



California Department of
Fish and Wildlife

DRAFT Shay Pond Area Hydrogeologic Assessment for the Unarmored Threespine Stickleback Fish

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1 Introduction

This report presents a hydrogeologic assessment of the Shay Pond Area in Big Bear City, California (see Figures 1 and 2) prepared for the California Department of Fish and Wildlife (CDFW). Located in the San Bernardino Mountains, Shay Pond provides a freshwater habitat for the Unarmored Threespine Stickleback fish (UTS), pictured below. The UTS can reach mature lengths of 8 centimeters (cm) (3.1 in), but lengths of 3–4 cm (1.2-1.6 in) are more common^[1].



Source: https://c1.staticflickr.com/3/2702/4324104953_6c90ef4cbe.jpg

Shay Pond (the pond) is a spring; therefore, its water level is largely controlled by groundwater levels, which in turn are controlled by precipitation and subsequent recharge along with groundwater withdrawals from public and private groundwater production wells (see Figure 2). In addition to these hydrologic processes, groundwater levels appear to also be affected by faults.

Following the issuance of a previous hydrogeologic analysis (Geoscience, 2004), the City of Big Bear Lake Department of Water and Power (DWP) and the Big Bear Community Services District (CSD) acquired approximately 2 acres of land encompassing the pond (now referred to as the Shay Pond UTS Preservation Lands) on which they installed a groundwater production well (Shay Pond Well) equipped with a direct discharge line to the pond. The purpose of the Shay Pond well is to provide supplemental water to help maintain the pond water elevations such that the outflow into Shay Creek is no less than 20 gallons per minute (gpm), as required by their special use permit. Data provided by CSD through December 2015 indicate that the Shay Pond

¹ https://en.wikipedia.org/wiki/Three-spined_stickleback

well began pumping in August 2007 at rates between 6 to 15 gpm with an average rate of approximately 9 gpm. The outflow from Shay Pond has dropped below 20 gpm on several occasions since the Shay Pond well has been operating and, since the pond was reconfigured during routine maintenance to remove overgrowth in June 2011 and again in August 2013, the pond no longer outflows to Shay Creek. Subsequently, to maintain pond levels as part of an informal agreement with CDFW, CSD and DWP engineered a supplemental discharge line to the pond that draws from their primary water main in the area such that the pond water level is maintained. This supplemental line discharges to the pond at a rate of approximately 40 gpm; therefore, the total discharge to the pond (i.e., Shay Pond well + CSD/DWP supplemental discharge line) is approximately 50 gpm. Numerous UTS were observed during a site visit in June 2017 and all indications are that the population is stable.

It has been hypothesized that pond levels have dropped due to pumping of the Lakewood well field located approximately ½ mile south of the pond (Figure 2). Because CSD/DWP have developed alternative sources of water that are located far from the pond (i.e., the Magnolia well and Maple well) to service the area, they have largely discontinued – and will soon completely cease - pumping the Lakewood wellfield in CSD Well #2. While taking this action would allay concerns regarding the effect of continued pumping of these wells on pond levels, it would also eliminate the source of water for the supplemental 40 gpm discharge line to the pond. Therefore, maintaining pond water levels will require either: 1) developing an alternative 40 gpm source or 2) lining the pond to reduce percolation through the pond bottom sediments such that the Shay Pond well is able to maintain pond water levels on its own.

1.1 Purpose and Scope

The primary purpose of this assessment was to identify the requirements necessary to restore and maintain water levels within Shay Pond for the UTS. The evaluation was conducted by updating and modifying a previously-developed calibrated numerical groundwater flow model presented in Geoscience (2004). Both the Geoscience model and updated model presented here utilize the United States Geological Survey (USGS) MODFLOW code (McDonald and Harbaugh, 1988). The previous model was calibrated from 1992 through 2000 and was updated through 2015 as part of this work using data collected since 2000; therefore, the model presented here is calibrated from 1992 through 2015.

Specific objectives of the assessment presented herein include:

- assessing surface water and groundwater inflows necessary to maintain the pond area;
- assessing the effectiveness of the Shay Pond well at maintaining water levels and outflows; and
- identifying an optimum location for an additional groundwater production well to provide supplemental water to Shay Pond.



Specific criteria for identification of the optimum groundwater production well site include:

- available and accessible land;
- adequate distance from existing public and private groundwater production wells to avoid pumping interference;
- proximity to Shay Pond (i.e., the additional supplemental groundwater production well will need to be as close to Shay Pond as possible without creating pumping drawdown that would interfere with the natural inflow of groundwater to the pond;
- adequate potential aquifer yield / pumping rates; and
- acceptable groundwater quality.



2 Site Description

The site description presented in this section is based on the geologic, hydrogeologic, basin operational, surface water hydrologic, and land use data provided primarily by CSD. The geologic and hydrogeologic data include reports and studies for the Big Bear Valley and Shay Pond area, borehole logs, preliminary estimates of aquifer parameters based on pumping test data, and groundwater levels. The basin operational data include measured pumping rates for public groundwater production wells and estimated pumping rates for private groundwater production wells. The surface water hydrologic data consist of measured precipitation, estimated evapotranspiration, and measured stream flow data. The land use data include historical aerial images of the Shay Pond area over time.

2.1 Location

Although the purpose of the hydrogeological analysis is specific to Shay Pond, the area selected for the model analysis (the Study Area) is larger and encompasses the drainage catchment that surrounds the pond (see Figure 1). The Study Area is an approximately 8-square mile rectangular area that is approximately 2.85 miles in the east-west direction and 2.75 miles in the north-south direction and centered over the drainage catchment.

The Study Area is south of Big Bear Valley and includes portions of the Erwin, East Baldwin, and West Baldwin Hydrologic Subunits of the Big Bear Valley (Figure 1). The pond lies completely within the Erwin Subunit (see Figure 2) and what has been previously defined as the “Shay Pond Drainage Basin” (Geoscience, 2004).

