South Fork of the Coeur d'Alene River Watershed: Basinwide Groundwater Flow Model Documentation

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South Fork of the Coeur d'Alene River Watershed: Basinwide Groundwater Flow Model Documentation

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Introduction

This Technical Memorandum (TM) describes the development and calibration of a groundwater flow model for the South Fork of the Coeur d'Alene River (SFCDR) Watershed. The objectives of this effort were to:

- Develop a numerical tool capable of defining the spatially varying water budget in the SFCDR Watershed.
- Use model-simulated flows between the groundwater and surface water systems along with measured dissolved metals concentrations in monitoring wells to estimate a metals loading budget.
- Apply this tool to evaluate potential remedial actions within Operable Units (OUs) 2 and 3 of the Bunker Hill Mining and Metallurgical Complex Superfund Site.

A similar numerical tool was developed for the evaluation of potential remedial actions within the Canyon Creek drainage area (CH2M HILL, 2007). The properties from the calibrated Canyon Creek model are included in the SFCDR model; however, the spatial resolution of the Canyon Creek drainage area in the SFCDR model is coarser (i.e., has a larger nodal density). Any future screening of potential remedial actions in the Canyon Creek drainage area will use the site-specific model.

The first step in developing the groundwater flow model for the SFCDR Watershed was to generate a conceptual model of the hydrologic system based on previous field investigations and data collection efforts. The conceptual model starts with the general physical

characteristics of the geologic materials present, then encompasses the Watershed hydrogeology and the movement of water through the Watershed. The conceptual model concludes with the associated transport of dissolved metals from the source areas, moving through the groundwater system, and finally discharging to the surface water system.

The following discussion summarizes the detailed descriptions of the physical setting presented in the *Remedial Investigation Report, Coeur d'Alene Basin Remedial Investigation/ Feasibility Study, Final (Revision 2)* (U.S. Environmental Protection Agency, 2001) and the *Current Status, Conceptual Site Model, Operable Unit 2, Bunker Hill Mining and Metallurgical Complex Superfund Site* (CH2M HILL, 2006).

Geologic Setting

Geomorphology

The SFCDR Watershed occupies approximately 300 square miles of land surface in the Panhandle of northern Idaho (Figure 1). The SFCDR flows approximately 35 miles from its headwaters in the Bitterroot Mountains to its confluence with the North Fork of the Coeur d'Alene River (NFCDR) near Enaville. The topographic relief in the Watershed is approximately 4,000 feet, with elevations ranging from 2,160 feet above mean sea level (msl) near the confluence of the SFCDR and NFCDR to 6,000 to 7,000 feet above msl in the Bitterroot Mountains. The SFCDR, upstream of Wallace, and its major tributaries are characterized by narrow, steep-walled (V-shaped) canyons with high relief. West of Wallace, the SFCDR canyon transitions to a wider U-shaped valley with a lower topographic gradient.

Lithology

Bedrock within the SFCDR Watershed is assigned to the Precambrian Belt Supergroup. The bedrock units consist of fine-grained clastic sediments originally deposited in a large north-to-northwest-trending geosyncline, resulting in a structural depression covering central and northern Idaho, western Montana, and southeastern British Columbia. The Belt Supergroup is composed of (in order of decreasing age) the Prichard, Burke, Revett, St. Regis, Wallace, and Striped Peak Formations. Sediments of the Belt Supergroup have been slightly metamorphosed on a regional scale; the dominant lithologies within these units are quartzites, dolomites, and argillites. Figure 2 presents a geologic map of the SFCDR Watershed, modified from Zientek et al. (2005).

Unconsolidated deposits in the SFCDR Watershed are composed of a heterogeneous mixture of clay, silt, sand, gravels, cobbles, and boulders resulting from the erosion of the Belt Supergroup, reworked glacial deposits, and recent volcanic ash. Sediments have been deposited in a variety of settings ranging from low-energy lacustrine to high-energy fluvial environments. The thickness of Quaternary deposits in the SFCDR valley ranges from 30 feet near Wallace to more than 150 feet near the confluence of the NFCDR and SFCDR at the western boundary of the Watershed.

Structural Geology

The SFCDR Watershed is located in an area of complex folding, faulting, and shearing. The dominant structural feature within the basin is the Osburn Fault, an approximately 100-mile-long east-west-trending strike-slip fault with approximately 16 miles of right-

lateral displacement. In addition to the Osburn Fault, two other sets of faults are present within the SFCDR Watershed. One set trends west-northwest, roughly parallel to the Osburn Fault, while the other trends north-south. Structural features within the Watershed are shown on Figure 2.

Hydrogeology

The hydrogeology of the SFCDR Watershed can be divided into two main aquifer systems: the bedrock aquifer and the alluvial aquifer. The bedrock aquifer consists primarily of the Precambrian formations of the Belt Supergroup. In general, the bedrock has very low permeability; however, secondary features, such as fractures, faults, or mine workings, may substantially increase the permeability in some areas.

Unconsolidated deposits within the SFCDR and tributary alluvial valleys generally form a network of shallow unconfined aquifers. Figure 2 presents the extent of the alluvial deposits, modified from data mapped by the U.S. Geological Survey (USGS) (Zientek et al., 2005). In most of the Watershed, unconsolidated deposits form a single unconfined alluvial aquifer. Within the Bunker Hill Box (the Box), the alluvial aquifer system is divided into an unconfined Upper Aquifer (UA) and a confined Lower Aquifer (LA), separated by a low-permeability lacustrine deposit referred to as the Confining Unit (CU). (The Box is the approximately 21-square-mile area that defines the boundary of OUs 1 and 2.)

Alluvial aquifer systems in the tributary gulches generally have a relatively steep hydraulic gradient, similar to the gradient of the local topography, while the alluvial aquifer system underlying the SFCDR has a lower hydraulic gradient. Aquifer systems in both tributary gulches and the main SFCDR valley are sustained by leakage from surface water, deep percolation of precipitation, or groundwater discharge from the bedrock aquifer system. Groundwater in these shallow alluvial aquifer systems tends to flow down-valley, with flowlines refracted towards or away from streams near gaining and losing stream reaches. (A gaining stream reach is an area where groundwater discharges to the surface water body, while a losing stream reach is an area where the surface water infiltrates, recharging the groundwater system.)

Along the main channel of the SFCDR, the configuration of the bedrock surface significantly affects the nature of groundwater flow patterns and the magnitude of hydraulic gradients. In areas where the SFCDR valley is constricted by bedrock narrows, the smaller cross-sectional area of aquifer available for flow tends to steepen hydraulic gradients and forces groundwater upward, creating areas of groundwater discharge to the SFCDR. In areas where the bedrock surface widens and aquifer transmissivity increases, hydraulic gradients tend to decrease, and the SFCDR loses water to the underlying aquifer. In the Box, the presence of the CU creates a barrier to vertical flow between the UA and LA. Limited vertical flow creates head differences of up to 10 feet between the aquifer systems. Figures 3 and 4 present groundwater elevation contour maps for the Box and Osburn Flats, respectively, developed from data collected in the fall of 2008.

Groundwater Conditions

Groundwater elevations in the alluvial and bedrock aquifer systems fluctuate seasonally. Few data are available to evaluate the magnitude of these fluctuations in the bedrock system

in the SFCDR Watershed. In the alluvial aquifer systems, the lowest groundwater levels are generally observed toward the end of the dry season (August and September), when sources of recharge are minimal and the groundwater basin is continuously discharging baseflow to the SFCDR and tributary streams. The highest groundwater levels are observed over the winter and spring months, when the Basin is recharged by precipitation, snowmelt, adit drainage, and leakage from losing stream reaches. The magnitude of seasonal fluctuations varies within the Watershed. Wells in upland tributary gulches, such as the Woodland Park area of the Canyon Creek drainage area and the Government Creek drainage area, typically fluctuate between 1 and 5 feet seasonally, with wells near losing stream reaches having larger fluctuations than those near gaining stream reaches. Within the Box, seasonal fluctuations in the UA typically range from 5 to 10 feet. Wells in the LA generally have smaller seasonal fluctuations, typically less than 3 feet. The monitoring network in Osburn Flats was established in the fall of 2008, and insufficient data are currently available to evaluate seasonal fluctuations in groundwater levels in this area.

Hydrology

The SFCDR is the main surface water feature of the Watershed. The headwaters of the stream are located in the Bitterroot Mountains near the Idaho-Montana state line at an elevation of approximately 6,000 feet above msl. The stream flows westward towards the town of Enaville (whose elevation is approximately 2,000 feet above msl), where it joins the NFCDR to form the main stem of the Coeur d'Alene River. Major tributaries of the SFCDR include Canyon Creek, Ninemile Creek, Placer Creek, Moon Creek, Big Creek, Milo Creek, Government Creek, and Pine Creek. High-gradient streams in the SFCDR Watershed predominantly contain water produced by melting snow. Peak discharge generally occurs in late spring and early summer as the snowpack melts, and discharge decreases through the summer and fall. Seasonal low stream discharge occurs during the fall, when streamflow is sustained primarily through groundwater discharge to the stream (baseflow). Large discharge events frequently occur during winter periods when storms produce "rain on snow" events. Over the past 10 years, annual maximum mean daily discharge of the SFCDR near Pinehurst has ranged from approximately 1,500 to nearly 6,500 cubic feet per second (cfs), while baseflow has generally been approximately 100 cfs (Figure 5).

Groundwater-Surface Water Interaction

The hydraulic interaction between the groundwater and surface water systems has been investigated at several locations within the SFCDR Watershed: the Woodland Park area of Canyon Creek, Osburn Flats, and the Box. Data collected have included continuous stream stage information along with groundwater elevation data from shallow and deep well pairs near the stream channel, the results of several groundwater-surface water interaction studies involving *in-situ* measurements of hydraulic gradients between the stream and shallow groundwater, and measurements of stream discharge at discrete sampling stations. *In-situ* measurements of hydraulic gradients between the stream and shallow groundwater systems, such as those measured during the 1999 USGS groundwater-surface water interaction study (Barton, 2002) and subsequently replicated by CH2M HILL, provide data at multiple locations over a specified stream reach for a narrow time-frame (generally three consecutive days during the baseflow period). Figures 6 and 7 present the general locations of gaining and losing stream reaches of the SFCDR measured during groundwater-surface

water interaction studies conducted in the Box and Osburn Flats, respectively, in September 2008 (CH2M HILL, 2009b, 2009c). Previous studies performed by CH2M HILL and USGS generally showed the same trends as the 2008 studies, with slight variations in the locations of gaining and losing stream reaches. These data were used as qualitative calibration targets during the development of the groundwater flow model, as discussed in the "Model Calibration" section of this TM.

Groundwater and surface water elevations collected in well clusters indicate longer-term trends in groundwater-surface water interaction at fewer geographic locations than *in situ* groundwater-surface water interaction studies. The groundwater elevation data collected during high stream stage events show the propagation of the pressure wave caused by the stream stage increase moving through the groundwater system. These data not only show whether the stream reach near the well cluster is gaining or losing, but also can be used in conjunction with the groundwater flow model for the SFCDR Watershed to calibrate the degree of hydraulic connection between the groundwater and surface water systems, and the flow of groundwater into, or out of, a particular stream reach. A description of how this type of data was used in the current numerical modeling effort is presented in the "Model Calibration" section.

Model Development

Software

MicroFEM© (Hemker and Nijsten, 2003), an integrated groundwater modeling software program developed in the Netherlands, was chosen to simulate the groundwater flow system in the SFCDR Watershed. MicroFEM is a widely used groundwater modeling platform that has been applied to a variety of hydrologic problems ranging from local-scale models of small industrial sites to regional-scale models of large groundwater basins. The current version of the program (4.0) has the ability to simulate up to 25 layers and 250,000 surface nodes. MicroFEM is capable of modeling saturated, single-density groundwater flow in layered systems. MicroFEM was the chosen modeling platform for the SFCDR Watershed for the following reasons:

- The finite-element gridding algorithm allowed for the construction of a model grid covering large geographic areas (nearly 300 square miles) with coarse node spacing outside the area of interest and finer node spacing in areas of interest (e.g., the Central Impoundment Area [CIA] and Osburn Flats areas). The finer node spacing in the area of interest provides greater resolution of simulated groundwater levels and stream impacts.
- The graphical interface allows rapid assignment of aquifer parameters and verification of these values by graphical means.

Model Grid

The SFCDR Watershed model grid consists of 134,535 surface nodes and 268,631 elements in each of the seven model layers described below (Figure 8). Nodal spacing varies from approximately 25 feet in the CIA area to as much as 1,000 feet near the model boundary. Nodal spacing was refined to 50 feet in the Osburn Flats, Page Ponds, and East Fork

Ninemile Creek areas in order to provide greater resolution when simulating potential remedial actions. Nodal spacing along the alluvial deposits underlying the SFCDR is approximately 100 feet, while nodal spacing within tributary drainage areas is approximately 250 feet. The finer spacing in the areas of interest allows for a more refined estimate of the groundwater levels and groundwater-surface water interaction. The lateral extent of the model grid represents the approximate extent of the SFCDR Watershed, roughly 300 square miles, as defined by the topographic divide (ridgeline).

For the purposes of model layering, the aquifer systems in the SFCDR Watershed were divided into the two categories described previously, the bedrock aquifer system and the alluvial aquifer system. Underlying the SFCDR alluvial aquifers, the bedrock aquifer system was further subdivided into three layers: a thin layer of weathered bedrock and two thicker layers of indurated bedrock. Outside the extent of alluvium, the bedrock aquifer is represented by up to seven model layers. The alluvial aquifer system in the SFCDR valley was divided into four model layers. In the Box two layers are used to represent the UA, one layer is used to simulate the CU, and one layer is used to simulate the LA. Beyond the extent of the CU, all four layers represent one alluvial aquifer system. The vertical discretization allows for refined estimates of groundwater surface water interaction and the ability to vary properties with depth. Field data were used, where available, to layer the model. Where no measurements were available, assumptions regarding the thicknesses of the various units were made based on knowledge of typical geomorphology of watersheds in mountains regions.

Because groundwater flow in the SFCDR Watershed is controlled primarily by the alluvial deposits, contours of the thickness of the various hydrostratigraphic units were developed to discretize the model vertically. The first step in model layering was the development of an accurate topographic coverage. Accurate elevations were also critical because the purpose of the model was to evaluate changes in the hydraulic relationship between the groundwater and surface water systems, which are controlled by differences in stream stage and hydraulic head. The process began with downloading a 10-meter digital elevation model from the USGS's National Elevation Dataset (NED).[1] Because of the age of the dataset and the fairly coarse resolution, additional topographic datasets were incorporated into the final topographic coverage. Sources of higher resolution data included:

- The 2-foot topographic contours developed for the Box by the U.S. Army Corps of Engineers
- Ground surface elevations surveyed at individual well points within the Box
- Ground surface elevations collected by Terragraphics as part of the tailings repository expansion work in the Page Ponds area in July 2008 (these data have not yet been published)
- The Canyon Creek topographic coverage developed as part of the Canyon Creek Hydrologic Study (CH2M HILL, 2007).

Additionally, in areas adjacent to the SFCDR where the ground surface elevation was lower than the stream elevation, the topographic coverage was adjusted by increasing the ground

[1] http://seamless.usgs.gov/

surface elevation by 4 feet. Figure 9 is a contour map of the ground surface elevation data within the extent of saturated alluvium in the Box.

The second component of creating the alluvial isopach distribution was to generate a contour map of the alluvium/bedrock contact. Depth to bedrock data (in feet below ground surface [bgs]) were obtained from boring logs for both project monitoring wells and logs obtained through the Idaho Department of Water Resources website.[2] A bedrock elevation coverage, for the SFCDR alluvial valley between Wallace and the western model boundary, was generated by subtracting the depth to bedrock contours from the topographic coverage. As data from the groundwater monitoring well installation program in Osburn Flats became available, the initial bedrock elevation contours in this area were updated (CH2M HILL, 2009a). Figures 10 and 11 present the alluvium/bedrock contact data as bedrock elevation contour maps for the Box and Osburn Flats, respectively. It was assumed that the bedrock elevation is equal to the land surface elevation beyond the lateral extent of alluvium. The total saturated alluvial thickness was calculated by subtracting the bedrock elevation from the 2008 groundwater elevation (Figures 3 and 4). Because the majority of the data were concentrated in the Box and Osburn Flats, the following simplifying assumptions were made:

- For numerical stability purposes, the total saturated alluvial thickness was assumed to have a minimum value of 8 feet at the lateral extent of the valley-fill deposits, as mapped by the USGS (Derkey et al., 1996, and Zientek et al., 2005).
- Total saturated alluvial thickness within smaller tributary valleys was assumed to be 15 feet.
- Total saturated alluvial thickness within larger tributary valleys was assumed to be between 20 and 25 feet.
- Total saturated alluvial thickness within the Canyon Creek Watershed was taken from the calibrated groundwater flow model for this area (CH2M HILL, 2007).
- Total saturated alluvial thickness within the SFCDR valley from Wallace east to the model boundary was assumed to be 25 feet along the SFCDR, transitioning to as little as 8 feet along the lateral extent of alluvium.

The first four (of the seven) model layers were assigned properties of the unconsolidated sediments. Within the Box, as noted previously, the alluvial aquifer system is divided into two units, the UA and the LA, separated by a fine-grained lacustrine deposit, the CU. The CU is a westward thickening wedge beginning in central Kellogg and extending to the western model boundary. The CU is also present in the lower Pine Creek valley. Figure 12 presents a contour map of the CU thicknesses. The thicknesses of the UA and LA were calculated based on the elevation of the top and bottom of the CU compared to the total saturated thickness of the alluvial deposits. Figures 13 and 14 present isopach maps of the UA and the LA, respectively.

Where the CU is present, model layering within the SFCDR valley-fill deposits was performed as follows:

[2] http://www.idwr.idaho.gov/

- Where the saturated alluvial thickness of the UA was greater than 20 feet, model layer 1 was assigned a thickness of 10 feet and the remainder was apportioned to model layer 2.
- Where the saturated alluvial thickness of the UA was less than 20 feet, the total UA thickness was divided equally between model layers 1 and 2.
- Layer 3 was assigned the thickness of the CU, as shown on Figure 12.
- Layer 4 was assigned the thickness of the LA, as shown on Figure 14.
- The minimum saturated thickness of layers 1 through 4 was assumed to be 2 feet per layer.

Figure 15 presents a schematic cross-section through the Box showing the model layering with respect to the various geologic units.

Beyond the eastern extent of the CU, model layers 1 through 4 within the SFCDR valley-fill deposits were discretized as follows:

- Where the total saturated alluvial thickness was greater than 40 feet, model layer 1 was assigned a thickness of 10 feet and the remainder was apportioned equally to model layers 2 through 4.
- Where the total saturated alluvial thickness was less than 40 feet, the total thickness was apportioned equally to model layers 1 through 4.
- The minimum saturated thickness of layers 1 through 4 was assumed to be 2 feet per layer.

Figure 16 presents an isopach map of saturated alluvial thickness in Osburn Flats. Within the tributary alluvial valleys, the total saturated thickness was apportioned as follows:

- Within smaller tributary valleys, model layer 1 was assigned a thickness of 15 feet to the lateral extent of alluvium mapped by the USGS (Derkey et al., 1996, and Zientek et al., 2005).
- Within larger tributary valleys, model layer 1 was assigned a thickness of 10 feet and model layer 2 was assigned a thickness of 10 to 15 feet, to the lateral extent of alluvium mapped by the USGS (Derkey et al., 1996, and Zientek et al., 2005). In the upper reaches, larger tributary valleys transition from two layers of alluvium, with a total thickness of 20 to 25 feet, to one layer of alluvium with a thickness of 15 feet.

Model layers used to represent the alluvial aquifer systems were assigned variable thicknesses, thinning laterally towards the extent of mapped alluvium. The bedrock layers were assigned constant thicknesses, as described below. In order to provide a smooth transition in aquifer properties between the relatively thin alluvial model layers and the relatively thick bedrock model layers, an approximately 1,500-foot buffer was used. Within this buffer, the model layers increase in thickness from the minimum alluvial thicknesses to the constant thicknesses of the bedrock layers.

Beyond the lateral extent of the alluvial deposits, the bedrock system was discretized vertically as follows:

- Model layers 1 through 4 transition from the minimum thicknesses at the extent of alluvium to a uniform thickness of 100 feet in each layer.
- Model layer 5 was assigned a uniform thickness of 5 feet.
- Model layer 6 was assigned a uniform thickness of 200 feet.
- Model layer 7 was assigned a uniform thickness of 400 feet.

Boundary Conditions

Boundary conditions are mathematical statements describing either the head or the flux within a model domain (Anderson and Woessner, 1992). Correct selection of boundary conditions is a critical step in model construction because boundaries largely determine the flow pattern in steady-state models. Boundary conditions can represent either physical boundaries, such as impermeable rock, or hydraulic boundaries, such as groundwater divides or streamlines. The three types of boundary conditions are as follows:

- Specified-flux boundaries, where a prescribed flux is defined along the boundary
- Head-dependent flow boundaries, where the flux across the boundary is calculated as a function of a defined head and a conductance term (which regulates seepage)
- Specified-head boundaries, where a constant head is defined along the boundary

A specified-flux boundary condition [was used to simulate deep percolation of precipitation within the SFCDR Watershed. Long-term (1971-2000) average annual precipitation data were downloaded from the website of the PRISM Group at Oregon State University.[3] These data are available in gridded form on 800-meter centers. A modification of the Turner (1986) approximation was used to convert the annual average precipitation to deep percolation of precipitation to the water table. The modified Turner approximation is as follows.

$$DP = PPN - 2.32 * PPN^{0.66} \quad (1)$$

where:

DP = Deep percolation of precipitation (inches per year)
PPN = Average annual precipitation (inches per year)

During model calibration, the distribution of deep percolation was scaled down between 50 and 75 percent to be consistent with the average annual baseflow in the SFCDR, as measured at the USGS stream gauge station at Pinehurst,[4] of approximately 100 cfs. Figure 17 presents the final distribution of deep percolation of precipitation simulated in the model.

Specified-flux boundaries were also used to simulate the seepage of wastewater from the Page and Smelterville wastewater treatment ponds. A study by Ralston Hydrologic Services

[3] http://prism.oregonstate.edu/
[4] http://nwis.waterdata.usgs.gov/id/nwis/qwdata/?site_no=12413470&agency_cd=USGS

(RHS, 2007) concluded that the total seepage from Page Ponds is approximately 71 gallons per minute (gpm). This value was apportioned to all nodes representing the extent of the ponds based on nodal area. As no estimates of seepage from the Smelterville wastewater treatment ponds were available, it was assumed that these ponds have the same leakage rate per unit area as the Page Ponds. This resulted in a total leakage rate of 12 gpm, which was apportioned to all nodes used to simulate the ponds based on nodal area.

A no-flow boundary is a special condition of a specified flux boundary, where the flow across the boundary is set equal to zero. A no-flow boundary was used along the entire model boundary (with the exception of the constant head boundaries described above) for all model layers to simulate the lateral extent of the groundwater basin. A no-flow boundary was also specified for the bottom boundary of the model.

A head-dependent boundary condition was assigned to model layer 1 to simulate 62 of the major streams, including the SFCDR and its braided channels, within the SFCDR Watershed. The MicroFEM wadi package was used to implement these hydrologic features within the model domain. The locations of the stream channels were digitized from aerial photographs and USGS quadrangle sheets of the Watershed. Throughout the area of the model where nodal spacing was refined, the locations of both stream banks were digitized. This allowed the flexibility to assign a wadi boundary condition to multiple nodes in areas where the stream channel width was greater than the nodal spacing. Electronic files containing stream locations were imported into the model domain. MicroFEM's wadi package calculates the magnitude and direction of nodal fluxes based on the relative values of stream stage and the head in the aquifer.

