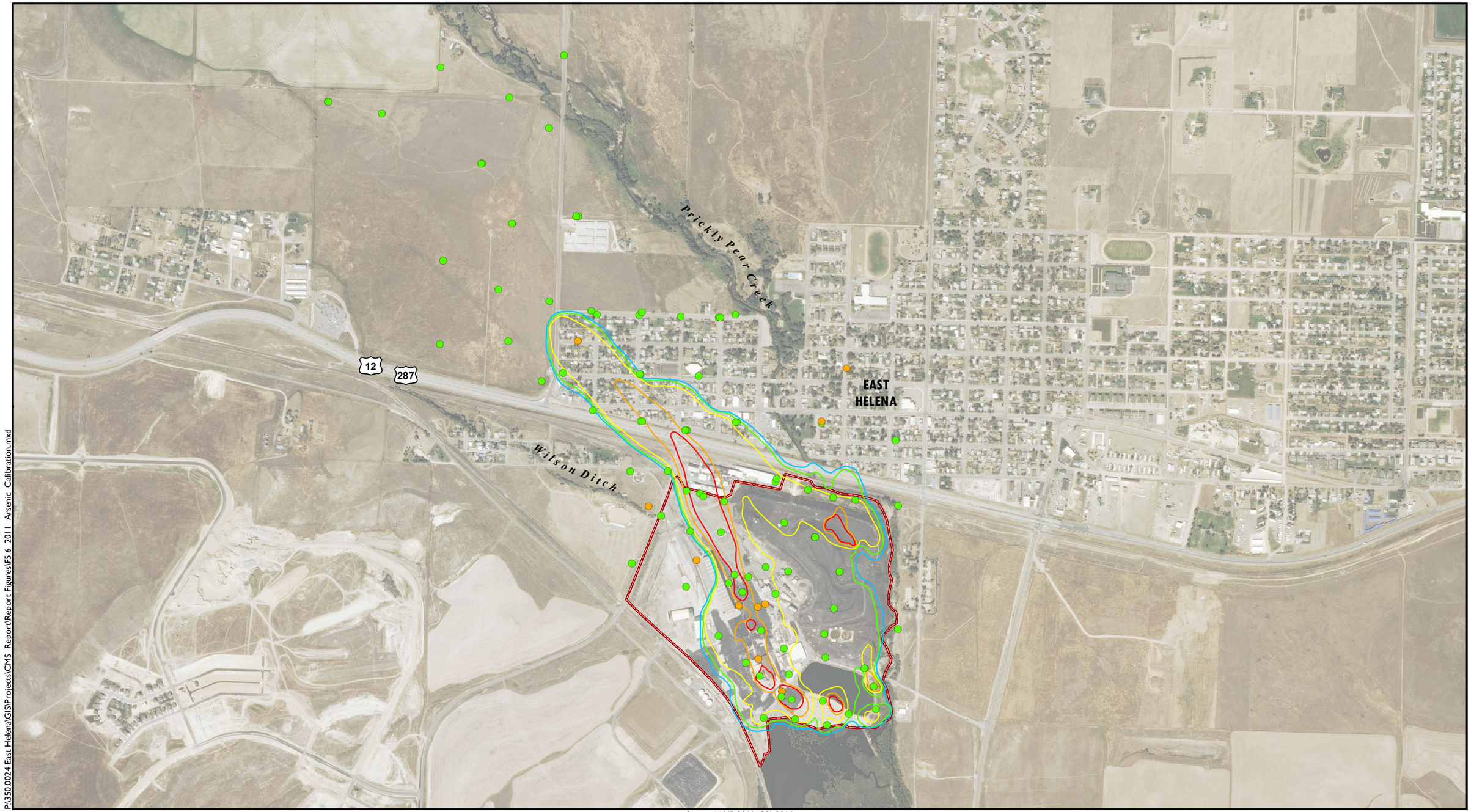
Monitoring Well

Former Smelter Site Boundary

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

2011 Observed and Simulated Selenium Isoconcentration Contours
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.5



P:\350\0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.6 2011 Arsenic Calibration.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

Calibration Target

- Not within calibration criteria
- Within calibration criteria

Isoconcentration Contour (mg/L)

- 0.01
- 0.1
- 1
- 10
- > 20

Former Smelter Site Boundary

2011 Arsenic Targets Within Calibration Criteria
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.6

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.7_2011_Selenium_Calibration.mxd

Prickly Pear Creek

Wilson Ditch

12

287

EAST HELENA

Source: NAIP, 2011; GSI, 2014

0 Feet 2,000

NewFields

Calibration Target

- Not within calibration criteria
- Within calibration criteria

Isoconcentration Contour (mg/L)

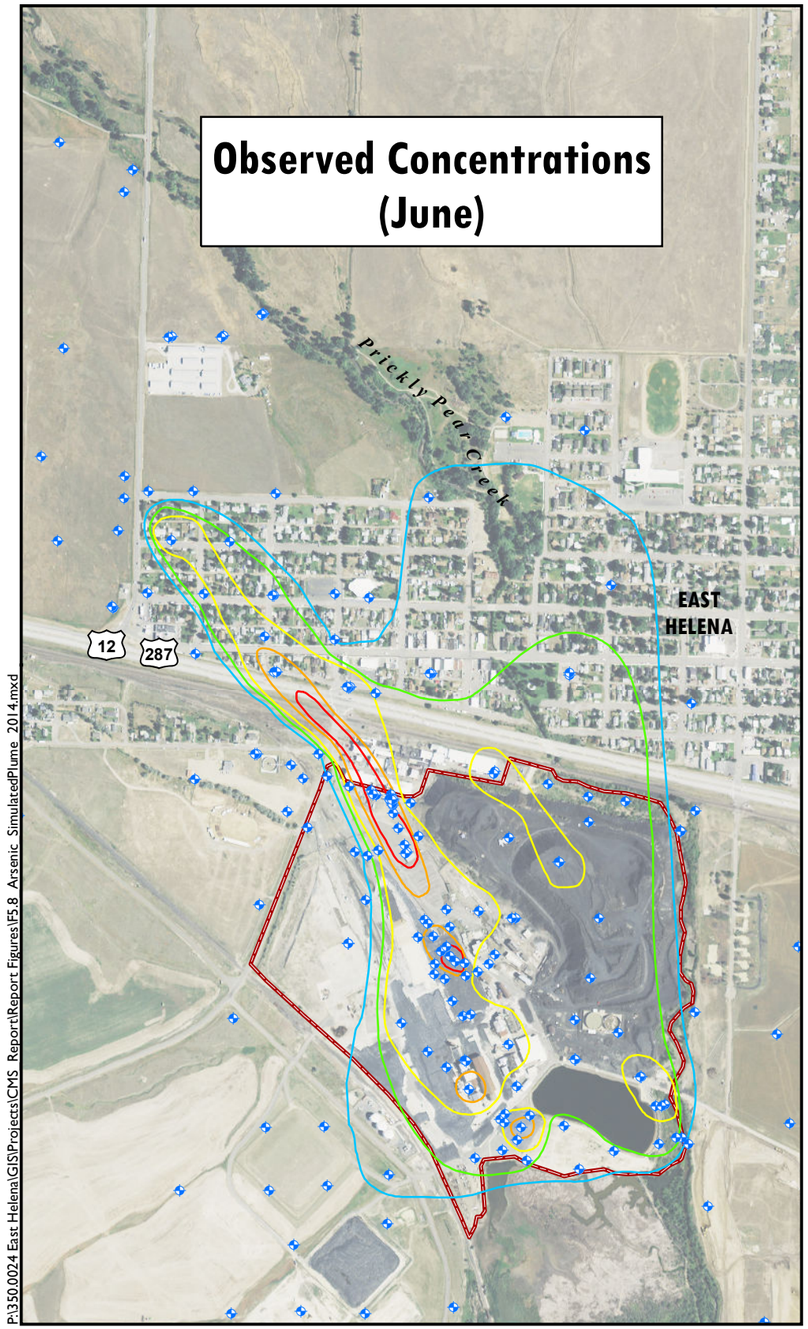
- 0.05
- 0.1
- 0.5
- 1
- > 3

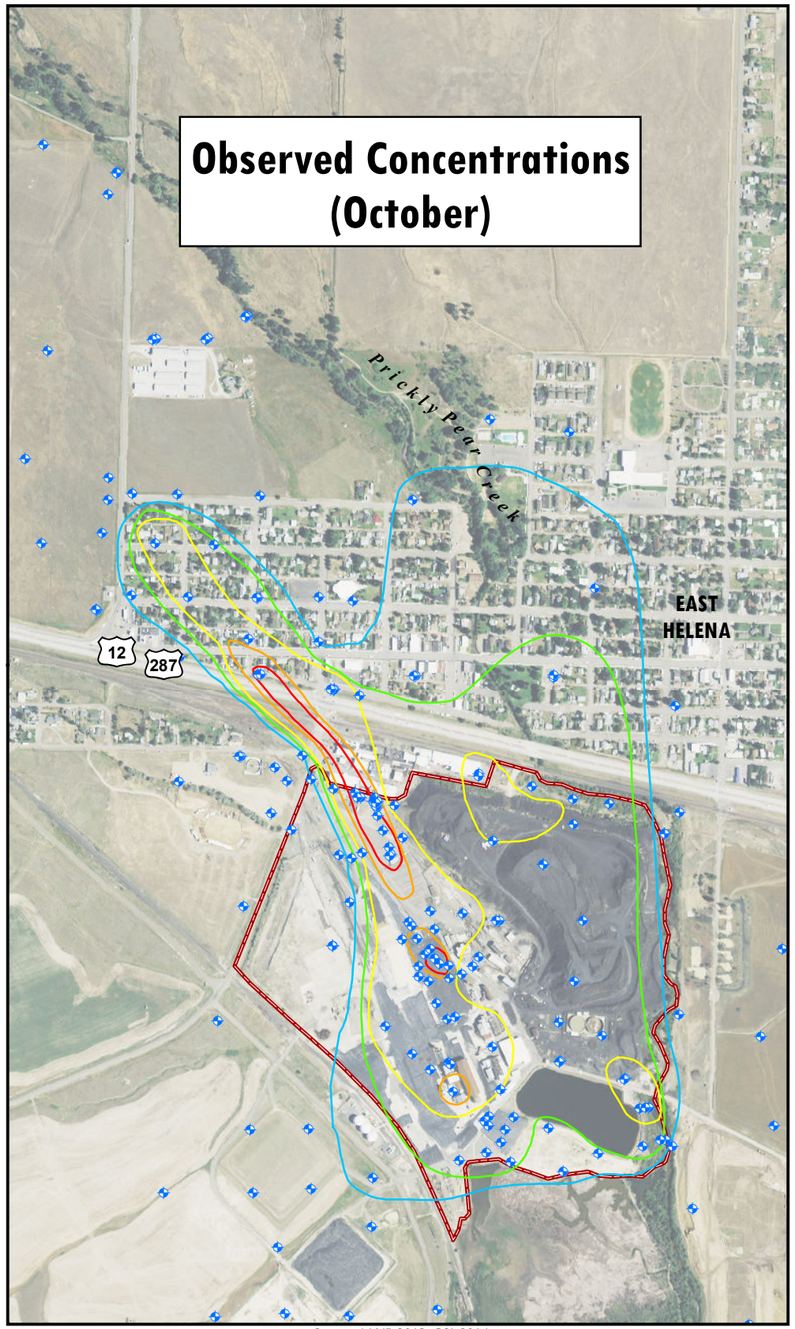
Former Smelter Site Boundary

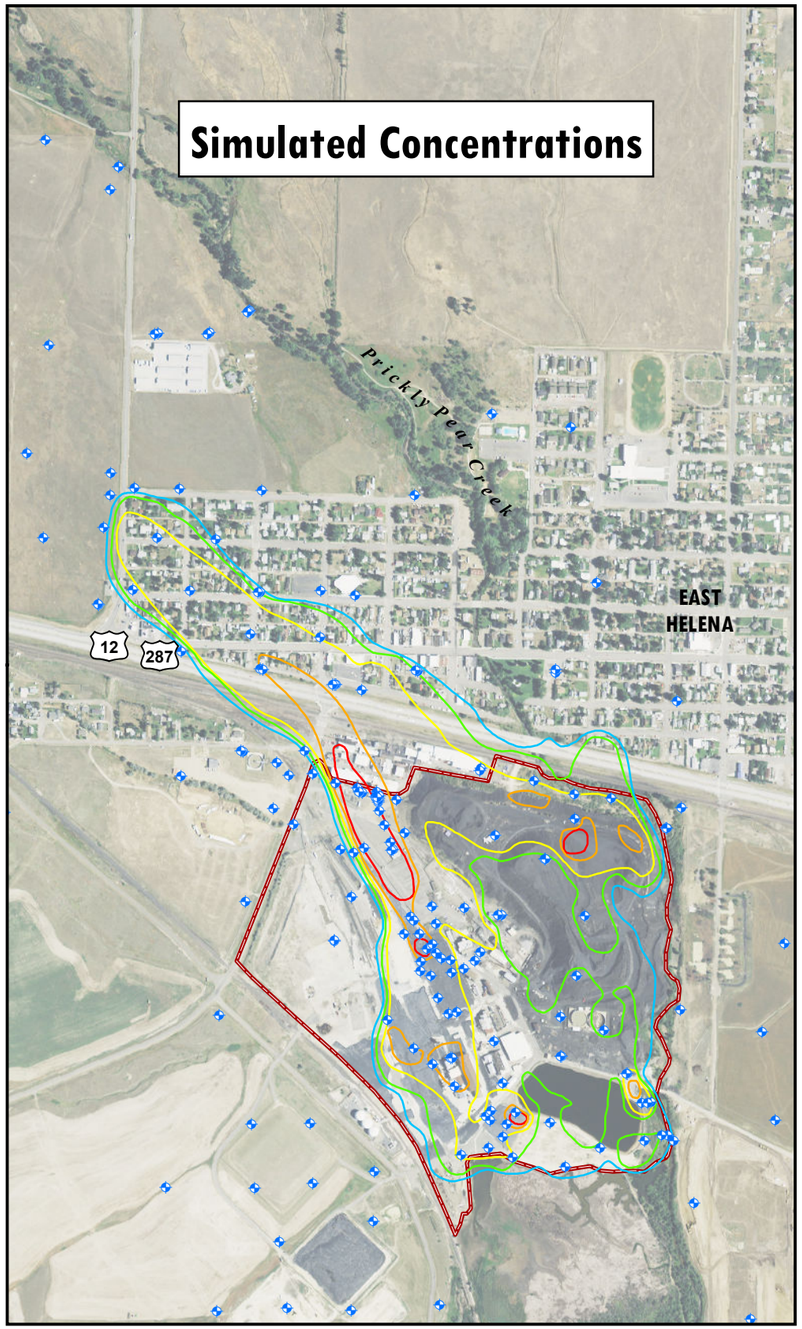
Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

2011 Selenium Targets Within Calibration Criteria
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.7







P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F5.8_Arsenic_SimulatedPlume_2014.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

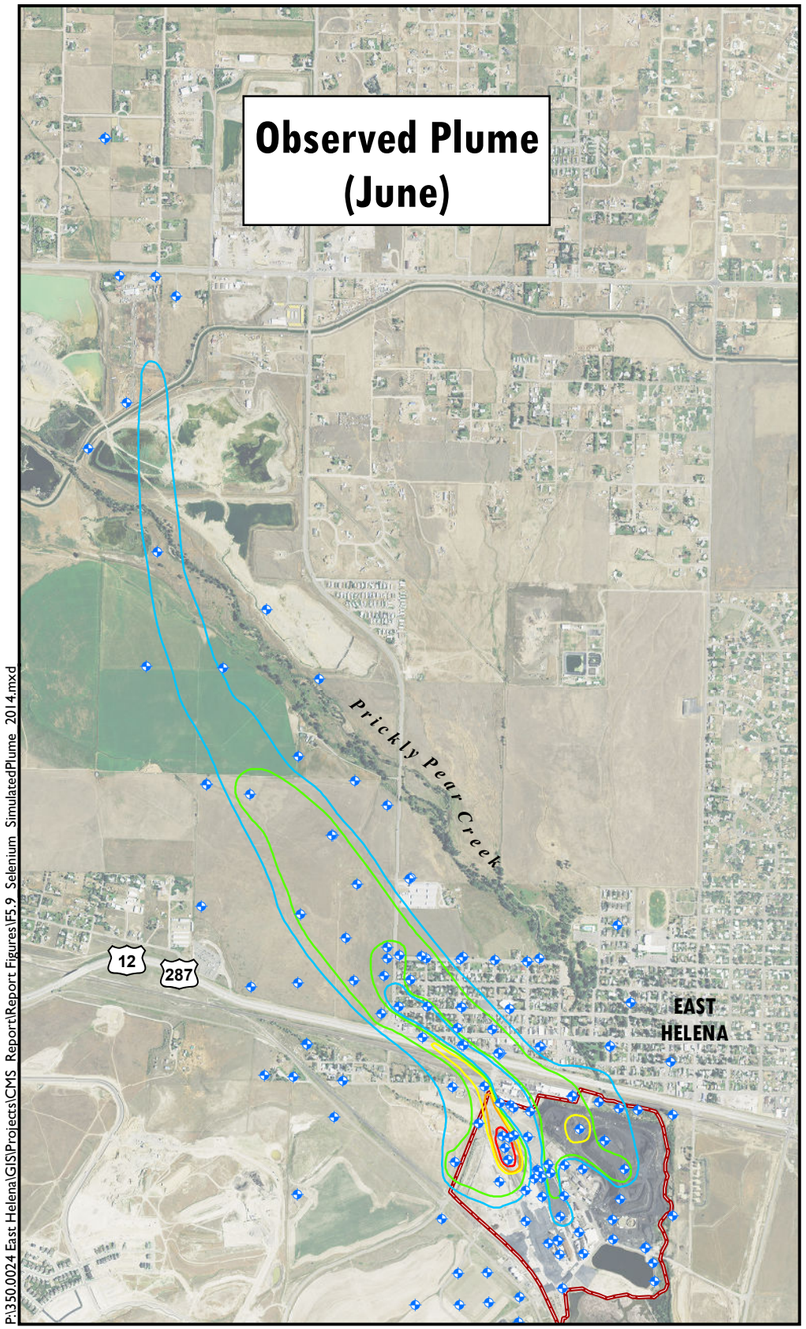
Isoconcentration Contour (mg/L)

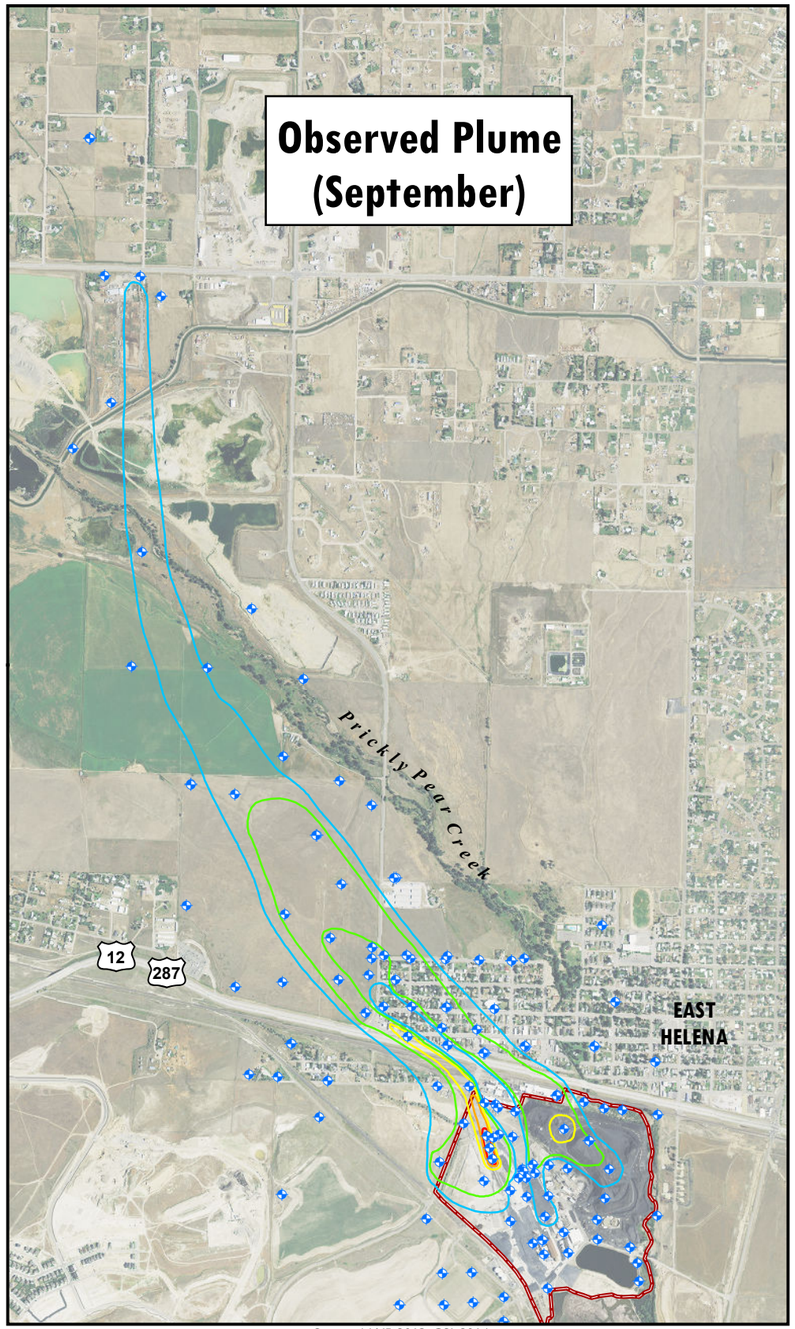
- 0.01
- 0.1
- 1
- 10
- > 20

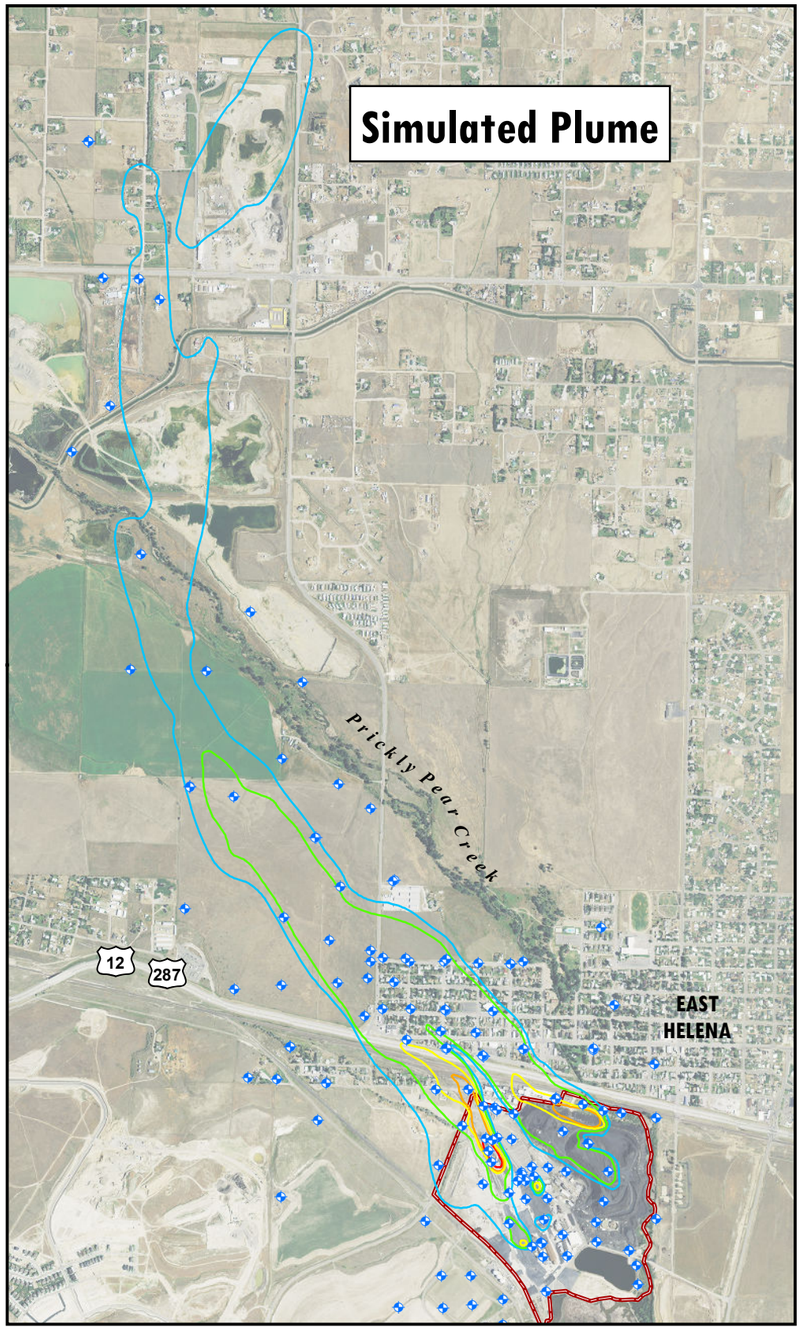
Monitoring Well

Former Smelter Site Boundary

2014 Observed and Simulated Arsenic Isoconcentration Contours
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.8







P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F5.9_Selenium_SimulatedPlume_2014.mxd

Source: NAIP, 2013; GSI, 2014

Isoconcentration Contour (mg/L)

0.05 | 0.1 | 0.5 | 1 | > 3

Monitoring Well

Former Smelter Site Boundary

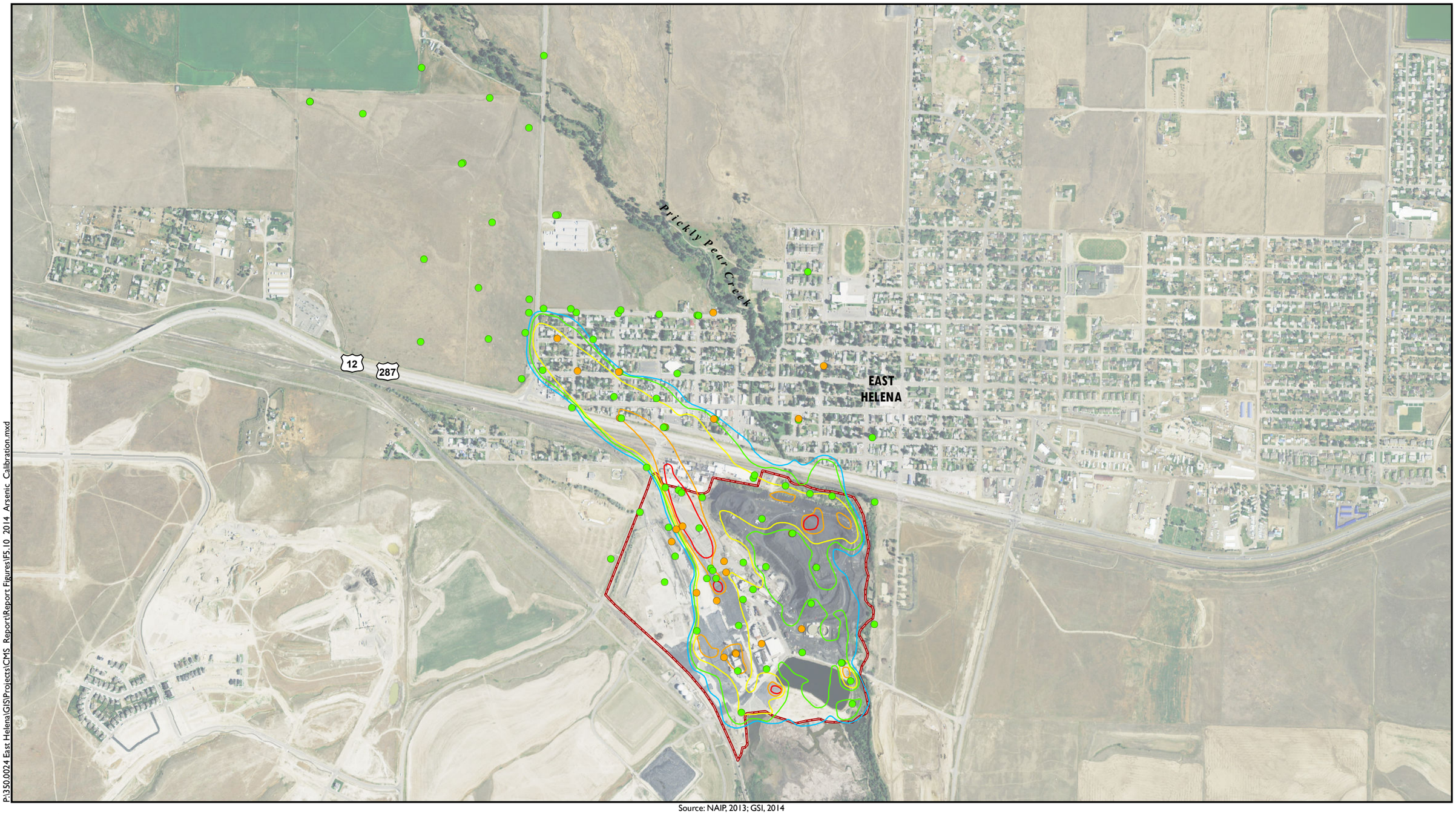
0 Feet 2,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

2014 Observed and Simulated Selenium Isoconcentration Contours
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.9



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5_10 2014 Arsenic Calibration.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Calibration Target

- Not within calibration criteria
- Within calibration criteria

Isoconcentration Contour (mg/L)

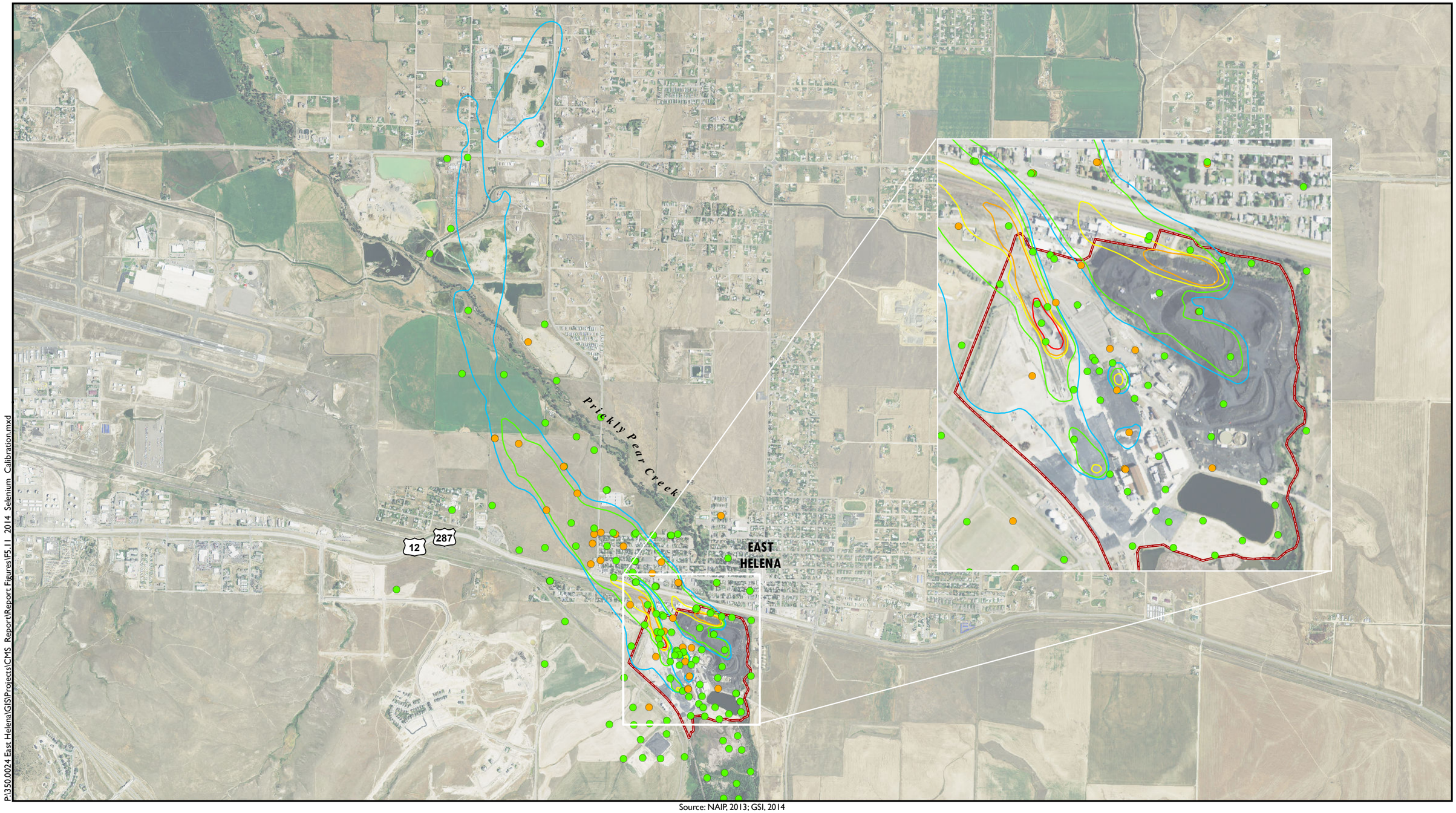
- 0.01
- 0.1
- 1
- 10
- > 20

Former Smelter Site Boundary

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

2014 Arsenic Targets Within Calibration Criteria
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.10



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.11 2014 Selenium Calibration.mxd

Source: NAIP, 2013; GSI, 2014

Calibration Target

- Not within calibration criteria
- Within calibration criteria

Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3

Former Smelter Site Boundary

0 Feet 2,200

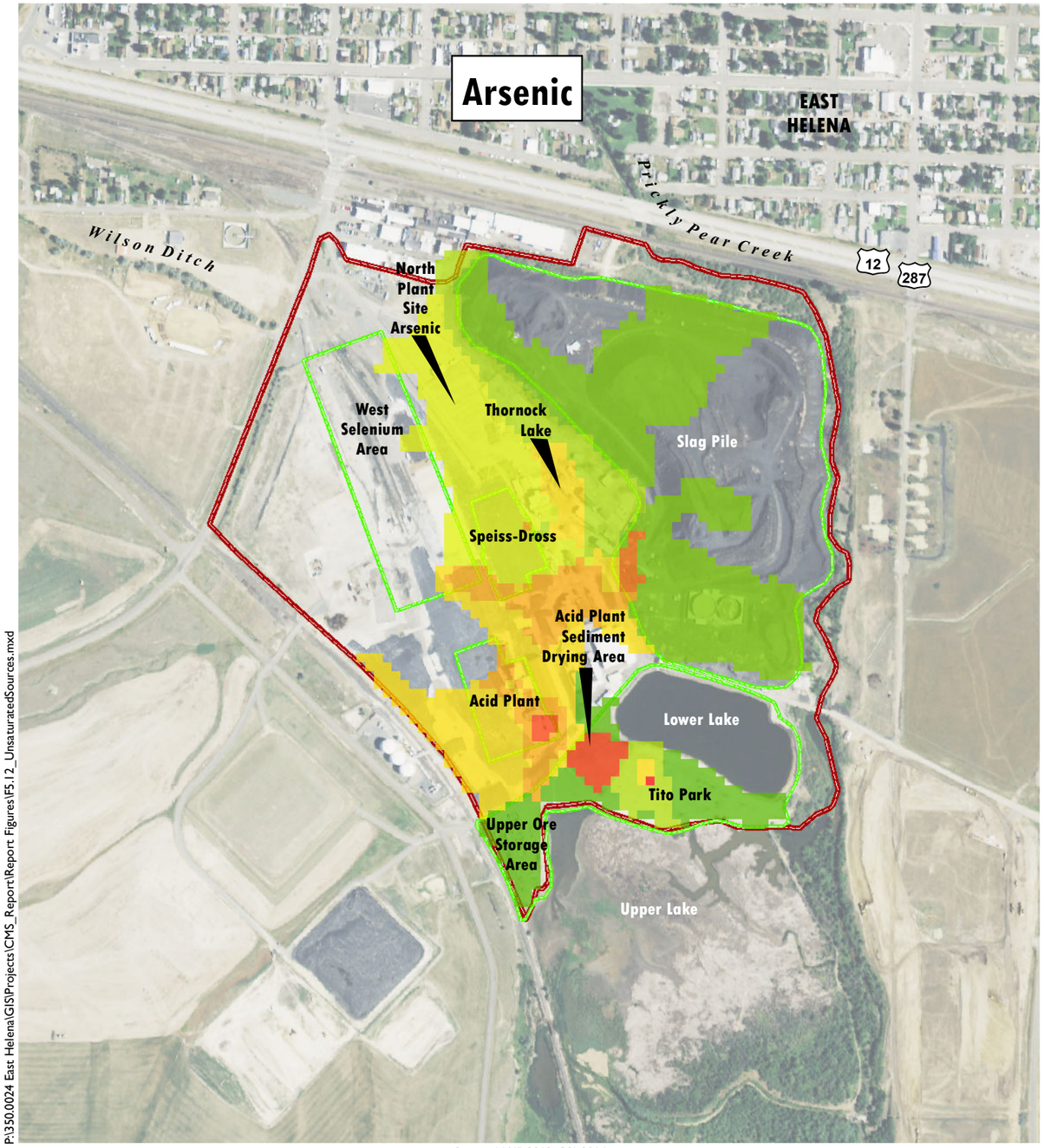
NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016a).

2014 Selenium Targets Within Calibration Criteria
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.11

Arsenic



Source: NAIP, 2013; GSI, 2014

Selenium

Source: NAIP, 2013; GSI, 2014

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F5.12_UnsaturatedSources.mxd

N

0 Feet 600

NewFields

Concentration (mg/L)

0.17	3.4	22.09
1.53	7.14	339.8
2.89	18.69	407.76

General Source Area (Hydrometrics)

Former Smelter Site Boundary

Note: Results are from NewFields (2016a).

Concentration (mg/L)

0.54

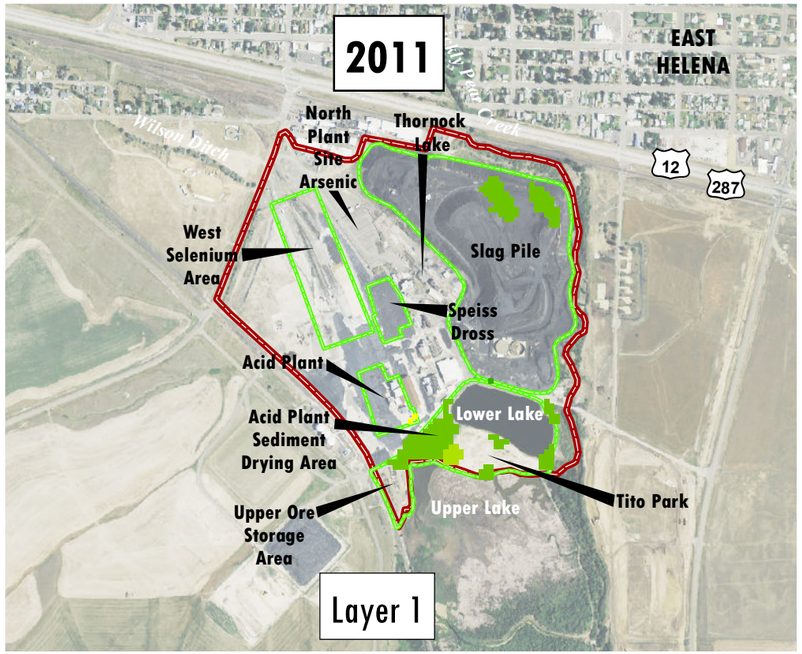
1.48

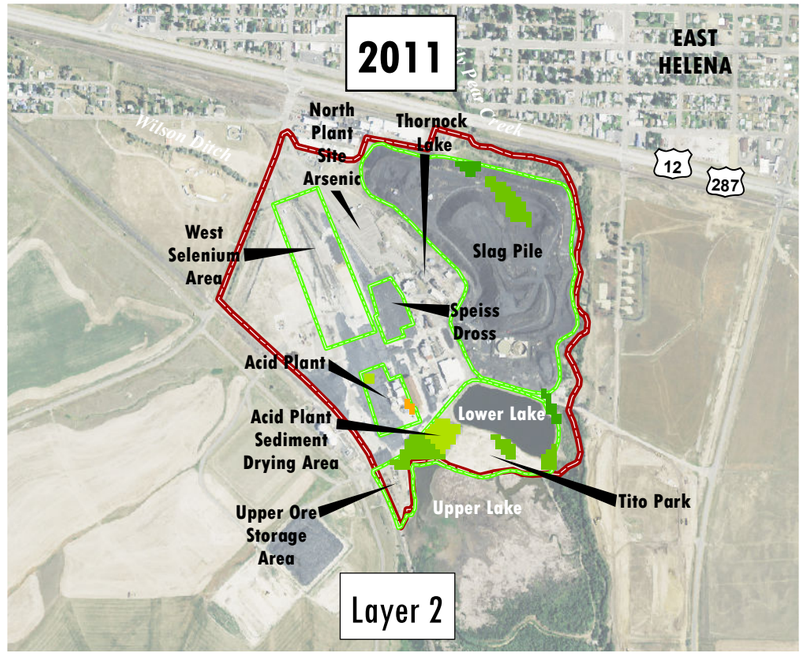
4.24

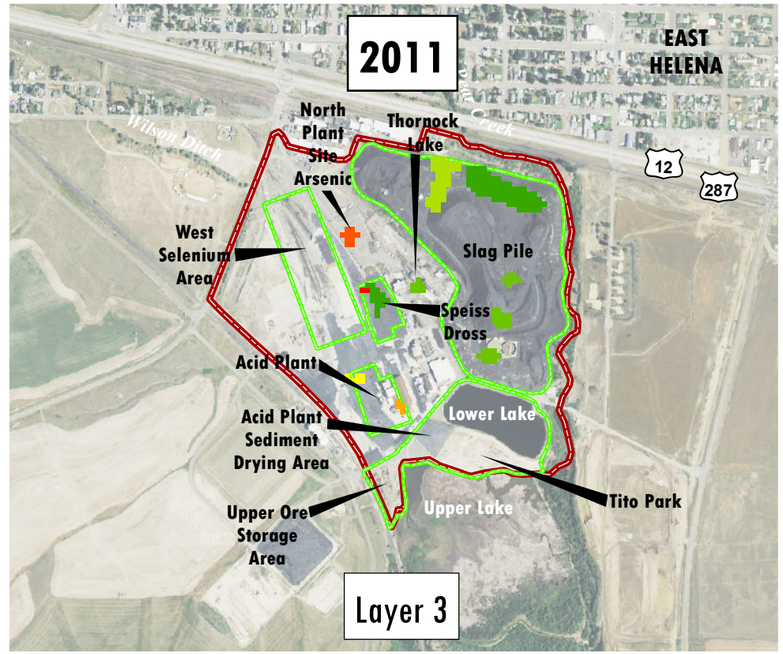
General Source Area (Hydrometrics)

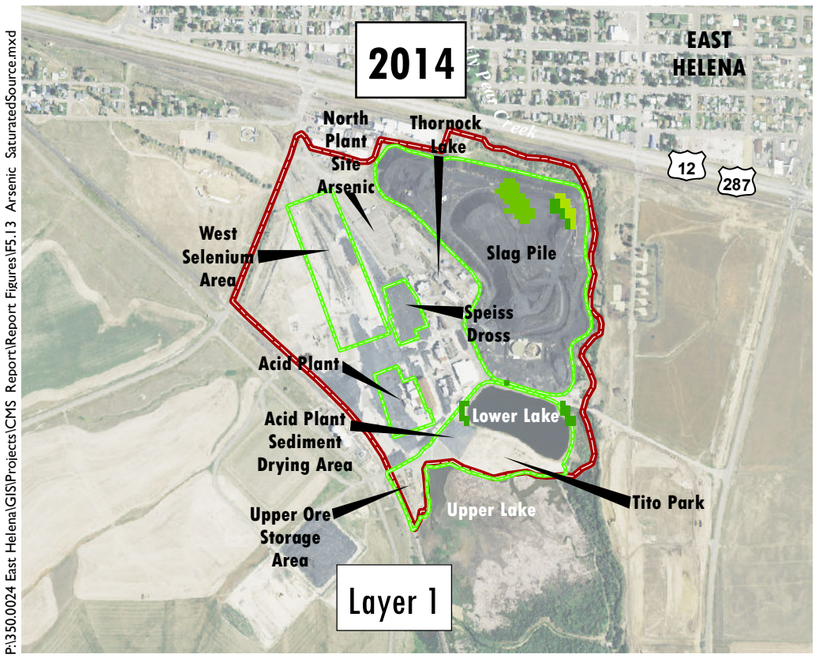
Former Smelter Site Boundary

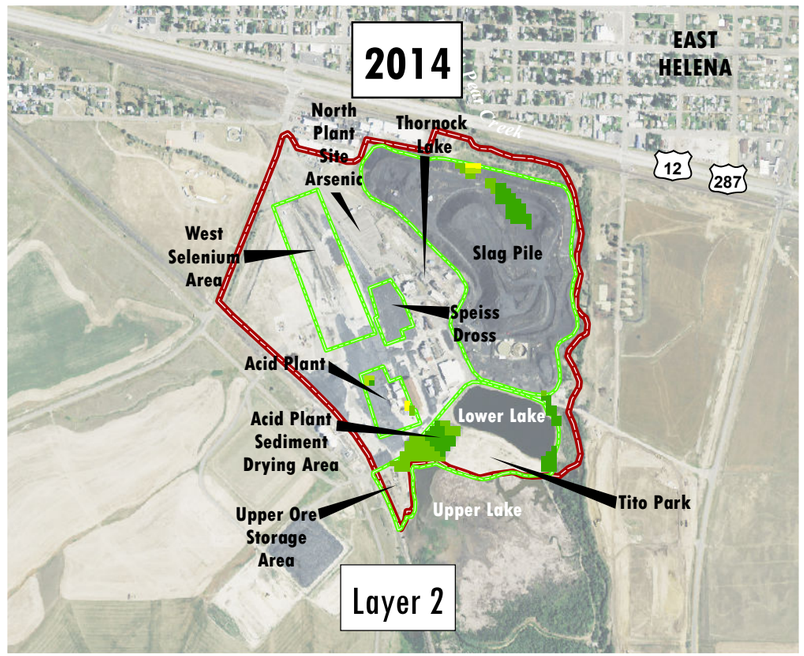
Unsaturated Source Area Concentrations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.12

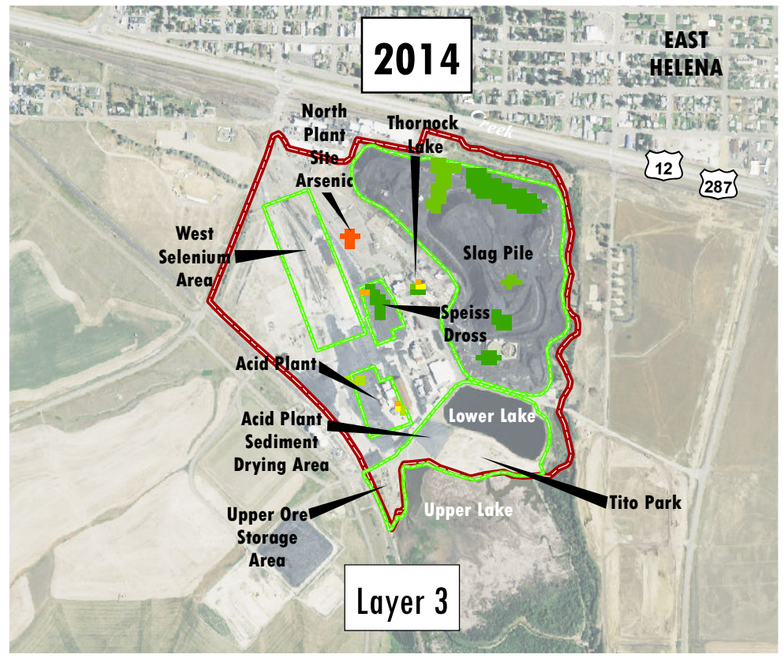












P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.13 Arsenic SaturatedSource.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

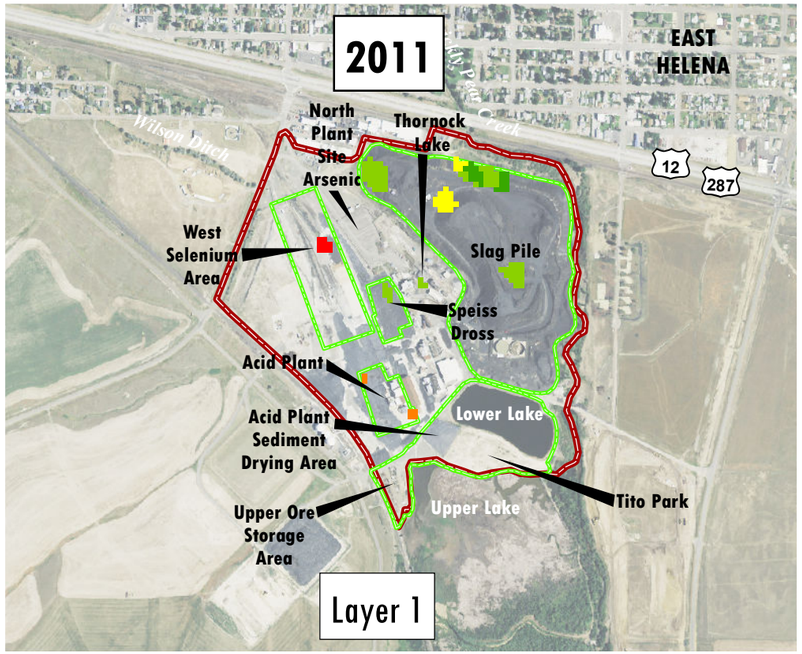
NewFields

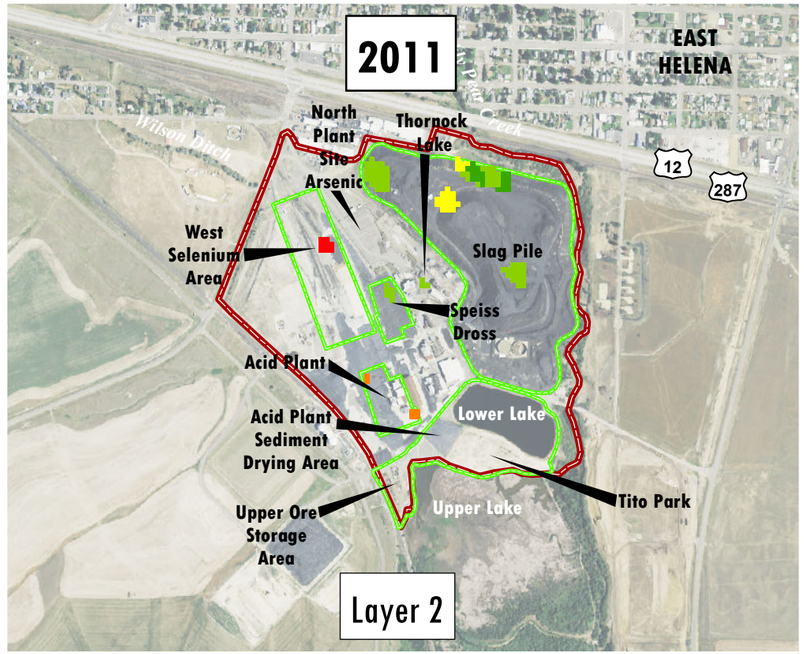
Note: Results are from NewFields (2016a).

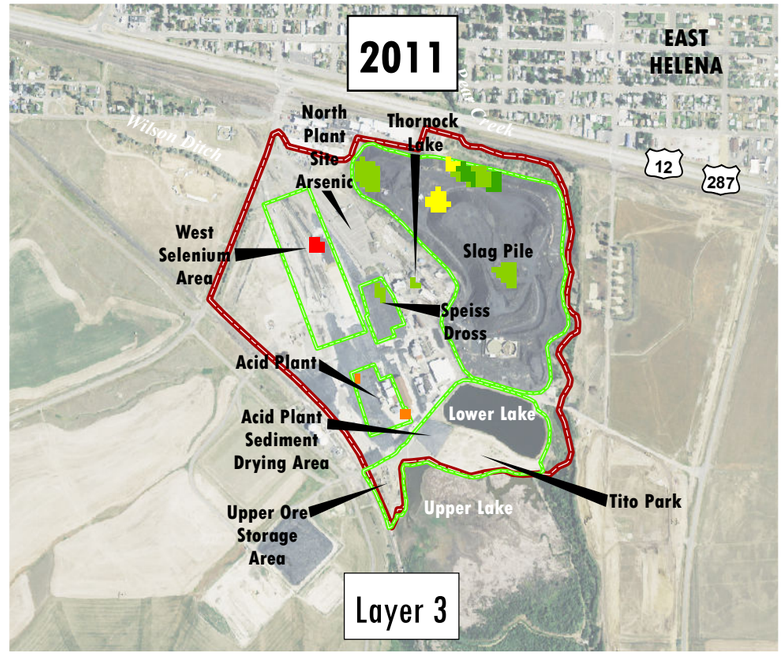
Mass Flux (mg/day)

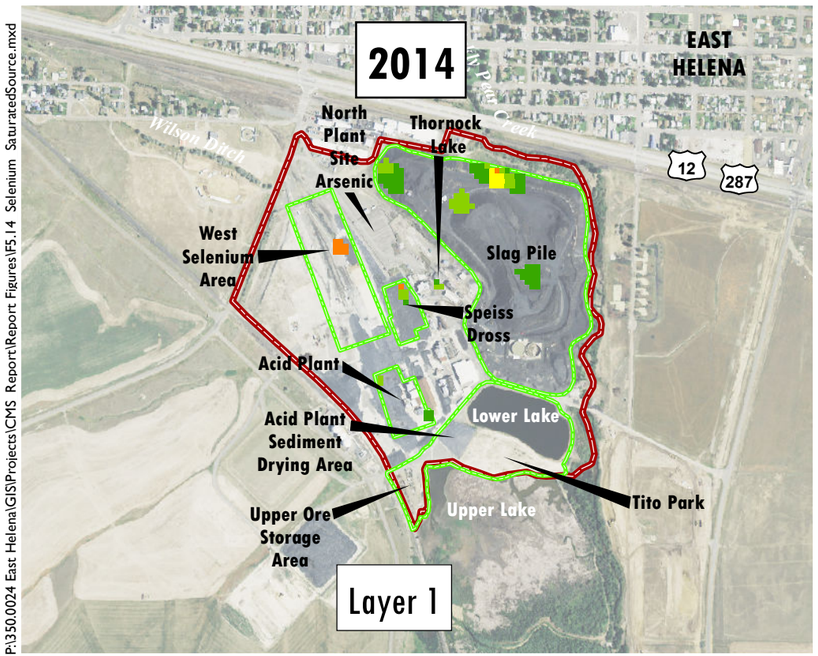
- <1,000
- 1,001 to 10,000
- 10,001 to 50,000
- 50,001 to 100,000
- 100,001 to 500,000
- 500,001 to 1,000,000
- > 1,000,000
- General Source Area (Hydrometrics)
- Former Smelter Site Boundary

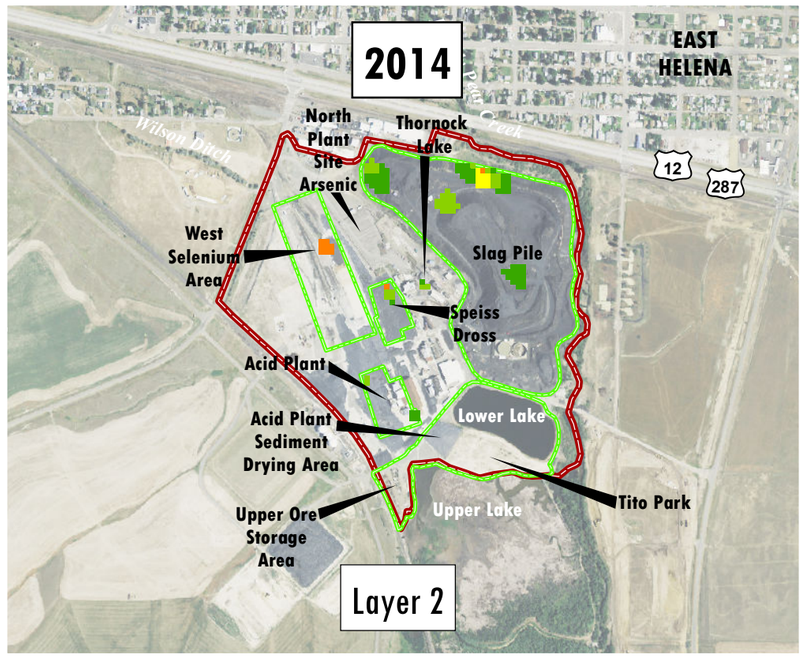
Saturated Source Arsenic Concentrations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.13

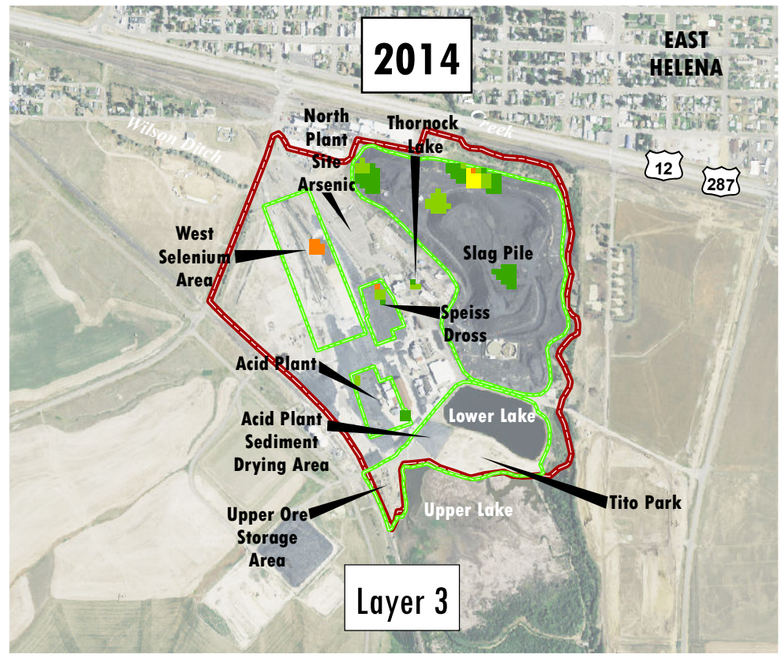












P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.14 Selenium SaturatedSource.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

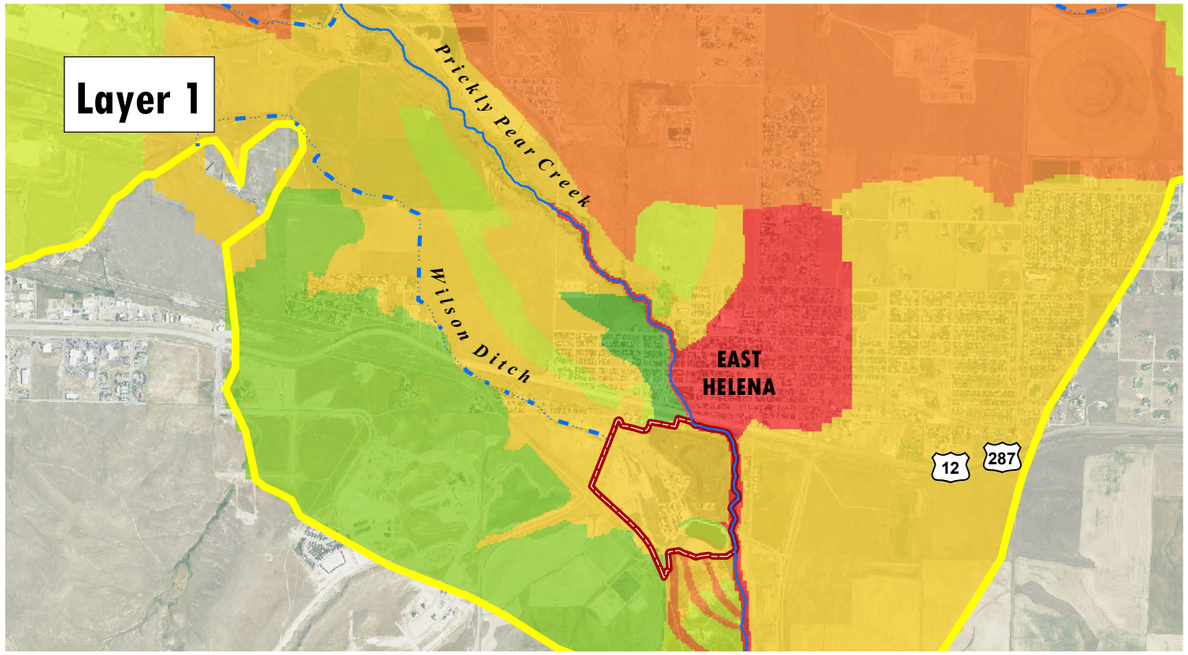
NewFields

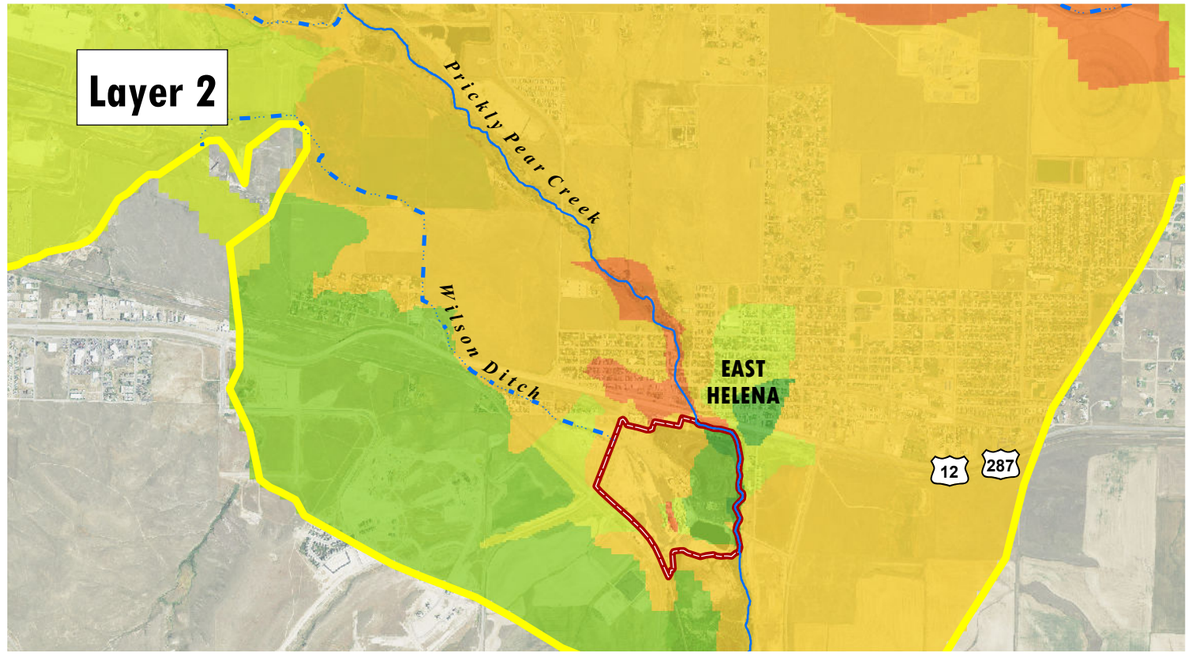
Note: Results are from NewFields (2016a).

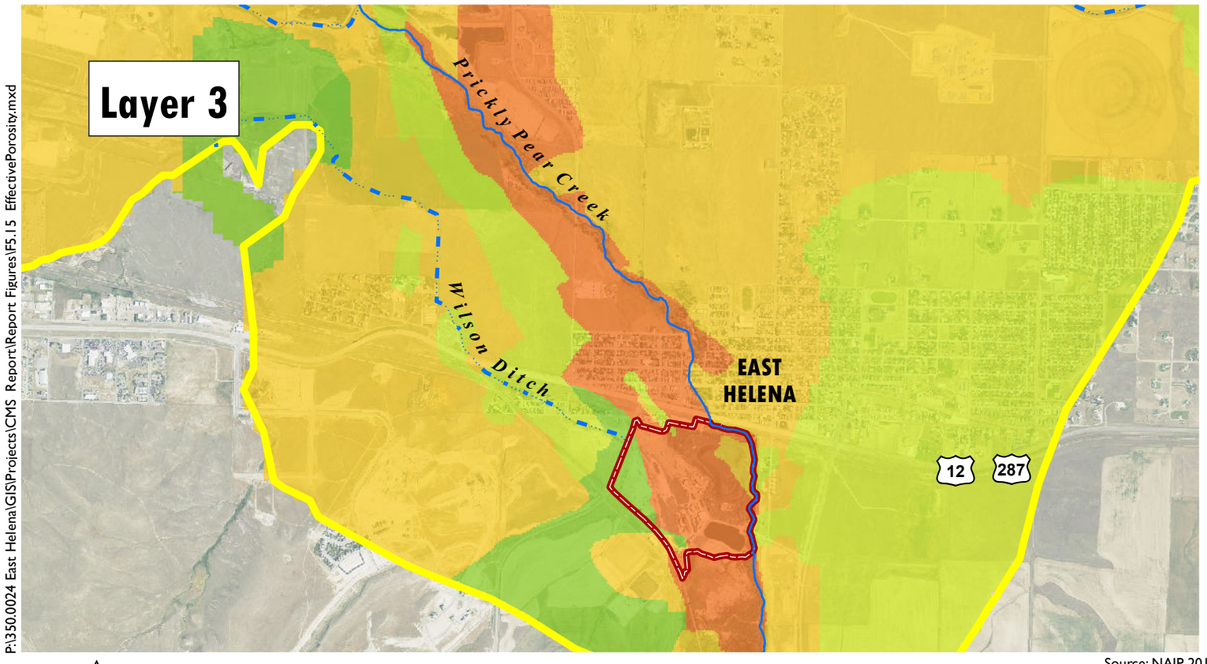
Mass Flux (mg/day)

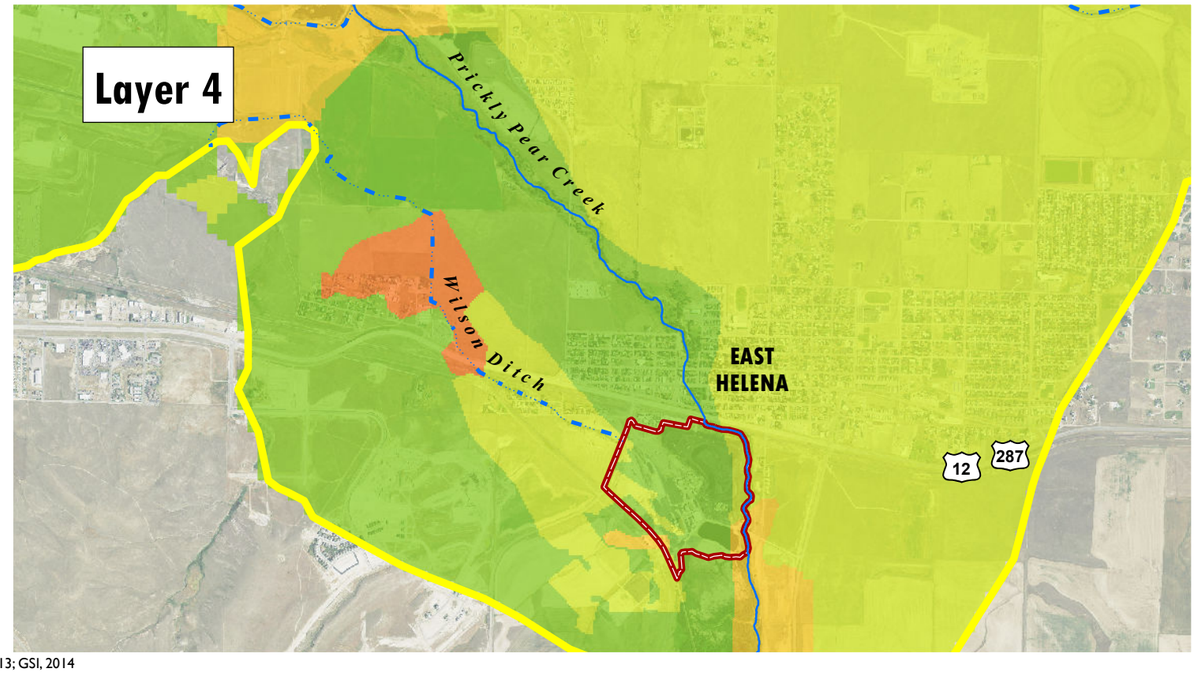
- <1,000
- 1,001 to 5,000
- 5,001 to 10,000
- 10,001 to 50,000
- >50,000
- General Source Area (Hydrometrics)
- Former Smelter Site Boundary

Saturated Source Selenium Concentrations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.14









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.15 EffectiveProsity.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 3,000

NewFields

Effective Porosity

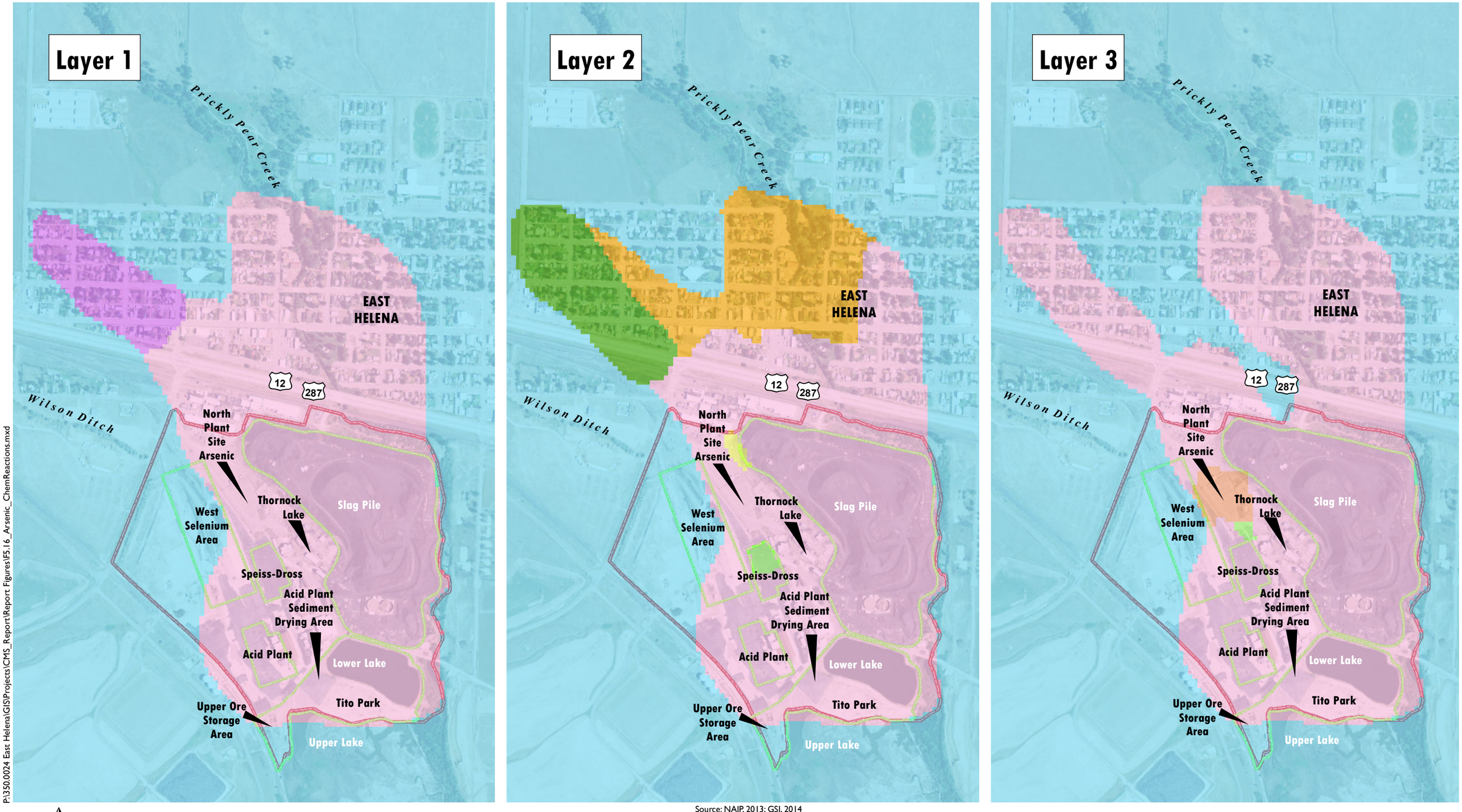
0.01	0.12
0.02	0.18
0.08	0.2

Former Smelter Site Boundary

Model Domain

Note: Results are from NewFields (2016a).