2.2 Topography and Geomorphology

The pond lies within a relatively small, flat valley bounded by an unnamed mountain ridge to the north and east, the Sugarloaf Fan to the west, and Deadmans Ridge to the south. Land surface elevations in the valley floor in the Shay Pond area are approximately 6740 to 6800 ft amsl with the ridges reaching elevations of approximately 7300 ft amsl. On aerial imagery, the valley plainly appears as a sparsely vegetated grassland with few trees whereas the bounding features consist of comparatively densely vegetated pine forests. The boundaries of the valley encompass the alluvial fan deposits shown as ‘Qal’ and ‘Qaa’ on Figure 3 and described in further detail in Section 2.3 below. A hydrologic (i.e., topographic) divide in the middle of the valley is the eastern boundary of the Shay Pond Drainage Basin in the eastern portion of the valley. The western portion of the valley drains from south to north towards Baldwin Lake through a narrow pass to the north. The eastern portion of valley, demarcated by the Shay Pond drainage basin boundary mentioned above drains from west to east toward Erwin Lake.



2.3 Geology

2.3.1 Geologic Units

In the Study Area, the San Bernardino Mountains consist of Late Proterozoic (2500 to 541 million years ago [Ma]) quartzite rocks that make up the ridges, Miocene (23 to 5.3 Ma) sedimentary rocks that make up the Sugarloaf Fan, and young to very young alluvial fan deposits that are Late Holocene (11,700 years ago to present) to late Pleistocene (2.5 Ma to 11,700 years ago) (Flint, L.E. and Martin P., 2012) as shown on Figure 3. In the Project Area, CSD's wells and monitoring wells are located on, and completed within, the alluvial fan sediment. As shown on the surface geology map (Figure 3), the pond lies within a valley filled with Quaternary unconsolidated surficial deposits consisting of laterally extensive alluvium and colluvium along with localized lake and meadow deposits. The pond itself lies on coalescing fans associated with channels dissecting Sugarloaf Fan to the west and Green Canyon to the south. Boring logs and cross-sections presented in Geoscience (2004) indicate these unconsolidated valley deposits to be interbedded and to vary widely in both texture (i.e., clays, silts, sands, and gravels) and thickness (i.e., approximately 200 to over 400 feet thick as discussed below).

The valley is bounded:

- to the north by the valley outlet through Shay Meadow (shown on Figure 2 and generally noted as 'Qal' on Figure 3) and towards Baldwin Lake and the aforementioned unnamed ridge composed of the Proterozoic quartzite of the Wildhorse Meadows formation;
- to the east by Erwin Lake;
- to the south by Deadmans Ridge, which is also composed of the Proterozoic quartzite of Wildhorse Meadows formation and a narrow valley at the western end of Deadmans Ridge through which California State Route 38 passes at the confluence of intermittent streams fed in part by May Spring and Green Spring (both of which emanate on the northern slope of Sugarloaf Mountain); and
- to the west by the dissected Sugarloaf Fan, which is comprised of moderately well-consolidated Tertiary siltstone, fine to coarse sandstone, pebbly sandstone, and minor greenish mudstone.

2.3.2 Structure

Several faults have been mapped within Sugarloaf Fan and the comparatively older ridges surrounding the valley. The presence of an unmapped fault extending southward from the valley inlet to the south and the valley outlet to the north is inferred by:

- the very presence of the southern inlet and northern outlet (indicating the presence of comparatively erodible materials), both of which are laterally bounded by moderately- to strongly-consolidated materials;



- geologic materials of significantly different ages bounding the northern outlet (i.e., the Tertiary materials comprising Sugarloaf Fan along the western margin of the valley and much older Proterozoic materials along the eastern margin);
- notable differences in groundwater temperature on either side of the fault, suggesting that the fault at least partially restricts groundwater flow.

The valley deposits range in thickness from approximately 200 feet in the eastern portion near Erwin Lake and thicken to the west to greater than 400 feet along the west-central margin near the Lakewood wellfield. The thickening of the valley deposits in this area may be attributable to the unmapped fault and deposition of sediments derived from Sugarloaf Fan.

2.4 Hydrology

The predominant hydrologic features within the Study Area are seasonal shallow lakes, Shay Pond, springs, and creeks. Flow of water within these features is controlled by precipitation/snowmelt and evapotranspiration; therefore, flow is generally intermittent (i.e., seasonal) or ephemeral (i.e., due to storm events). Groundwater levels generally correlate with annual fluctuation of precipitation, with peak water levels occurring during winter months and the highest peaks occurring during years with increased annual precipitation^[2].

Within the Shay Pond drainage area, both surface and groundwater flow from the higher topographic elevations in the south (i.e., Sugarloaf Mountain) towards the lower topographic elevations to the north and east (i.e., Baldwin Lake and Erwin Lake).

2.4.1 Precipitation and Evapotranspiration

Within CSD's service area, the climate has been characterized as transitional, with marine coastal influences to the west and arid Mojave Desert influences to the east (Flint and Martin, 2012).

Precipitation in the Study Area measured at the CSD weather station, approximately 2 miles northwest of Shay Pond, is 14.0 inches per year. From 1992 to 2015, the annual precipitation ranged from 5 inches to 29 inches. Figure 4 shows annual precipitation data for the period of record, as well as the cumulative departure from the mean annual precipitation. Monthly average precipitation is highest during the winter months (generally November to March), and lowest in summer months (generally June to October).

Evapotranspiration (ET) is the loss of water to the atmosphere from free-water evaporation, soil-moisture evaporation, and transpiration by plants (Fetter, 1994). The majority of ET occurs at the land surface although evaporation and transpiration will also remove water from the shallow subsurface. Monthly evapotranspiration was estimated for the Study Area based on the average

² http://www.water.ca.gov/pubs/groundwater/bulletin_118/basindescriptions/8-9.pdf



annual reference ET (ET_0) for the Big Bear Valley California Irrigation Management Information System (CIMIS) station, located approximately 3.5 miles west of the Study Area.

2.4.2 Surface Water

Named and unnamed springs associated with creeks/streams within the Shay Pond drainage basin identified on USGS topographic maps or otherwise named by previous investigators are shown on Figure 3. These named springs include Green Spot Spring, Fish Hatchery Spring, May Spring (within May Van Canyon), and Green Spring (within Green Canyon) whereas unnamed springs include:

- a spring downslope of May Spring along May Van Canyon Road;
- a spring immediately east of the pond; and
- although not mapped as such, the pond is itself a spring.

Water discharged from Green Spot Spring is captured and transferred via a subgrade pipeline to an aboveground storage reservoir approximately 900 feet to the south. The stored spring water is used as a secondary water supply (groundwater production wells are the primary water supply). During rare periods of high precipitation, the reservoir overflows into an unlined drainage that extends from the reservoir northward along Willow Lane and towards the pond. Given discussions with CSD representatives during a June 2017 site visit and its distance from the pond, it is highly unlikely that any overflow water discharging to this unlined drainage supplements the pond in any significant way.