Groundwater discharge to a stream is simulated as follows:

If $h_1 > wh_1$:

$$Q_{outflow} = \frac{a * (h_1 - wh_1)}{|wc_1|} \tag{2}$$

In coupled streams (groundwater elevation is above the stream bottom elevation), groundwater recharge from a stream is simulated as follows:

If $h_1 < wh_1$ and $h_1 > wl_1$:

$$Q_{\inf low} = \frac{a * (wh_1 - h_1)}{|wc_1|} \tag{3}$$

In de-coupled streams (groundwater elevation is below the stream bottom elevation), groundwater recharge from a stream is simulated as follows:

If $h_1 < wh_1$ and $h_1 < wl_1$:

$$Q_{\inf low} = \frac{a * (wh_1 - wl_1)}{|wc_1|} \tag{4}$$

where:

Q = Volumetric flow (cubic feet per day)
a = Nodal area (square feet)
h_1 = Simulated head in layer 1 (feet)
wh_1 = Simulated stream stage (feet)
wl_1 = Stream bottom elevation (feet)
wc_1 = Resistance across the stream bed ($days^{-1}$)

The stream stage (wh_1) distribution was developed from a combination of available stream stage survey data points (primarily for the SFCDR), stream elevation breakpoints digitized from the USGS quadrangles, and data from the calibrated Canyon Creek groundwater flow model. Linear interpolation of stage data was performed between these points in order to estimate stage values for all model nodes used to represent streams. The stream bottom elevation (wl_1) was assumed to be between 2 and 10 feet below the stream stage, depending on the size of the stream.

Nodal area is a grid-dependent parameter that can be automatically calculated by MicroFEM. In general, the area of the actual streambed is less than the nodal area used to represent the stream in the model. The effective resistance term (wc_1) incorporates an areal correction factor to account for this discrepancy. Additionally, streambed resistance accounts for the relationship between the streambed sediments and aquifer properties in the upper half of model layer 1 when calculating stream seepage. Wadi resistances are calculated as follows:

$$wc_1 = \left[\left(\frac{Dr}{Kr} + \frac{(0.5 \cdot mt_1)}{Kv_1}\right] \cdot \left(\frac{a}{LW}\right) \tag{5}$$

where:

wc_1 = Wadi resistance term ($days^{-1}$)

Dr = Thickness of streambed sediments (assumed to be 5 feet)

Kr = Vertical hydraulic conductivity of streambed sediments (assumed to be 1 foot per day)

mt_1 = Saturated thickness of model layer 1 (feet)

Kv_1 = Vertical hydraulic conductivity of model layer 1 (feet per day)

L = Stream length represented by the model node (feet)

W = Field width of the wetted river channel within the stream reach represented by L (square feet)

Although estimates of wc_1 were made during preliminary model development, this term was optimized during model calibration for the SFCDR between the Elizabeth Park and Pinehurst stream gauges. Additionally, wc_1 values for Canyon Creek were taken from the calibrated groundwater flow model for the SFCDR Watershed. Further, to limit leakage from or groundwater discharge to streams flowing through culverts, the wc_1 in these areas was assigned a relatively high value of 5,000 $days^{-1}$.

A wadi boundary condition was also used to represent the standing water within the Hecla-Star Tailings Pond 6 (in the Woodland Park area of the Canyon Creek drainage area), the Osburn Tailings Ponds, and portions of the Page Swamps where the land surface elevation is lower than the elevation of the weirs. The extent of the Page Swamps was digitized from aerial photography and imported onto the model grid. It was assumed that the pond stage (wh_1) was equal to the land surface. The pond bottom elevation (wl_1) was assumed to be 10 feet below the pond stage. The assumptions for components of the wadi resistance term were the same as those listed above for streams. No areal correction was made to the wadi resistance term, because it was assumed that the ponded water encompassed the entire area of each node that was assigned wadi parameters.

A final head-dependent boundary, the MicroFEM drain package, was used to represent hydraulic features not explicitly simulated in the SFCDR model. These features include small tributaries, areas of the Page Swamps where the land surface elevation is higher than the weir elevation, and areas where groundwater discharges to the land surface. The drain package differs from the wadi package in that it is a one-way boundary condition, only removing water from the model. MicroFEM calculates the magnitude of nodal fluxes based on the drain elevation and head in the aquifer as follows:

If $h_1 > dh_1$:

$$Q_{outflow} = \frac{a * (h_1 - dh_1)}{|dc_1|} \tag{6}$$

If $h_1 < dh_1$:

$$Q_{outflow} = 0 \tag{7}$$

where:

Q = Volumetric flow (cubic feet per day)
a = Nodal area (square feet)
h_1 = Simulated head in model layer 1 (feet)
dh_1 = Simulated drainage elevation (feet)
dc_1 = Resistance across the drainage surface ($days^{-1}$)

The drain elevations were set equal to land surface elevations for all nodes. The drain resistance term was calculated by:

$$dc1 = \frac{mt1^2 / 2}{T1} \tag{8}$$

where:

dc_1 = Drain conductance term ($days^{-1}$)
mt_1 = Saturated thickness of model layer 1 (feet)
T_1 = Transmissivity of model layer 1 (square feet per day)

A constant head boundary condition was assigned to the SFCDR alluvial valley at the western model boundary for model layers 1 through 4. The constant head in layers 1 and 2 were set equal to the stream stage at the western model boundary. The constant head in

layer 4 was estimated by the hydraulic gradient between the two LA monitoring wells closest to the western boundary. The constant head in layer 3 was set mid-way between the head of layers 2 and 4.

Aquifer Properties

Hydraulic Conductivity Distribution

Aquifer testing programs usually employ analytical solutions to estimate aquifer transmissivity from observed field data (typically using the measured specific capacity of the pumping well or time versus drawdown analysis). Hydraulic conductivity can then be calculated by dividing the estimated transmissivity by some assumed saturated thickness, generally the length of the well screen, the total depth of the well, or the total saturated thickness of the aquifer at the time of the test, by:

$$K = \frac{T}{b} \tag{9}$$

where:

K = Hydraulic conductivity (feet per day)
T = Transmissivity (square feet per day)
b = Saturated thickness (feet)

During construction of the groundwater flow model for the SFCDR Watershed, available hydraulic conductivity data were generally limited to those collected during past aquifer testing programs within the Box and the Canyon Creek drainage area. Between March and May 2003, hydraulic data were collected from approximately 70 wells within the Box during sampling and redevelopment of groundwater monitoring wells (CH2M HILL, 2004). Data from these single-well pumping tests were re-evaluated and used to develop the initial distribution of hydraulic conductivity for the SFCDR alluvial aquifer systems. Additional assumptions that influenced the initial distribution of aquifer properties were as follows:

- Re-evaluated data from single-well aquifer tests in the Box were interpolated across the Box to develop the initial distribution of hydraulic conductivity of the UA, ranging from approximately 112 feet/day in the narrows between Kellogg and Smelterville to nearly 1,400 feet per day in the wider portions of the SFCDR valley.
- The hydraulic conductivity of the LA was assumed to be half that of the UA.
- The hydraulic conductivity of the CU was assigned a constant value of 0.2835 feet/day [10^{-4} centimeters/second (cm/sec)]
- Beyond the assumed eastern extent of the CU, model layers 1 through 4 were assigned the same hydraulic conductivity values, based on data from the 2003 field program.
- From the eastern extent of available hydraulic data from the 2003 field program to Wallace (including Osburn Flats), the hydraulic conductivity of the SFCDR alluvial system was assumed to be 600 feet/day.
- From Wallace to the eastern model boundary, the hydraulic conductivity of the SFCDR alluvial system was assumed to be 100 feet/day.

- The hydraulic conductivity within the alluvial aquifers of smaller tributary gulches was assumed to be 10 feet/day.
- The hydraulic conductivity within the alluvial aquifers of larger tributary gulches was assumed to be 60 feet/day.
- The hydraulic conductivity distribution for the Canyon Creek drainage area was taken from the calibrated groundwater flow model for that watershed (CH2M HILL, 2007).
- The hydraulic conductivity of the weathered bedrock underlying the SFCDR alluvial aquifer system (model layer 5) was assumed to be 1 foot/day.
- The hydraulic conductivity of the competent bedrock (model layers 1 through 5 outside of the lateral extent of the alluvial aquifer, and model layers 6 and 7 throughout the model domain) was assigned a uniform value of 0.028 feet/day (10^{-5} centimeters/second).

Both the spatial distribution of and range in hydraulic conductivity values were adjusted as part of the model calibration process (see the "Model Calibration" section). As part of model calibration, the groundwater flow model for the SFCDR Watershed was updated with estimates of aquifer properties modified from hydraulic data collected during aquifer testing of new groundwater monitoring wells in Osburn Flats (CH2M HILL, 2009d). The final distributions of hydraulic conductivity for the UA, the LA, and the alluvial aquifer system in Osburn Flats are shown on Figures 18 through 20, respectively. The hydraulic conductivity of the UA was not changed during model calibration. Various configurations of hydraulic conductivity of the CU were tested during calibration; however, the final value was ultimately the same as the initial value (10^{-4} cm/sec). Final model calibration resulted in deviations from the initial hydraulic conductivity distributions as follows:

- The hydraulic conductivity of the LA was ultimately set equal to that of the UA, and was modified during calibration such that the values in the eastern portion were increased by 50 percent and those in the western portion were decreased by 50 percent.
- From the eastern extent of available hydraulic data from the 2003 field program to Wallace (except where updated with data from aquifer testing at Osburn Flats), the hydraulic conductivity of the SFCDR alluvial system was assumed to be 400 feet/day.
- A "window" in the CU was assigned at the mouth of Government Creek, where the hydraulic conductivity of the CU was set equal to that of the UA as observed in soil boring logs for monitoring well Transect 4 (CH2M HILL, 2006).
- The hydraulic conductivity of the indurated bedrock was assumed to decrease with depth, and was assigned values ranging from 10^{-5} cm/sec in model layer 1 to 10^{-9} cm/sec in model layer 7.

The initial assumptions regarding the horizontal to vertical hydraulic conductivity ratio (Kh:Kv) were that the bedrock was isotropic (Kh:Kv ratio equals 1) and the Kh:Kv ratio of the alluvial sediments was 10. MicroFEM uses the vertical resistance term to calculate flow between model layers by:

$$Vx = \frac{mt_x / 2}{T_x / mt_x / AF} + \frac{mt_{x+1} / 2}{T_{x+1} / mt_{x+1} / AF} \tag{10}$$

where:

V_x = Vertical resistance to flow of model layer x (days^{-1})
mt_x = Saturated thickness of model layer x (feet)
T_x = Transmissivity of model layer x (square feet per day)
AF = Anistropy factor (Kh:Kv ratio)

Extremely low values of vertical resistance to flow between model layers can create instability in the numerical solution, causing the model to not meet specified convergence criteria. In order to increase the stability of the numerical solution, the vertical resistance term was increased by two orders of magnitude in the alluvial aquifer system. This implies an increase in the Kh:Kv ratio from 10 to 1,000, meaning that groundwater flows more readily in the horizontal direction than in the vertical.

Storage Coefficient Distribution

The majority of model calibration assumed steady-state baseflow conditions; therefore, aquifer storage was assumed to be zero throughout the model domain. For transient calibration to the spring runoff period (discussed in the following section), aquifer-specific yield was assumed to be 10 percent in model layers 1 and 2 in the unconfined alluvial materials, and the storativity was calculated as the specific storage (2×10^{-6} ft^{-1}) multiplied by the layer thickness (in feet) in the bedrock areas of model layers 1 and 2 and for layers 3 through 7 throughout the model domain.

Model Calibration

The next step in the development of the numerical groundwater model was to calibrate the model to a series of observed conditions within the SFCDR Watershed. This process ensured that the numerical model could accurately replicate the hydrologic processes observed in the Watershed, and that it was a reliable tool to forecast future hydraulic conditions in response to changes in the natural system that may occur with the implementation of remedial actions. The groundwater flow model was calibrated to a series of observed hydrologic characteristics of the SFCDR Watershed, including:

- Measured baseflow in the SFCDR
- Groundwater elevations measured in monitoring wells in the fall of 2008
- Vertical hydraulic gradients
- Observed gaining and losing stream reaches of the SFCDR
- The response of the aquifer system to high stage events during the spring 2008 runoff period

Each of these calibration targets is discussed in more detail in the following sections, and a comparison between simulated and observed conditions is presented.

SFCDR Baseflow

The first step in the model calibration process was to compare the simulated quantity of groundwater moving through the hydrologic system with the observed baseflow quantities measured in the SFCDR at the USGS stream gauge near Pinehurst[5] during the late fall of 2008. During the late summer months, all significant surface water runoff contributions to streamflow cease; therefore, the remaining flow in the river is sustained by (1) groundwater discharge and (2) discharge from the Central Treatment Plant in Kellogg. When the model is run under steady-state conditions, the simulated baseflow quantities in the SFCDR are defined by the assumed quantity of deep percolation of rainfall and snowmelt across the watershed. As such, the deep percolation of precipitation imposed in the model was adjusted until the simulated baseflow discharge to the SFCDR roughly matched measured baseflow data. The final calibrated model simulated a groundwater discharge to the SFCDR of approximately 130 cfs. This simulated discharge rate is slightly higher than the minimum baseflow value measured in late summer/fall of approximately 100 cfs. This is because the model-simulated value represents an annual average baseflow rate, and baseflow tends to increase during the higher flow winter periods. Therefore, a simulated baseflow value slightly higher than the minimum value observed during late fall is appropriate.

To achieve this calibration condition, the final distribution of deep percolation of precipitation was reduced from the initial distribution described in the "Model Development" section by 75 percent in the bedrock areas and by 50 percent in alluvium. The average annual recharge rate implemented across the model domain was approximately 4.5 inches. Deep percolation rates ranged from approximately 3.5 to 8 inches per year over the majority of the alluvial valleys but were as high as 12.5 inches per year in the upper portions of the SFCDR Watershed, near the headwaters. In the bedrock areas, deep percolation rates ranged from approximately 1.75 to 8.5 inches per year. Because the CIA and the Smelter Closure Area (SCA) are capped, deep percolation of precipitation was assigned a value of zero in these areas. Additionally, because anecdotal evidence suggests that all of the deep percolation falling within the West Fork of the Milo Creek drainage area infiltrates into the mine workings and discharges at the Kellogg Tunnel for treatment at the Central Treatment Plant, rather than recharging the bedrock groundwater system, deep percolation of precipitation was assigned a value of zero within this drainage area.

Groundwater Elevations

The next calibration target evaluated was groundwater elevations measured across the SFCDR Watershed. During this stage of calibration, hydraulic properties of the aquifer materials were adjusted to achieve a suitable match between simulated and observed groundwater elevations in monitoring wells and piezometers within the Watershed. The most recent Basinwide groundwater level dataset available for use as a calibration target that reflects baseflow conditions was collected in September and October 2008. The comparison of simulated versus observed groundwater elevations for that period is presented in Figure 21. This figure illustrates that a very close match between simulated and observed groundwater elevations was achieved by the model. Box wells completed in model layer 1 that show larger residuals between measured and simulated groundwater elevations are those located near the SCA and in the upper portions of the Government Creek drainage

[5] http://nwis.waterdata.usgs.gov/id/nwis/qwdata/?site_no=12413470&agency_cd=USGS

area. Groundwater elevations in these areas are significantly influenced by the complex flow characteristics of the bedrock aquifer that are not explicitly simulated by the groundwater modeling software and, therefore, larger errors are expected. The distribution of residuals between measured and simulated groundwater elevations (simulated minus measured) in map views for the Eastern Box, Western Box, and Osburn Flats areas are presented on Figures 22 through 24, respectively.

The data presented on Figures 22 and 23 indicate that the model does well in replicating groundwater elevations in the UA, with residuals typically within +/- 5 feet. As previously discussed, residuals in the SCA and Government Creek areas are higher, likely due to the conceptualization of the bedrock in these areas. The model-simulated groundwater elevations are approximately 12 to 15 feet higher than those measured in wells BH-SF-E-0104 and BH-SF-E-0201 shown in Figure 22. Historical water-level measurements recorded at these wells have been anomalous, and piezometers were installed in 2008 to refine measurements at these locations. The model does a better job of replicating the measured groundwater elevations at the new piezometers (Figure 22). The model-simulated groundwater elevations in piezometers BH-SF-W-PZ-01 and BH-SF-W-PZ-02 in the Page area (Figure 23) are approximately 20 feet too low. This is likely due to the assumed simulated leakage rates from Page Ponds. It is also possible that these piezometers were completed in a perched system underlying Page Ponds rather than the UA. Figures 22 and 23 also indicate that residuals in LA monitoring wells are higher than those in the UA, but are still less than 15 feet. Residuals presented on Figure 24 show that the model does well in replicating measured groundwater elevations throughout Osburn Flats.

Vertical Hydraulic Gradients

Another important component of the hydrologic system is vertical flow within the alluvial aquifer, particularly between the UA and the LA within the Box. The presence of upward and downward vertical gradients is associated with groundwater recharge and discharge areas, respectively. These vertical gradients can have a significant impact on contaminant migration within the aquifer systems and on assessment of the performance of potential remedial actions. Within the Box, 17 UA/LA well pairs were monitored during the fall 2008 field effort. In the Osburn area, the drilling activities associated with piezometer and monitoring well installation resulted in seven shallow/deep well pairs within the alluvial aquifer system. The match between simulated and observed vertical gradients in groundwater elevations is summarized in Tables 1 and 2 for the Box and Osburn Flats, respectively.

In most of the well pairs in the Box, the model does well in replicating the direction of the vertical gradient, but underestimates the magnitude. In Osburn Flats, the model is able to replicate the direction of the vertical gradients in well pairs in the central portion of the valley, but the directions of simulated vertical gradients near the SFCDR are opposite of those calculated from observed data. The measured data collected at well pairs near the confluence with Twomile Creek show a downward hydraulic gradient in this area, while the model is simulating an upward gradient. Historical in-situ groundwater-surface water interaction studies have suggested that the SFCDR is a gaining stream along this reach. In areas near gaining stream reaches, an upward vertical gradient would be expected. In the well pairs near the confluence with Terror Gulch and near the Osburn Tailings Ponds, downward hydraulic gradients were measured; however, the model is simulating upward gradients. These

stretches of the SFCDR are losing stream reaches, where a downward hydraulic gradient would be expected. The simulated upward gradient is likely the result of simulated groundwater underflow from Terror Gulch and the leakage from the tailings ponds.

TABLE 1
Simulated Versus Observed Vertical Head Gradients in Well Pairs – Bunker Hill Box
South Fork Coeur d'Alene River, Basinwide Groundwater Flow Model Documentation

Well Name	Difference in Well Screen Mid-Points (feet)	Observed Groundwater Elevation (ft above msl)	Observed Vertical Gradient (ft/ft)	Simulated Groundwater Elevation (ft above msl)	Simulated Vertical Gradient (ft/ft)
BH-SF-E-0002 BH-SF-E-0003	35.0	2,341.6 2,341.1	0.012	2,340.03 2,339.94	0.002
BH-SF-E-PZ-03 BH-SF-E-0104	50.5	2,283.4 2,267.5	0.315	2,287.15 2,283.11	0.080
BH-SF-E-0202-U BH-SF-E-0203-L	50.5	2,275.8 2,267.0	0.175	2,277.97 2,275.87	0.042
BH-SF-E-0301-U BH-SF-E-0302-L	53.0	2,268.3 2,265.2	0.059	2,271.41 2,269.92	0.028
BH-SF-E-0306-U BH-SF-E-0305-L	42.5	2,266.2 2,265.6	0.014	2,270.25 2,269.95	0.007
BH-SF-E-0309-U BH-SF-E-0310-L	45.5	2,272.4 2,266.4	0.133	2,271.06 2,270.16	0.020
BH-SF-E-0314-U BH-SF-E-0315-U	6.0	2,269.7 2,269.6	0.027	2,268.49 2,268.27	0.037
BH-SF-E-0423-U BH-SF-E-0424-L	62.0	2,243.5 2,244.8	-0.021	2,246.01 2,250.91	-0.079
BH-SF-E-0425-U BH-SF-E-0426-L	51.0	2,243.1 2,241.7	0.027	2,246.00 2,248.52	-0.049
BH-SF-E-0427-U BH-SF-E-0428-L	58.5	2,246.6 2,240.7	0.100	2,248.31 2,249.85	-0.026
BH-SF-W-0003-U BH-SF-W-0004-L	66.5	2,214.4 2,215.4	-0.014	2,219.39 2,218.53	0.013
BH-SF-W-0005-U BH-SF-W-0006-L	75.0	2,215.6 ,2218.4	-0.037	2,217.72 2,216.98	0.010
BH-SF-W-0010-U BH-SF-W-0011-L	59.0	2,210.2 2,209.5	0.012	2,208.91 2,209.51	-0.010
BH-SF-W-0121-U BH-SF-W-0122-L	72.5	2,188.8 2,194.4	-0.077	2,188.57 2,188.71	-0.002
BH-SF-W-0201-U BH-SF-W-0202-L	92.5	2,187.0 2,190.9	-0.042	2,186.12 2,186.07	0.001
BH-SF-W-0204-U BH-SF-W-0205-L	100.5	2,172.9 2,171.8	0.011	2,171.25 2,170.44	0.008
BH-SF-W-0206-U BH-SF-W-0207-L	119.0	2,171.7 2,171.0	0.006	2,170.07 2,169.17	0.008

Note:

A positive value indicates a downward vertical gradient.

TABLE 2
Simulated Versus Observed Vertical Head Gradients in Well Pairs – Osburn Flats
South Fork Coeur d'Alene River, Basinwide Groundwater Flow Model Documentation

Well Name	Difference in Well Screen Mid-Points (feet)	Observed Groundwater Elevation (ft above msl)	Observed Vertical Gradient (ft/ft)	Simulated Groundwater Elevation (ft above msl)	Simulated Vertical Gradient (ft/ft)
SF-OB-MW-01S	9.6	2,547.8	0.055	2,543.7	-0.005
SF-OB-MW-01D		2,547.2		2,543.8	
SF-OB-PZ-17	11.3	2,499.5	0.304	2,500.5	-0.067
SF-OB-MW-02		2,496.1		2,501.3	
SF-OB-PZ-24	17.8	2,451.9	0.041	2,451.8	-0.023
SF-OB-MW-03		2,451.1		2,452.3	
SF-OB-MW-06	1.8	2,503.2	-0.003	2,505.3	0.120
SF-OB-PZ-16		2,503.2		2,505.1	
SF-OB-PZ-14	15.4	2,504.5	0.023	2,504.9	0.002
SF-OB-MW-07		2,504.2		2,504.9	
SF-OB-PZ-13	8.1	2,511.3	0.028	2,511.7	-0.042
SF-OB-MW-09		2,511.1		2,512.0	
SF-OB-PZ-23	5.4	2,452.9	0.015	2,455.1	0.030
SF-OB-MW-11		2,452.8		2,455.0	

Note:
A positive value indicates a downward vertical gradient.

Gaining and Losing Stream Reaches of the SFCDR

The next calibration parameter was the observed gaining and losing stream reaches of the SFCDR. In 1999 the USGS studied groundwater-surface water interactions along the SFCDR in Osburn Flats and the Box under baseflow conditions, to gain a better understanding of where groundwater containing dissolved metals enters the SFCDR (Barton, 2002). The USGS study was replicated in the Box in and in Osburn Flats in September 2008 (CH2M HILL, 2009b, 2009c). The baseline study and subsequent studies performed by CH2M HILL provide information on the locations of gaining and losing stream reaches of the SFCDR, which were compared to model predictions. The results of the USGS study and the later CH2M HILL studies generally suggest that within the Box:

- The SFCDR is losing from the eastern boundary of the Box, where the valley widens, to the eastern edge of the CIA.
- The SFCDR is gaining from the eastern edge of the CIA to the valley narrows near the confluence with Government Creek.
- The SFCDR is losing from the narrows near the confluence with Government Creek to mid-way through Smelterville Flats.
- The SFCDR is gaining from mid-way through Smelterville Flats to the Pinehurst narrows.

The results of baseflow groundwater-surface water interaction studies generally suggest that within Osburn Flats:

- The SFCDR is losing from the eastern extent of Osburn Flats, where the valley widens, to just upstream of the confluence with Twomile Creek.
- The SFCDR is gaining from just upstream of the confluence with Twomile Creek west to the valley constriction approximately 0.5 miles upstream from Terror Gulch.
- The SFCDR is losing from the valley constriction approximately 0.5 miles upstream from Terror Gulch to the western edge of Osburn Flats where the valley constricts near the Evolution Mine.
- The SFCDR is gaining from the western extent of Osburn Flats into the narrows.