Simulated Effective Porosity
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.15



P:\350.0024 East Helena\GISProjects\CMS_Report\Report Figures\F5.16_Arsenic_ChemReactions.mxd

Source: NAIP, 2013; GSI, 2014

N

0 Feet 800

NewFields

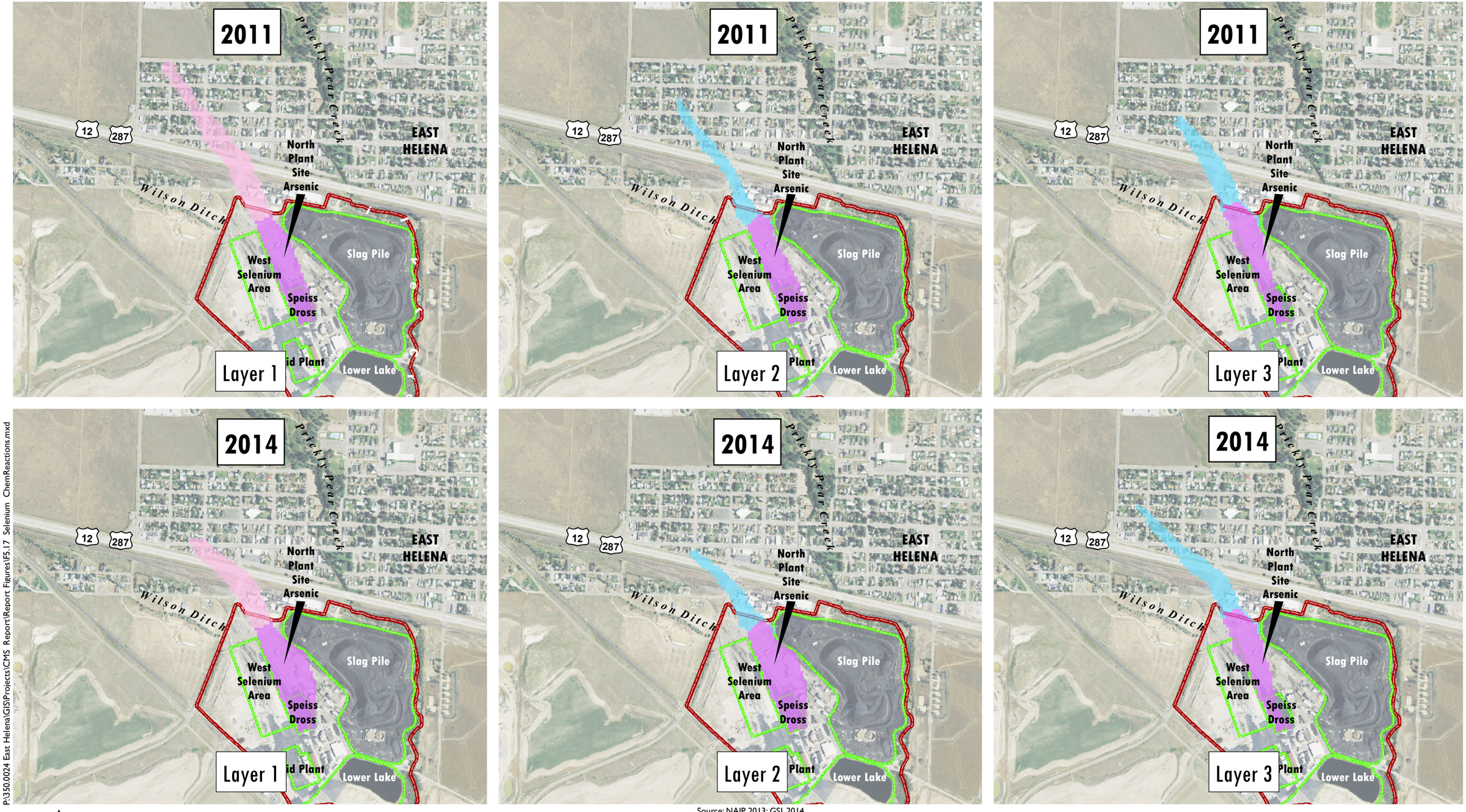
Note:
1) Decay zones were the same for the 2011 and 2014 calibrations;
2) Decay (half-life) is used to simulate chemical precipitation;
3) Retardation is used to simulate adsorption.
4) Results are from NewFields (2016a).

Retardation and Decay Zones

- Langmuir Coefficient = 2.16
- Langmuir Coefficient = 2.16; Half Life = 0.001 days
- Langmuir Coefficient = 2.3
- Langmuir Coefficient = 2.16; Half Life = 150 days
- Langmuir Coefficient = 2.16; Half Life = 100 days
- Langmuir Coefficient = 2.16; Half Life = 40 days
- Langmuir Coefficient = 2.16; Half Life = 20 days

- General Source Area (Hydrometrics, 2015)
- Former Smelter Site Boundary

Arsenic Calibrated Decay Zones
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.16



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.17 Selenium ChemReactions.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,200

NewFields

Simulated Half-Life (days)

- 0.01
- 0.5
- 5

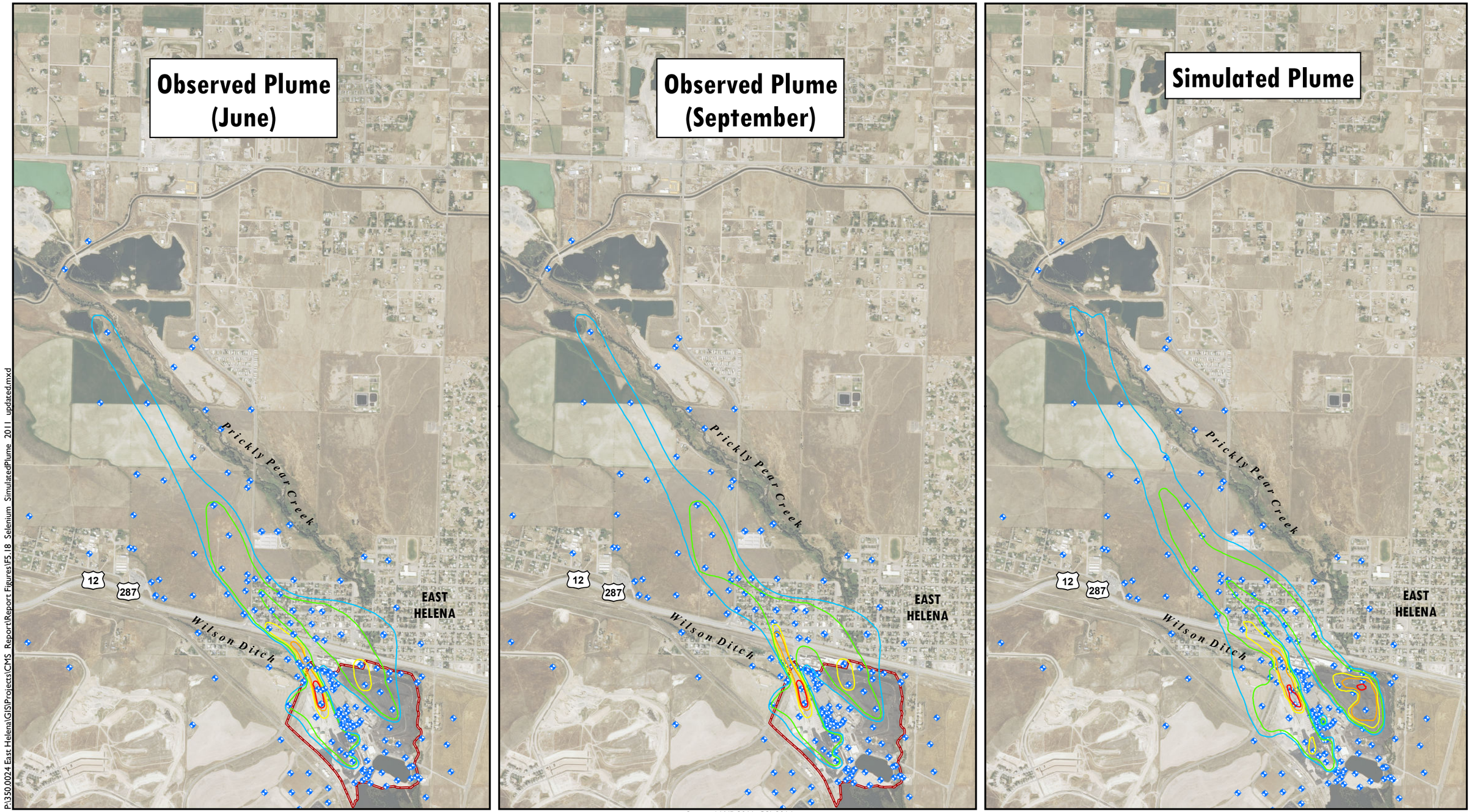
General Source Area (Hydrometrics)

Former Smelter Site Boundary

Note:
1) Decay in the model is used to simulate chemical precipitation.

2) Results are from NewFields (2016a).

Selenium Calibrated Decay Zones
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.17



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.18 Selenium SimulatedPlume 2011 updated.mxd

Source: NAIP, 2011; GSI, 2014

Isoconcentration Contour (mg/L)

0.05 — 0.1 — 0.5 — 1 — > 3

Monitoring Well

Former Smelter Site Boundary

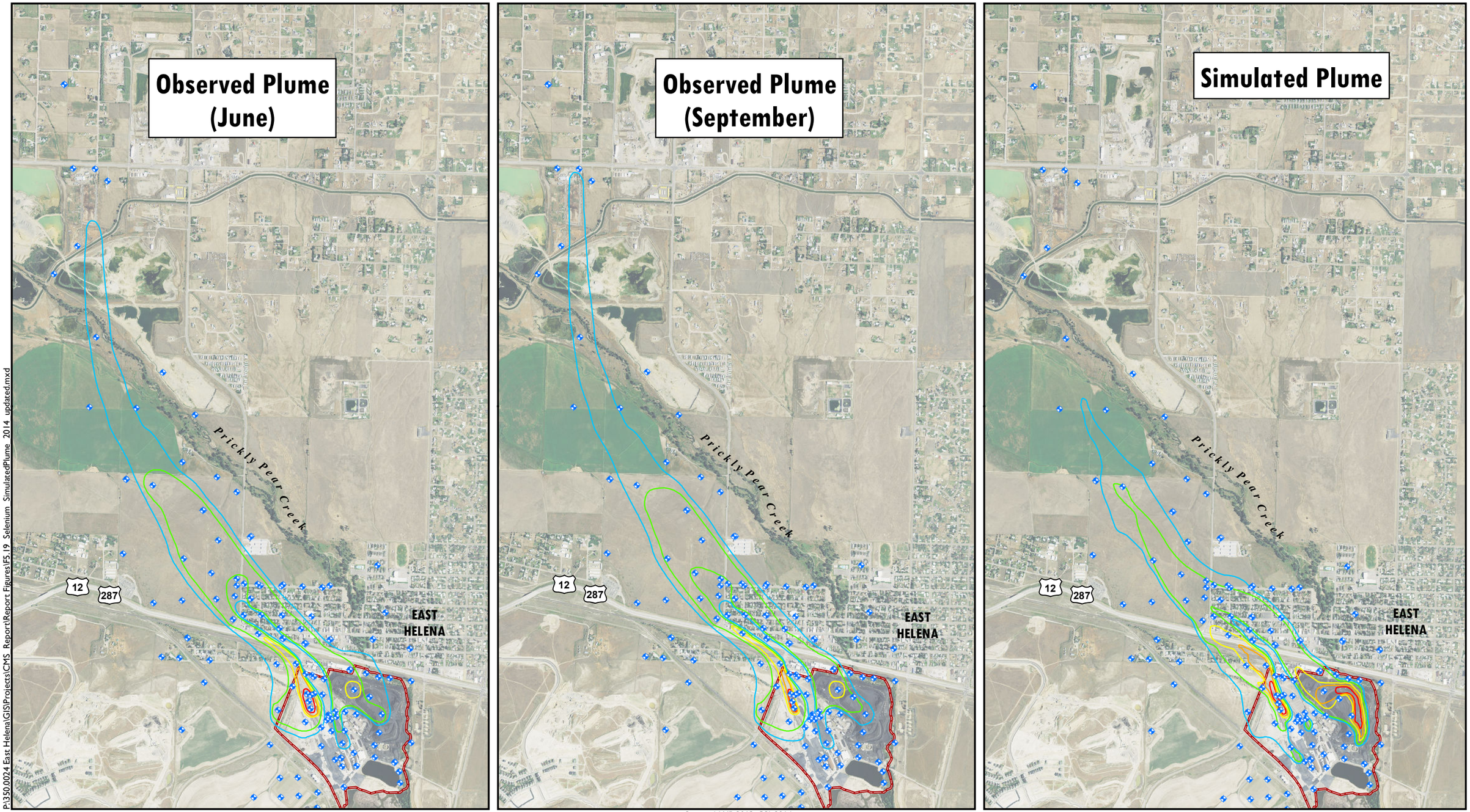
0 Feet 2,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016b).

Updated 2011 Observed and Simulated Selenium Isoconcentration Contours
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.18



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.19 Selenium SimulatedPlume 2014 updated.mxd

Source: NAIP, 2013; GSI, 2014

Isoconcentration Contour (mg/L)

0.05 | 0.1 | 0.5 | 1 | > 3

Monitoring Well

Former Smelter Site Boundary

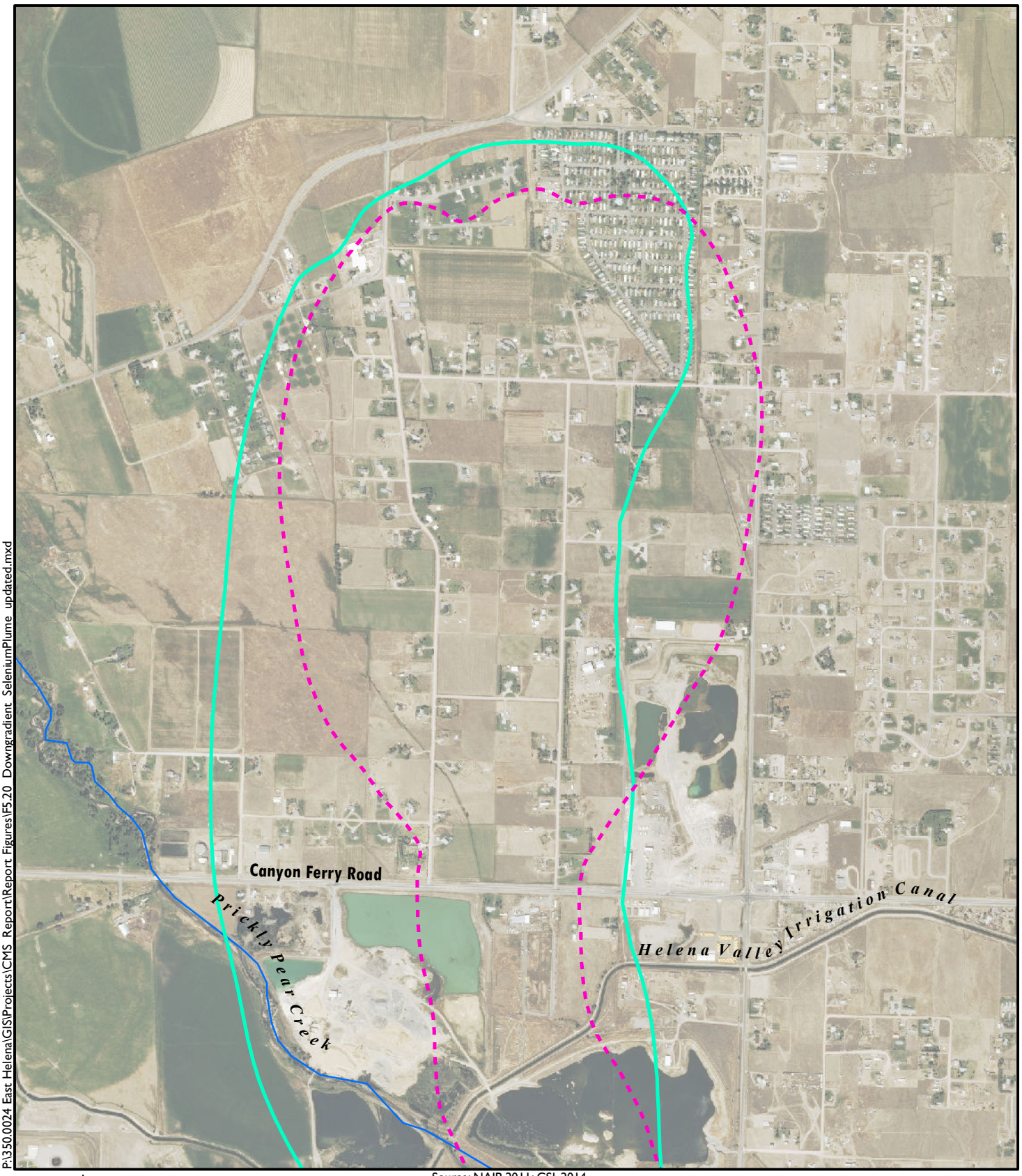
0 2,000 Feet

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, 3, and 4.

2) Results are from NewFields (2016b).

Updated 2014 Observed and Simulated Selenium Isoconcentration Contours
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.19



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F5.20 Downgradient SeleniumPlume updated.mxd

Source: NAIP, 2011; GSI, 2014

N

0 Feet 1,400

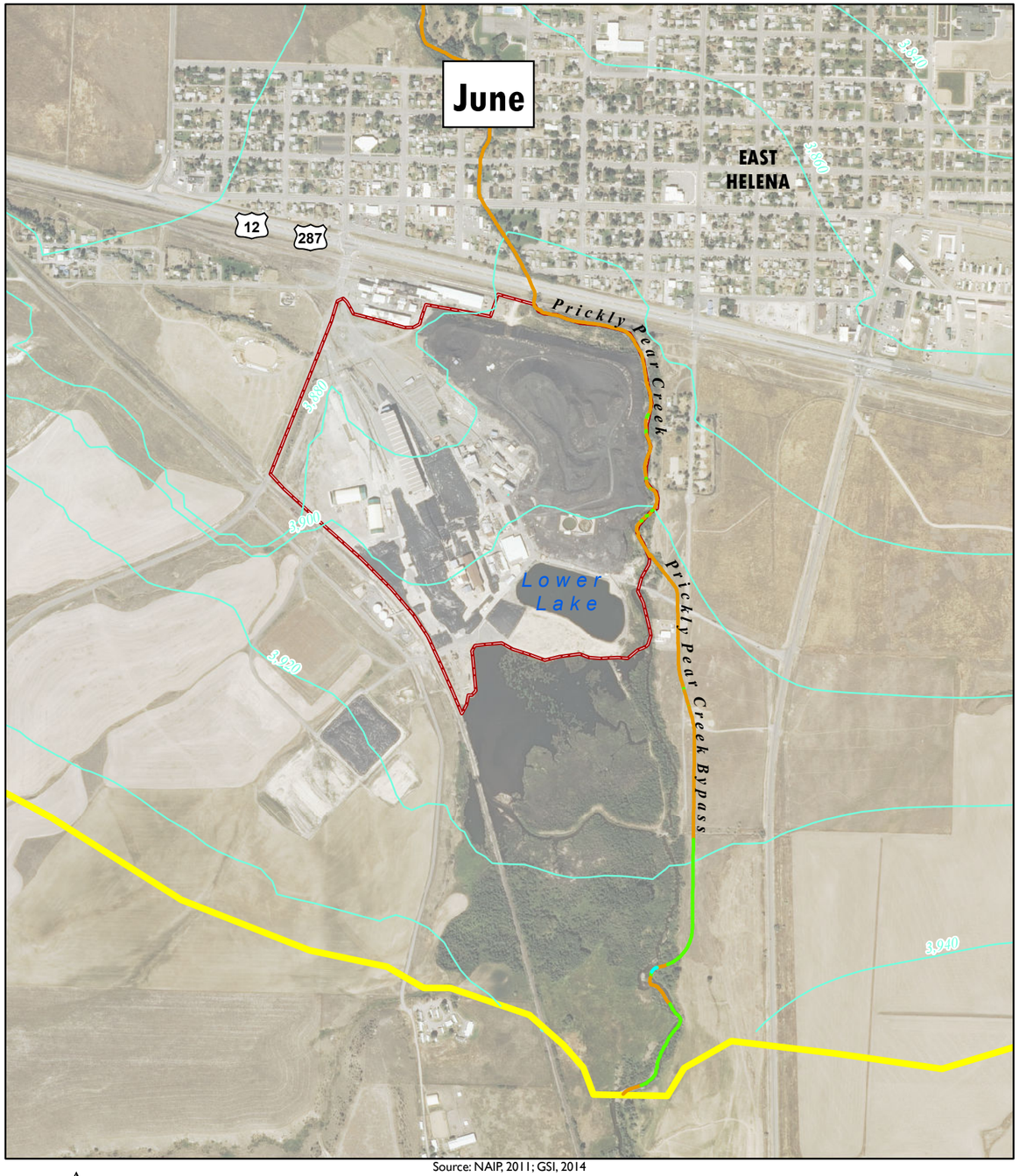
NewFields

Simulated Extent of Detectable Selenium

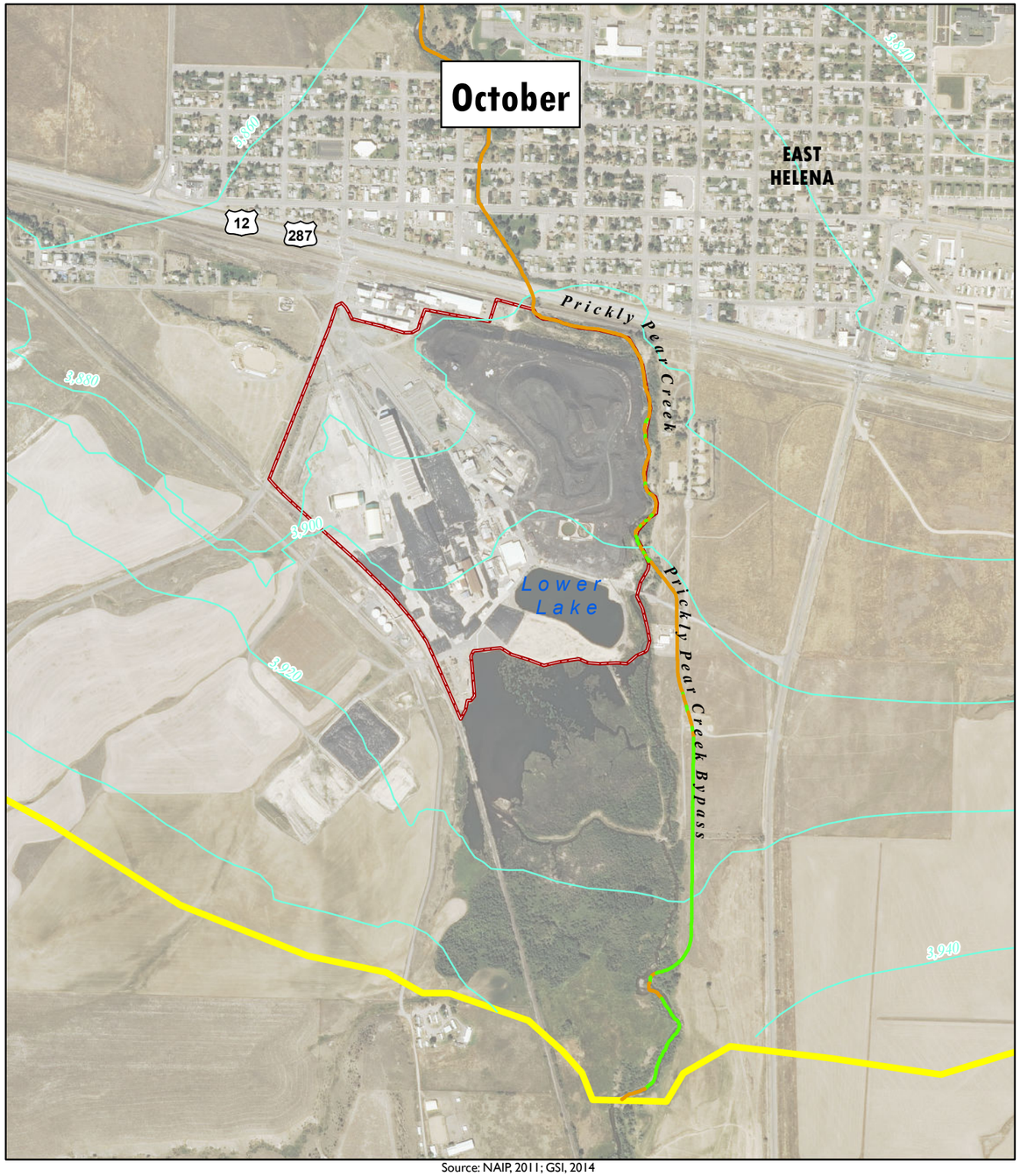
Observed Extent of Detectable Selenium

Note: Results are from NewFields (2016b).

2011 Observed and Simulated Extent of Detectable Selenium Downgradient of the Former Smelter Site
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 5.20



Source: NAIP, 2011; GSI, 2014



Source: NAIP, 2011; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) The model was run until groundwater elevations reached equillibrium.

2) Results are from NewFields (2014d).

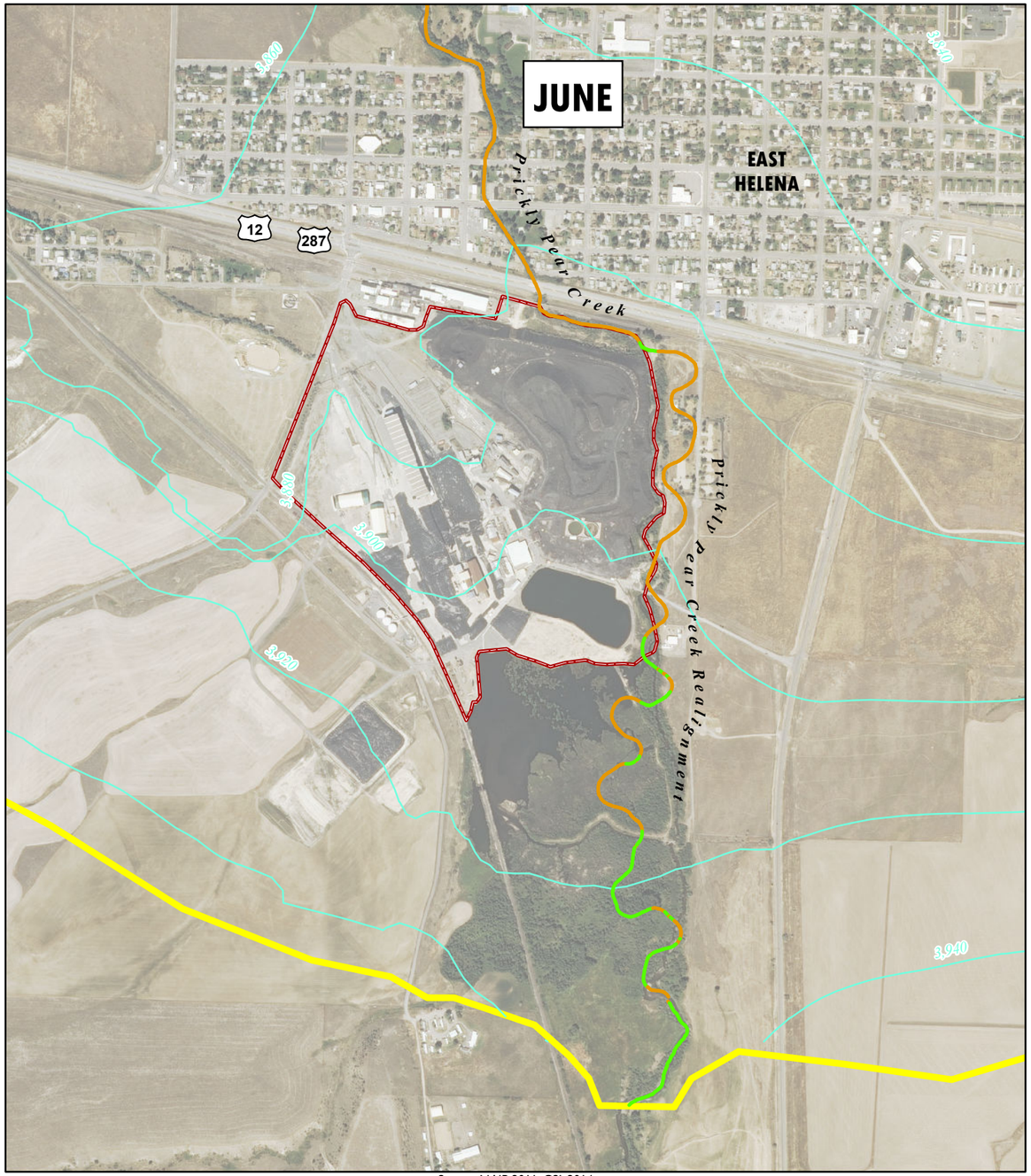
Simulated Potentiometric Surface (feet)

Prickly Pear Creek and Bypass
- Gain
- Loss

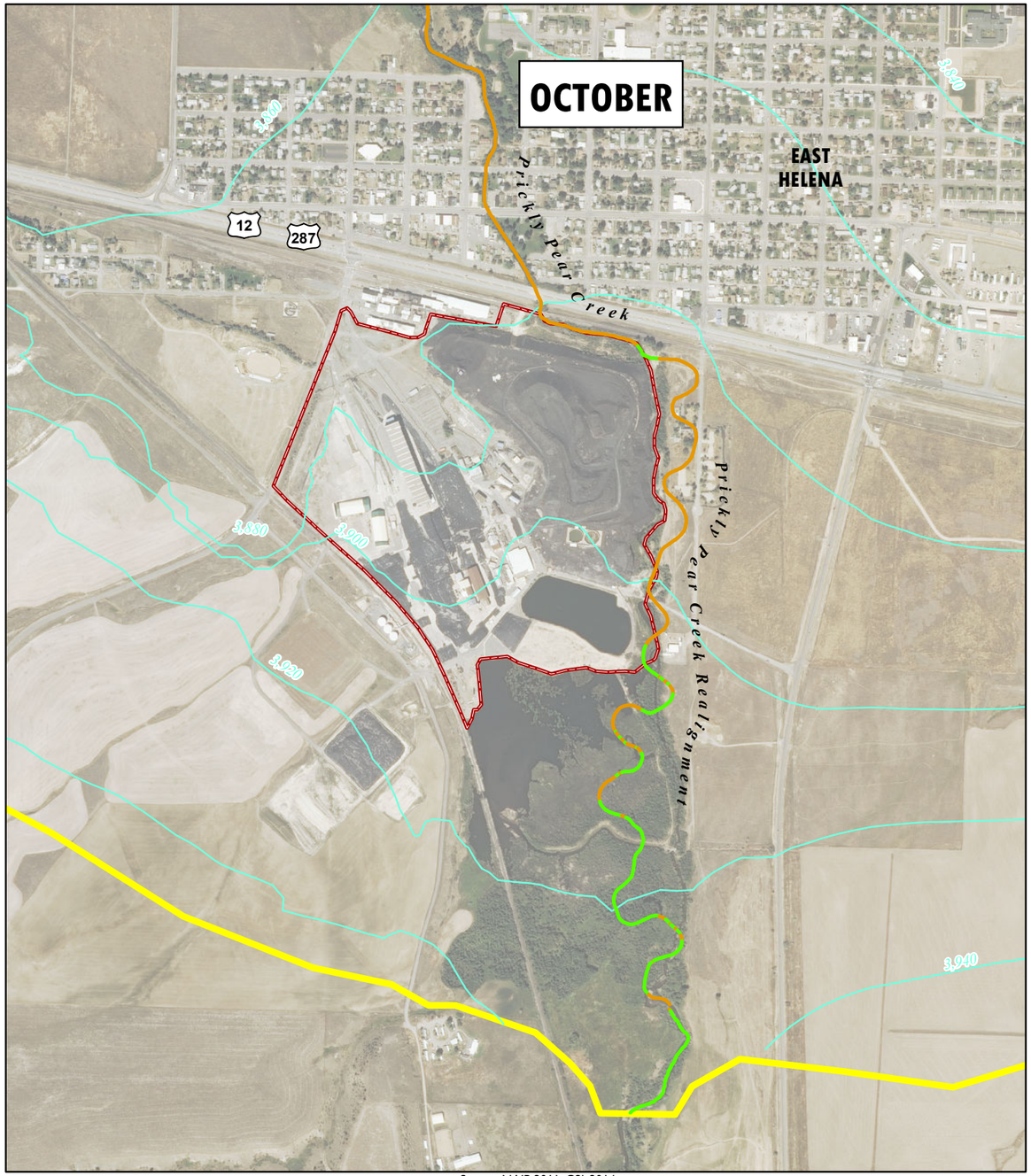
Former Smelter Site Boundary

Model Domain

Steady-State Flow
Predicted Potentiometric Surface and Prickly Pear Creek and Bypass Gain/Loss
June and October
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.1



Source: NAIP, 2011; GSI, 2014



Source: NAIP, 2011; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) The model was run until groundwater elevations reached equillibrium.

2) Results are from NewFields (2014d).

Simulated Potentiometric Surface

Prickly Pear Creek and Realignment

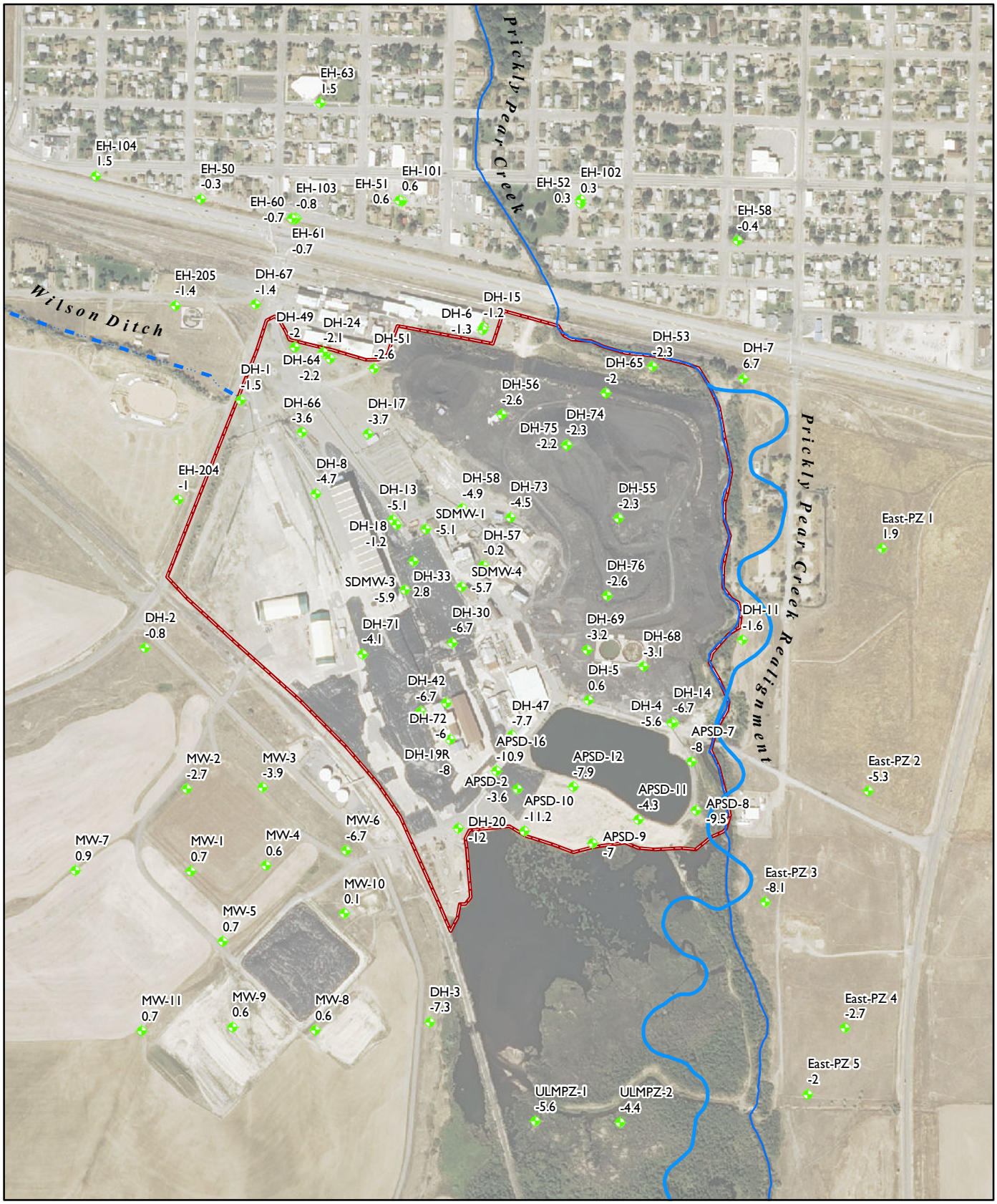
Gain

Loss

Former Smelter Site Boundary

Model Domain

Steady-State Flow
Predicted Potentiometric Surface and Prickly Pear Creek and Realignment Gain/Loss
June and October
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.2



Source: NAIP, 2011; GSI, 2014

Well

Former Smleter Site Boundary

0 Feet 700

NewFields

Notes:
1) Change = Steady State 2011 - Realignment (Positive value represents a decline in groundwater elevation).

2) Results are from NewFields (2014d).

Steady-State Flow
Predicted Change in Groundwater Elevation Pre- and Post-Interim Measures
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.3

Source: NAIP, 2011; GSI, 2014

0 Feet 500

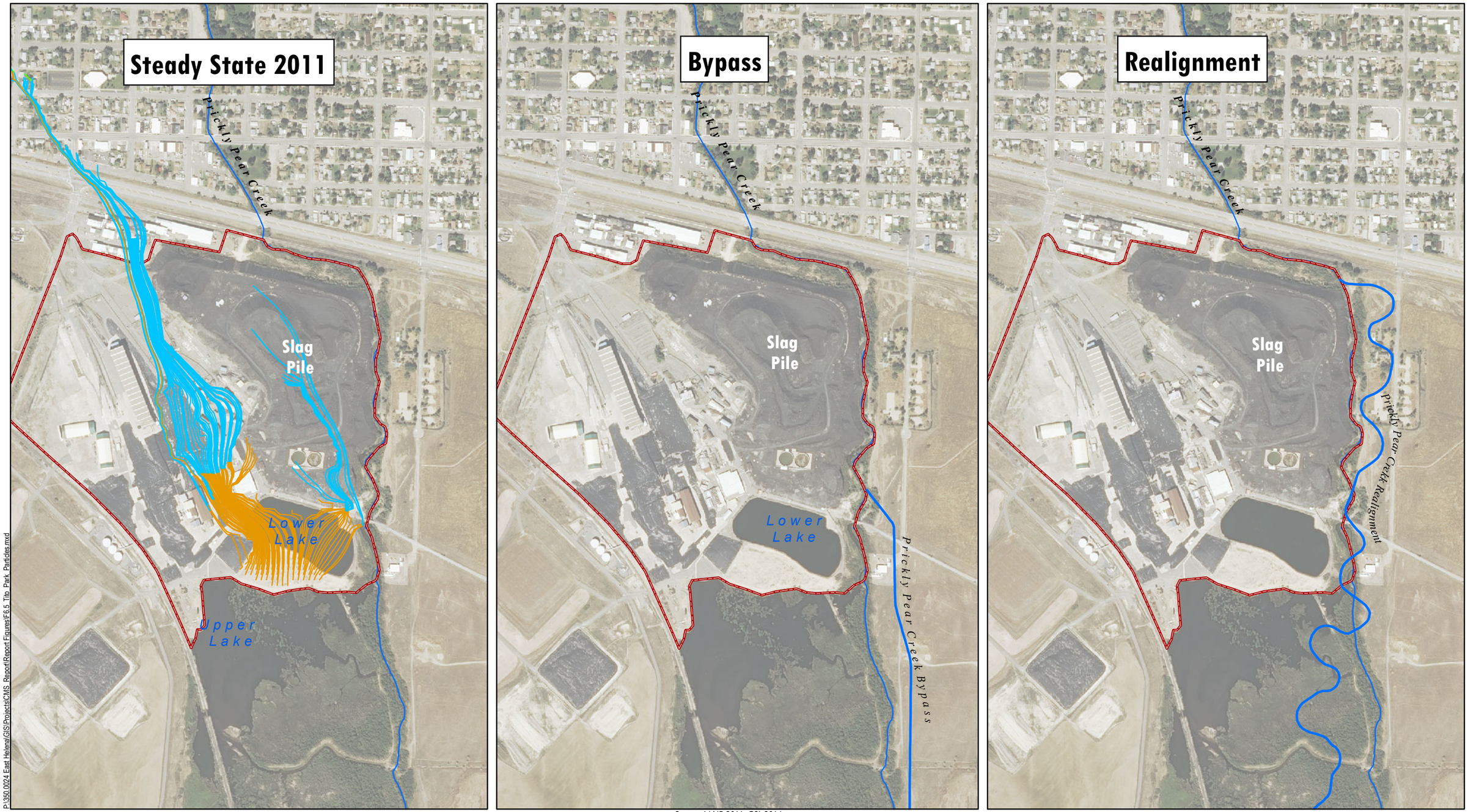
NewFields

Estimated Flux Location

Former Smelter Site Boundary

Notes:
1) Flux was estimated perpendicular to groundwater flow;
2) Flux estimates are presented in Table 6.1.
3) Results are from NewFields (2014d).

Steady-State Flow
Location of Flux Estimates
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.4



P:\360.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.5 Tito Park Particles.mxd

Source: NAIP, 2011; GSI, 2014

0 700 Feet

NewFields

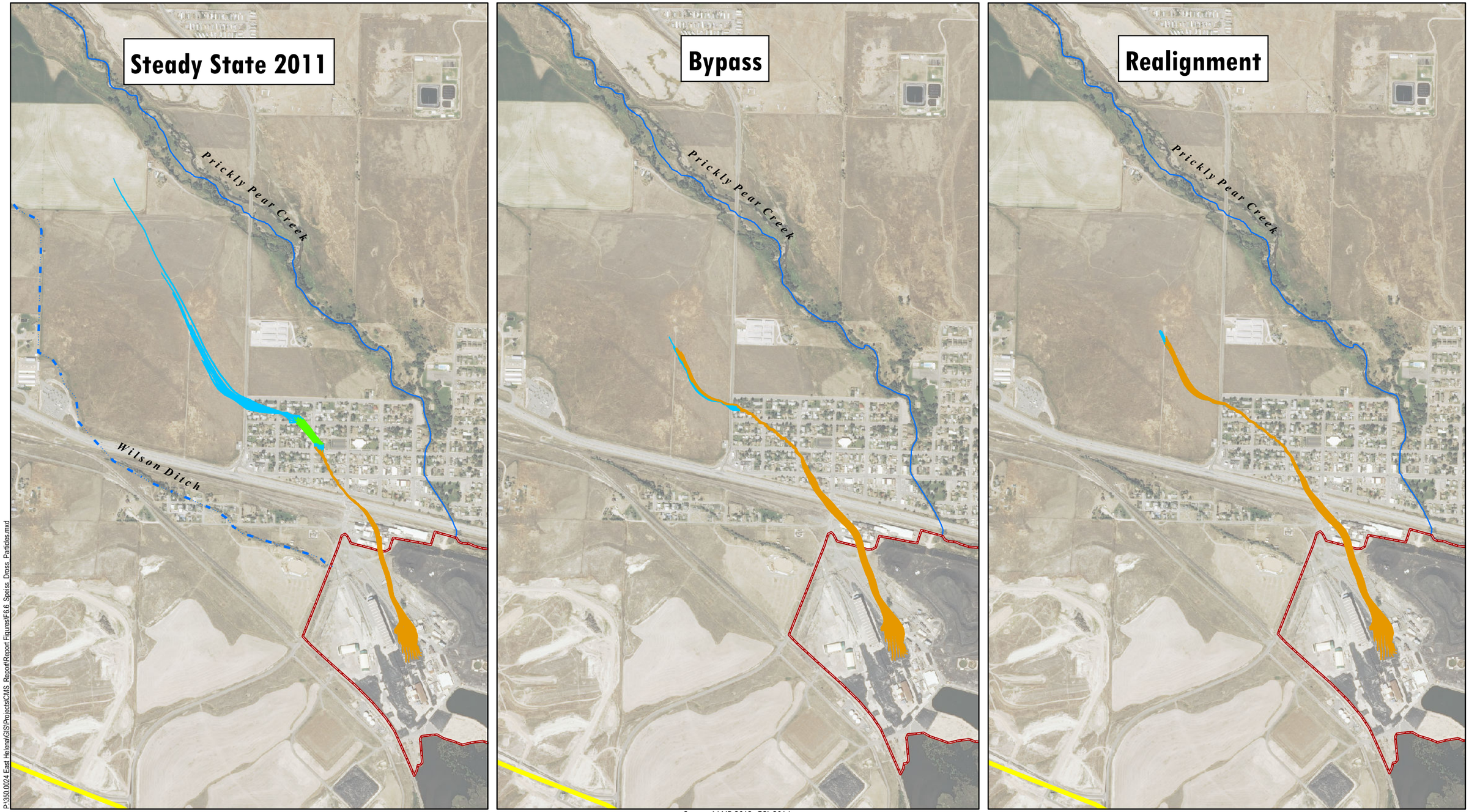
Notes:
1) Particles are not active if the source area is dry.

2) Results are from NewFields (2014d).

Particle Track
- Layer 1
- Layer 2
- Layer 3

Former Smelter Site Boundary

Steady-State Flow
Particle Track Analysis - Tito Park
Forward Particle Tracking
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.5



P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.6_Speiss_Dross_Particles.mxd

Source: NAIP, 2013; GSI, 2014

0 1,200 Feet

NewFields

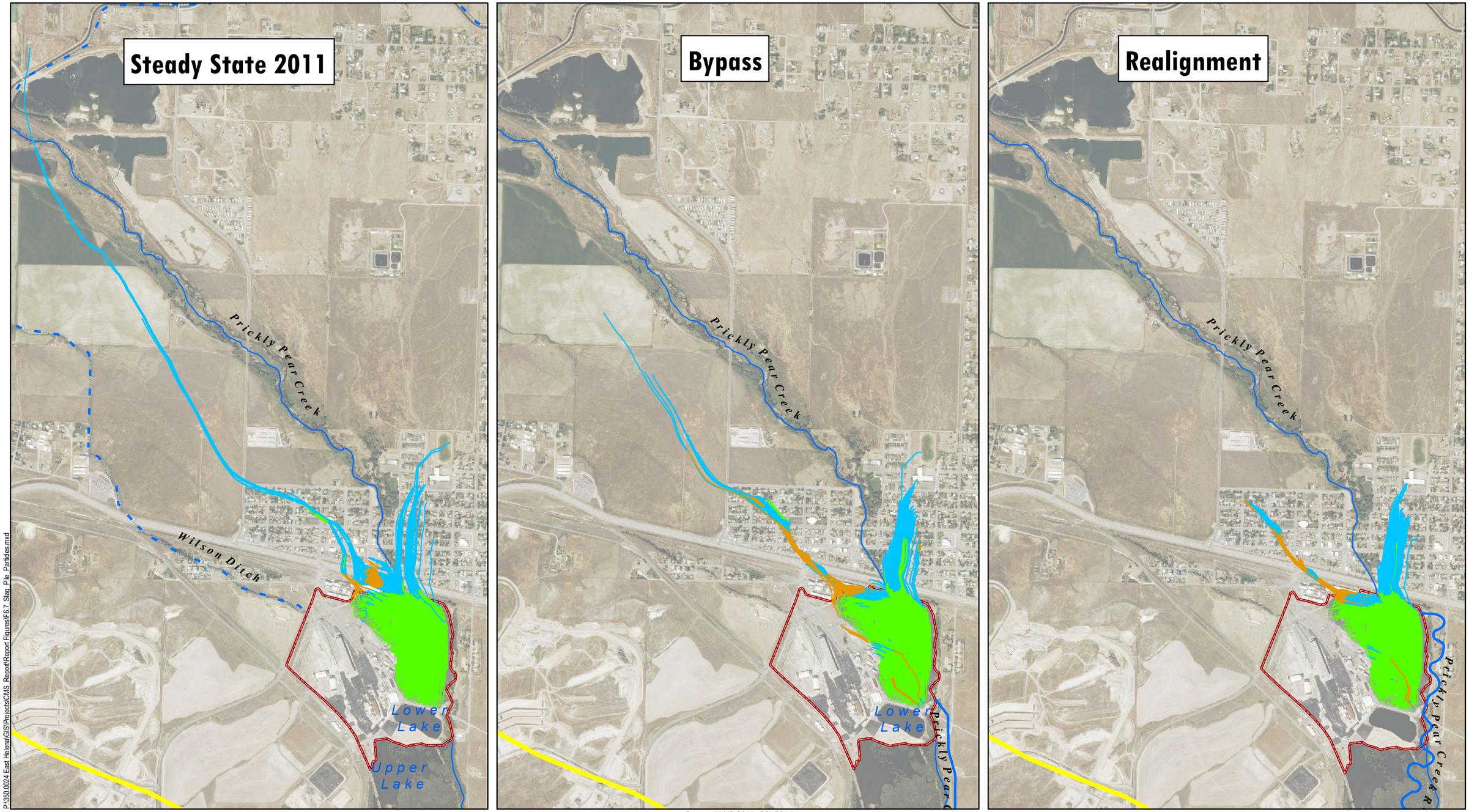
Notes:
1) Particles are not active if the source area is dry.

2) Results are from NewFields (2014d).

Particle Track
- Layer 1
- Layer 2
- Layer 3

Former Smelter Site Boundary
Model Domain

Steady-State Flow
Particle Track Analysis - Speiss-Dross
Forward Particle Tracking
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.6



P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.7 Slag_Pile_Particles.mxd

Source: NAIP, 2011; GSI, 2014

0 1,600 Feet

NewFields

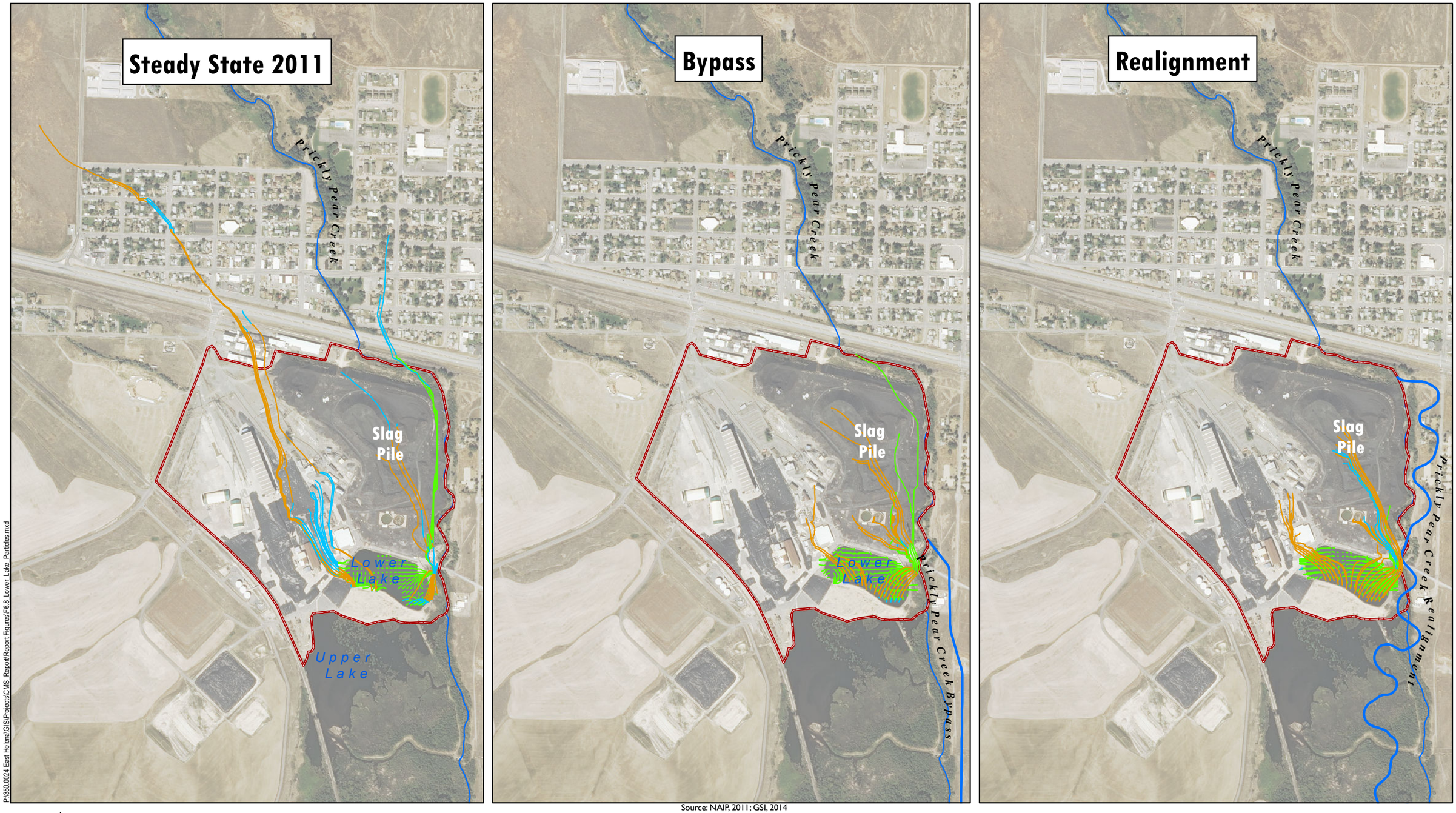
Notes:
1) Particles are not active if the source area is dry.

2) Results are from NewFields (2014d).

Particle Track
- Layer 1
- Layer 2
- Layer 3

Facility Boundary
Model Domain

Steady-State Flow
Particle Track Analysis - Slag Pile
Forward Particle Tracking
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.7



P:\360.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.8_Lower_Lake_Particles.mxd

Source: NAIP, 2011; GSI, 2014

0 900 Feet

NewFields

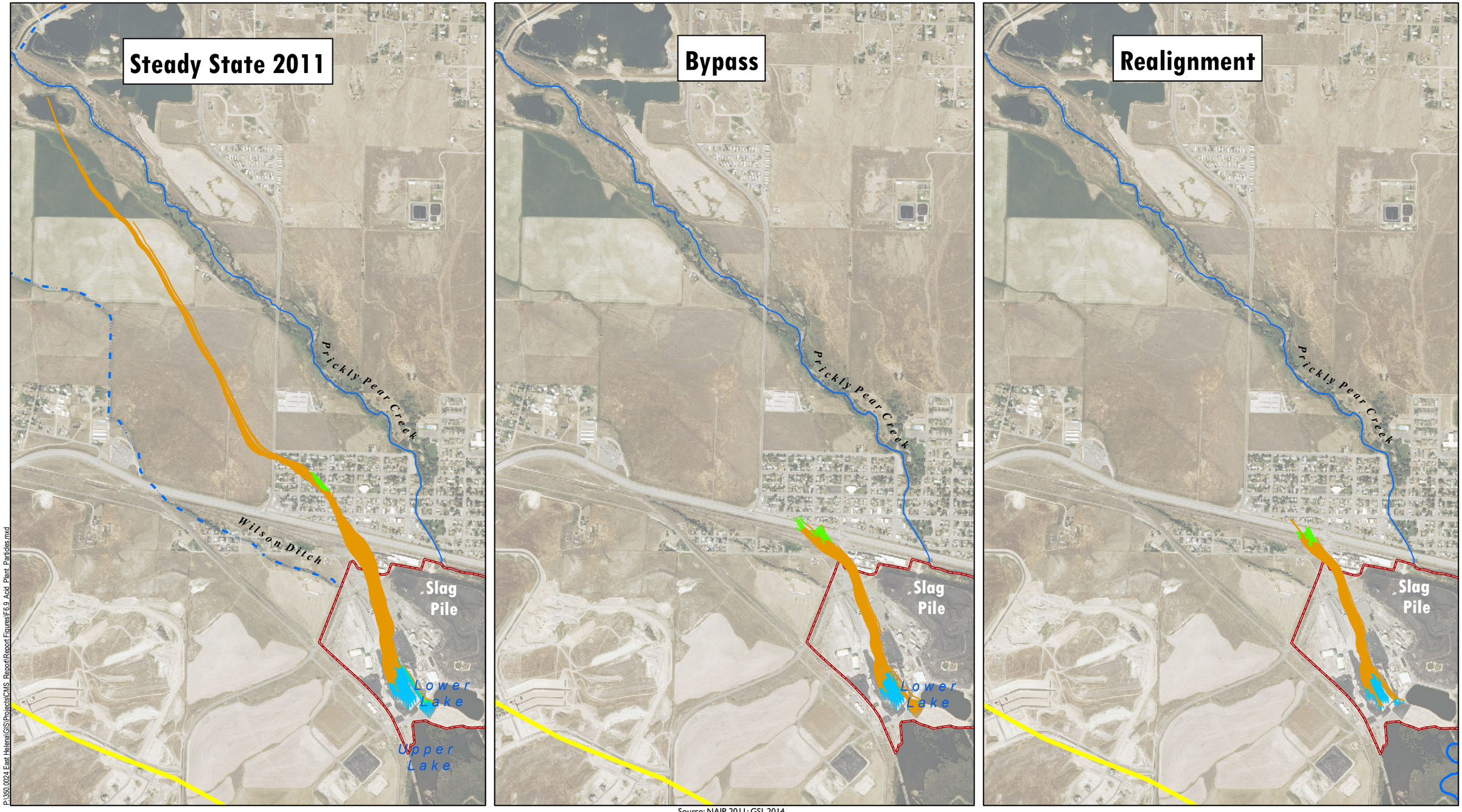
Notes:
1) Particles are not active if the source area is dry.

2) Results are from NewFields (2014d).

Particle Track
- Layer 1
- Layer 2
- Layer 3

Former Smelter Site Boundary

Steady-State Flow
Particle Track Analysis - Lower Lake
Forward Particle Tracking
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.8



P:\050.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.9 Acid Plant Particles.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 1,500

NewFields

Notes:
1) Particles are not active if the source area is dry.

2) Results are from NewFields (2014d).

Particle Track
- Layer 1
- Layer 2
- Layer 3
- Former Smelter Site Boundary
- Model Domain

Steady-State Flow
Particle Track Analysis - Acid Plant
Forward Particle Tracking
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.9

2011 Calibrated Plume

Bypass

Realignment

Prickly Pear Creek

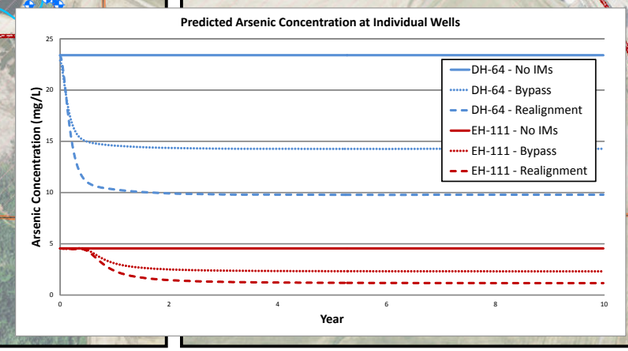
EH-111

DH-64

EAST HELENA

12

287



P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.10_Arsenic_IMs_Norealign.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area.

4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

- 0.01
- 0.1
- 1
- 10
- > 20

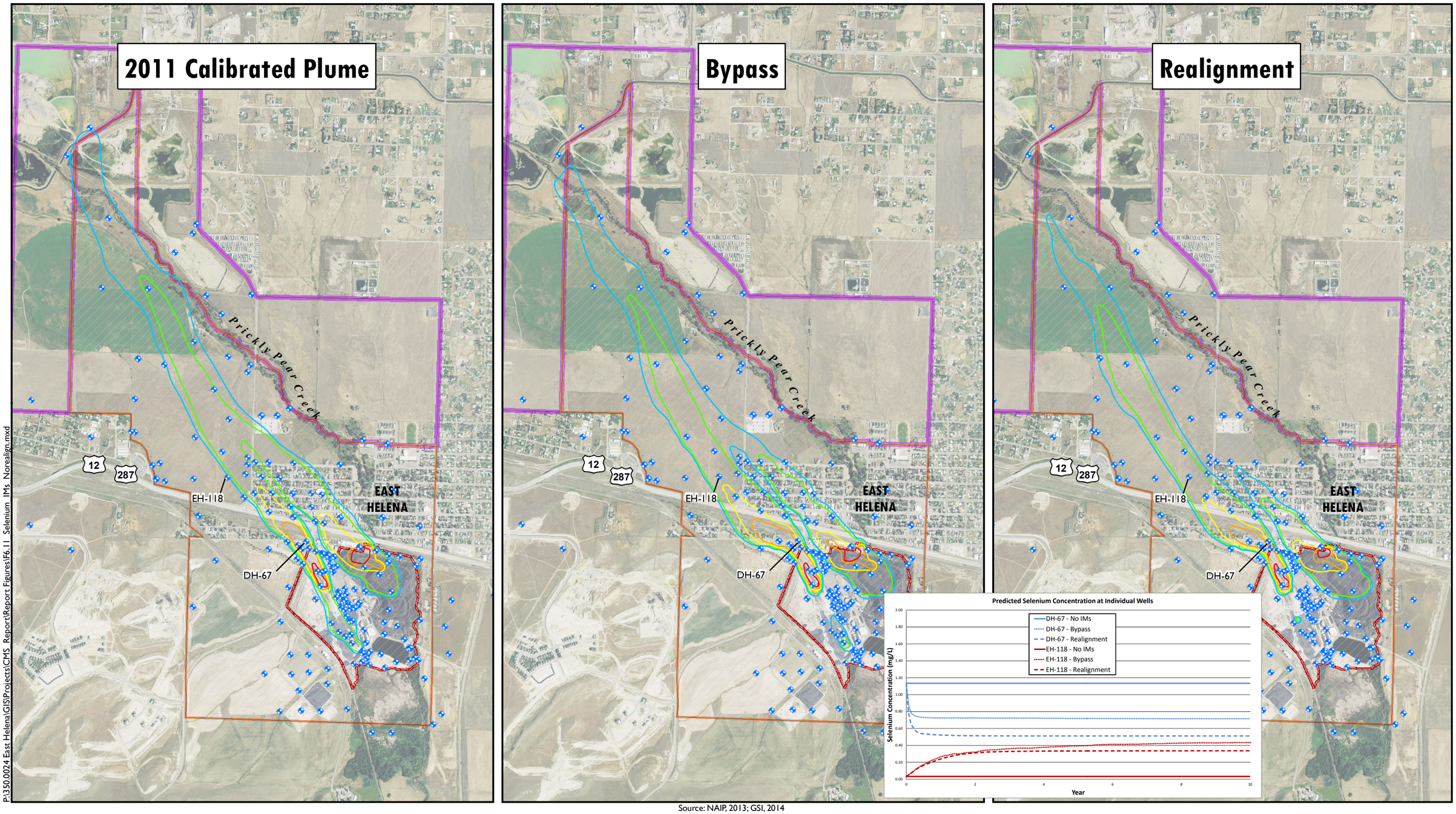
Monitoring Well

Former Smelter Site Boundary

Permanent CGWA - Subarea1

Permanent CGWA - Subarea 2

Steady-State Flow and Transient Transport
Predicted Isoconcentration Contrours
Arsenic IM Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.10



Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area.

4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3

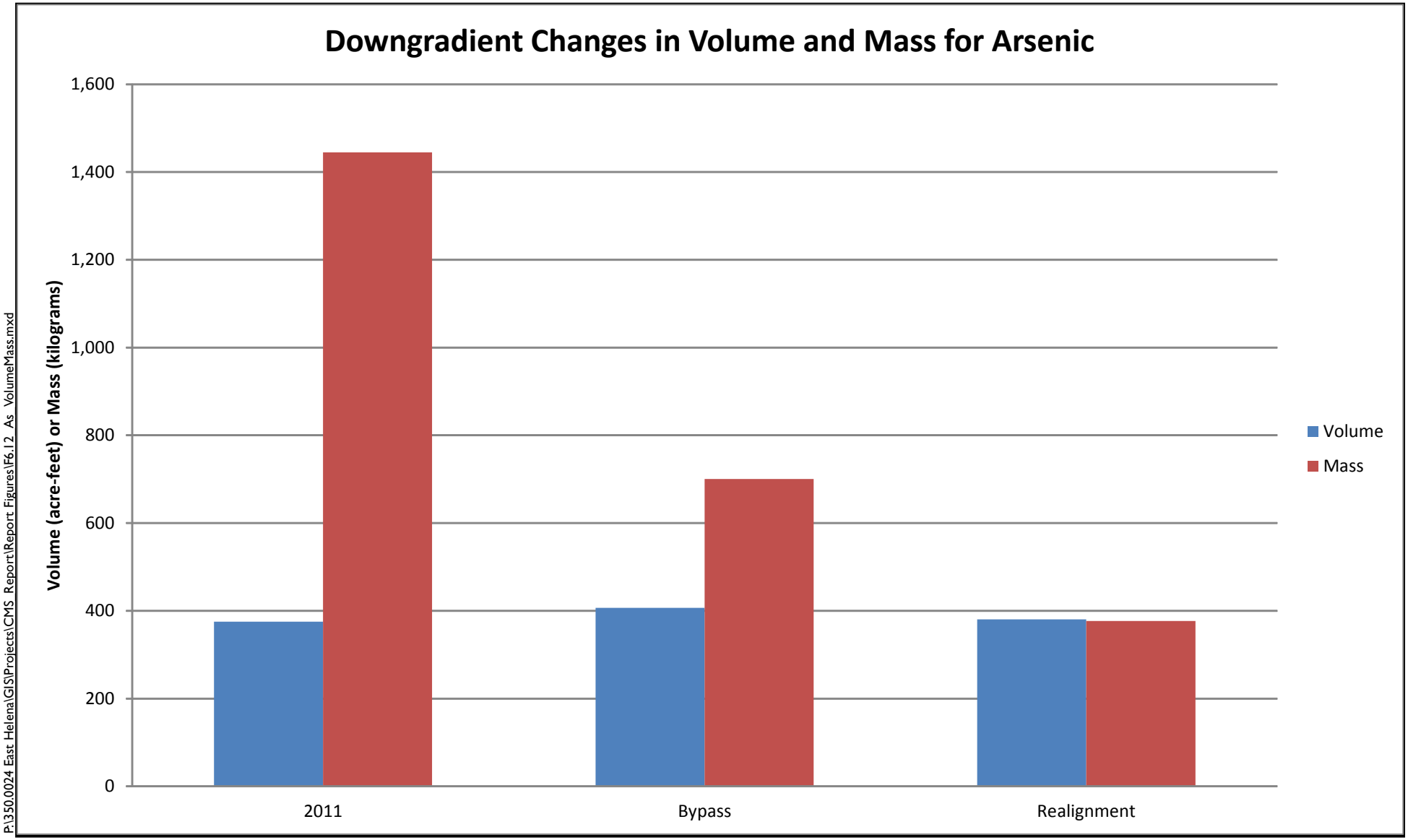
Monitoring Well

Former Smelter Site Boundary

Permanent CGWA - Subarea1

Permanent CGWA - Subarea 2

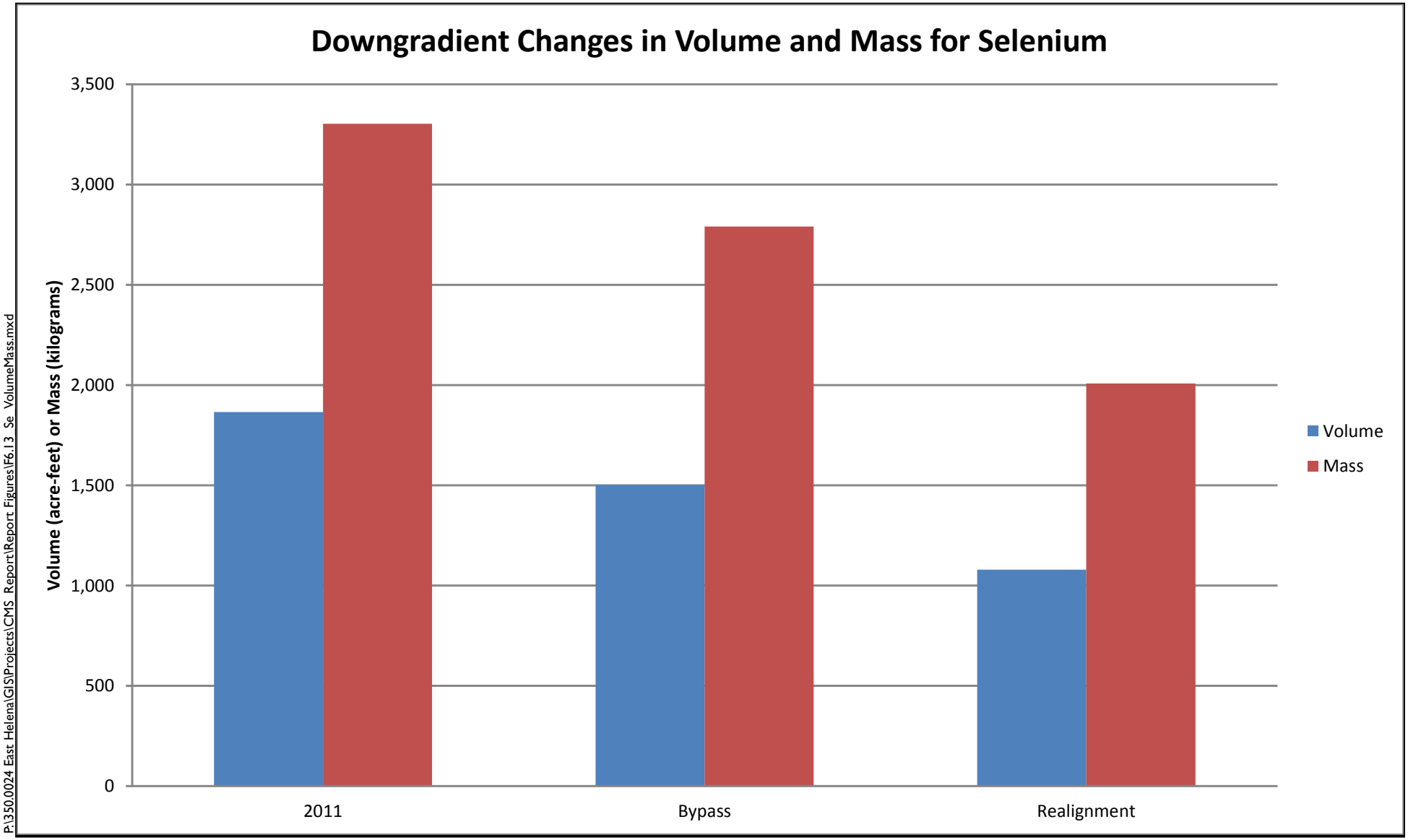
Steady-State Flow and Transient Transport
Predicted Isoconcentration Contrours
Selenium IM Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.11



Note: Results are from NewFields (2015b).