None of the creeks are named on the USGS topographic maps, perhaps owing to their generally low and/or otherwise discontinuous discharge; however, the creek originating in Green Canyon to the south and extending northward through the valley towards the pond has been named ‘Green Canyon Creek’ by previous investigators. Similarly, the creek extending northward from the outlet of the pond through the valley has been named ‘Shay Creek’ by previous investigators.

As can be seen on Figure 3, the presence of several unnamed creeks dissecting Sugarloaf Fan can be inferred by its irregularly-shaped eastern margin and confirmed through inspection of aerial imagery. The unnamed creek to the west of the Lakewood wellfield was observed during the June 2017 site visit. In addition to Green Canyon Creek, these unnamed dissecting creeks discharge water into the valley in which the pond is situated and terminate at the Sugarloaf Fan boundary suggesting that the discharged water serves to recharge groundwater at those specific locations during periods of sufficiently high flow.

2.4.3 Groundwater

Groundwater within the western portion of the valley (within the Shay Pond Drainage Basin) flows to the north, whereas it flows to the east toward Erwin Lake in the eastern portion of the valley (i.e., that portion of the valley outside of, and the east of, the Shay Pond Drainage Basin).



The majority of groundwater flow occurs in the western portion of the valley ultimately discharges through the Shay Meadow area towards Baldwin Lake.

Groundwater is derived from precipitation and subsequent recharge. As such, groundwater elevations vary in response to precipitation as noted above. That is, groundwater elevations are highest during those years with comparatively high precipitation (e.g., 1993, 2005, and 2010) and during those months when precipitation is comparatively high (generally December through March) as shown on Figure 5 for the Erwin groundwater monitoring well and Vaqueros groundwater monitoring well.



3 Conceptual Model

Based on the site characteristics presented in the previous section, the site is conceptualized with respect to the occurrence and hydraulic properties of the water-bearing sediments, and a description of sources and sinks (i.e., recharge and discharge areas/points). Given the objectives of this assessment, a conceptual water budget focusing on Shay Pond is also presented.

3.1 Aquifer System

The aquifer system considered in this assessment consists of the unconsolidated Quaternary valley deposits. The aquifer system is bounded:

- at its surface by the water table;
- at its bottom by bedrock;
- laterally along its western margin by the unmapped fault along the eastern margin of the moderately-consolidated Tertiary deposits comprising the Sugarloaf Fan;
- laterally along its northern and northeastern margins by the consolidated Proterozoic deposits of the unnamed ridge; and
- laterally along its southern margin by the consolidated Proterozoic deposits of Deadmans Ridge.

The outlets of the aquifer system are Shay Meadow to the north, Erwin Lake to the east whereas its single inlet is Green Canyon Creek at Deadmans Ridge to the south.

3.2 Hydraulic Properties

The hydraulic properties of the aquifer system for this analysis include hydraulic conductivity and storage coefficient. Pumping tests conducted at wells CSD 2, Lakewood 7, and a private well (located north-east of Erwin monitoring well near the intersection Shady and Willow) yielded hydraulic conductivity values ranging from 2 to 15 ft/day. Storage coefficients were not reported for these tests.

The comparatively low hydraulic conductivity values are as expected given the presence of extensive fine-grained interbeds shown on boring logs and in the conceptual cross-sections presented in Geoscience (2004). These low values result in comparatively low pumping rates for the production wells in the area (i.e., the Lakewood wells and CSD Well #2), which typically range from 25 to 100 gallons per minute (gpm) with maximum rates less than 200 gpm.

Comparison of groundwater levels relative to the occurrence of fine-grained units noted on boring logs, along with the comparatively high storativity values, suggests that groundwater is best conceptualized as occurring under unconfined conditions.



3.3 Sources and Sinks

Sources and sinks are surface and subsurface features that supply and remove water, respectively, and are presented separately for both the valley deposits comprising the aquifer system and for the pond.

The surface sources are:

- precipitation;
- runoff (overland sheet flow); and
- surface water flow concentrated in the unnamed creeks dissecting Sugarloaf Fan that recharge the aquifer system where they emanate along the eastern margin of the fan and into the fan deposits along the western margin of the valley.

The subsurface source is:

- groundwater entering the southern inlet through Green Canyon Creek at Deadmans Ridge to the south.

The surface sinks are:

- evapotranspiration; and
- surface water flow from Shay Creek^[3] downstream of the pond toward Baldwin Lake to the north.

The subsurface sinks are:

- public and private supply (groundwater production) wells;
- the northern inlet through which Shay Creek passes towards Baldwin Lake;
- the trending south-west fault on the eastern side of the Sugarloaf fan just south of the Lakewood wells; and
- groundwater exiting to the east toward Erwin Lake.

In the valley, CSD operates one production well for municipal supply water (CSD Well #2) whereas DWP operates four municipal supply wells (Lakewood Wells #5, #6, #7, and the 10th Lane Well #3). The locations of these wells are shown on Figure 2. There are 51 private wells that have an estimated average consumptive use of 18 ft³/day based on past, current and projected customer deliveries for 2010 according to the 2015 Urban water Management Plan - Final Draft (Water Systems Consulting, Inc., 2016).

Exchange of groundwater between the valley deposits and the bounding deposits of the unnamed ridge and Deadmans ridge is assumed to be negligible due to the strongly consolidated nature of the ridge materials. Exchange of groundwater between the valley deposits and the moderately-