The extent of the gaining and losing stream reaches predicted by the groundwater flow model under baseflow conditions, along with the interpretation of the field results of the 2008 groundwater-surface water interaction studies, are shown on Figures 25 and 26 for the Box and Osburn Flats, respectively. The model simulated and measured gaining and losing stream reaches within the Box match well, with slight deviations in the locations of transition between gaining and losing reaches. The calibrated groundwater flow model also replicates these qualitative targets well in Osburn Flats. The simulated data show a gaining reach near the Osburn Tailings Ponds at the mouth of Nuckols Gulch. Although the 2008 study did not show a gain between stations B-1.1 and B-2 ALT, the 1999 study showed a gain over this reach. The observed and model-simulated gain in this area is likely the result of groundwater flow from Nuckols Gulch. Additionally, model results suggest that the SFCDR begins to gain upstream from Terror Gulch, where the groundwater-surface water interaction studies suggest that the stream is losing between stations B-5 ALT and B-7. Again, the model results are likely due to simulated groundwater flow from the alluvial aquifer system in Terror Gulch into the aquifer beneath the SFCDR.

Table 3 presents a comparison of model-simulated groundwater gains and losses from the SFCDR to the field-measured data from the 2008 groundwater-surface water interaction studies. In the eastern portion of the Box, the model-simulated groundwater gains and losses in streamflow match reasonably well with those estimated from field data. In the western portion of the Box, the magnitude of the model-simulated gains and losses in streamflow are an order of magnitude lower than those estimated from field data. This is likely a result of both inadequate topographic control of ground surface elevations and inaccurate stream stage estimates in this area of the Box.

In Osburn Flats, the model generally underestimates the magnitude of gains and losses in streamflow as compared to field-measured data. Additionally, the model-simulated data suggest that there is a net gain in streamflow between Sites B-5 ALT and B-7, while the field-measured data suggest that this is a losing stream reach. The discrepancies between model-simulated and field-measured data in Osburn Flats could also be the result of inadequate resolution of the ground surface elevations in this area. Discrepancies could also be a function of the streambed conductance term assigned to the SFCDR in this area. The groundwater flow model has not been calibrated to spring runoff in Osburn Flats as the monitoring network was not in place during the 2008 runoff season. Additional calibration

in this area will be performed once additional data are collected and processed from the spring 2009 high-flow period.

TABLE 3
Comparison of Simulated Stream Gains and Losses to Data Measured During the 2008 Groundwater-Surface Water Interaction Studies
South Fork Coeur d'Alene River, Basinwide Groundwater Flow Model Documentation

SFCDR Reaches[a]	Gain/Loss Condition	SFCDR Discharge Gain/Loss (cfs)				
		9/23/2008	9/24/2008	9/25/2008	3-day Average	Model-Simulated
BH-SF-LF-0001 to BH-SF-LF-0003	Losing	-6	-10	-7	-7.7	-2.7
BH-SF-LF-0003 to BH-SF-LF-0006	Gaining	5	-1	6	3.3	4.8
BH-SF-LF-0006 to BH-SF-LF-0008	Losing	-5	3	-11	-4.3	-0.4
BH-SF-LF-0008 to BH-SF-LF-0010	Gaining	23	9	15	15.7	3.1
BH-SF-LF-0010 to BH-SF-LF-0011	Gaining	32	41	28	33.7	NA[b]
		9/9/2008	9/10/2008	9/11/2008	3-day Average	Model-Simulated
Site B-1 ALT to Site B-2 ALT	Losing	-12.7	-14.5	-7.9	-11.7	-3.0
Site B-2 ALT to Site B-5 ALT	Gaining	9.1	12.1	8.6	9.9	2.4
Site B-5 ALT to Site B-7	Losing	-5.5	-9.2	-6.2	-7.0	0.25
Site B-7 to Site B-8	Gaining	14.9	17.9	15.8	16.2	0.5

[a]Although the reaches are the same approximate geographic location between the field-measured and simulated data, the exact location of the transitions between gaining and losing vary slightly.

[b]The change in flow for this reach was not evaluated due to anomalous surface water flow measurements in the western portion of the Box as noted in CH2M HILL 2009b.

It should be noted that the groundwater-surface water interaction studies measure the change in streamflow and vertical hydraulic gradients at discrete points in the streambed. These data are extrapolated to the entire reach between consecutive seepage stations; therefore, slight deviations between the measured and model-simulated data are not significant. The model does well in replicating the overall pattern of gaining and losing stream reaches within the Box and Osburn Flats.

Response to Spring Runoff

One of the primary objectives of the groundwater flow modeling analysis was to develop a tool to estimate the quantity of groundwater that discharges into, and leaks from, various sections of the river within the SFCDR Watershed. The data used to establish accurate estimates of hydraulic connectivity between the surface water and groundwater systems were the observed stage changes in the SFCDR during high runoff events in the spring, and the associated groundwater responses to those stage changes. The fluctuations in stream stage act as extremely large-scale aquifer tests. As the stream stage increases rapidly during intense rainfall events, or rain-on-snow events, a pressure wave is propagated through the aquifer system that causes groundwater elevation changes in nearby monitoring wells.

Calibration to these data allow for estimates of the hydraulic conductance of the creek bed and the degree of hydraulic connection between the stream and the underlying aquifer.

Transient spring runoff calibration simulations were performed using stream stage and groundwater level data collected between April and July 2008. An approximately 120-day period was selected during which a cumulative change in stream stage fluctuations of up to 6 feet was observed. Changes in stream stage were estimated from data measured at the USGS stream gauge stations at Elizabeth Park (SF-268)[6] and Pinehurst (SF-271) over the calibration period. Rather than simulating changes in water level on a daily basis, the calibration period was discretized into 21 stress periods ranging in length from two to 11 days. Figure 27 presents plots showing how the changes in stream stage were implemented in the groundwater flow model during transient calibration. The locations of the USGS stream gauges and the groundwater monitoring wells used as calibration targets are shown on Figure 28. During the calibration process, riverbed conductance (wc_1) was adjusted until a good match was obtained between simulated and measured groundwater responses. The comparisons of simulated and measured groundwater responses are provided on Figure 29. These plots show that, in most cases, the simulated streambed properties result in a good match between measured and simulated responses in groundwater levels to the spring runoff in the SFCDR. Well BH-SF-E-0101 had no measured data for the first few weeks of the calibration period; therefore, this well is not considered as appropriate a target as the other seven monitoring wells. The simulated water-level response at well BH-SF-E-0502-U does not decrease as rapidly as the measured data. This is likely due to the assumption of uniform aquifer storativity over the model domain. The calibration results shown on Figure 29 indicate close agreement between the simulated and observed changes in groundwater levels throughout the calibration period.

Calibration Summary

As discussed in the previous sections, the groundwater flow model developed to support this hydrologic study has been calibrated to a wide range of data that describe the critical aspects of the groundwater and surface water systems in the SFCDR Watershed. Model simulations agree well with these observed data, and the degree of hydraulic connection between the groundwater and surface water systems appears to be well replicated. As such, this model will reliably support, in conjunction with measured dissolved metals concentrations in monitoring wells, evaluation of both baseline metals loading conditions to the SFCDR and various remedial strategies to address contamination. Additional refinement and recalibration of the groundwater flow model for the SFCDR Watershed will be made as data (including stage changes and related groundwater-level responses in Osburn Flats, Bunker Creek, and lower Government Creek) become available.

Sources of Dissolved Metals to the SFCDR

The calibrated groundwater flow model was used to improve estimates of the water budget components in the Box and Osburn Flats and the resulting baseline metals loadings to the SFCDR. The SFCDR Watershed model is a groundwater flow model; therefore, metals transport and geochemical reactions are not simulated. Dissolved metals loadings to the

[6] http://waterdata.usgs.gov/nwis/inventory/?site_no=12413210&

SFCDR were estimated by dividing the gaining portions of the river into reaches, and selecting representative monitoring wells that are assumed to reflect the dissolved metals concentrations entering the river over that reach. The average dissolved metals concentrations over a particular reach can then be multiplied by the simulated groundwater flow to the SFCDR reach predicted by the groundwater flow model to yield estimates of metals loadings. These values can then be compared with more traditional loading calculations derived from comparing calculated upstream and downstream loads based on surface water flows and surface water metals concentrations to evaluate consistency in the independent loading estimates. If the estimates agree reasonably well, confidence is gained that the independent predictions of metals loadings to the river over certain reaches are reasonably accurate. This methodology assumes that (a) dissolved zinc can be used as a surrogate for other metals (i.e., the reaches with the greatest zinc loads are also areas with the highest cadmium loads), and (b) there is no change in dissolved metals concentrations in groundwater between the location of the groundwater monitoring well and the discharge area into the stream (e.g., metals transport in the groundwater system is conservative between the monitoring well and stream discharge area). The most recent dissolved zinc concentration data (collected in the fall of 2008) were used in this analysis.

Baseline Metals Loadings to the SFCDR

Dissolved zinc loadings to the SFDDR were estimated by combining the simulated groundwater discharge rates to the stream with the dissolved zinc concentrations measured in nearby groundwater monitoring wells. Figures 30 through 32 present the distribution of dissolved zinc in the groundwater system measured during the fall 2008 sampling event in the Eastern Box, the Western Box, and Osburn Flats, respectively. The total groundwater discharge to the SFCDR in gaining reaches under baseflow conditions in the Box estimated by the model is approximately 3,500 gpm (7.8 cfs). To estimate the metals loadings from groundwater discharge, the gaining reaches of the SFCDR were subdivided into five reaches. The geographic locations of these reaches are shown on Figure 33, which also presents the simulated groundwater discharge to the river, the average dissolved zinc concentration in groundwater, and the estimated dissolved zinc load to the SFCDR for each reach. These data suggest that the total dissolved zinc load to the gaining reaches of the SFCDR, from the groundwater system, in the Box is approximately 540 pounds per day (lb/day). Model results further suggest that nearly 70 percent of the load enters the SFCDR in the reach along the western portion of the CIA. This is the area of observed groundwater seepage along the northern edge of the CIA. Table 4 presents the gain/loss in dissolved zinc load to the SFCDR calculated using model simulated flow to/from the SFCDR and measured dissolved zinc concentrations in nearby monitoring wells with estimates made from field-measured data collected during the 2008 groundwater-surface water interaction studies in the Box and Osburn Flats. The dissolved zinc load to gaining reaches of the SFCDR estimated from model results agrees reasonably well with the dissolved zinc load of approximately 460 lb/day estimated, between stations BH-SF-LF-0001 and BH-SF-LF-0010, during the most recent groundwater-surface water interaction study performed in the Box (CH2M HILL, 2009b). Estimates of dissolved zinc loads from the model combine groundwater analytical data with simulated groundwater discharge to the SFCDR. The groundwater-surface water interaction studies measure changes in dissolved zinc load between consecutive sampling points within the surface water system. The agreement of dissolved zinc loading calculated from these two independent data sources provides further

TABLE 4
Comparison of Simulated Dissolved Zinc Loading to Data Measured During the 2008 Groundwater-Surface Water Interaction Studies
South Fork Coeur d'Alene River, Basinwide Groundwater Flow Model Documentation

SFCDR Reaches[a]	Gain/ Loss Condition	Dissolved Zinc Gain/Loss (lb/day)								
		9/23/2008	9/24/2008	9/25/2008	3-day Average	Model-Simulated				
BH-SF-LF-0001 to BH-SF-LF-0003	Losing[b]	-24	-24	-17	-22	-26				
BH-SF-LF-0003 to BH-SF-LF-0006	Gaining	324	303	317	315	450				
BH-SF-LF-0006 to BH-SF-LF-0008	Losing[b]	-45	-32	-96	-58	-28				
BH-SF-LF-0008 to BH-SF-LF-0010	Gaining	251	95	95	147	91				
BH-SF-LF-0010 to BH-SF-LF-0011	Gaining	124	232	210	189	NA[c]				
		9/9/2008	9/10/2008	9/11/2008	3-day Average	Model-Simulated	9/9/2008 Diel Adjusted	9/10/2008 Diel Adjusted	9/11/2008 Diel Adjusted	3-day Average Diel Adjusted
Site B-1 ALT to Site B-2 ALT	Losing[b]	-23	-17	-11	-17	-11	-40	-36	-26	-34
Site B-2 ALT to Site B-5 ALT	Gaining	123	149	135	136	27	95	120	102	106
Site B-5 ALT to Site B-7	Losing[b]	-15	-29	-33	-26	2	-28	-42	-40	-37
Site B-7 to Site B-8	Gaining	104	99	100	101	1	83	76	83	80

[a]Although the reaches are the same approximate geographic location between the field-measured and simulated data, the exact location of the transitions between gaining and losing vary slightly.

[b]The simulated change in dissolved zinc load for losing reaches was calculated using the model-simulated stream leakage and the dissolved zinc concentration measured in the main-stem seepage stations within the reach.

[c]The change in load for this reach was not evaluated due to anomalous surface water flow measurements in the western portion of the Box as noted in CH2M HILL 2009b.

evidence that the calibrated groundwater model is an accurate depiction of site conditions, and is a reasonable tool for use in estimating the potential reductions in metals loadings to surface water that would result from the implementation of various remedial actions in the SFCDR Watershed.

Figure 34 presents the locations of the subdivided gaining reaches of the SFCDR in Osburn Flats. This figure also presents the simulated groundwater discharge to the river, the average dissolved zinc concentration in groundwater, and the estimated dissolved zinc load to the SFCDR for each reach. These data suggest that the total dissolved zinc load to the gaining reaches of the SFCDR, from the groundwater system, in Osburn Flats is approximately 30 lb/day. Table 4 presents a comparison of dissolved zinc loading from the groundwater-surface water interaction study with estimates made using simulated flows and measured groundwater concentrations. Data from both sources indicate that the reach of the SFCDR with the highest dissolved zinc load from groundwater is located near the mouth of Twomile Creek. The total dissolved zinc loading, to gaining reaches of the SFCDR, estimated from model results is lower than historical estimates for Osburn Flats, which have generally been approximately 200 lb/day under baseflow conditions. The discrepancy could be due to diel fluctuations in metals concentrations in samples collected at different times of the day (Nimick et al., 2003). As shown in Table 4, the 2008 groundwater-surface water interaction study conducted in Osburn Flats considered diel fluctuations in metals concentrations. The resulting adjustment to dissolved zinc loading reduced the estimated total dissolved zinc loading to the gaining reaches of the SFCDR from approximately 240 lb/day to approximately 190 lb/day (CH2M HILL, 2009c). As part of the analysis of data from the 2008 groundwater-surface water interaction study, diel adjustments were made to data collected during the 1999 study (Barton, 2001), resulting in an estimated dissolved zinc load to the SFCDR of approximately 90 lb/day through Osburn Flats. Although the diel adjustments decrease the total estimated dissolved zinc load to the SFCDR, estimates made using the simulated flows and groundwater concentrations are approximately 15 percent of those estimated using field data. This is consistent with the groundwater flow gains and losses predicted by the model also being lower than those suggested from field-based measurements, and may be improved with the collection of additional high-flow calibration targets.

Another potential cause of the discrepancy between dissolved zinc load estimates generated from model results and historical estimates is monitoring well placement. As shown on Figure 34, the dissolved zinc concentrations measured in groundwater monitoring wells in the fall of 2008 were less than 4 milligrams per liter (mg/L). It is possible that areas of higher concentrations of zinc in groundwater are present in Osburn Flats but are not being detected by the current monitoring network.

Model Limitations

Mathematical models can only approximate processes of physical systems. Models are inherently inexact because the mathematical description of the physical system is imperfect and the understanding of interrelated physical processes is incomplete. During model construction for this project, efforts were made to incorporate as many details of the physical system into the numerical model as possible within the scope, schedule, and budgetary constraints. The numerical model described in this document is a powerful tool

that, when used carefully, can provide useful insight into processes of the physical system. The subsequent sections of this TM discuss the potential sources of input and output error.

Potential Sources of Error

Calibration target values and simulated output each have associated errors or the potential for errors, resulting in an overall uncertainty in results. The sources of uncertainty include transient effects, human errors, scaling effects, interpolation errors, and numerical errors (Anderson and Woessner, 1992).

Transient Effects

Groundwater-level measurements in wells could reflect the presence of transient effects in the groundwater system that might not be represented in the model. The only available subsurface access to directly monitor groundwater conditions is through groundwater wells. Groundwater wells allow for measurement of groundwater levels and collection of water quality samples. If transient effects of the groundwater system are manifested in groundwater levels at shorter time scales than those in the numerical model, some portion of the residual error between the field-measured groundwater level and the simulated output could be due to these transient effects. Thus, if the time scale of the field measurement is different than the model time-step duration, some of the residual error could be due to transient effects.

Human Errors

It is not possible to guarantee that all of the modeling results presented in this report are free from human error. However, efforts were made to avoid introducing human errors into the SFCDR model by adhering to quality assurance (QA) protocols. The following are examples of potential sources of human errors:

- **Measurement Errors.** Calibration-target values can include measurement errors related to the accuracy and consistency of the measurement device or structure, the accuracy and consistency of the elevation survey datum, and the diligence of the field or laboratory technician who collected or analyzed the data. Thus, some portion of the residual error between the field-measured data and the simulated output could also be due to measurement error in the calibration target value.

- **Data Management Errors.** Errors can also be introduced as a result of data management activities. Examples of data management errors include (but are not limited to) associating input data with an incorrect location (resulting in spatial errors), assigning time-series data incorrectly (resulting in temporal errors), or otherwise inputting values incorrectly. Thus, some portion of the residual between the field-measured data and the simulated output could also be due to data management errors.

- **Conceptualization Errors.** Errors can also be introduced as a result of inadequately conceptualizing the field problem. For example, if there were significant errors in the assigned boundary conditions, some portion of the residual between the field-measured data and the simulated output would be due to conceptualization errors.

Scaling Effects

A numerical model uses discrete space to represent the hydrologic system. The SFCDR model grid was built in an effort to strike a balance between maximizing the number of nodes in key areas of the domain and minimizing the numerical burden and associated model run times. However, all numerical grids are subject to errors resulting from scaling effects.

Errors associated with scaling effects result when and where significant spatial heterogeneities in the field problem are not represented at the scale of the numerical grid-blocks. For example, the height to which water rises in a groundwater well is the result of the average head conditions of the depth interval over which the groundwater well is screened. Groundwater wells in the SFCDR Watershed have variable-length well screens within a highly complex three-dimensional flow system. Thus, a portion of the residual error between field-measured heads and the simulated output could be due to scaling effects resulting from the differences between model layer thicknesses and the well-screen lengths of calibration-target wells.

Interpolation Effects

Calibration target locations would ideally be represented in the SFCDR model to coincide perfectly with locations of the SFCDR model nodes, but in practice this is not possible. Thus, interpolation errors can be introduced in the calibration evaluation. Interpolation errors can also result from spatially distributing point values of parameters or stresses over the model domain. In an effort to manage potential interpolation errors, one of the goals for selecting calibration target locations was to seek a relatively uniform spatial distribution of calibration targets over the model domain. Having a reasonable number of spatially distributed calibration targets and types of calibration targets (i.e., qualitative and quantitative) helps make model output more reliable over a wide range of conditions for the entire domain.

Numerical Errors

Errors associated with the way a model solves the governing flow and transport equations, coupled with the assumptions underlying the governing equations being solved, are inherent in all numerical models. Numerical errors are also associated with the selection of convergence-closure criteria by the user. User selection of convergence-closure criteria is an iterative process during calibration that seeks to strike a balance between making progress with calibration, by completing as many simulations as possible within the project schedule, and achieving sufficient accuracy in the numerical solution. Selecting convergence-closure criteria that are too low during the initial stages of model calibration will result in completion of fewer simulations because of longer run times and possible convergence problems. In this project, the introduction of potential numerical errors was minimized by selecting convergence-closure criteria that resulted in converged solutions providing mass balances of flow.

While the above sources of error are unavoidable and an inherent part of the field investigation and modeling process, the uncertainty introduced by these potential sources of error can be successfully accommodated in later phases of the decision-making process. The purpose of developing the modeling tools described herein is to better define the existing conditions in the SFCDR Watershed, and to simulate the future performance of various

remedial alternatives designed to achieve the remedial objectives of the project. During the screening and comparison of the competing remedial alternatives in the Focused Ecological Feasibility Study, the degree of uncertainty contained in the model forecasts of each alternative can be tested using the sensitivity analysis process. This process consists of varying the numerical value of the key model parameters, within an acceptable range of values, to quantify the effect of changing that parameter on the estimate of the overall effectiveness of the remedial alternative. When the results of numerous sensitivity analysis runs are compiled, the controlling parameters can be identified and ranked. This allows an assessment to be made of whether the existing uncertainty in model parameters is large enough to potentially change the ranking of the costs and benefits of the competing alternatives. The other advantage of a sensitivity analysis is to identify the key controlling site parameters that impart the greatest uncertainty in estimating remedy effectiveness. Future field investigations can then be focused on collecting data to better define these parameters, thereby reducing the uncertainty associated with the remedy selection process.

Conclusions

A numerical tool has been developed for use in evaluating and screening potential remedial actions in OUs 2 and 3. This tool:

- Encompasses the entire SFCDR Watershed, approximately 300 square miles and 35 river miles along the SFCDR.
- Incorporates field data regarding the geometry and properties of the various hydrostratigraphic units.
- Is calibrated to groundwater conditions measured in the fall of 2008.
- Is able to replicate the groundwater response to the spring 2008 runoff period in the SFCDR through the Bunker Hill Box.
- Simulates the locations of gaining and losing stream reaches of the SFCDR in the Box and Osburn Flats, as observed during *in-situ* groundwater-surface water interaction studies.
- Provides estimates of groundwater discharge to and leakage from the SFCDR and other surface streams within the model domain.
- Can be used, in conjunction with observed dissolved metals concentrations in monitoring wells, to estimate dissolved metals loadings to gaining stream reaches of the SFCDR. These estimates agree well with dissolved zinc loading rates estimated during *in-situ* groundwater-surface water interaction studies.