NewFields

Steady-State Flow and Transient Transport
Changes in Arsenic Volume/Mass for SPHC IMs
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.12

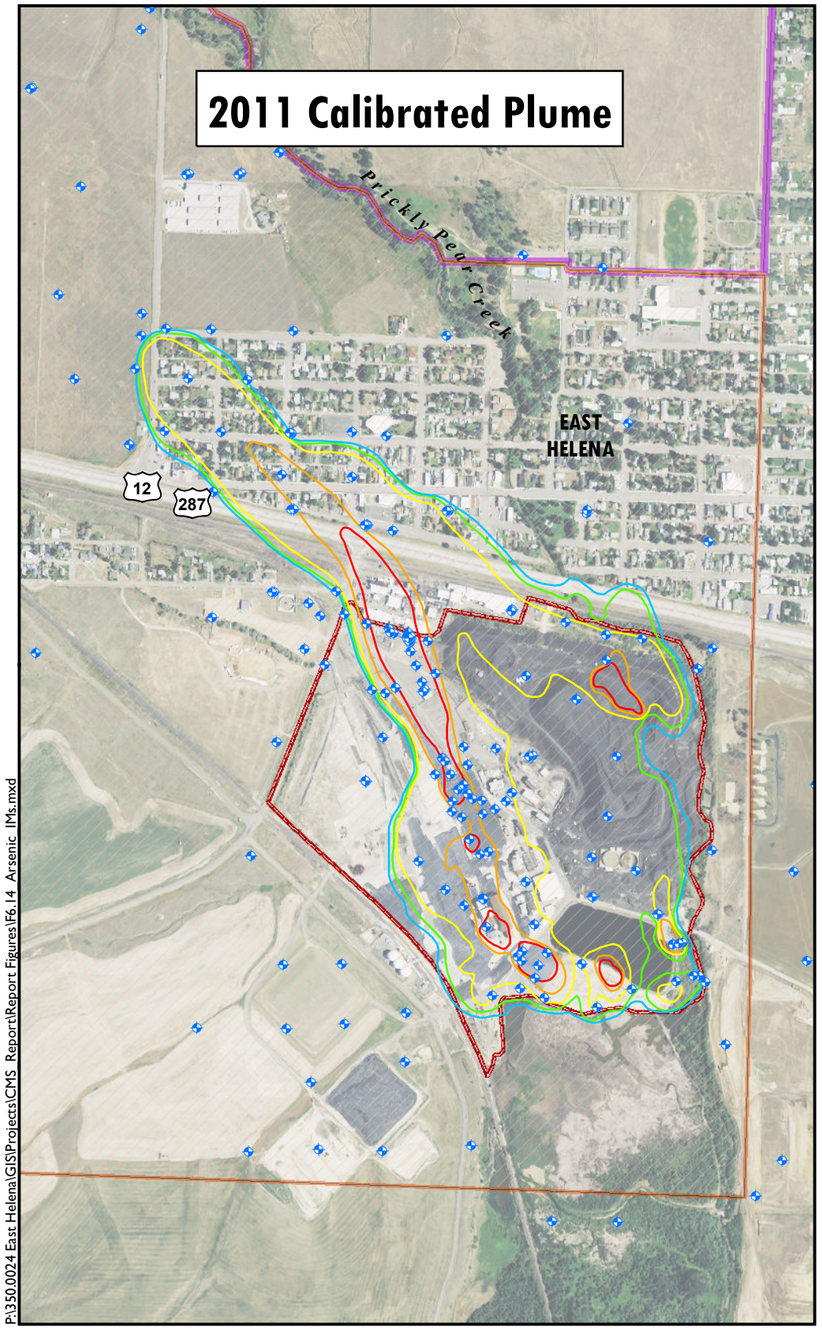


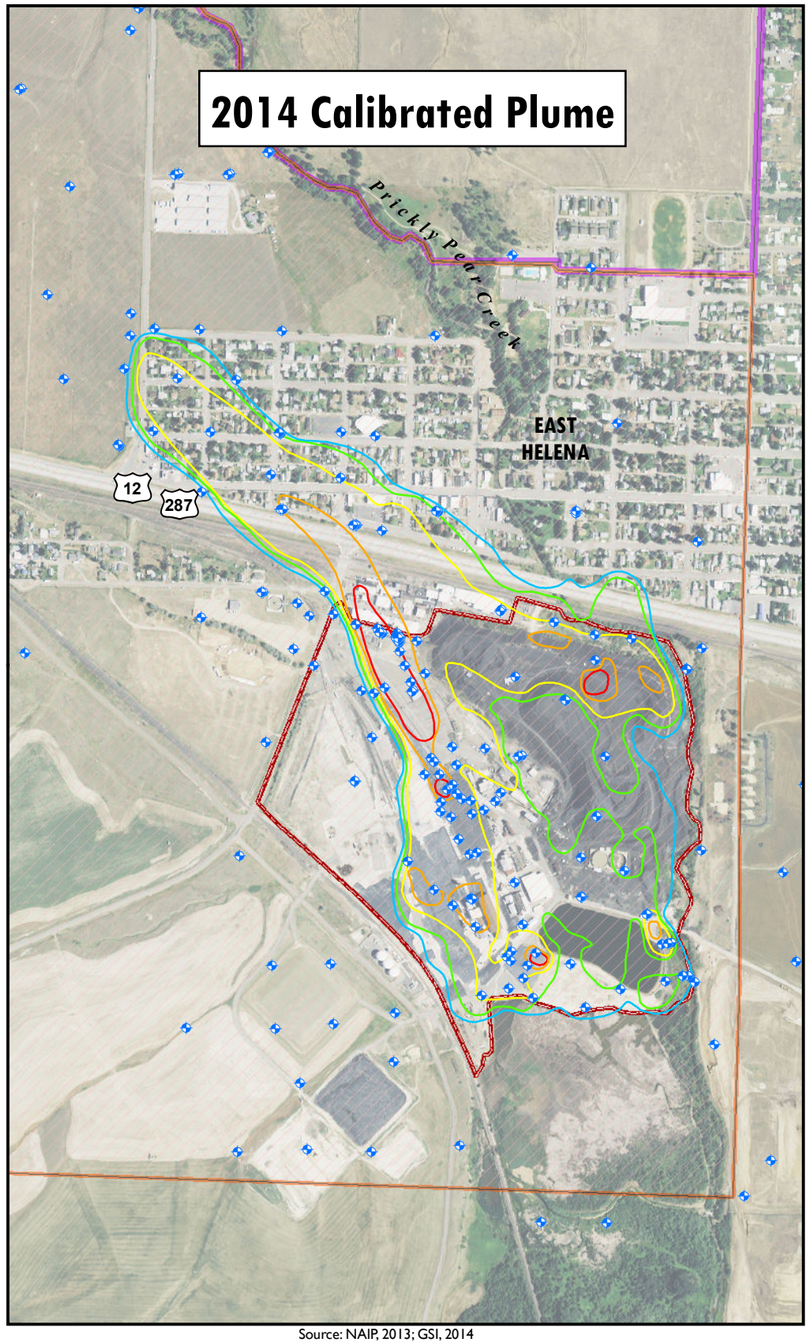
P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.13 Se VolumeMass.mxd

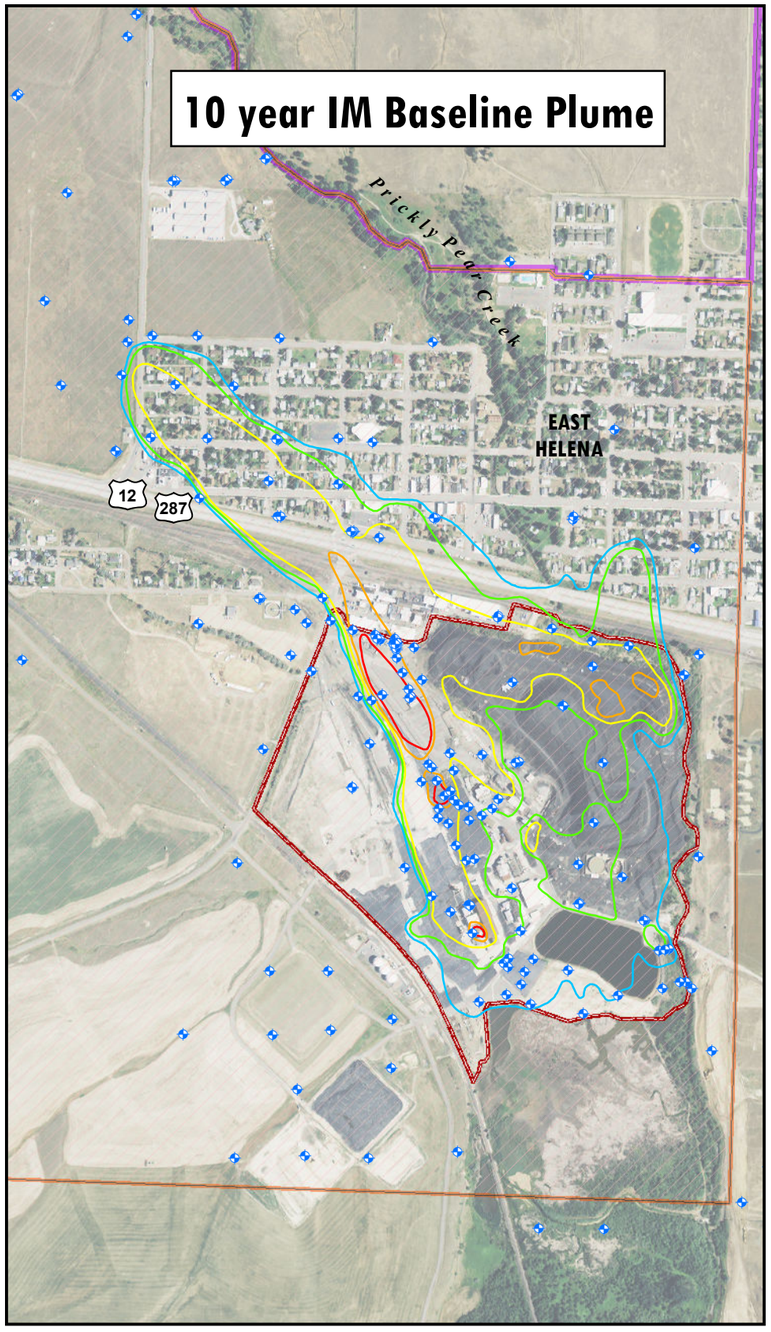
Note: Results are from NewFields (2015b).

Steady-State Flow and Transient Transport
Changes in Selenium Volume/Mass for SPHC IMs
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.13

NewFields







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.14 Arsenic IMs.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4;

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state;

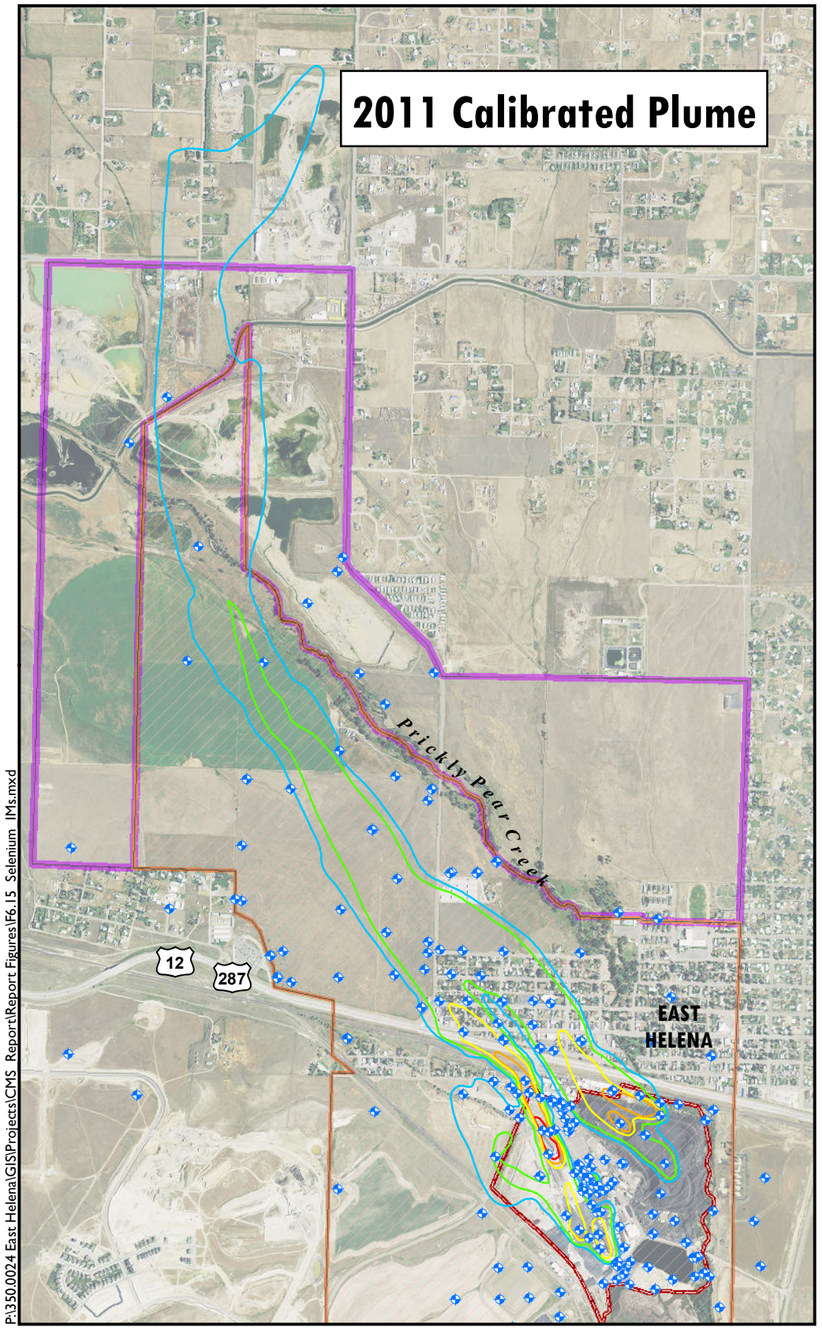
3) mg/L = milligram per liter.

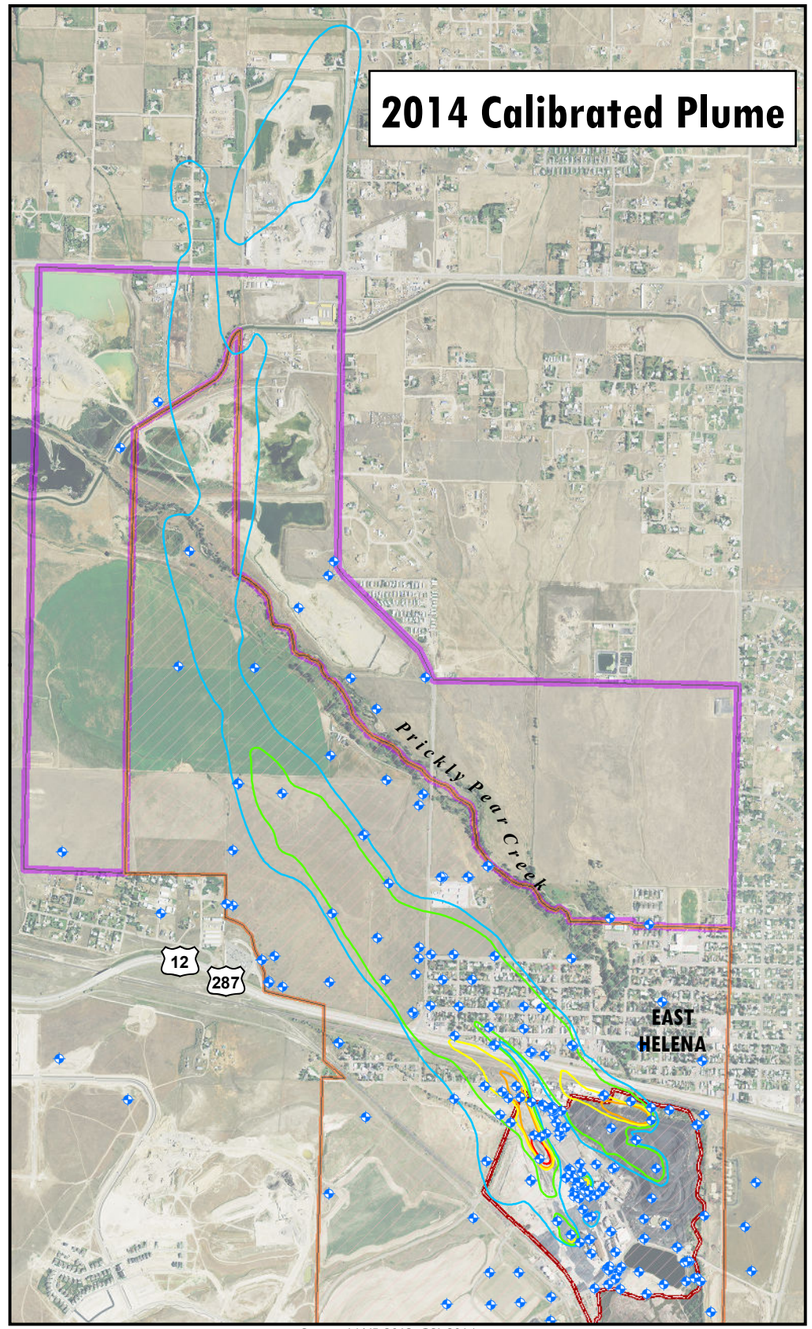
4) Results are from NewFields (2016a).

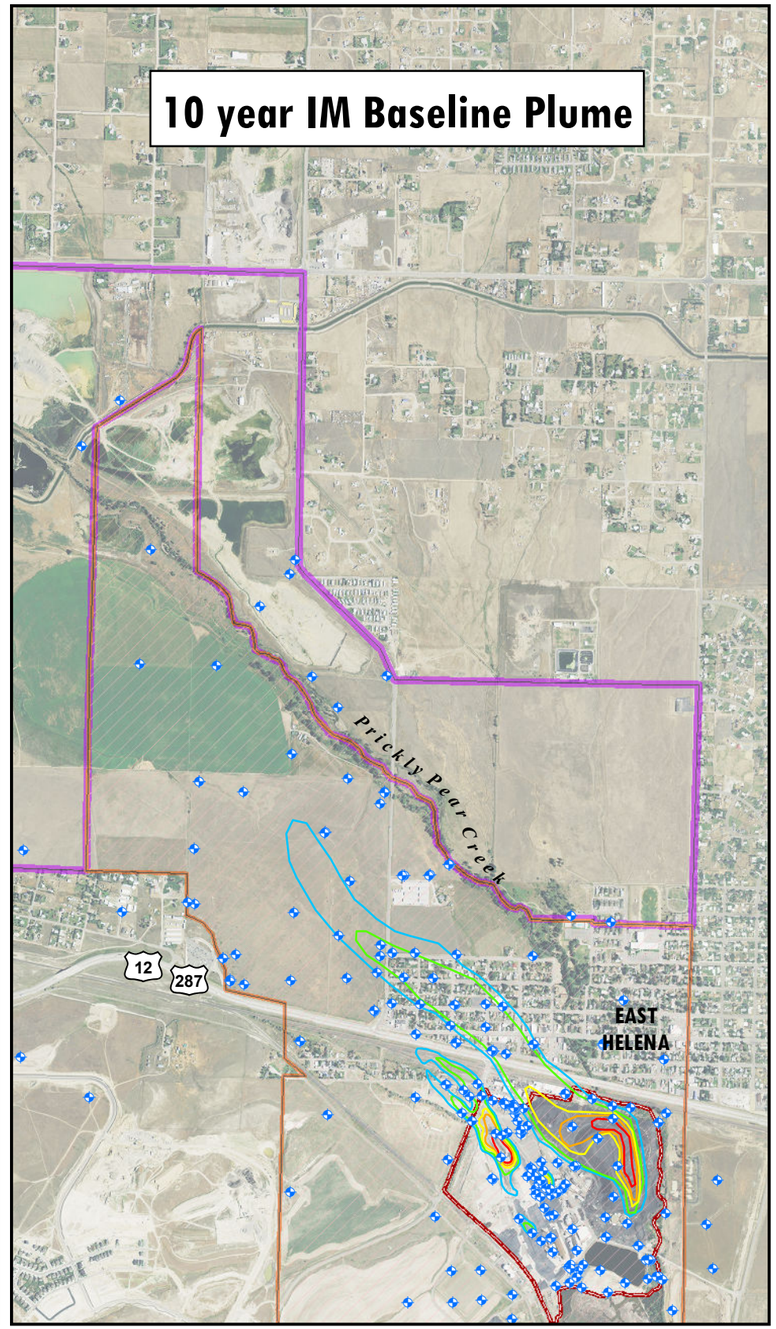
Isoconcentration Contour (mg/L)
- 0.01
- 0.1
- 1
- 10
- > 20

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Transient Flow and Trasnport
Predicted Isoconcentration Contours
Arsenic IM Baseline Simulation
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.14







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.15 Selenium IMs.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4;

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state;

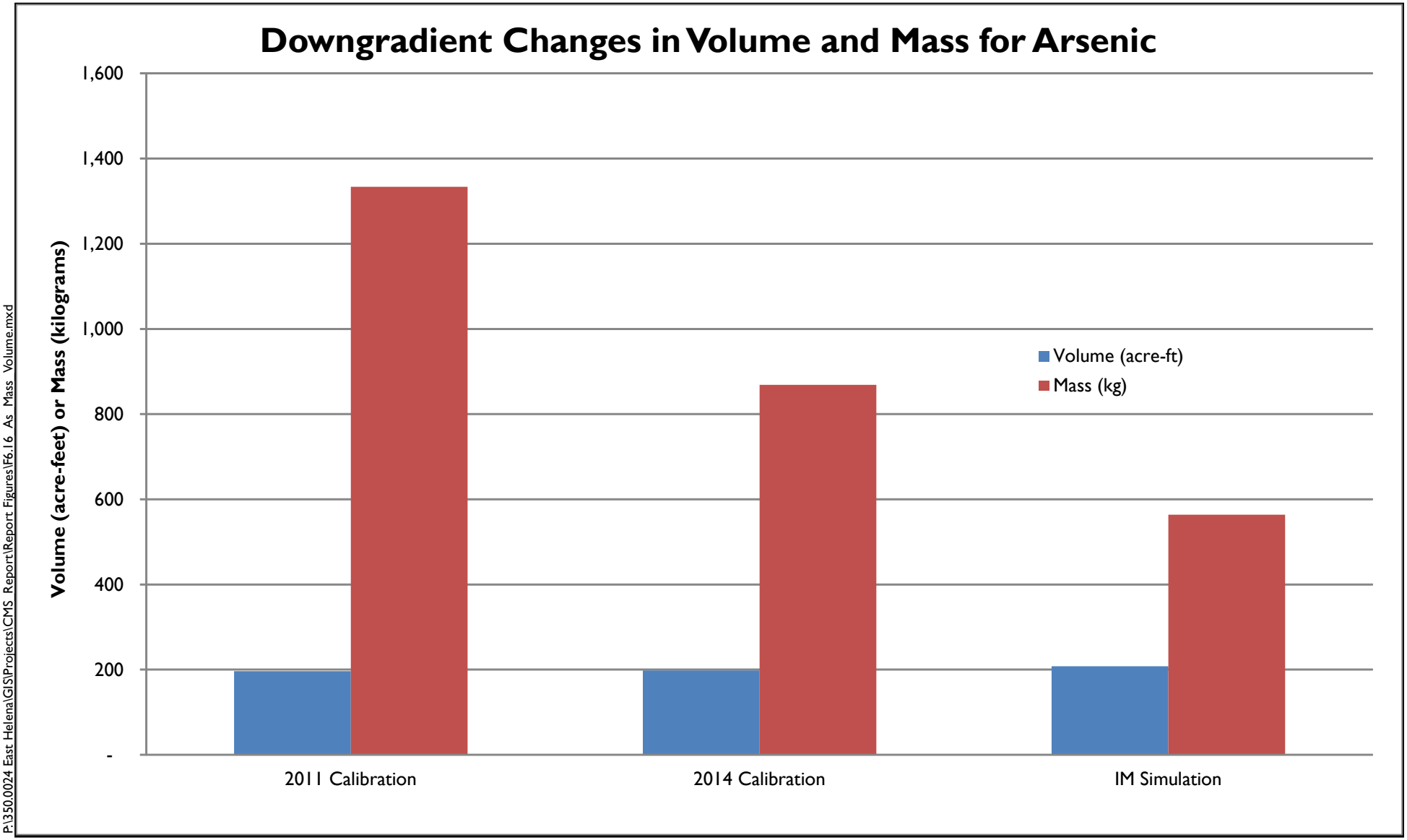
3) mg/L = milligram per liter.

4) Results are from NewFields (2016a).

Isoconcentration Contour (mg/L)
- 0.05
- 0.1
- 0.5
- 1
- > 3

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Transient Flow and Trasnport
Predicted Isoconcentration Contours
Selenium IM Baseline Simulation
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.15



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.16 As Mass Volume.mxd

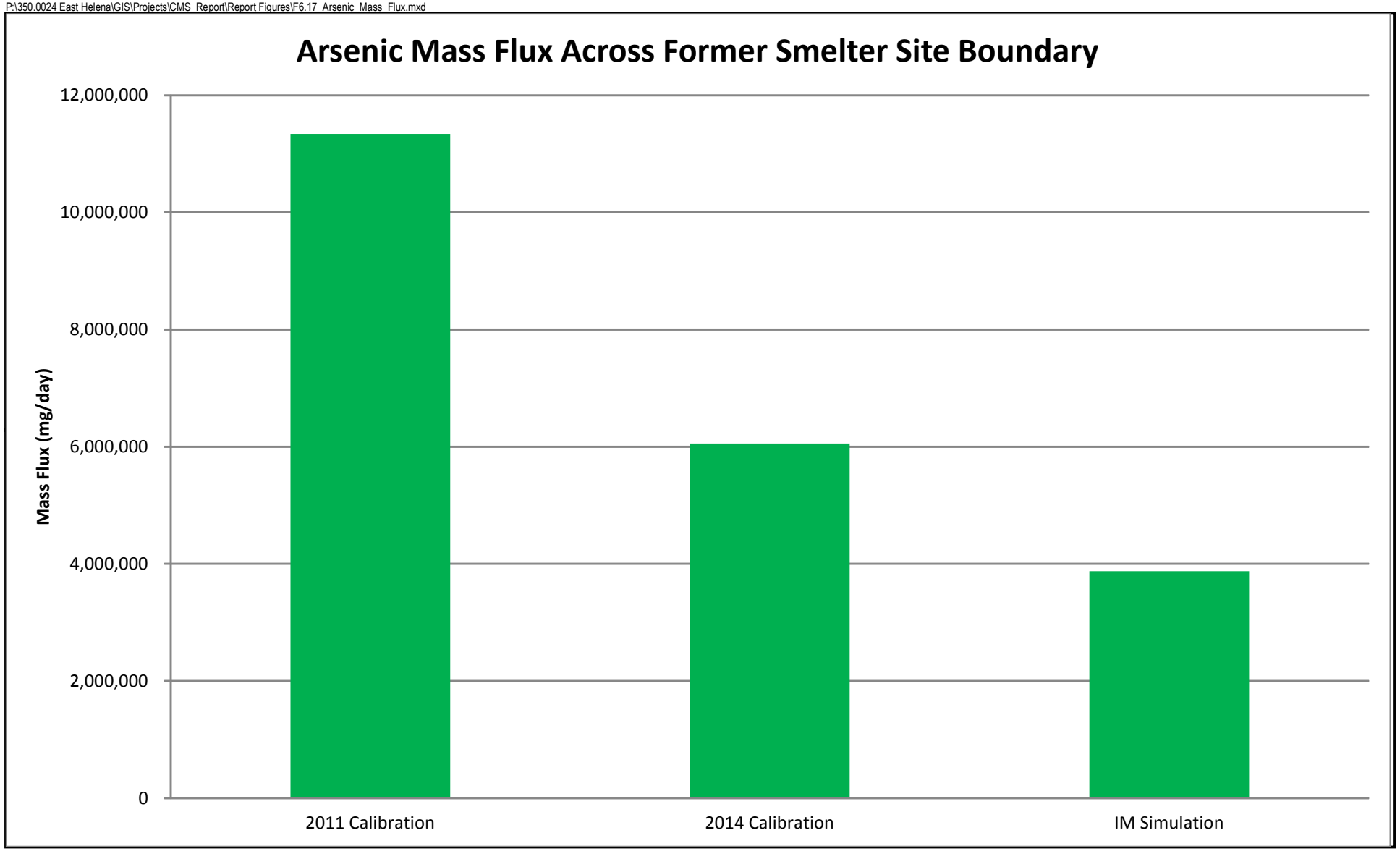
Notes:
1) Predictive results were calculated using stress period 66 of the model.

2) Results are from NewFields (2016a).

NewFields

Transient Flow and Trasnport
Predicted Change in Arsenic Volume/Mass for SPHC IMs
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.16

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.17_Arsenic_Mass_Flux.mxd



Notes:
1) Predictive results were calculated using stress period 66 of the model.

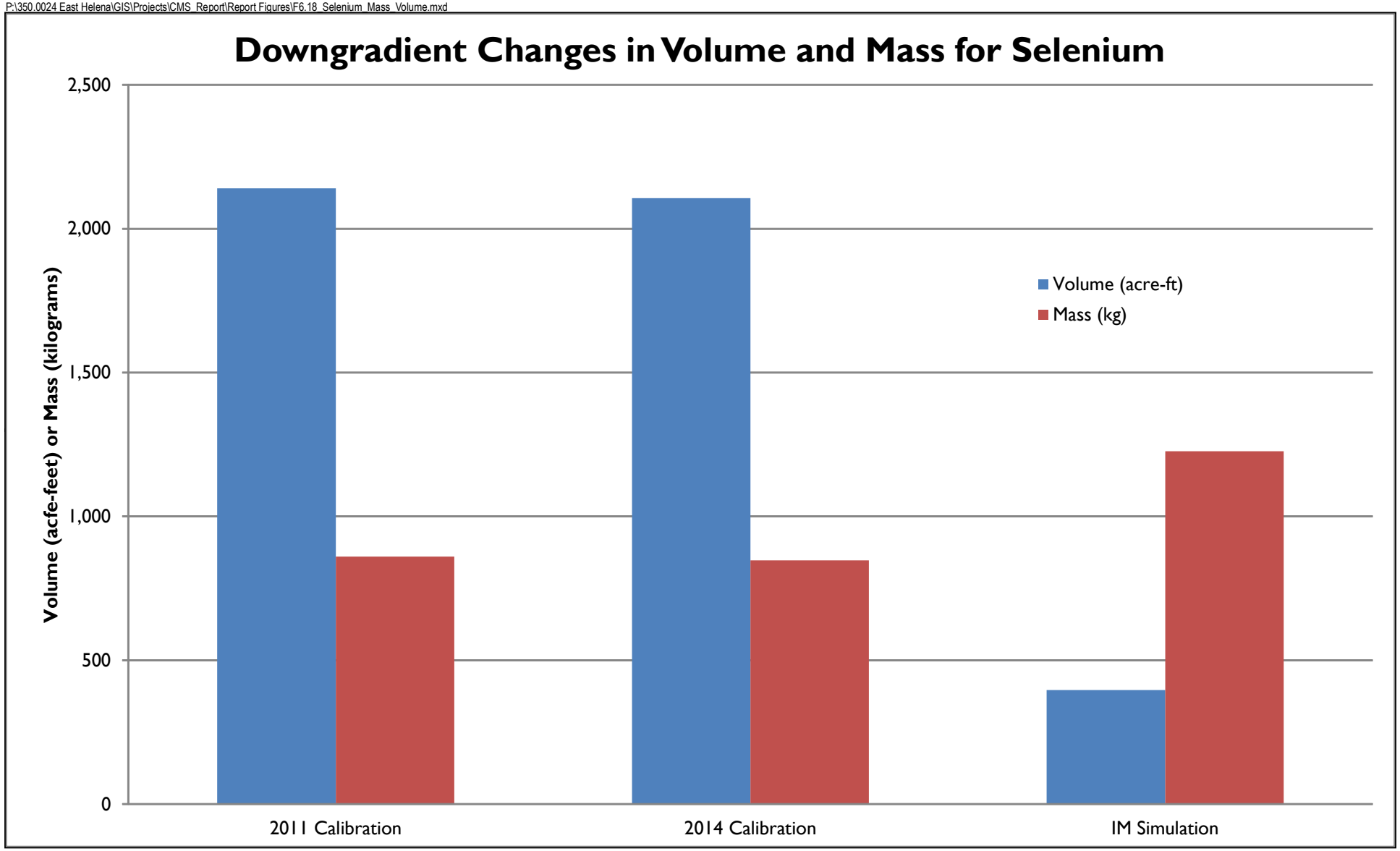
2) mg/day = milligram per day.

3) Results are from NewFields (2016a).

NewFields

Transient Flow and Trasnport
Predicted Change in Arsenic Mass Flux Across Site Boundary for SPHC IMs
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.17

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.18_Selenium_Mass_Volume.mxd



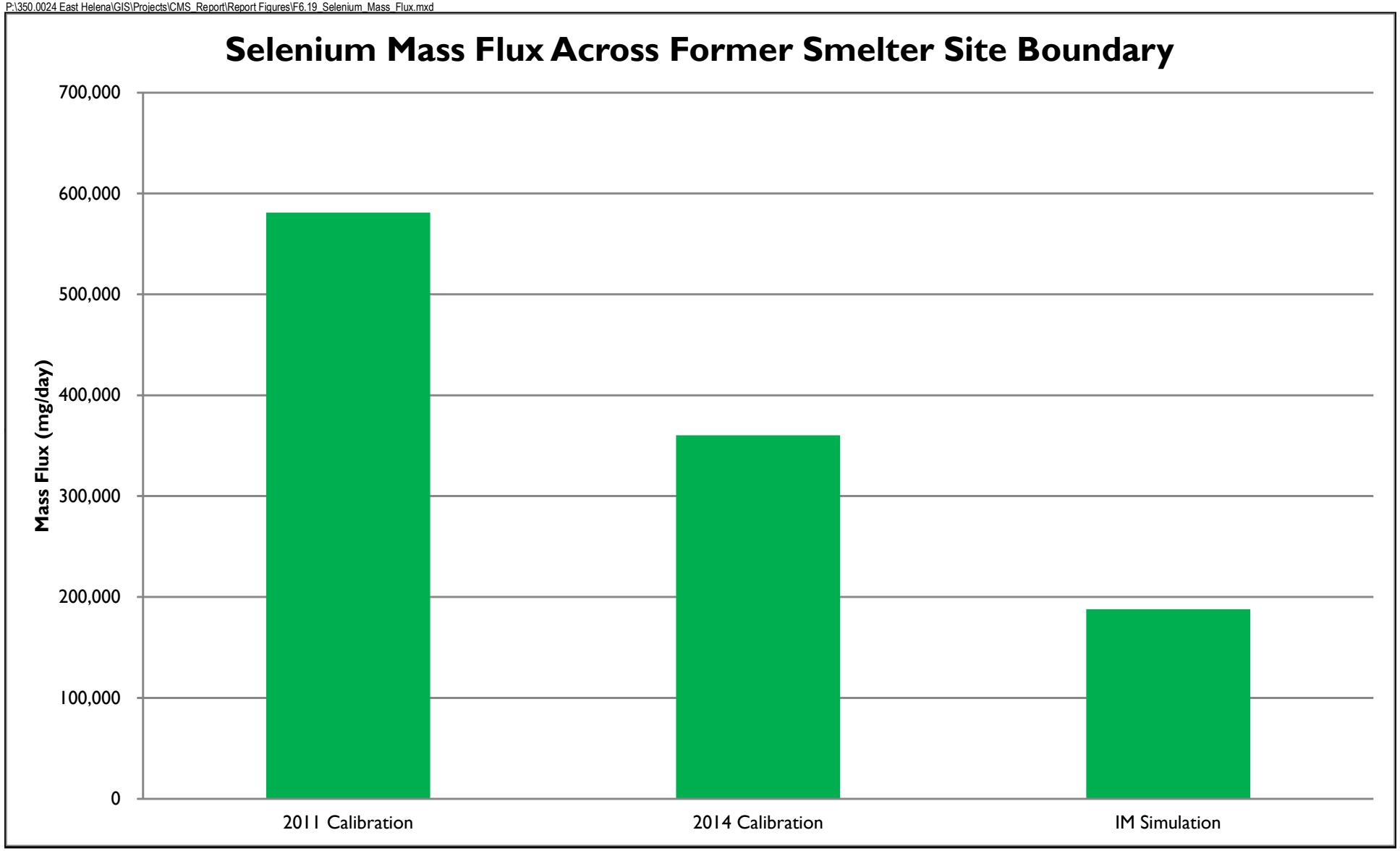
Notes:
1) Predictive results were calculated using stress period 66 of the model.

2) Results are from NewFields (2016a).

NewFields

Transient Flow and Trasnport
Predicted Change in Selenium Volume/Mass for SPHC IMs
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.18

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.19_Selenium_Mass_Flux.mxd



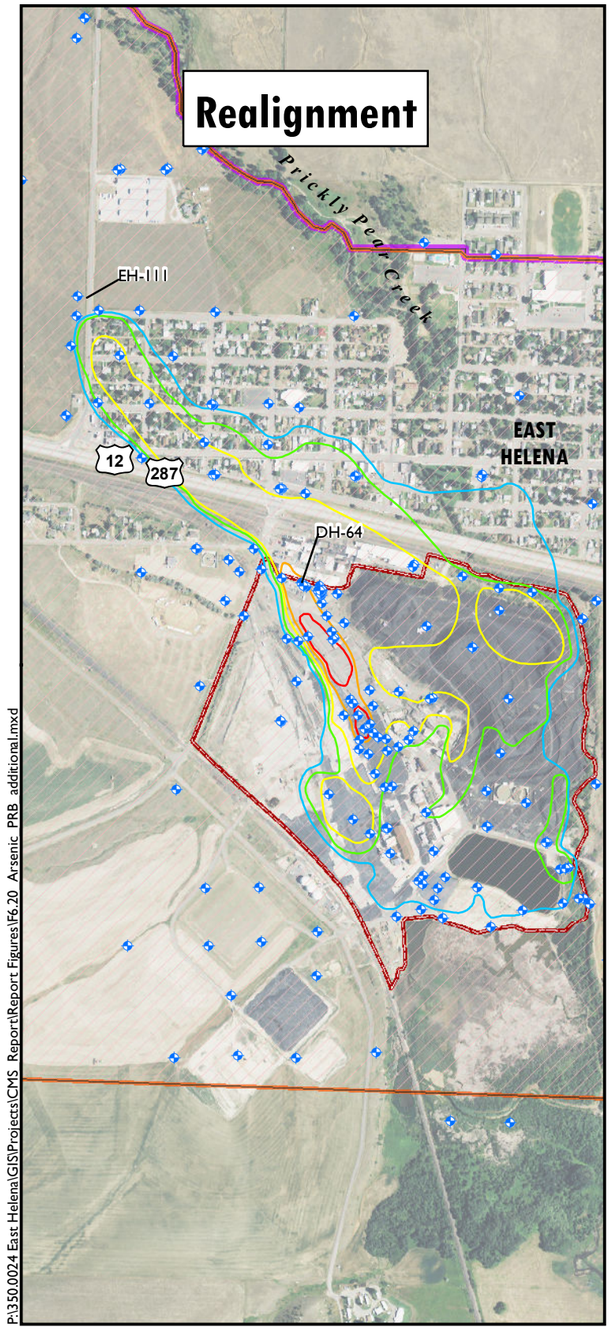
Notes:
1) Predictive results were calculated using stress period 66 of the model.

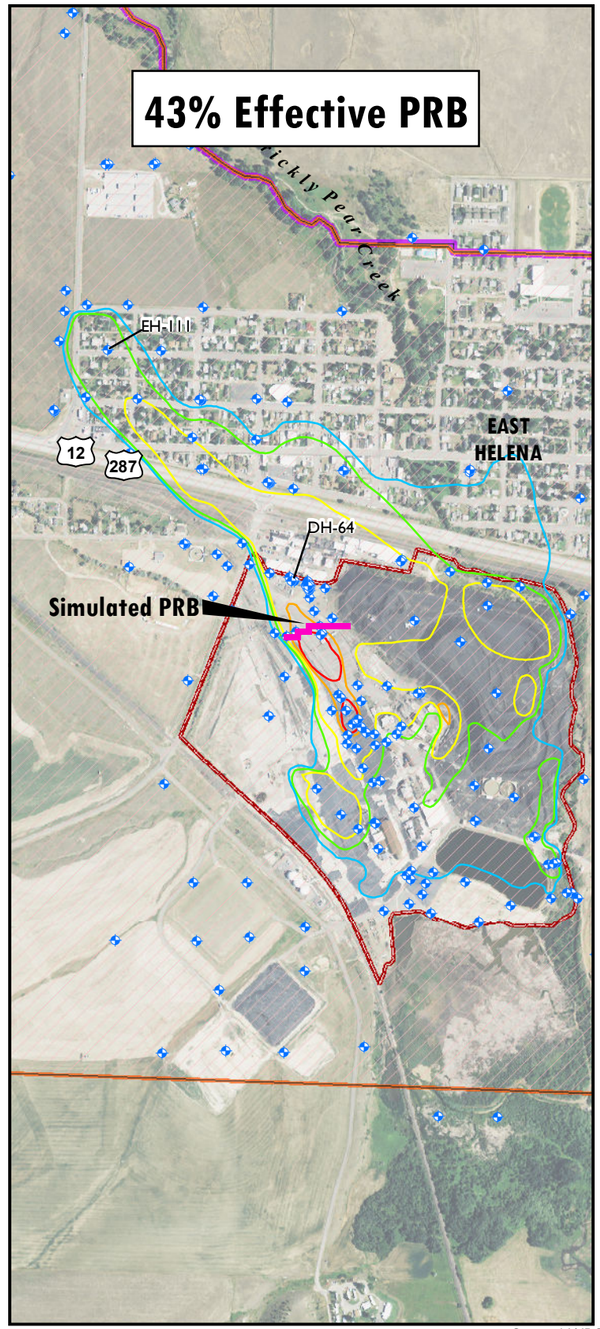
2) mg/day = milligram per day.

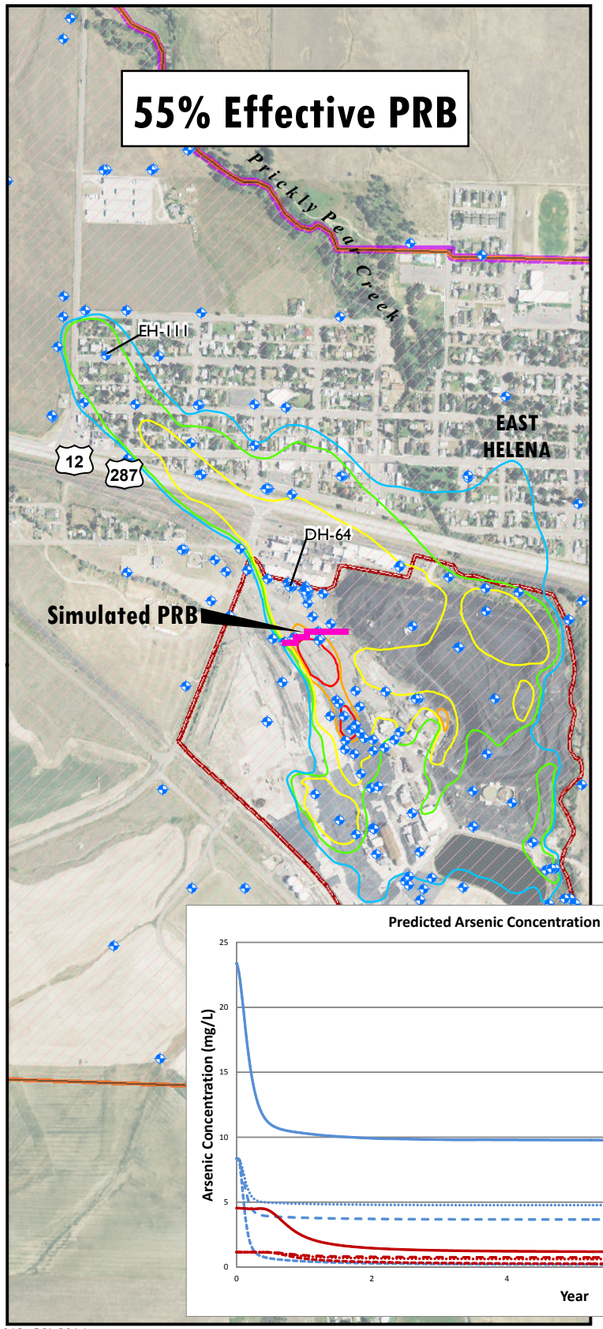
3) Results are from NewFields (2016a).

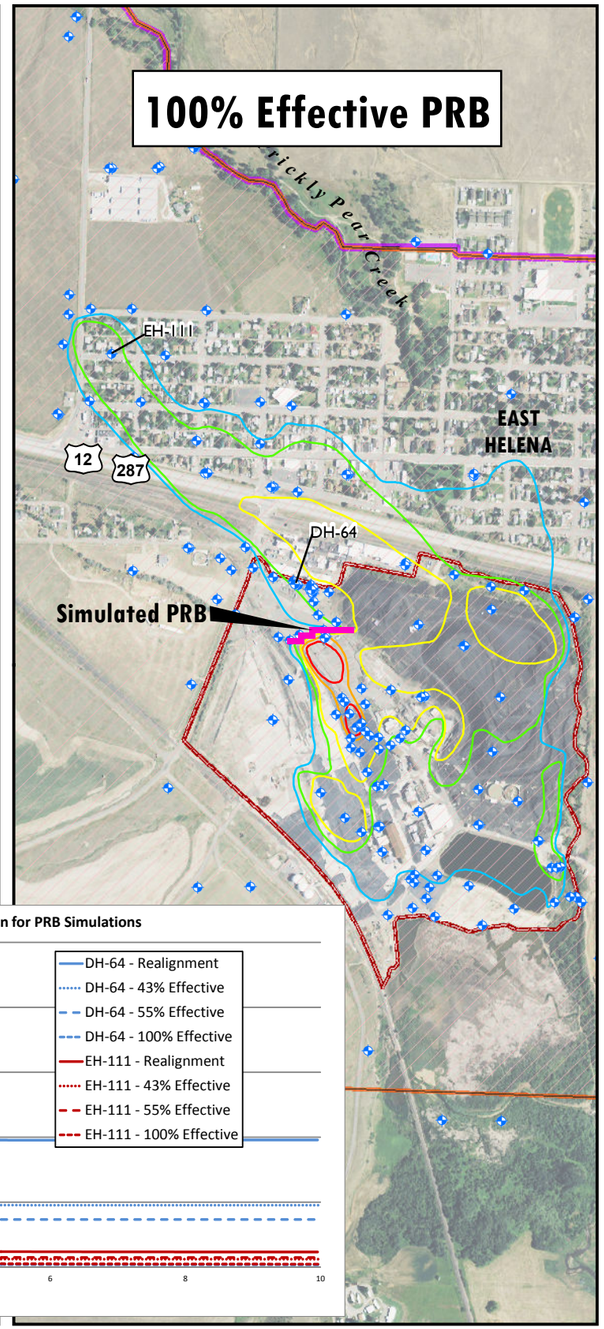
NewFields

Transient Flow and Trasnport
Predicted Change in Selenium Mass Flux Across Site Boundary for SPHC IMs
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.19









P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\f6.20_Arsenic_PRB_additional.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,100

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

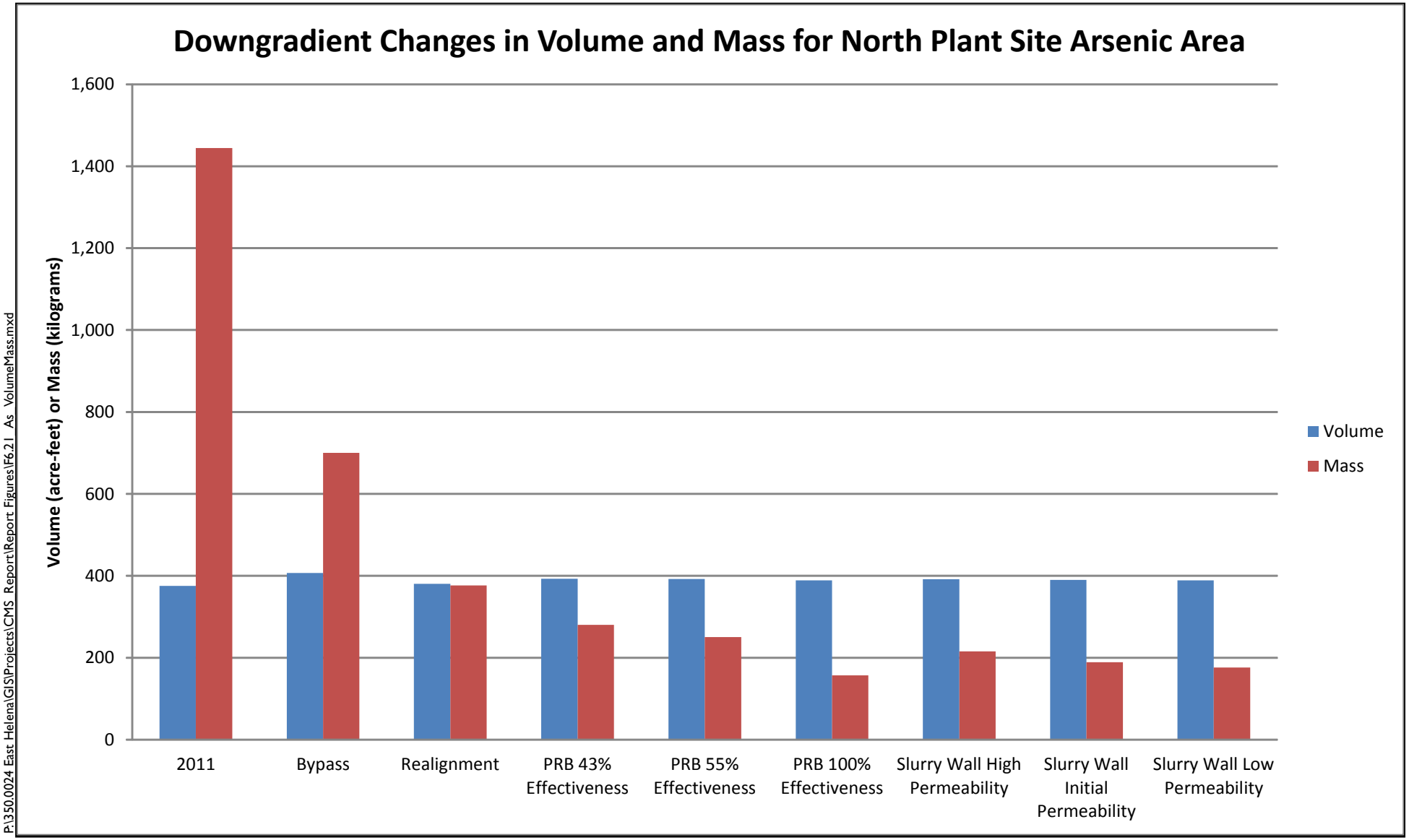
3) CGWA = Controlled Groundwater Area

4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)
0.01
0.1
1
10
> 20

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

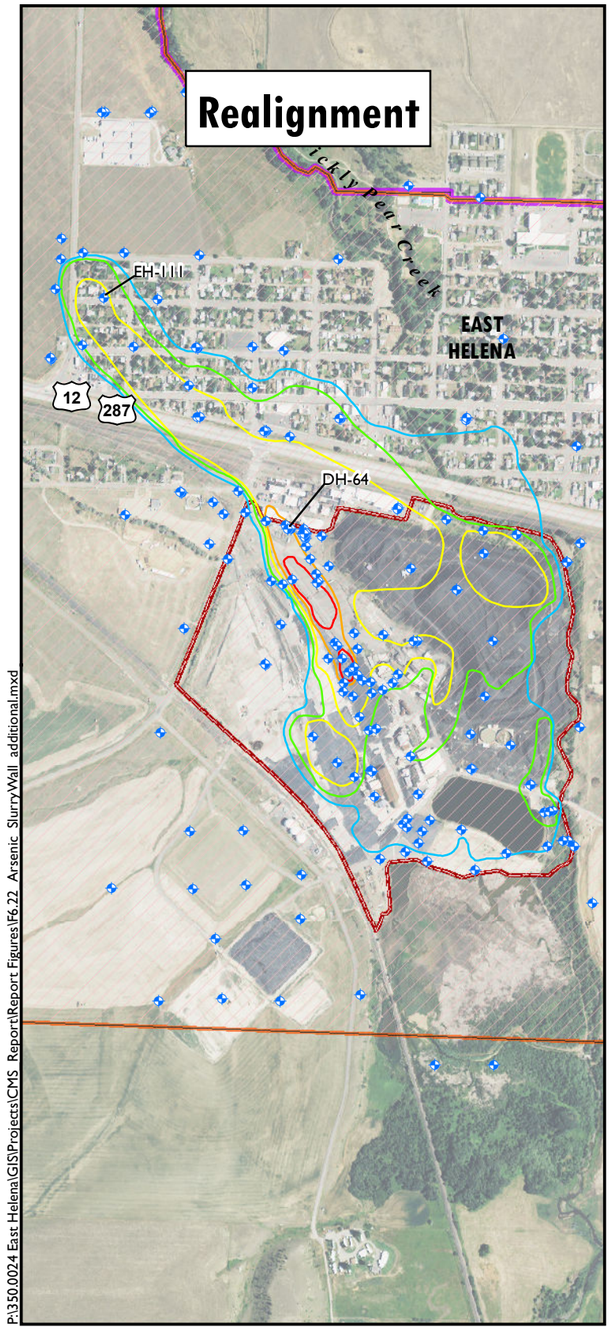
Steady-State Flow and Transient Trasnport
Predicted Isoconcentration Contrours
Arsenic PRB Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.20

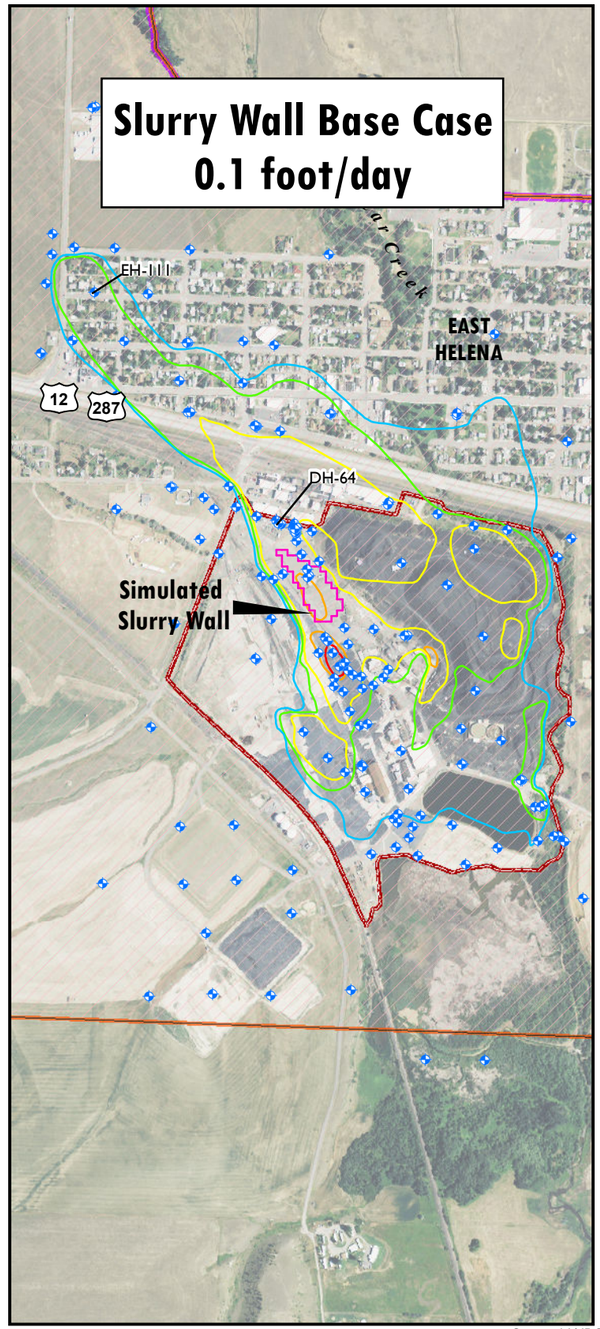


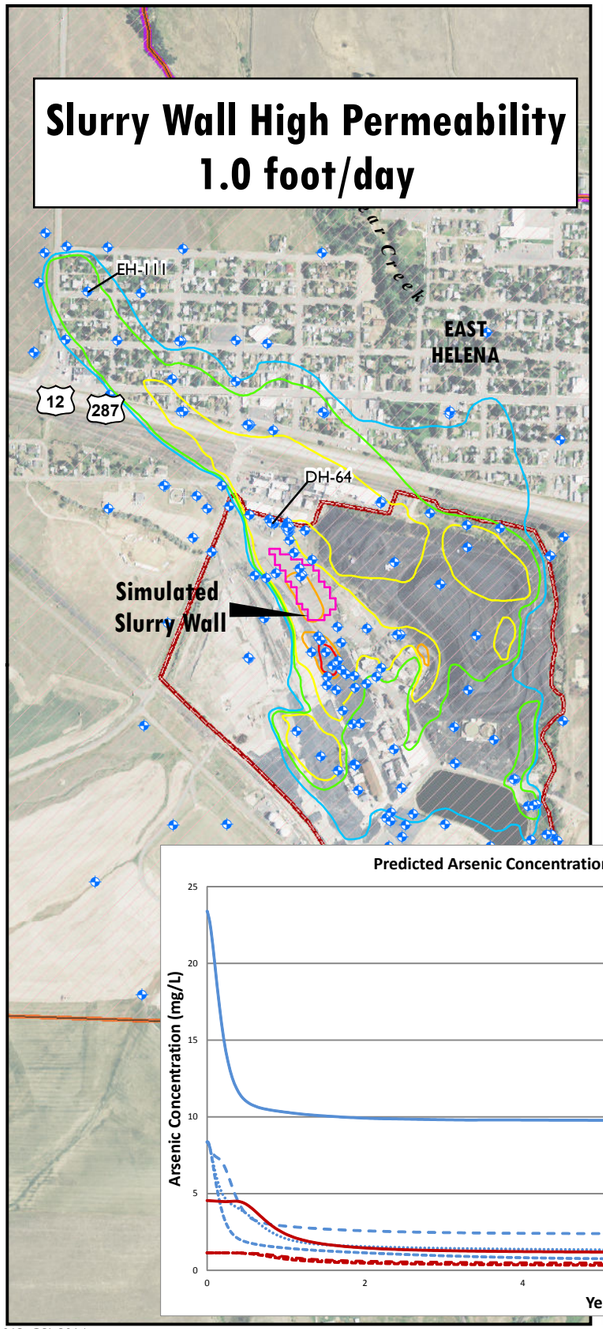
Note: Results are from NewFields (2015b).

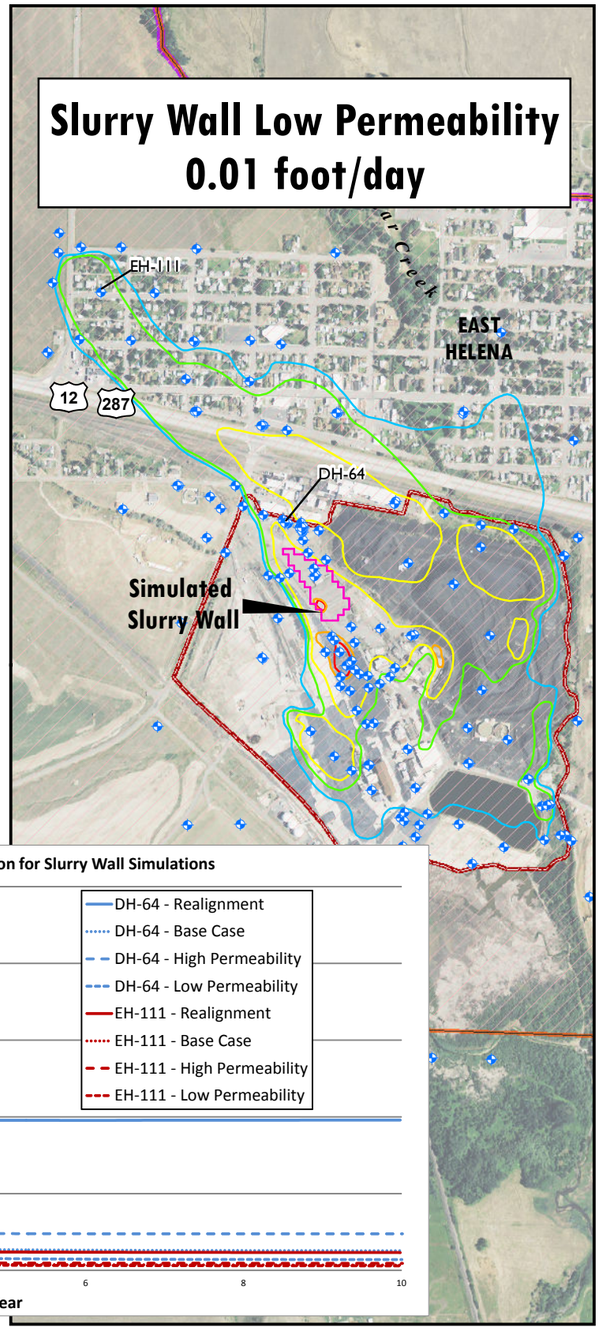
Steady-State Flow and Transient Transport
Changes in Arsenic Volume/Mass for Source Control Measures
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.21

NewFields









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.22_Arsenic_SlurryWall_additional.mxd

Source: NAIP, 2013; GSI, 2014

N

0 Feet 1,100

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area

4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

- 0.01
- 0.1
- 1
- 10
- > 20

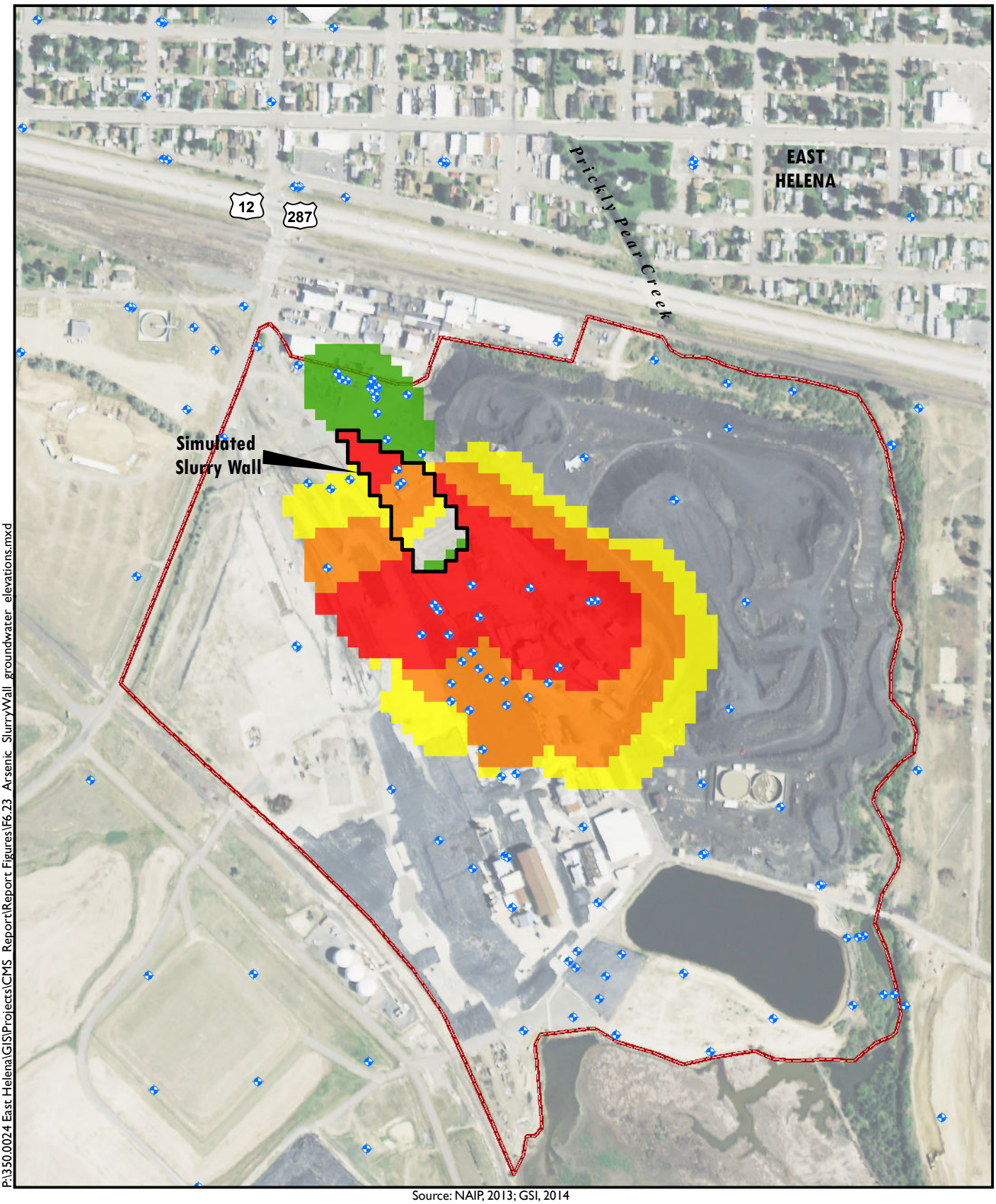
Monitoring Well

Former Smelter Site Boundary

Permanent CGWA - Subarea1

Permanent CGWA - Subarea 2

Steady-State Flow and Transient Transport
Predicted Isoconcentration Contrours
Arsenic Slurry Wall Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.22



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.23 Arsenic SlurryWall groundwater elevations.mxd

Source: NAIP, 2013; GSI, 2014

N

0 Feet 500

NewFields

Monitoring Well

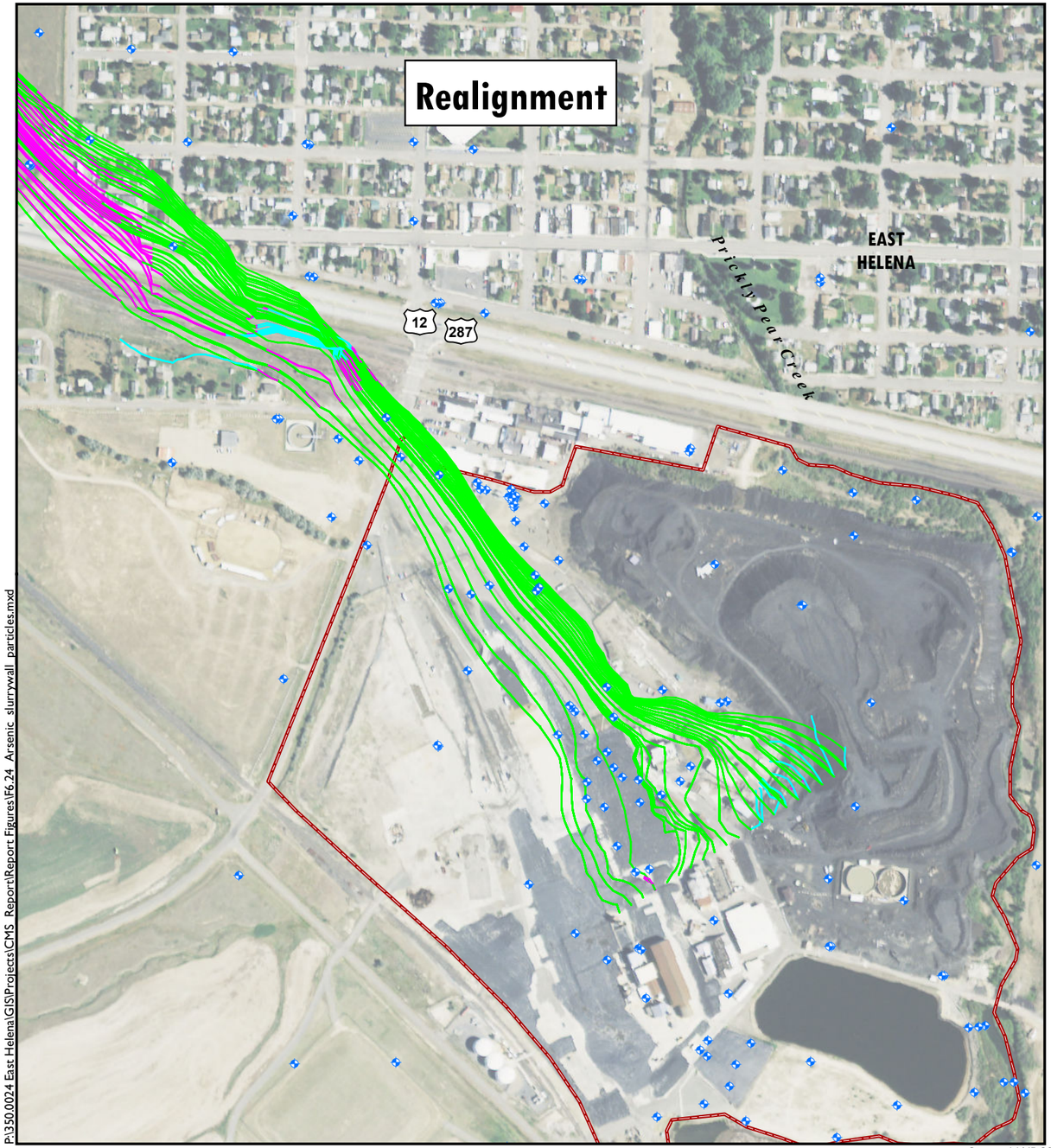
Former Smelter Site Boundary

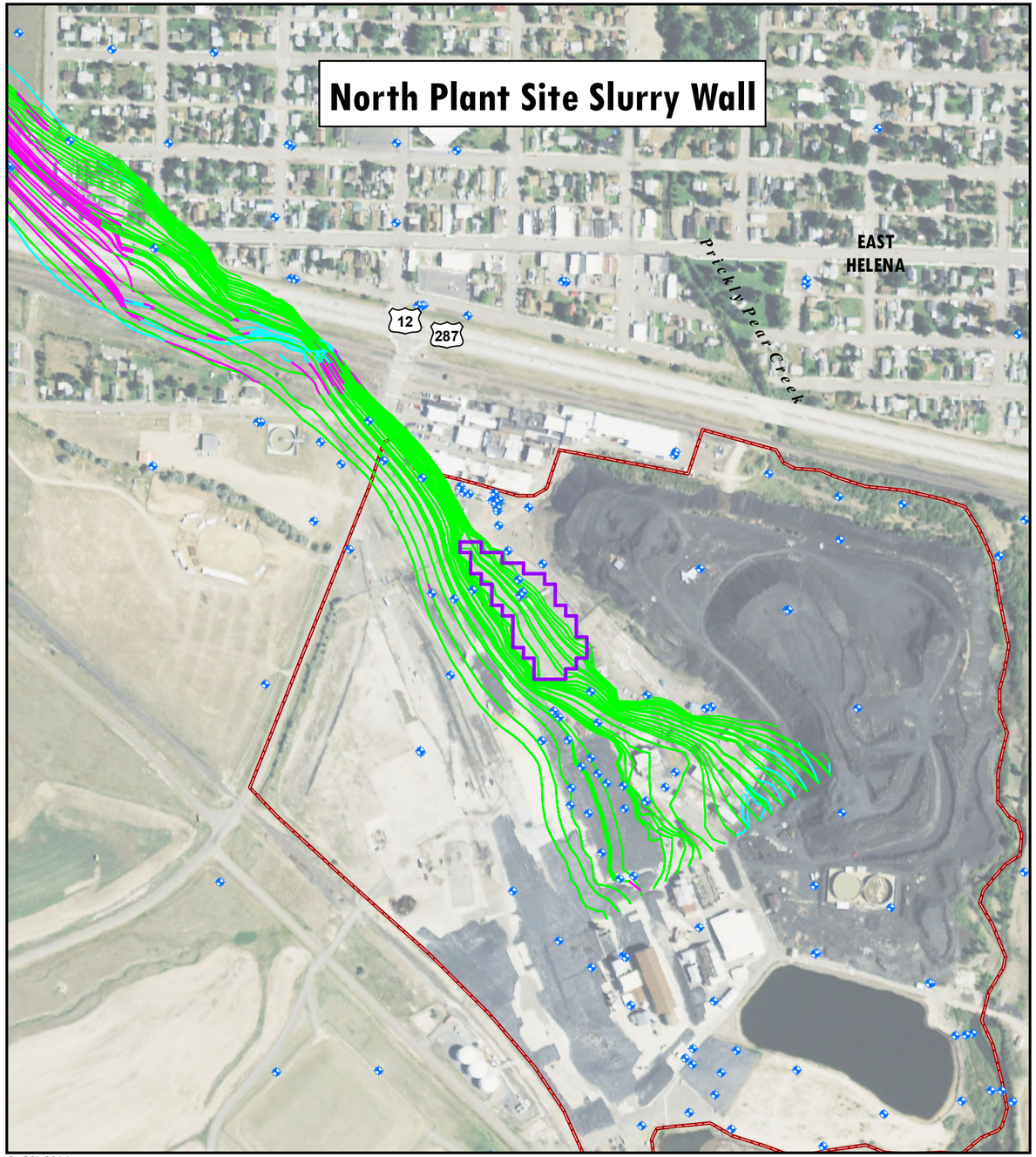
Notes: 1) Change in groundwater elevation is the difference between the slurry wall and realignment simulations.
2) Results are from NewFields (2015b).