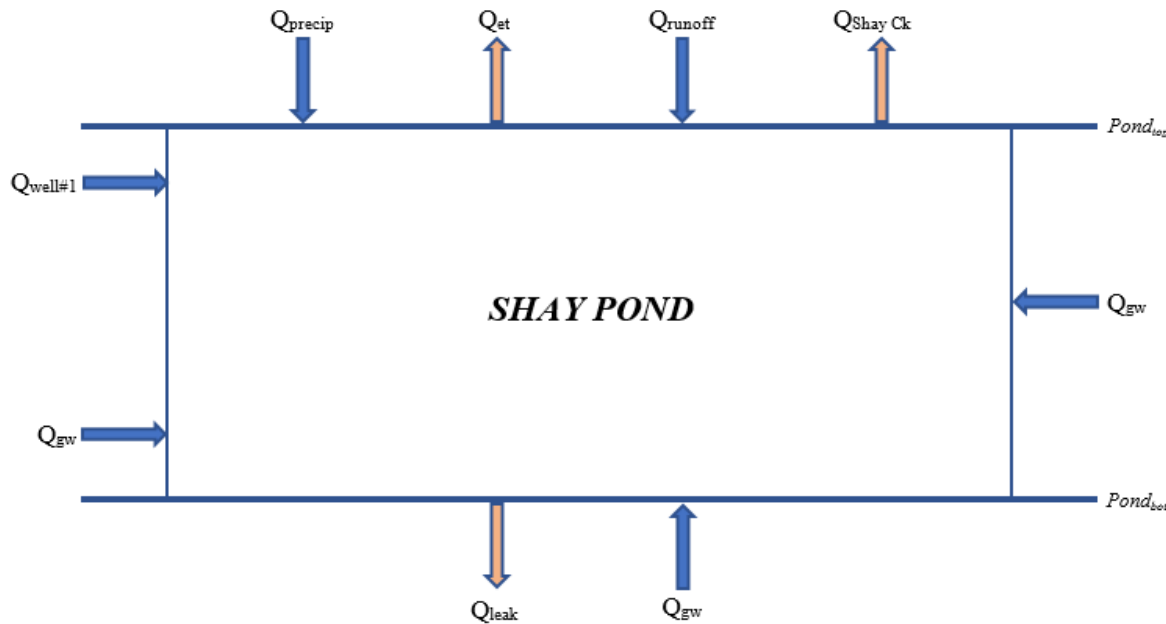
³ Shay Creek is conceptualized as extending north from the northwestern corner (i.e., the outlet) of Shay Pond through the northern outlet of the valley and towards Baldwin Lake.



consolidated deposits comprising Sugarloaf Fan are also conceptualized as being negligible due to the inferred presence of the unmapped fault along the common boundary.

3.4 Conceptual Water Budget

Given the objective of the study, the conceptual water budget for the pond consists of the inflows and outflows (in units of volume per time) identified above and is conceptualized as follows with inflows shown by blue arrows and outflows shown by orange arrows:



where the inflows are:

- Q_{precip} = Precipitation directly into the pond;
- Q_{runoff} = Surface water runoff (overland 'sheet' flow);
- $Q_{well\#1}$ = Discharge of the Shay Pond well (and supplemental discharge line) into the pond;
- Q_{gw} = Groundwater discharge ('rising water'); and

the outflows are:

- Q_{et} = Evapotranspiration;
- $Q_{Shay\ Ck}$ = Discharge from the pond into Shay Creek at northwestern outlet; and
- Q_{leak} = Leakage through the pond bottom.

Assuming Q_{precip} and Q_{runoff} to be negligible, and given that $Q_{Shay\ Ck}$ is now zero due to the June 2011 and August 2013 pond rehabilitation, the water balance to maintain the pond is:

$$\underbrace{(Q_{well\#1} + Q_{gw})}_{Inflows} = \underbrace{(Q_{et} + Q_{leak})}_{Outflows} \quad \{Eq. 1\}$$

Therefore, in the absence of any contribution of groundwater to the pond (i.e., during low groundwater level conditions associated with dry seasons/years), the Shay Pond well and supplemental discharge line must pump water into the pond at a high enough rate to overcome losses due to evapotranspiration and pond bottom leakage.



4 Computer Model

The quantitative hydrogeologic assessment of the conceptual model presented in the previous section was conducted using a three-dimensional numerical groundwater flow model calibrated from 1992 to 2015 using groundwater production and aquifer test data for wells near Shay Pond, precipitation and evapotranspiration data from nearby weather stations, and transpiration data associated with the local flora.

The groundwater flow model was developed using MODFLOW. MODFLOW is a widely-used three-dimensional numerical groundwater flow code developed by the United States Geological Survey (originally by McDonald and Harbaugh, 1988) and includes modules ('packages') that can be added as necessary to increase functionality. Given the conceptual model, the following packages were used in the model:

- Basic Package (McDonald and Harbaugh, 1988);
- Block Centered Flow Package (McDonald et al., 1991);
- Well Package (McDonald and Harbaugh, 1988);
- Recharge Package (McDonald and Harbaugh, 1988);
- Evapotranspiration Package (McDonald and Harbaugh, 1988);
- Drain Package (McDonald and Harbaugh, 1988); and
- Preconditioned Conjugate-Gradient Method (PCG2) Package (Hill, 1990).

Consistent with Geoscience (2004), a single unconfined model layer was used to simulate the alluvial aquifer system. The primary differences between the model presented here from that presented in Geoscience (2004) listed below.

1. The model presented here is calibrated from 1992 to 2015 using data that have become available subsequent to the Geoscience model, which is calibrated from 1992 to 2000.
2. Based on an evaluation of groundwater elevations within the Sugarloaf Fan and within the valley immediately east of the fan and west of the Lakewood wellfield, along with the presence of a creek dissecting the fan that likely discharges surface water into the valley in this area and an unmapped fault, the model presented here is based on the concept that groundwater is not exchanged between the valley and Sugarloaf Fan. The Geoscience model simulated groundwater exchange between the Sugarloaf Fan and the valley.
3. The model presented here and the Geoscience model both use the Drain Package to simulate discharge of groundwater to Shay Pond as a spring; however, the model presented here is based on pond boundaries that extend over a smaller, and we believe, more representative area given historical pond extents.



4. Leakage through the pond bottom in the model presented here is based on the current observed performance of the pond with approximately 50 gpm being required to maintain the current pond level.
5. The model presented here relies primarily on time-variant constant head cells (“head boundaries”, described below) whereas the Geoscience model relied primarily on the use time-variant well cells (“flux boundaries”). The boundaries of both models are distributed such that they result in similar groundwater flow patterns.
6. Unlike the Geoscience model, and based on discussions held during the June 2017 site visit, the model presented here does not explicitly simulate surface water flow. Rather, the effect of surface water flow on pond levels and groundwater levels is implicitly simulated through the aforementioned head boundaries.
7. The head change and residual closure criteria used in the PCG2 package is 0.01 feet and 0.01 ft³/sec (864 ft³/d), respectively, consistent with generally-accepted industry standards.

4.1 Model Domain and Discretization

The model boundaries are the same as the Study Area, which is hereafter referred to as the Model Domain. The site coordinate system was established in State Plane Zone 5. The Model Domain is approximately 2.85 miles in the north-south direction and 2.75 miles in the east-west direction (approximately 8 square miles). The model domain is discretized into 381 columns and 342 rows with 50-foot by 50-foot cells away from the pond and cells as small as 10-feet by 10-feet surrounding the pond (Figure 6). This discretization results in a grid consisting of a single layer as described above and of varying thickness as shown in Figure 7 that is subdivided into 130,302 cells.