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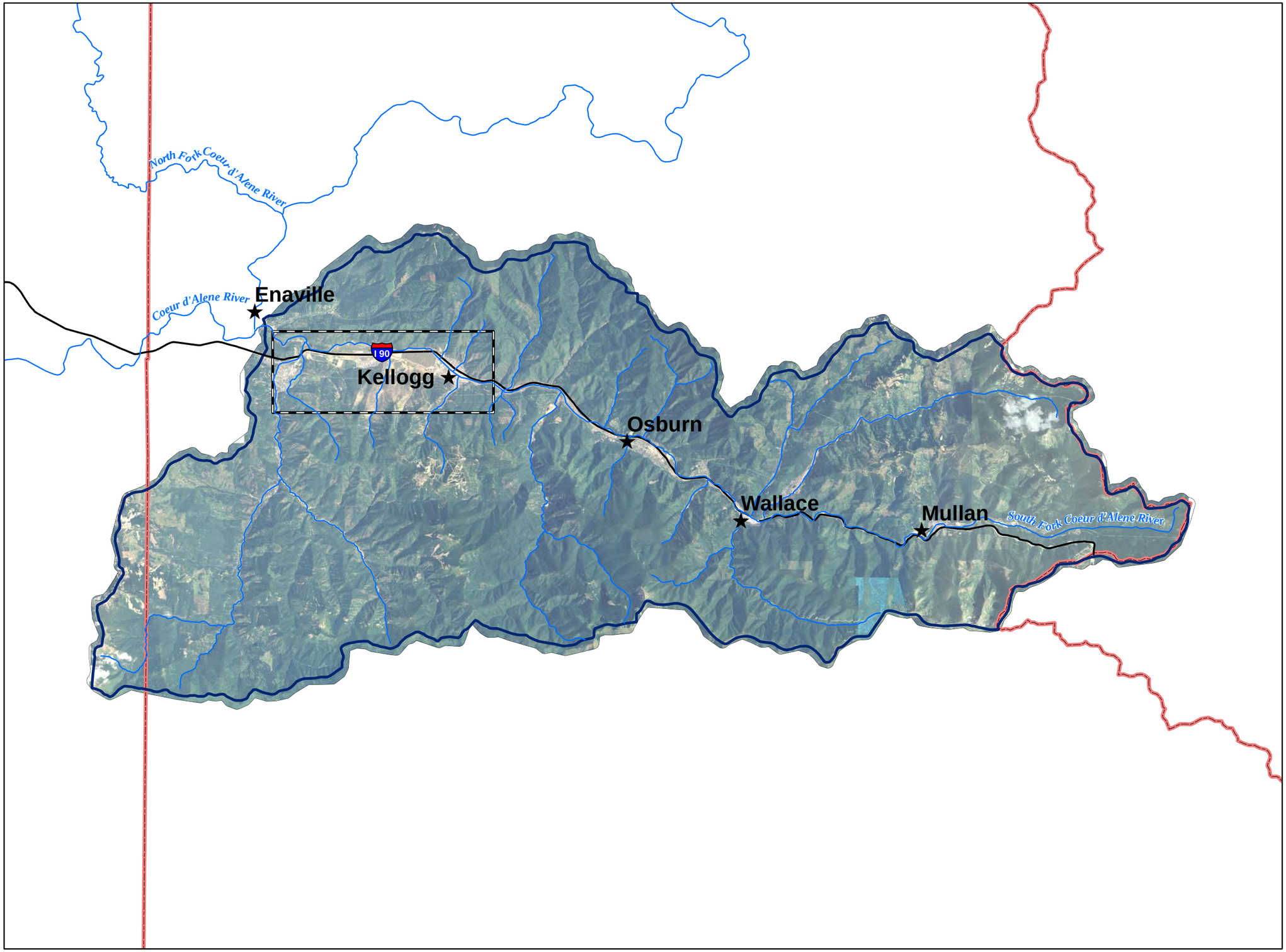
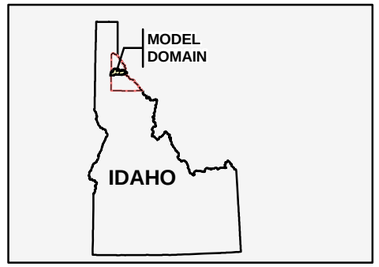
Figures





LEGEND

- ★ CITY
- MAJOR STREAMS
- BUNKER HILL BOX
- BOUNDARY OF SOUTH FORK COEUR d'ALENE RIVER WATERSHED
- SHOSHONE COUNTY

N

0 1.5 3 6 Miles

Figure 1
Location Map
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model
Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL

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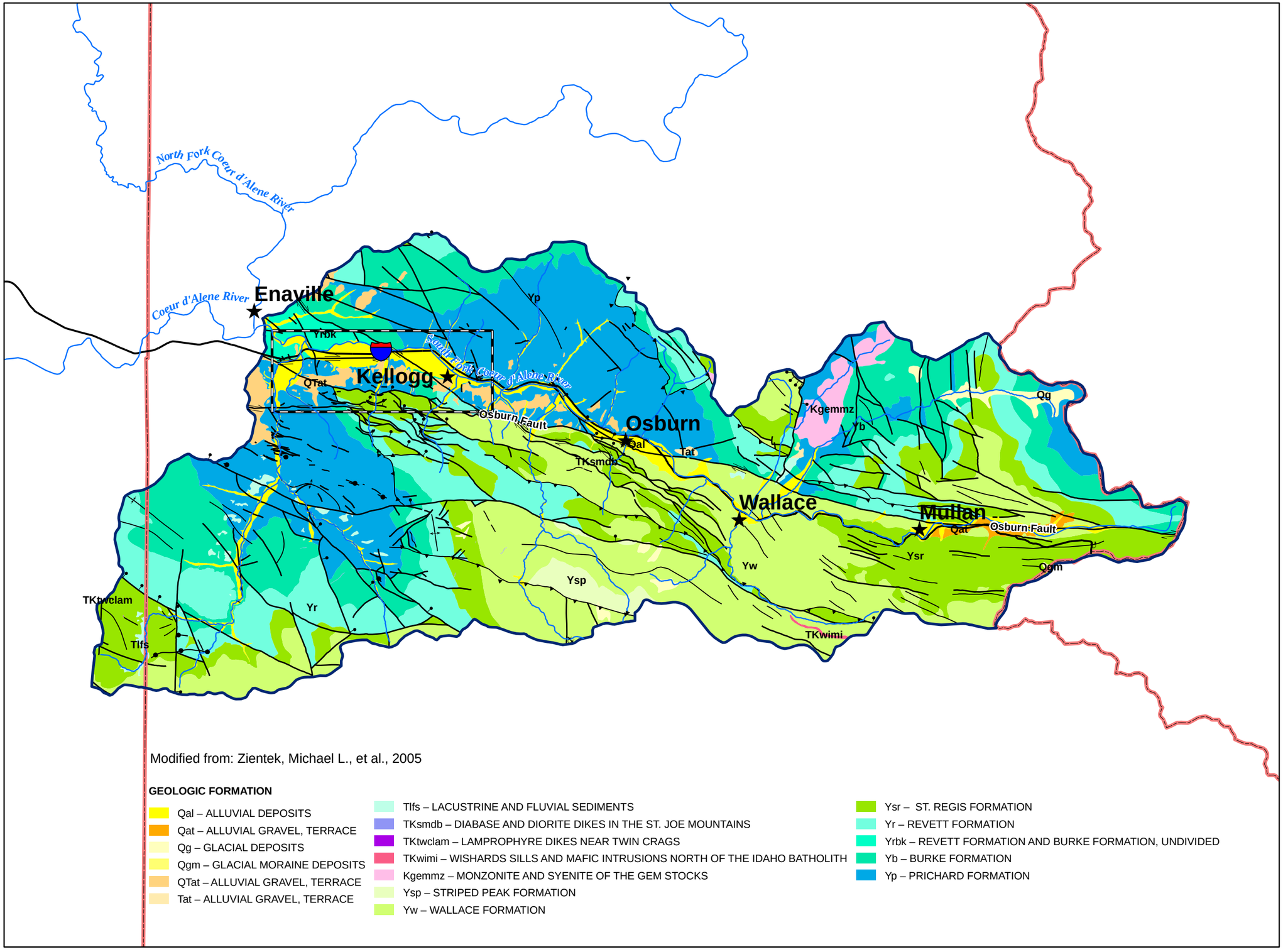
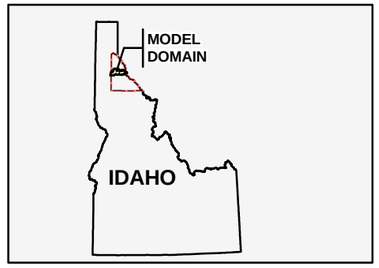


Modified from: Zientek, Michael L., et al., 2005

GEOLOGIC FORMATION

- Qal – ALLUVIAL DEPOSITS
- Qat – ALLUVIAL GRAVEL, TERRACE
- Qg – GLACIAL DEPOSITS
- Qgm – GLACIAL MORAINE DEPOSITS
- QTat – ALLUVIAL GRAVEL, TERRACE
- Tat – ALLUVIAL GRAVEL, TERRACE
- Tlfs – LACUSTRINE AND FLUVIAL SEDIMENTS
- TKsmdb – DIABASE AND DIORITE DIKES IN THE ST. JOE MOUNTAINS
- TKtwclam – LAMPROPHYRE DIKES NEAR TWIN CRAGS
- TKwimi – WISHARDS SILLS AND MAFIC INTRUSIONS NORTH OF THE IDAHO BATHOLITH
- Kgemmz – MONZONITE AND SYENITE OF THE GEM STOCKS
- Ysp – STRIPED PEAK FORMATION
- Yw – WALLACE FORMATION
- Ysr – ST. REGIS FORMATION
- Yr – REVETT FORMATION
- Yrbk – REVETT FORMATION AND BURKE FORMATION, UNDIVIDED
- Yb – BURKE FORMATION
- Yp – PRICHARD FORMATION



LEGEND

- CITY
- MAJOR STREAMS
- BUNKER HILL BOX
- BOUNDARY OF SOUTH FORK COEUR d'ALENE RIVER WATERSHED
- SHOSHONE COUNTY

GEOLOGIC STRUCTURE

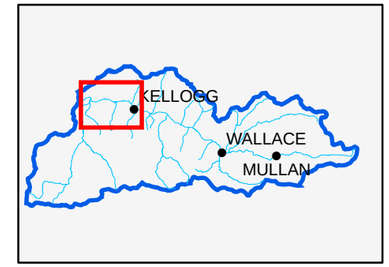
- ANTICLINE
- OVERTURNED ANTICLINE
- SYNCLINE
- OVERTURNED SYNCLINE
- FAULT
- NORMAL FAULT
- REVERSE FAULT
- STRIKE-SLIP FAULT
- THRUST FAULT
- VEINS

N

0 1.5 3 6 Miles

Figure 2
Geologic Map
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model
Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

GROUNDWATER ELEVATION (feet above msl)

- 2,172 to 2,180
- 2,181 to 2,190
- 2,191 to 2,200
- 2,201 to 2,210
- 2,211 to 2,220
- 2,221 to 2,230
- 2,231 to 2,240
- 2,241 to 2,250
- 2,251 to 2,260
- 2,261 to 2,270
- 2,271 to 2,280
- 2,281 to 2,290
- 2,291 to 2,300
- CONTOUR OF EQUAL GROUNDWATER ELEVATION (feet above msl)

Notes:
1) Groundwater elevation contours are presented for the Upper Aquifer.
2) msl = mean sea level

N

0 1,250 2,500 5,000 Feet

Figure 3
Fall 2008 Groundwater Elevation Contour Map – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

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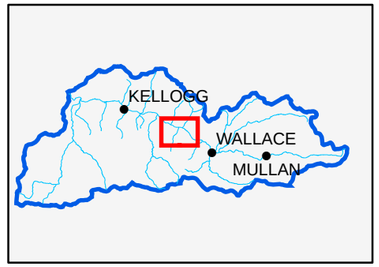


LEGEND

GROUNDWATER ELEVATION (feet above msl)

- 2,438 to 2,440
- 2,441 to 2,450
- 2,451 to 2,460
- 2,461 to 2,470
- 2,471 to 2,480
- 2,481 to 2,490
- 2,491 to 2,500
- 2,501 to 2,510
- 2,511 to 2,520
- 2,521 to 2,530
- 2,531 to 2,540
- 2,541 to 2,550
- 2,551 to 2,560
- 2,561 to 2,570
- 2,571 to 2,580
- 2,581 to 2,590
- 2,591 to 2,600
- 2,601 to 2,610
- CONTOUR OF EQUAL GROUNDWATER ELEVATION (feet above msl)

Note: msl = mean sea level

N

0 750 1,500 3,000 Feet

Figure 4
Fall 2008 Groundwater Elevation Contour Map – Osburn Flats

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation

BUNKER HILL SUPERFUND SITE

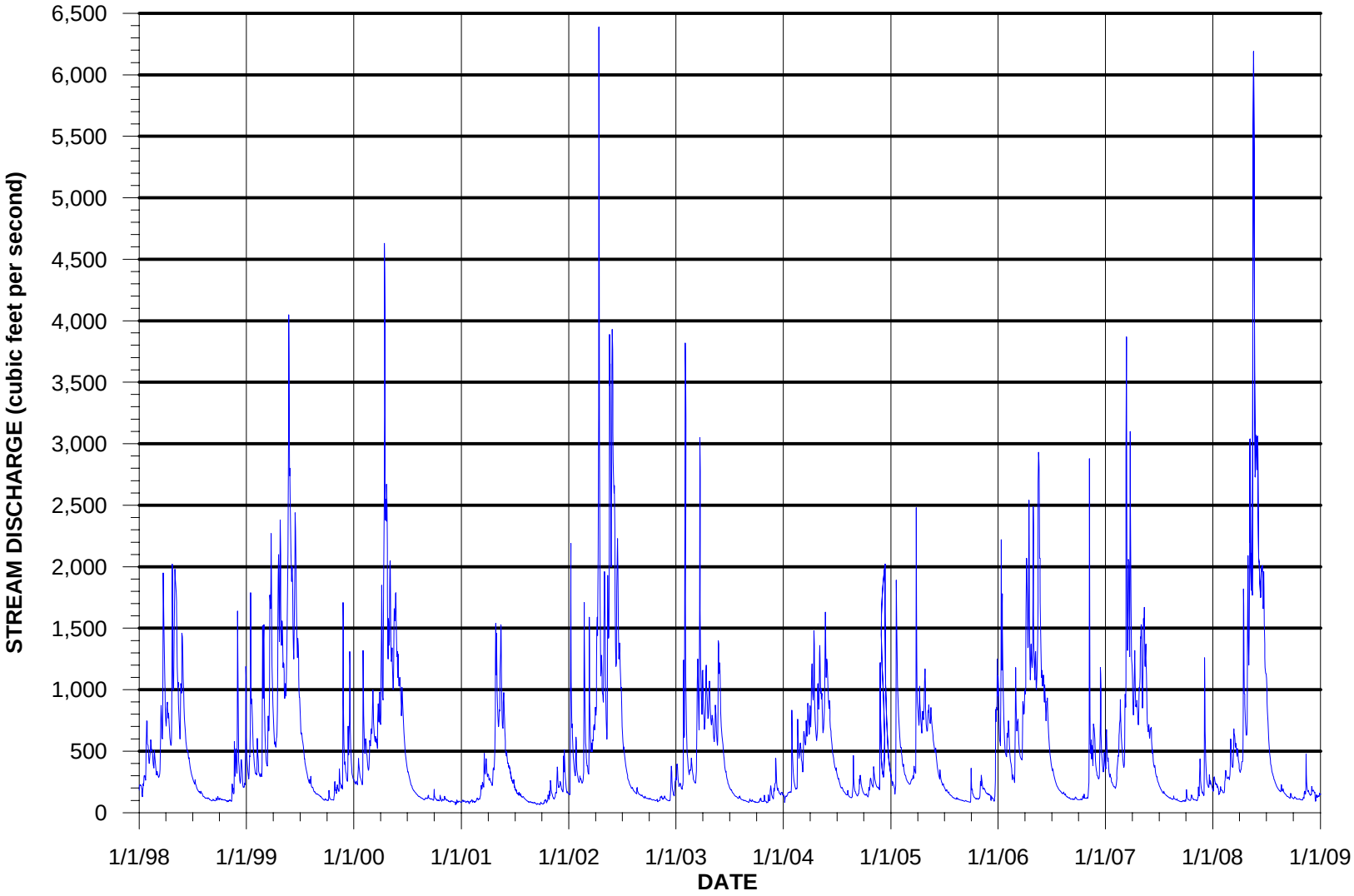
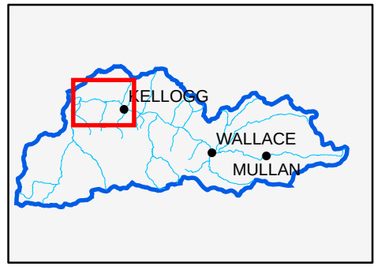


Figure 5
Measured Discharge in the SFCDR Near Pinehurst
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE



LEGEND

BH-SF-LF-0001 SEEPAGE STUDY STATION IDENTIFIER

MAIN STEM SEEPAGE STUDY STATION

MEASURED DATA

GAINING STREAM REACH

LOSING STREAM REACH

Note: Data collected in September 2008.

N

0 1,250 2,500 5,000 Feet

Figure 6
Results of the 2008 Seepage Study – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

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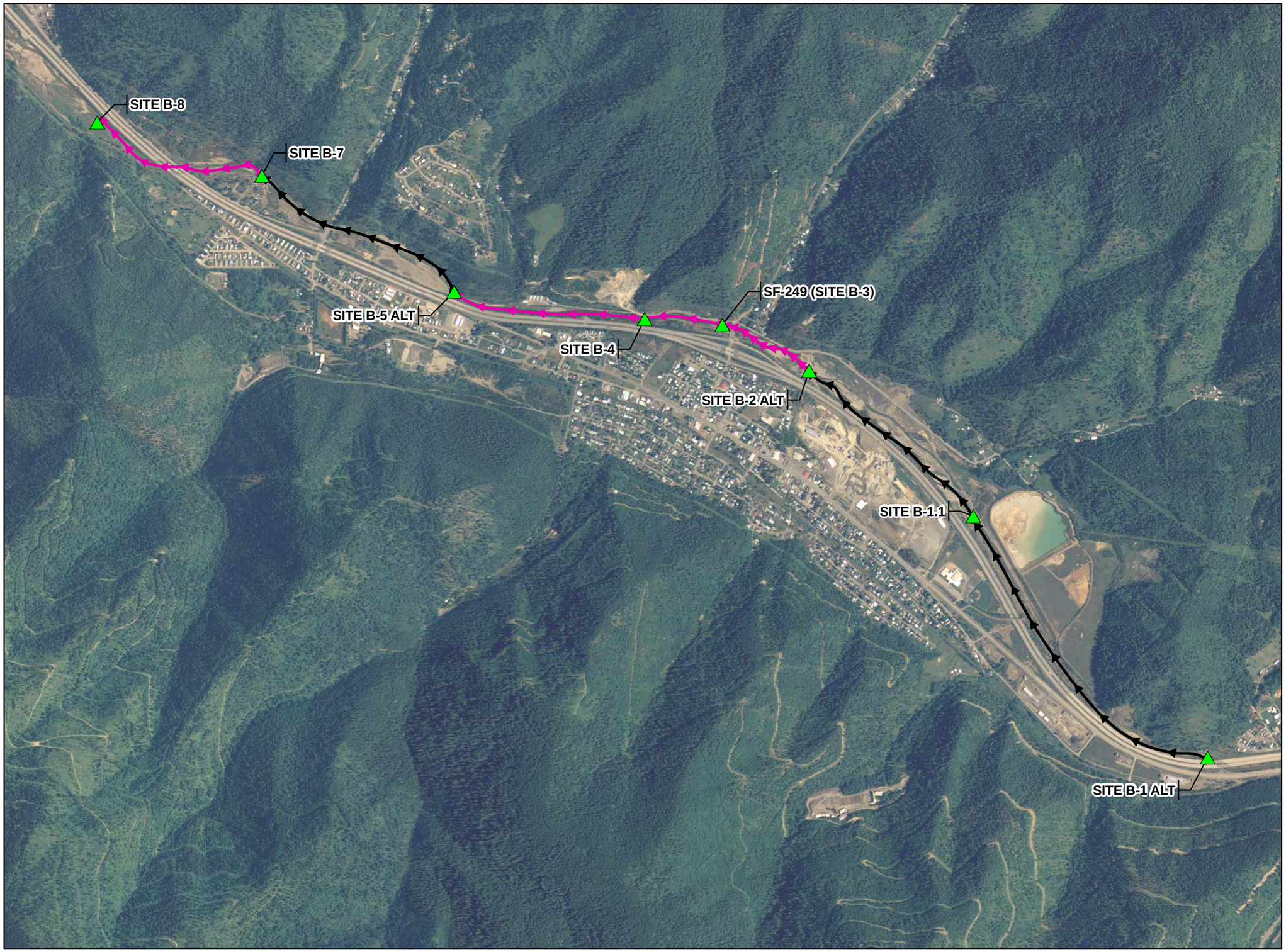

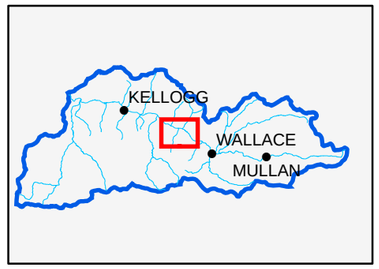

LEGEND

B-1.1 SEEPAGE STUDY STATION IDENTIFIER

MAIN STEM SEEPAGE STUDY STATION

MEASURED DATA

GAINING STREAM REACH

LOSING STREAM REACH

Note: Data collected in September 2008.

N

0 750 1,500 3,000 Feet

Figure 7
Results of the 2008 Seepage Study – Osburn Flats
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

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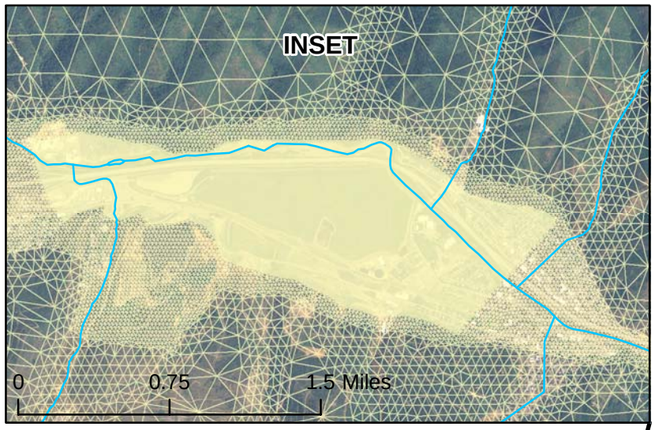
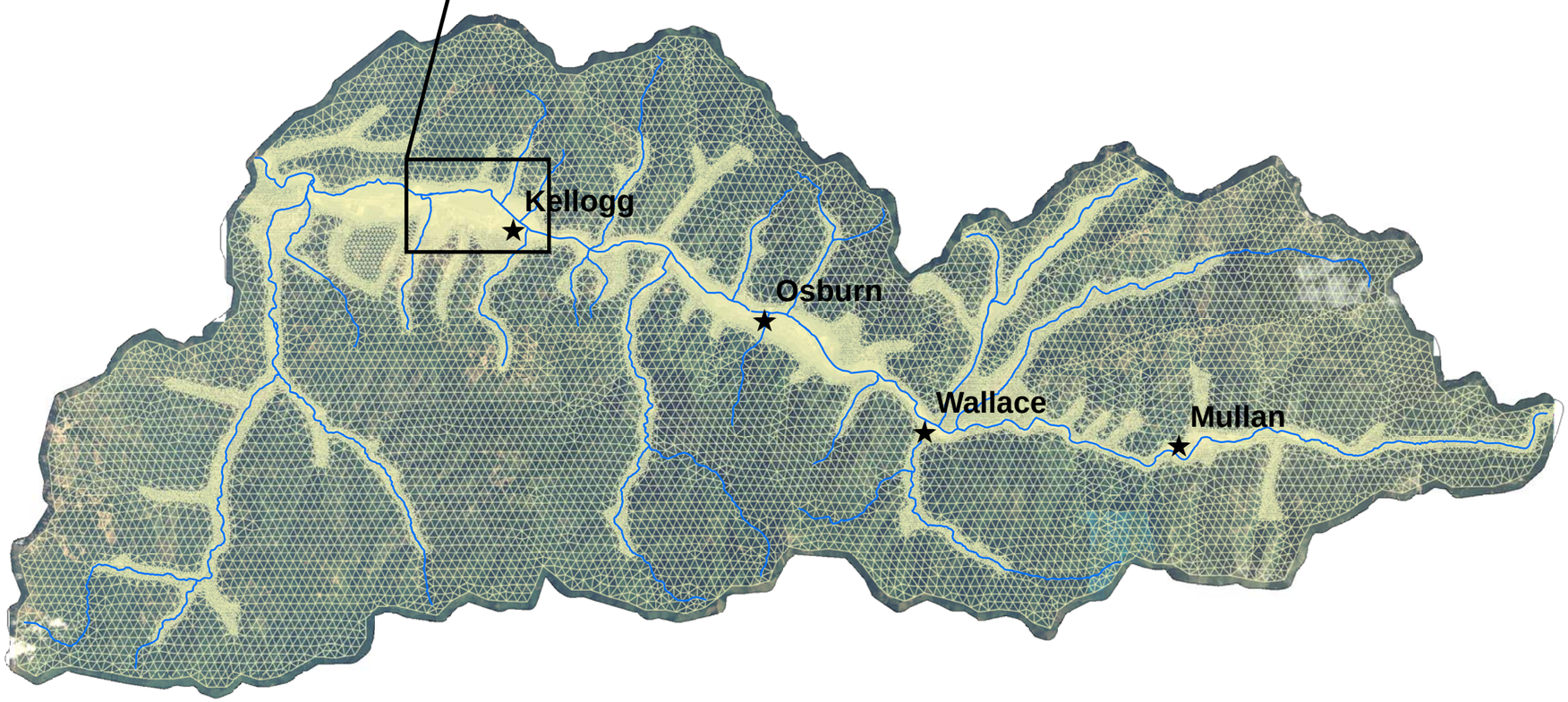
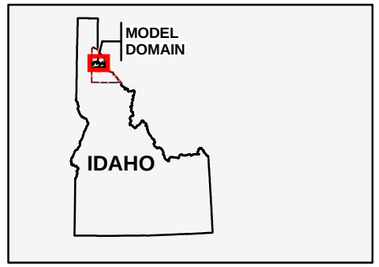






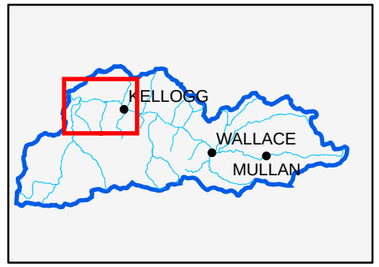
LEGEND

- ★ CITY
- MODEL GRID
- MAJOR STREAMS

N

0 1.5 3 6 Miles

Figure 8
Groundwater Flow Model Grid
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model
Documentation
BUNKER HILL SUPERFUND SITE



LEGEND

GROUND SURFACE ELEVATION (feet above msl)