Change in Groundwater Elevation (feet)

- -0.76 to -0.25
- 0.25 to 0.5
- 0.5 to 1.0
- >1.0

Steady-State Flow and Transient Trasnport
Predicted Change in Groundwater Elevations
Arsenic Slurry Wall Simulation
Former ASARCO East Helena Smelter
East Helena, Montana
Figure 6.23





P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.24 Arsenic slurrywall particles.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 500

NewFields

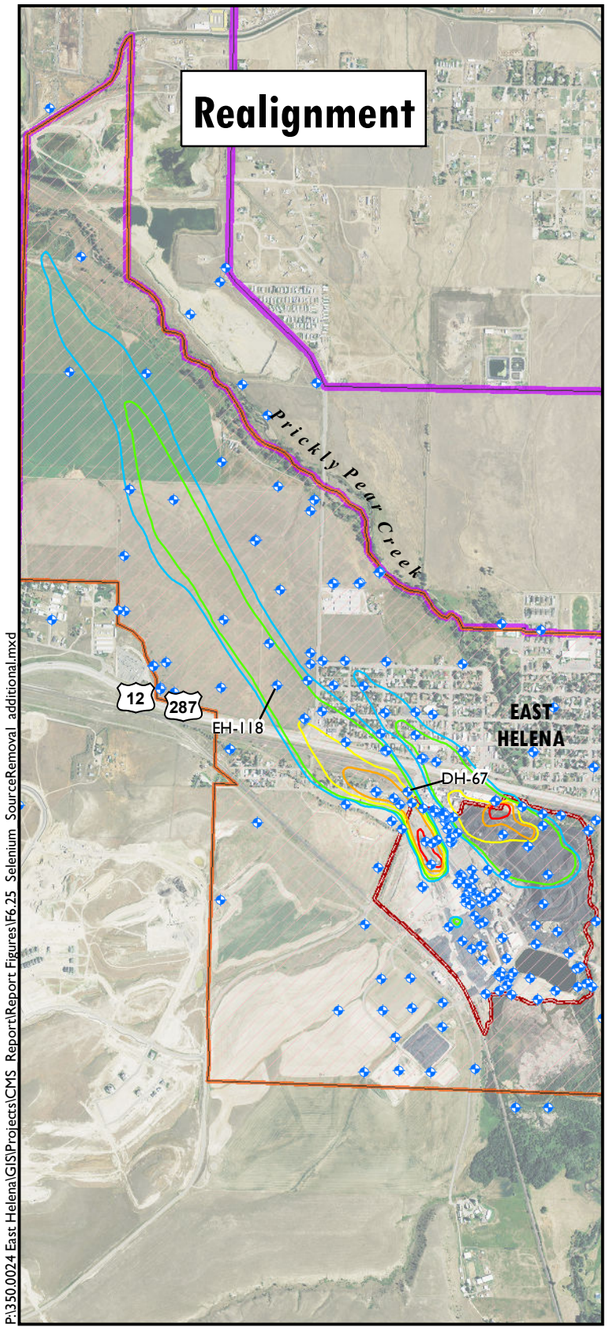
Note: Results are from NewFields (2015b).

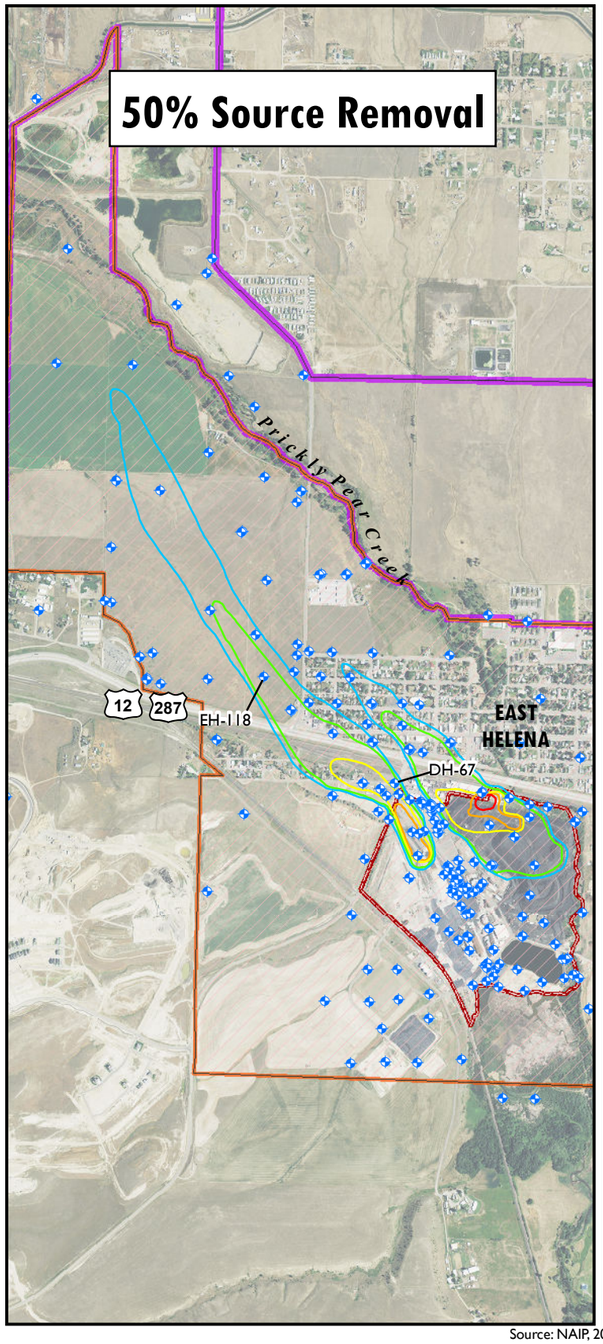
Monitoring Well
North Plant Site Slurry Wall
Former Smelter Site Boundary

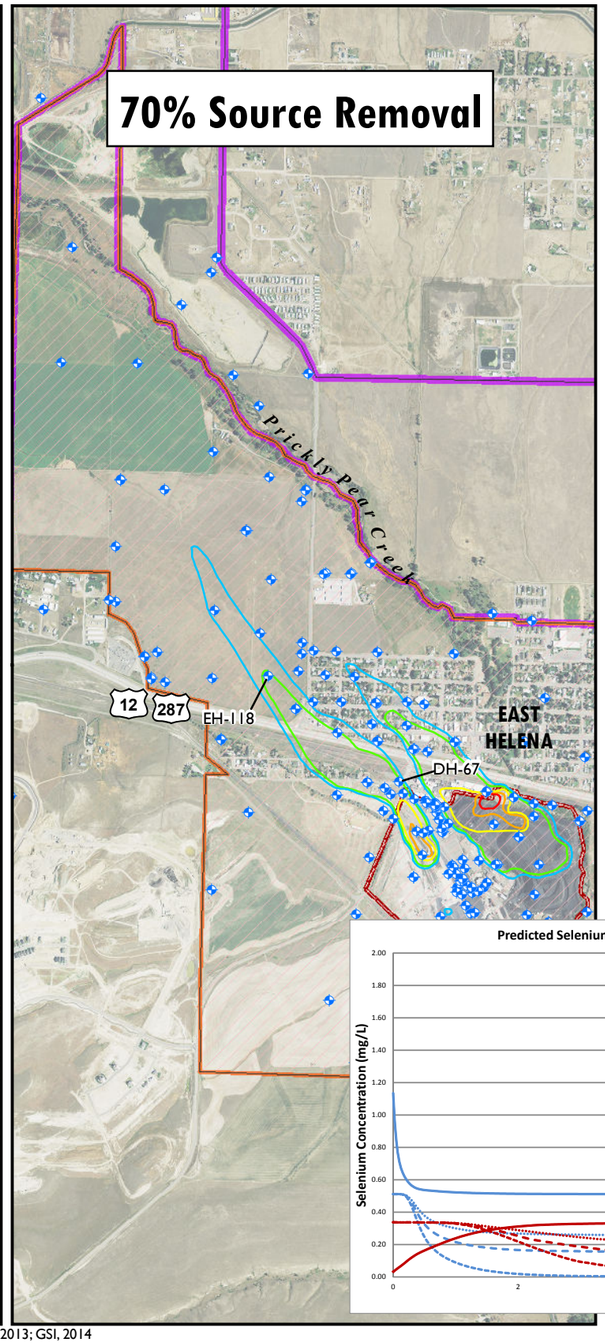
Particle Track Layer
1
2
3

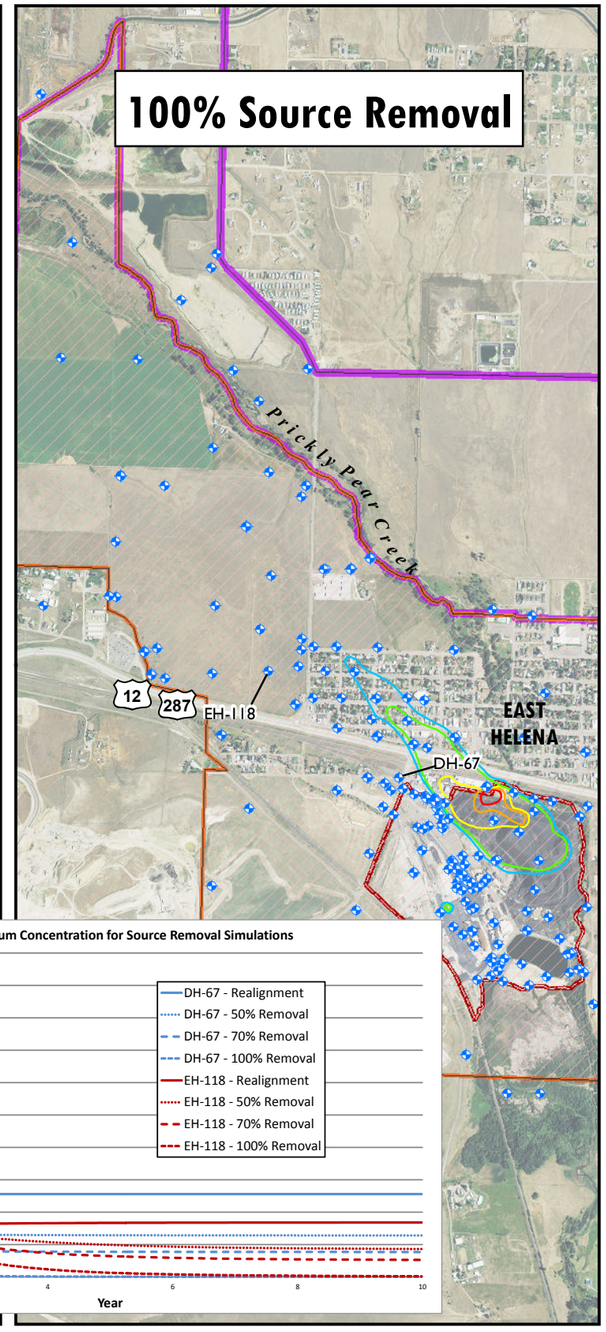
Steady-State Flow and Trasnient Trasnport
North Plant Site Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
Figure 6.24

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.25_Selenium_SourceRemoval_additional.mxd









Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area.

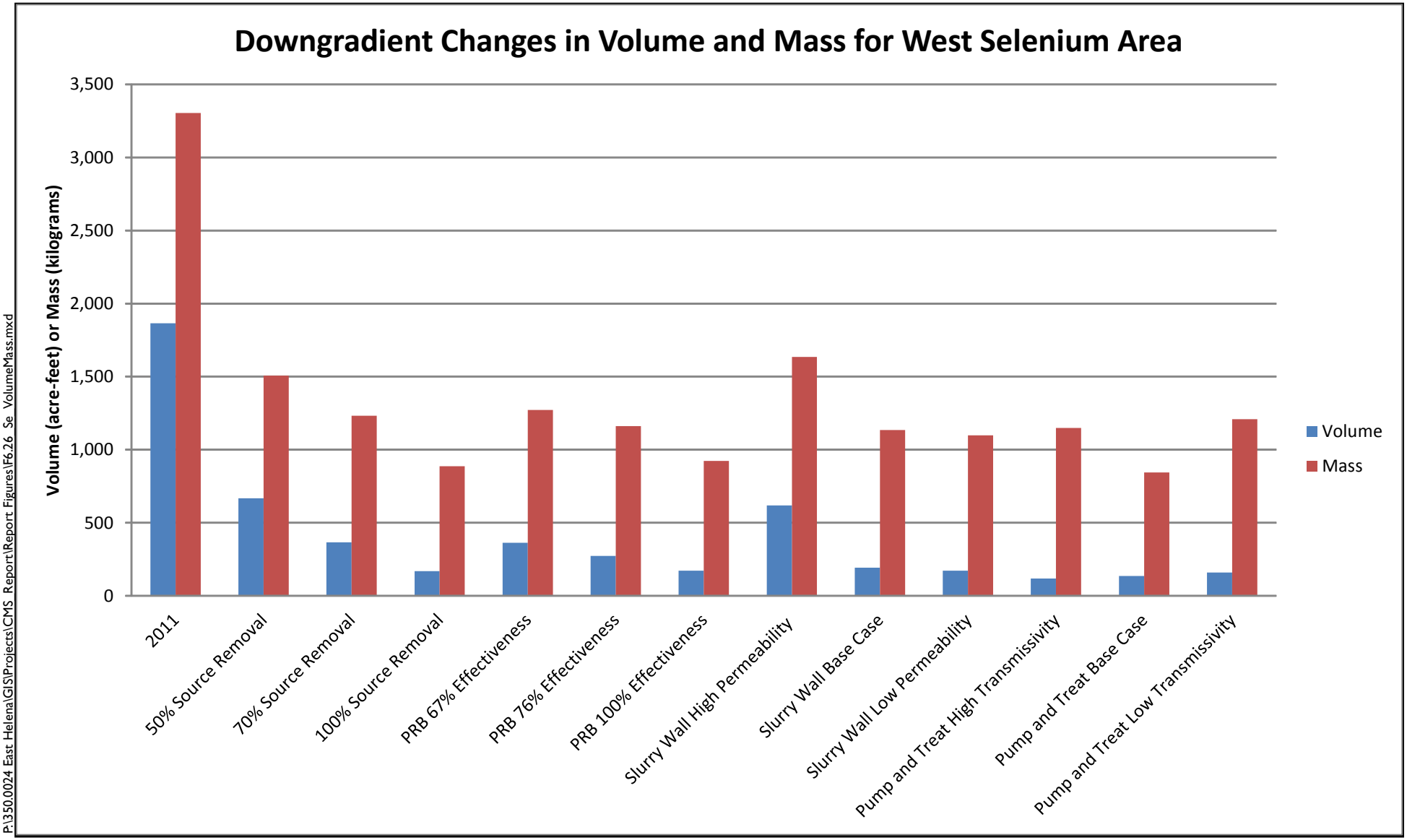
4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

0.05
0.1
0.5
1
> 3

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Steady-State Flow and Trasnient Trasnport
Predicted Isoconcentration Contrours
Selenium Source Removal Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.25



Note: Results are from NewFields (2015b).

NewFields

Steady-State Flow and Transient Transport
Changes in Selenium Volume/Mass for Source Control Measures
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.26

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\f6.27 Selenium PRB additional.mxd

Realignment

67% Effective PRB

76% Effective PRB

100% Effective PRB

Prickly Pear Creek

12

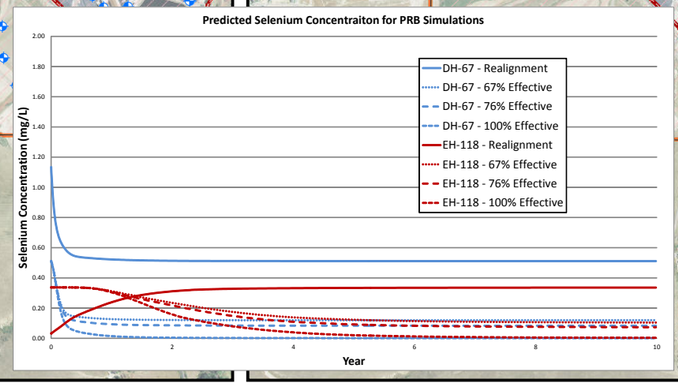
287

EH-118

DH-67

EAST HELENA

Simulated PRB



Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area.

4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

0.05 — 0.1 — 0.5 — 1 — > 3

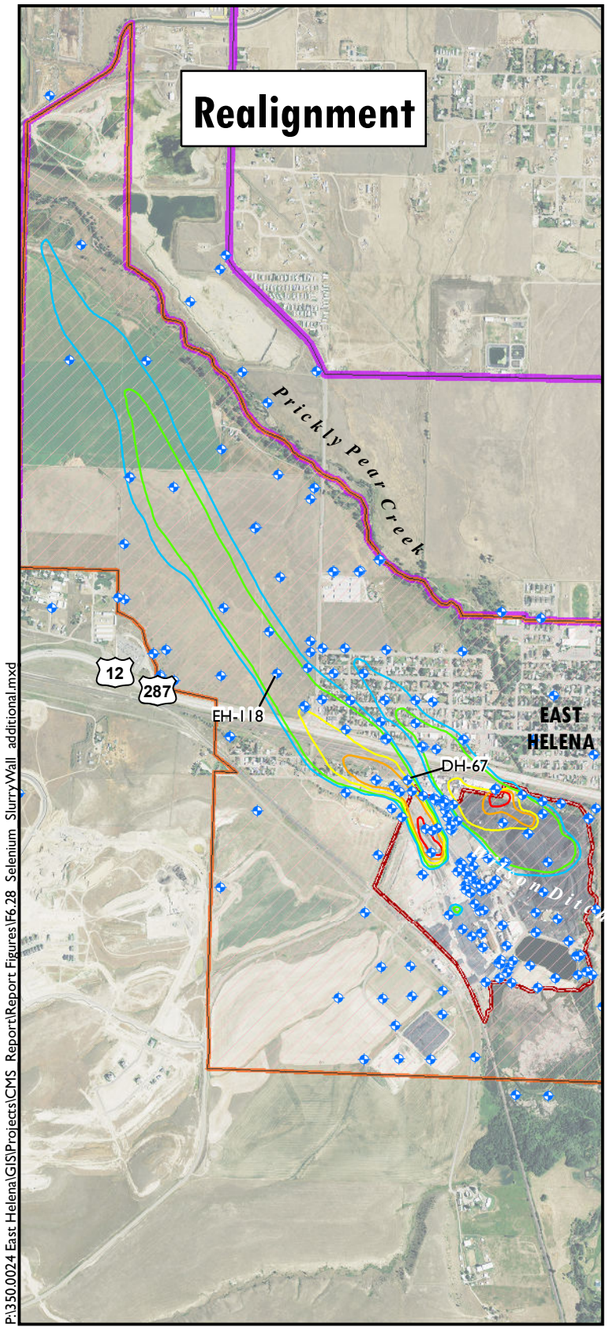
Monitoring Well

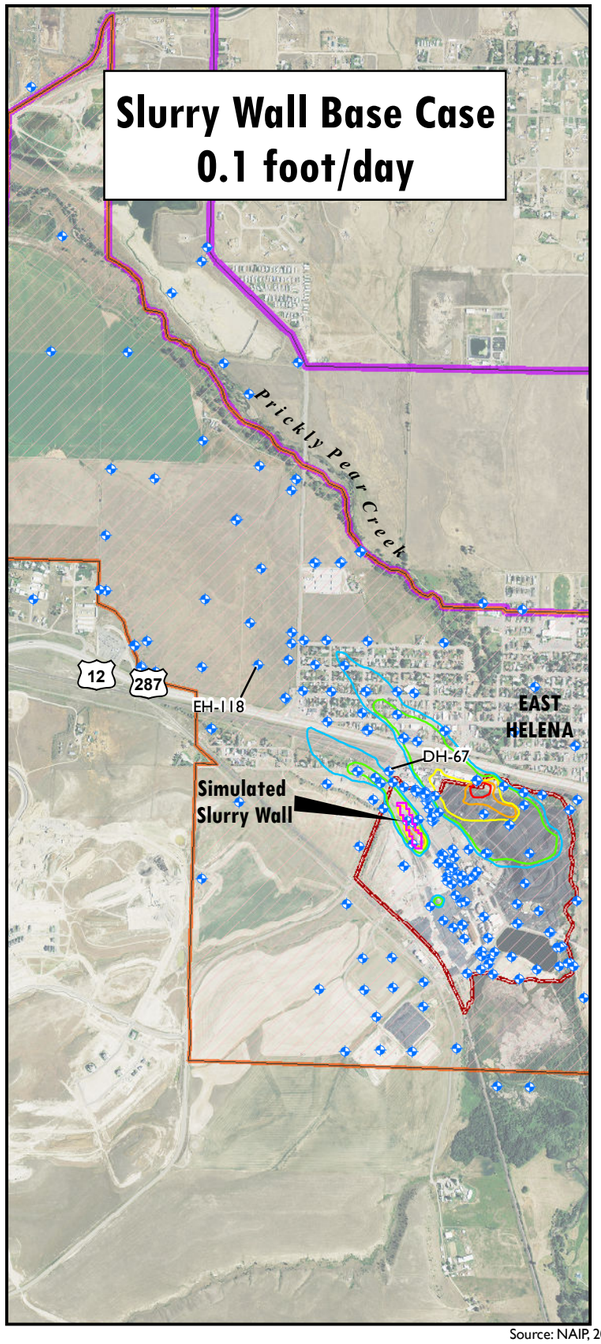
Former Smelter Site Boundary

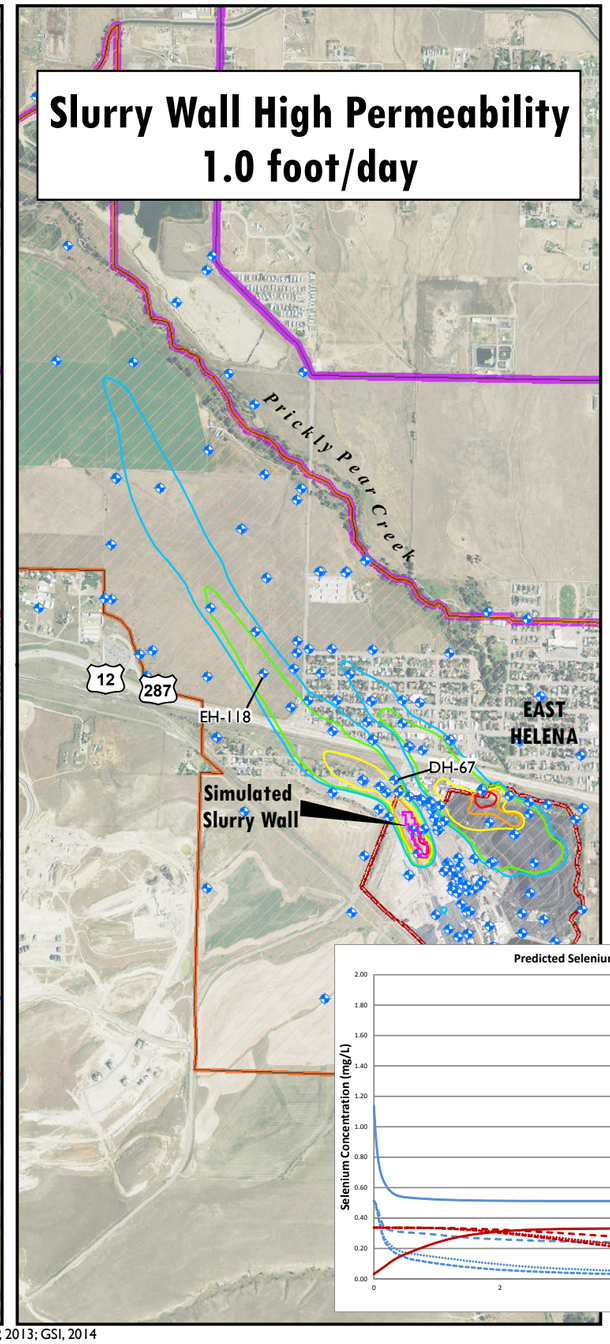
Permanent CGWA - Subarea1

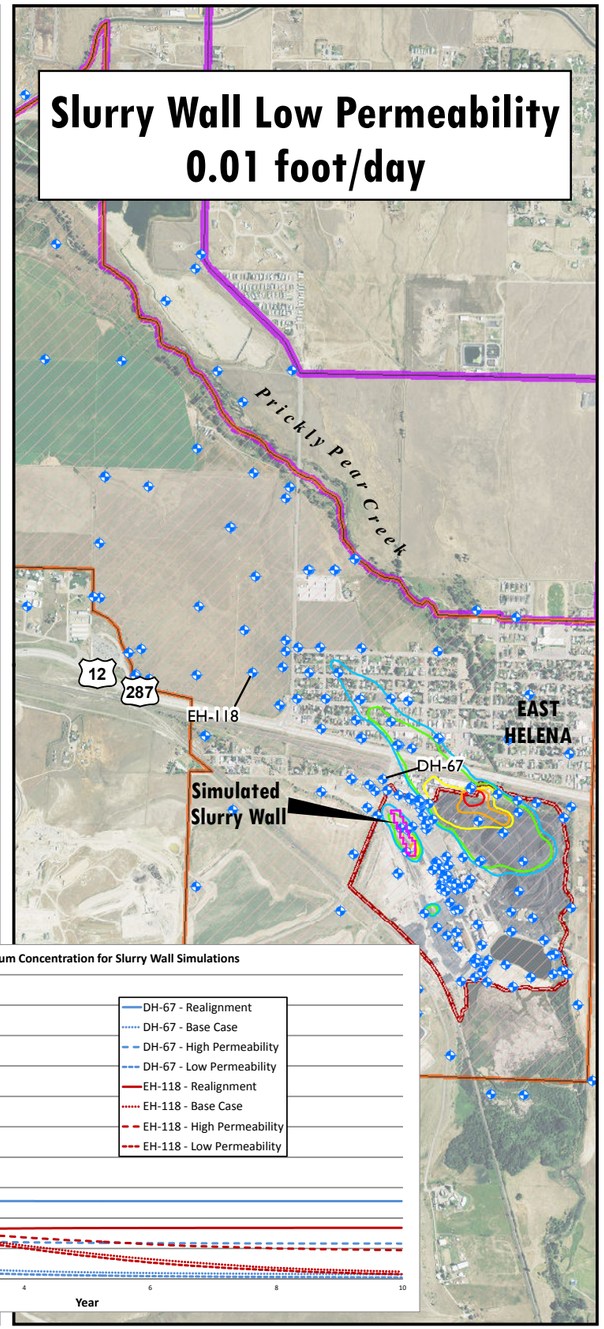
Permanent CGWA - Subarea 2

Steady-State Flow and Transient Transport
Predicted Isoconcentration Contrours
Selenium PRB Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.27









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.28 Selenium SlurryWall additional.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area.

4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

0.05 — 1

0.1 — > 3

0.5

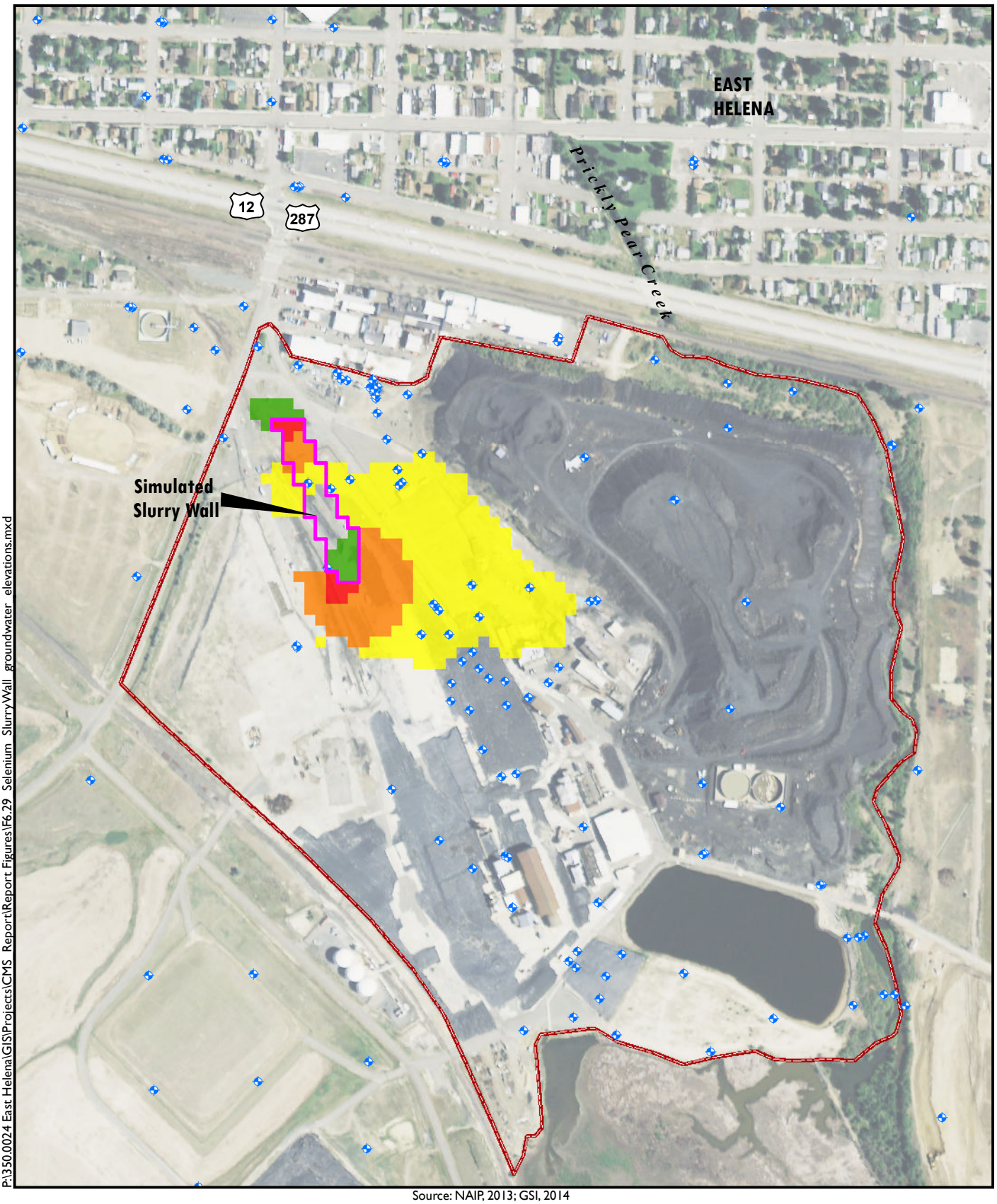
Monitoring Well

Former Smelter Site Boundary

Permanent CGWA - Subarea1

Permanent CGWA - Subarea 2

Steady-State Flow and Transient Transport
Predicted Isoconcentration Contrours
Selenium Slurry Wall Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.28



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.29 Selenium SlurryWall groundwater elevations.mxd

Source: NAIP, 2013; GSI, 2014

N

0 Feet 500

NewFields

Monitoring Well

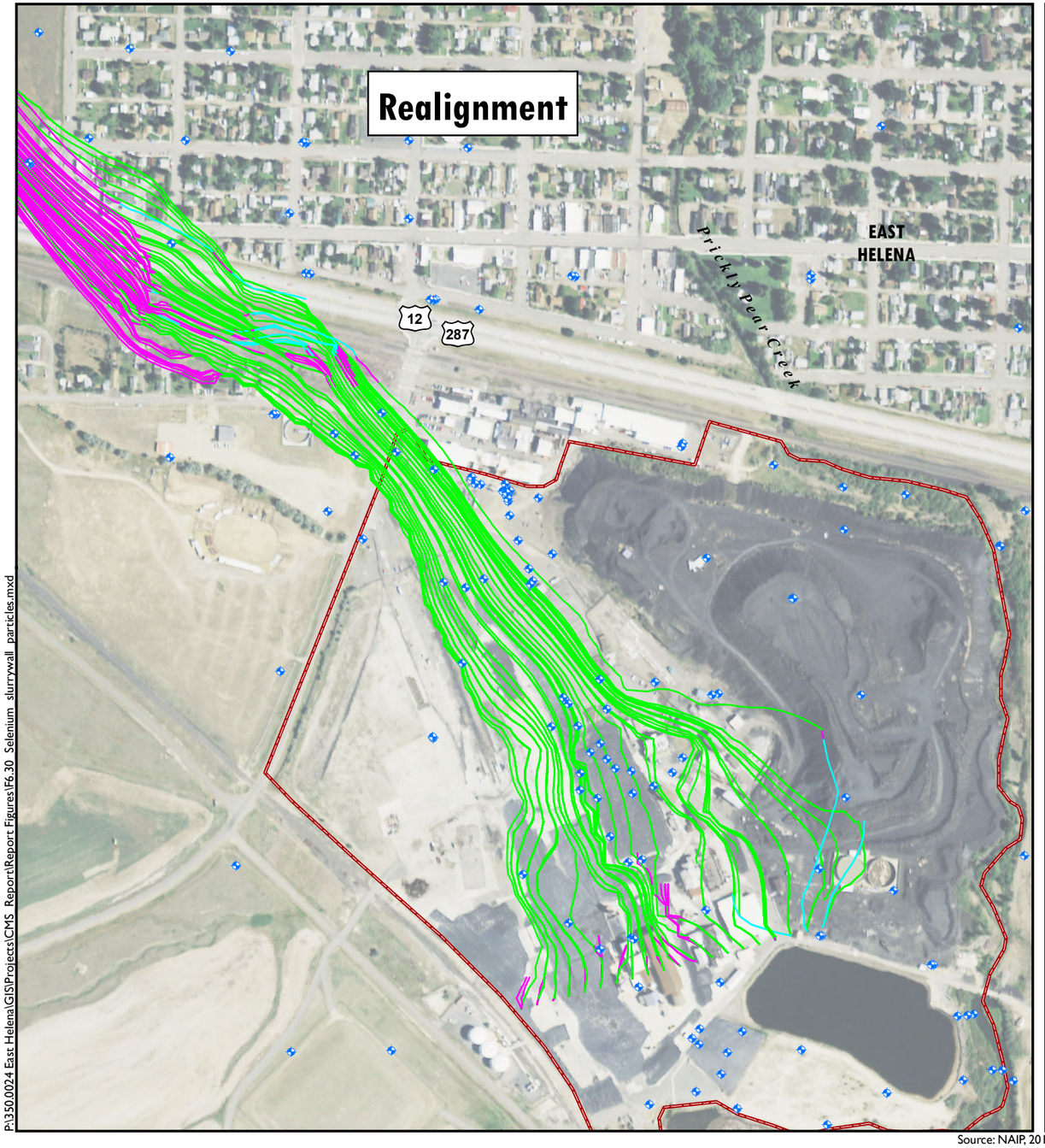
Former Smelter Site Boundary

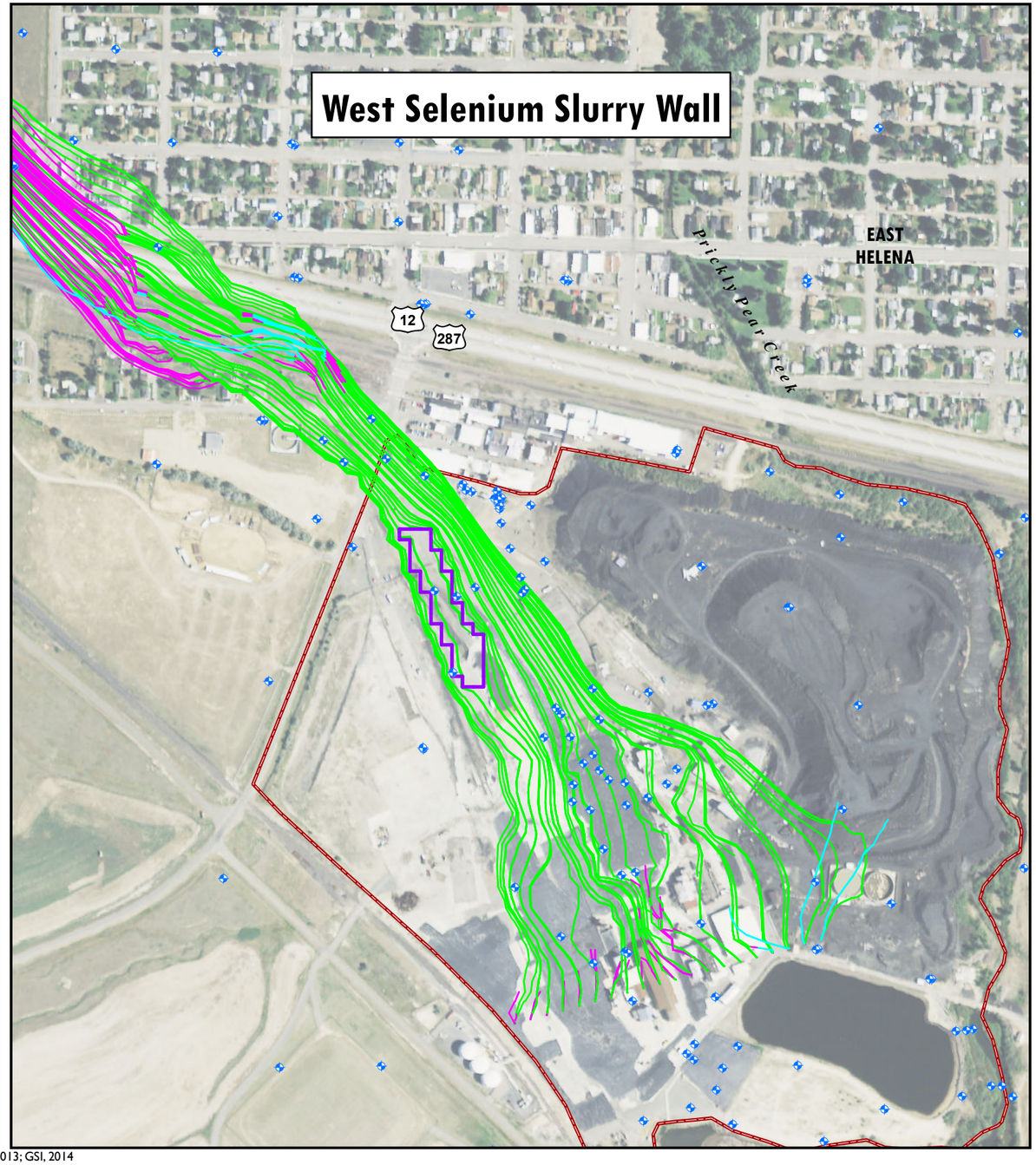
Notes: 1) Change in groundwater elevation is the difference between the slurry wall and realignment simulations.
2) Results are from NewFields (2015b).

Change in Groundwater Elevation (feet)

- -0.76 to -0.25
- 0.25 to 0.5
- 0.5 to 1.0
- >1.0

Steady-State Flow and Transient Transport
Predicted Change in Groundwater Elevations
Selenium Slurry Wall Simulation
Former ASARCO East Helena Smelter
East Helena, Montana
Figure 6.29





P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.30 Selenium slurrywall particles.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 500

NewFields

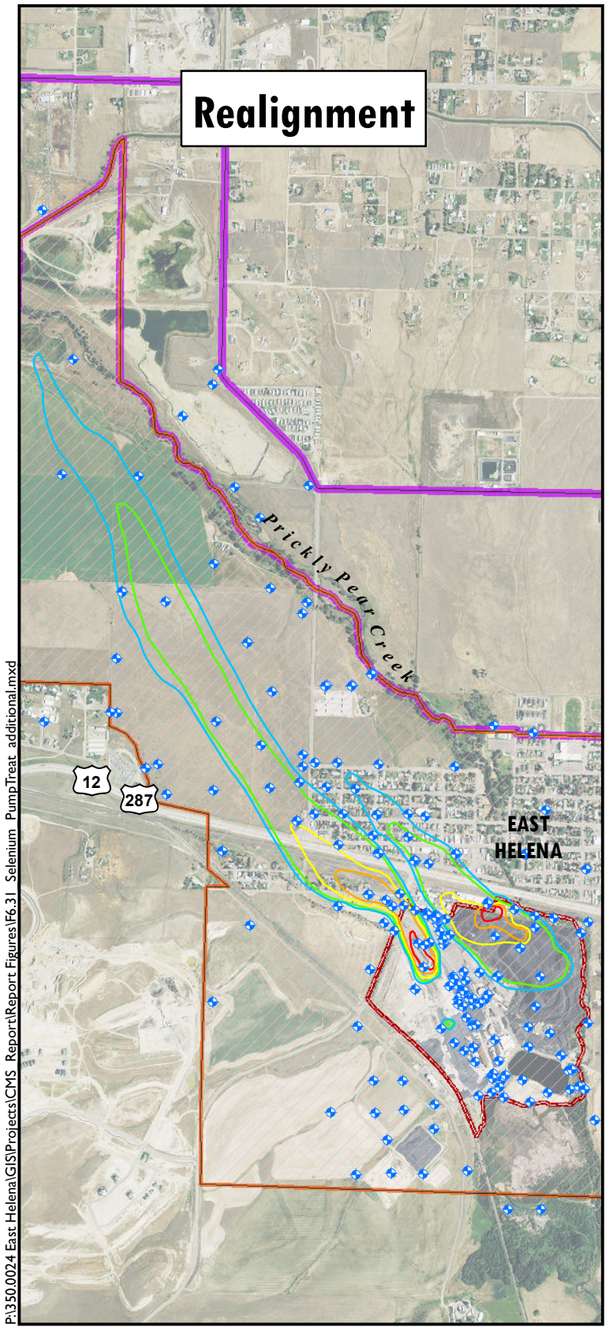
Note: Results are from NewFields (2015b).

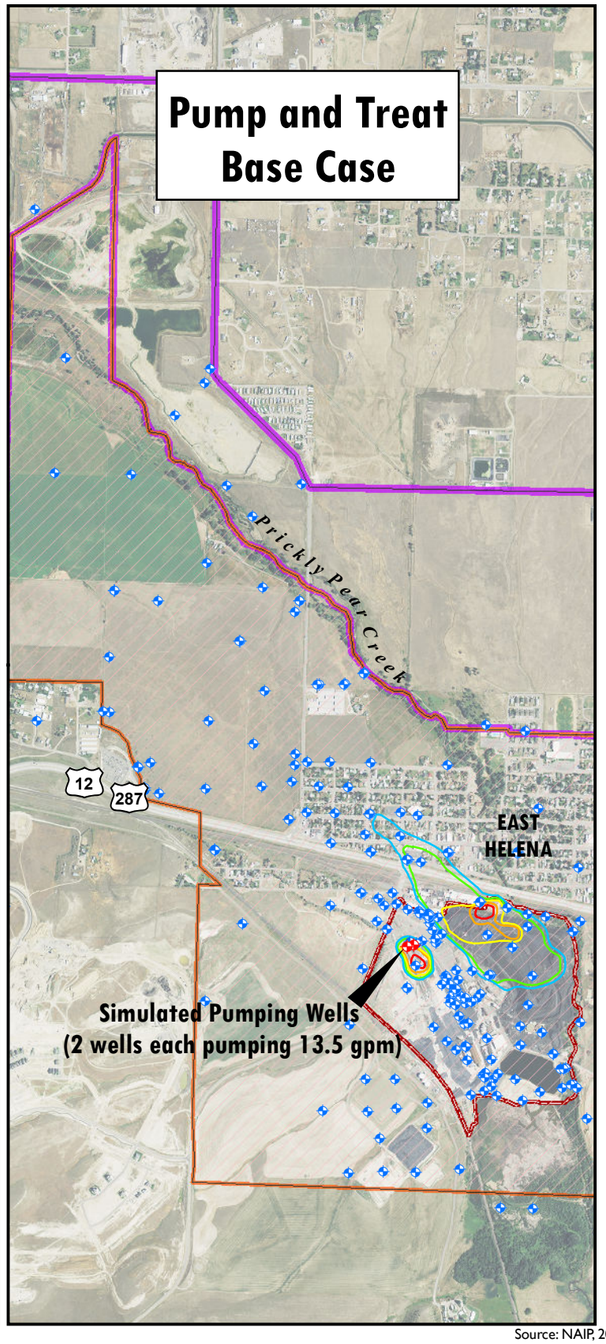
Monitoring Well
West Selenium Slurry Wall
Former Smelter Site Boundary

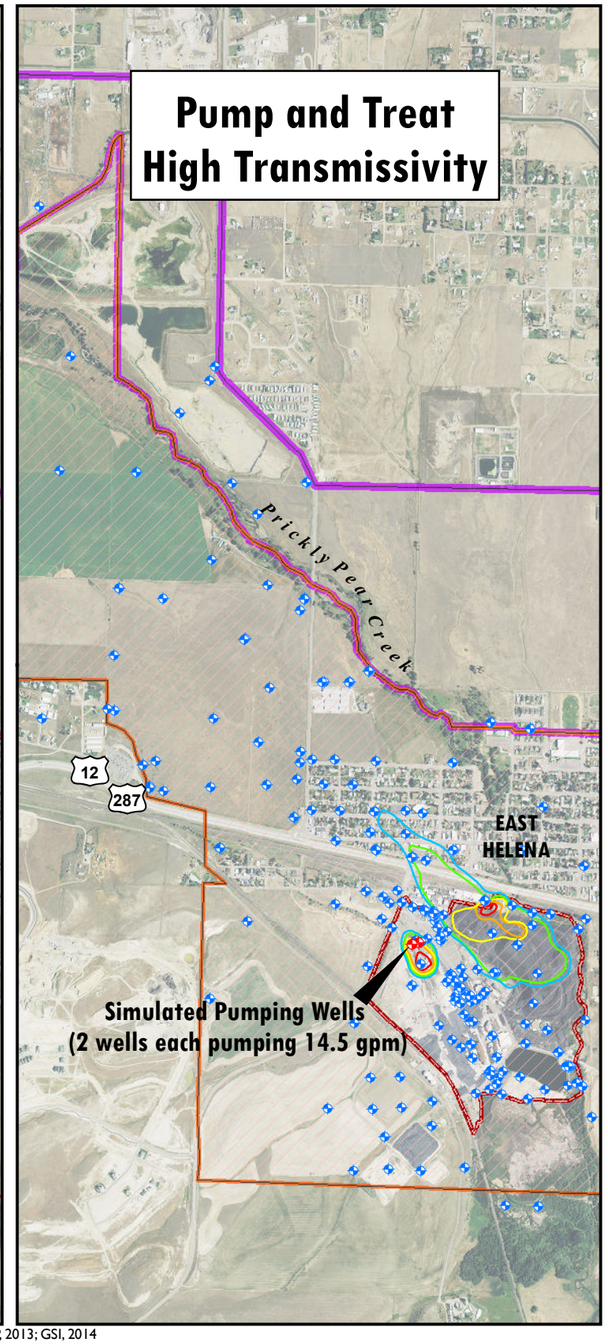
Particle Track Layer
1
2
3

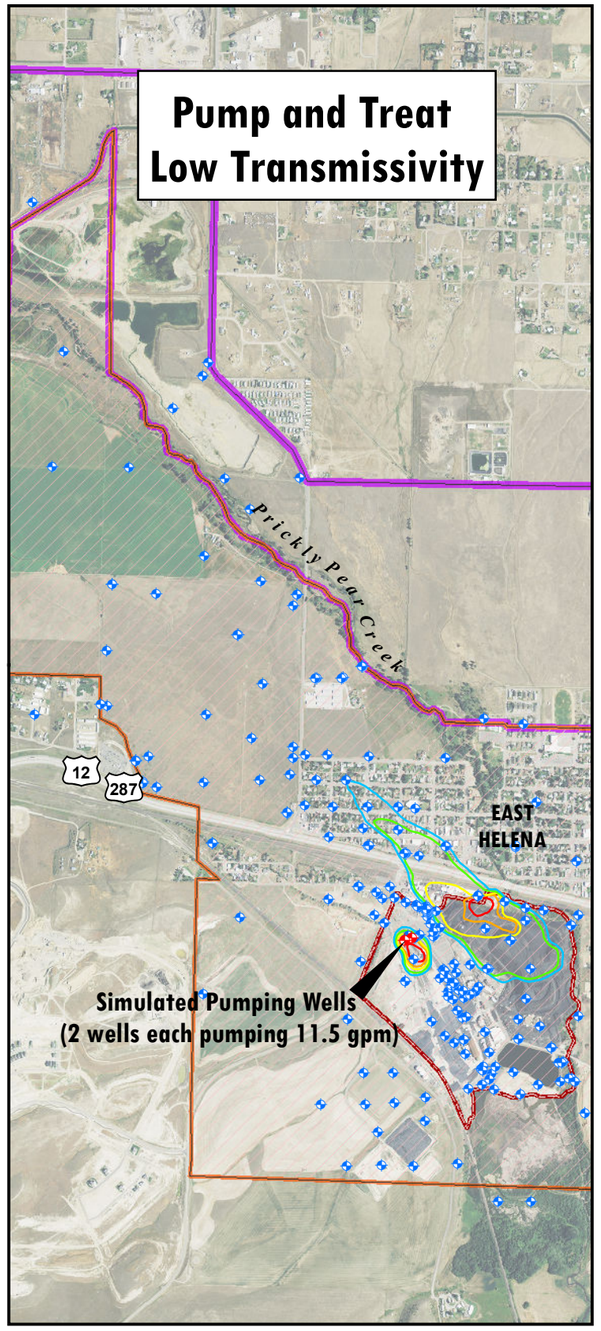
Steady-State Flow and Transient Transport
West Selenium Area Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
Figure 6.30

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.31 Selenium PumpTreat additional.mxd









Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) CGWA = Controlled Groundwater Area.

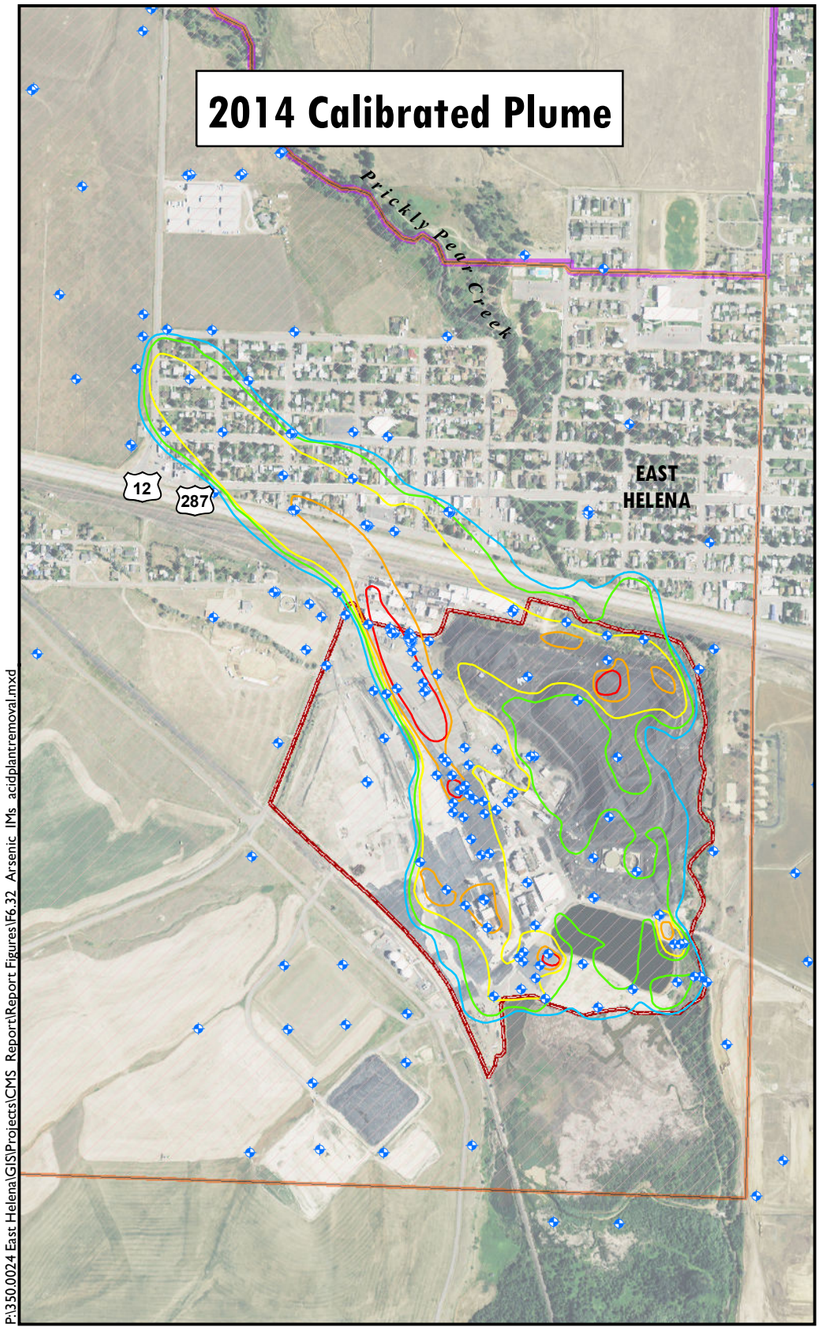
4) Results are from NewFields (2015b).

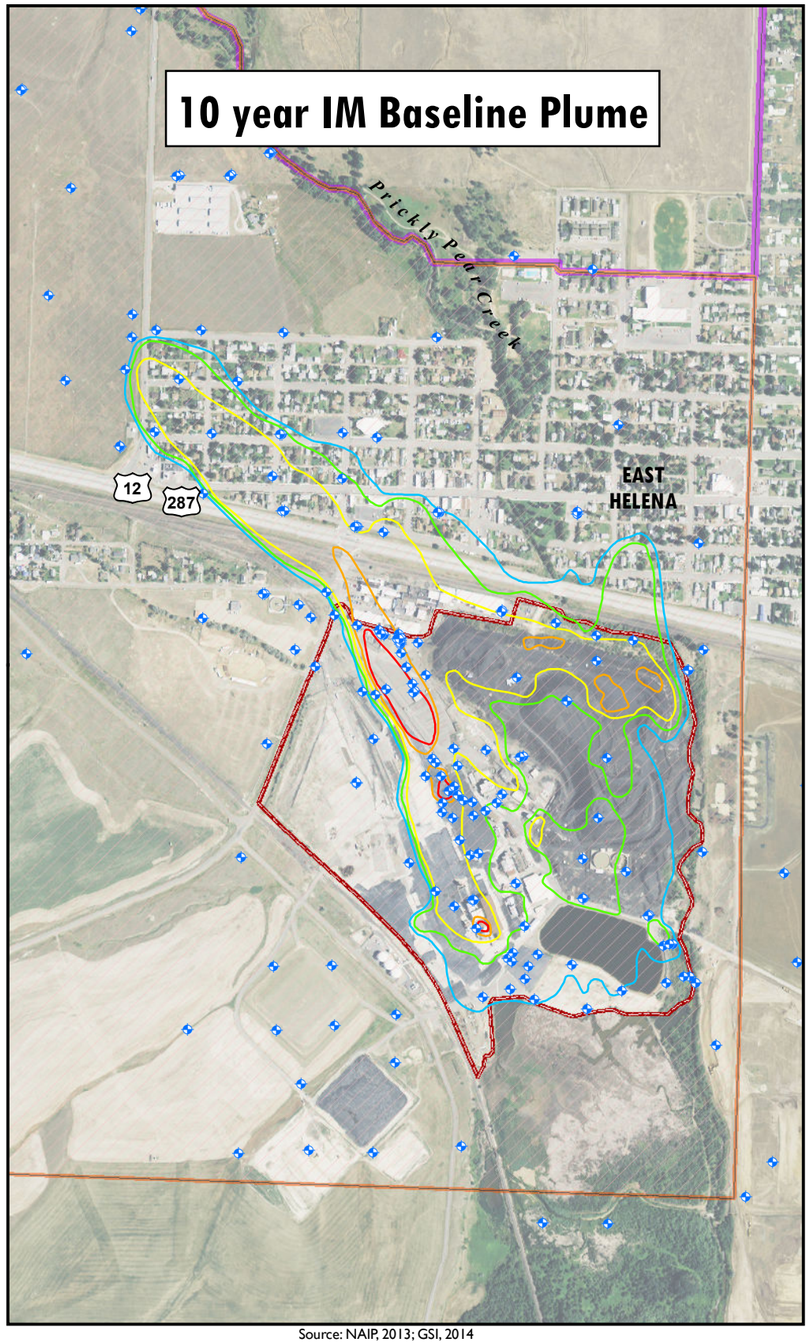
Isoconcentration Contour (mg/L)

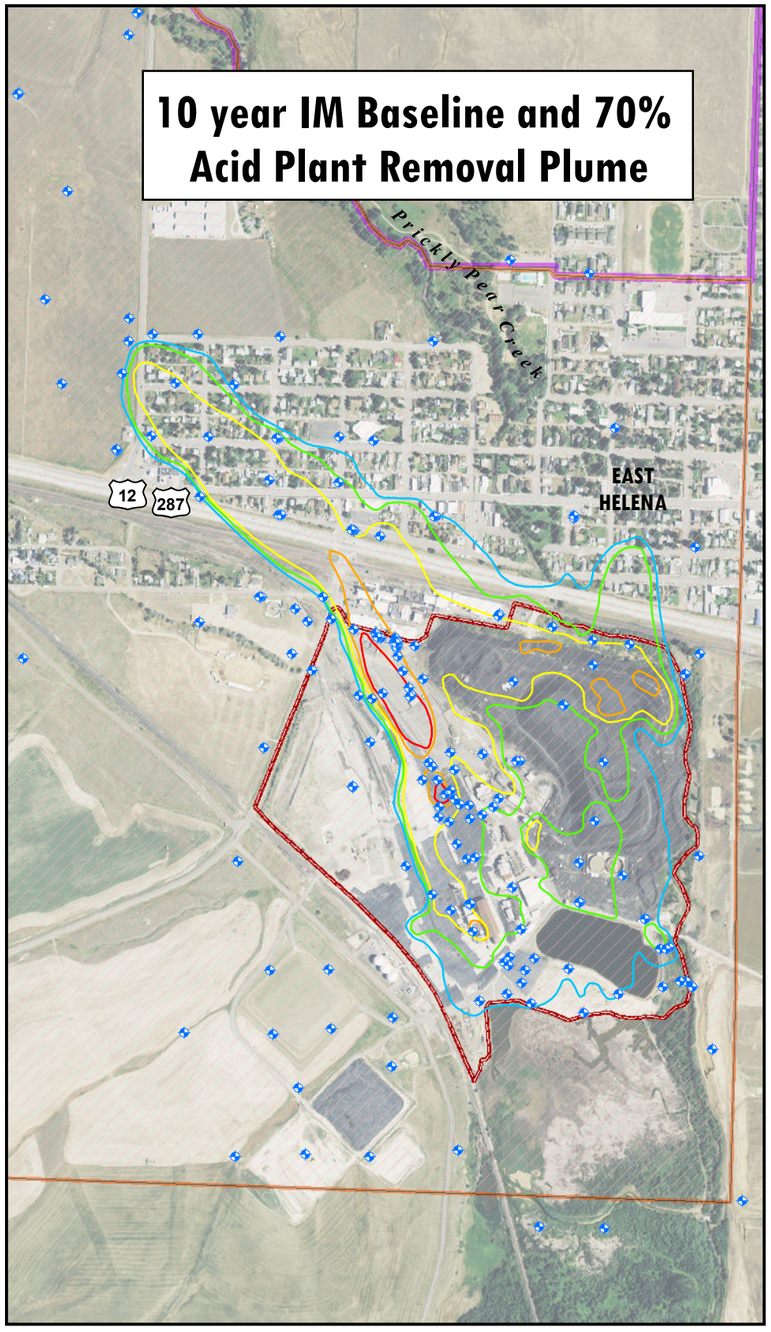
0.05
0.1
0.5
1
> 3

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Steady-State Flow and Transient Transport
Predicted Isoconcentration Contrours
Selenium Pump and Treat Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.31







P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.32_Arsenic_IMs_acidplantremoval.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4.

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state.

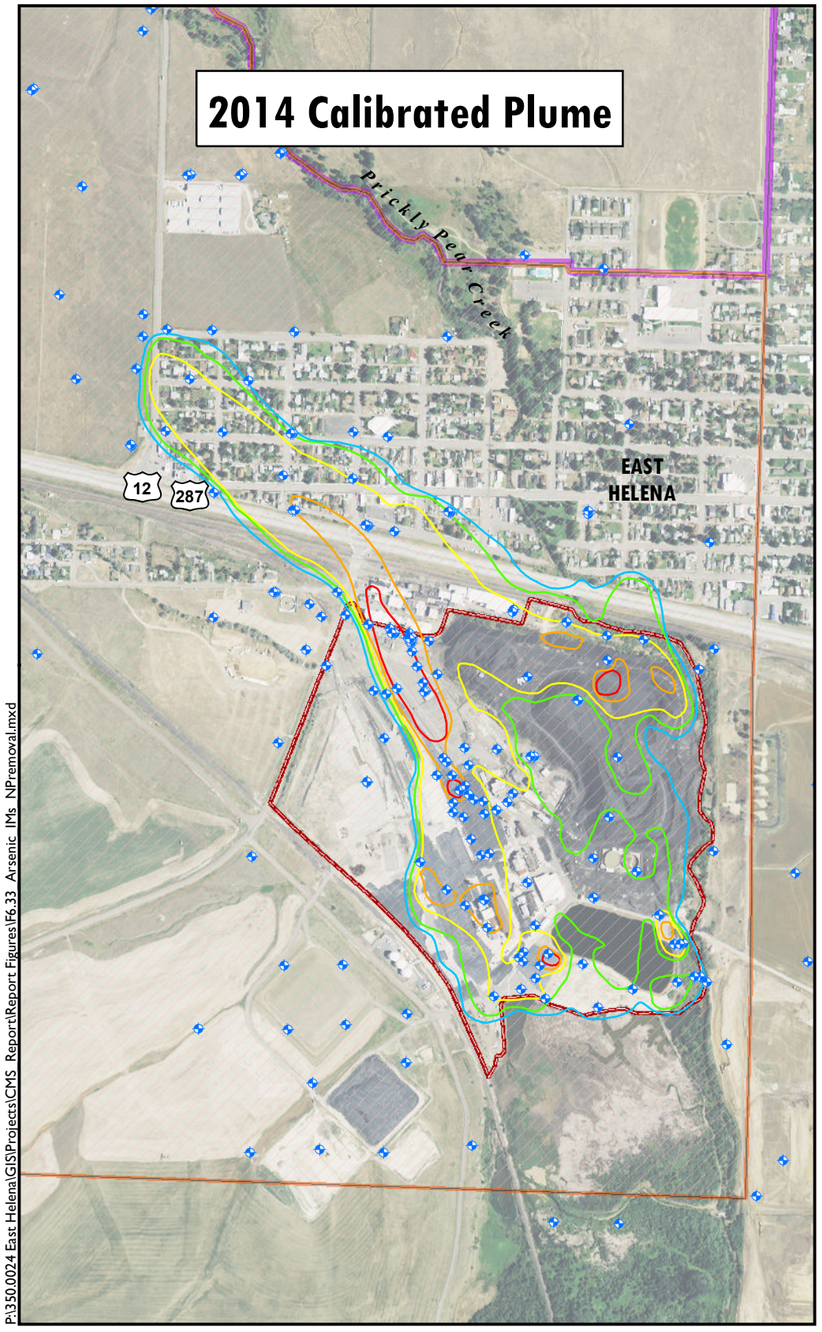
3) mg/L = milligram per liter; CGWA = Controlled Groundwater Area.

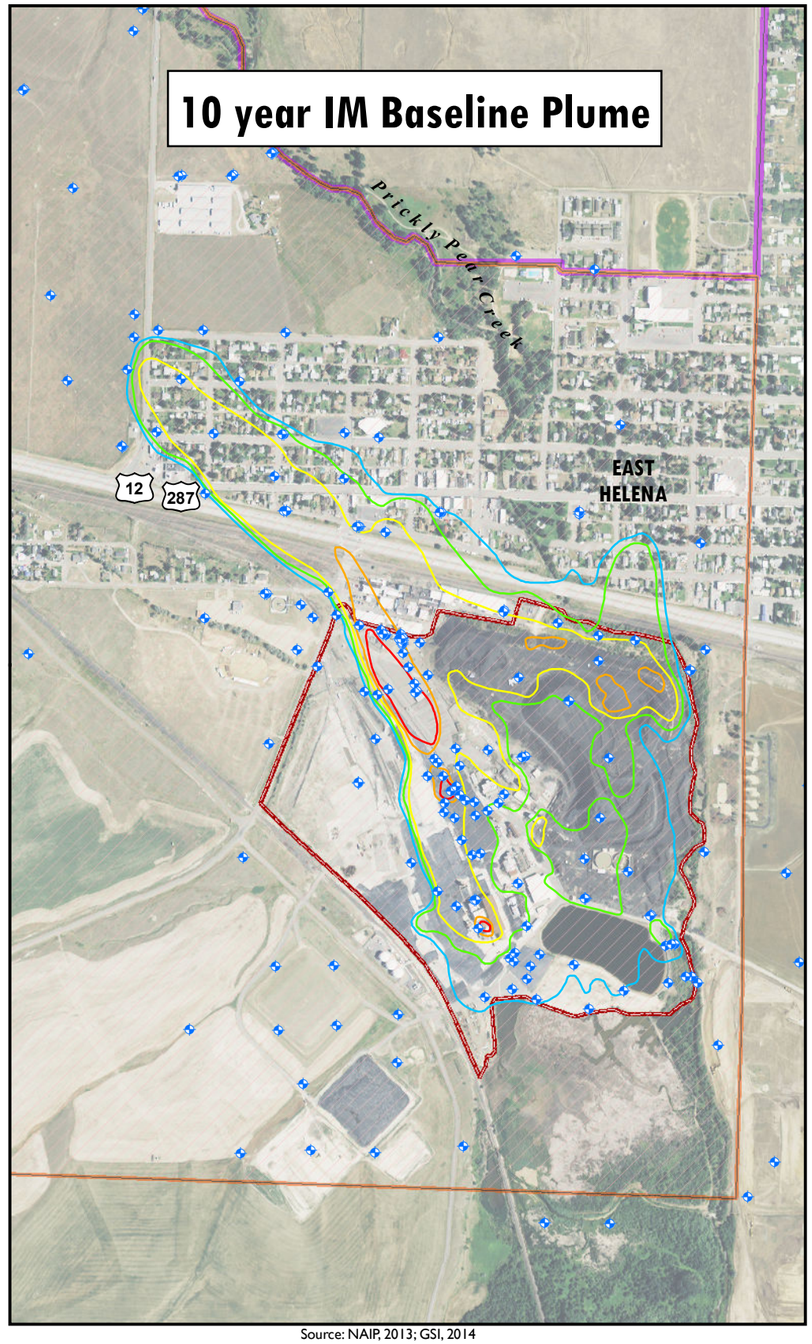
4) Results are from NewFields (2016a).