As shown in Figure 7, the model domain includes active and inactive portions. Active portions are those areas considered to be sufficiently permeable and through which water moves freely whereas inactive portions are those that are not. As such, the active model domain is that portion of the model in which groundwater flow is simulated and equates to the unconsolidated alluvial valley deposits shown on Figure 3.

4.2 Boundary Conditions

Boundary conditions in the model consist of groundwater elevation (‘head’) boundaries and groundwater flow (‘flux’) boundaries, the locations of which are shown on Figure 7.

4.2.1 Head Boundaries

The active model domain consists of time-varying constant head boundary conditions using the MODFLOW constant head (‘CHD’) package. These boundaries simulate inflow to and outflow from the unconsolidated valley deposits via the inlet to the south and the outlets to the north and east. These boundaries were based on measured groundwater elevations at the Erwin monitoring well and CSD Well #2, and estimated groundwater elevations beneath Erwin Lake, respectively,



and were quantified through the calibration process described below. An additional time-varying constant head boundary condition was inserted at the mouth of an intermittent creek dissecting the Sugarloaf Fan along its eastern margin just west of the Lakewood wellfield based on groundwater elevations measured at Vaqueros Monitoring Well. This boundary acts as a source during wet periods when water enters the valley via the intermittent creek and as a sink during dry periods. Its behavior as a sink is attributed to the unmapped fault along the eastern margin of Sugarloaf Fan where groundwater not captured by the wellfield is conceptualized to drain from the valley in this area via the fault.

4.2.2 Flux Boundaries

The flux boundaries used in the model include:

- the public wells, private wells, and the Shay Pond Well depicted on Figure 2 and implemented using the Well Package;
- areal recharge implemented using the Recharge Package for all active model cells based on precipitation data;
- evapotranspiration implemented using the Evapotranspiration Package for all active model cells based on evapotranspiration data and estimated root zones for the local flora; and
- groundwater discharge into the pond (spring flow) implemented using the Drain Package for model cells coinciding with the historical footprint of the pond based on historical aerial photos, current site photos, and estimated pond depth observed during the June 2017 site visit.

The flux boundaries associated with the wells are independent of head provided groundwater elevations are sufficiently high to supply the simulated wells and are based on metered pumping readings provided by CSD and estimated private pumping based on per capita water usage in 2010 (137 gallons per day (gpd) per connection). Similarly, the flux boundaries associated with areal recharge are also independent of head and are based on a correlation to the measured precipitation.

Conversely, the flux boundaries associated with evapotranspiration and spring flow only remove water from the model and are dependent on head. As such, they are commonly referred to as head-dependent flux boundaries. The flux boundaries associated with evapotranspiration only function as such (only remove water from the model) when groundwater elevations are close enough to the surface such that they exceed the user-specified “extinction depth”, which for the local flora was estimated to range from 1 to 4 feet below land surface.

The flux boundaries associated with spring flow (i.e., discharge of groundwater or ‘rising water’) into the pond is simulated by setting the drain cells to a uniform depth of 4 feet below the surrounding ground surface (ft bgs) based on observed topography and pond depth during the



June 2017 site visit. The ground surface elevation (6,761 ft amsl) is assumed to be coincident with the pond water surface when the pond is full; therefore, the drains are set at a uniform elevation of 6,757 ft amsl. When groundwater elevations exceed 6,757 ft amsl, groundwater is discharged into the pond (i.e., the pond is simulated as a spring) at a rate directly and linearly proportional to the groundwater head above the drain and a lumped parameter conductance term (C). Conversely, when groundwater elevations are less than 6,757 ft amsl, no groundwater flows into the pond.

When the head in the aquifer is above the drain, water is removed from the model at a rate based on the assigned conductance of the drain and the difference between the head and the drain elevation. The value for conductance is estimated through calibration by comparing the simulated flow into the pond to the measured outflows.

4.3 Aquifer Parameters

The primary aquifer parameters quantified as input to the model are hydraulic conductivity and the storage coefficient (storativity).

4.3.1 Hydraulic Conductivity

Hydraulic conductivity values are spatially represented in the groundwater flow model as zones as shown in Figure 8. Each zone of equal hydraulic conductivity was determined for the model based on soil lithologic properties, professional judgment, previous studies conducted in the area, and the model calibration process described below.

4.3.2 Storativity (Specific Yield)

Because the aquifer system is conceptualized as an unconfined system, the storativity is quantified as specific yield. Initial zones and values for specific yield were estimated based on the borehole lithologic records, literature values (Freeze and Cherry, 1979 and Driscoll, 1986), and professional judgment. The final specific yield value of 0.04 for the entire active model area was established through model calibration, is in close agreement with that used in the Geoscience (2004) model (0.05), and is reasonable given the unconfined nature and texture of the aquifer system.

4.4 Model Calibration

The groundwater model was calibrated by modifying aquifer parameters and parameters associated with the head boundaries and the flux boundary condition associated with the pond until model-predicted groundwater elevations reasonably matched measured groundwater elevations in seven “calibration target” wells: the Erwin monitoring well, the Vaqueros monitoring well, the Lakewood wellfield production wells (#3, #5, #6, and #7), and CSD

Well #2.



The calibration is based on 1,606 groundwater levels measured between January 1992 and December 2015 in the seven calibration target wells. The calibration scatter plot is included as Figure 9 and shows that model-predicted values are generally equally dispersed and closely clustered above and below the idealized 45-degree calibration line indicating that model-predicted groundwater elevations:

- are not biased high or low; and
- reasonably match measured values (measured and model-generated groundwater levels for the seven calibration target wells are shown on the figures included as Appendix A).

The root mean square error (RMSE) of the calibrated model is 5%. A generally-held industry standard is that an RMSE value less than 10% is characteristic of an acceptably-calibrated model suitable for predictive simulations. The water budget error for the calibrated model was -0.25 percent with respect to cumulative water volume, which is within the industry standard of ± 1 percent (Hill and Tiedeman, 2007). The high positive correlation coefficient (0.92) indicates that the model-predicted groundwater elevations are strongly and directly related to the observed groundwater elevations as expected for an acceptably-calibrated model. The absolute residual mean of 5 feet is also as expected given the RMSE of 5% and the approximately 100-foot range for a majority of groundwater elevations for the target calibration wells and indicates that model-predicted values are, on average, within 5 feet of measured values.