- 2,162 to 2,175
- 2,176 to 2,200
- 2,201 to 2,225
- 2,226 to 2,250
- 2,251 to 2,275
- 2,276 to 2,300
- 2,301 to 2,325
- 2,326 to 2,350

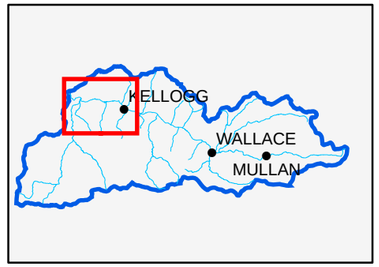
Note: msl = mean sea level

N

0 1,500 3,000 6,000 Feet

Figure 9
Composite Alluvial Topography – Bunker Hill Box
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model
Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

LOCATION TYPE

- IDWR WELL
- MONITORING WELL

2222 BEDROCK ELEVATION (feet above msl)

BEDROCK ELEVATION (feet above msl)

- 2,021 to 2,050
- 2,051 to 2,100
- 2,101 to 2,150
- 2,151 to 2,200
- 2,201 to 2,250
- 2,251 to 2,300
- 2,301 to 2,350
- 2,351 to 2,400
- 2,401 to 2,450

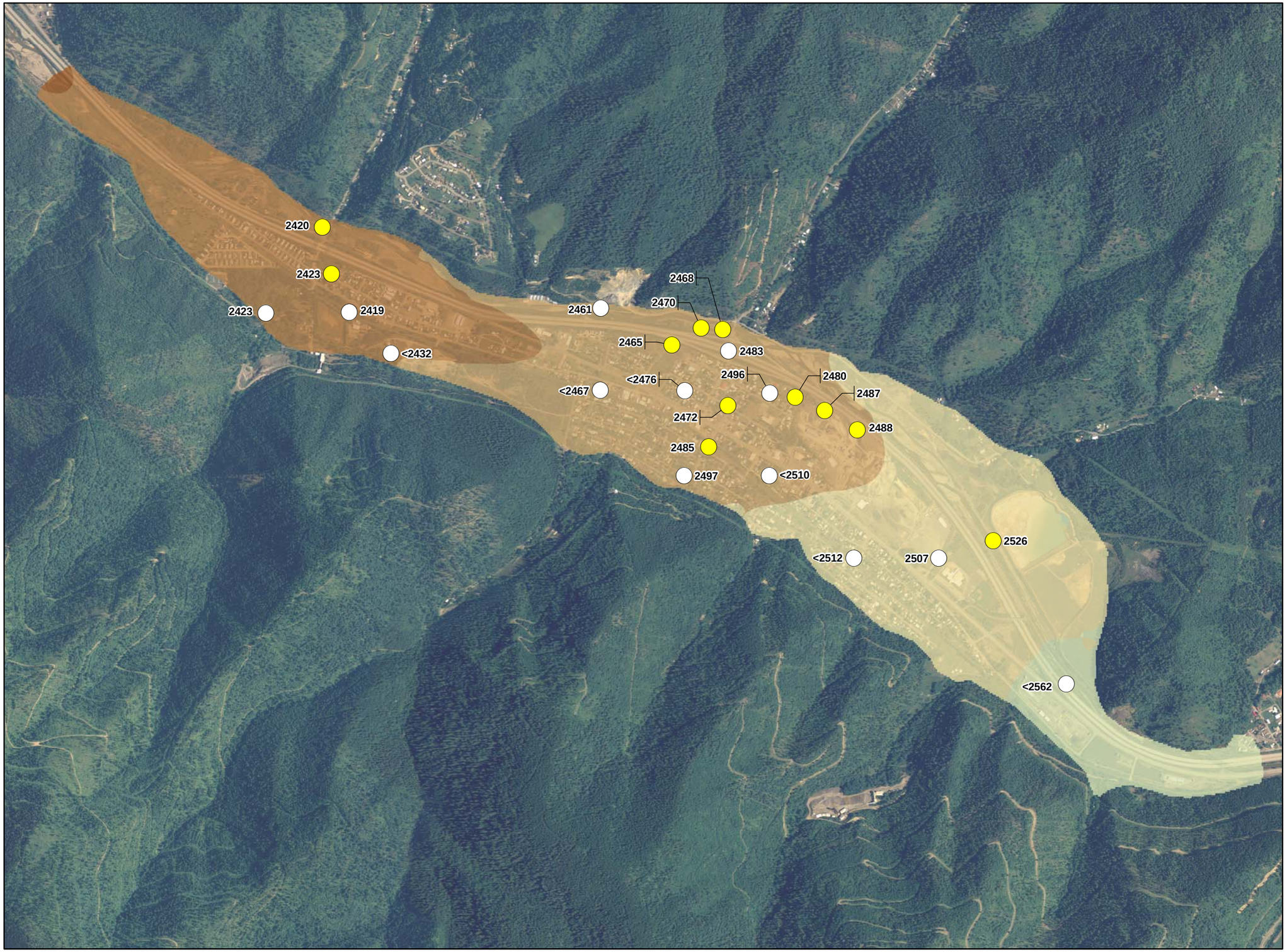
Notes:
1) IDWR wells located to the quarter-quarter section.
2) IDWR = Idaho Department of Water Resources
3) msl = mean sea level

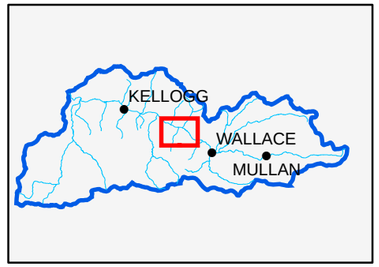
N

0 1,500 3,000 6,000 Feet

Figure 10
Bedrock Elevations – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

LOCATION TYPE

- IDWR WELL
- MONITORING WELL

2526 BEDROCK ELEVATION (feet above msl)

BEDROCK ELEVATION (feet above msl)

- 2,351 to 2,400
- 2,401 to 2,450
- 2,451 to 2,500
- 2,501 to 2,550
- 2,551 to 2,600
- 2,601 to 2,650
- 2,651 to 2,700
- 2,701 to 2,750

Notes:
1) IDWR wells located to the quarter-quarter section.
2) IDWR = Idaho Department of Water Resources
3) msl = mean sea level

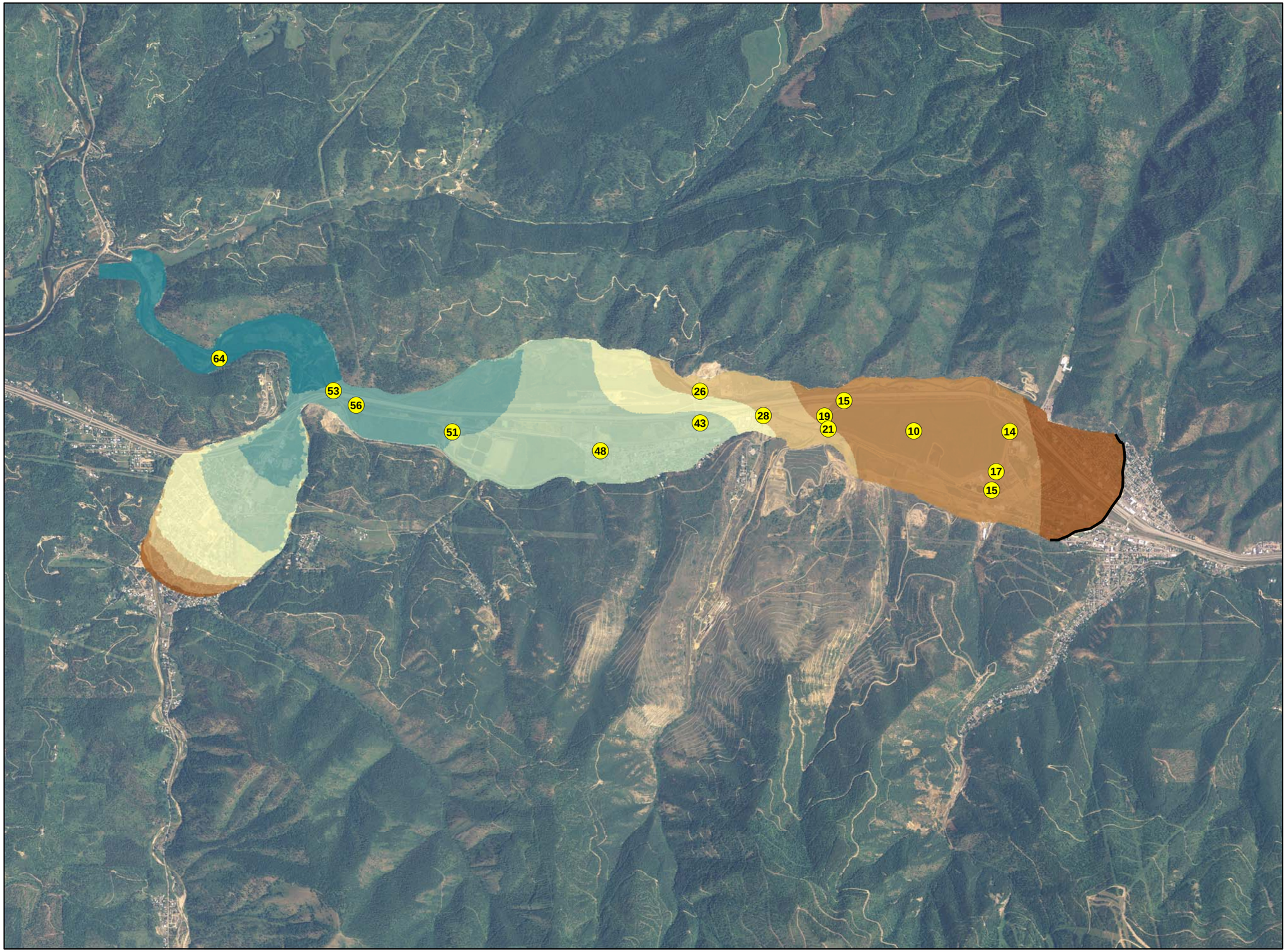
N

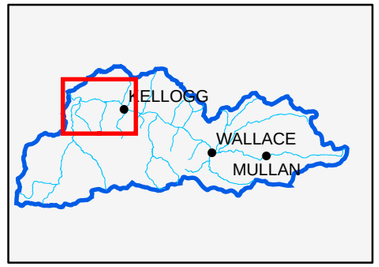
0 550 1,100 2,200 Feet

Figure 11
Bedrock Elevations – Osburn Flats
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL

\\ODIN\PROJ\USEPA\323031\BUNKERHILL\FIGURES\MXD\2009_02_BASINWIDEMODELDOCUMENTATION\FIGURE-11_BDRK_ELEV_OSBURN.MXD FELHADID 4/29/2009 17:20:00





LEGEND

LOCATION TYPE

- MONITORING WELL
- 14 CONFINING UNIT THICKNESS (feet)
- APPROXIMATE EXTENT OF CONFINING UNIT

SATURATED THICKNESS (feet)

- 0 to 10
- 10 to 20
- 20 to 30
- 30 to 40
- 40 to 50
- 50 to 60
- 60 to 70

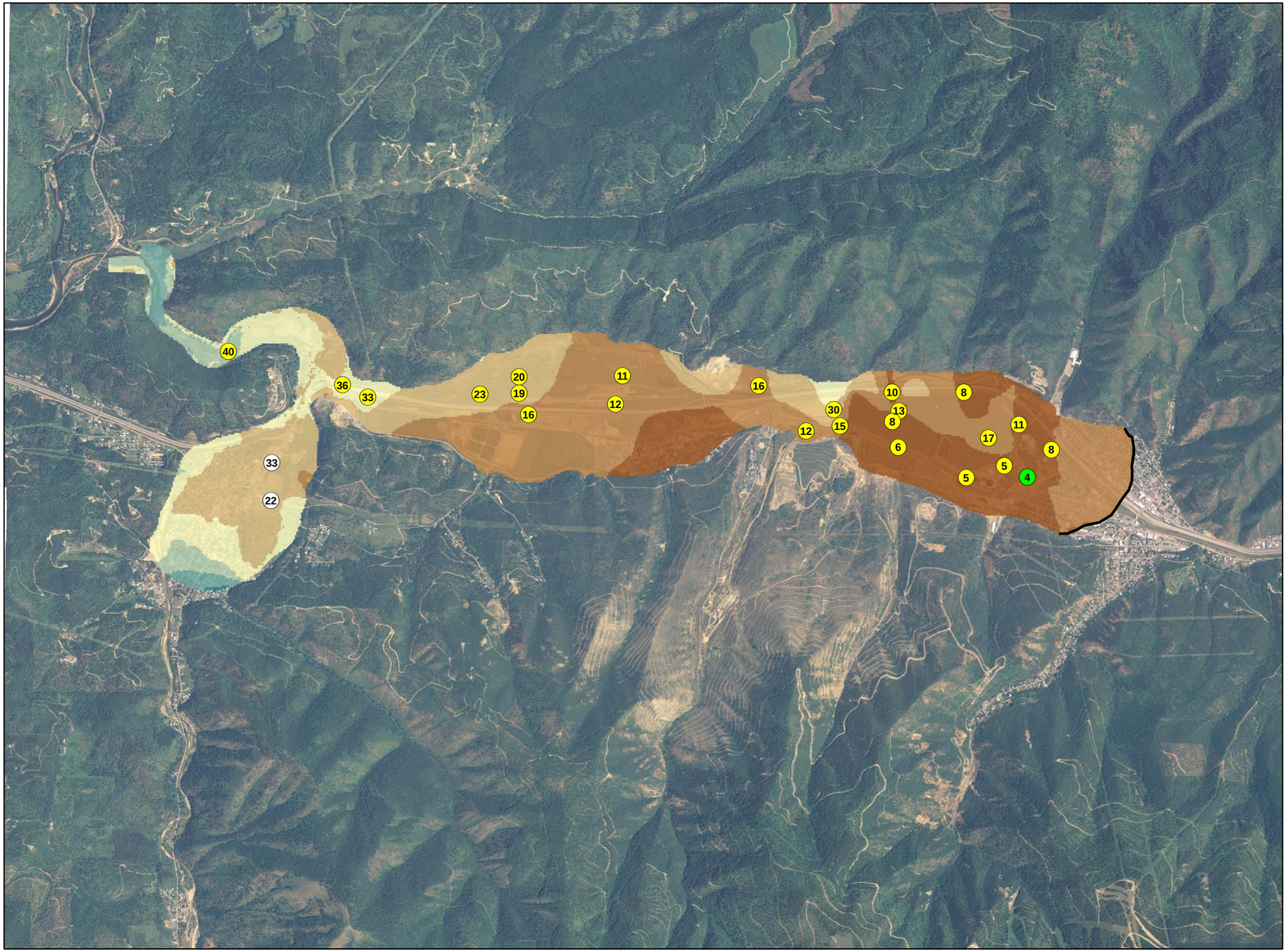
N

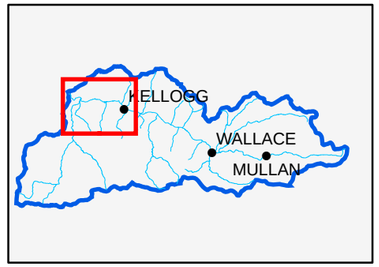
0 1,500 3,000 6,000 Feet

Figure 12
Confining Unit Thicknesses – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL

\\ODIN\PROJ\USEPA\323031\BUNKERHILL\FIGURES\MXD\2009_02_BASINWIDEMODELDOCUMENTATION\FIGURE-12_CU_THICKNESS.MXD FELHADID 4/20/2009 17:23:36





LEGEND

LOCATION TYPE

- IDWR WELL
- MONITORING WELL
- PIEZOMETER
- 11 UPPER AQUIFER THICKNESS (feet)
- APPROXIMATE EXTENT OF CONFINING UNIT

SATURATED THICKNESS (feet)

- 0 to 10
- 11 to 20
- 21 to 30
- 31 to 40
- 41 to 50
- 51 to 60
- 61 to 70

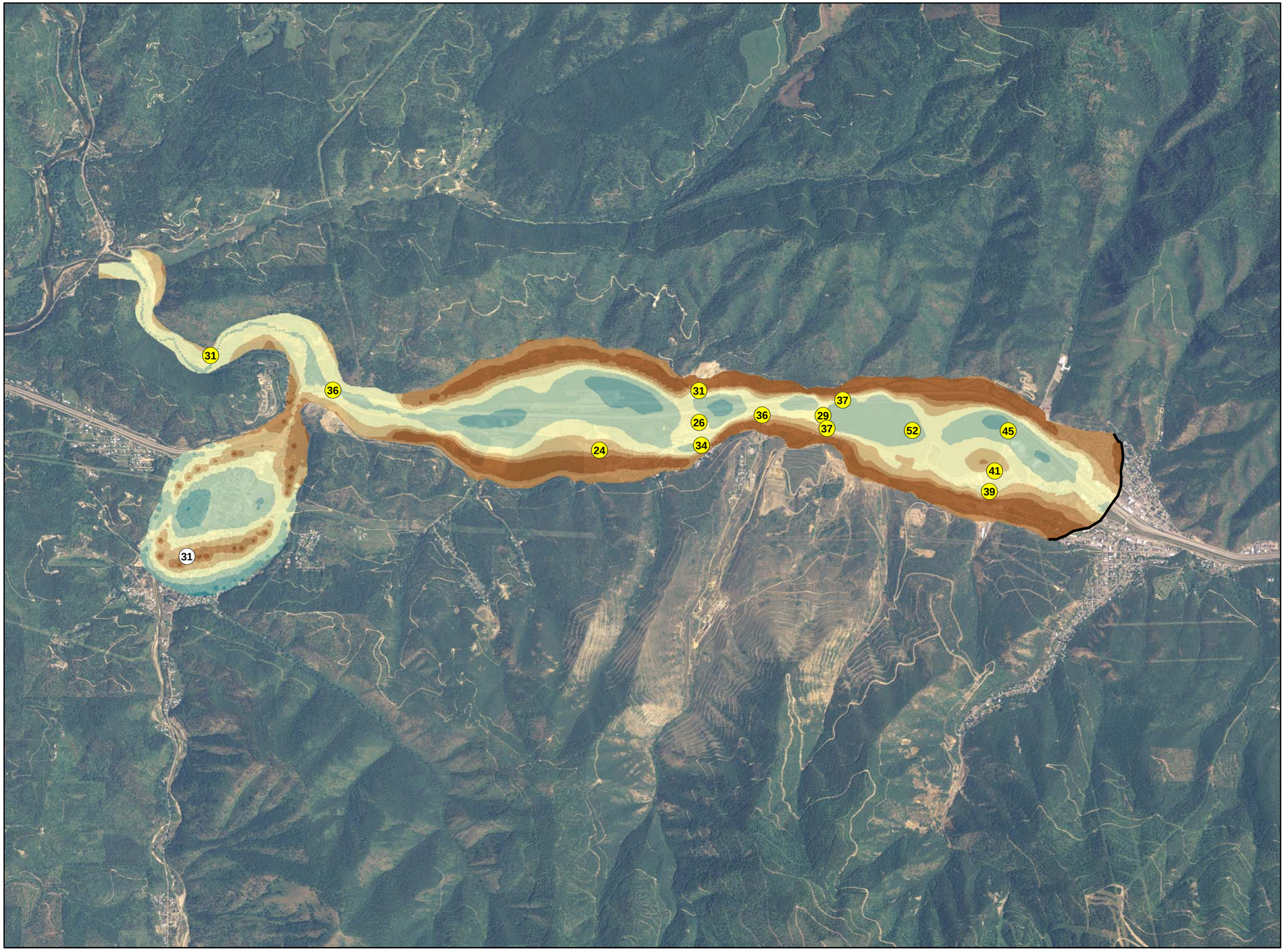
Notes:
1) IDWR wells located to the quarter-quarter section.
2) IDWR = Idaho Department of Water Resources

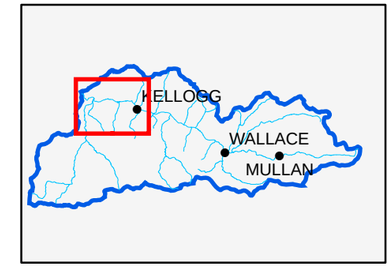
N

0 1,500 3,000 6,000 Feet

Figure 13
Upper Aquifer Saturated Thicknesses – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

LOCATION TYPE

- IDWR WELL
- MONITORING WELL
- 39 LOWER AQUIFER THICKNESS (feet)
- APPROXIMATE EXTENT OF CONFINING UNIT

SATURATED THICKNESS (feet)

- 0 to 10
- 10 to 20
- 20 to 30
- 30 to 40
- 40 to 50
- 50 to 60
- 60 to 70

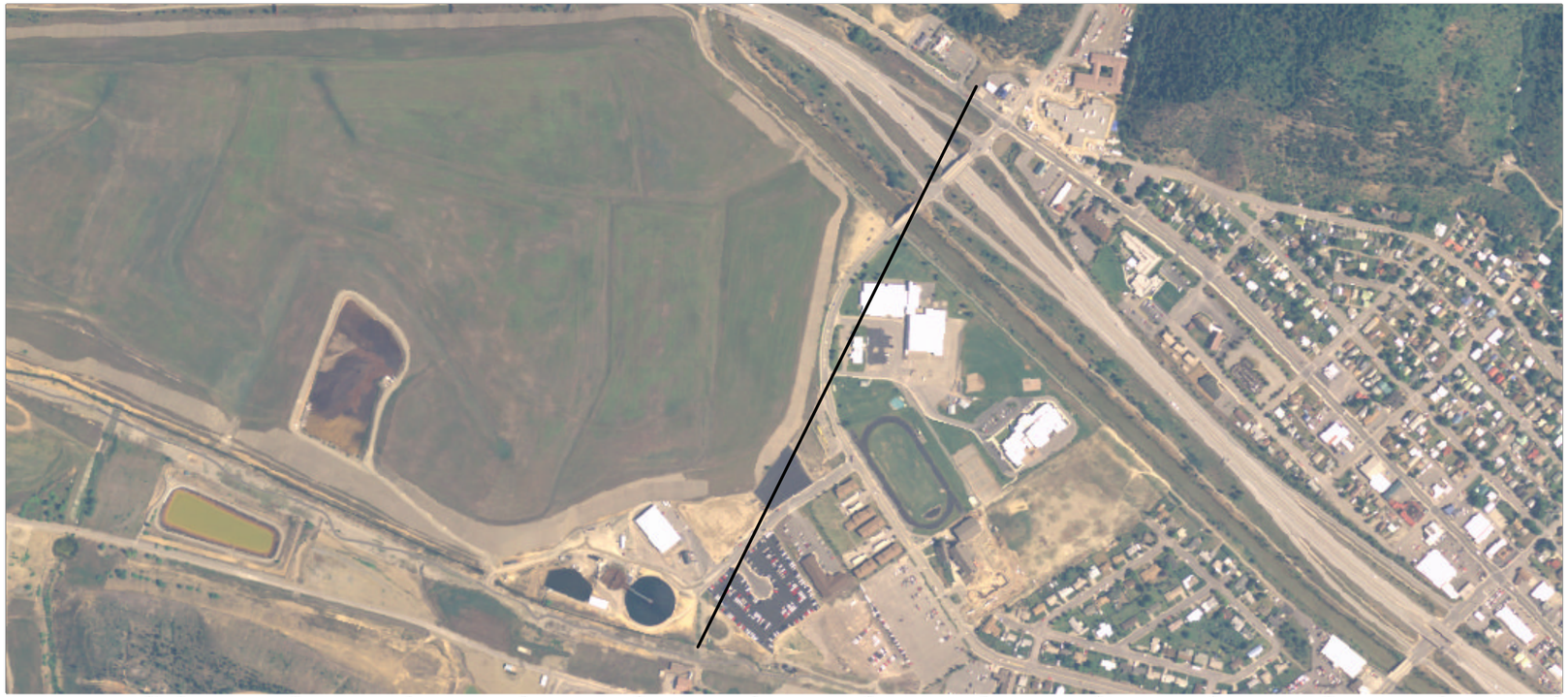
Notes:
1) IDWR wells located to the quarter-quarter section.
2) IDWR = Idaho Department of Water Resources