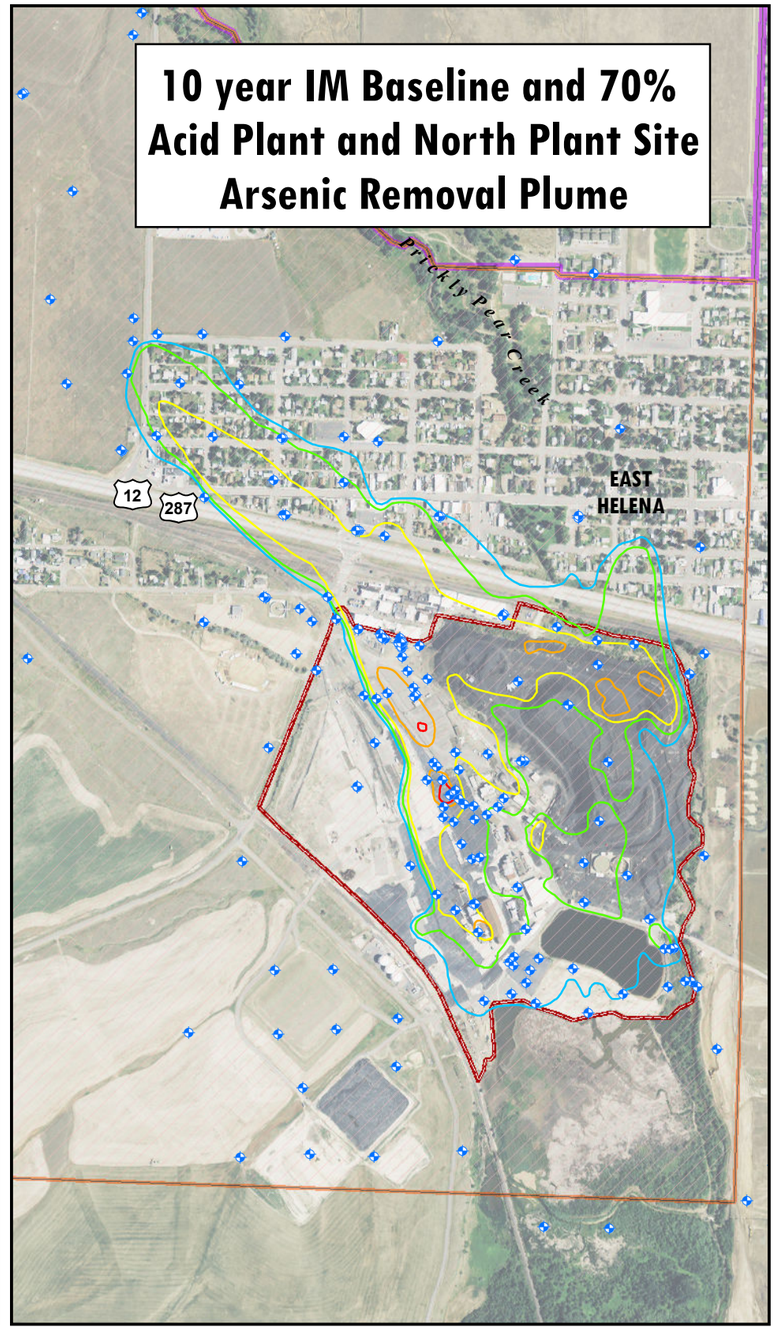
Isoconcentration Contour (mg/L)
- 0.01
- 0.1
- 1
- 10
- > 20

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Transient Flow and Transport
Predicted Isoconcentration Contours
Arsenic IM Bypass and Acid Plant Removal Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.32







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.33 Arsenic IMs NPremoval.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4.

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state.

3) mg/L = milligram per liter; CGWA = Controlled Groundwater Area.

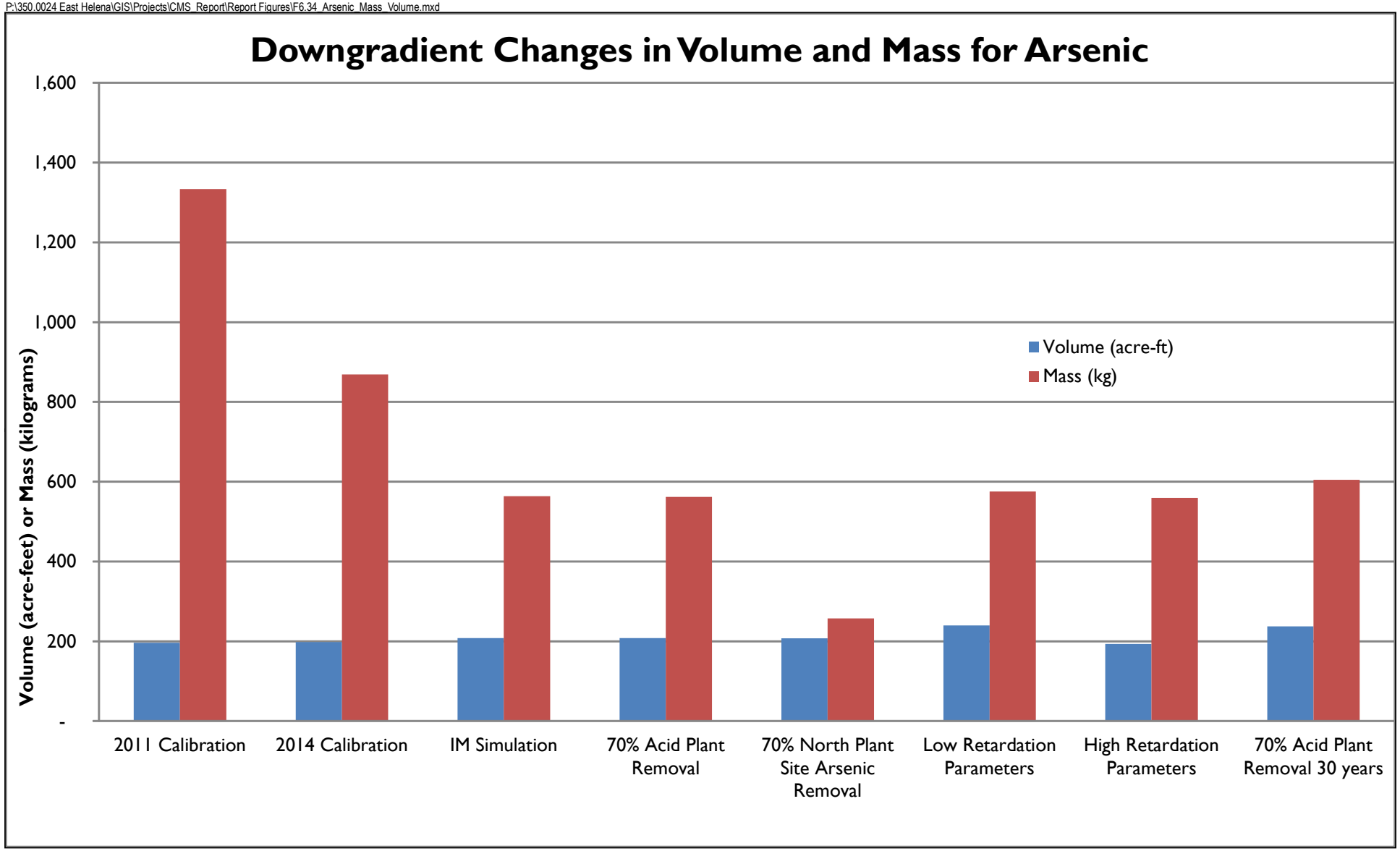
4) Results are from NewFields (2016a).

Isoconcentration Contour (mg/L)
- 0.01
- 0.1
- 1
- 10
- > 20

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Transient Flow and Transport
Predicted Isoconcentration Contours
Arsenic IM Baseline and Acid Plant/North Plant Site Arsenic Removal Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.33

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.34_Arsenic_Mass_Volume.mxd



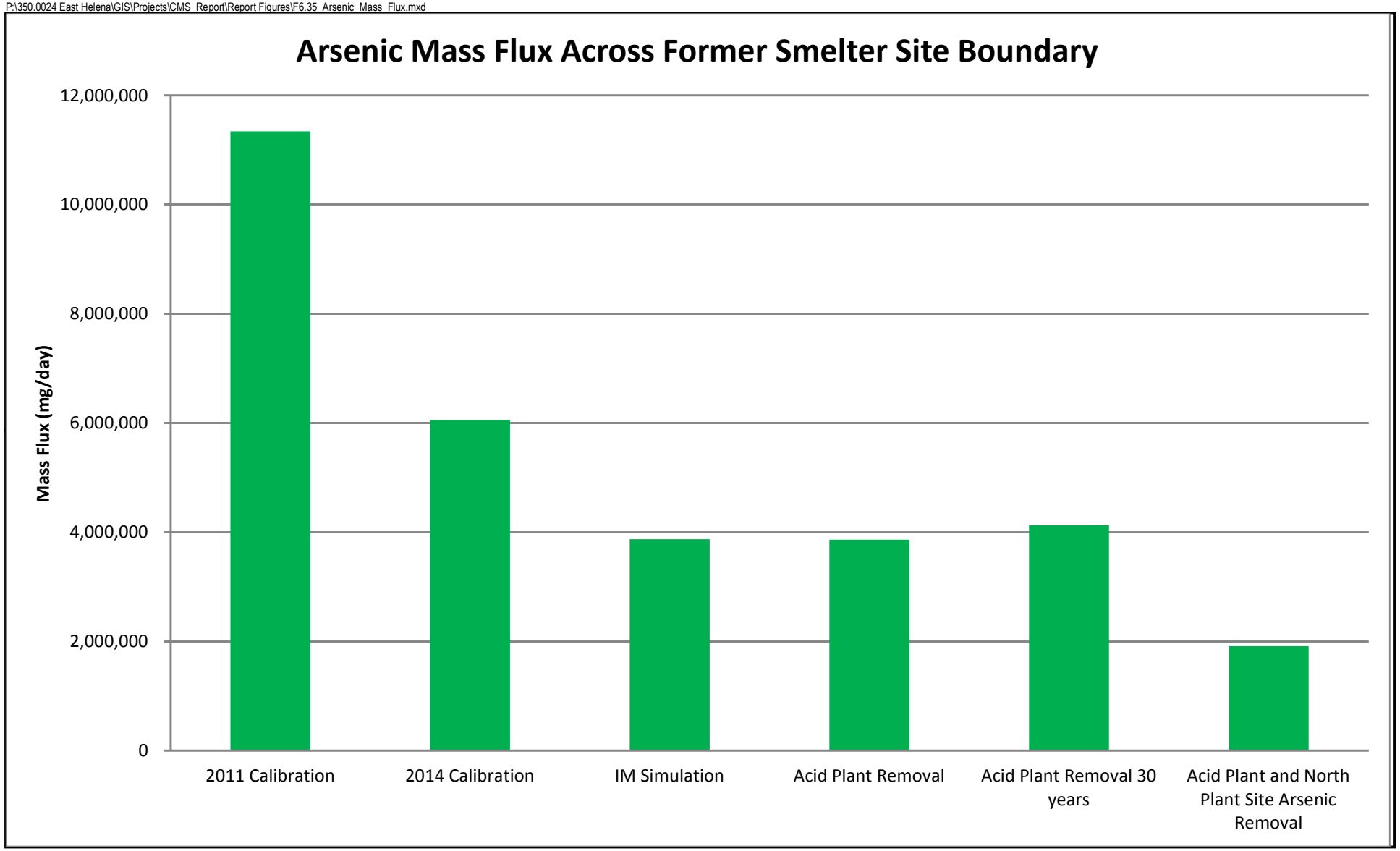
Notes:
1) Predictive results were calculated using stress period 66 of the model.

2) Results are from NewFields (2016a).

NewFields

Transient Flow and Transport
Predicted Change in Arsenic Volume/Mass for Source Control Measures
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.34

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.35_Arsenic_Mass_Flux.mxd



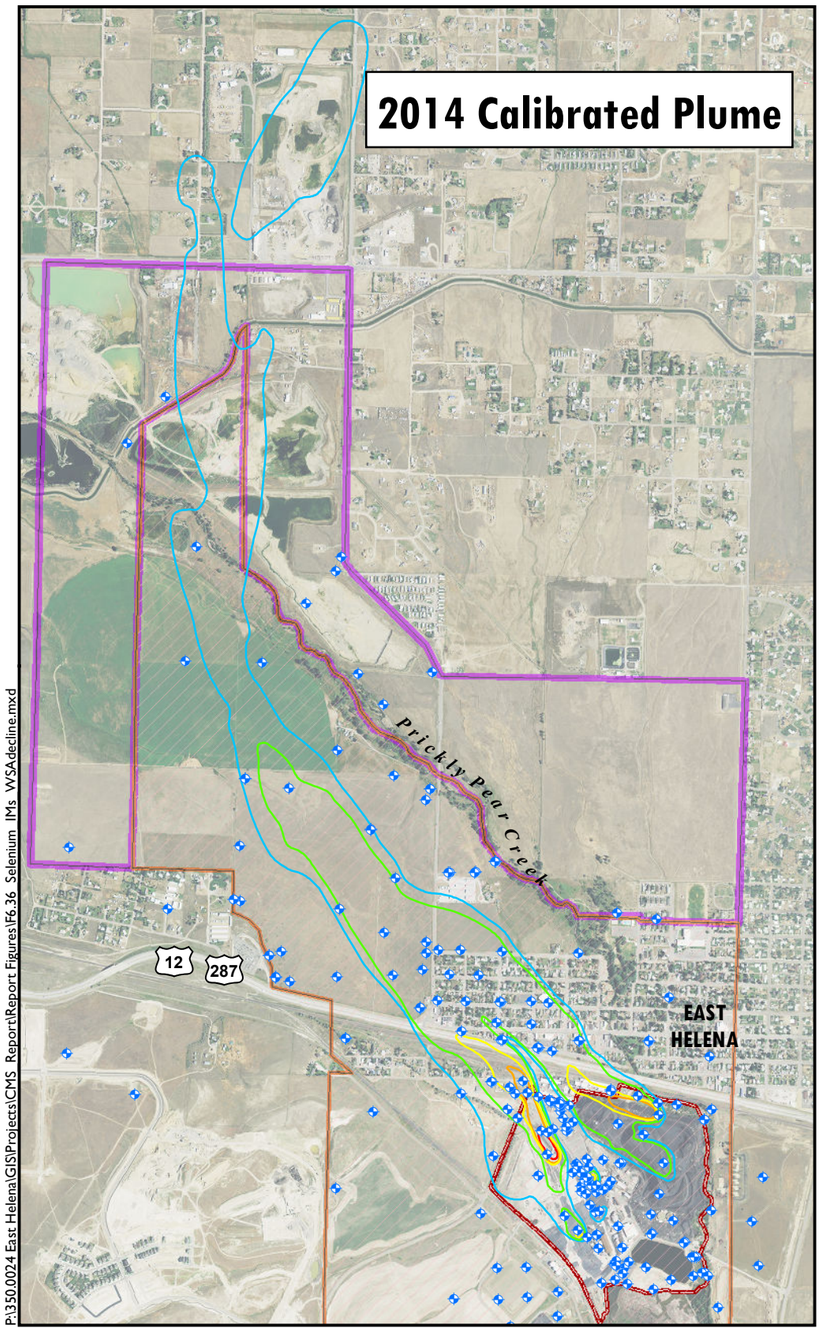
Notes:
1) Predictive results were calculated using stress period 66 of the model.

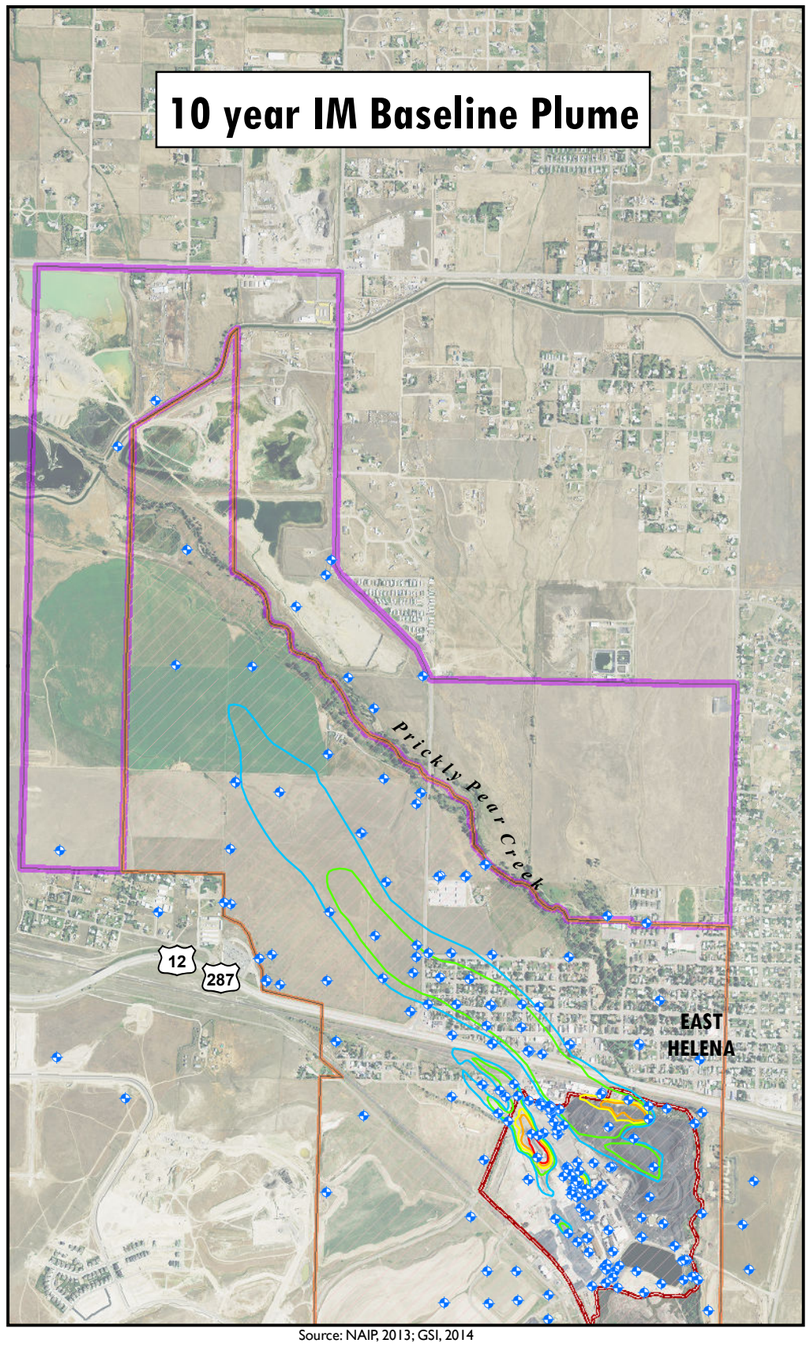
2) mg/day = milligram per day.

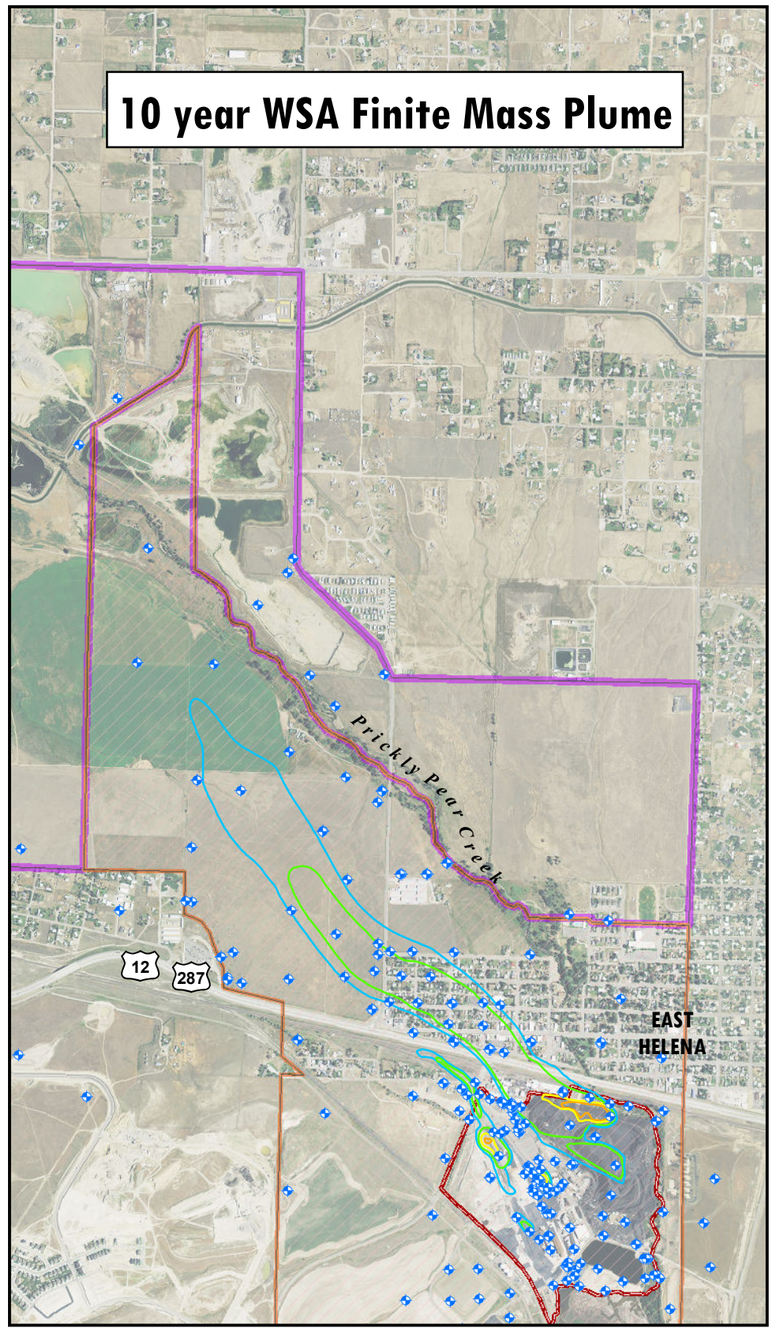
3) Results are from NewFields (2016a).

NewFields

Transient Flow and Trasnport
Predicted Change in Arsenic Mass Flux Across Site Boundary
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.35







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.36 Selenium IMs WSAdecline.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4.

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state.

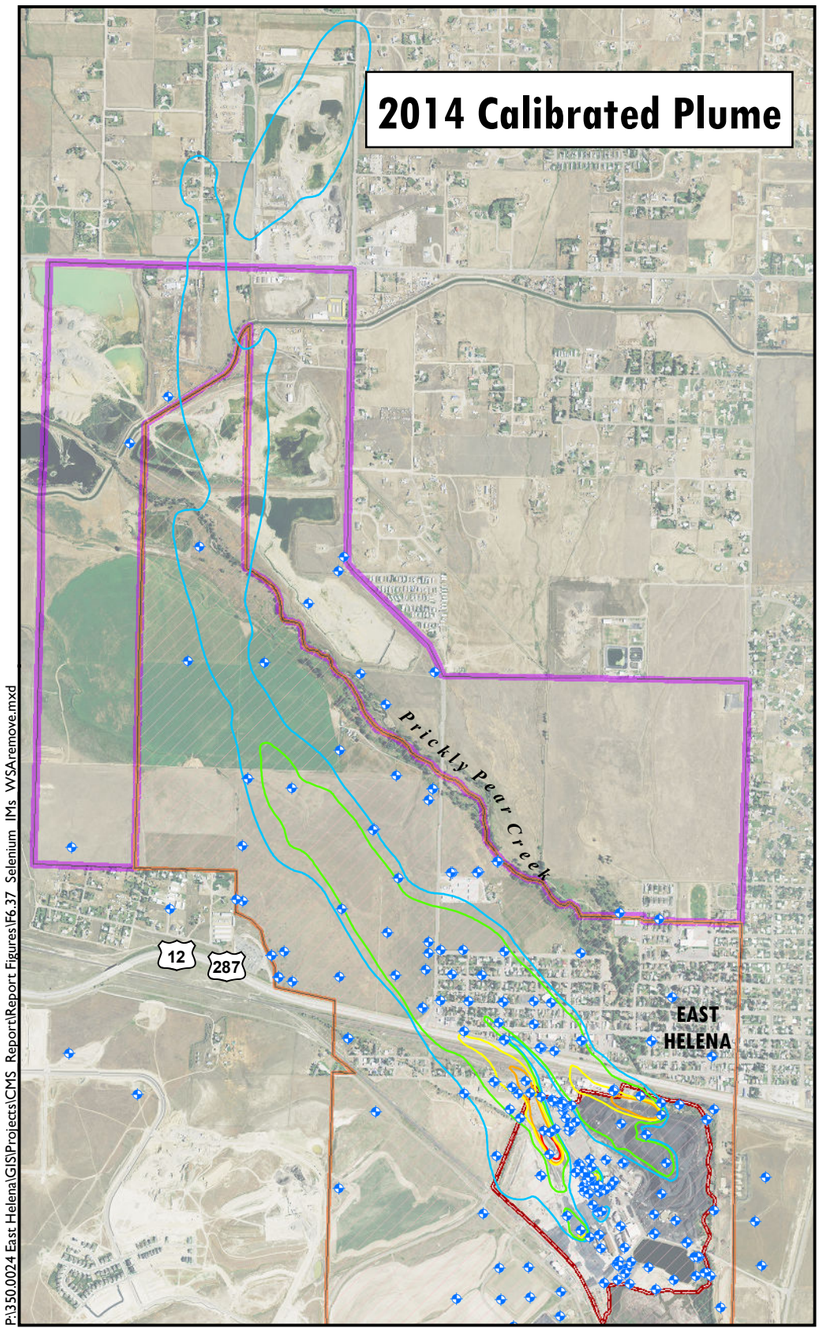
3) mg/L = milligram per liter; CGWA = Controlled Groundwater Area.

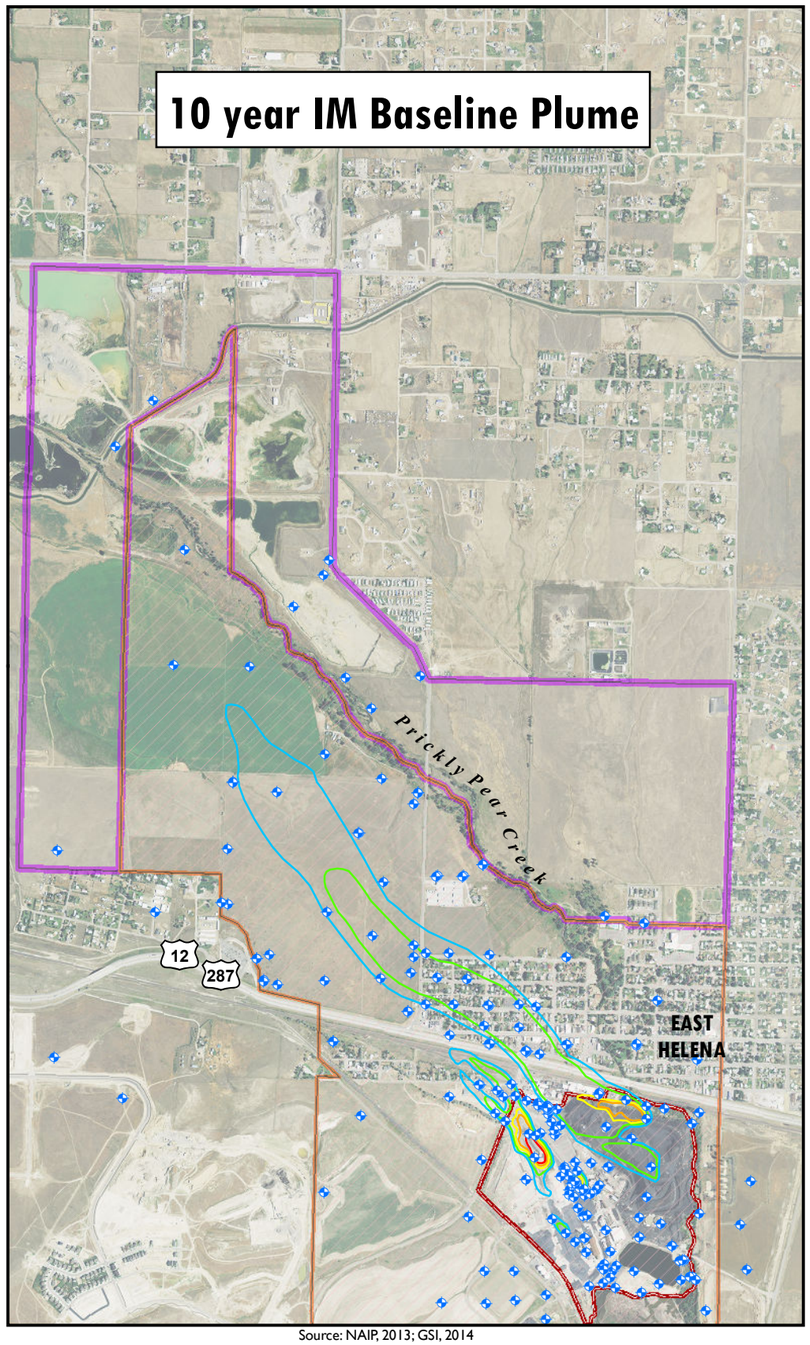
4) Results are from NewFields (2016a).

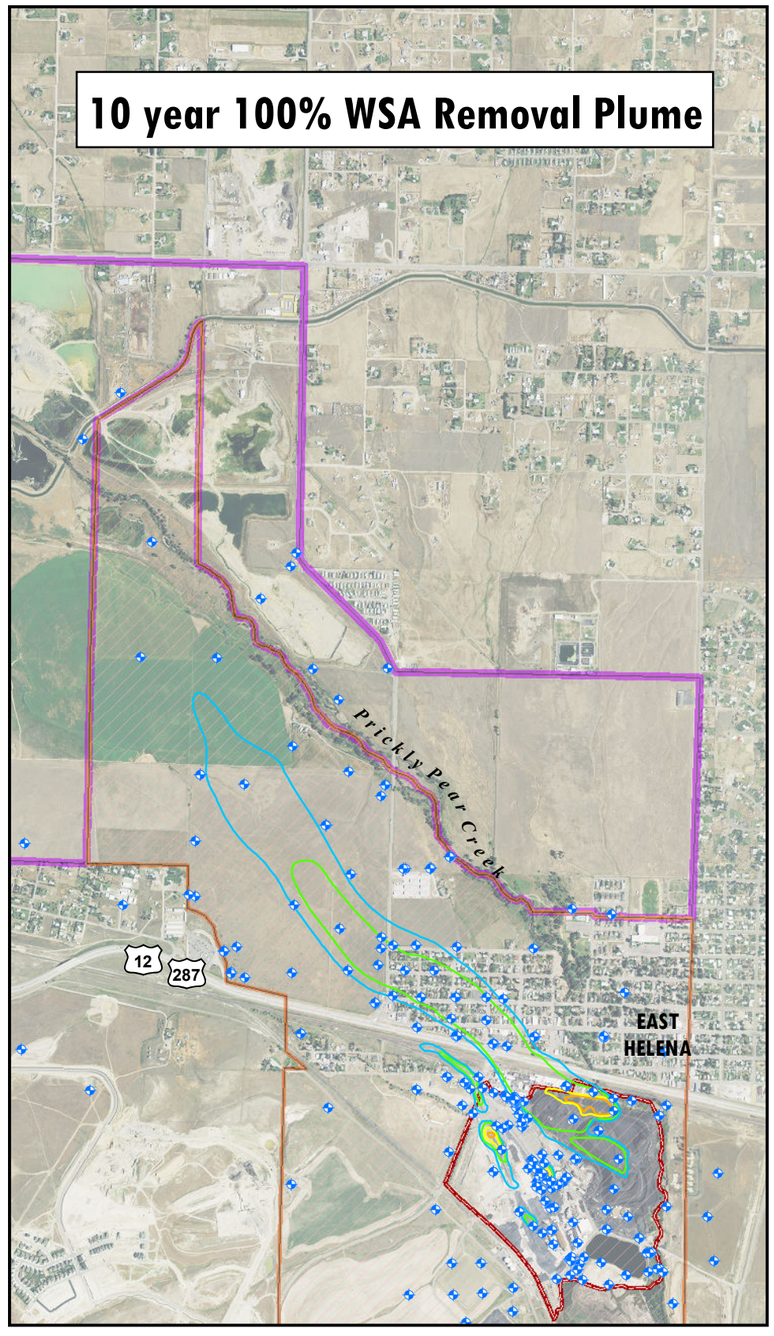
Isoconcentration Contour (mg/L)
- 0.05
- 0.1
- 0.5
- 1
- > 3

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Transient Flow and Trasnport
Predicted Isoconcentration Contours
Selenium IM Baseline and WSA Finite Mass Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.36







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.37 Selenium IMs WSAremove.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4.

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state.

3) mg/L = milligram per liter; CGWA = Controlled Groundwater Area.

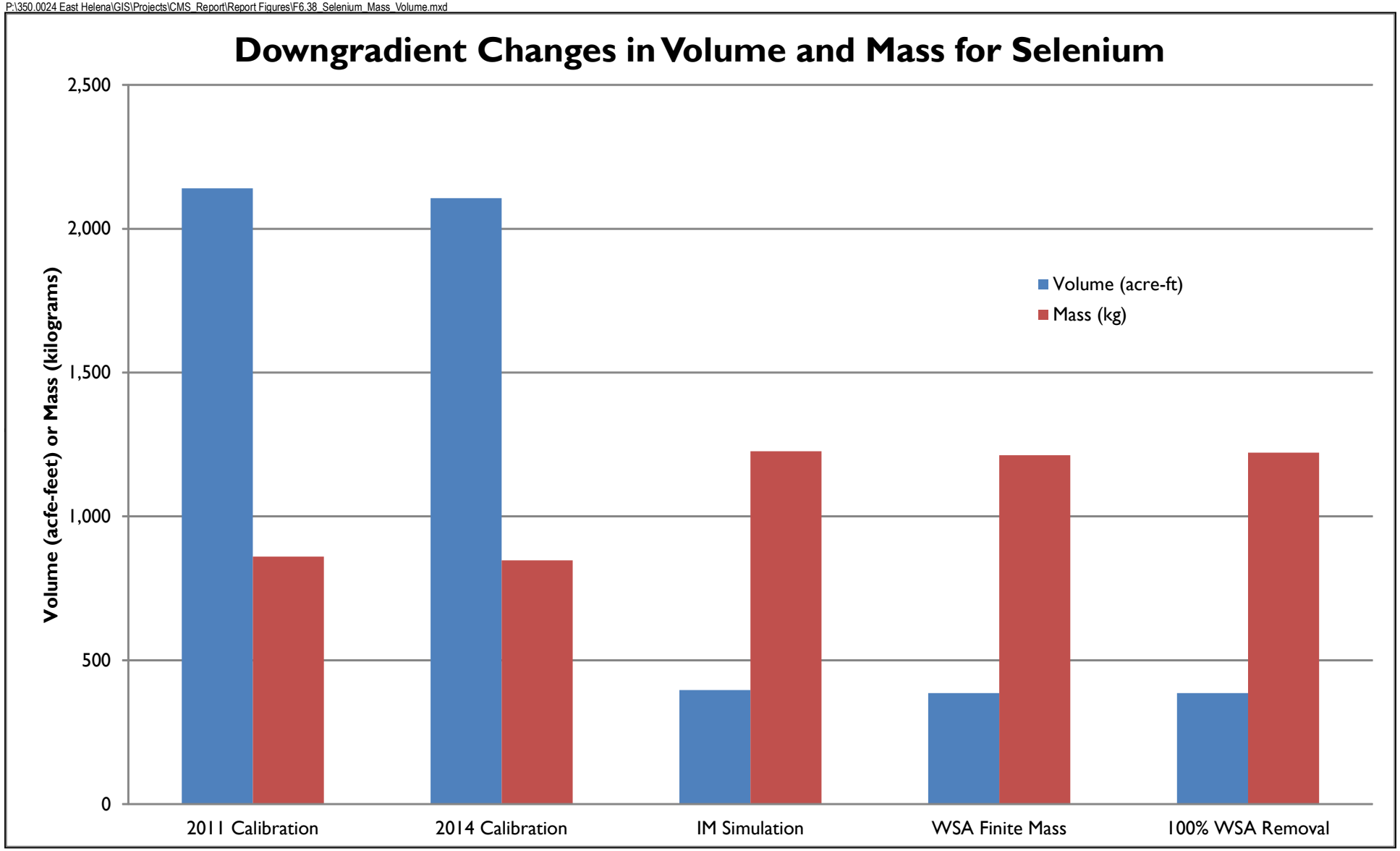
4) Results are from NewFields (2016a).

Isoconcentration Contour (mg/L)
- 0.05
- 0.1
- 0.5
- 1
- > 3

Monitoring Well
Former Smelter Site Boundary
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Transient Flow and Trasnport
Predicted Isoconcentration Contours
Selenium IM Baseline and 100% WSA removal Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.37

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.38_Selenium_Mass_Volume.mxd



Notes:
1) Predictive results were calculated using stress period 66 of the model.

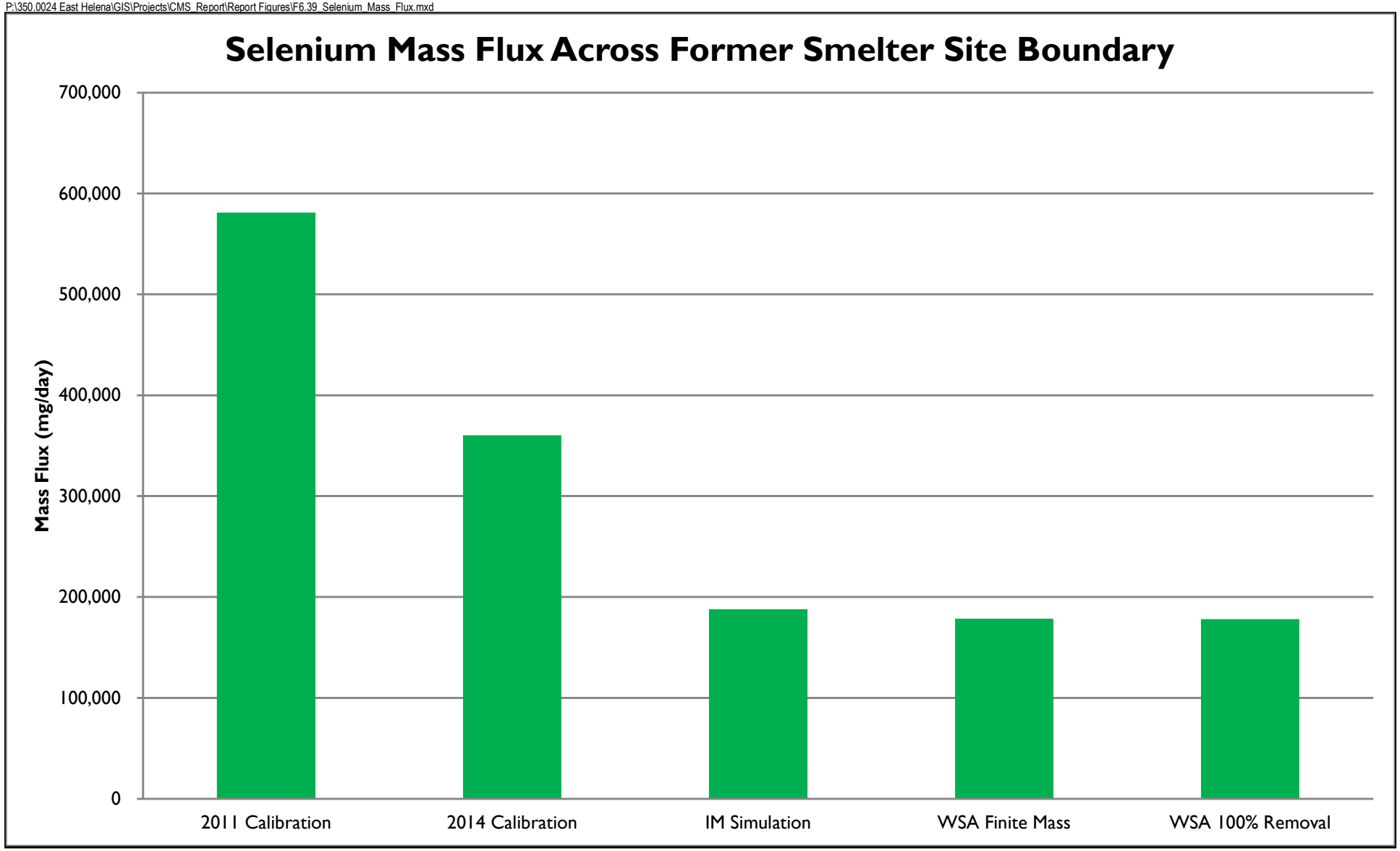
2) WSA = West Selenium Area.

3) Results are from NewFields (2016a).

NewFields

Transient Flow and Trasnport
Predicted Change in Selenium Volume/Mass for Source Control Measures
Former ASARCO East Helena Smleter
East Helena, Montana
FIGURE 6.38

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.39_Selenium_Mass_Flux.mxd



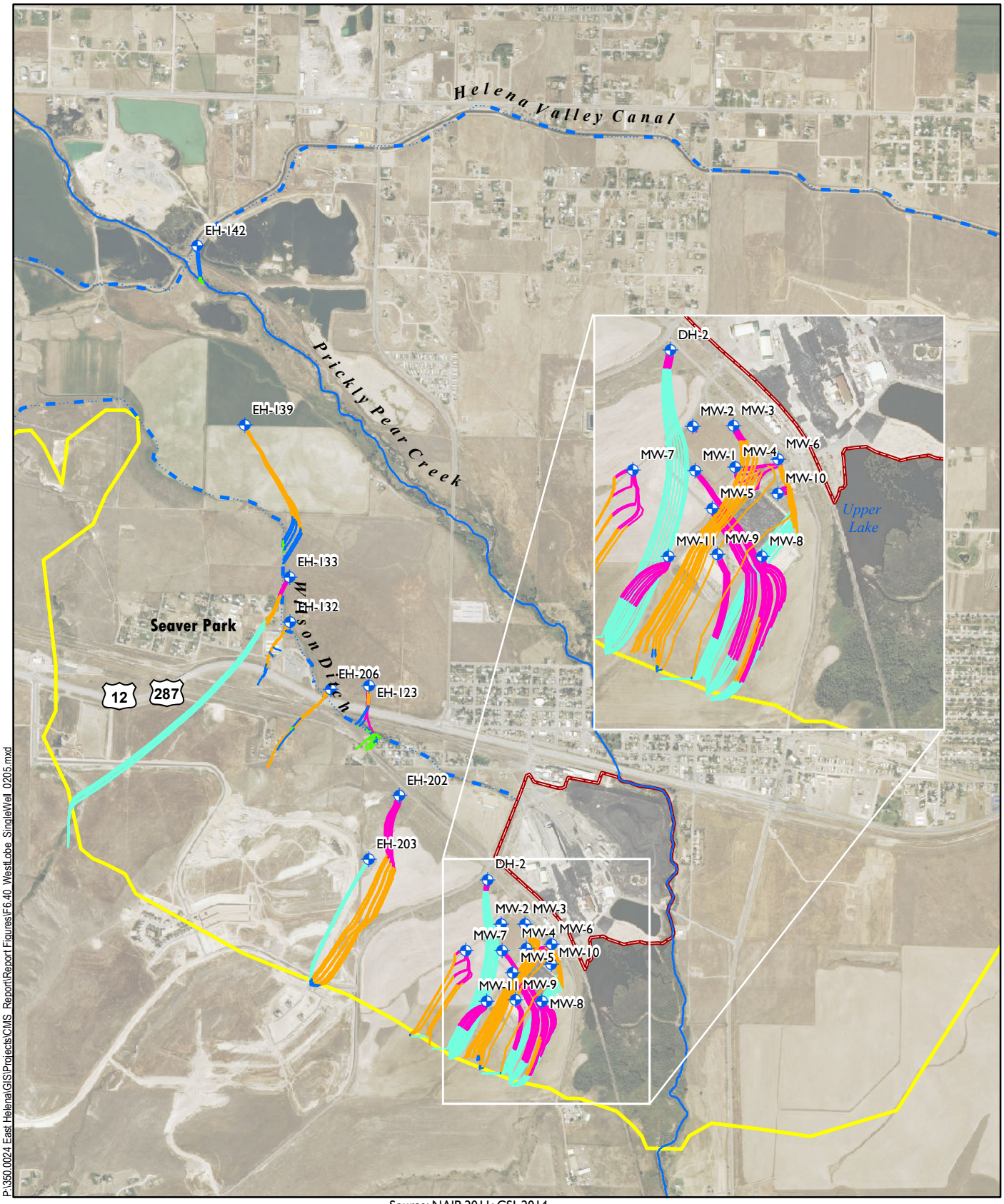
Notes:
1) Predictive results were calculated using stress period 66 of the model;

2) mg/day = milligram per day; WSA = West Selenium Area.

3) Results are from NewFields (2016a).

NewFields

Transient Flow and Trasnport
Predicted Change in Selenium Mass Flux Across Site Boundary
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.39



Source: NAIP, 2011; GSI, 2014

Note: Results are from NewFields (2014c).

0 2,200
Feet

NewFields

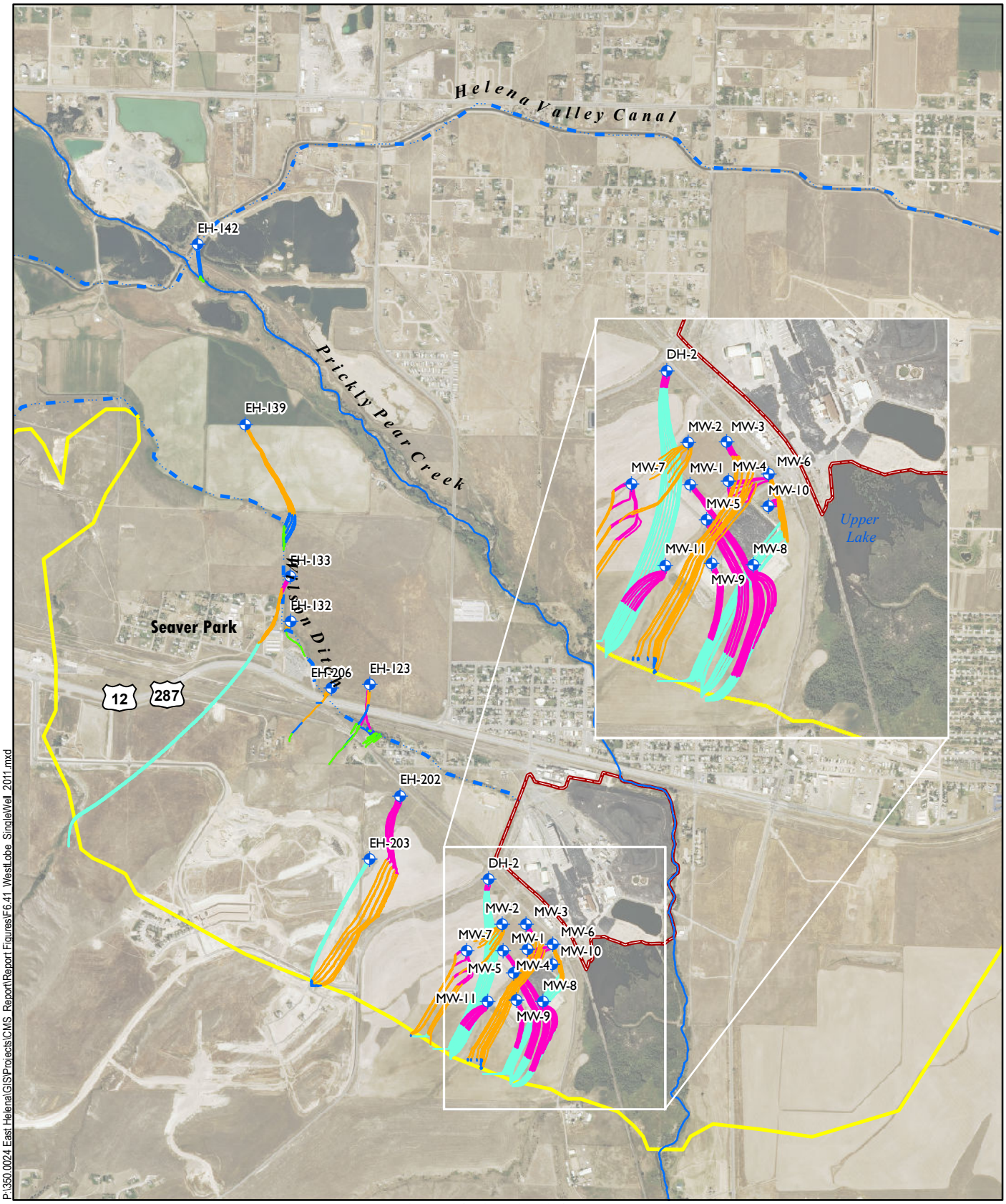
Particle Track

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

Former Smelter Site Boundary

Model Domain

Pre-Slurry Wall Reverse Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.40



Source: NAIP, 2011; GSI, 2014

Note: Results are from NewFields (2014c).

0 2,200 Feet

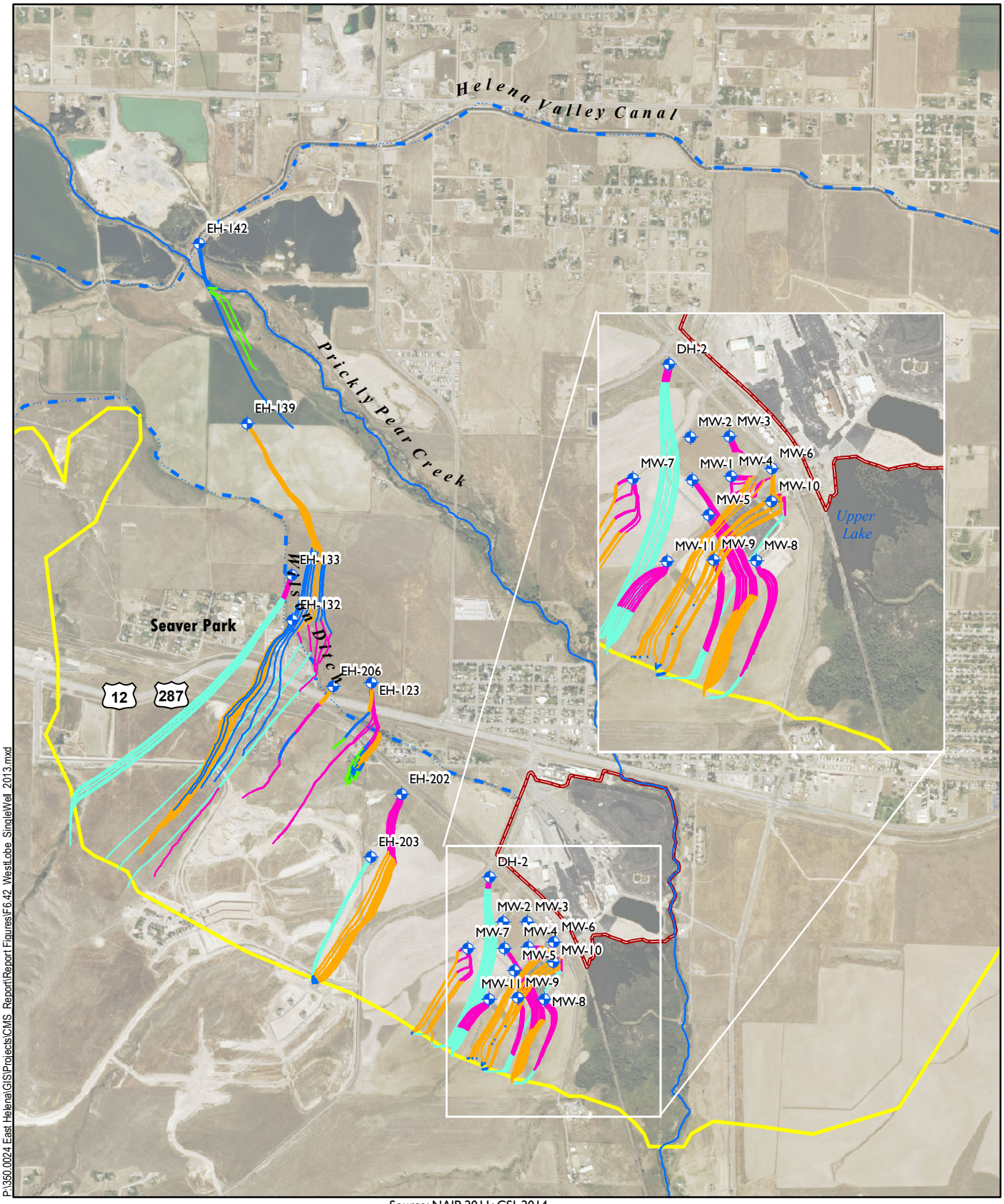
Particle Track

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

- Former Smelter Site Boundary
- Model Domain

NewFields

2011 Reverse Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.41



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.42 WestLobe SingleWell 2013.mxd

Source: NAIP, 2011; GSI, 2014

Note: Results are from NewFields (2014c).

0 2,200
Feet

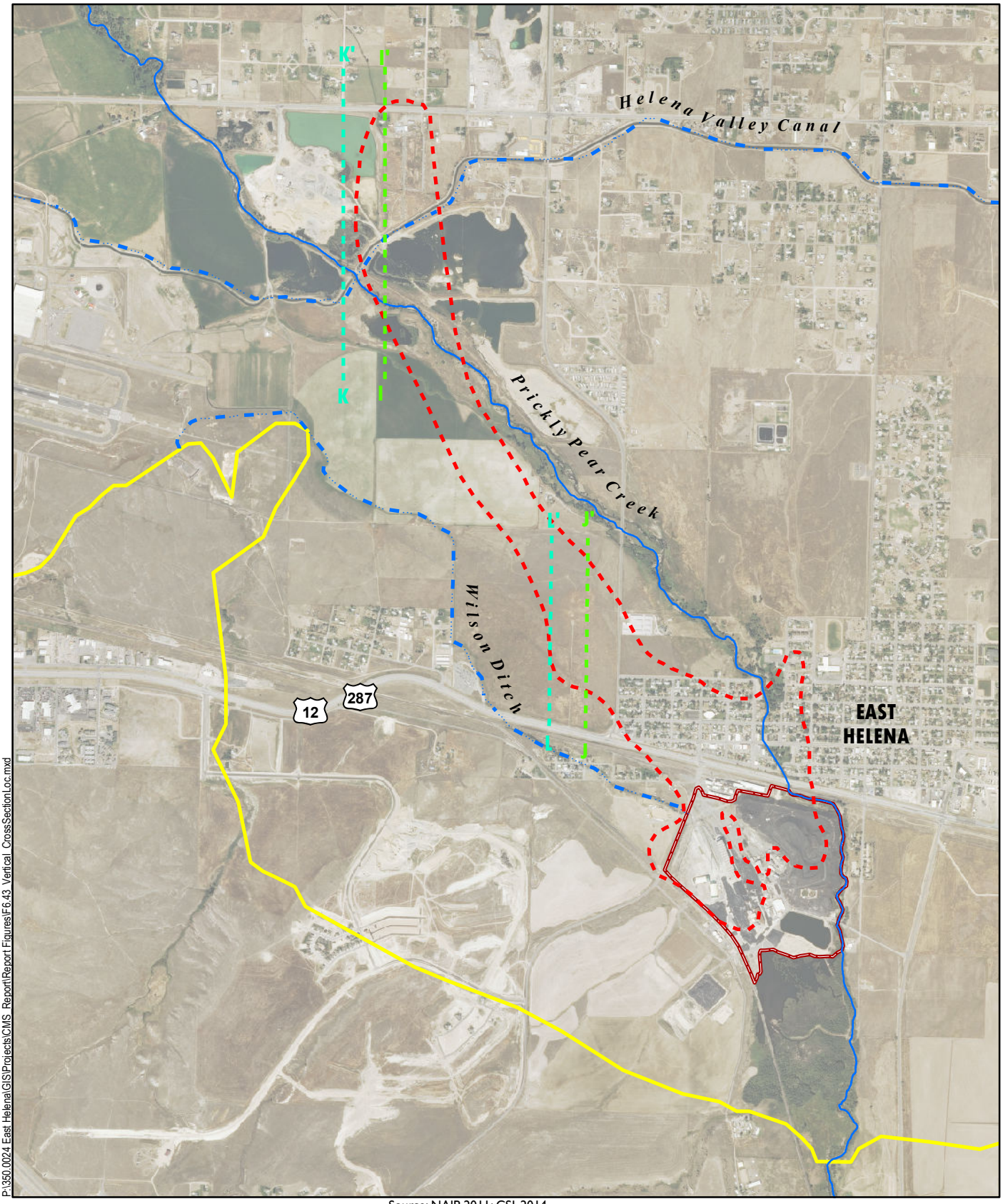
NewFields

Particle Track

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

- Former Smelter Site Boundary
- Model Domain

2013 Reverse Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.42



P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.43_Vertical_CrossSectionLoc.mxd

Source: NAIP, 2011; GSI, 2014

N

0 Feet 2,200

Selenium > 0.01 mg/L (2010)

Facility Boundary

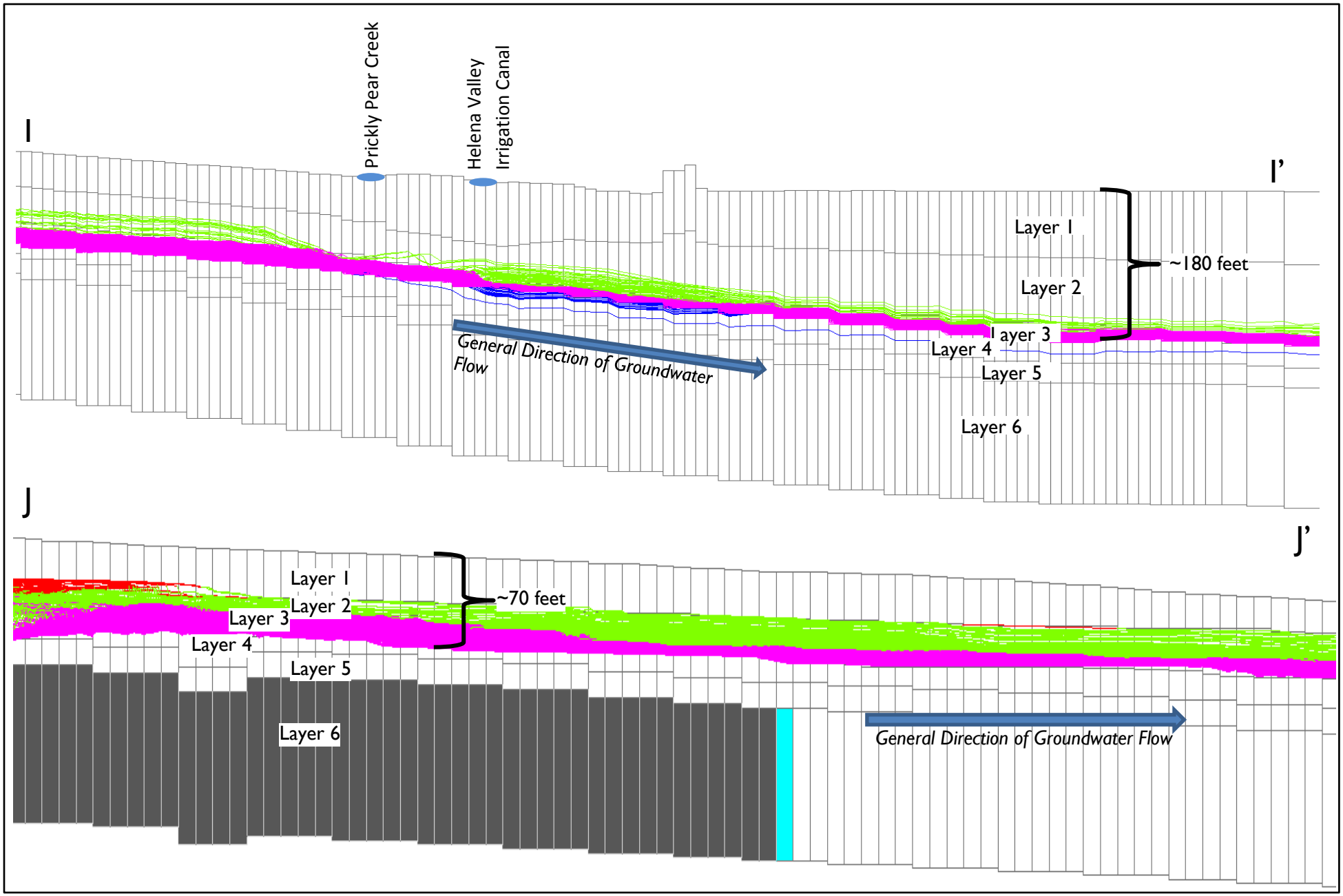
Model Domain

Notes:
1) Cross sections are shown on Figures 6.44 and 6.45.

2) Results are from NewFields (2014c).

NewFields

Cross Section Locations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.43



Particle Tracks

- Layer 1
- Layer 2
- Layer 3
- Layer 4

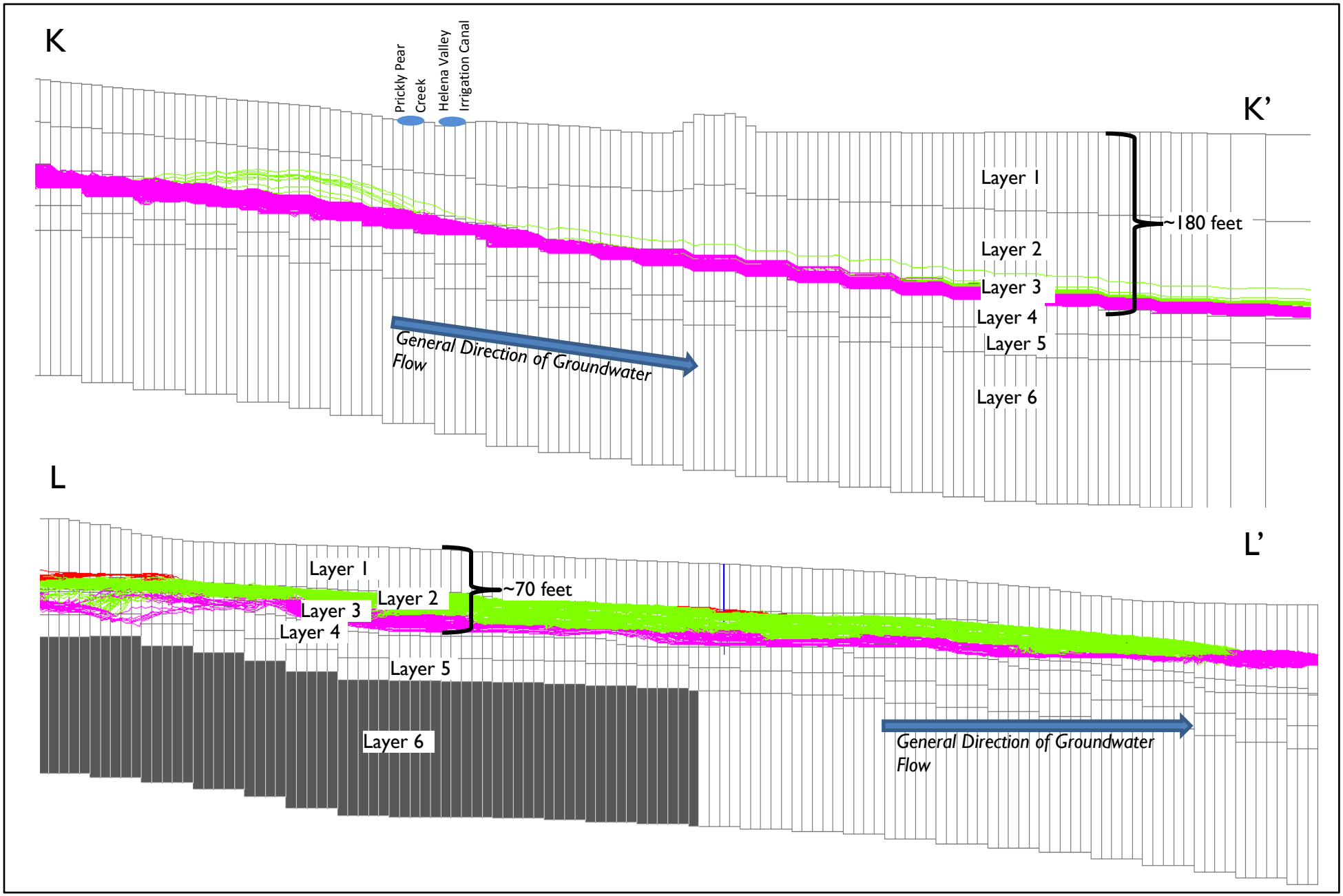
Notes:

1) Location of cross-section shown on Figure 6.43.

2) Results are from NewFields (2014c).

NewFields

Cross Sections I-I' and J-J'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.44



Particle Tracks

- Layer 1
- Layer 2
- Layer 3
- Layer 4

Notes:

1) Location of cross-section shown on Figure 6.43.

2) Results are from NewFields (2014c).

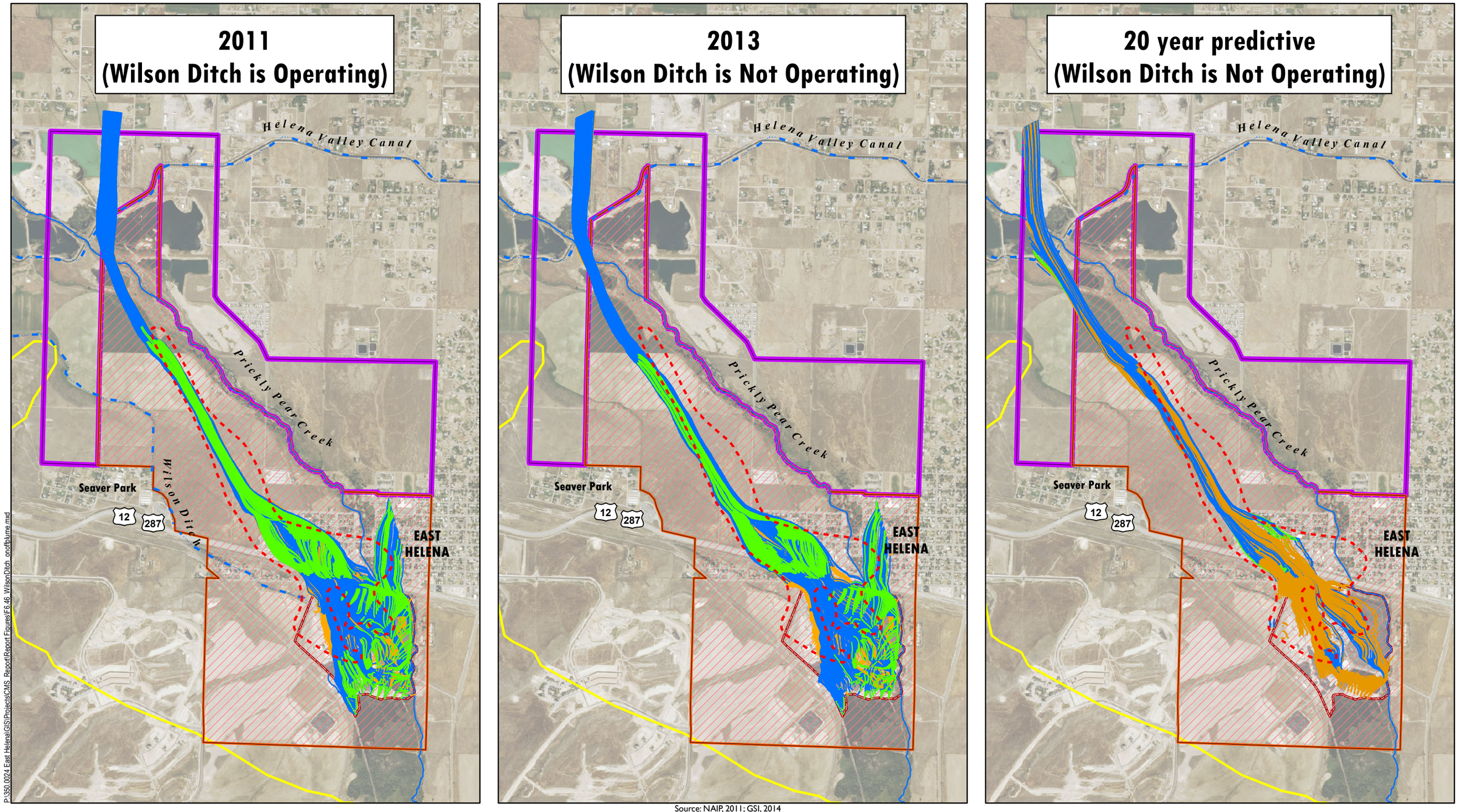
NewFields

Cross Sections K-K' and L-L'
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.45

2011
(Wilson Ditch is Operating)

2013
(Wilson Ditch is Not Operating)

20 year predictive
(Wilson Ditch is Not Operating)



Source: NAIP, 2011; GSI, 2014

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.46 WilsonDitch onoffplume.mxd

0 Feet 2,200

NewFields

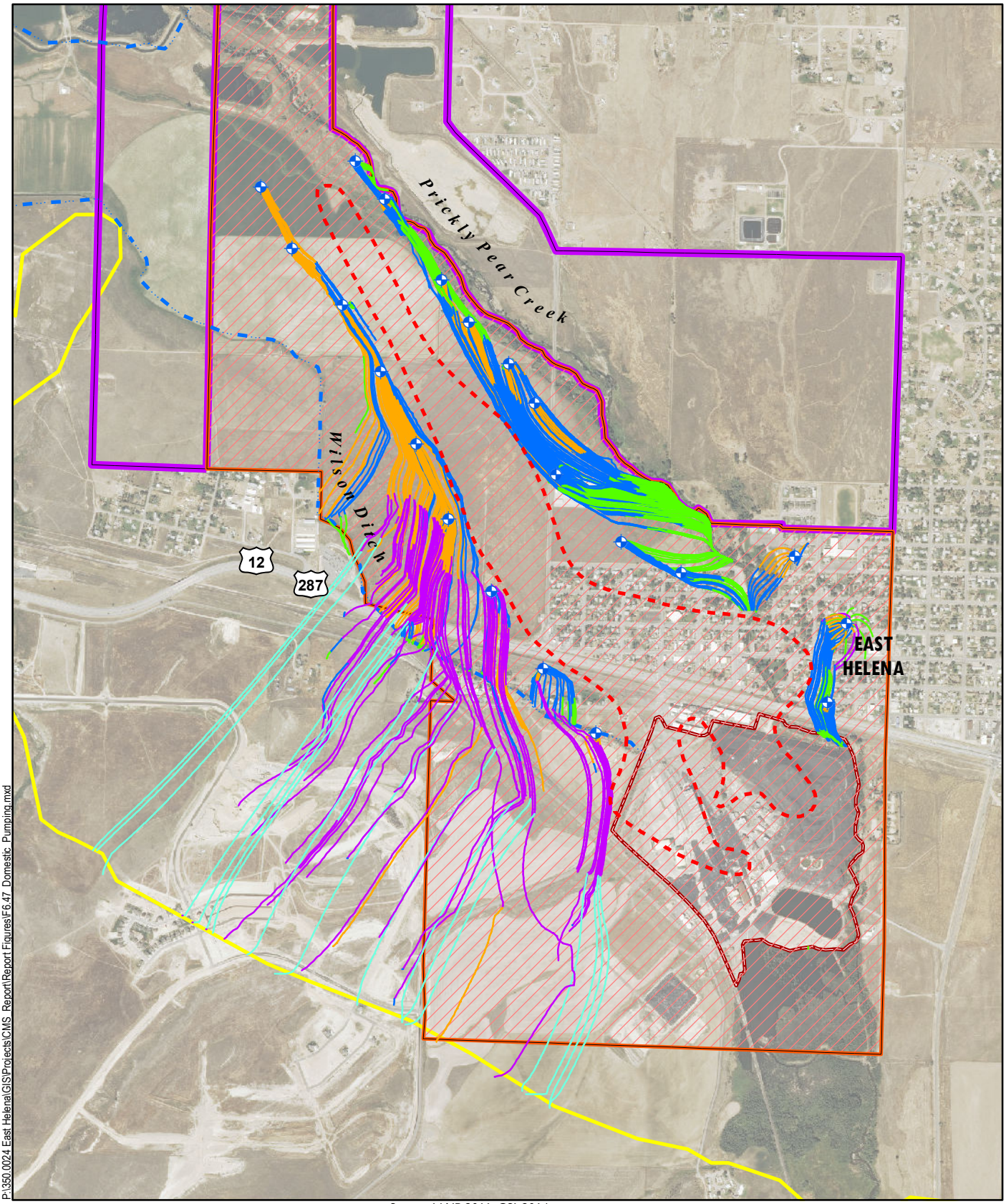
Note: Results are from NewFields (2014c).

Particle Track

- Layer 1
- Layer 2
- Layer 3

- Selenium > 0.05 mg/L (2012)
- Former Smelter Site Boundary
- Model Domain
- Permanent CGWA - Subarea1
- Permanent CGWA - Subarea 2

Wilson Ditch Forward Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.46



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.47 Domestic Pumping.mxd

Source: NAIP, 2011; GSI, 2014

N

0 Feet 1,600

Hypothetical Pumping Well

Selenium > 0.05 mg/L (2012)

Former Smelter Site Boundary

Model Domain

Particle Track

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

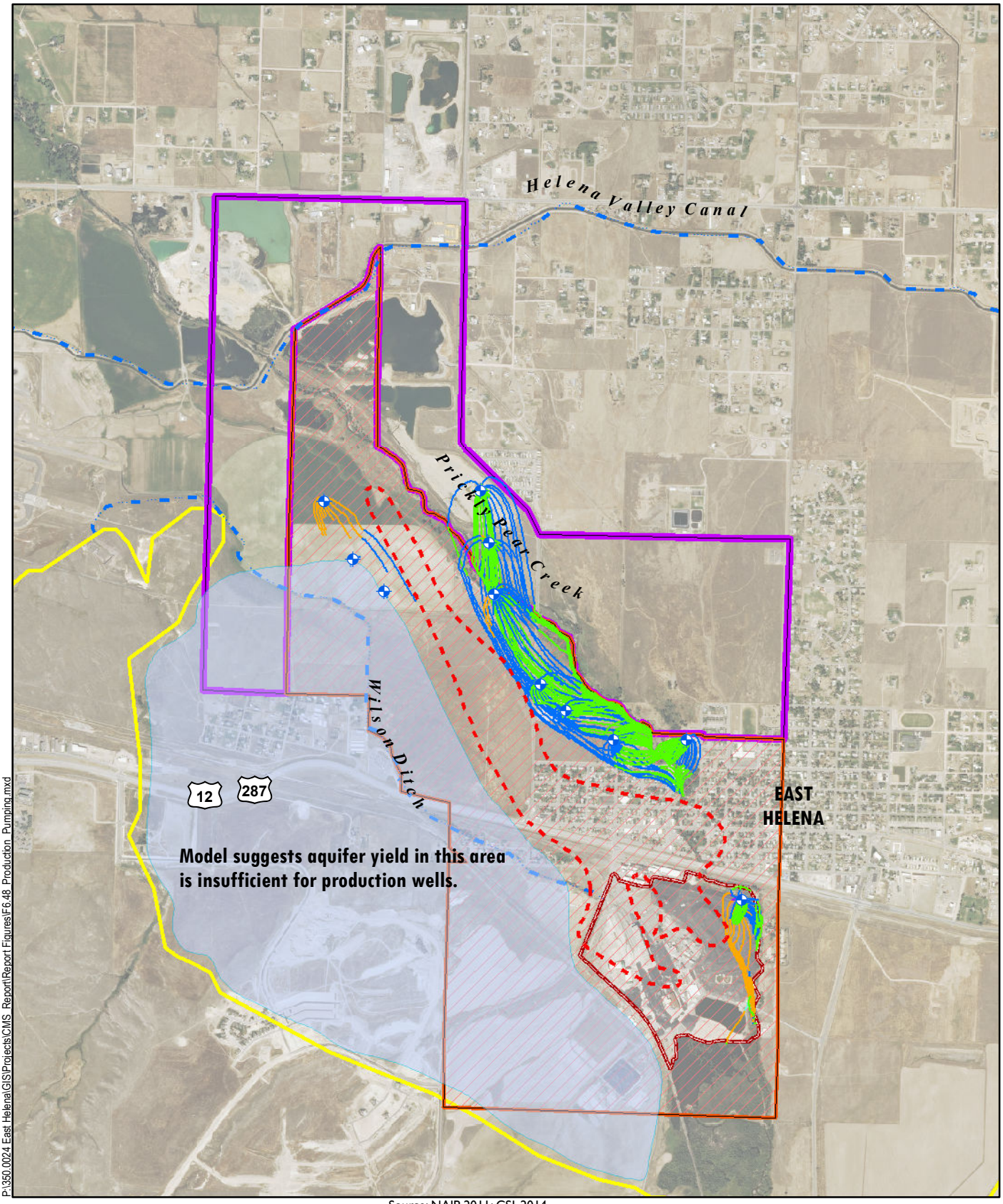
Permanent CGWA - Subarea1

Permanent CGWA - Subarea 2

Note: Results are from NewFields (2014c).

NewFields

Domestic Well Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.47



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.48 Production Pumping.mxd

Source: NAIP, 2011; GSI, 2014

Hypothetical Pumping Well
Selenium > 0.05 mg/L (2012)
Former Smelter Site Boundary
Model Domain

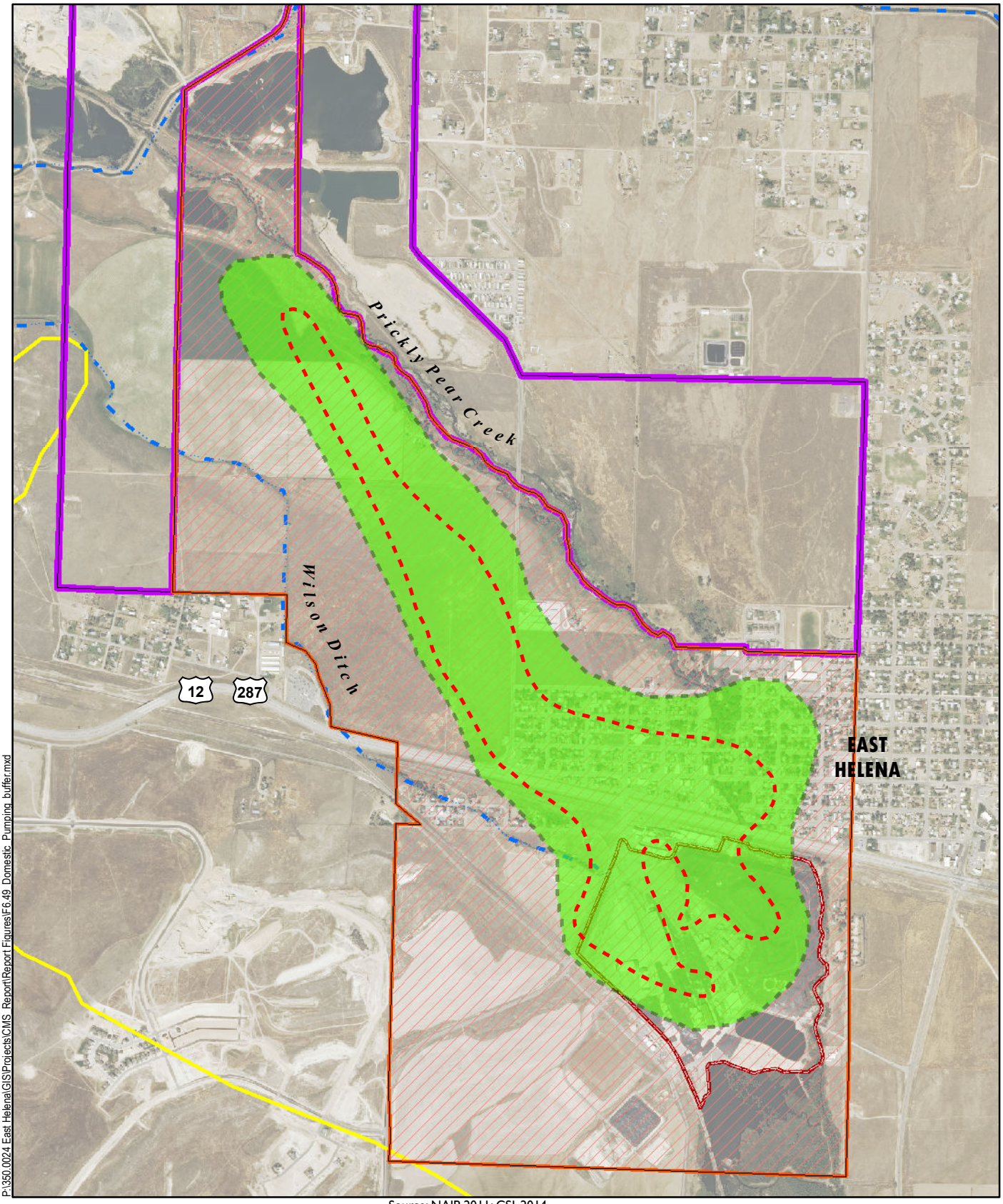
Particle Track
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5

Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

0 2,200
Feet

NewFields

Production Well Particle Tracks
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.48



P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.49_Domestic_Pumping_buffer.mxd

Source: NAIP, 2011; GSI, 2014

Note: Results are from NewFields (2014c).

0 Feet 1,600

NewFields

Buffer Zone

Selenium > 0.05 mg/L (2012)

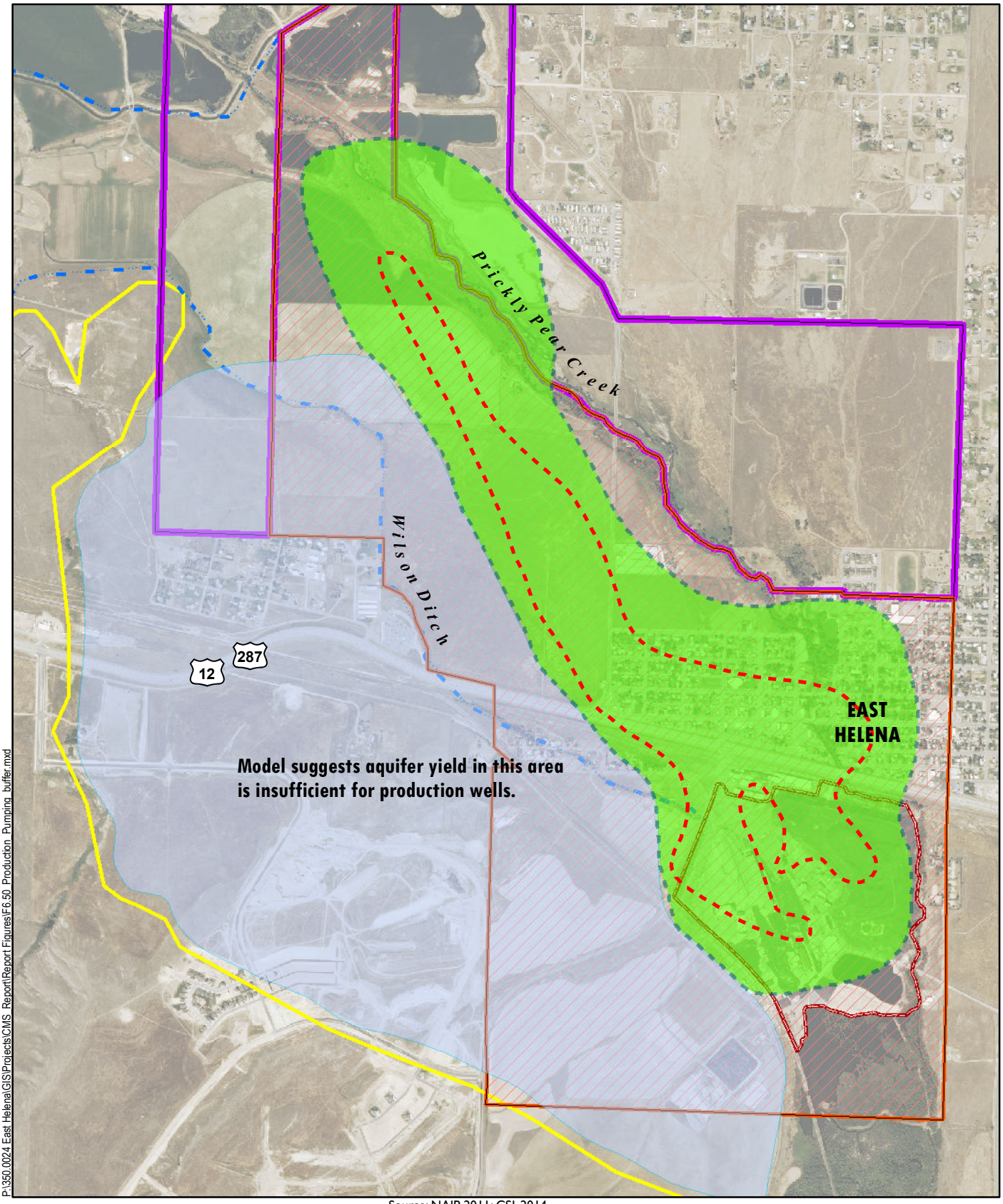
Former Smelter Site Boundary

Model Domain

Permanent CGWA - Subarea1

Permanent CGWA - Subarea 2

Domestic Well Buffer Zone
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.49



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.50 Production Pumping buffer.mxd

Source: NAIP, 2011; GSI, 2014

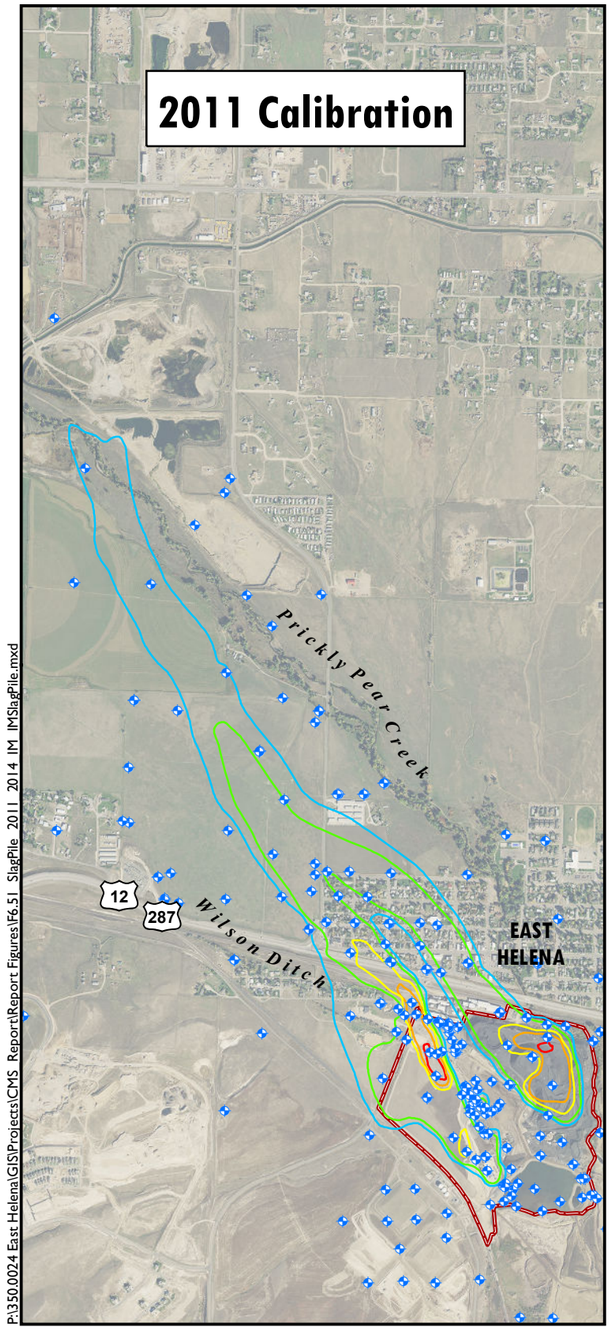
Note: Results are from NewFields (2014c).

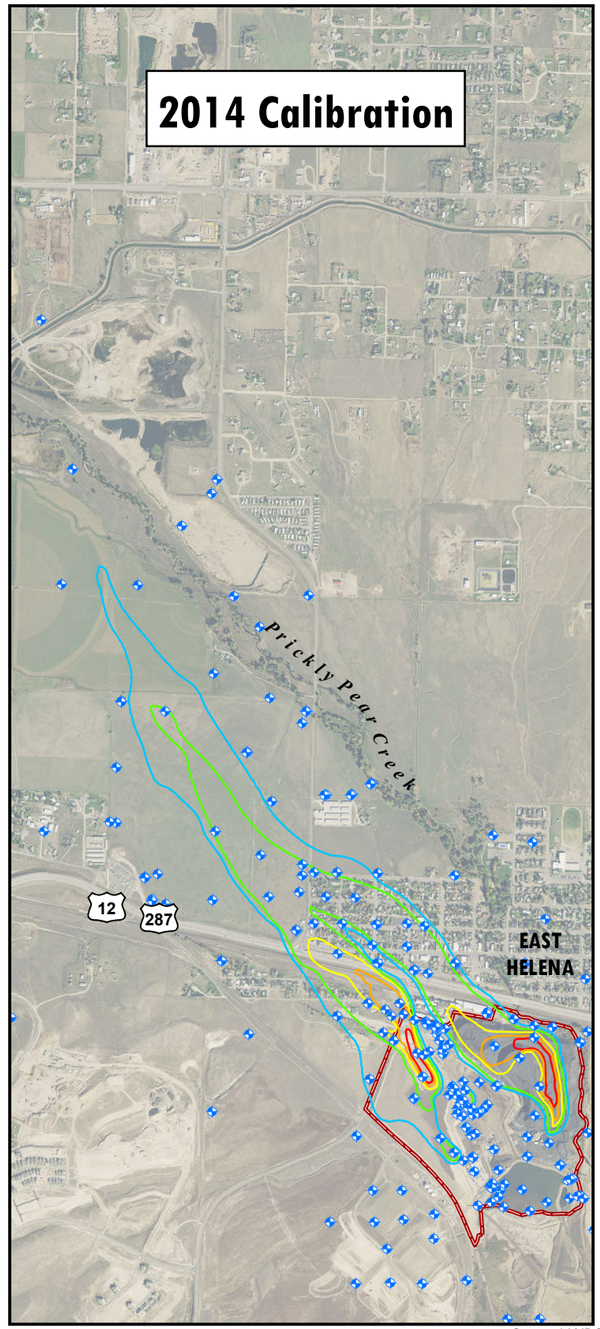
0 1,600 Feet

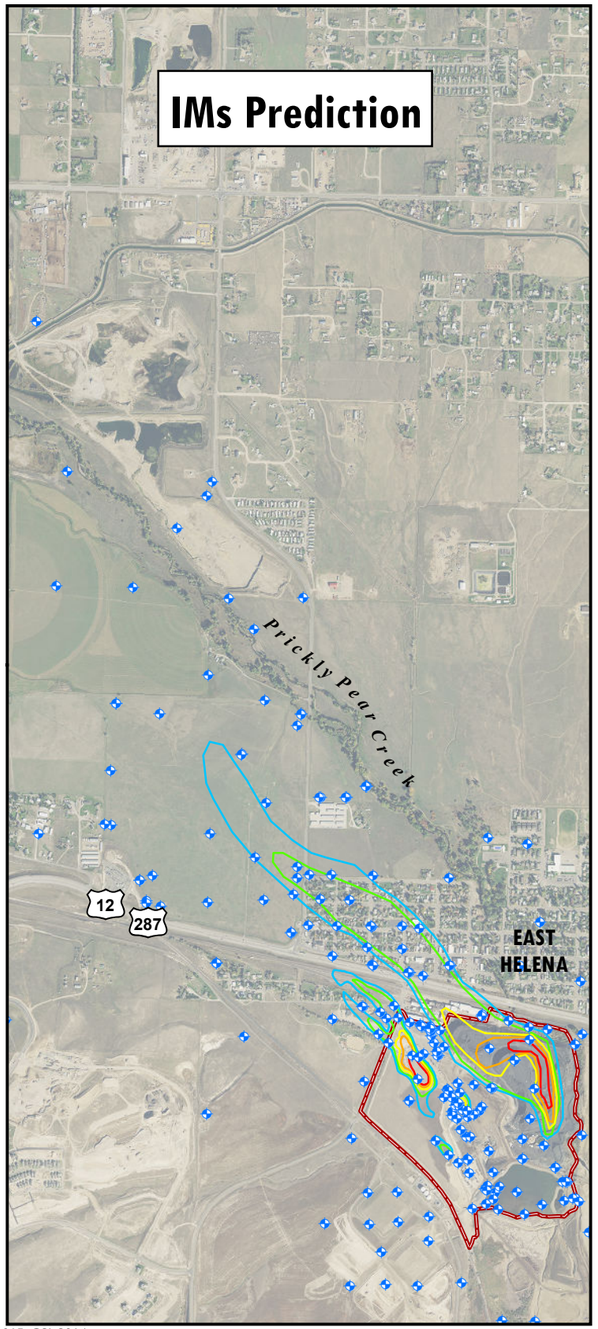
NewFields

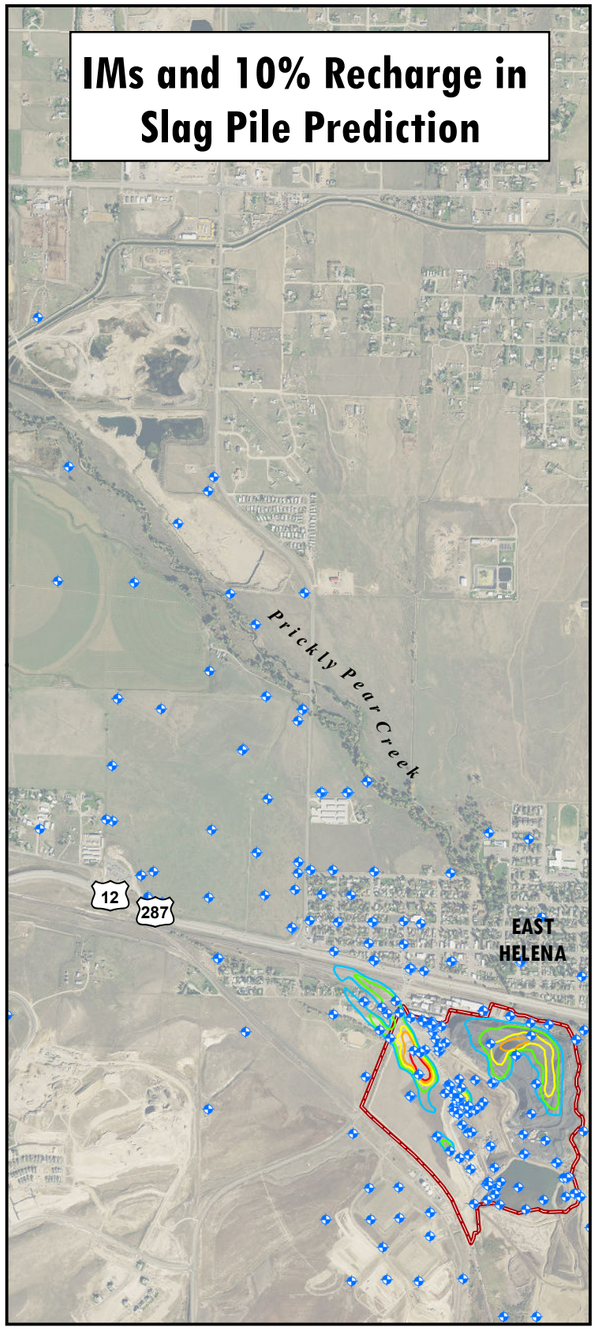
Buffer Zone
Selenium > 0.05 mg/L (2012)
Former Smelter Site Boundary
Model Domain
Permanent CGWA - Subarea1
Permanent CGWA - Subarea 2

Production Well Buffer Zone
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.50









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F6.51 SlagPile 2011 2014 IM IMSlagPile.mxd

Source: NAIP, 2015; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represents a composite of model layers 1, 2, 3, and 4.

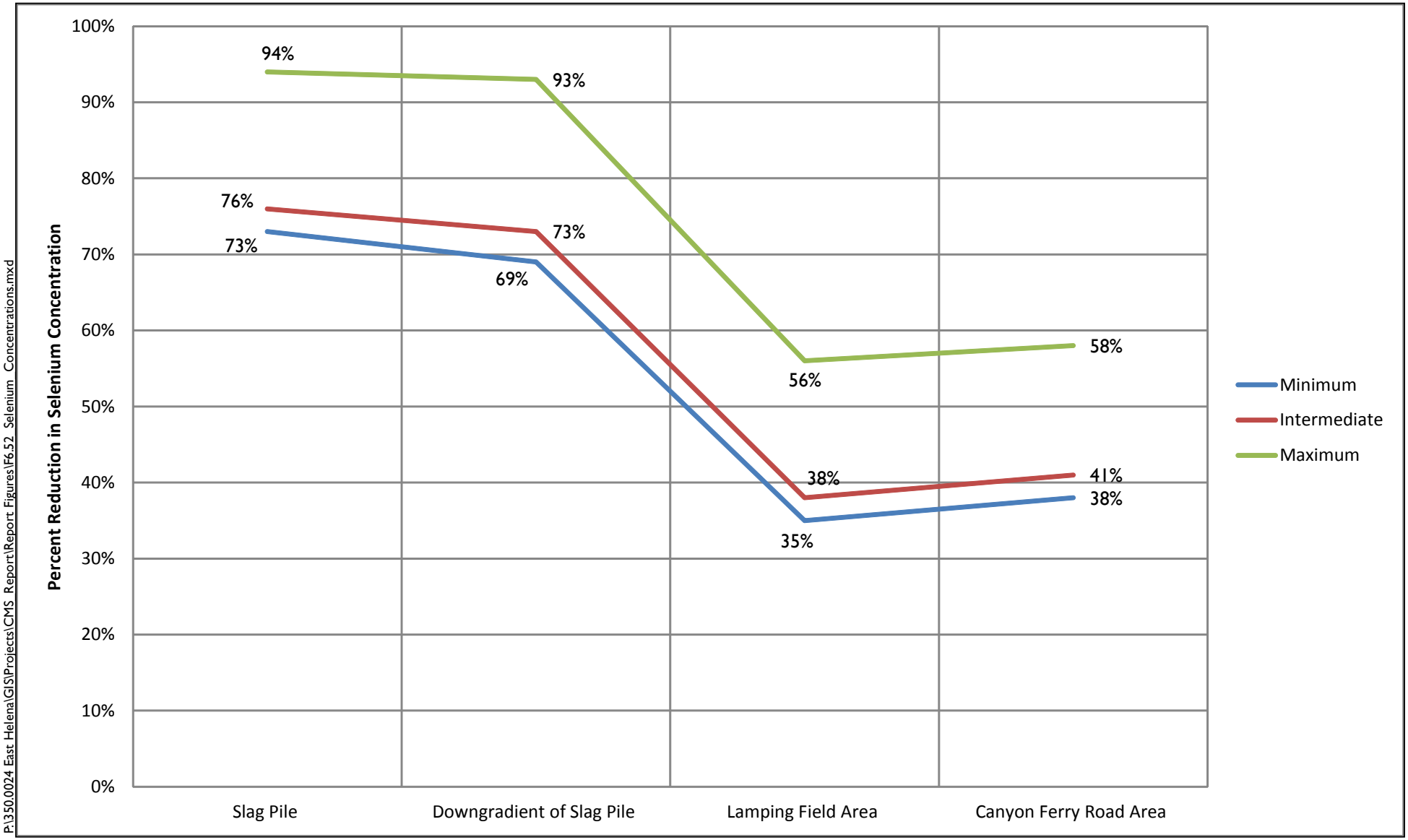
2) IM and 10% Slag Pile Recharge results show are predicted after 10 years.

3) Results are from NewFields (2016b).

Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3
- Monitoring Well
- Former Smelter Site Boundary

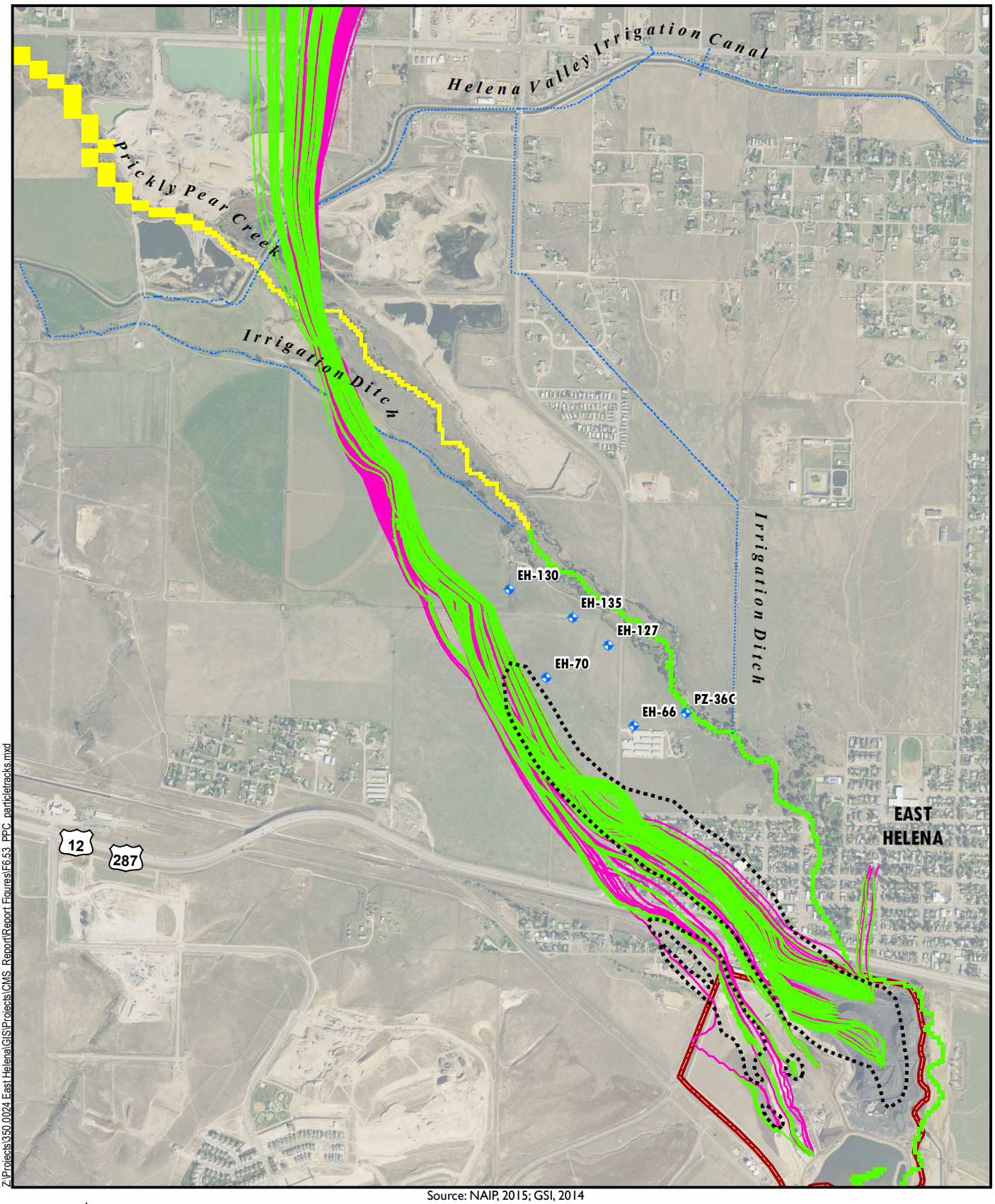
Predicted Selenium Isoconcentration Contours
IM and 10% Rechare in Slag Pile Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.51



Note: Results are from NewFields (2016b).

NewFields

Estimated Reduction in Selenium Concentrations for Slag Pile Cover Alternatives
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.52



Z:\Projects\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F6.53_PPC_particletracks.mxd

Source: NAIP, 2015; GSI, 2014

N

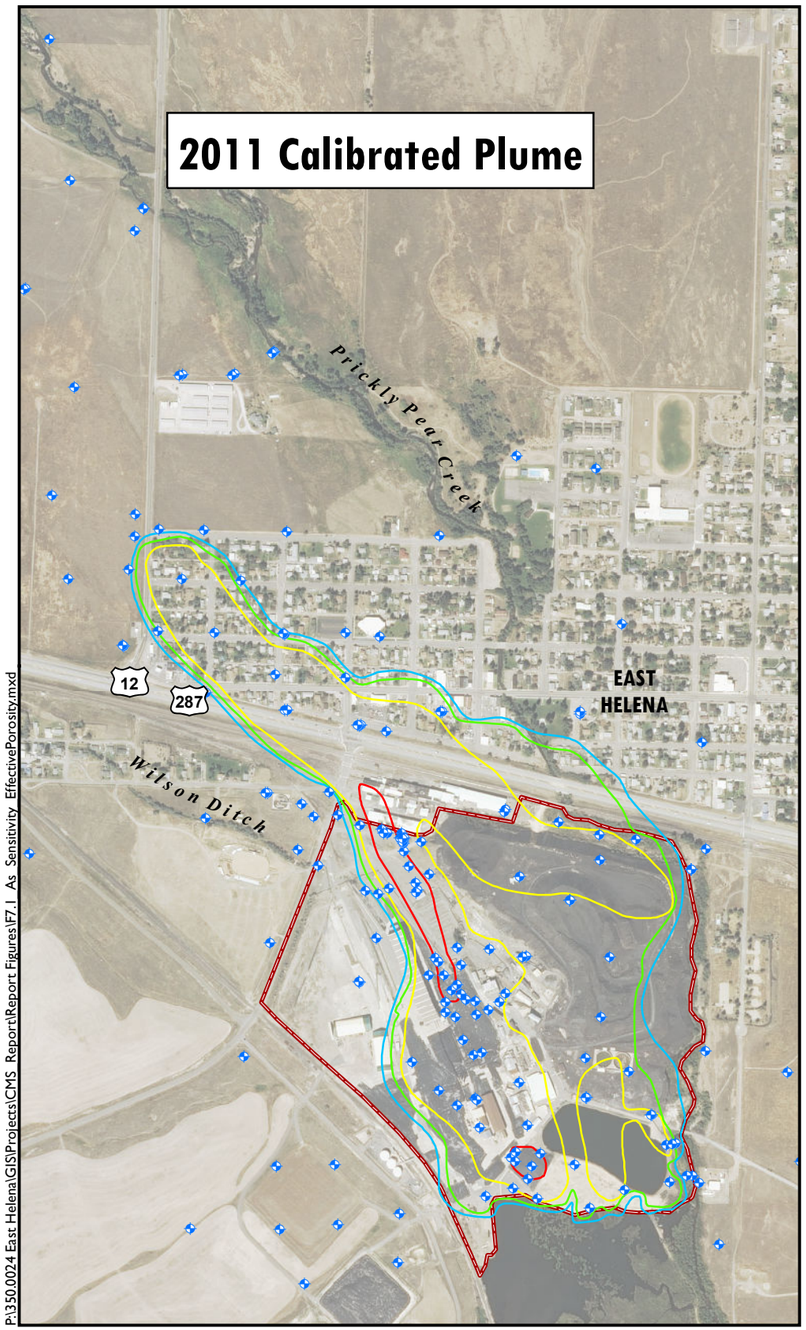
0 Feet 1,600

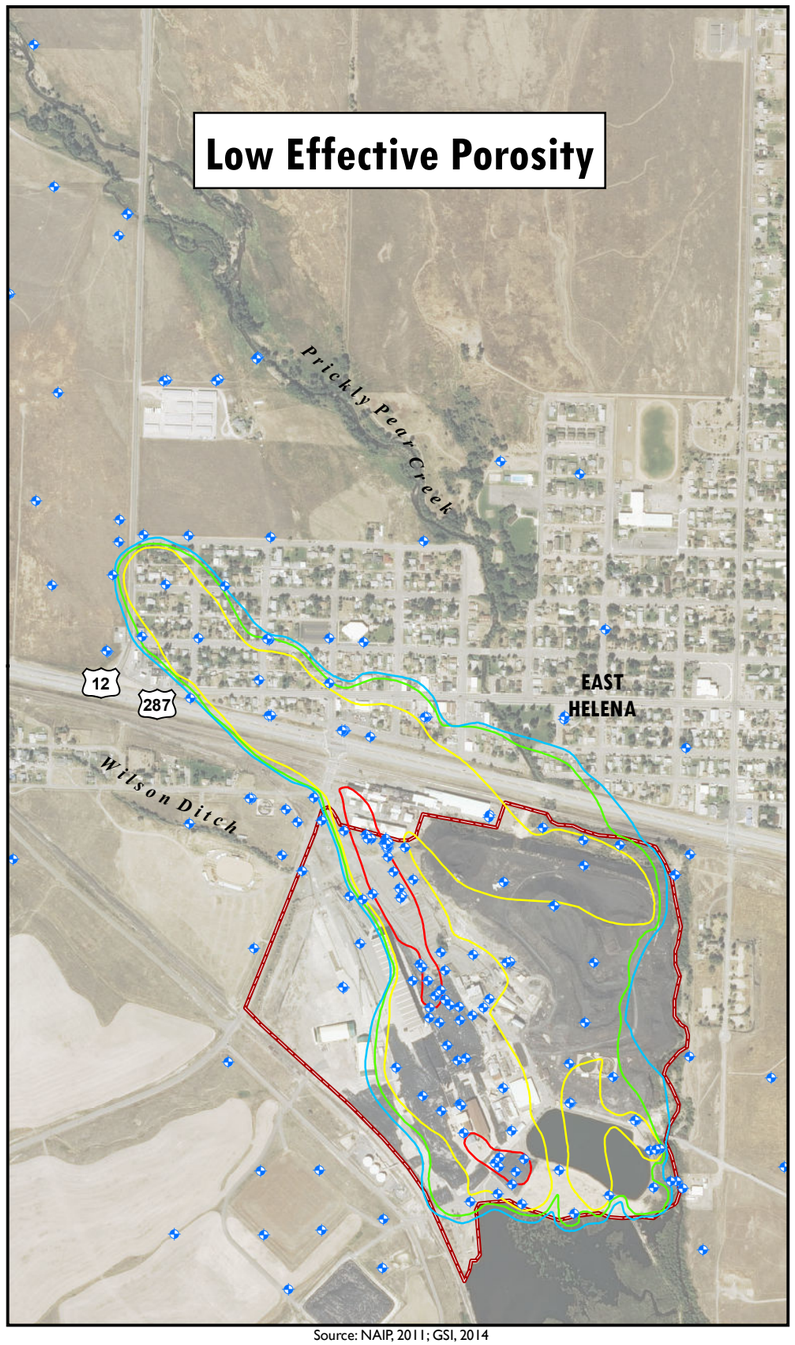
NewFields

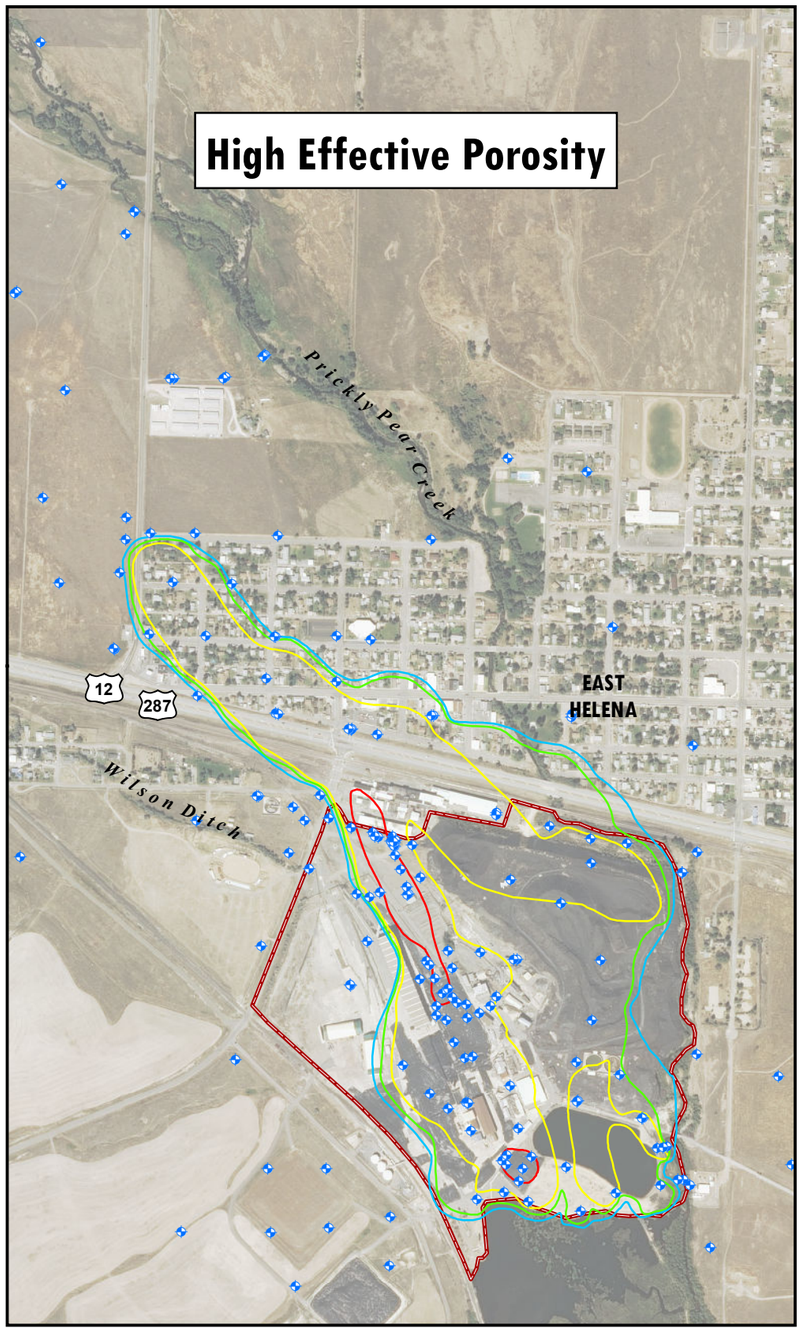
- Monitoring Well
- Prickly Pear Creek Predictive Particle Tracks
- 2014 Particle Tracks
- IM Predicted MCL Selenium Plume (NewFields, 2015)
- Drain Package Cell
- River Package Cell
- Former Smelter Site Boundary

Particle Track Results - Prickly Pear Creek Analysis
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 6.53

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.1 As Sensitivity EffectivePorosity.mxd







Source: NAIP, 2011; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

2) Effective Porosity was increased and decreased by 50 percent.

3) Results are from NewFields (2015a).

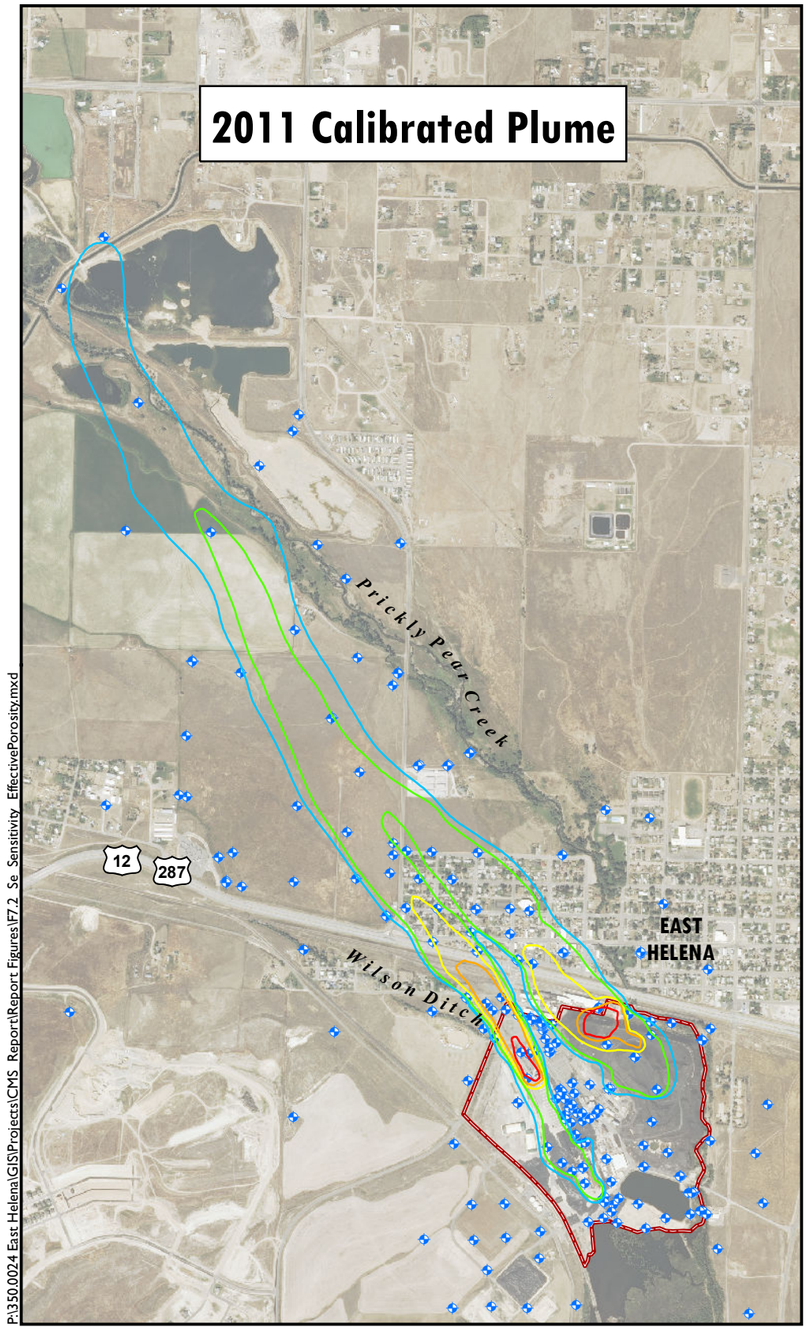
Isoconcentration Contour (mg/L)

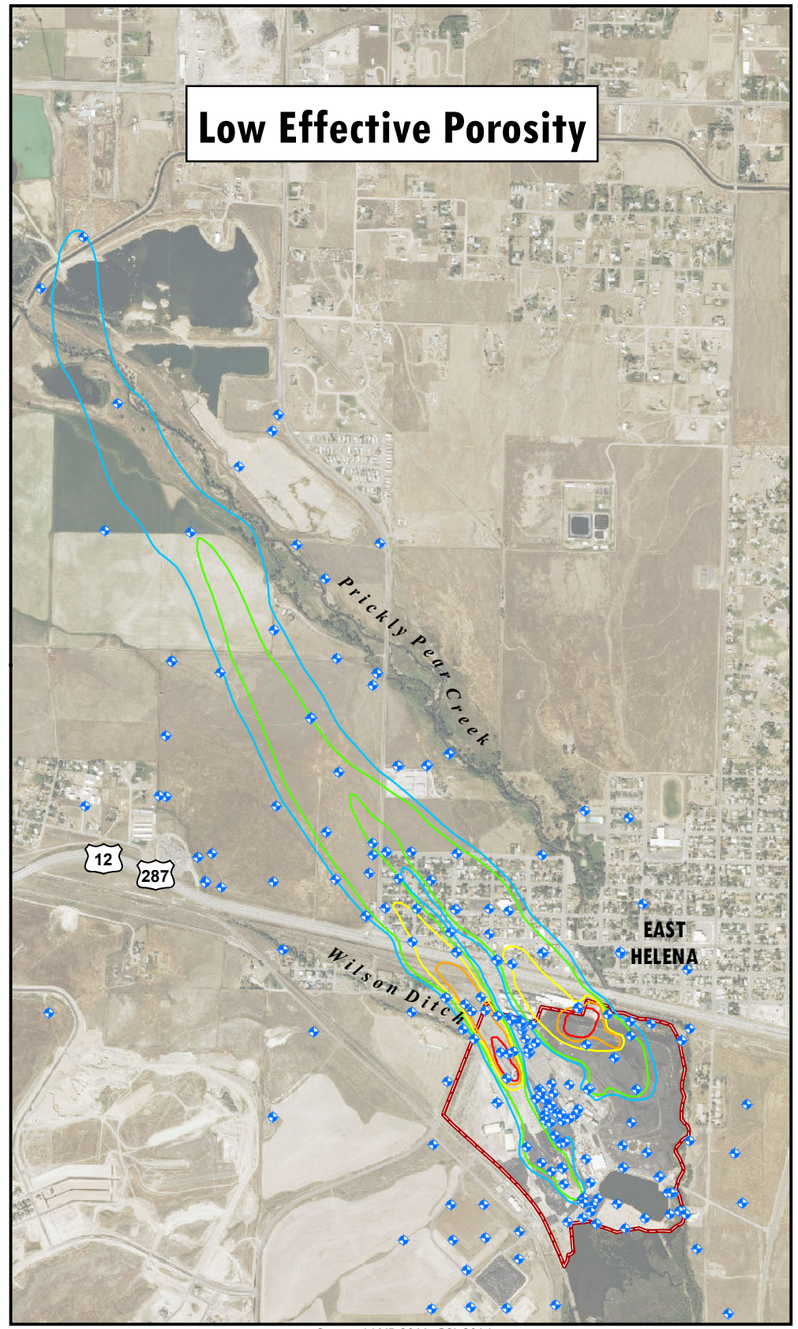
0.01 | 0.1 | 1 | > 20

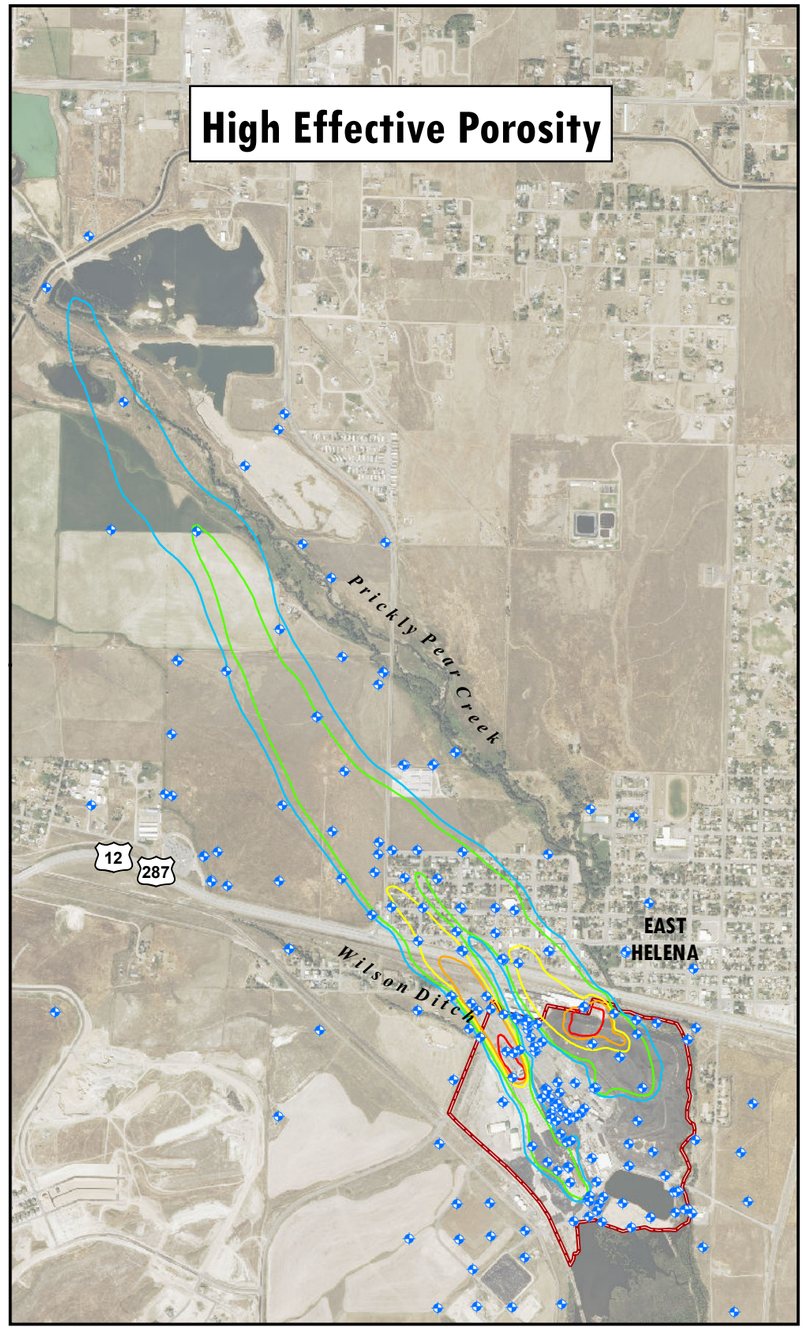
Monitoring Well

Former Smelter Site Boundary

Arsenic Sensitivity Analysis for Effective Porosity
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.1







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.2 Se Sensitivity EffectivePorosity.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 1,800

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

2) Effective porosity was increased and decreased by 50 percent.

3) Results are from NewFields (2015a).

Isoconcentration Contour (mg/L)

0.05 — 0.1 — 0.5 — 1 — > 3

Monitoring Well

Former Smelter Site Boundary

Selenium Sensitivity Analysis for Effective Porosity
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.2

2011 Calibrated Plume

Reduced Saturated Sources

Increased Saturated Sources

Prickly Pear Creek

Wilson Ditch

EAST HELENA

12

287

P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.3 As Sensitivity SaturatedSources.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

2) Saturated sources were increased and decreased by 50 percent.

3) Results are from NewFields (2015a).

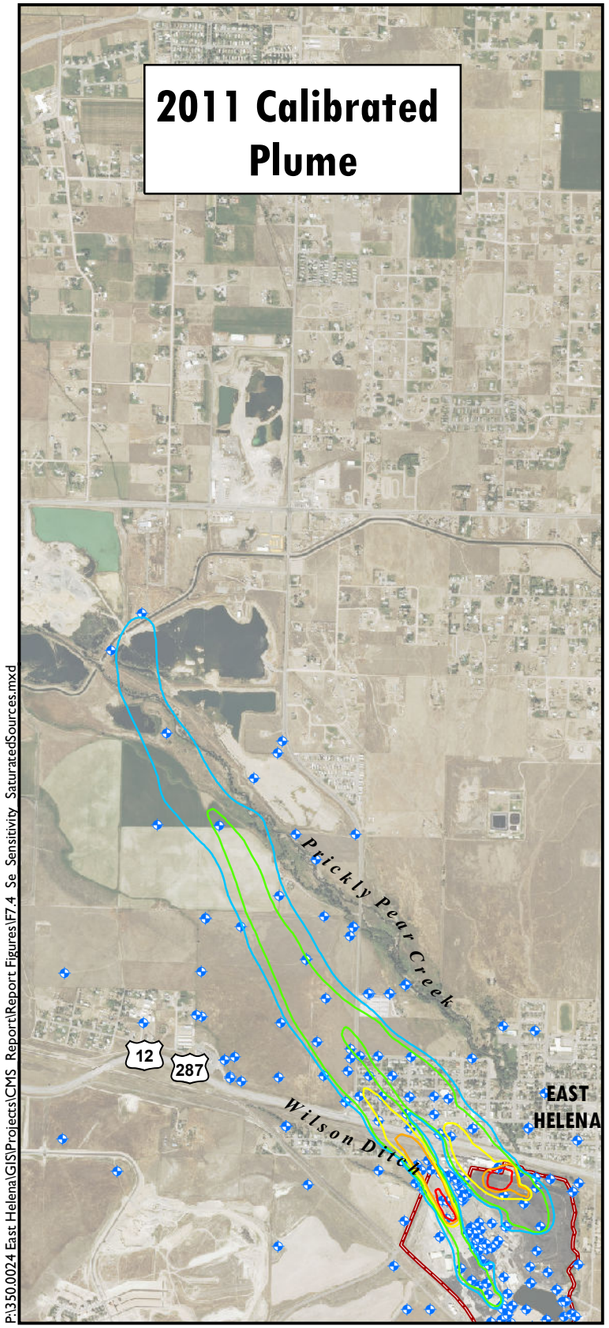
Isoconcentration Contour (mg/L)

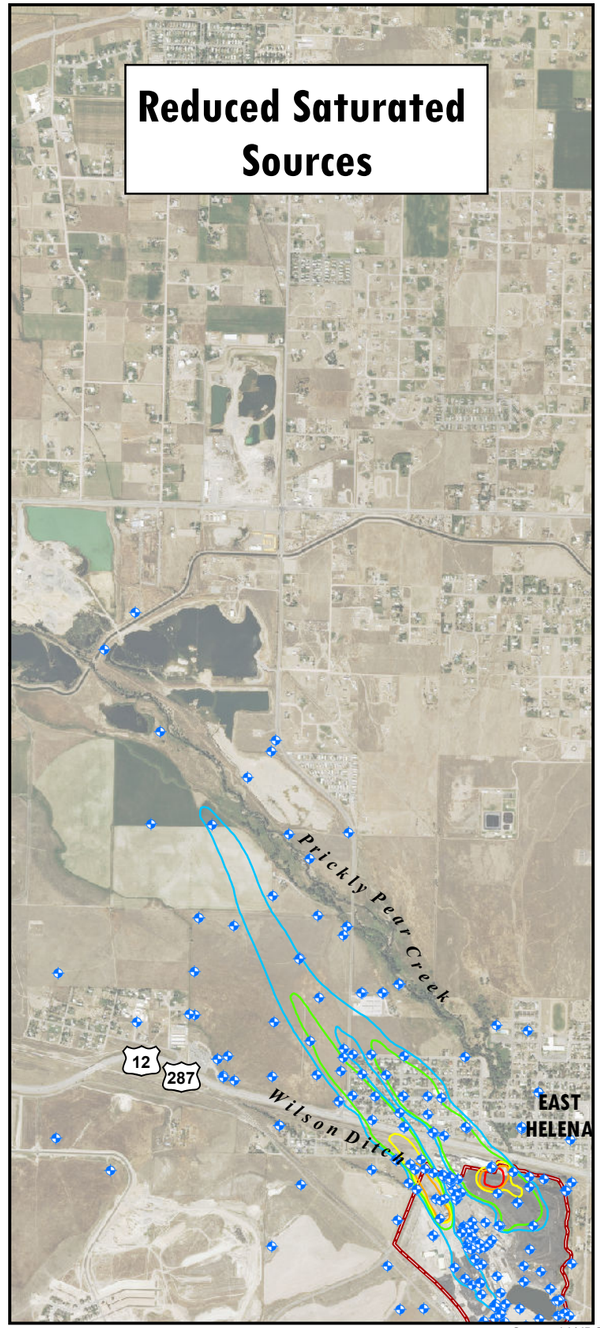
0.01 — 1 — 0.1 — > 20

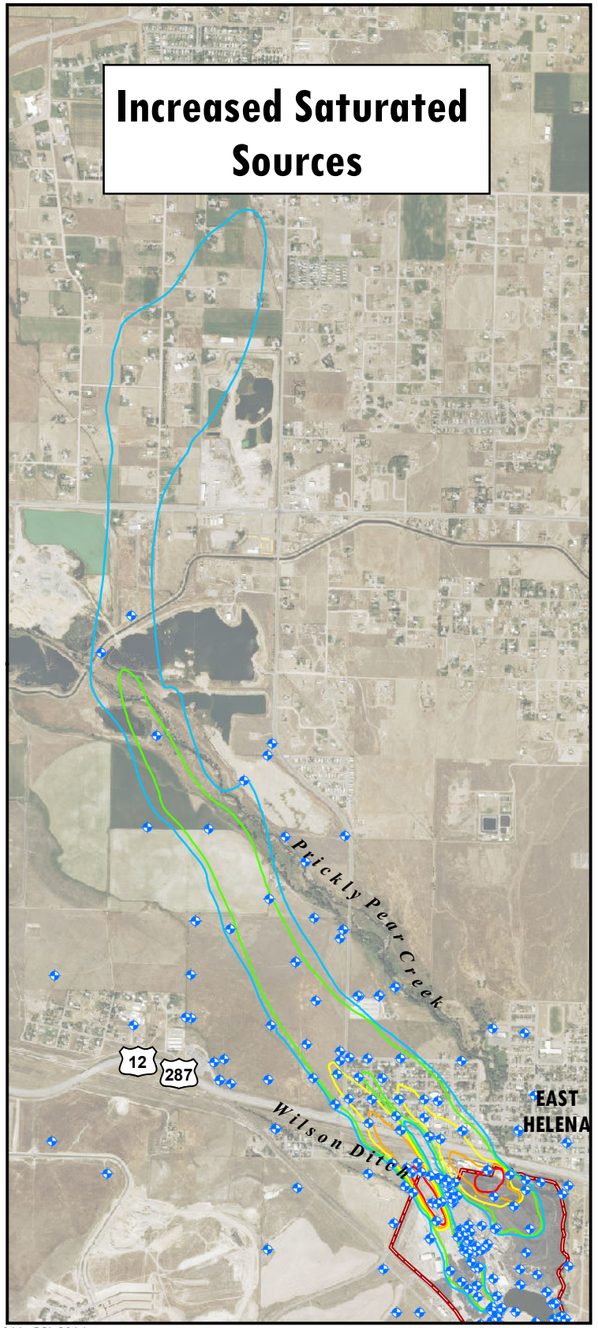
Monitoring Well

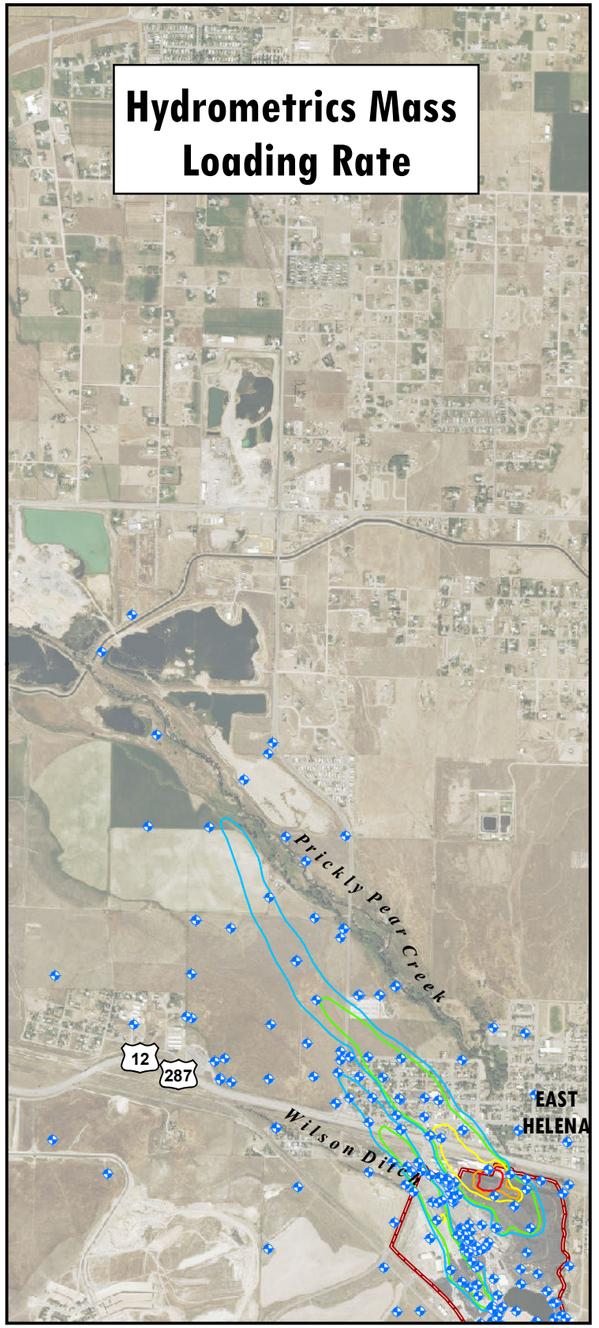
Former Smelter Site Boundary

Arsenic Sensitivity Analysis for Satutated Source Mass Loading Rates
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.3









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.4 Se Sensitivity SaturatedSources.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 2,500

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

2) Saturated sources were increased and decreased by 50 percent.

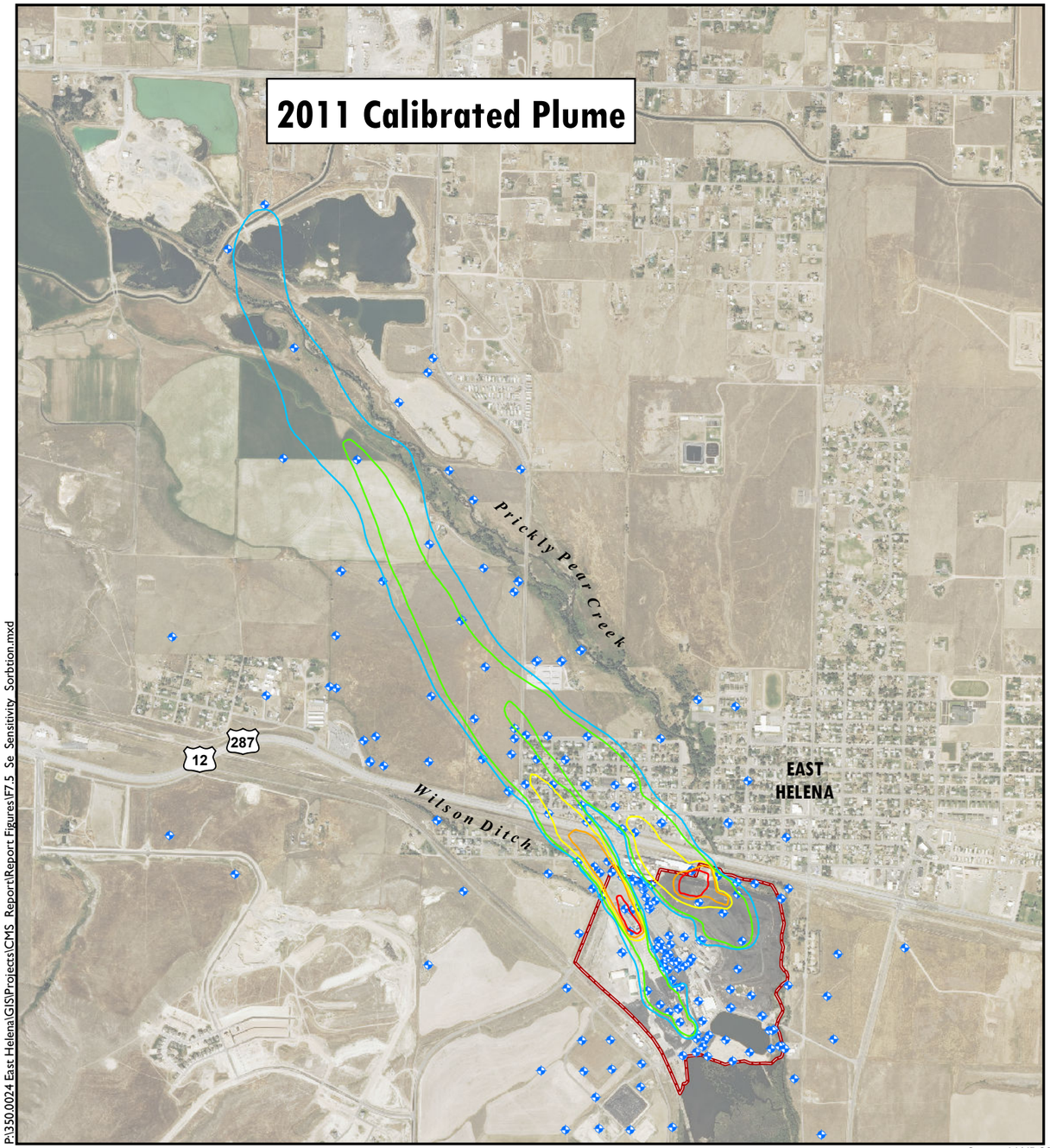
3) The Hydrometrics mass loading rate for the West Selenium area was approximately one order of magnitude less that the 2011 calibrated rate.

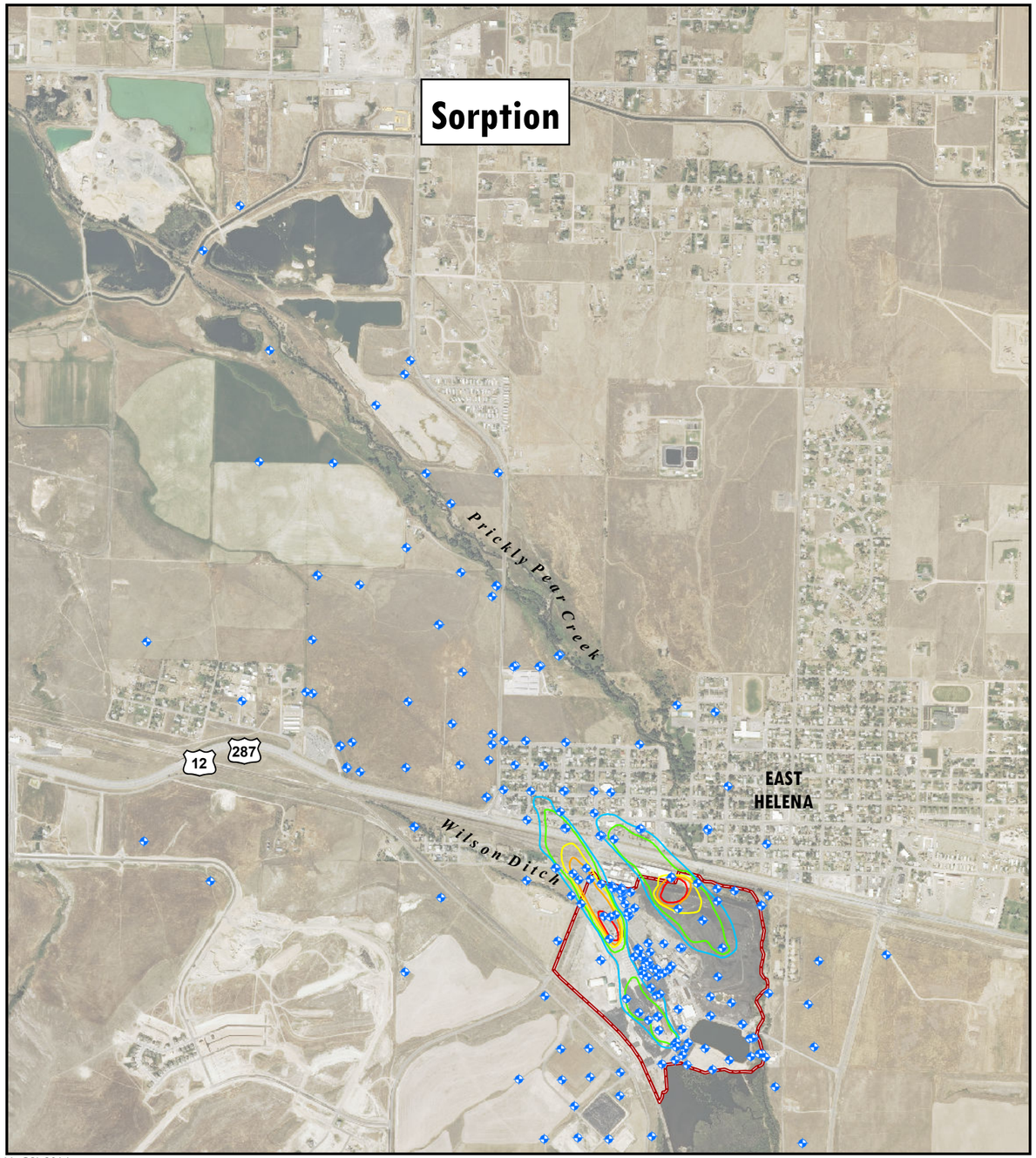
4) Results are form NewFields (2015a).

Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3
- Monitoring Well
- Former Smelter Site Boundary

Selenium Sensitivity Analysis for Saturated Source Mass Loading Rates
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.4





P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.5 Se Sensitivity Sorbtion.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 1,800

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

2) A sorption coefficient of 5 liters per kilorgam was used for the sorption simulation.

3) Results are from NewFields (2015a).

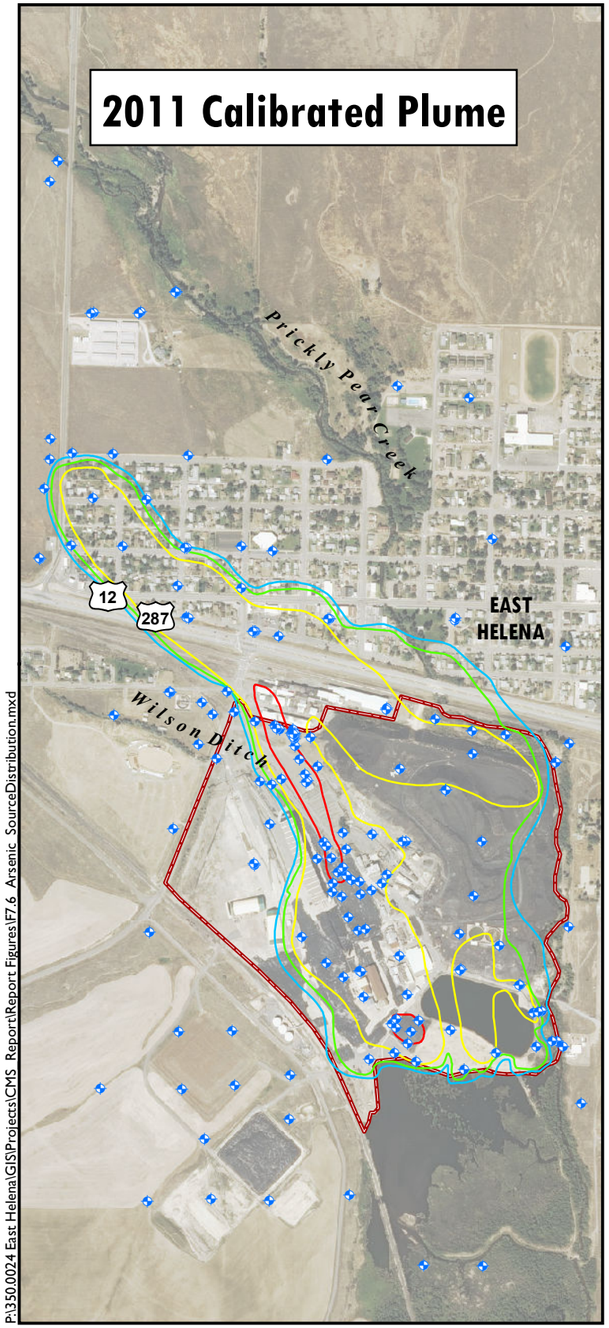
Isoconcentration Contour (mg/L)

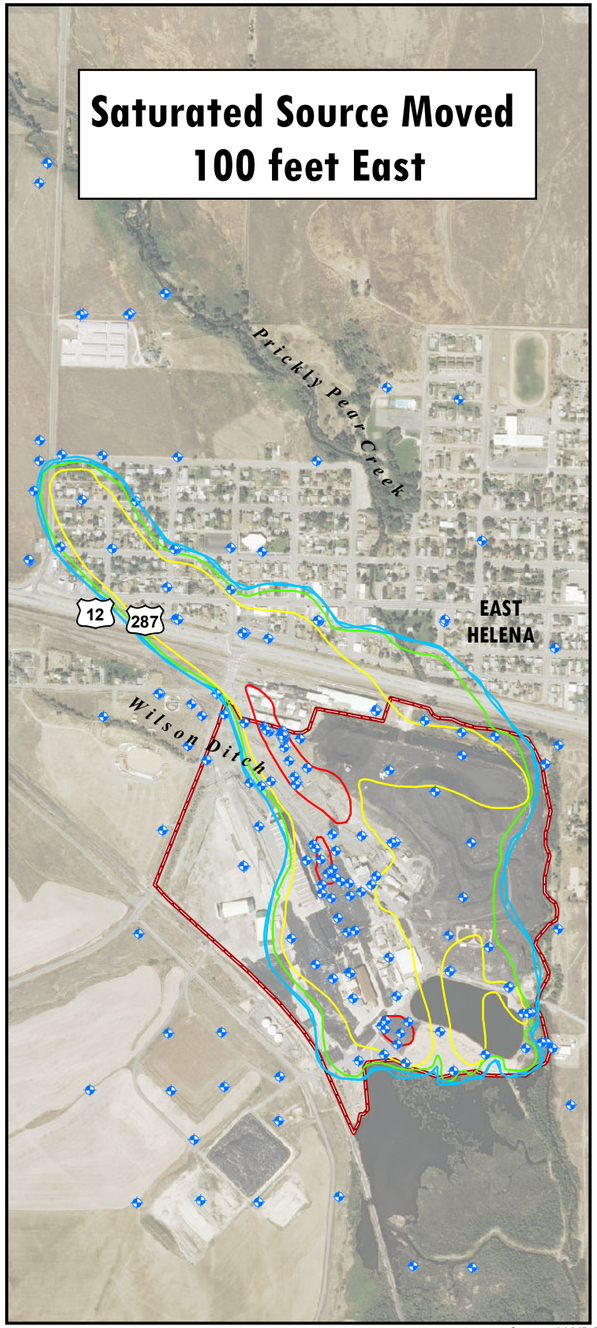
0.05 — 1 — Monitoring Well

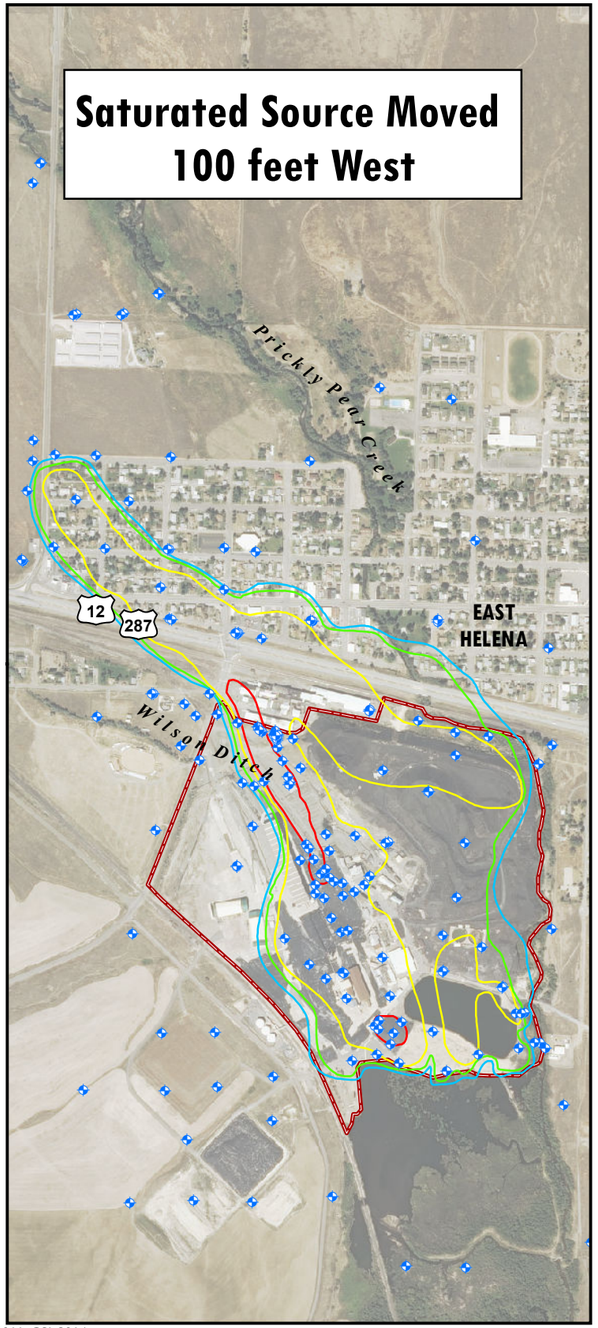
0.1 — > 3 — Former Smelter Site Boundary

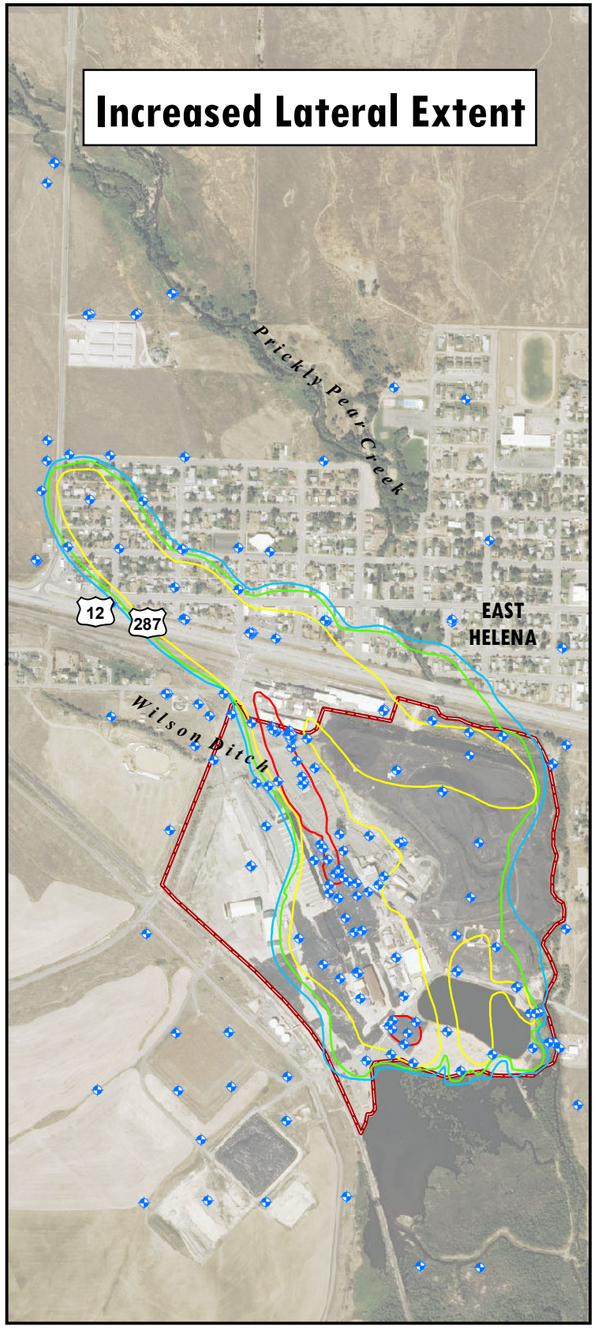
0.5

Selenium Sensetivity Analysis for Sorption
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.5









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.6 Arsenic SourceDistribution.mxd

Source: NAIP, 2011; GSI, 2014

Isoconcentration Contour (mg/L)

0.01 — 1 — 0.1 — > 20

Monitoring Well

Former Smelter Site Boundary

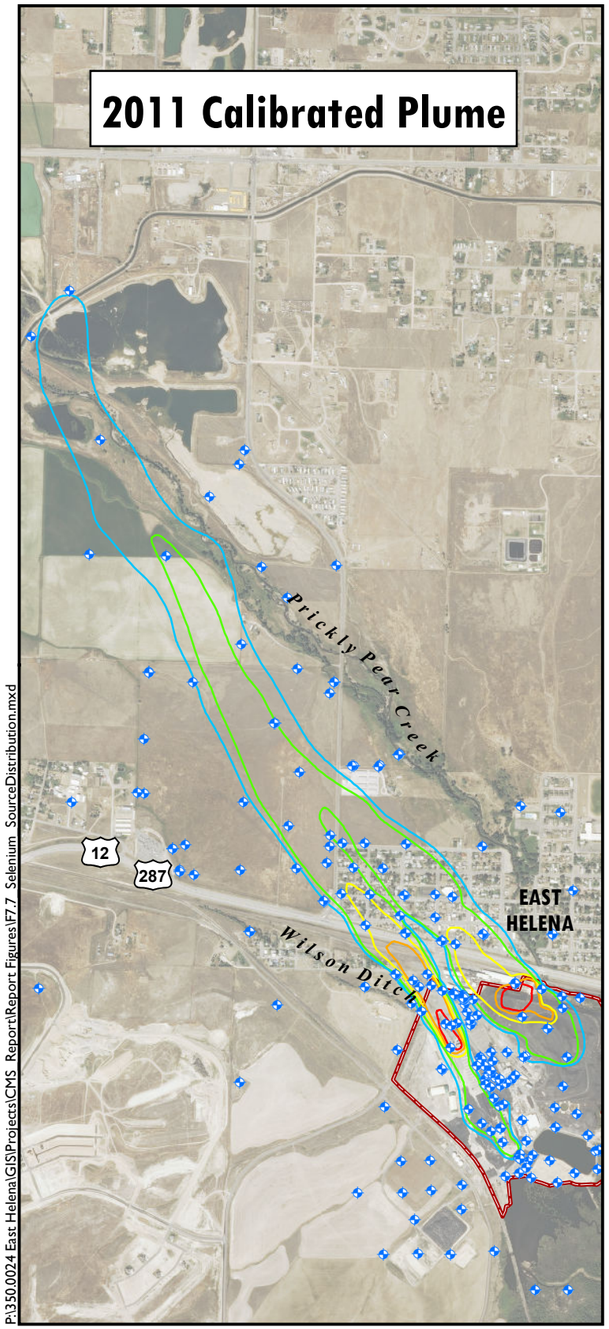
0 Feet 1,100

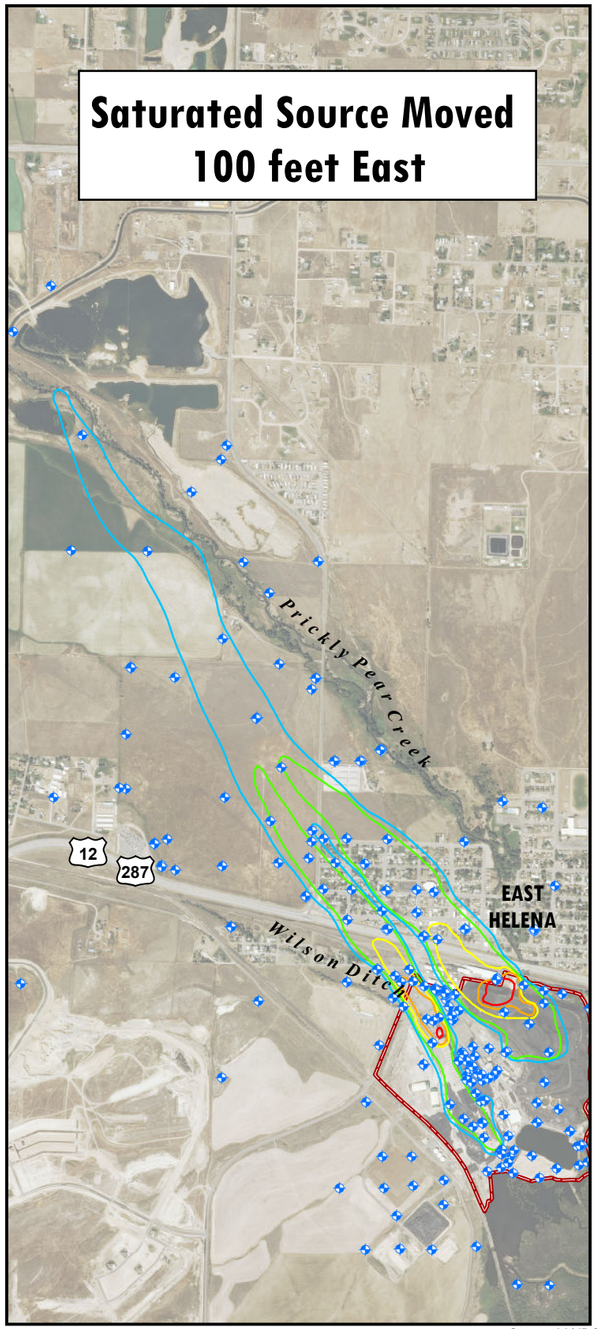
NewFields

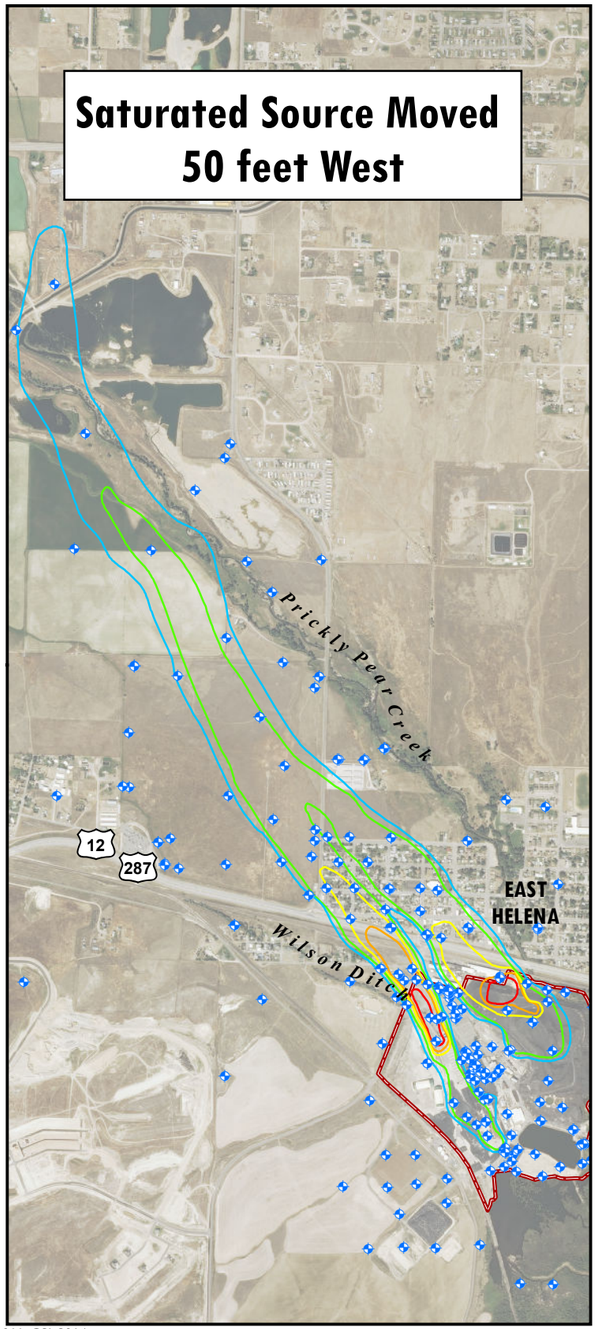
Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

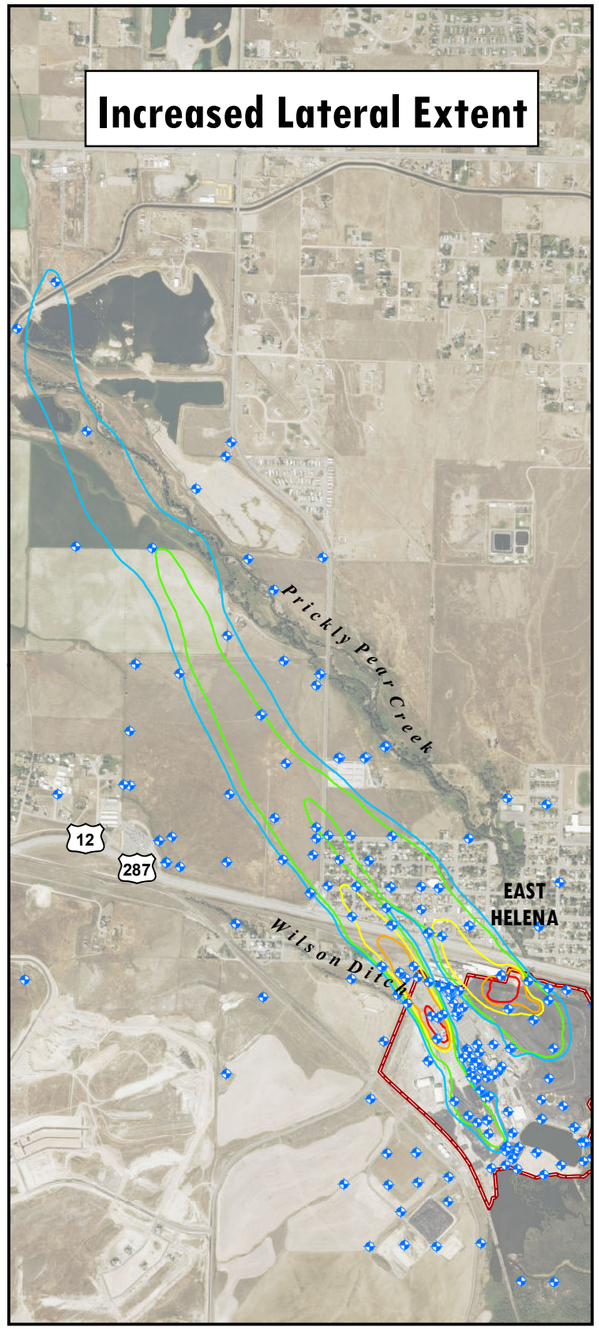
2) Results are from NewFields (2015a).

Sensitivity Analysis for Arsenic Source Distribution
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.6









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.7 Selenium SourceDistribution.mxd

Source: NAIP, 2011; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plume represents a composite of model layers 1, 2, and 3.

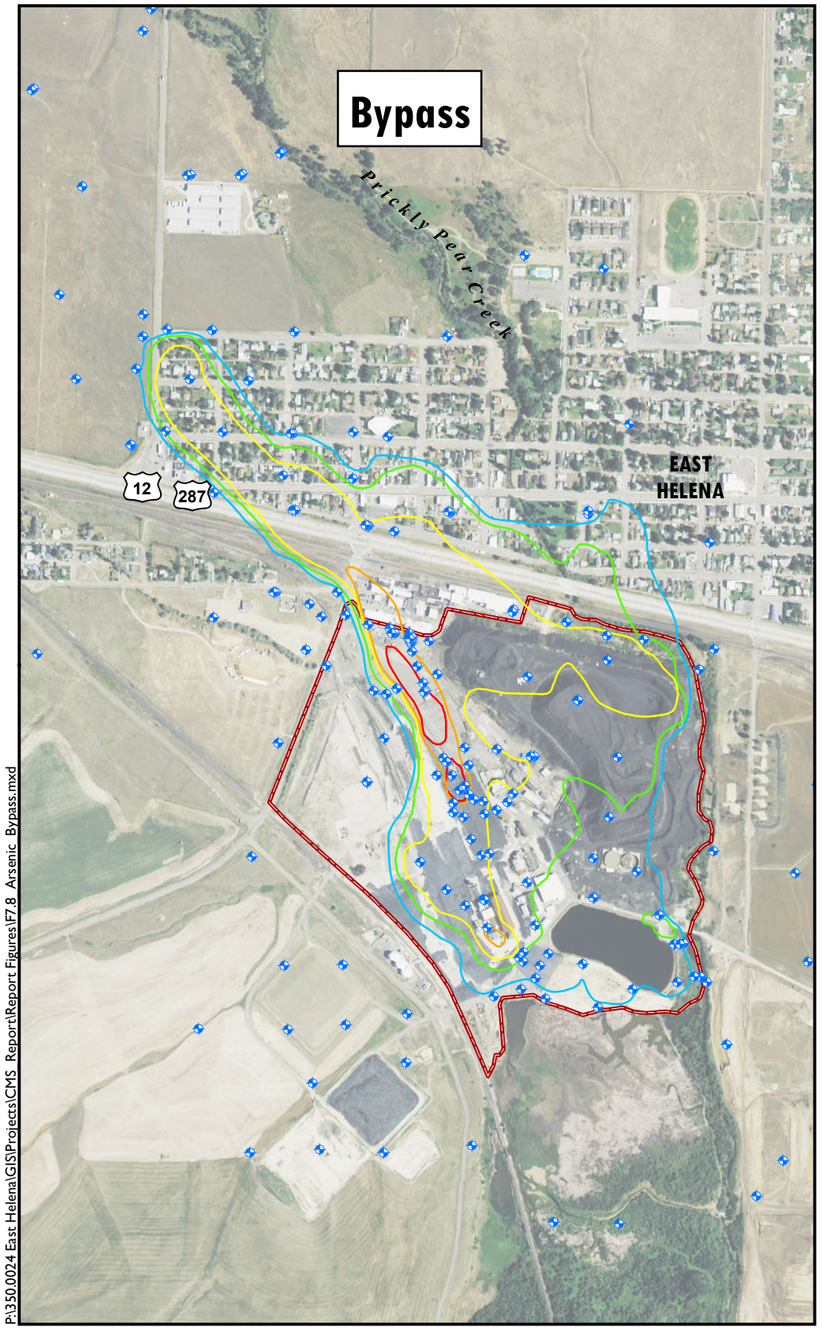
2) Results are from NewFields (2015a).

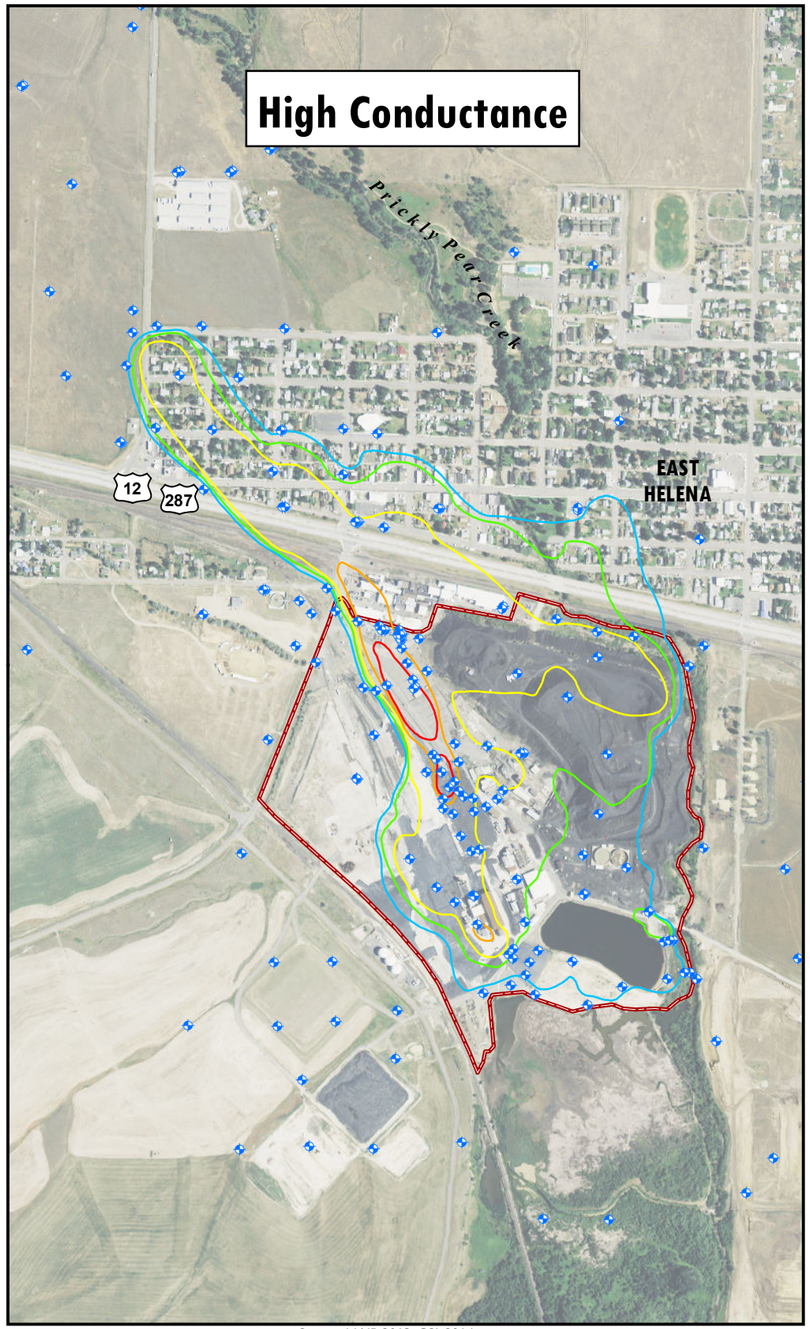
Isoconcentration Contour (mg/L)

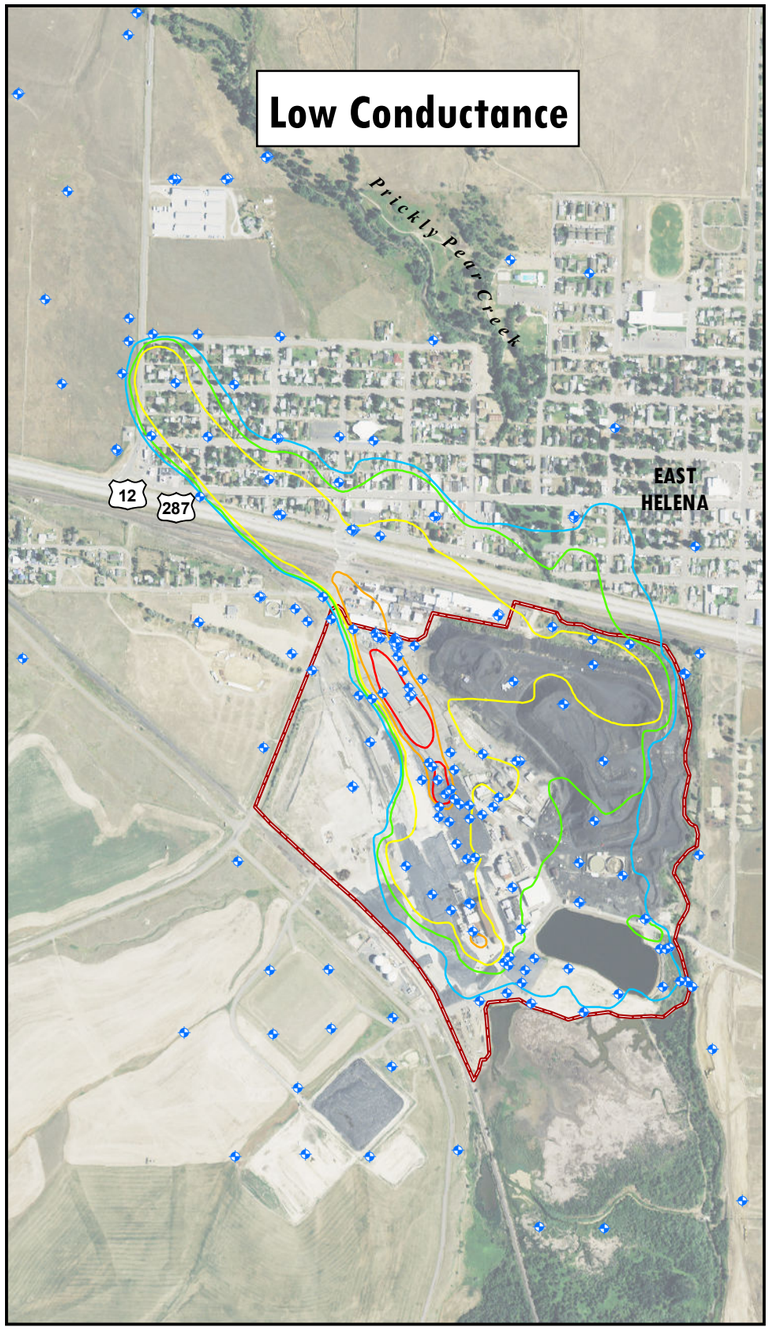
- 0.05
- 0.1
- 0.5
- 1
- > 3

- Monitoring Well
- Former Smelter Site Boundary

Sensitivity Analysis for Selenium Source Distribution
Selenium Slurry Wall Simulations
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.7







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.8 Arsenic Bypass.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predicted results depict concentratins after model has reached steady-state.

3) Bypass conductance was increased and decreased by 50 percent.

4) Results are from NewFields (2015b).

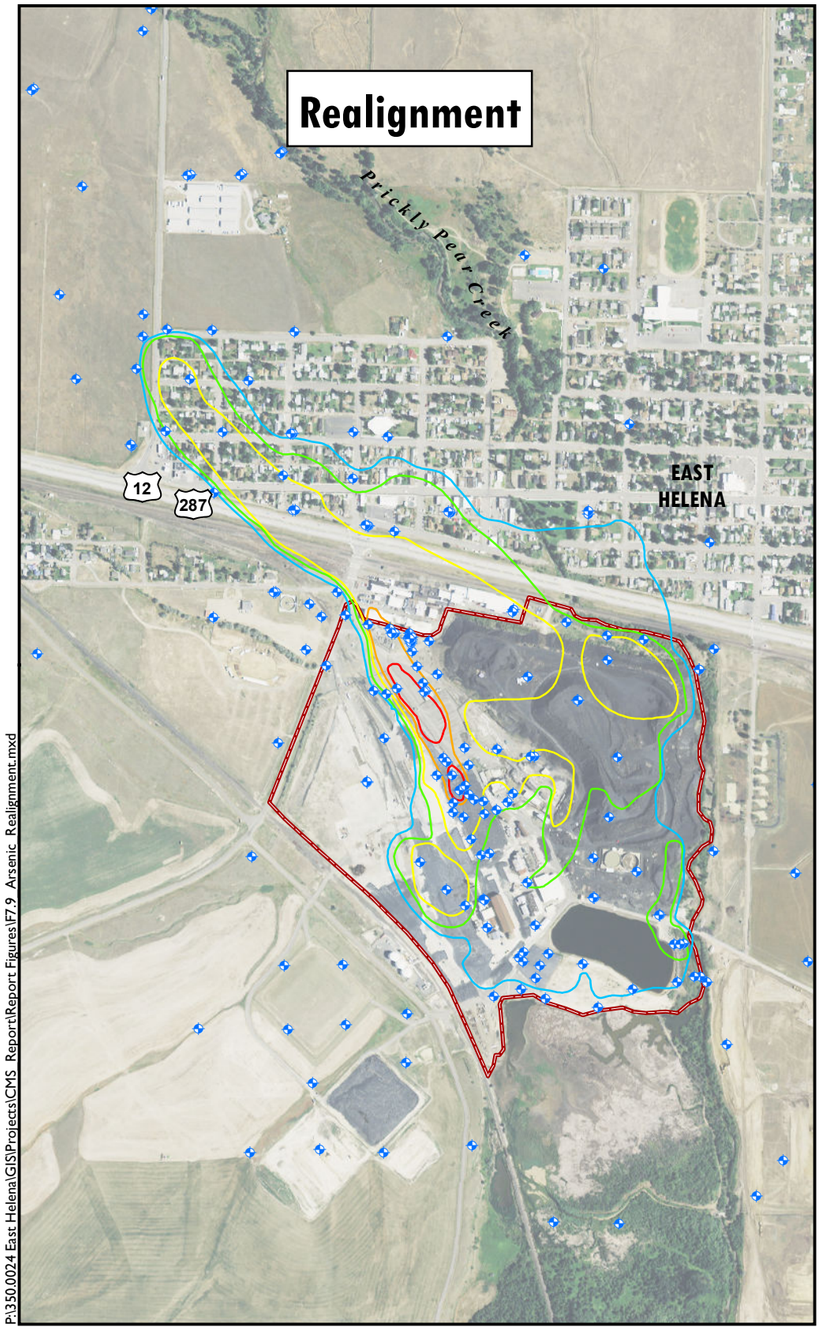
Isoconcentration Contour (mg/L)

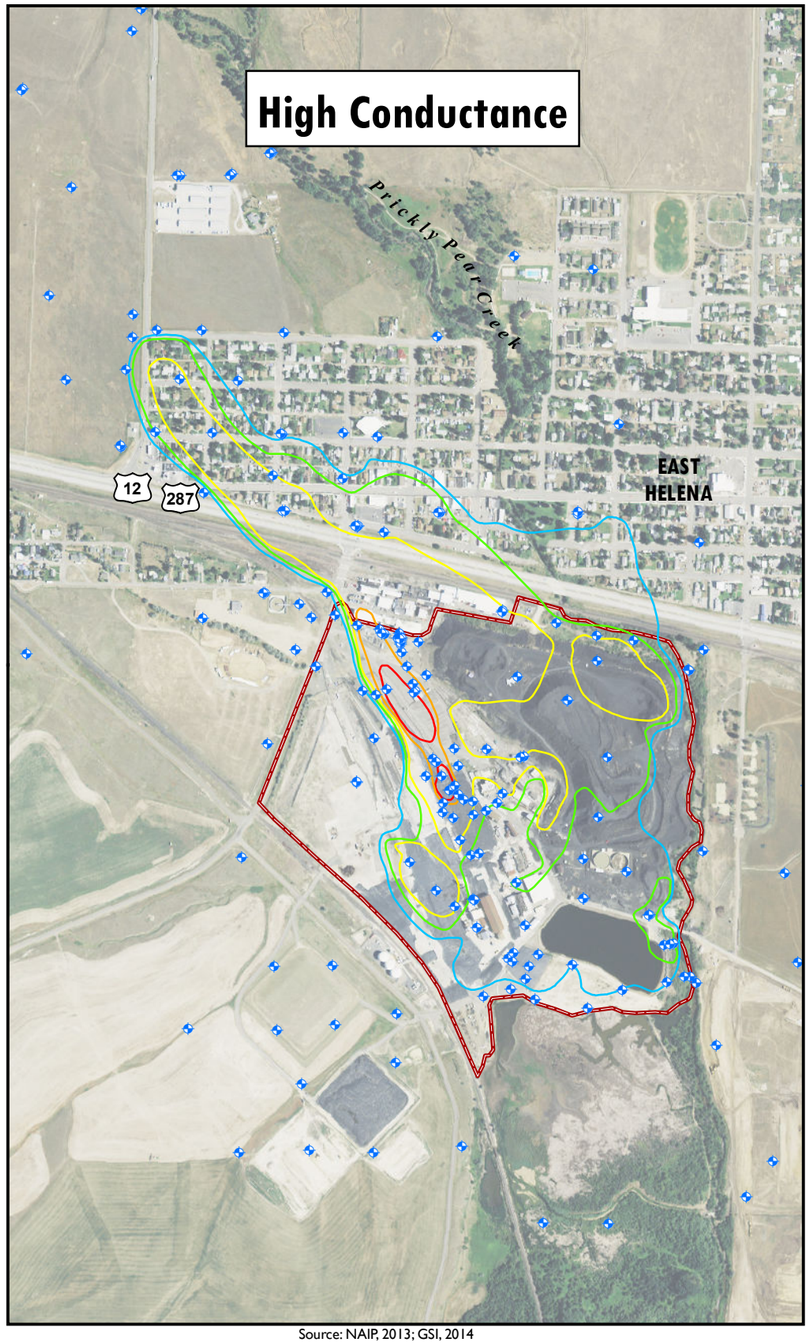
- 0.01
- 0.1
- 1
- 10
- > 20

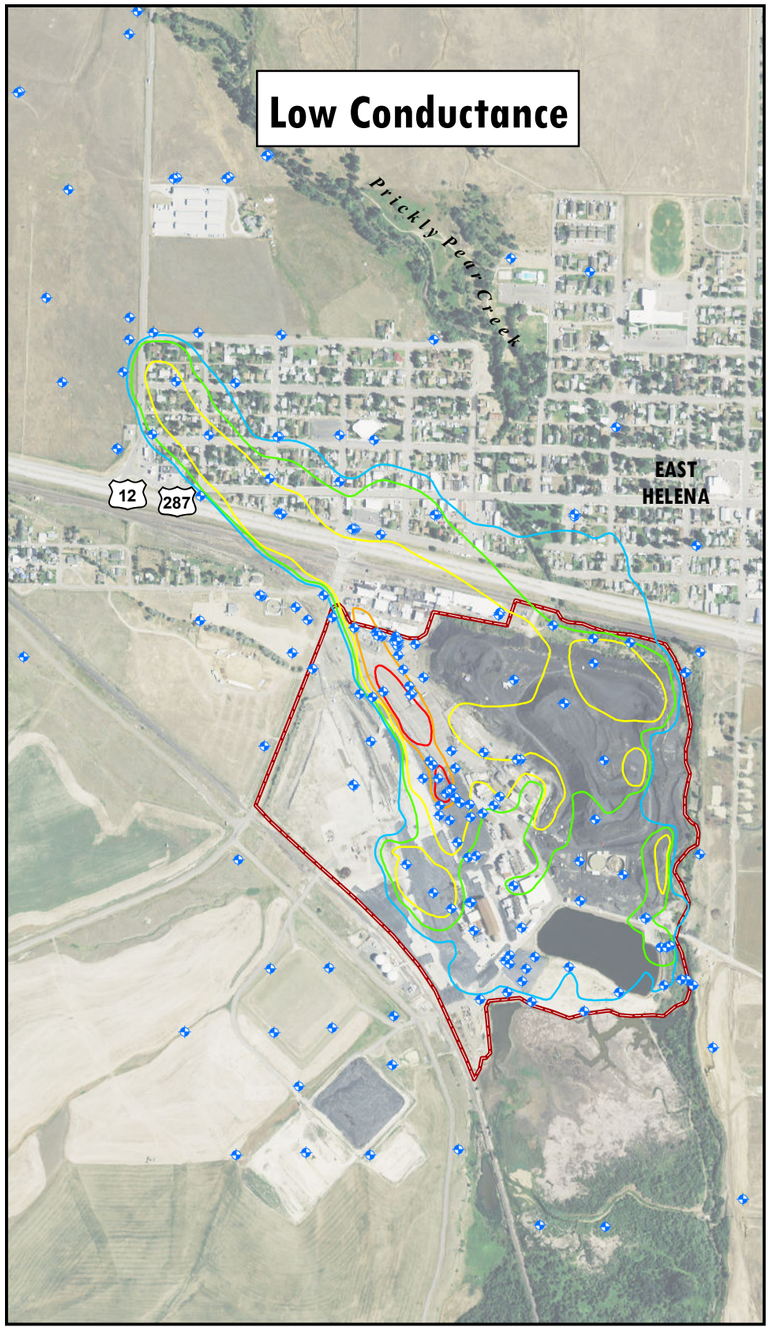
Monitoring Well

Former Smelter Site Boundary

Arsenic Sensitivity Analysis for Bypass Conductance
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.8







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.9 Arsenic Realignment.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predicted results depict concentrations after model has reached steady-state.

3) Realignment conductance was increased and decreased by 50 percent.

4) Results are from NewFields (2015b).

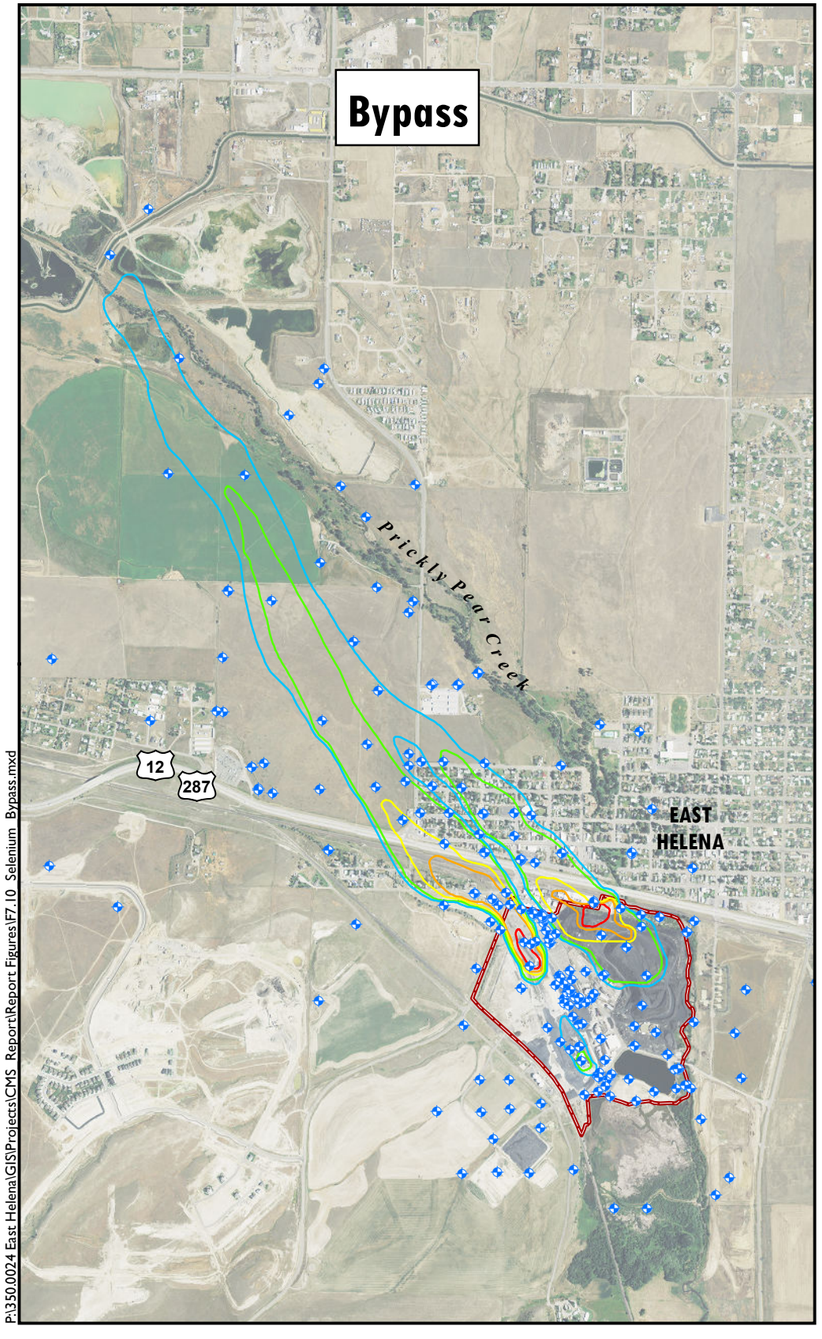
Isoconcentration Contour (mg/L)

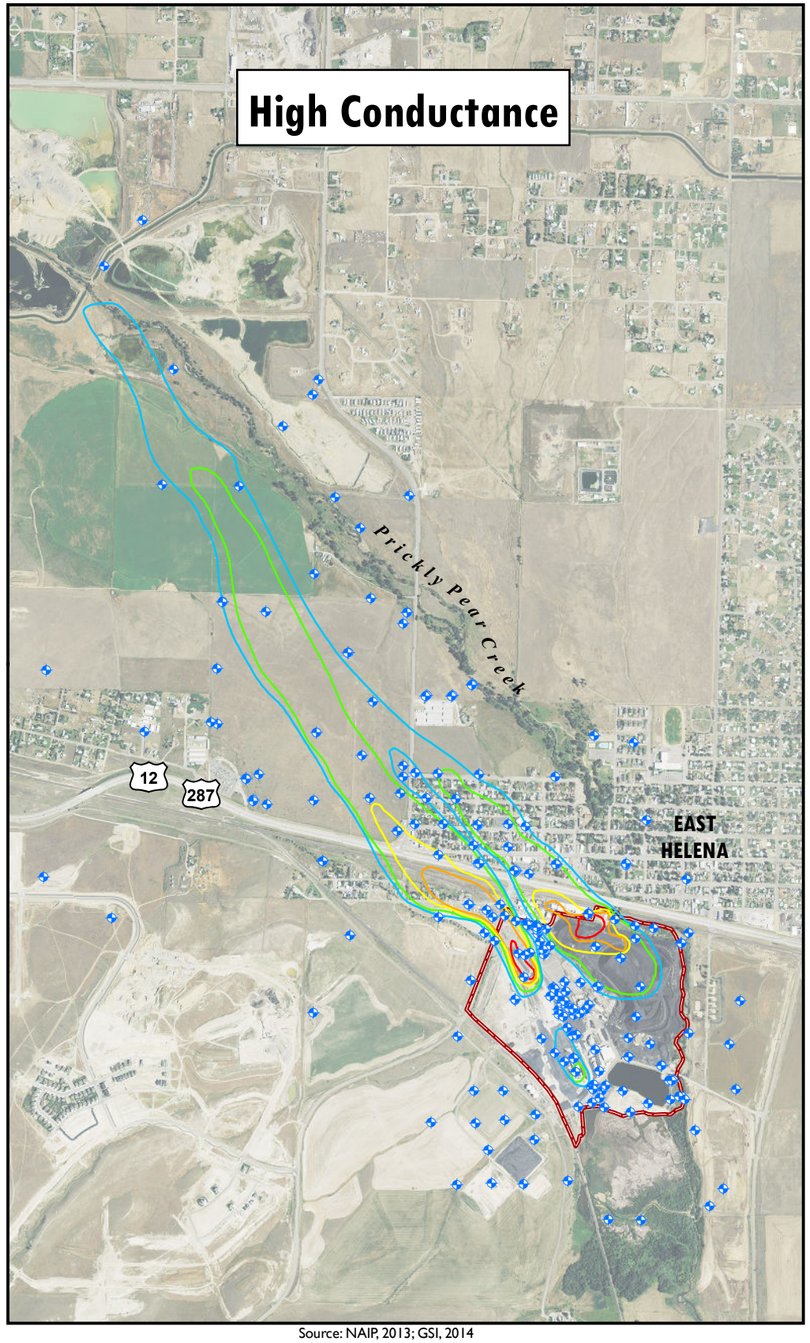
- 0.01
- 0.1
- 1
- 10
- > 20

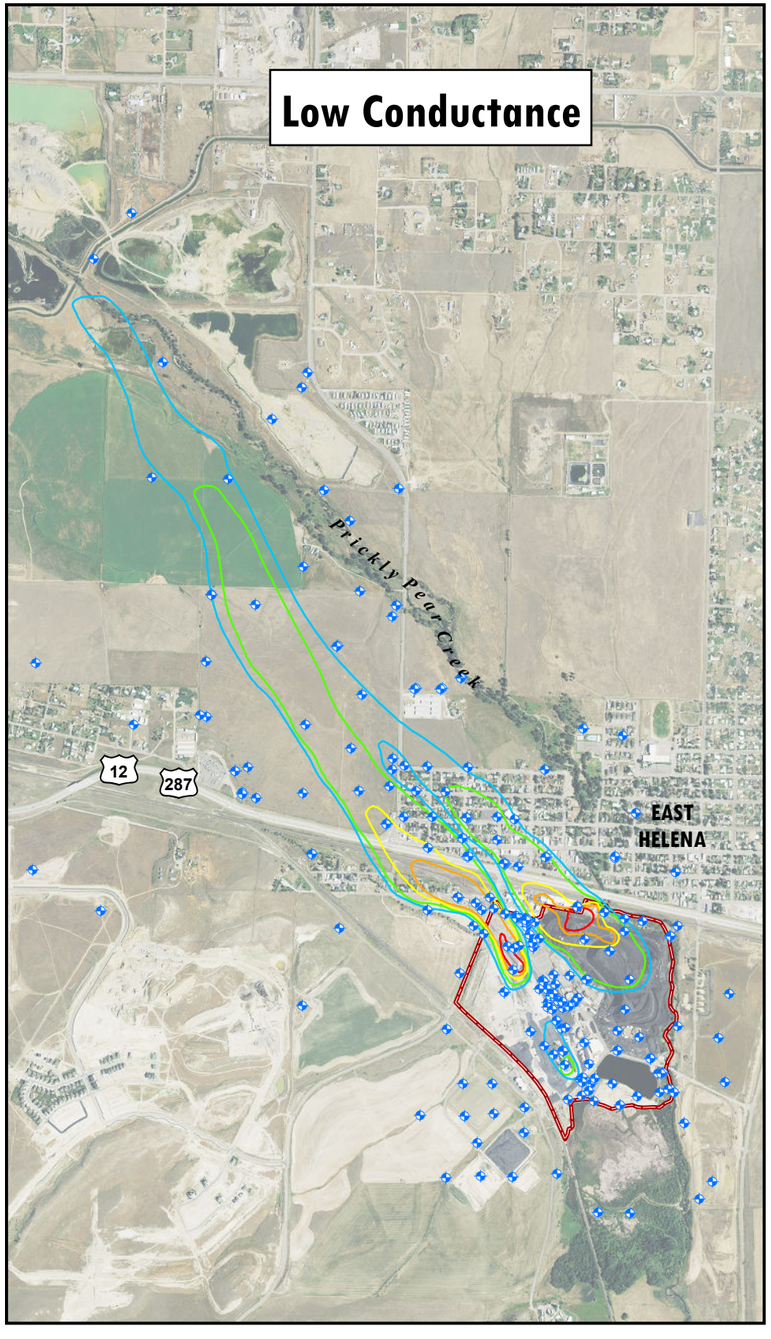
Monitoring Well

Former Smelter Site Boundary

Arsenic Sensitivity Analysis for Realignment Conductance
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.9







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.10 Selenium Bypass.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predicted results depict concentratins after model has reached steady-state.

3) Bypass conductance was increased and decreased by 50 percent.

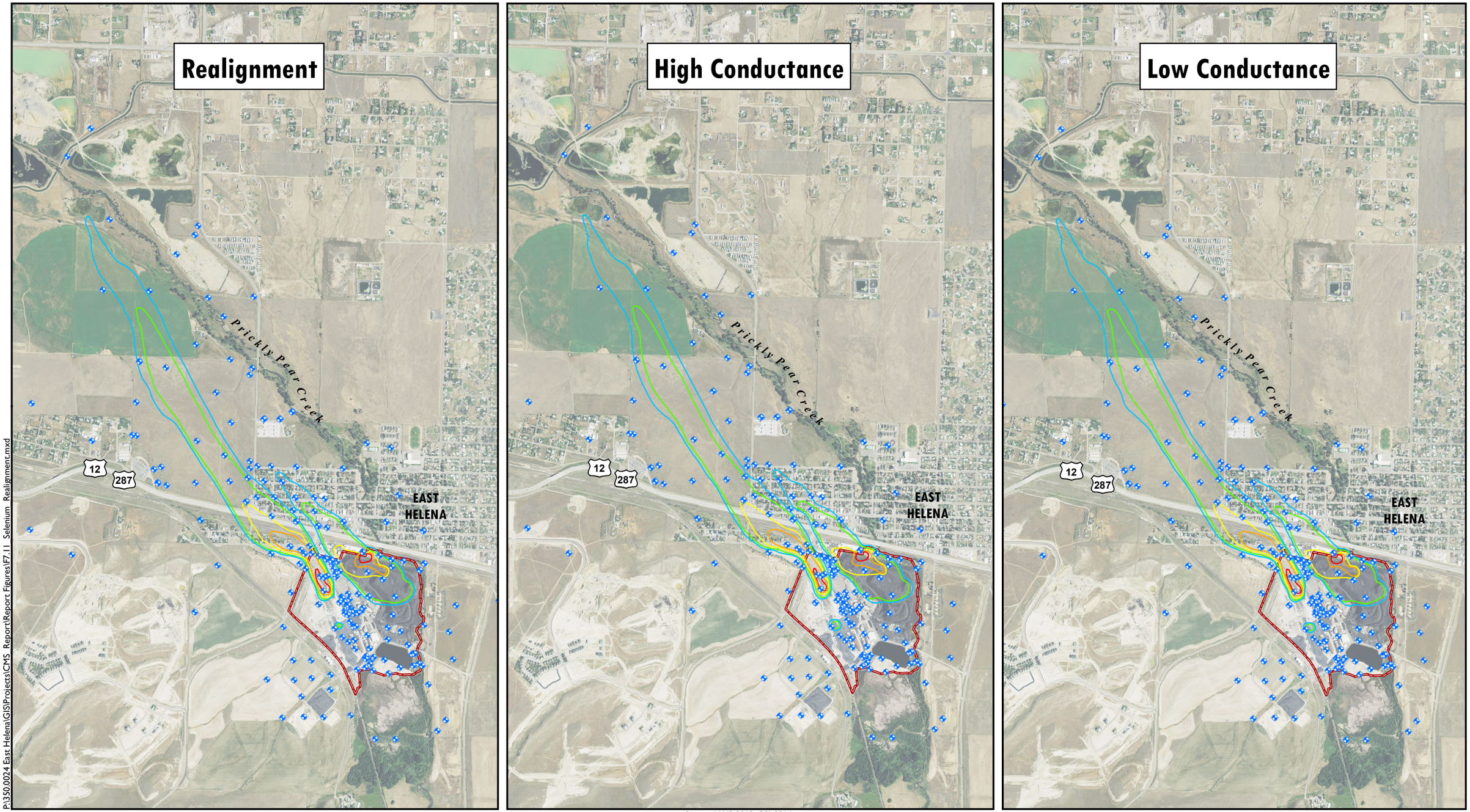
4) Results are from NewFields (2015b).

Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3

- Monitoring Well
- Former Smelter Site Boundary

Selenium Sensitivity Analysis for Bypass Conductance
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.10



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.11 Selenium Realignment.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predicted results depict concentratins after model has reached steady-state.

3) Realignment conductance was increased and decreased by 50 percent.

4) Results are from NewFields (2015b).

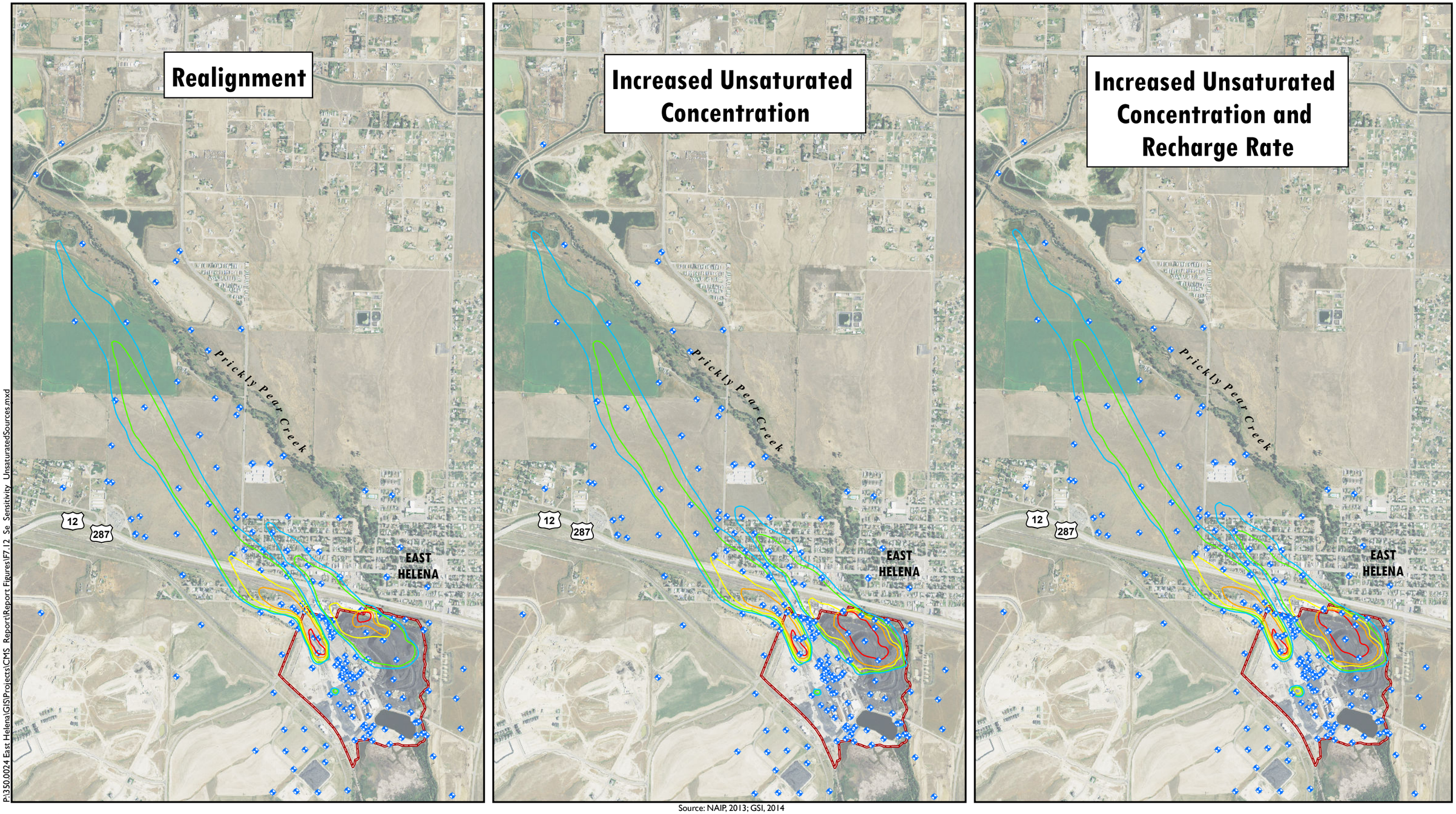
Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3

Monitoring Well

Former Smelter Site Boundary

Selenium Sensitivity Analysis for Realignment Conductance
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.11



P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.12 Se Sensitivity UnsaturatedSources.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,800

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predicted results depict concentratins after model has reached steady-state.

3) Unsaturated source area concentrations were increased by one order-of-magnitude.

4) The recharge rate in the central plant site area was increased to 10 percent of annual precipitation.

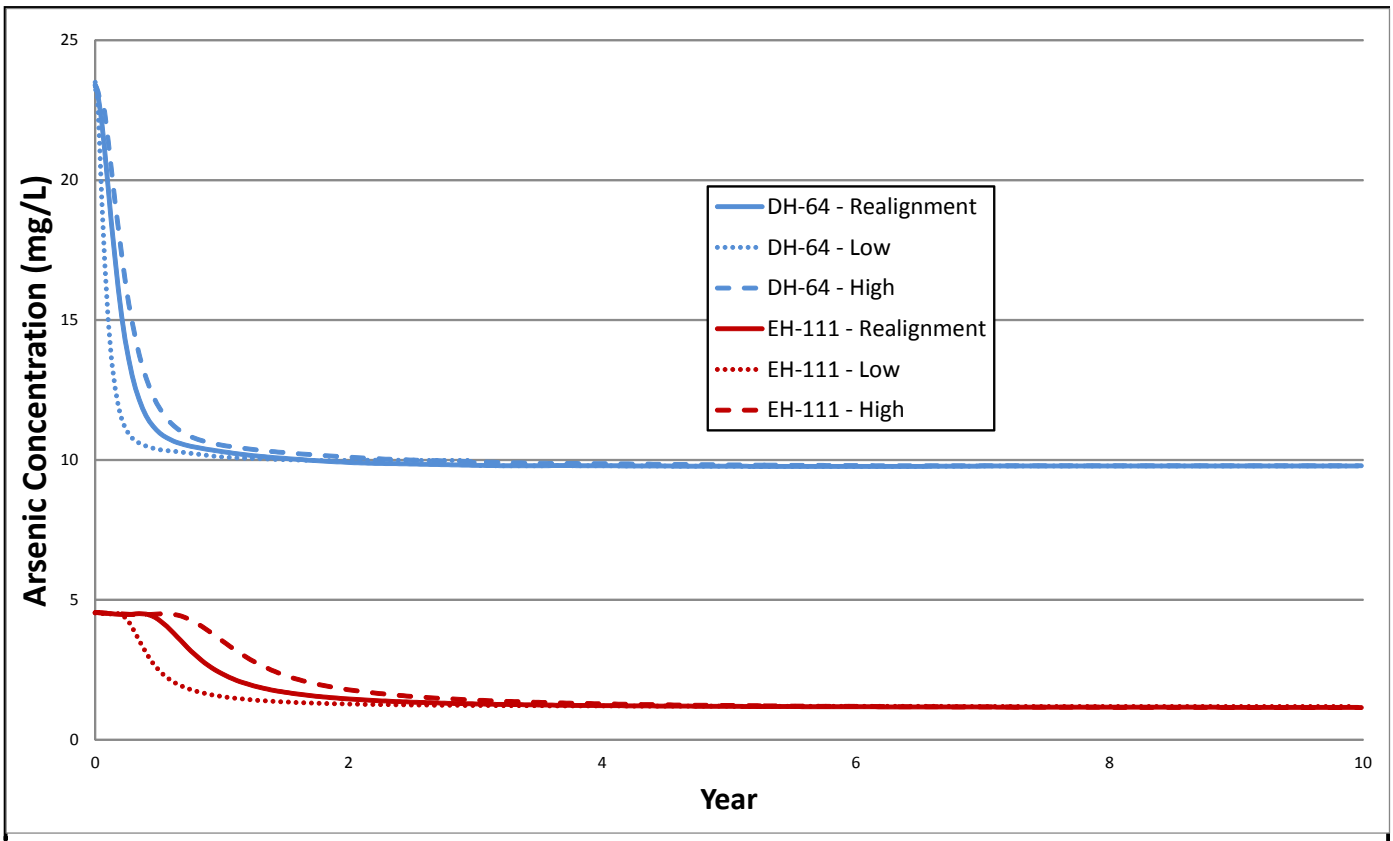
5) Results are from NewFields (2015b).

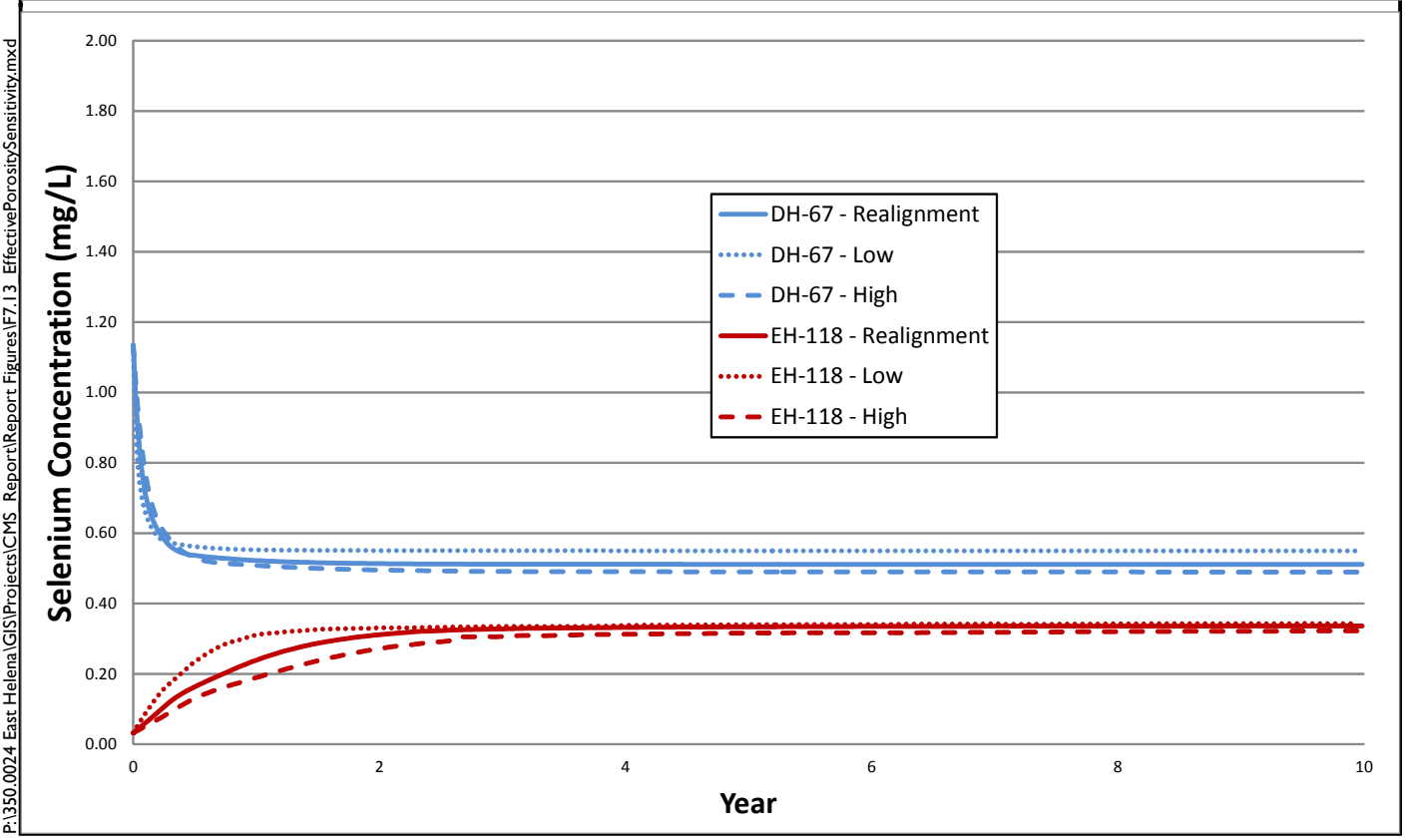
Isoconcentration Contour (mg/L)

- 0.05
- 0.1
- 0.5
- 1
- > 3

- Monitoring Well
- Former Smelter Site Boundary

Selenium Sensitivity Analysis for Unsaturated Sources
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.12





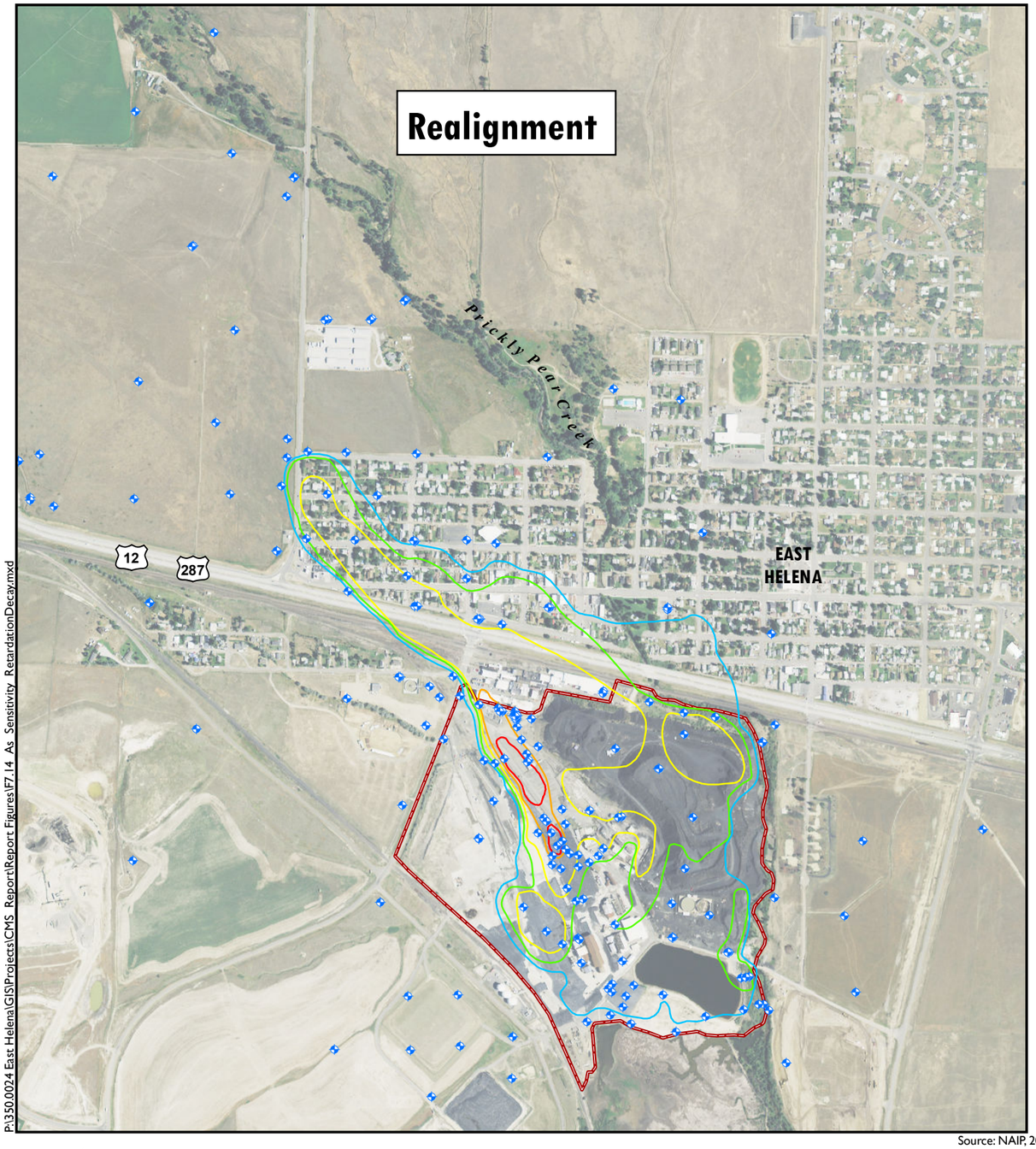
P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.13 EffectivePorositySensitivity.mxd

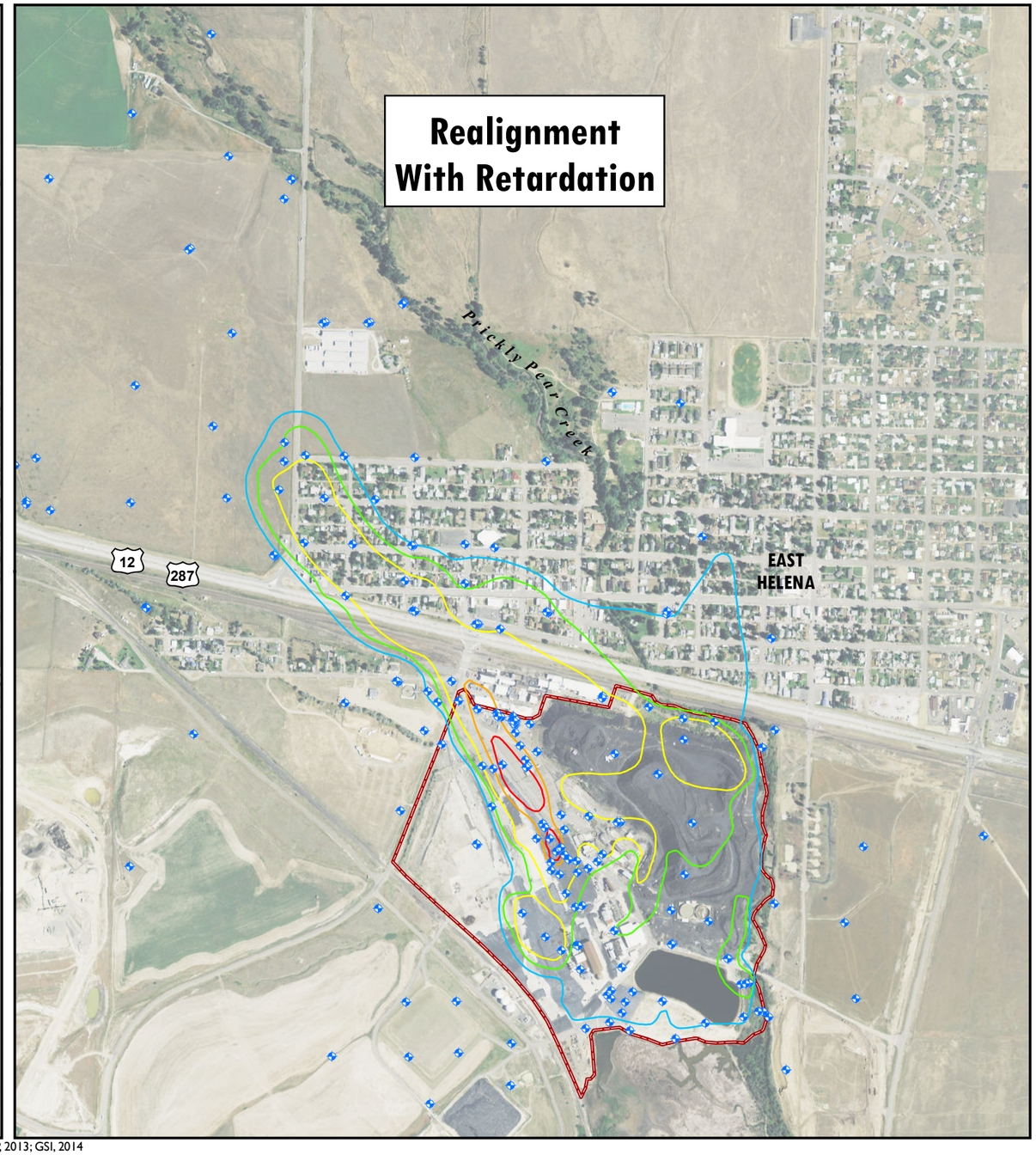
Notes:
1) Effective porosity was increased and decreased by 50 percent.