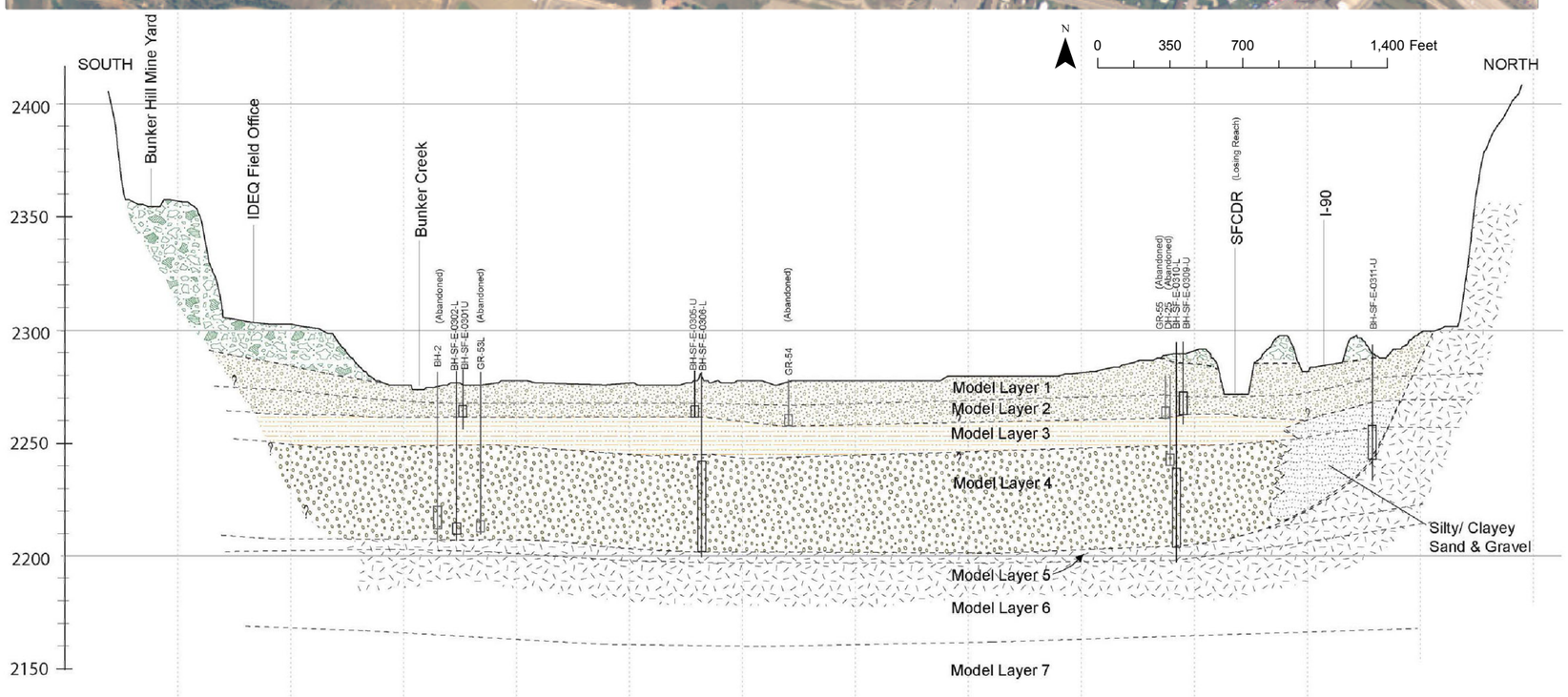
N

0 1,500 3,000 6,000 Feet

Figure 14
Lower Aquifer Saturated Thicknesses – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





Transect 2
Scale 6:1 (V:H)
1-inch = 50 feet Vertical

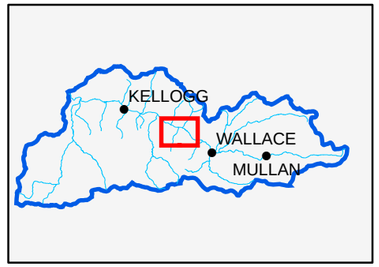
LEGEND

- Well Location
- Contaminated Fill
- Lacustrine Silt/Clay
- Upper Alluvial Sand & Gravel
- Lower Alluvial Sand & Gravel
- Bedrock
- Silty Fine Sand/ Gravel
- Inferred Geologic Contact
- Inferred Surface Topography (CH2M HILL, 1996)
- BH-SF-E-0002 Well Information
- Well Screen Interval

Notes:
1.) Contact between fill material and alluvial sediment is inferred.
2.) A layer of tailings mixed with alluvium mantles the majority of the SFCDR and tributary floodplains in OU2 except where removal actions have occurred. This layer is not depicted on this figure.

Figure 15
Vertical Discretization of Model Layers
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

MONITORING WELL

22 SATURATED THICKNESS (feet)

SATURATED THICKNESS (feet)

- 0 TO 10
- 10 TO 20
- 20 TO 30
- 30 TO 40
- 40 TO 50

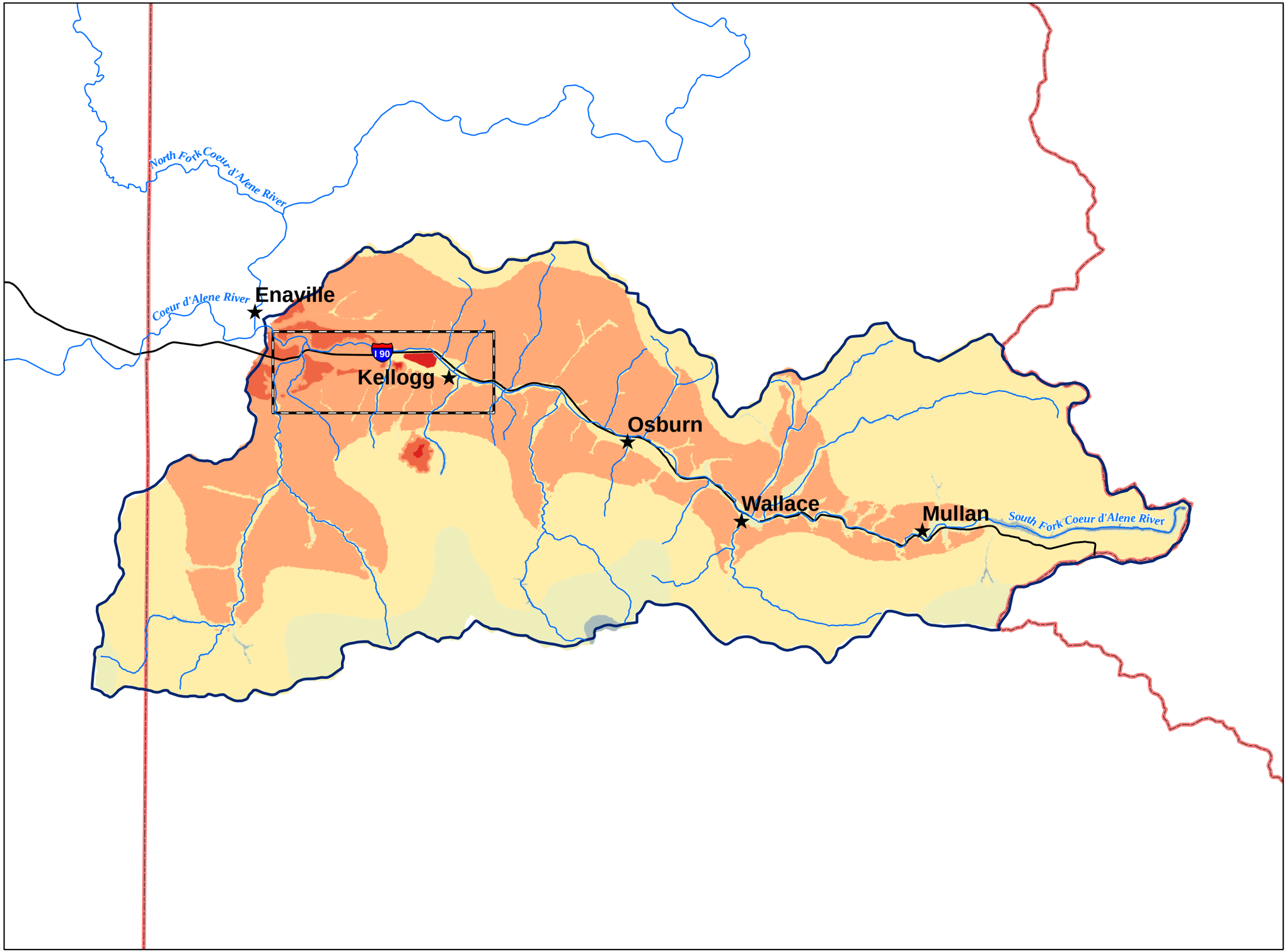
N

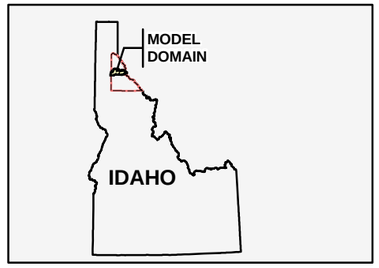
0 750 1,500 3,000 Feet

Figure 16
Total Saturated Alluvial Thickness – Osburn Flats
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL

\\ODIN\PROJ\USEPA\323031\BUNKERHILL\FIGURES\MXD\2009_02_BASINWIDEMODELDOCUMENTATION\FIGURE-16_ALLUV_THICK_OSBURN.MXD FELHADID 4/27/2009 18:02:35





LEGEND

- ★ CITY
- MAJOR STREAMS
- BUNKER HILL BOX
- BOUNDARY OF SOUTH FORK COEUR d'ALENE RIVER WATERSHED
- SHOSHONE COUNTY

INCHES PER YEAR

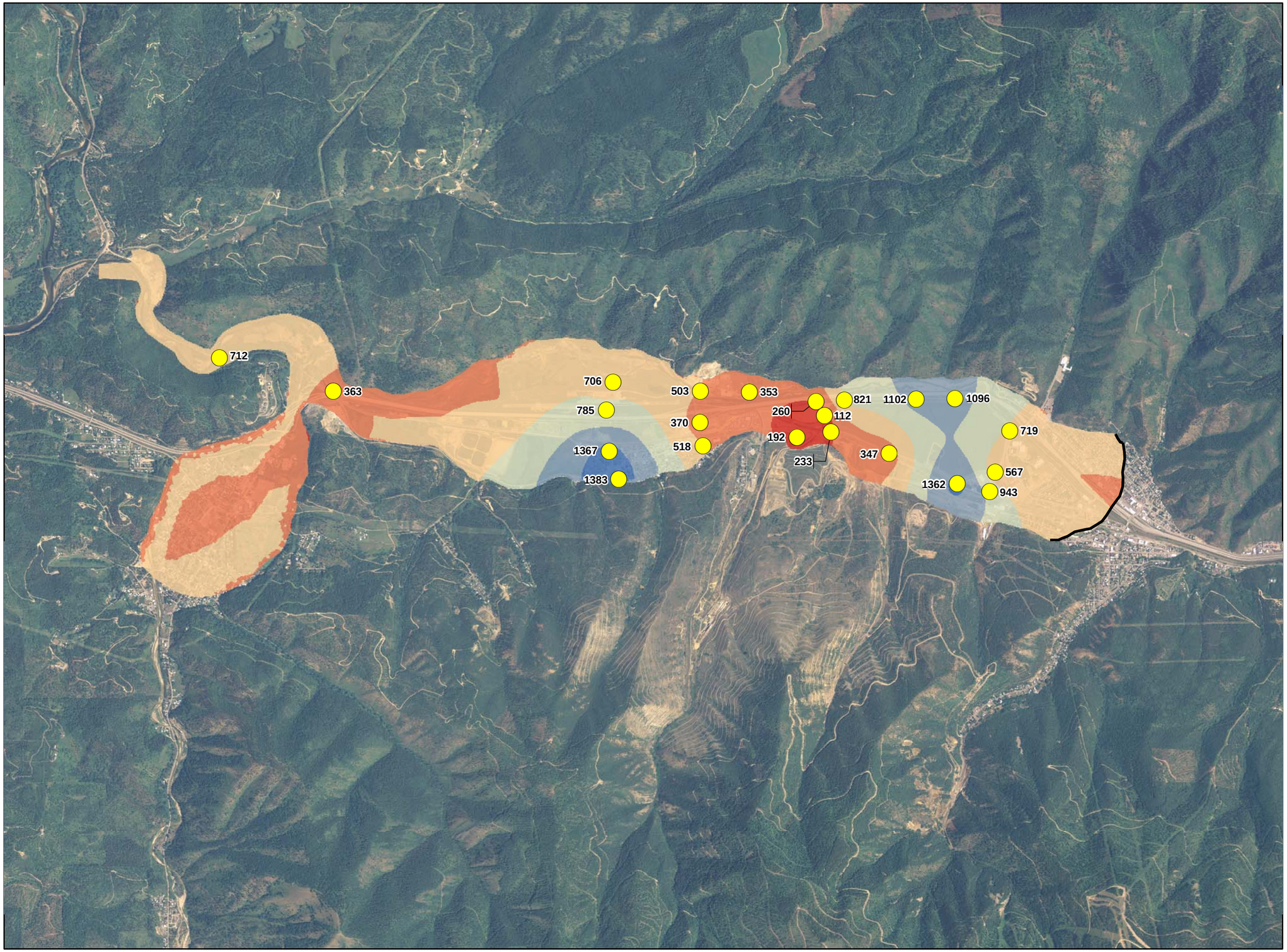
- 0
- < 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14

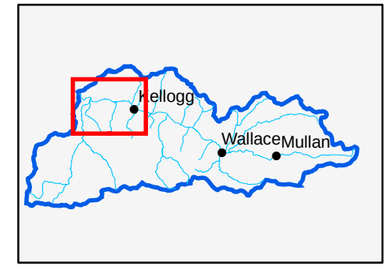
N

0 1.5 3 6 Miles

Figure 17
Calibrated Distribution of Deep Percolation of Precipitation
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

- SINGLE-WELL AQUIFER TEST LOCATION
- 567 HYDRAULIC CONDUCTIVITY (feet/day)
- APPROXIMATE EXTENT OF CONFINING UNIT

HYDRAULIC CONDUCTIVITY (feet/day)

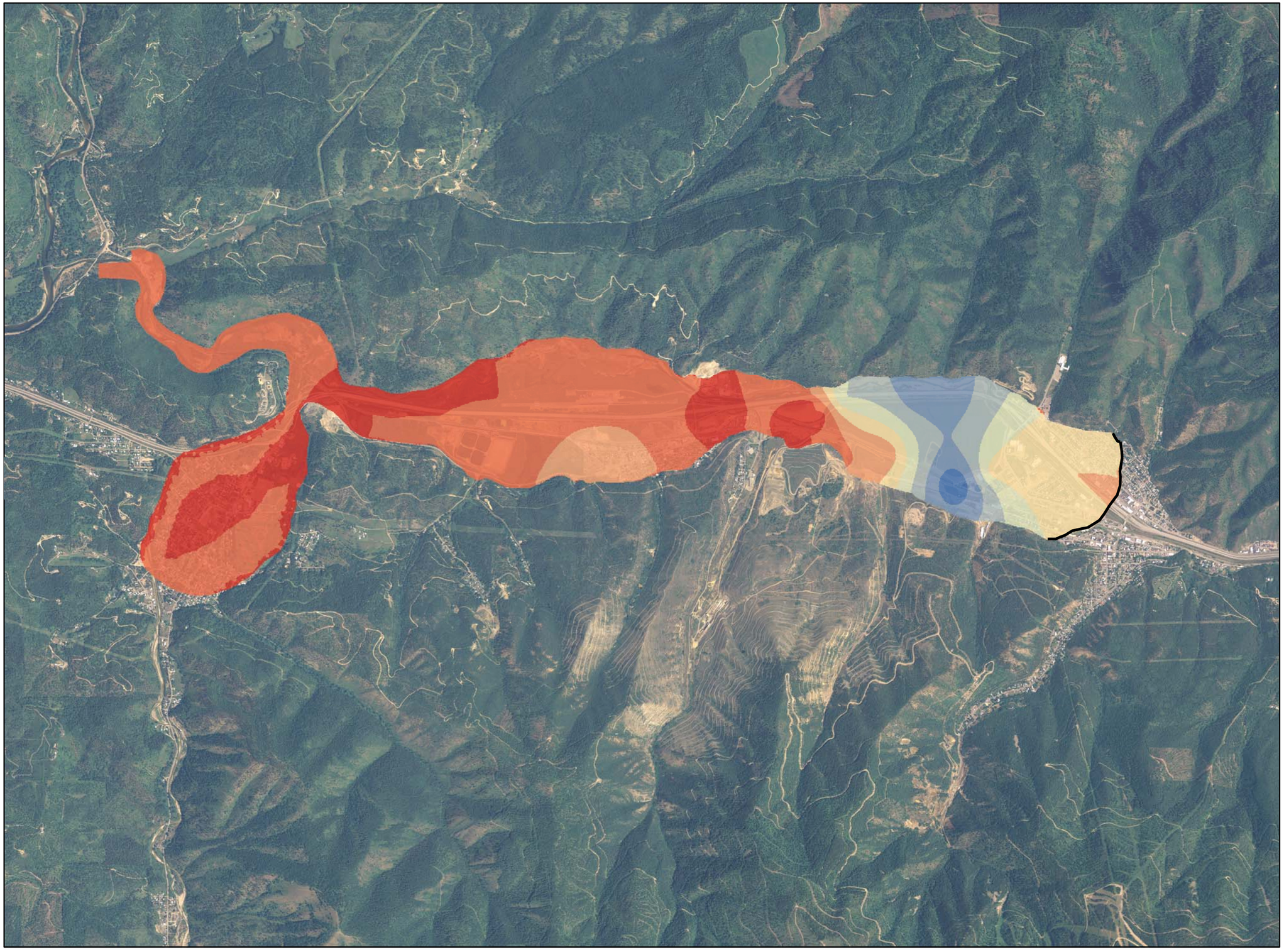
- <250
- 250 to 500
- 500 to 750
- 750 to 1,000
- 1,000 to 1,250
- 1,250 to 1,400

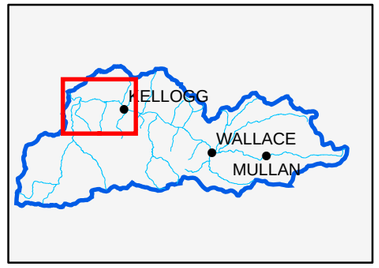
N

0 1,500 3,000 6,000 Feet

Figure 18
Calibrated Hydraulic Conductivity of the Upper Aquifer – Bunker Hill Box
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

APPROXIMATE EXTENT OF CONFINING UNIT

HYDRAULIC CONDUCTIVITY (feet/day)

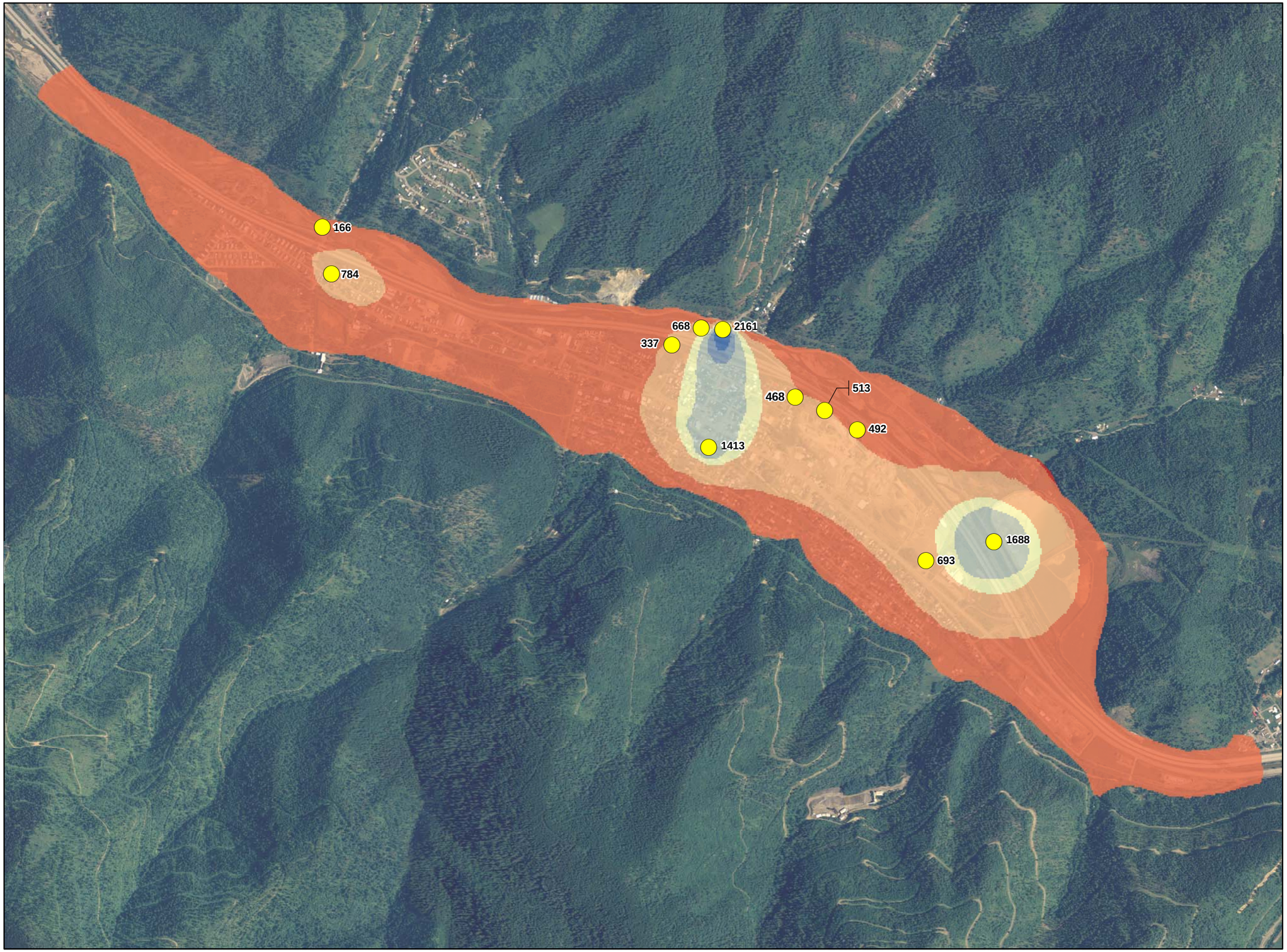
- <250
- 250 to 500
- 500 to 750
- 750 to 1,000
- 1,000 to 1,250
- 1,250 to 1,500
- 1,500 to 1,750
- 1,750 to 2,010

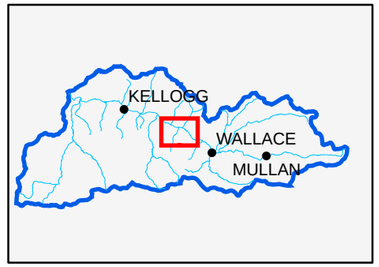
N

0 1,500 3,000 6,000 Feet

Figure 19
Calibrated Hydraulic Conductivity of the Lower Aquifer – Bunker Hill Box
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

AQUIFER TEST LOCATION

1688 HYDRAULIC CONDUCTIVITY (feet/day)

HYDRAULIC CONDUCTIVITY (feet/day)

- <250
- 250 to 500
- 500 to 750
- 750 to 1,000
- 1,000 to 1,250
- 1,250 to 1,500
- 1,500 to 2,200

Note: Modified from CH2M HILL, 2009d.