2) Results are from NewFields (2015b).

NewFields

Sensitivity Analysis for Effective Porosity
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.13





P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.14 As Sensitivity Retardation Decay.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, and 3.

2) Predictive results depict concentrations after model has reached steady-state.

3) Sorption was simulated with sorption coefficient of 5 liters per kilogram and a linear isotherm.

4) Results are from NewFields (2015b).

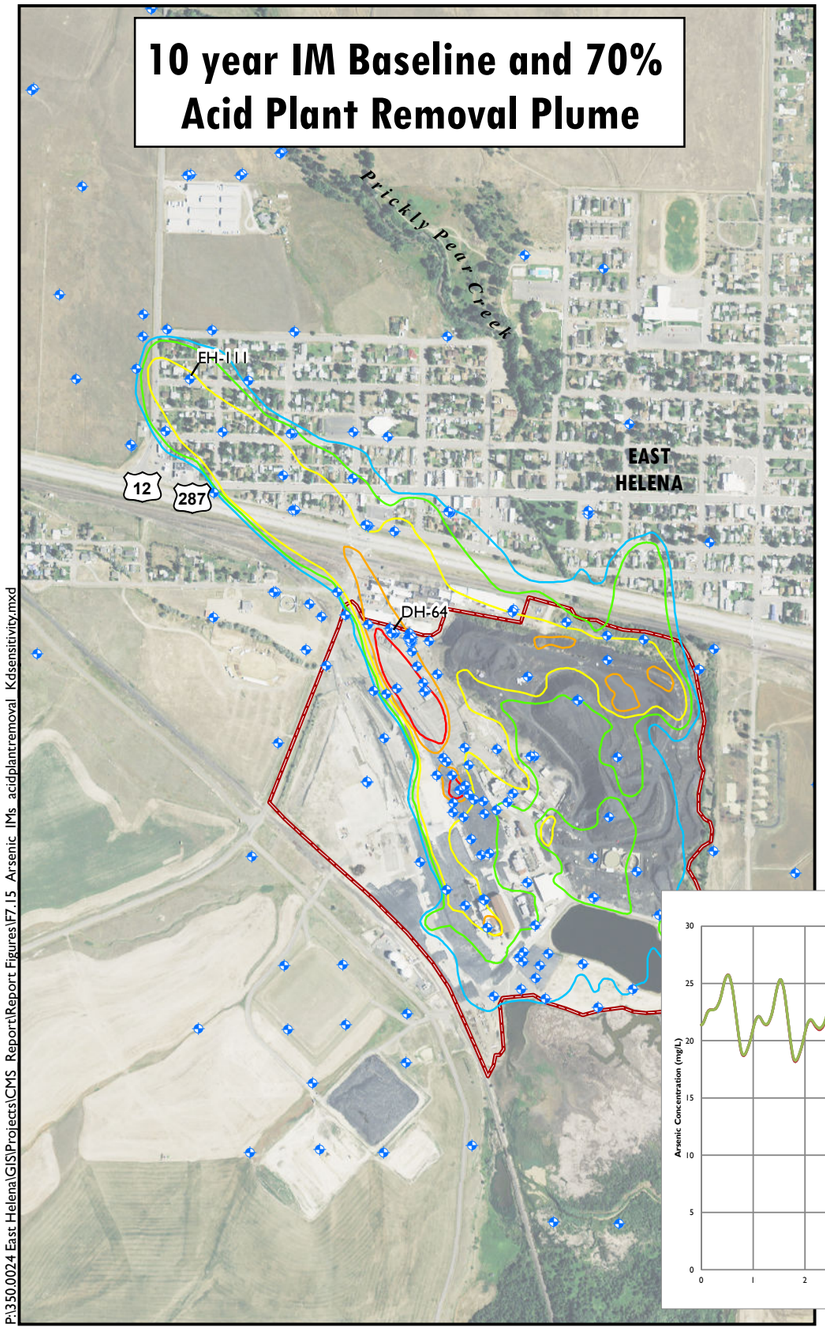
Isoconcentration Contour (mg/L)

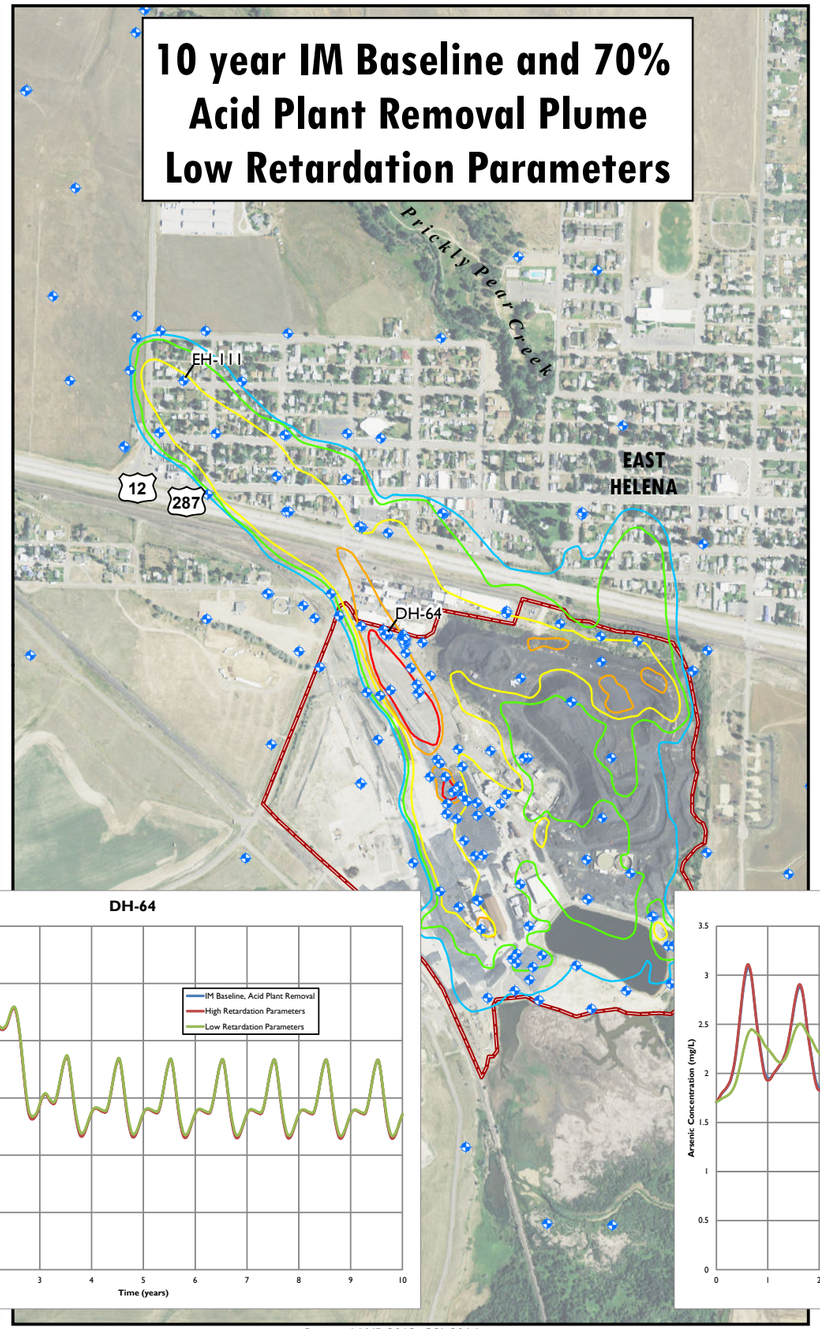
- 0.01
- 0.1
- 1
- 10
- > 20

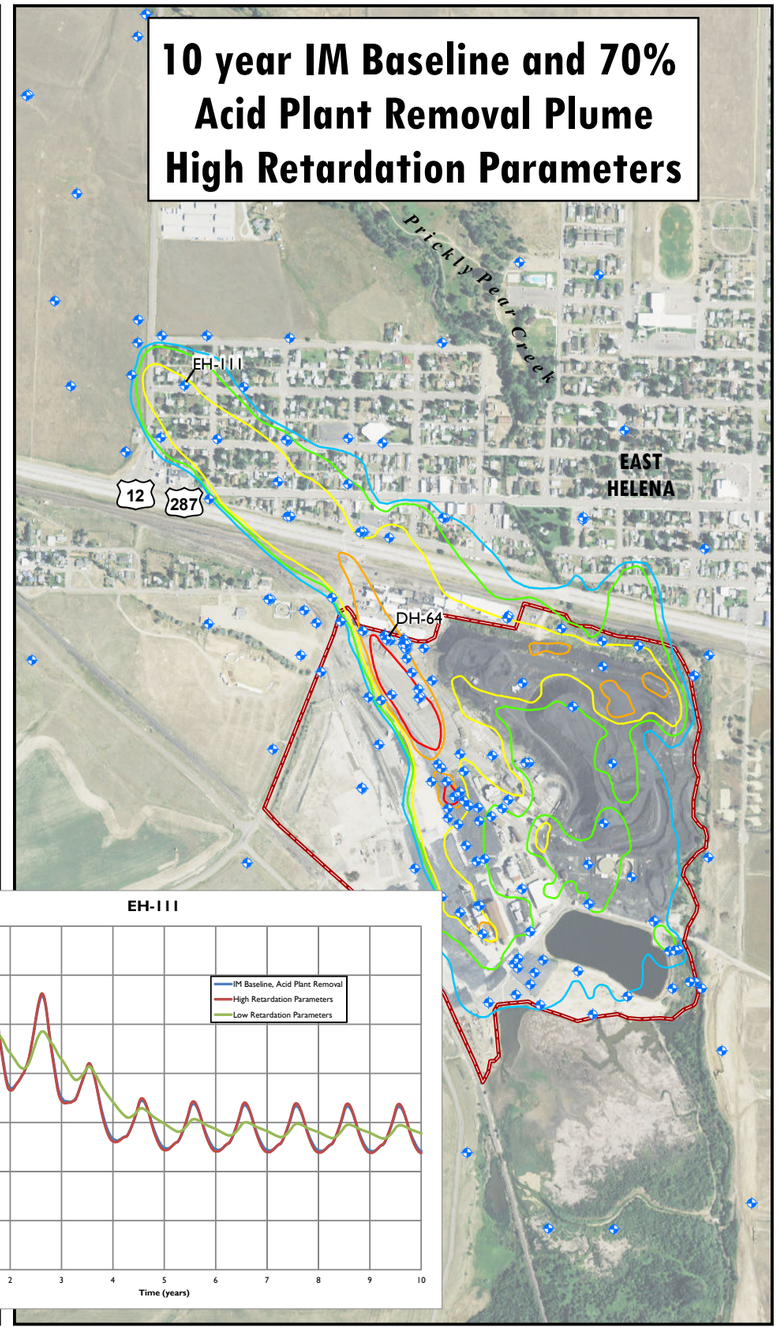
Monitoring Well

Former Smelter Site Boundary

Arsenic Sensitivity Analysis for Attenuation
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.14







P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.15 Arsenic IMs acidplantremoval K-sensitivity.mxd

Source: NAIP, 2013; GSI, 2014

0 Feet 1,000

NewFields

Notes:
1) Simulated plumes represent a composite of model layers 1, 2, 3, and 4.

2) Predictive results depict concentrations in stress period 66, after model has reached steady-state.

3) mg/L = milligram per liter; % = percent.

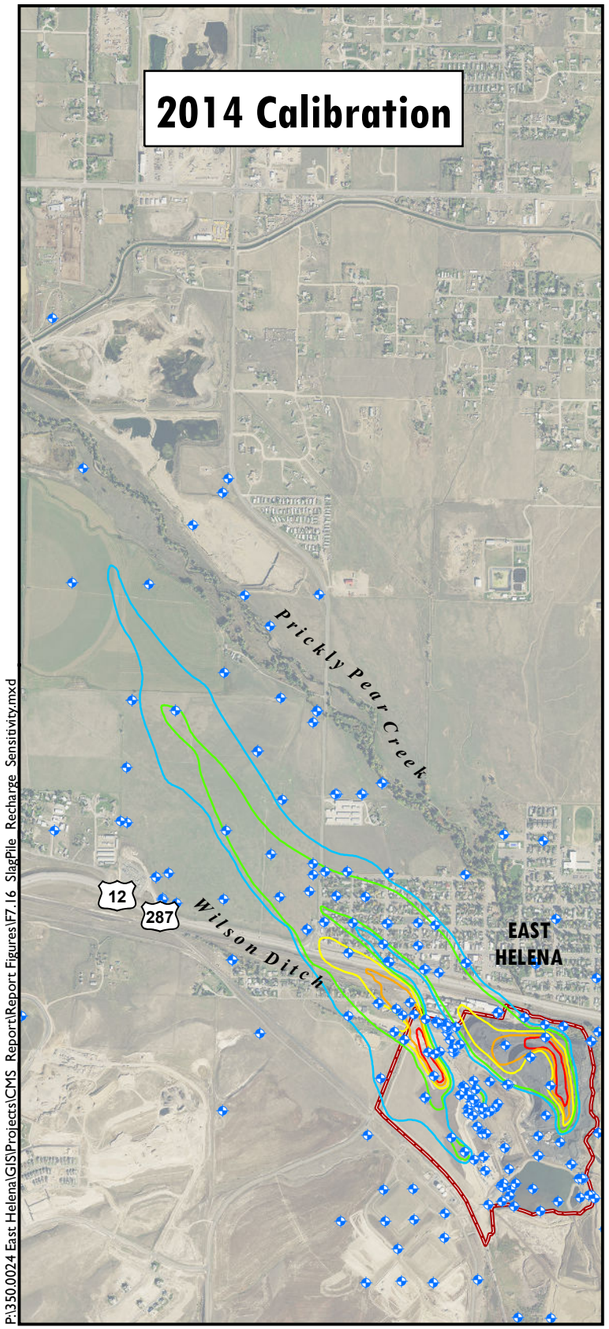
4) Results are from NewFields (2016a).

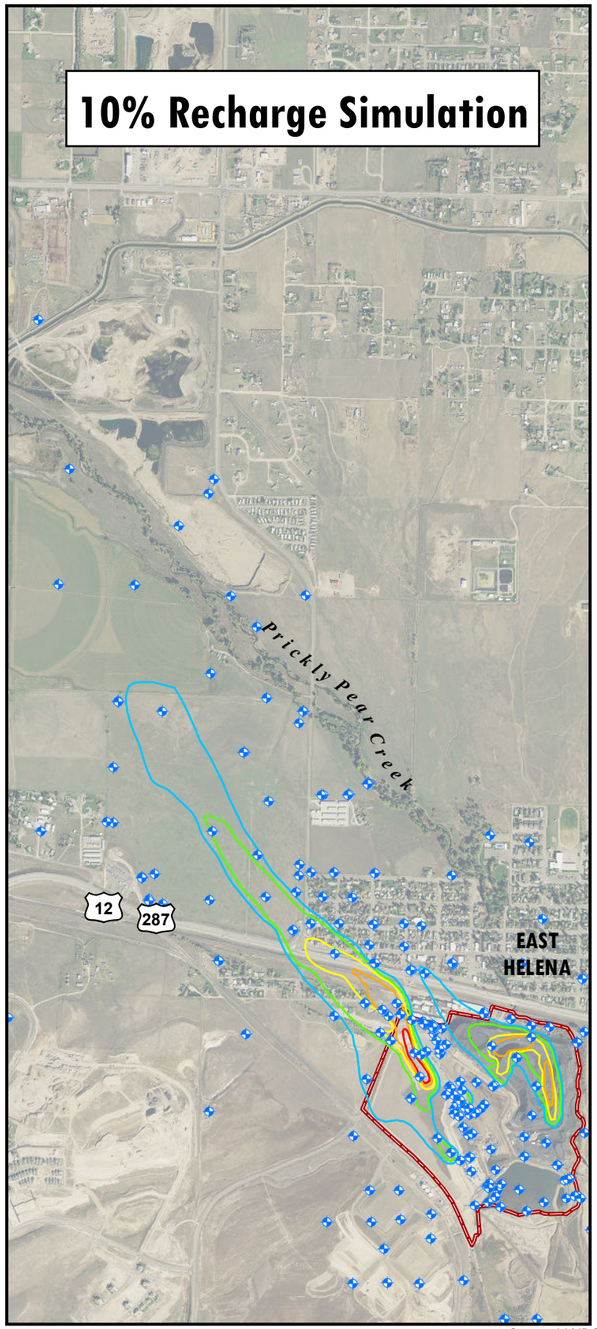
Isoconcentration Contour (mg/L)

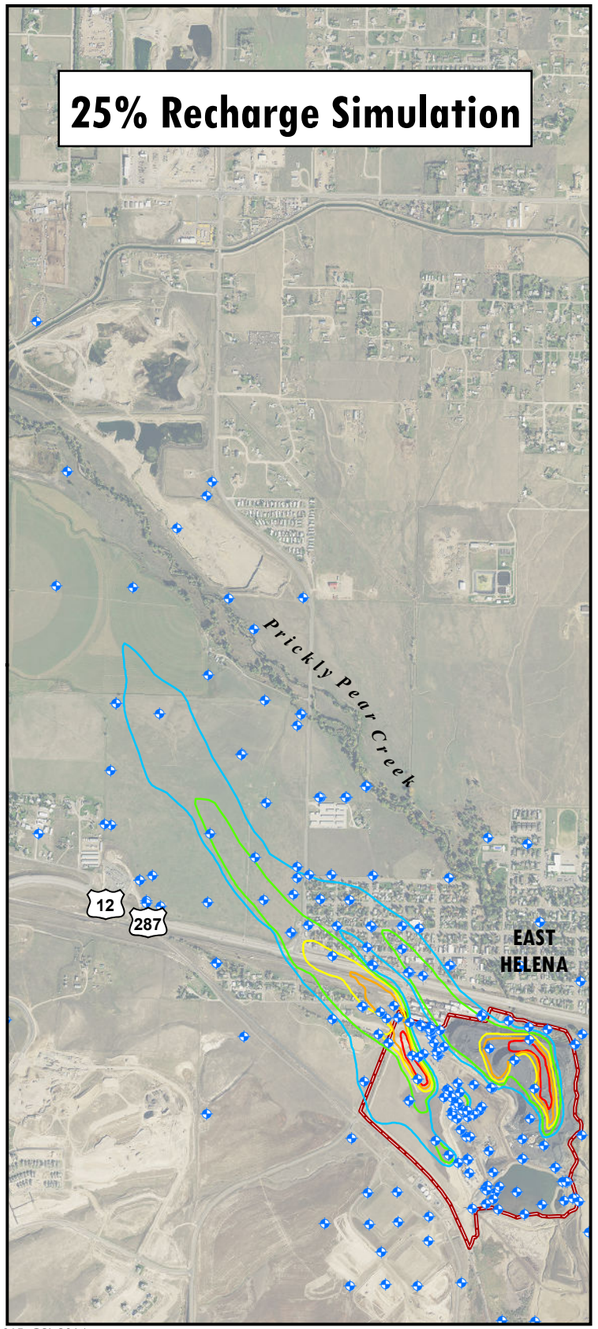
0.01
0.1
1
10
> 20

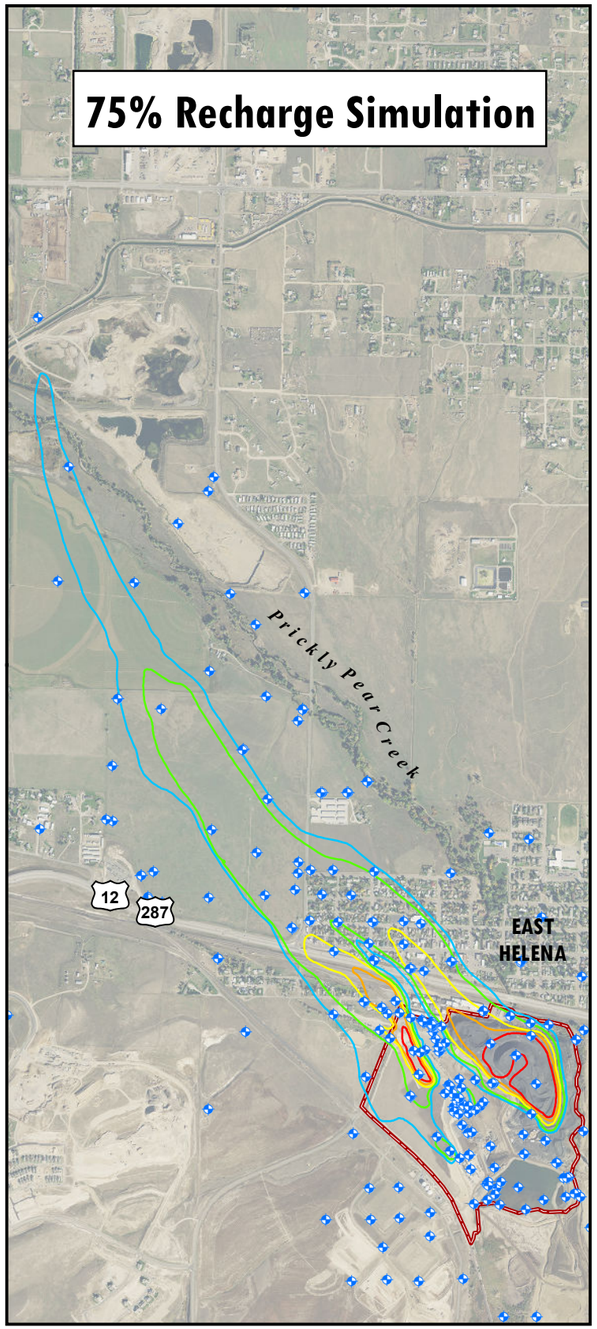
Monitoring Well
Former Smelter Site Boundary

Predicted Isoconcentration Contours
Arsenic Retardation Parameters Sensitivity Analysis
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.15









P:\350.0024 East Helena\GIS\Projects\CMS Report\Report Figures\F7.16 SlagPile Recharge Sensitivity.mxd

Source: NAIP, 2015; GSI, 2014

0 Feet 2,000

NewFields

Notes:
1) Simulated plumes represents a composite of model layers 1, 2, 3, and 4.

2) % = percent.

3) Results are from NewFields (2016b).

Isoconcentration Contour (mg/L)

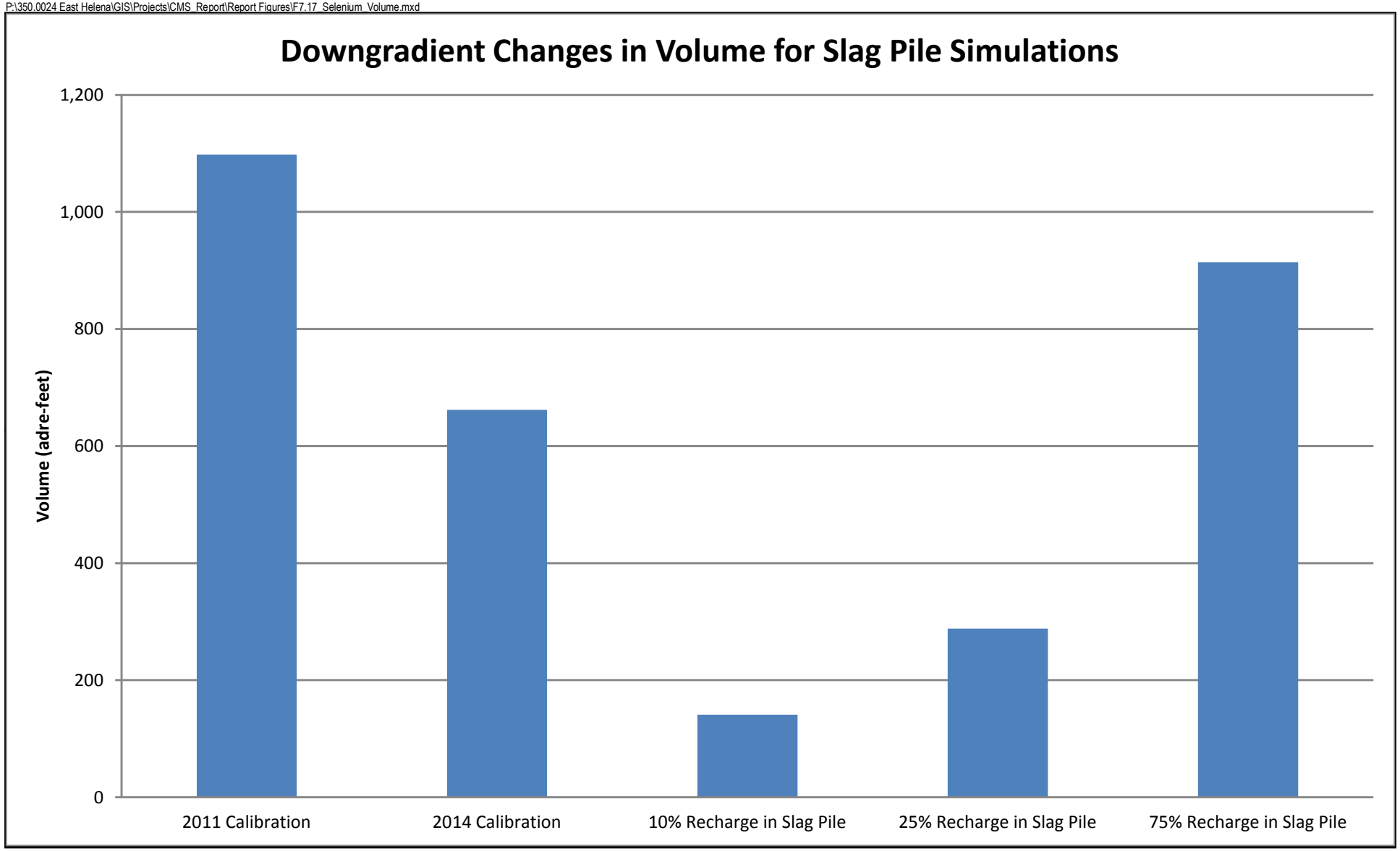
- 0.05
- 0.1
- 0.5
- 1
- > 3

Monitoring Well

Former Smelter Site Boundary

Predicted Selenium Isoconcentration Contours
Selenium Slag Pile Recharge Rate Sensitivity Analysis
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.16

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F7.17_Selenium_Volume.mxd



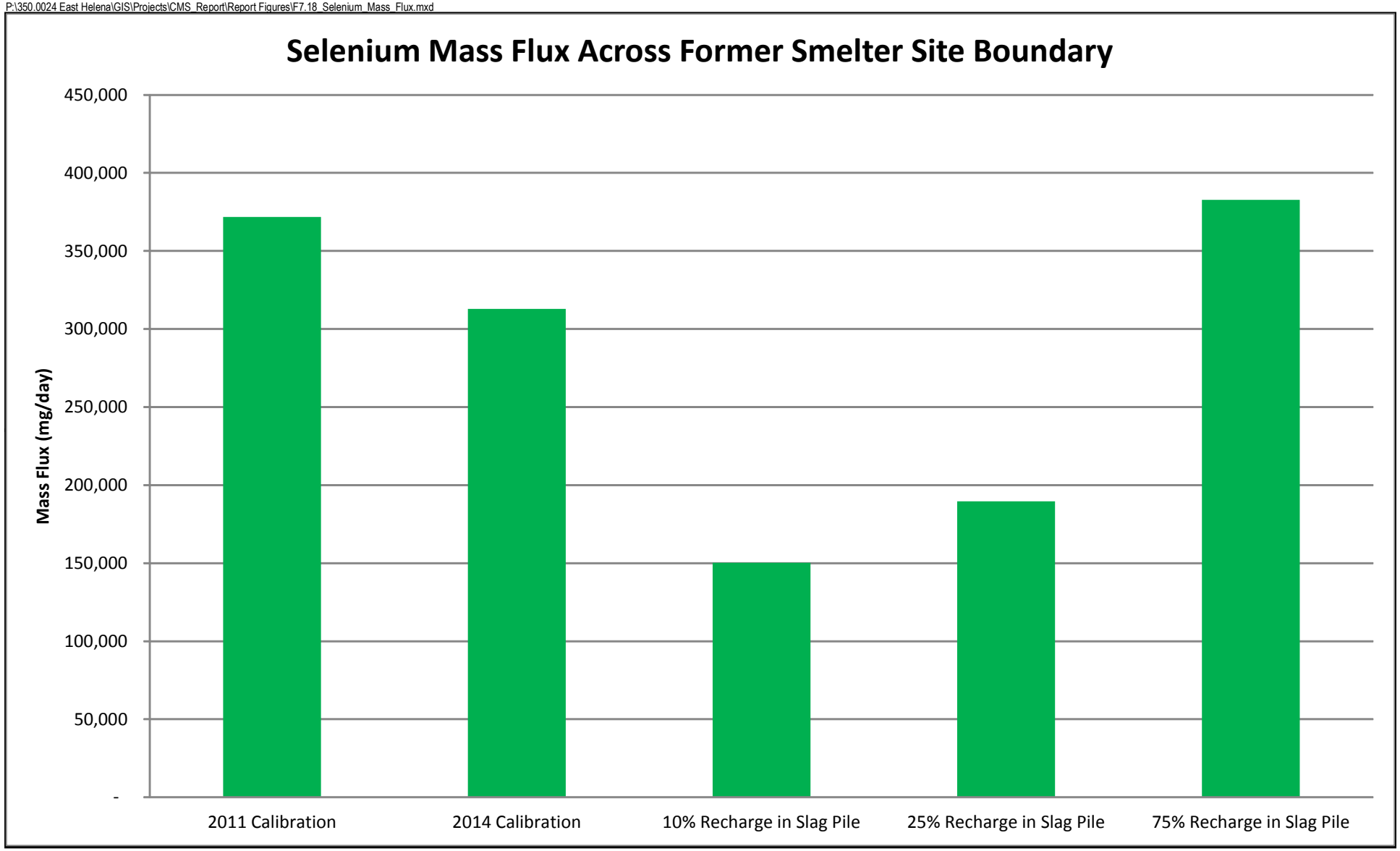
Notes:
1) % = percent.

2) Results are from NewFields (2016b).

NewFields

Sensitivity Analysis for Slag Pile Recharge Rate
Changes in Selenium Volume
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.17

P:\350.0024 East Helena\GIS\Projects\CMS_Report\Report Figures\F7.18_Selenium_Mass_Flux.mxd



Notes:
1) % = percent; mg/day = milligram per day.

2) Results are from NewFields (2016b).

NewFields

Sensitivity Analysis for Slag Pile Recharge Rate
Changes in Selenium Mass Flux
Former ASARCO East Helena Smelter
East Helena, Montana
FIGURE 7.18

TABLES

Table 2.1
Geologic Unit Descriptions for Bedrock Geology
Former ASARCO East Helena Smelter, East Helena,

Unit Label[a]	Description of Map Units
Cc	Upper and Middle Cambrian carbonate rocks
Cd	Middle Cambrian clastic rocks
Dtj	Three Forks Formation and Jefferson Formation, undivided
EOv	Eocene volcanic rocks
Jme	Jurassic sedimentary rocks
Kck	Upper and Lower Cretaceous sedimentary rocks
Kev	Elkhorn Mountains Volcanics
Kg	Cretaceous intrusive rocks, mainly granitic
Mb	Big Snowy Group
Mml	Madison Group
No bedrock	No bedrock data
OGs	Oligocene sedimentary rocks
OGv	Oligocene volcanic rocks
OGvt	Oligocene volcanic rocks (tuffaceous)
Open water	Significant water bodies
PIPqa	Permian and Pennsylvanian sedimentary rocks
POMIs	Pliocene(?) and Miocene sedimentary rocks
Ybo	Bonner Quartzite
Yg	Greyson Formation
Yhe	Helena and Empire Formations, undivided
Yms	Mount Shields Formation
Ys	Spokane Formation
Yss	Shepard and Snowslip Formations, undivided
Zg	Intrusive rocks

[a] Geologic Units shown on **Figure 2.1**.

Source: Thamke and Reynolds (2000).

Table 2.2

Geologic Unit Descriptions for Surface Geology

Former ASARCO East Helena Smelter, East Helena, Montana

Unit Label[a]	Description of Map Units
Mmu	Madison Group, undivided (Upper and Lower Mississippian)
OGbp	Basalt in plug or volcanic neck (Oligocene)
OGs	Sedimentary rocks, undivided (Oligocene)
OGts	Tuff and tuffaceous sedimentary rocks (Oligocene)
Qa	Alluvium (Holocene)
Qac	Alluvium and colluvium, undivided (Holocene)
Qc	Colluvium (Holocene)
Qt	Terrace gravel (Holocene and Pleistocene)
QTg	Older gravel (Pleistocene and Pliocene)
QTp	Older pediment gravel, undivided (Pleistocene and Pliocene)
Water	Open water
Yg	Greyson Formation (Mesoproterozoic)
Yh	Helena Formation (Mesoproterozoic)
Ys	Spokane Formation (Mesoproterozoic)

[a] Geologic Units shown on **Figure 2.2**.

Source: Reynolds and Brandt (2005).

Table 2.3

Vertical Groundwater Gradients[a]

Former ASARCO East Helena Smelter, East Helena, Montana

Wells	Aquifer[b]	June 2011 Vertical Gradient[c]	November 2011 Vertical Gradient[c]	Average 2011 Vertical Gradient[c]	June 2014 Vertical Gradient[c]	November 2014 Vertical Gradient[c]	Average 2014 Vertical Gradient[c]
DH-12[d]/DH-13	Upper Aquifer	0.097	-0.003	0.047	NA	NA	NA
DH-13/DH-18	Upper Aquifer-DGS	0.010	0.111	0.061	0.050	0.107	0.078
DH-12[d]/DH-18	Upper Aquifer-DGS	0.048	0.062	0.055	NA	NA	NA
DH-16[d]/DH-17	Upper Aquifer	-0.003	-0.172	-0.087	NA	NA	NA
DH-24/DH-64	Upper Aquifer	0.005	0.003	0.004	0.015	0.014	0.014
DH-6/DH-15	Upper Aquifer	-0.004	-0.003	-0.004	-0.001	-0.007	-0.004
EH-66/EH-121	Upper Aquifer	-0.019	-0.009	-0.014	-0.014	-0.008	-0.011
EH-67/EH-122	Upper Aquifer	-0.062	-0.018	-0.040	-0.028	-0.022	-0.025
EH-134/EH-129	Upper Aquifer	0.000	-0.006	-0.003	-0.001	-0.003	-0.002
EH-50/EH-100	Upper Aquifer	-0.007	-0.003	-0.005	-0.013	-0.007	-0.010
EH-51/EH-101	Upper Aquifer	-0.027	-0.029	-0.028	-0.023	-0.016	-0.020
EH-52/EH-102	Upper Aquifer	-0.074	-0.050	-0.062	-0.080	-0.046	-0.063
EH-60/EH-61	Upper Aquifer	-0.042	-0.017	-0.029	-0.038	-0.035	-0.037
EH-60/EH103	Upper Aquifer	-0.010	-0.004	-0.007	-0.010	-0.008	-0.009
EH-61/EH-103	Upper Aquifer	0.010	0.004	0.007	0.006	0.008	0.007
EH-65/EH-107	Upper Aquifer	0.053	0.047	0.050	0.059	0.058	0.058

[a] Vertical gradient locations shown on **Figure 2.7**. All values in table have units of feet/foot.

[b] DGS = Deeper Groundwater System.

[c] Negative values indicate downward vertical gradients.

[d] Groundwater elevation was not measured during 2014; NA = not available.

Table 2.4a

2009 and 2010 Prickly Pear Creek Synoptic Stream Gaging

Former ASARCO East Helena Smelter, East Helena, Montana

December 2009

Inflow Gage[a]	Outflow Gage[a]	Inflow[b]	Outflow[b]	Tributary Inflow/Outflow[b]		Gain from Upper Lake[b]		Diversions[b]		Change in Surface Water Flow[b]	Relative Percent Difference (percent)	Stream Gain/Loss
SG-01	PPC-3A (SG-02)	28.18	32.80							4.62	16%	Gain
PPC-3A (SG-02)	PPC-22 (SG-03A)	32.80	29.03					SG-04	5.69	1.92	6%	Gain
PPC-22 (SG-03A)	SG-06	29.03	31.21	TB-6	0.11	SG-05	7.84			-5.77	-20%	Loss
SG-06	PPC-5 (SG-07)	31.21	31.67							0.46	1%	Gain
PPC-5 (SG-07)	PPC-23 (SG-08)	31.67	32.43							0.76	2%	Gain
PPC-23 (SG-08)	PPC-7 (SG-09)	32.43	33.21							0.78	2%	Gain
PPC-7 (SG-09)	PPC-8 (SG-10)	33.21	35.20							1.99	6%	Gain
PPC-8 (SG-10)	PPC-36 (SG-11)	35.20	33.51							-1.69	-5%	Loss
PPC-36 (SG-11)	SG-12	33.51	33.93					ID-11		0.42	1%	Gain
SG-12	SG-13A	33.93	34.75					SG-13B	0.20	1.02	3%	Gain
SG-13A	SG-14	34.75	35.90	SG-13B	0.20			ID-14		0.95	3%	Gain
SG-14	SG-15	35.90	32.25	TB-14	0.37					-4.02	-11%	Loss
SG-15	SG-16	32.25	30.68							-1.57	-5%	Loss

August 2010

Inflow Gage[a]	Outflow Gage[a]	Inflow[b]	Outflow[b]	Tributary Inflow/Outflow[b]		Gain from Upper Lake[b]		Diversions[b]		Change in Surface Water Flow[b]	Relative Percent Difference (percent)	Stream Gain/Loss
SG-01	PPC-3A (SG-02)	72.72	81.52							8.80	12%	Gain
PPC-3A (SG-02)	PPC-22 (SG-03A)	81.52	29.19					SG-04	44.39	-7.94	-10%	Loss
PPC-22 (SG-03A)	SG-06	29.19	63.37	TB-6	0.05	SG-04	41.28			-7.15	-24%	Loss
SG-06	PPC-5 (SG-07)	63.37	70.03							6.66	11%	Gain
PPC-5 (SG-07)	PPC-23 (SG-08)	70.03	71.17							1.14	2%	Gain
PPC-23 (SG-08)	PPC-7 (SG-09)	71.17	65.90							-5.27	-7%	Loss
PPC-7 (SG-09)	PPC-8 (SG-10)	65.90	63.92							-1.98	-3%	Loss
PPC-8 (SG-10)	PPC-36 (SG-11)	63.92	63.28							-0.64	-1%	Loss
PPC-36 (SG-11)	SG-12	63.28	36.83					ID-11	25.63	-0.82	-1%	Loss
SG-12	SG-13A	36.83	36.55							-0.28	-1%	Loss
SG-13A	SG-14	36.55	33.03					ID-14	1.57	-1.95	-5%	Loss
SG-14	SG-15	33.03	30.36	TB-14	0.86					-3.53	-11%	Loss
SG-15	SG-16	30.36	26.99							-3.37	-11%	Loss

Table 2.4b

2014 Prickly Peak Creek Synoptic Stream Gaging

Former ASARCO East Helena Smelter, East Helena, Montana

June 2014

Inflow Gage[a]	Outflow Gage[a]	Inflow[b]	Outflow[b]	Change in Surface Water Flow[b]	Relative Percent Difference (percent)	Stream Gain/Loss
PPC-3A (SG-02)	PPC-5 (SG-07)	137.66	130.36	-7.30	-5%	Loss
PPC-5 (SG-07)	PPC-7 (SG-09)	130.36	141.35	10.99	8%	Gain
PPC-7 (SG-09)	PPC-36 (SG-11)	141.35	132.27	-9.08	-6%	Loss
PPC-36 (SG-11)	PPC-10	132.27	123.11	-9.16	-7%	Loss
PPC-10	SG-16	123.11	116.2	-6.91	-6%	Loss

October 2014

Inflow Gage[a]	Outflow Gage[a]	Inflow[b]	Outflow[b]	Change in Surface Water Flow[b]	Relative Percent Difference (percent)	Stream Gain/Loss
PPC-3A (SG-02)	PPC-5 (SG-07)	44.7	40.9	-3.80	-9%	Loss
PPC-5 (SG-07)	PPC-7 (SG-09)	40.90	42.80	1.90	5%	Gain
PPC-7 (SG-09)	PPC-36 (SG-11)	42.80	40.60	-2.20	-5%	Loss
PPC-36 (SG-11)	PPC-10	40.60	29.10	-11.50	-28%	Loss
PPC-10	SG-16	29.1	30.6	1.5	5%	Gain

[a] Locations shown on **Figure 2.12.**

[b] Cubic feet per second.

Source for 2009 and 2010: GSI (2014); Source for 2014: Hydrometrics.

Table 4.1

Initial Conductance for Head-Dependent Boundaries

Former ASARCO East Helena Smelter, East Helena, Montana

Boundary[a]	Hydraulic Conductivity (feet/day)	Thickness (feet)	Width (feet)	Length (feet)	Conductance ($feet^2$/day)
Drains	10	1	5	200	10,000
Prickly Pear Creek	1	1	15 - 45	0.67 - 313	10 - 14,085
Tenmile Creek	1	1	15	33 - 313	495 - 4,695
Upper Lake	0.034	2	40	40 - 200	27 - 136
Lower Lake	0.155	2	40	40	124
Lake Helena	0.1	2	200	40 - 200	400 - 2,000
General Head (south)	3.6 - 64.3	5 - 60	40 - 200	40 - 200	0.5 - 552
General Head (north)	3.6 - 64.3	5 - 60	40 - 200	40 - 200	0.01 - 1,810

[a] Locations shown on **Figure 4.5**.

Table 4.2

2011 Steady-State Groundwater Flux Targets

Former ASARCO East Helena Smelter, East Helena, Montana

Inflow	Minimum[a]	Maximum[a]
Seepage from Upper Lake	245	439
Seepage from Lower Lake	16	24
Seepage from Prickly Pear Creek	1,536	12,952
Seepage from Wilson Ditch	349	581
Seepage from Helena Valley Irrigation Canal	1,169	1,948
Seepage from Other Irrigation Canals	1,667	2,778
Underflow from South and Southwest	1,695	364,337
Underflow from East	149	230,651
Seepage from Tenmile Creek	1,397	4,192
Total Infiltrating Recharge	9,778	12,952
Total Inflow	18,001	630,854
Outflow	**Minimum[a]**	**Maximum[a]**
Seepage to Prickly Pear Creek	4,289	13,605
Drainage to Irrigation Drains	4,240	6,359
Evapotranspiration from Wetlands	341	4,091
Evaporation from Gravel Ponds	197	296
Seepage to Tenmile Creek	1,861	2,308
Seepage to Lake Helena	22,344	25,197
Total Outflow	33,272	51,856

[a] Values are in acre-feet per year.

Table 4.3

2011 Steady-State Residual Statistics

Former ASARCO East Helena Smelter, East Helena, Montana

Statistic	Result
Residual Mean (feet)	-0.03
Residual Standard Deviation (feet)	1.57
Absolute Residual Mean (feet)	1.24
Sum of Squares (feet)	461
Root Mean Square Error (feet)	1.57
Minimum Residual (feet)	-4.74
Maximum Residual (feet)	3.57
Number of Observations	187
Range in Observations (feet)	266.62
Scaled Standard Deviation (percent)	0.6
Scaled Absolute Mean (percent)	0.5
Scaled Root Mean Square (percent)	0.6

Note: Results are from NewFields (2016a).

Table 4.4

2014 Steady-State Residual Statistics

Former ASARCO East Helena Smelter, East Helena, Montana

Statistic	Result
Residual Mean (feet)	-0.06
Residual Standard Deviation (feet)	1.81
Absolute Residual Mean (feet)	1.44
Sum of Squares (feet)	662
Root Mean Square Error (feet)	1.81
Minimum Residual (feet)	-4.02
Maximum Residual (feet)	4.78
Number of Observations	203
Range in Observations (feet)	266.46
Scaled Standard Deviation (percent)	0.7
Scaled Absolute Mean (percent)	0.5
Scaled Root Mean Square (percent)	0.7

Note: Results are from NewFields (2016a).

Table 4.5

Updated 2011 and 2014 Steady-State Residual Statistics

Former ASARCO East Helena Smelter, East Helena, Montana

Statistic	2011 Result	2014 Result
Residual Mean (feet)	-0.12	-0.2
Residual Standard Deviation (feet)	1.54	1.95
Absolute Residual Mean (feet)	1.24	1.61
Sum of Squares (feet)	448	779
Root Mean Square Error (feet)	1.55	1.96
Minimum Residual (feet)	-4.93	-4.12
Maximum Residual (feet)	4	4.83
Number of Observations	187	203
Range in Observations (feet)	266.62	266.46
Scaled Standard Deviation (percent)	0.6	0.7
Scaled Absolute Mean (percent)	0.5	0.6
Scaled Root Mean Square (percent)	0.6	0.7

Note: Results are from NewFields (2016b).

Table 5.1

Calibration Criteria for Residual Absolute Value

Former ASARCO East Helena Smelter, East Helena, Montana

Observed Concentration Range (mg/L)	Calibration Criteria (mg/L)[a]
<0.02	0.005
0.02 to 0.05	0.01
0.051 to 0.1	0.02
0.11 to 0.2	0.05
0.21 to 0.5	0.1
0.51 to 1.0	0.2
1.1 to 2.0	0.5
2.1 to 5.0	1
5.0 to 10	2
>10	5

[a] R* value (see **Section 5.2.1.2**).

Table 6.1

Estimated Flux Through Potential Source Areas

Former ASARCO East Helena Smelter, East Helena, Montana

Underflow Into the Former Smelter Site				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	3,225	8	156	-95%
2	7,867	433	165	-98%
3	16,530	12,343	12,331	-25%
Total	27,622	12,784	12,652	-54%

In/Out of Tito Park				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	1,176	4	4	-100%
2	2,312	29	4	-100%
3	9,220	6,142	6,646	-28%
Total	12,708	6,175	6,654	-48%

In/Out of Acid Plant Sediment Drying Area				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	515	75	0	-100%
2	2,047	152	0	-100%
3	3,558	1,947	1,884	-47%
Total	6,120	2,174	1,884	-69%

In/Out of Speiss-Dross				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	1	0	0	-100%
2	733	0	0	-100%
3	8,867	6,034	5,296	-40%
Total	9,601	6,034	5,296	-45%

Into the Slag Pile				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	1,046	752	524	-50%
2	1,688	1,555	1,489	-12%
3	7,124	7,351	6,661	-6%
Total	9,858	9,658	8,674	-12%

Out of Lower Lake West				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	2,059	1,859	55	-97%
2	945	1,053	19	-98%
3	4,559	2,834	2,362	-48%
Total	7,563	5,746	2,436	-68%

Out of the Slag Pile				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	279	208	191	-32%
2	1,100	655	511	-54%
3	5,090	3,535	3,209	-37%
Total	6,469	4,398	3,911	-40%

In/Out of the Acid Plant				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	0	0	0	NA
2	7,657	1,880	1,124	-85%
3	6,712	5,173	4,594	-32%
Total	14,369	7,053	5,718	-60%

Out of Lower Lake East				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	170	389	19	-89%
2	0	3	1	NA
3	842	1,603	1,433	70%
Total	1,012	1,995	1,453	44%

In/Out of Thornock Lake				
Layer	Steady State 2011	PPC Bypass	PPC Realignment	Change in Flux
1	3	1	1	-67%
2	613	1	1	-100%
3	1,927	1,434	1,277	-34%
Total	2,543	1,436	1,279	-50%

Notes:

Figure 6.4 presents the location of estimated flux; Flux values are in feet^3 per day;

Total decline is the percent difference between Steady State 2011 and PPC Realignment; Flux was estimated perpendicular to flow;

PPC = Prickly Pear Creek; NA = Not Applicable.

Results are from NewFields (2014d).

Table 6.2a

Steady-State Flow and Transient Transport - Change in Volume of Groundwater with Arsenic Concentrations Above the MCL for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	375	NA	407	NA	783	NA
Bypass	407	-8%	416	-2%	823	-5%
Realignment	381	-1%	357	12%	737	6%

Table 6.2b

Steady-State Flow and Transient Transport - Change in Total Mass of Arsenic in Groundwater for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	1,445	NA	1,526	NA	2,971	NA
Bypass	700	52%	883	42%	1,583	47%
Realignment	377	74%	647	58%	1,024	66%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Results are fron NewFields (2015b).

Table 6.3a

Steady-State Flow and Transient Transport - Change in Volume of Groundwater with Selenium Concentrations Above the MCL for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	1,865	NA	186	NA	2,050	NA
Bypass	1,502	19%	170	8%	1,672	18%
Realignment	1,079	42%	158	15%	1,237	40%

Table 6.3b

Steady-State Flow and Transient Transport - Change in Total Mass of Selenium in Groundwater for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	3,304	NA	141	NA	3,444	NA
Bypass	2,791	16%	119	15%	2,910	16%
Realignment	2,008	39%	101	28%	2,108	39%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for selenium is 0.05 mg/L.

Results are fron NewFields (2015b).

Table 6.4a

Transient Flow and Transport - Change in Volume of Groundwater with Arsenic Concentrations Above the MCL for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	196	NA	309	NA	505	NA
2014 Calibrated Model	198	-1%	279	10%	477	6%
Interim Measure Simulation	208	-6%	282	9%	490	3%

Table 6.4b

Transient Flow and Transport - Change in Total Mass of Arsenic in Groundwater for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	1,334	NA	1,639	NA	2,973	NA
2014 Calibrated Model	869	35%	911	44%	1,780	40%
Interim Measure Simulation	564	58%	700	57%	1,264	57%

Table 6.4c

Transient Flow and Transport - Change in Arsenic Mass Flux Across Site Boundary for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Mass Flux (miligrams per day)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	11,340,856	NA
2014 Calibrated Model	6,054,348	47%
Interim Measure Simulation	3,873,601	66%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Predictive results are from stress period 66 of the model.

Results are fron NewFields (2016a).

Table 6.5a

Transient Flow and Transport - Change in Volume of Groundwater with Selenium Concentrations Above the MCL for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	2,141	NA	186	NA	2,327	NA
2014 Calibrated Model	2,106	2%	161	13%	2,267	3%
Interim Measure Simulation	396	82%	120	35%	516	78%

Table 6.5b

Transient Flow and Transport - Change in Total Mass of Selenium in Groundwater for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	861	NA	114	NA	975	NA
2014 Calibrated Model	847	2%	94	18%	941	3%
Interim Measure Simulation	1,226	-42%	44	61%	1,270	-30%

Table 6.5c

Transient Flow and Transport - Change in Selenium Mass Flux Across Site Boundary for SPHC IMs

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Mass Flux (miligrams per day)	Percent Change from 2011 Calibrated Model
2011 Calibrated Model	581,109	NA
2014 Calibrated Model	360,303	38%
Interim Measure Simulation	187,805	68%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for selenium is 0.05 mg/L.

Predictive results are from stress period 66 of the model.

Results are fron NewFields (2016a).

Table 6.6a

Steady-State Flow and Transient Transport - Change in Volume of Groundwater with Arsenic Concentrations Above the MCL for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	Total (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation
2011 Calibrated Model	375	NA	NA	407	NA	NA	783	NA	NA
Realignment	381	-1%	NA	357	12%	NA	737	6%	NA
PRB 43% Effectiveness	393	-5%	-3%	363	11%	-2%	756	3%	-3%
PRB 55% Effectiveness	392	-5%	-3%	363	11%	-2%	756	3%	-2%
PRB 100% Effectiveness	389	-4%	-2%	360	12%	-1%	748	4%	-2%
Slurry Wall High Permeability	392	-4%	-3%	365	10%	-2%	757	3%	-3%
Slurry Wall Base Case	390	-4%	-2%	368	10%	-3%	758	3%	-3%
Slurry Wall Low Permeability	389	-4%	-2%	370	9%	-4%	759	3%	-3%

Table 6.6b

Steady-State Flow and Transient Transport - Change in Total Mass of Arsenic in Groundwater for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	Total (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation
2011 Calibrated Model	1,445	NA	NA	1,526	NA	NA	2,971	NA	NA
Realignment	377	74%	NA	647	58%	NA	1,024	66%	NA
PRB 43% Effectiveness	281	81%	26%	590	61%	9%	870	71%	15%
PRB 55% Effectiveness	250	83%	34%	564	63%	13%	815	73%	20%
PRB 100% Effectiveness	157	89%	58%	488	68%	25%	644	78%	37%
Slurry Wall High Permeability	215	85%	43%	401	74%	38%	616	79%	40%
Slurry Wall Base Case	189	87%	50%	380	75%	41%	569	81%	44%
Slurry Wall Low Permeability	176	88%	53%	364	76%	44%	540	82%	47%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Results are fron NewFields (2015b).

Table 6.7a

Steady-State Flow and Transient Transport - Change in Volume of Groundwater with Selenium Concentrations Above the MCL for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	Total (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation
2011 Calibrated Model	1,865	NA	NA	186	NA	NA	2,050	NA	NA
Realignment	1,079	42%	NA	158	15%	NA	1,237	40%	NA
50% Source Removal	668	64%	38%	158	15%	0%	826	60%	33%
70% Source Removal	366	80%	66%	158	15%	0%	524	74%	58%
100% Source Removal	170	91%	84%	145	22%	8%	315	85%	75%
PRB 67% Effectiveness	363	81%	66%	159	14%	0%	522	75%	58%
PRB 76% Effectiveness	273	85%	75%	158	15%	0%	432	79%	65%
PRB 100% Effectiveness	173	91%	84%	155	17%	2%	328	84%	74%
Slurry Wall High Permeability	619	67%	43%	155	17%	2%	773	62%	38%
Slurry Wall Base Case	193	90%	82%	155	16%	2%	348	83%	72%
Slurry Wall Low Permeability	172	91%	84%	153	18%	4%	325	84%	74%
Pump and Treat High Transmissivity	119	94%	89%	141	24%	11%	261	87%	79%
Pump and Treat Base Case	137	93%	87%	148	20%	7%	285	86%	77%
Pump and Treat Low Transmissivity	160	91%	85%	158	15%	0%	318	84%	74%

Table 6.7b

Steady-State Flow and Transient Transport - Change in Total Mass of Selenium in Groundwater for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation	Total (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from Realignment Simulation
2011 Calibrated Model	3,304	NA	NA	141	NA	NA	3,444	NA	NA
Realignment	2,008	39%	NA	101	28%	NA	2,108	39%	NA
50% Source Removal	1,507	54%	25%	85	40%	16%	1,592	54%	24%
70% Source Removal	1,233	63%	39%	79	44%	22%	1,312	62%	38%
100% Source Removal	887	73%	56%	69	51%	31%	957	72%	55%
PRB 67% Effectiveness	1,272	61%	37%	103	27%	-3%	1,376	60%	35%
PRB 76% Effectiveness	1,162	65%	42%	102	27%	-2%	1,264	63%	40%
PRB 100% Effectiveness	923	72%	54%	99	29%	1%	1,022	70%	52%
Slurry Wall High Permeability	1,635	51%	19%	92	35%	9%	1,726	50%	18%
Slurry Wall Base Case	1,135	66%	43%	76	46%	25%	1,211	65%	43%
Slurry Wall Low Permeability	1,099	67%	45%	73	48%	27%	1,172	66%	44%
Pump and Treat High Transmissivity	1,149	65%	43%	69	51%	31%	1,218	65%	42%
Pump and Treat Base Case	845	74%	58%	78	44%	22%	923	73%	56%
Pump and Treat Low Transmissivity	1,209	63%	40%	98	30%	3%	1,307	62%	38%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for selenium is 0.05 mg/L.

Results are fron NewFields (2015b).

Table 6.8a

Transient Flow and Transport - Change in Volume of Groundwater with Arsenic Concentrations Above the MCL for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	196	NA	NA	309	NA	NA	505	NA	NA
2014 Calibrated Model	198	-1%	NA	279	10%	NA	477	6%	NA
Interim Measure Simulation	208	-6%	-5%	282	9%	-1%	490	3%	-3%
Acid Plant Removal	208	-6%	-5%	282	9%	-1%	490	3%	-3%
Acid Plant and North Plant Site Arsenic Removal	207	-6%	-5%	282	9%	-1%	489	3%	-3%

Table 6.8b

Transient Flow and Transport - Change in Total Mass of Arsenic in Groundwater for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	1,334	NA	NA	1,639	NA	NA	2,973	NA	NA
2014 Calibrated Model	869	35%	NA	911	44%	NA	1,780	40%	NA
Interim Measure Simulation	564	58%	35%	700	57%	23%	1,264	57%	29%
Acid Plant Removal	562	58%	35%	679	59%	25%	1,241	58%	30%
Acid Plant and North Plant Site Arsenic Removal	257	81%	70%	374	77%	59%	631	79%	65%

Table 6.8c

Transient Flow and Transport - Change in Arsenic Mass Flux Across Site Boundary for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Mass Flux (miligrams per day)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	11,340,856	NA	NA
2014 Calibrated Model	6,054,348	47%	NA
Interim Measure Simulation	3,873,601	66%	36%
Acid Plant Removal	3,861,926	66%	36%
Acid Plant and North Plant Site Arsenic Removal	1,914,610	83%	68%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Predictive results are from stress period 66 of the model.

Results are fron NewFields (2016a).

Table 6.9a

Transient Flow and Transport - Change in Volume of Groundwater with Selenium Concentrations Above the MCL for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	2,141	NA	NA	186	NA	NA	2,327	NA	NA
2014 Calibrated Model	2,106	2%	NA	161	13%	NA	2,267	3%	NA
Interim Measure Simulation	396	82%	81%	120	35%	25%	516	78%	77%
West Selenium Area Finite Source	386	82%	82%	117	37%	27%	503	78%	78%
West Selenium Area Removal	386	82%	82%	114	39%	29%	500	79%	78%

Table 6.9b

Transient Flow and Transport - Change in Total Mass of Selenium in Groundwater for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	861	NA	NA	114	NA	NA	975	NA	NA
2014 Calibrated Model	847	2%	NA	94	18%	NA	941	3%	NA
Interim Measure Simulation	1,226	-42%	-45%	44	61%	53%	1,270	-30%	-35%
West Selenium Area Finite Source	1,212	-41%	-43%	32	72%	66%	1,244	-28%	-32%
West Selenium Area Removal	1,222	-42%	-44%	32	72%	66%	1,254	-29%	-33%

Table 6.9c

Transient Flow and Transport - Change in Selenium Mass Flux Across Site Boundary for Source Control Measures

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Mass Flux (miligrams per day)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	581,109	NA	NA
2014 Calibrated Model	360,303	38%	NA
Interim Measure Simulation	187,805	68%	48%
West Selenium Area Finite Source	178,450	69%	50%
West Selenium Area Removal	178,120	69%	51%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for selenium is 0.05 mg/L.

Predictive results are from stress period 66 of the model.

Results are fron NewFields (2016a).

Table 6.10

Groundwater Elevations for the 2014 Calibration and Prickly Pear Creek Simulation

Former ASARCO East Helena Smelter, East Helena, Montana

Well	Simulated Groundwater Elevation (ft amsl)		Difference (ft)
	2014 Calibration Simulation	Prickly Pear Creek Predictive Simulation	
PZ-36C	3,850.88	3,843.45	7.43
EH-66	3,847.45	3,839.42	8.03
EH-70	3,831.27	3,822.41	8.86
EH-127	3,835.14	3,826.68	8.46
EH-135	3,824.91	3,815.14	9.77
EH-130	3,811.22	3,796.90	14.32

Notes:

Well locations are shown on **Figure 6.53**.

ft = feet; amsl = above mean sea level.

Table 6.11

Groundwater Elevations for the IM Predictive and Prickly Pear Creek Simulations

Former ASARCO East Helena Smelter, East Helena, Montana

Well	Simulated Groundwater Elevation (ft amsl)		Difference (ft)
	IM Baseline Simulation	Prickly Pear Creek Predictive Simulation	
PZ-36C	3,847.87	3,843.45	4.42
EH-66	3,844.97	3,839.42	5.55
EH-70	3,831.96	3,822.41	9.55
EH-127	3,834.20	3,826.68	7.52
EH-135	3,826.06	3,815.14	10.92
EH-130	3,816.40	3,796.90	19.5

Notes:

Well locations are shown on **Figure 6.53**.

ft = feet; amsl = above mean sea level.

Table 7.1a

Phase 2 Sensitivity - Change in Volume of Groundwater with Arsenic Concentrations Above the MCL

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from Bypass or Realignment Base Simulation	On-Site (acre-feet)	Percent Change from Bypass or Realignment Base Simulation	Total (acre-feet)	Percent Change from Bypass or Realignment Base Simulation
Bypass Base Simulation	407	NA	416	NA	823	NA
Bypass High Conductance	407	0%	416	0%	824	0%
Bypass Low Conductance	407	0%	416	0%	823	0%
Realignment Base Simulation	381	NA	357	NA	738	NA
Realignment High Conductance	362	5%	357	0%	719	3%
Realignment Low Conductance	370	3%	370	-4%	741	0%

Table 7.1b

Phase 2 Sensitivity - Change in Total Mass of Arsenic in Groundwater

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilogram)	Percent Change from Bypass or Realignment Base Simulation	On-Site (kilogram)	Percent Change from Bypass or Realignment Base Simulation	Total (kilogram)	Percent Change from Bypass or Realignment Base Simulation
Bypass Base Simulation	700	NA	883	NA	1,583	NA
Bypass High Conductance	701	0%	883	0%	1,584	0%
Bypass Low Conductance	700	0%	883	0%	1,584	0%
Realignment Base Simulation	377	NA	647	NA	1,024	NA
Realignment High Conductance	378	0%	649	0%	1,027	0%
Realignment Low Conductance	370	2%	647	0%	1,016	1%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Results are fron NewFields (2015b).

Table 7.2a

Phase 2 Sensitivity - Change in Volume of Groundwater with Selenium Concentrations Above the MCL

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from Bypass or Realignment Base Simulation	On-Site (acre-feet)	Percent Change from Bypass or Realignment Base Simulation	Total (acre-feet)	Percent Change from Bypass or Realignment Base Simulation
Bypass Base Simulation	1,502	NA	170	NA	1,672	NA
Bypass High Conductance	1,525	-2%	172	-1%	1,698	-2%
Bypass Low Conductance	1,445	4%	167	2%	1,612	4%
Realignment Base Simulation	1,079	NA	158	NA	1,237	NA
Realignment High Conductance	1,080	0%	159	0%	1,239	0%
Realignment Low Conductance	1,056	2%	156	1%	1,212	2%
Increased Unsaturated Concentration	1,113	-3%	174	-10%	1,287	-4%
Increased Recharge Rate	1,181	-9%	186	-18%	1,367	-11%

Table 7.2b

Phase 2 Sensitivity - Change in Total Mass of Selenium in Groundwater

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilogram)	Percent Change from Bypass or Realignment Base Simulation	On-Site (kilogram)	Percent Change from Bypass or Realignment Base Simulation	Total (kilogram)	Percent Change from Bypass or Realignment Base Simulation
Bypass Base Simulation	2,791	NA	119	NA	2,910	NA
Bypass High Conductance	2,803	0%	119	0%	2,922	0%
Bypass Low Conductance	2,763	1%	119	0%	2,883	1%
Realignment Base Simulation	2,008	NA	101	NA	2,108	NA
Realignment High Conductance	2,051	-2%	99	2%	2,150	-2%
Realignment Low Conductance	1,986	1%	105	-4%	2,091	1%
Increased Unsaturated Concentration	2,066	-3%	116	-15%	2,182	-3%
Increased Recharge Rate	2,055	-2%	134	-33%	2,189	-4%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Results are fron NewFields (2015b).

Table 7.3a

Phase 3 Sensitivity - Change in Volume of Groundwater with Arsenic Concentrations Above the MCL

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	On-Site (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	Total (acre-feet)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	196	NA	NA	309	NA	NA	505	NA	NA
2014 Calibrated Model	198	-1%	NA	279	10%	NA	477	6%	NA
Acid Plant Removal	208	-6%	-5%	282	9%	-1%	490	3%	-3%
Low Retardation Parameters	240	-22%	-21%	306	1%	-10%	546	-8%	-14%
High Retardation Parameters	194	1%	2%	266	14%	5%	460	9%	4%

Table 7.3b

Phase 3 Sensitivity - Change in Total Mass of Arsenic in Groundwater

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	On-Site (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model	Total (kilograms)	Percent Change from 2011 Calibrated Model	Percent Change from 2014 Calibrated Model
2011 Calibrated Model	1,334	NA	NA	1,639	NA	NA	2,973	NA	NA
2014 Calibrated Model	869	35%	NA	911	44%	NA	1,780	40%	NA
Acid Plant Removal	562	58%	35%	679	59%	25%	1,241	58%	30%
Low Retardation Parameters	575	57%	34%	689	58%	24%	1,264	57%	29%
High Retardation Parameters	560	58%	36%	671	59%	26%	1,231	59%	31%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for arsenic is 0.01 mg/L.

Predictive results are from stress period 66 of the model.

Results are fron NewFields (2016a).

Table 7.4a

Phase 4 Sensitivity - Change in Volume of Groundwater with Selenium Concentrations Above the MCL

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Downgradient (acre-feet)	Percent Change from 2014 Calibrated Model
2014 Calibration	662	NA
10% Recharge in Slag Pile	141	79%
25% Recharge in Slag Pile	288	56%
75% Recharge in Slag Pile	914	-38%

Table 7.4b

Phase 4 Sensitivity - Change in Selenium Mass Flux Across Site Boundary

Former ASARCO East Helena Smelter, East Helena, Montana

Simulation	Mass Flux (miligrams per day)	Percent Change from 2014 Calibrated Model
2014 Calibration	312,935	NA
10% Recharge in Slag Pile	150,212	52%
25% Recharge in Slag Pile	189,546	39%
75% Recharge in Slag Pile	382,723	-22%

Notes:

NA = Not Applicable. A negative value indicates an increase.

U.S. EPA MCL for selenium is 0.05 mg/L.

Results are fron NewFields (2016b).