N

0 750 1,500 3,000 Feet

Figure 20
Calibrated Hydraulic Conductivity – Osburn Flats
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

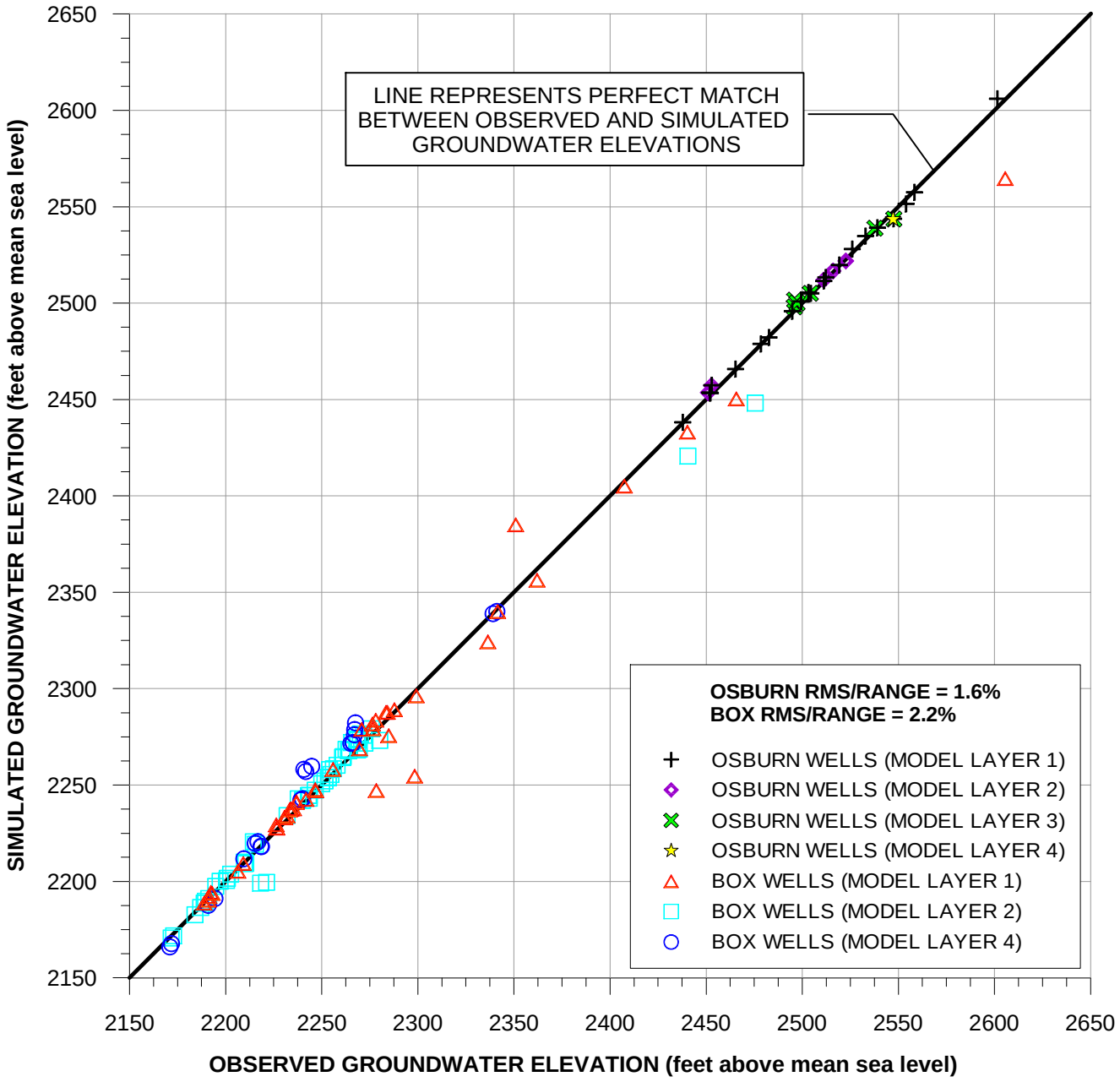
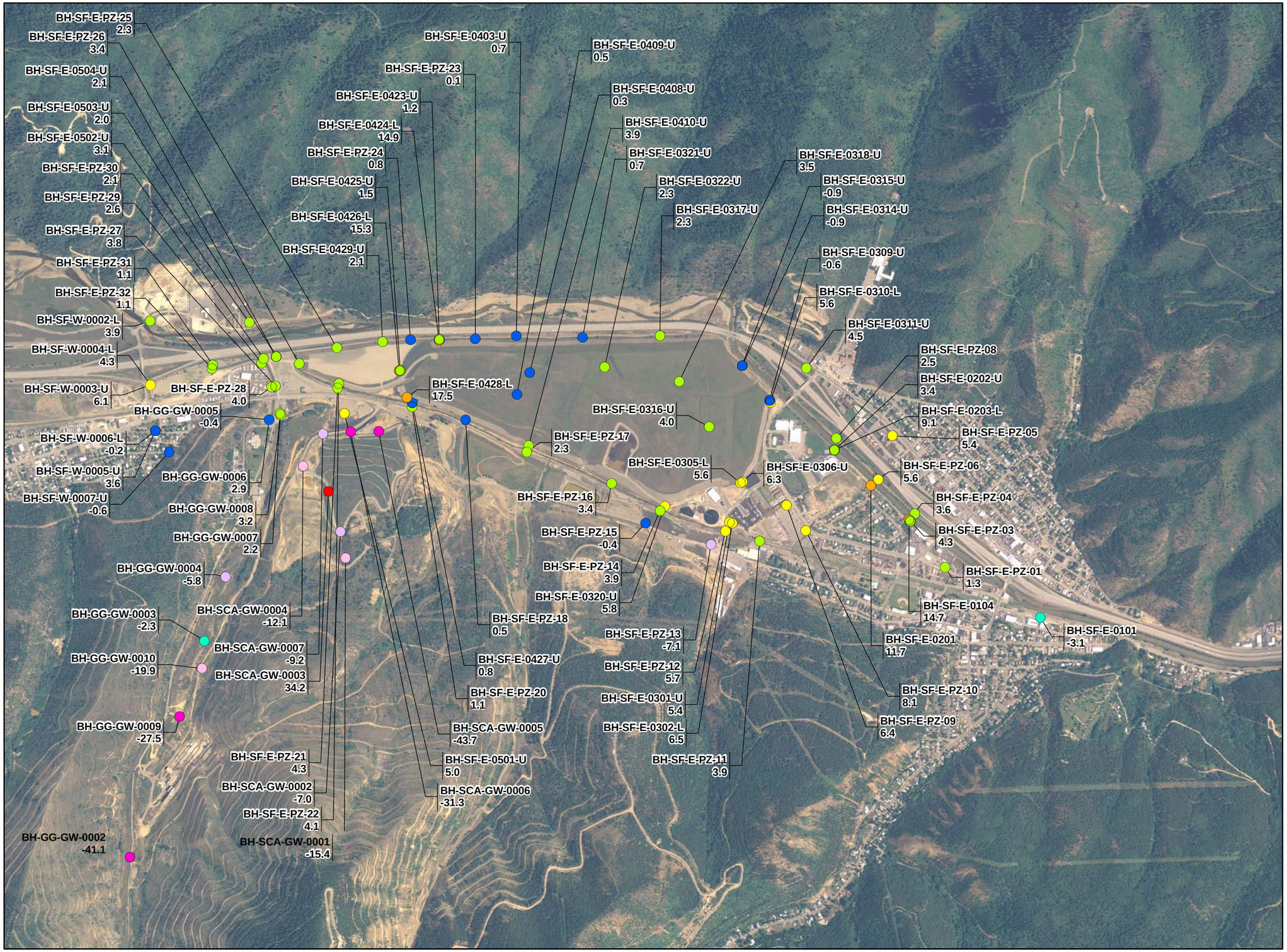
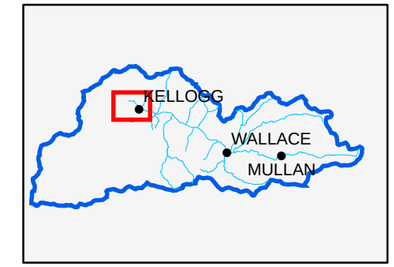


Figure 21
Simulated Versus Observed Groundwater Elevations – Fall 2008
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE





LEGEND

RESIDUAL (feet)

- -51 to -25
- -25 to -10
- -10 to -5
- -5 to -1
- -1 to 1
- 1 to 5
- 5 to 10
- 10 to 25
- 25 to 35

Note: Residual is equal to simulated groundwater elevation minus measured groundwater elevation.

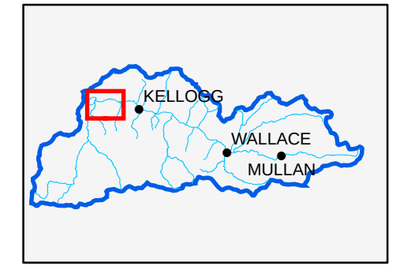
N

0 750 1,500 3,000 Feet

Figure 22
Residuals Between Measured and Simulated Groundwater Elevations – Eastern Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

RESIDUAL (feet)

- -51 to -25
- -25 to -10
- -10 to -5
- -5 to -1
- -1 to 1
- 1 to 5
- 5 to 10
- 10 to 25
- 25 to 35

Note: Residual is equal to simulated groundwater elevation minus measured groundwater elevation.

N

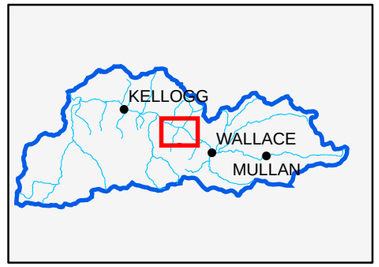
0 750 1,500 3,000 Feet

Figure 23
Residuals Between Measured and Simulated Groundwater Elevations – Western Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation

BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

RESIDUAL (feet)

- -51 to -25
- -25 to -10
- -10 to -5
- -5 to -1
- -1 to 1
- 1 to 5
- 5 to 10
- 10 to 25
- 25 to 35

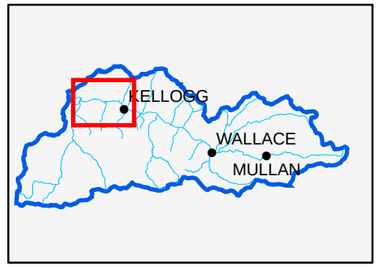
Note: Residual is equal to simulated groundwater elevation minus measured groundwater elevation.

N

0 750 1,500 3,000 Feet

Figure 24
Residuals Between Measured and Simulated Groundwater Elevations – Osburn Flats
South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

BH-SF-LF-0001 SEEPAGE STUDY STATION IDENTIFIER

MAIN STEM SEEPAGE STUDY STATION

MEASURED DATA

GAINING STREAM REACH

LOSING STREAM REACH

MODEL SIMULATED DATA

GAINING STREAM REACH

LOSING STREAM REACH

Note: Data collected in September 2008.

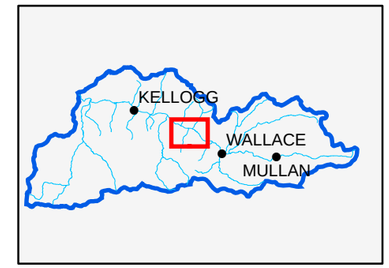
N

0 1,250 2,500 5,000 Feet

Figure 25
Comparison of Measured and Simulated Gaining and Losing Stream Reaches – Bunker Hill Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation

BUNKER HILL SUPERFUND SITE



LEGEND

B-1.1 SEEPAGE STUDY STATION IDENTIFIER

MEASURED DATA

GAINING STREAM REACH

LOSING STREAM REACH

MODEL SIMULATED DATA

GAINING STREAM REACH

LOSING STREAM REACH

Note: Data collected in September 2008.

N

0 750 1,500 3,000 Feet

Figure 26
Comparison of Measured and Simulated Gaining and Losing Stream Reaches – Osburn Flats

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation

BUNKER HILL SUPERFUND SITE

CH2MHILL

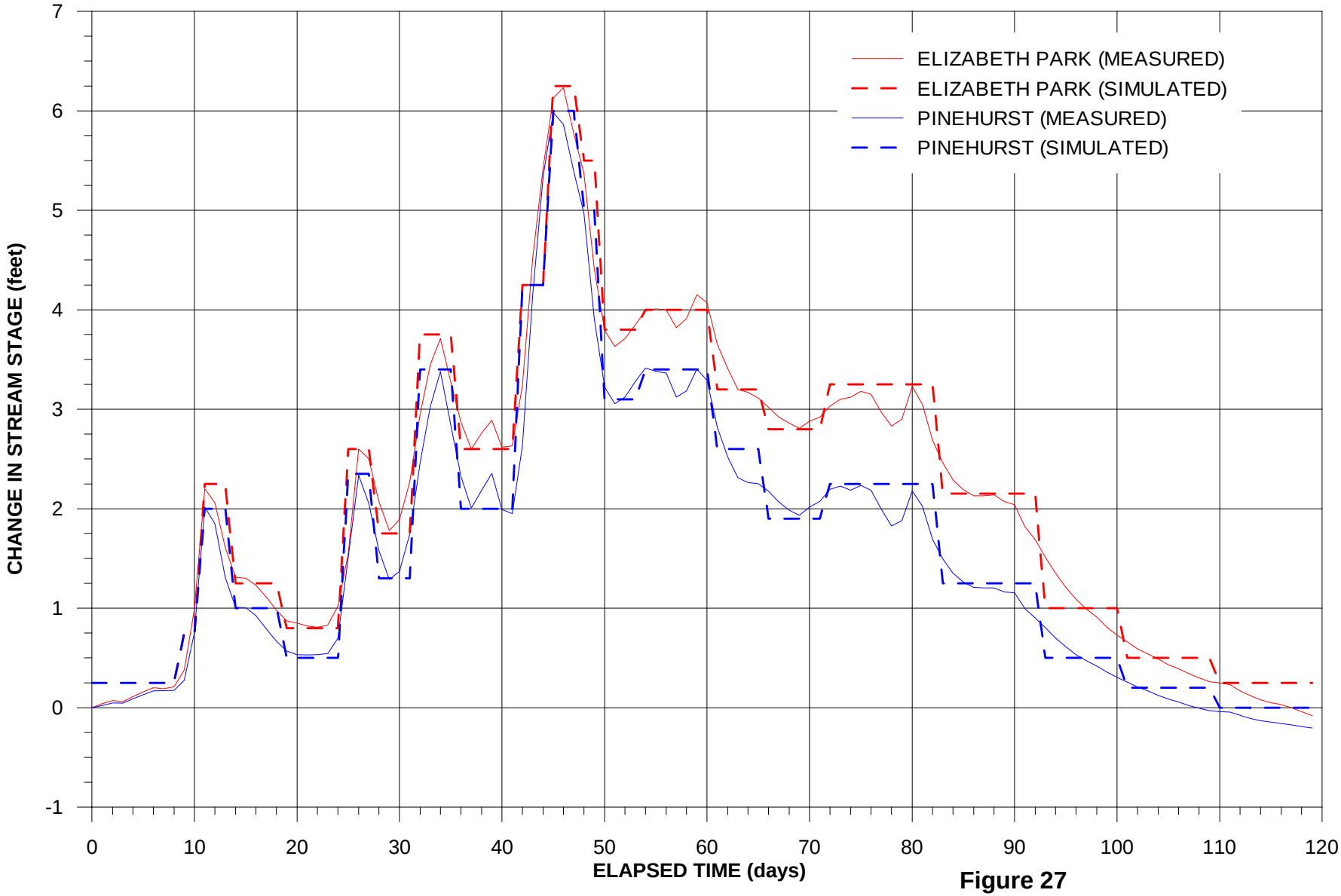
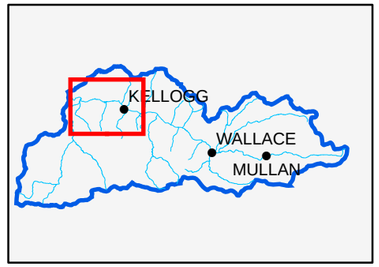


Figure 27
Changes in Stream Stage During the Spring 2008 Runoff Period
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE



LEGEND

LOCATION TYPE

- MONITORING WELL
- STREAM GAUGE

N

0 1,500 3,000 6,000 Feet

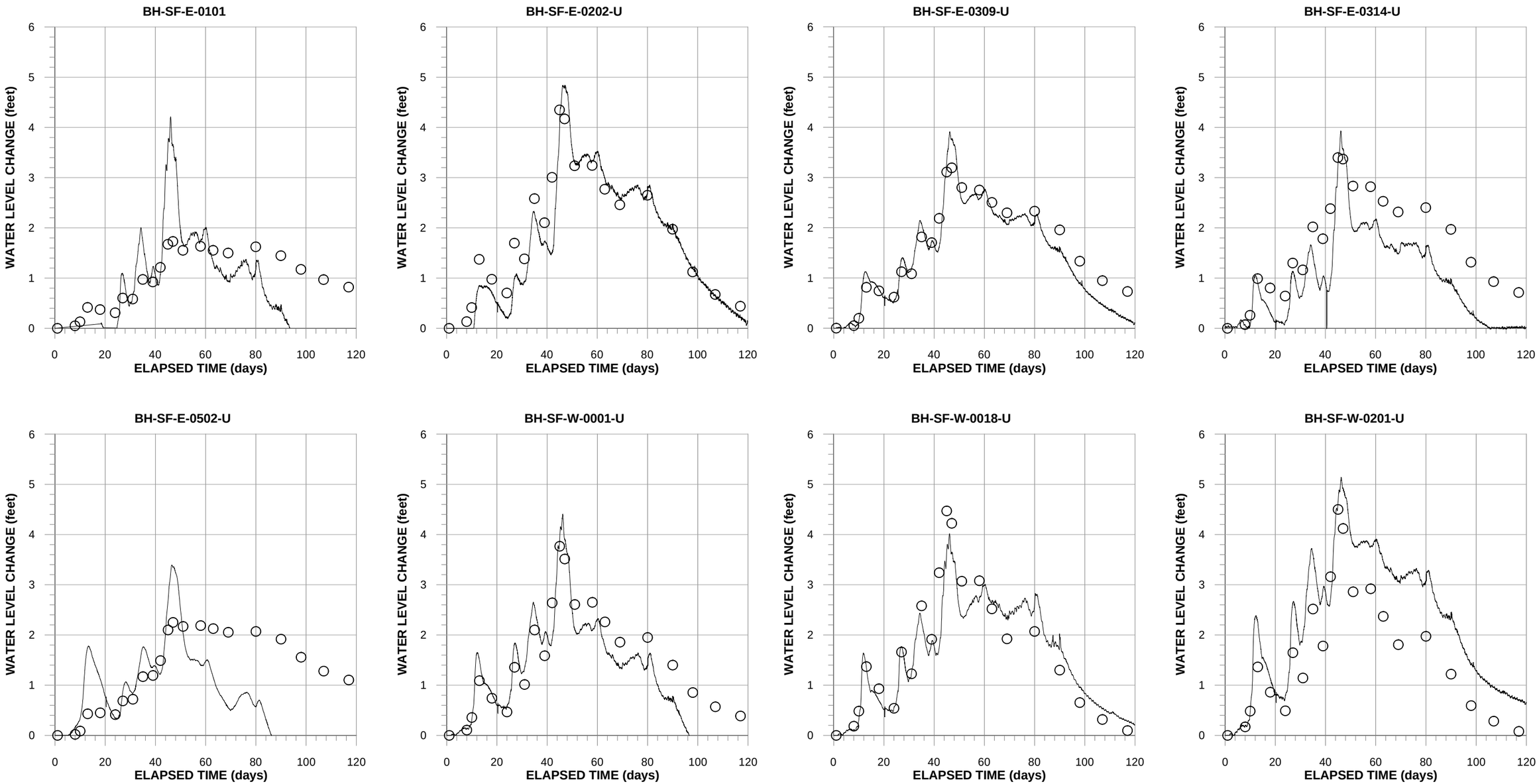
Figure 28
Locations of Transient Calibration Targets – Bunker Hill Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation

BUNKER HILL SUPERFUND SITE

CH2MHILL

\\ODIN\PROJ\USEPA\323031\BUNKERHILL\FIGURES\MXD\2009_02_BASINWIDEMODELDOCUMENTATION\FIGURE-28_TRANSIENT_TARGETS.MXD HPERRY 3/18/2009 22:02:22



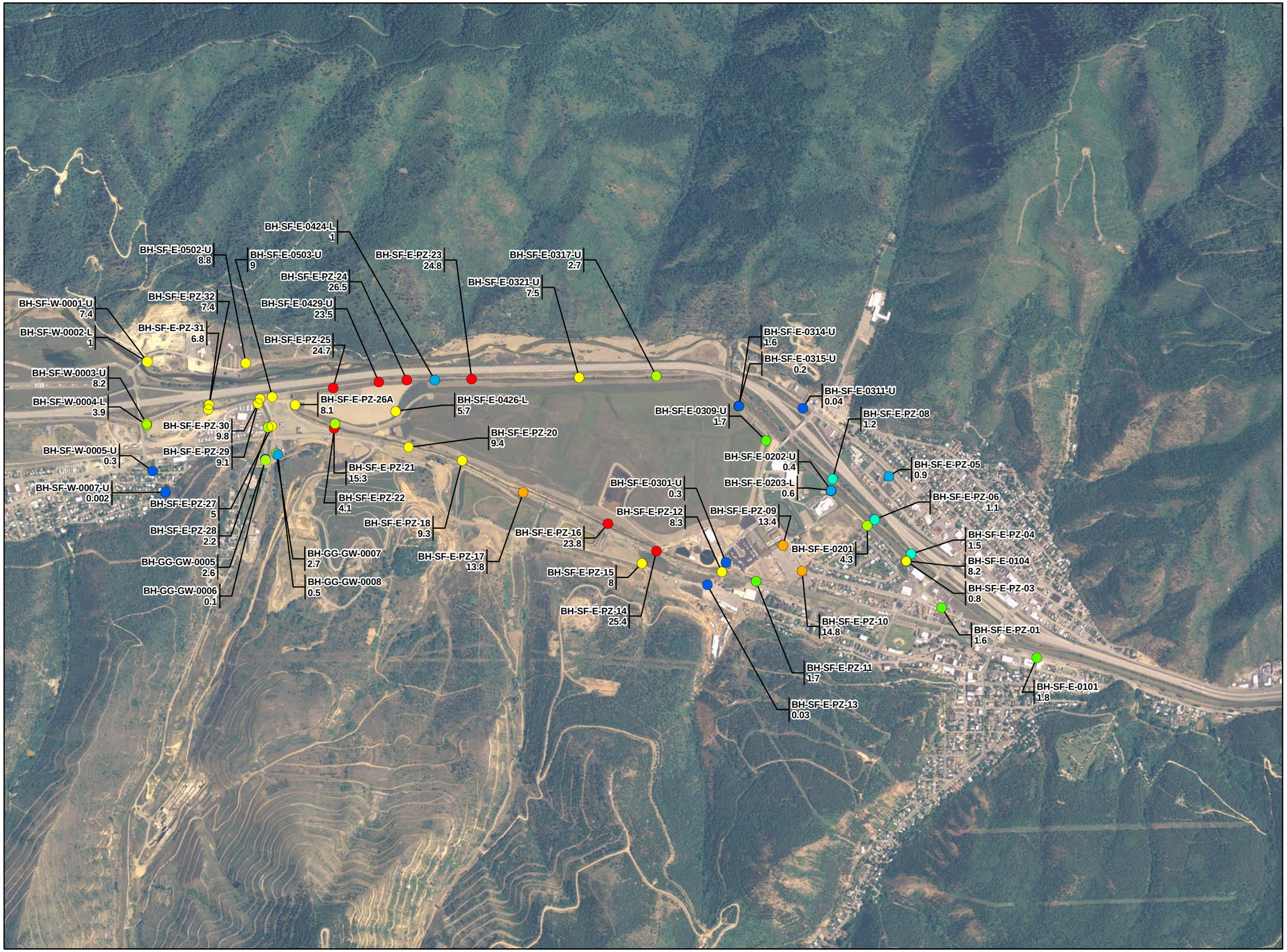
LEGEND

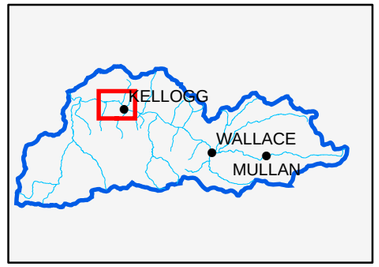
○ SIMULATED

—— MEASURED

Figure 29
Simulated Versus Measured Changes in Groundwater Levels – Spring 2008 Runoff Period
South Fork Coeur d'Alene River
Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

DISSOLVED ZINC CONCENTRATION (mg/L)

- <0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 5.0
- 5.0 to 10
- 10 to 15
- 15 to 26.5

Note: mg/L = milligram(s) per liter

N

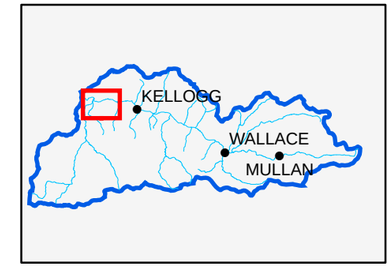
0 750 1,500 3,000 Feet

Figure 30
Dissolved Zinc Concentrations in Groundwater, Fall 2008 – Eastern Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL

\\ODIN\PROJ\USEPA\323031\BUNKERHILL\FIGURES\MXD\2009_02_BASINWIDEMODELDOCUMENTATION\FIGURE-30_EAST_BOX_ZN.MXD FELHADID 3/18/2009 21:56:58



LEGEND

DISSOLVED ZINC CONCENTRATION (mg/L)

- <0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 5.0
- 5.0 to 10
- 10 to 15
- 15 to 26.5

Note: mg/L = milligram(s) per liter

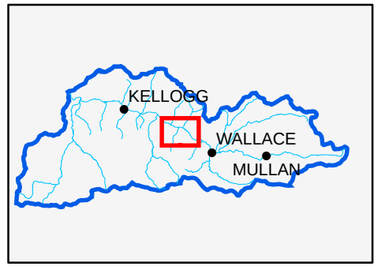
N

0 750 1,500 3,000 Feet

Figure 31
Dissolved Zinc Concentrations in Groundwater, Fall 2008 – Western Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL



LEGEND

DISSOLVED ZINC CONCENTRATION (mg/L)

- <0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 5.0
- 5.0 to 10
- 10 to 15
- 15 to 26.5

Note: mg/L = milligram(s) per liter

N

0 750 1,500 3,000 Feet

Figure 32
Dissolved Zinc Concentrations in Groundwater, Fall 2008 – Osburn Flats

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
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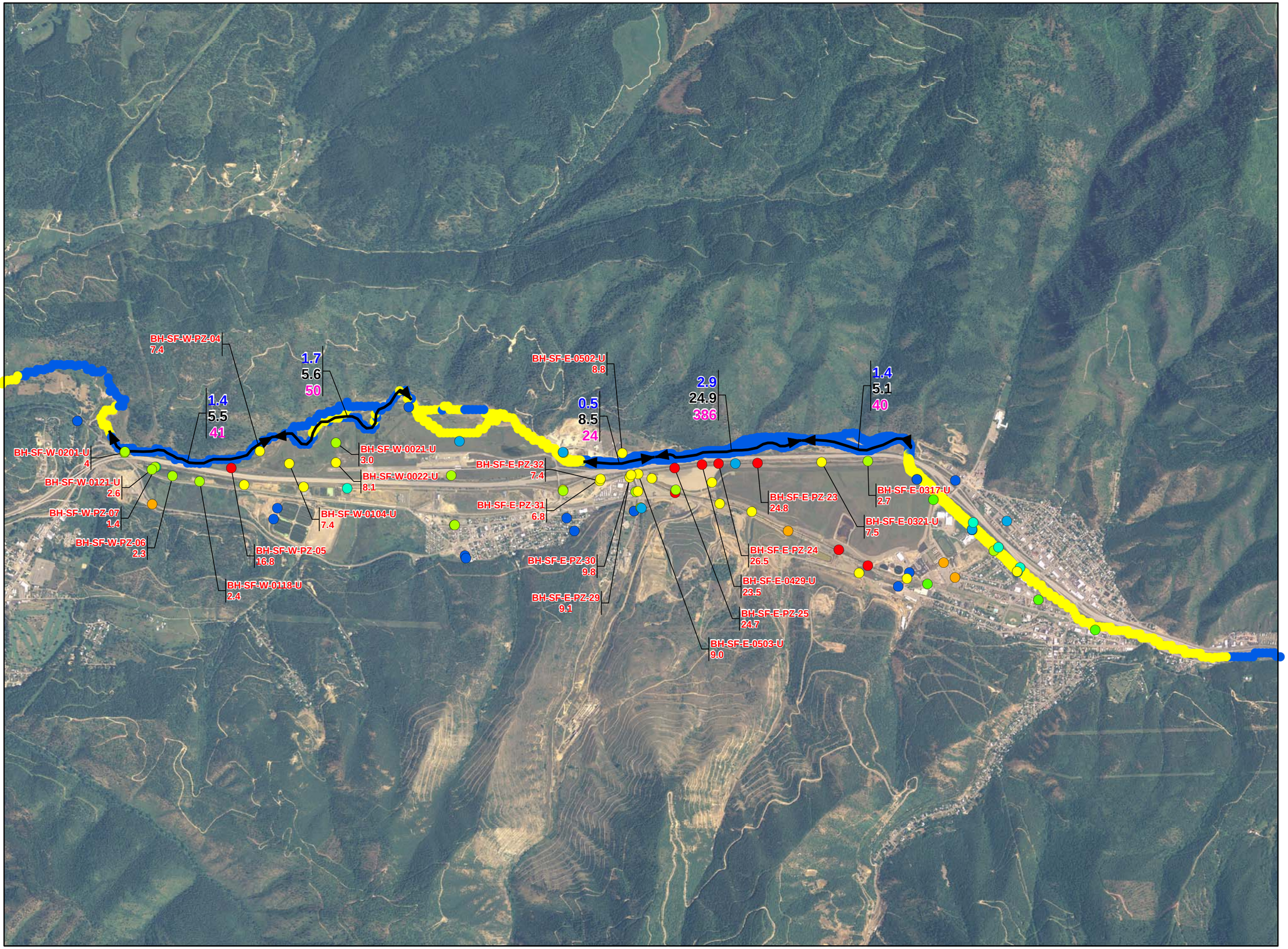
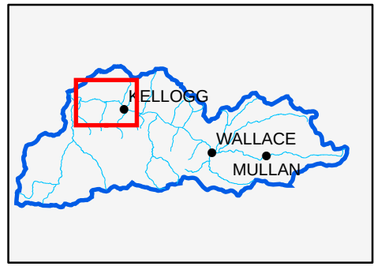




LEGEND

2.3 GROUNDWATER DISCHARGE (cfs)

24.9 AVERAGE DISSOLVED ZINC CONCENTRATION (mg/L)

309 DISSOLVED ZINC LOAD (pounds/day)

ZINC LOADING REACH

MODEL SIMULATED DATA

GAINING STREAM REACH

LOSING STREAM REACH

26.5 DISSOLVED ZINC CONCENTRATION (mg/L) USED TO AVERAGE BY REACH

DISSOLVED ZINC CONCENTRATION (mg/L)

- <0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 5.0
- 5.0 to 10
- 10 to 15
- 15 to 26.5

Notes:
1) cfs = cubic feet per second
2) mg/L = milligram(s) per liter

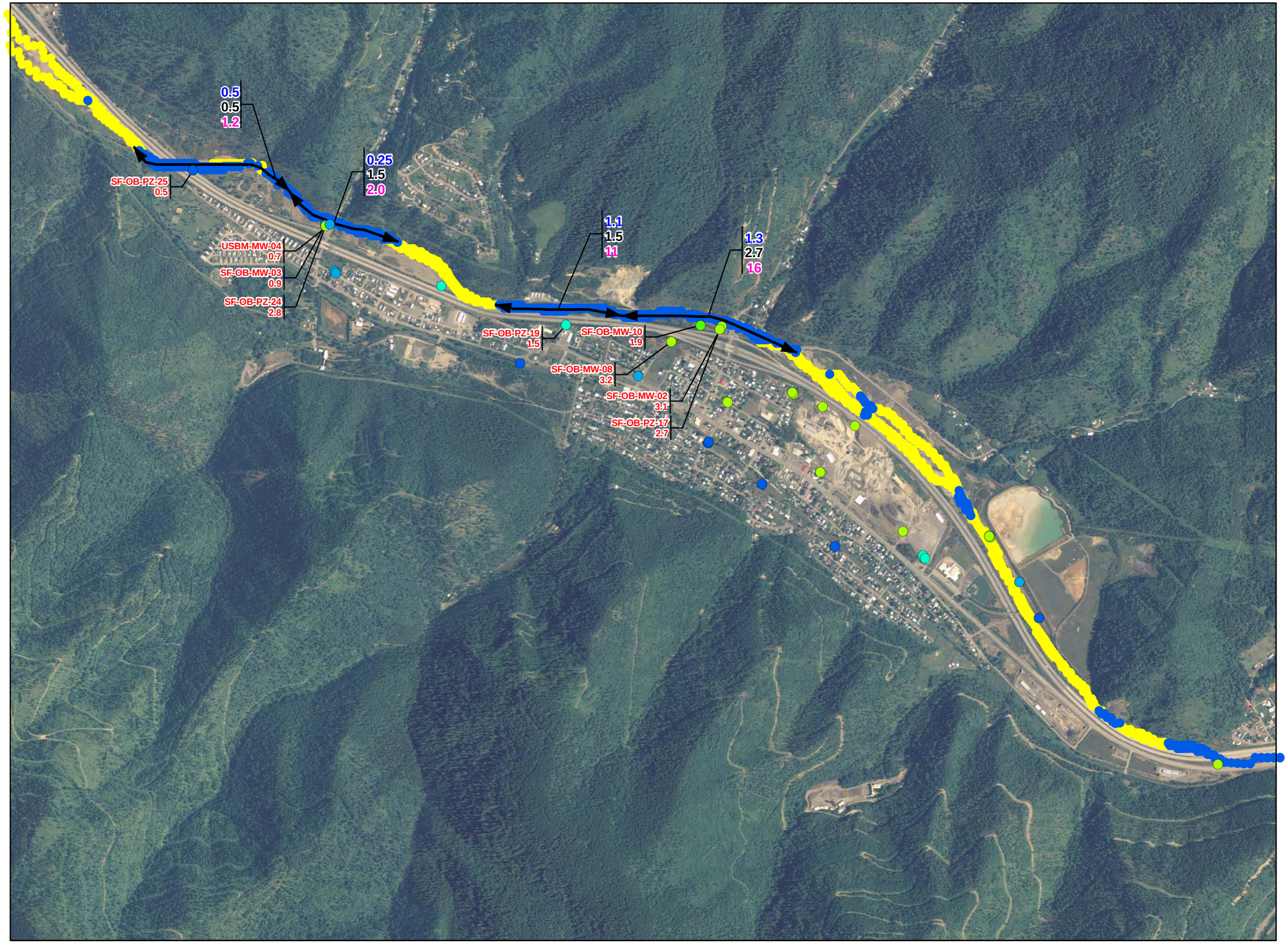
N

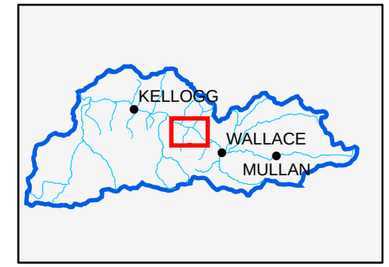
0 1,250 2,500 5,000 Feet

Figure 33
Estimated Dissolved Zinc Loads to the SFCDR – Bunker Hill Box

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation
BUNKER HILL SUPERFUND SITE

CH2MHILL





LEGEND

1.6 GROUNDWATER DISCHARGE (cfs)

2.7 AVERAGE DISSOLVED ZINC CONCENTRATION (mg/L)

23 DISSOLVED ZINC LOAD (pounds/day)

ZINC LOADING REACH

MODEL-SIMULATED DATA

GAINING STREAM REACH

LOSING STREAM REACH

3.2 DISSOLVED ZINC CONCENTRATION (mg/L) USED TO AVERAGE BY REACH

DISSOLVED ZINC CONCENTRATION (mg/L)

- <0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 5.0
- 5.0 to 10
- 10 to 15
- 15 to 26.5

Notes:
1) cfs = cubic feet per second
2) mg/L = milligram(s) per liter

N

0 750 1,500 3,000 Feet

Figure 34
Estimated Dissolved Zinc Loads to the SFCDR – Osburn Flats

South Fork Coeur d'Alene River Basinwide Groundwater Flow Model Documentation

BUNKER HILL SUPERFUND SITE

CH2MHILL

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Attachment 1
Response to Comments

Document Title: Draft Technical Memorandum, South Fork of the Coeur d'Alene River Watershed: Basinwide Groundwater Flow Model Documentation
Lead Author: CH2M HILL
Date: 3/24/2009

Reviewer	Comment #	Section #	Page #	Figure/Table #	Comment	Comment Response
Anne Dailey, U.S. EPA, Region 10					In the interest of full disclosure, it would be helpful and informative to identify the areas of uncertainty and if possible some approximation of the error associated with the model results. I think that we need to address this somewhere in the memo and in the conclusions section.	A section discussing potential sources of error and uncertainty was added to the document prior to the "Conclusions" section.
Anne Dailey, U.S. EPA, Region 10			17		Vertical Hydraulic Gradients; 2nd Para, 1st sent -- wording issue	The word "good" was removed from this sentence.
Anne Dailey, U.S. EPA, Region 10			20		2nd full Para - We discuss the gaining/losing reaches with respect to the modeling effort and the 1999 gw/sw interaction study. Can we link these reaches to the more recent gw/sw interaction studies?	Discussions of the 1999 groundwater-surface water interaction study were updated with field data collected during the 2008 studies.
Anne Dailey, U.S. EPA, Region 10			20		3rd Para (and maybe elsewhere) - I think it is more clear (but longer) to say "groundwater surface water interaction study" than "Barton study"	Terminology was changed from "Barton-type study" to "groundwater-surface water interaction study/studies" throughout the document.
Anne Dailey, U.S. EPA, Region 10			23		1st bullet - It would be helpful to add the river mileage to the description of the watershed since this is also a significant descriptor (35 river miles, I think...)	The first bullet was edited to read: "• Encompasses the entire SFCDR Watershed, approximately 300 square miles and 35 river miles along the SFCDR"
Anne Dailey, U.S. EPA, Region 10				12, 13, and 14	The legend should include a definition of what the # in the circle is measuring. The figures suggest that this is the saturated thickness measured in various wells, piezometers and IDWR records. If this is the case, then the color coding of the saturated thicknesses seems to be mis-aligned or mis-contoured. See for example - Fig. 12 - Pine Creek 10, 14 and 16 thicknesses don't seem to match the inferred thickness.	The legends on the contour maps were updated to include a description of the posted parameters on all of the contour figures. The figures were edited such that values not used in the contouring were not posted.
Anne Dailey, U.S. EPA, Region 10			18		The contour lines do not fully match up with the values on the figure. See for example the 680, 580, 650 and 800 in the middle of the figure.	The single-well aquifer tests were re-evaluated during initial model construction. Figure 18 was updated with re-evaluated data points.
Anne Dailey, U.S. EPA, Region 10			16-17	22 and 23	Some of the measured and simulated gw elevations are very similar --- and others differ significantly and not necessarily consistently between nearby wells/piezometers. For example on Fig. BH-SF-E-0104 is +15.6' and the two nearby points PZ-04 and PZ-03 differ by less than +4'. It seems like this is going to introduce some significant uncertainty into the model results. Can you address this in the text somehow?	The third through fifth sentences of the second paragraph of the Groundwater Elevations section read: "The model-simulated groundwater elevations are approximately 12 to 15 feet higher than those measured in wells BH-SF-E-0104 and BH-SF-E-0201 shown in Figure 22. Historical water-level measurements recorded at these wells have been anomalous, and piezometers were installed in 2008 to refine measurements at these locations. The model does a better job of replicating the measured groundwater elevations at the new piezometers."
Bill Rust, Shoshone County TLG Representative					During the presentation on the use of the groundwater model CH2M Hill came up with the amount of zinc that could be removed from the river load by pumping and treating the groundwater captured by two different drain scenarios. They did this by using the groundwater flow rates and the concentration of the nearest well to the drain. I am going to be asking to have that estimate redone for phosphorus. In previous rough estimates it looked to me like the load from here was larger than the 4400 kg/yr discharged by the Page WWTP. If you pump and treat for zinc you will also get the phosphate as it is almost completely removed by lime treatment. This is an issue for the Coeur d'Alene Lake Management Plan. I think it is a number we should know.	Steve Hicks provided this information at the 4/1/09 meeting.
Nick Zilka, Idaho DEQ			3		Para. 2 – The 'box' defines the boundary of OU1 And OU2	This text was edited to read: "(The Box is the approximately 21-square-mile area that defines the boundary of OUs 1 and 2.)"
Nick Zilka, Idaho DEQ			7, 8		Were any of these assigned thicknesses compared to well/direct push logs?	Points posted on the thickness figures are locations where field data were available to incorporate into the groundwater flow model layering. The legends of the figures were edited to include a description of what parameter value the points are presenting.
Nick Zilka, Idaho DEQ			10		The 3 formulas are the same, so why discuss stream types?	Equations 3 and 4 were edited to read: "If $h_1 < wh_1$ and $h_1 > wl_1$: $Qinflow=a*(wh_1-h_1)/wc_1$ (3) In de-coupled streams (groundwater elevation is below the stream bottom elevation), groundwater recharge from a stream is simulated as follows: If $h_1 < wh_1$ and $h_1 < wl_1$: $Qinflow-a*(wh_1-wl_1)/wc_1$ (4)

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Nick Zilka, Idaho DEQ			15, 23		Why rely solely on 2008 data? Wouldn't be useful to compare actual data and simulations for a couple other years (1996) might be interesting)?	A primary goal of the groundwater model was to evaluate current conditions in the SFCDR Watershed in order to serve as a baseline for evaluation of the benefit of future remedial actions. As such, the model was calibrated to the most recent dataset.
Nick Zilka, Idaho DEQ			16	22	Is there a way to adjust the model to address large residuals for the SCA and Gov't Gulch?	The model was constructed primarily to simulate the movement of groundwater through the alluvial floodplain aquifers in the SFCDR Watershed, and to estimate the degree of groundwater-surface water interaction that occurs. Groundwater flow of this type occurs through porous media and is accurately simulated using a Darcy's Law-based approach. Groundwater flow in the vicinity of the SCA occurs through a bedrock aquifer system. This type of flow system is heavily influenced by small scale fracture flow that is beyond the resolution of this model grid. Therefore, accurate calibration to all water levels measured within the bedrock aquifer flow system is beyond the capabilities of this tool.
Nick Zilka, Idaho DEQ			16		The lake west of the SCA is lined	The irrigation ponds for the golf course are not included as features in the groundwater flow model.
Nick Zilka, Idaho DEQ			20, Para. 22; P.23, Bullet 5	26	Appears to show a poor match between actual measurements and simulations in Osburn.	The groundwater flow model was modified to provide a better match to the gaining/losing reaches of the SFCDR along the western end of Osburn Flats.
Terragraphics Environmental Engineering Inc.				3,4	The contours of water-level elevation shown on Figures 3 and 4 are likely drawn wrong. Drawing the north and south ends of contours curving to the east indicates that groundwater in the alluvial aquifer flows into the surrounding bedrock. The contours should either be drawn as roughly north-south (which indicates very little flow from the surrounding bedrock) or drawn with the north and south ends curving to the west. In the latter case, this would indicate groundwater flow from the bedrock aquifers into the alluvium.	The ends of the contour lines on Figures 3 and 4 were edited so that they trend roughly north/south, indicating little flow from the bedrock system.
Terragraphics Environmental Engineering Inc.			6		There should be a comma instead of a colon after UA (top of page 6) since the document states there are four layers in the alluvial aquifer system (two layers in the UA, one layer in the clay, and one layer in the LA).	The text on page 6 was edited such that the colon was changed to a comma.
Terragraphics Environmental Engineering Inc.				15	The cross-section on Figure 15 should have the representing transect showed on a map.	An inset map showing the location of the cross-section was added to Figure 15.
Terragraphics Environmental Engineering Inc.			9		The bullet list should include "no-flow boundaries" and the number of boundaries should then be changed to four (page 9).	The no-flow discussion was moved to the end of the specified flux boundary condition section, and the following introductory sentence was added: "A no-flow boundary is a special condition of a specified flux boundary, where the flow across the boundary is set equal to zero."
Terragraphics Environmental Engineering Inc.			9		There are "]" and "[" on the top and bottom of page 9, respectively, that should be removed.	The brackets referenced by the reviewer do not appear in our version of either the Microsoft Word text file or the Adobe PDF version of the entire document.
Terragraphics Environmental Engineering Inc.					In equation 8, should there be a parenthesis before "/2"?	Equation 8 was modified such that the (mt1)^2/2 was changed to $mt1^2/2$.
Terragraphics Environmental Engineering Inc.			15		The storage coefficient of 0.01 used in model layers 1 and 2 in the alluvial material (top of page 15) seems about an order of magnitude low. In the same paragraph, the equation for specific storage appears to be stated wrong. Specific storage is equal to storativity (in this case 2 x 10-6) divided by thickness. The units would thus be 1/feet.	The transient calibration was rerun with a specific yield of 10% in alluvial deposits of Layers 1 and 2. The text was edited to read as follows: "...aquifer-specific yield was assumed to be 10 percent in model layers 1 and 2 in the unconfined alluvial materials, and the storativity was calculated as the specific storage (2×10^{-6} ft^{-1}) multiplied by the layer thickness (in feet) in the bedrock areas of model layers 1 and 2 and for layers 3 through 7 throughout the model domain."
Terragraphics Environmental Engineering Inc.			15		The discussion of SFCDR baseflow on the bottom of page 15 should include the discharge of the CTP. The statement "…the remaining flow in the river is sustained by groundwater discharge" is not totally correct.	The text was edited to read: "therefore, the remaining flow in the river is sustained by (1) groundwater discharge and (2) discharge from the Central Treatment Plant in Kellogg."

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Terragraphics Environmental Engineering Inc.			19-20		A table should be added to the section entitled “Gaining and Losing Reaches of the SFCDR” (pages 19 and 20) that compares the measured gains and losses to the model-predicted gains and losses. This comparison is very important to the ultimate purpose of the model which is to evaluate alternative remedial actions.	A new Table 3, which compares the field-estimated groundwater discharge to and recharge from the SFCDR to simulated values, was added to the document.
Terragraphics Environmental Engineering Inc.			21		The section entitled “Calibration Summary” on page 21 needs to be expanded to present a discussion of the value of the model in representing hydrologic conditions during high flow conditions. An additional calibration approach would be to compare the model-predicted gains and losses to available field data. Greg Clark of the USGS in Boise indicated during a meeting on April 1, 2009 that stream loss data during high flow are available for some reaches in OU2. Comparison of model results to the USGS data would help the reader understand the validity of the model to represent impacts of remediation under high flow conditions.	Greg Clark discussed 1-d flow modeling that he performed in the Box using the mass balance difference between the Elizabeth Park and Pinehurst gauges. In order to evaluate gaining and losing reaches during high-flow conditions, one would need accurate flow data at the Elizabeth Park gauge, the Pinehurst gauge, and all surface inflow between the two gauges (from all tributaries and dispersed surface flow sources). Such data are currently unavailable. The SFCDR model was calibrated to the 2008 runoff period, as discussed in the Model Calibration Section, by varying the measured change in stage in the SFCDR and adjusting the stream conductance term until a reasonable response in nearby groundwater monitoring wells was observed.
Terragraphics Environmental Engineering Inc.			21-23		The section of the report entitled “Sources of Dissolved Metals to the SFCDR” on pages 21 – 23 needs additional text to describe the geochemical assumption underlying this analysis. The analysis as presented is only valid if the dissolved metals are assumed to be conservative (i.e. not changing because of geochemical reactions). The geochemistry discussion is essential if the model is to be used to predict changes in metal loading to the SFCDR from alternative remediation activities.	The second-to-last sentence in the "Sources of Dissolved Metals to the SFCDR" section reads: "This methodology assumes that (a) dissolved zinc can be used as a surrogate for other metals (i.e., the reaches with the greatest zinc loads are also areas with the highest cadmium loads), and (b) there is no change in dissolved metals concentrations in groundwater between the location of the groundwater monitoring well and the discharge area into the stream". The following was added: "(e.g., metals transport in the groundwater system is conservative between the monitoring well and stream discharge area)"
Terragraphics Environmental Engineering Inc.					In the same section, the calculated metal concentrations in groundwater from the SW/GW interaction studies is a more valid value to use in a gaining reach than the concentration values from specific wells. This approach should be evaluated to see if the results are significantly altered.	The concentrations of dissolved zinc from the streambed piezometers were compared to concentrations from nearby groundwater monitoring wells. In most cases the concentrations were lower in the piezometers. This is likely a result of construction; the piezometers are pounded into the streambed with no surface seal to prevent mixing with surface water. Because of this issue, it is believed that properly constructed groundwater monitoring wells provide more representative dissolved zinc concentrations with which to estimate loads.
Terragraphics Environmental Engineering Inc.					A table should be added to the section entitled “Baseline Metals Loading to the SFCDR” that includes a comparison of the model results to the results of the various SW/GW studies. This would serve as an additional calibration step for this application of the model.	A new Table 4, which compares the field-estimated gain/loss in dissolved zinc load to/from the SFCDR to estimates made using model-simulated flows and analytical data from groundwater monitoring wells, was added to the document.