Model-predicted groundwater discharges compared to measured pond outflows for different values of conductance (C) are shown on Figure 10. As shown in the figure, the model-predicted discharges are well-correlated with measured outflow. Attempts to more closely match the model-predicted discharges with the measured pond outflows required unrealistically large values of pond depth and/or pond area. Model-predicted discharges for realistic pond depth and pond area are generally insensitive to increases in C beyond 1,000 ft²/day and lead to model instability at values much beyond 10,000 ft²/day. Given these findings, the difference between model-predicted discharges and pond outflows is attributed to surface water sheet flow (overland flow) into and subsequent discharge from the pond – likely from the unnamed ridge adjacent to, and north/northeast of the pond.

There is no explicit formulation of C for the drain package. Using the formulation associated with the MODFLOW stream package by analogy, values of C ranging from 1,000 to 10,000 ft²/day are reasonable based on the observation during the June 2017 site visit that 50 gpm is required to sustain the pond with a lateral extent of approximately 1,600 ft² and the assumption that pond-bottom sediment thicknesses range from 1 to 3 feet. Given this finding, the value of C used in the predictive simulations presented below was 10,000 ft²/day.

Figure 11 shows model-predicted groundwater elevations for a hypothetical monitoring well adjacent to the pond (the solid red line) and the Vaqueros monitoring well (the solid blue line) along with model-predicted pond outflows. Given the manner in which the drain package functions, groundwater elevations in the hypothetical monitoring well never exceed the pond



bottom (i.e., the drain elevation) and there is generally no pond outflow when the groundwater elevation in the hypothetical monitoring well drops below the pond bottom. The model predictions are also consistent with the observation of Geoscience (2004) that there was no pond outflow when the groundwater elevation at the Vaqueros monitoring well is less than approximately 6,754 ft amsl (i.e., when the depth to groundwater in the Vaqueros monitoring well is greater than 18 feet below land surface).

4.5 Predictive Simulations

The calibrated model was used to assess the impact of:

- The Shay Pond well on groundwater elevations beneath the pond; and
- CSD and DWP pumping on groundwater elevations beneath the pond.

The first predictive simulation was accomplished by idling the Public Supply wells in the calibrated model. The second predictive simulation idling the Shay Pond Well and the Public Supply production wells. Idling the Public Supply production wells required modifying the time-variant constant head boundary condition immediately west of the Lakewood wellfield such that the model-predicted groundwater gradient between the Erwin monitoring well and Vaqueros monitoring well was relatively uniform and did not reflect a depression characteristic of pumping. The groundwater elevations beneath the pond are those in the hypothetical monitoring well adjacent to the pond.

Model-predicted groundwater elevations beneath the pond for the predictive simulations are shown on Figure 12 and 13, respectively. As these figures show, neither the Shay Pond well nor the Public Supply wells have a significant effect on groundwater elevations beneath Shay Pond and, therefore, groundwater discharge into and subsequent outflow from the pond. Conversely, the groundwater elevations beneath Shay Pond are strongly correlated to precipitation as shown in Figure 14. The implication is that the pond, as it is currently configured, will go dry regardless of CSD and DWP pumping in the valley unless precipitation-driven rising groundwater and surface water runoff along with the supplemental Shay Pond well + CSD/DWP discharge line system delivers 50 gpm to the pond.



5 Conclusions and Recommendations

The conclusions and recommendations based on the analysis presented herein are presented in this section.

5.1 Conclusions

- Due to the reconfiguration of Shay Pond in 2011 and again in 2013 associated with removal of overgrowth, outflow from Shay Pond into Shay Creek no longer occurs.
- Groundwater elevations beneath, and outflow from Shay Pond are strongly correlated to precipitation.
- Prior to reconfiguration, Shay Pond outflow occurred during wet periods.
- Groundwater discharge into Shay Pond occurs (i.e., Shay Pond functions as a spring) during wet periods.
- A majority of the historical outflow from Shay Pond is attributed to surface water sheet flow (overland flow) into the pond during wet periods. A majority of the outflow was likely derived from the unnamed ridge adjacent to, and north/northeast of the pond.
- Neither the Shay Pond well nor the CSD and DWP wells have a significant effect on groundwater elevations beneath Shay Pond and, therefore, neither have a significant effect on groundwater discharge into and subsequent outflow from of the pond.

5.2 Recommendations

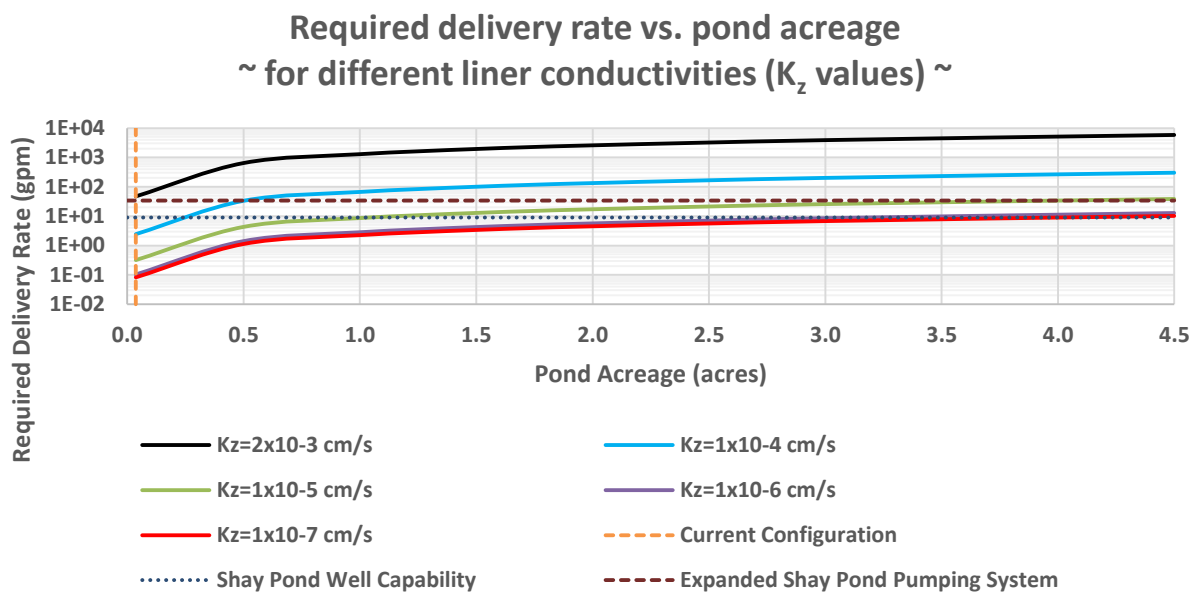
Under its current configuration, Shay Pond will go dry regardless of CSD and DWP pumping in the valley unless precipitation-driven rising groundwater and surface water runoff along with the supplemental Shay Pond well + CSD/DWP discharge line system delivers 50 gpm to the pond. Under its current configuration, Shay Pond requires approximately 50 gpm per 1600 ft². Increasing the pond to its historical maximum extent of approximately 4.5 acres would require more than 5000 gpm. Given the general scarcity of water in the valley and overall impracticality of engineering a system to accomplish this, it is recommended that lining the pond with a low permeability material be considered. The topographically depressed area adjoining the pond to the east, which has been submerged in the past during wet periods but is currently dry could be lined to expand the pond habitat. Once lined, the UTS could conceivably be relocated to this newly-lined area while the currently submerged area is lined to maximize the size of the habitat. It is recommended that:

- a subdrain system be installed prior to lining these areas to prevent rising groundwater from damaging the liner during wet periods; and



- the culvert at the northwest corner of the current pond that runs under Cascade Street be rehabilitated to allow the pond to discharge to Shay Creek during wet periods to keep the pond from topping its banks and flooding the outlying the area.

The chart below shows the required water delivery rates for different liner conductivities assuming an average annual evapotranspiration loss of 42 inches per year and no contribution from precipitation or surface water flow. The chart shows the Shay Pond well, with its average pumping rate of 9 gpm will be sufficient for a 4.5-acre pond area only if the liner conductivity does not exceed approximately 1×10^{-7} cm/sec. If the liner conductivity is 10 times larger (i.e., 1×10^{-6} cm/sec), the Shay Pond well will be able to sustain a 3-acre pond.



The cost to procure and install a low permeability liner (e.g., 1×10^{-6} cm/sec or less) should be compared against the cost to install a new supplemental well, likely at the eastern end of the expanded pond. Assuming that a new supplemental well can be designed so as to pump 25 gpm, a liner with a comparatively higher K_z of 1×10^{-5} cm/sec would be sufficient to maintain a 4-acre habitat.

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May

11th.

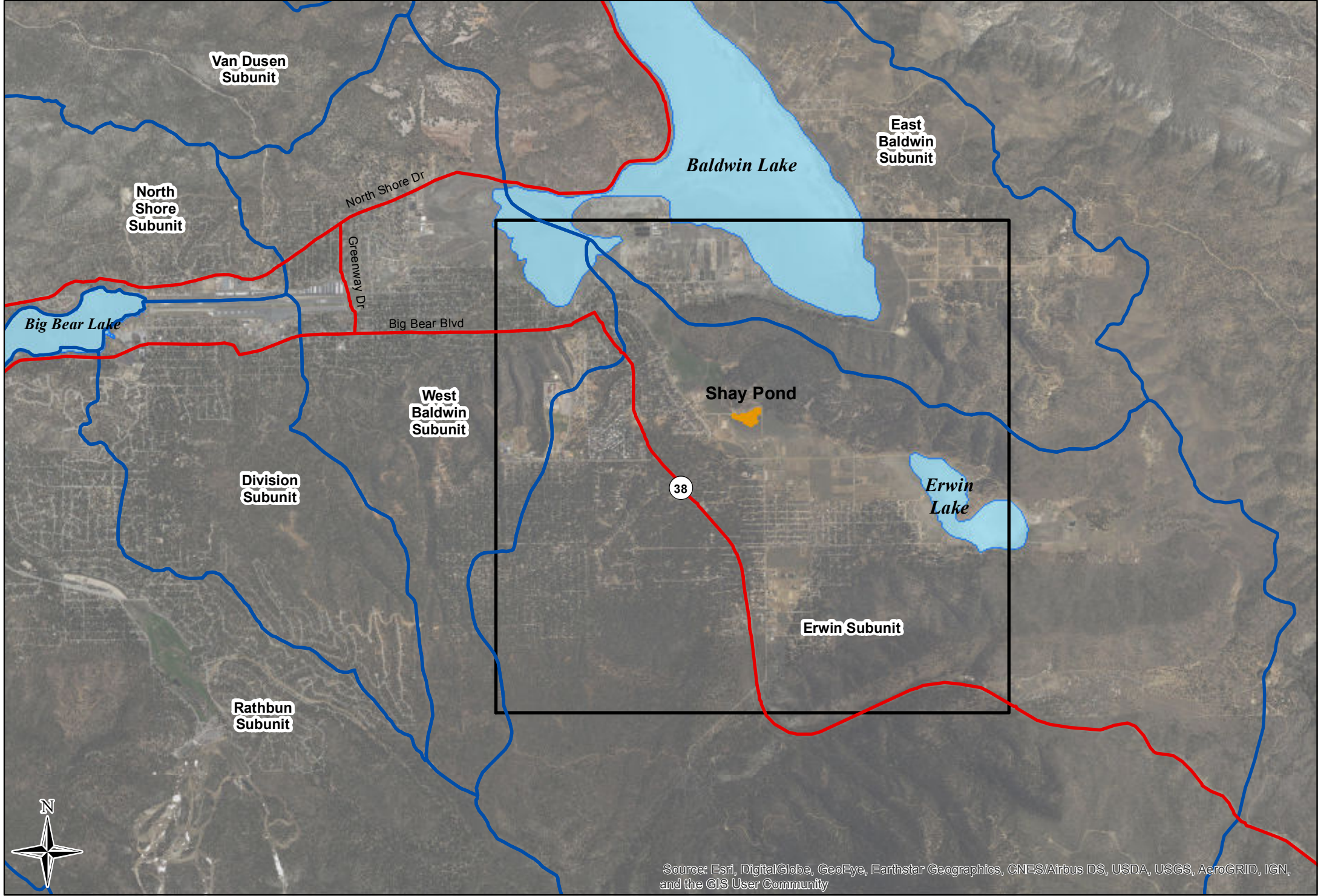


Figures





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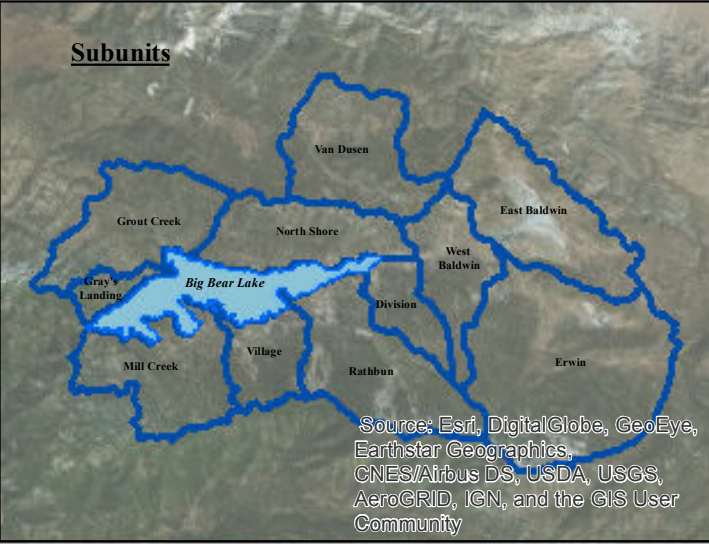
Map Features

Study Area

Hydrologic Subunit

Lake

Road / Highway



0 0.25 0.5 1 Miles
NAD 83 UTM Zone 11

Basemap Source: esri.com

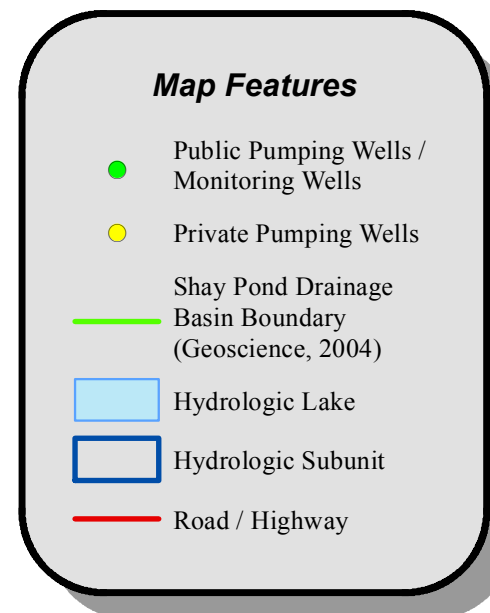
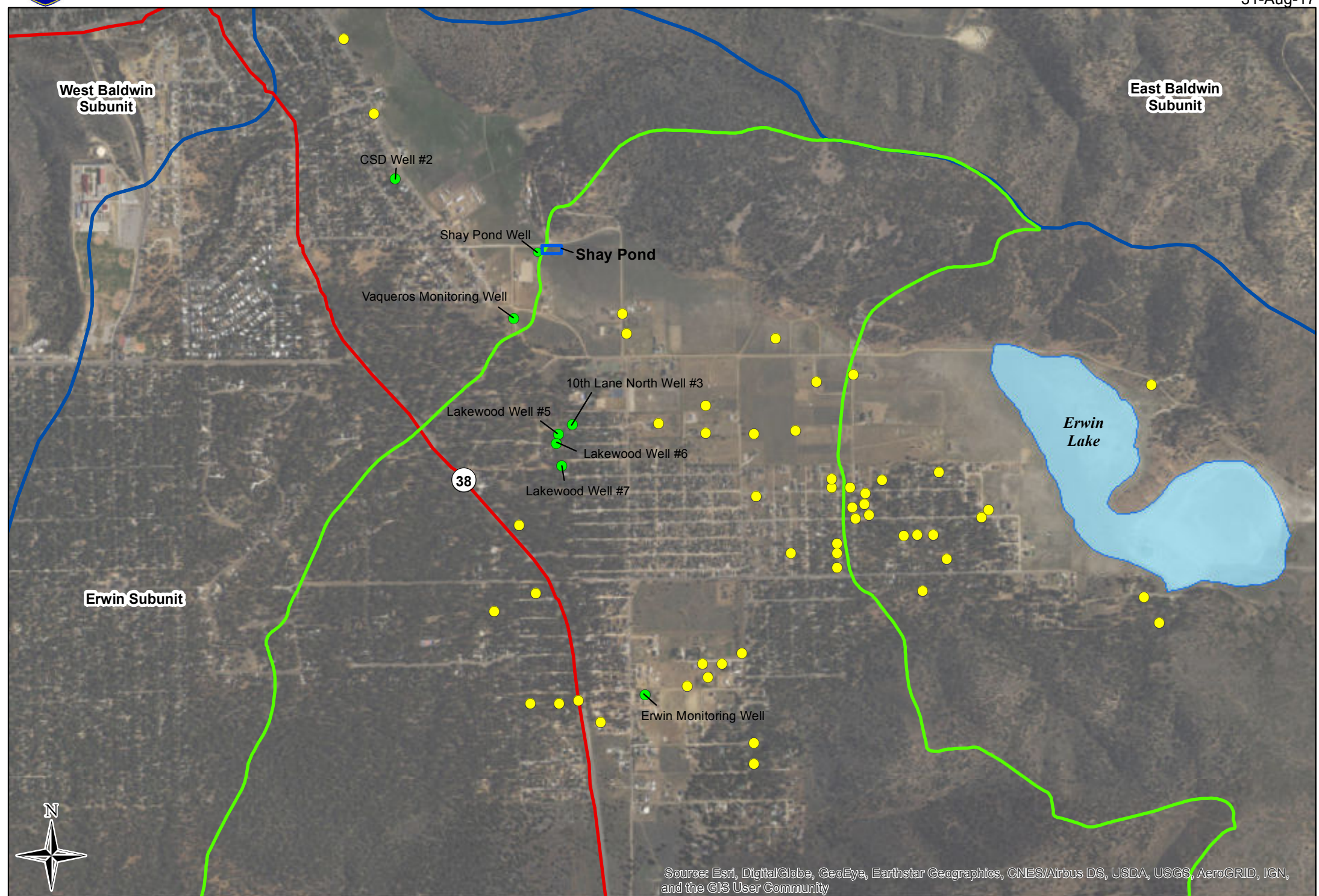
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Regional Map

Figure 1



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0 0.225 0.45 0.9 Miles

NAD 83 UTM Zone 11

Basemap Source: esri.com

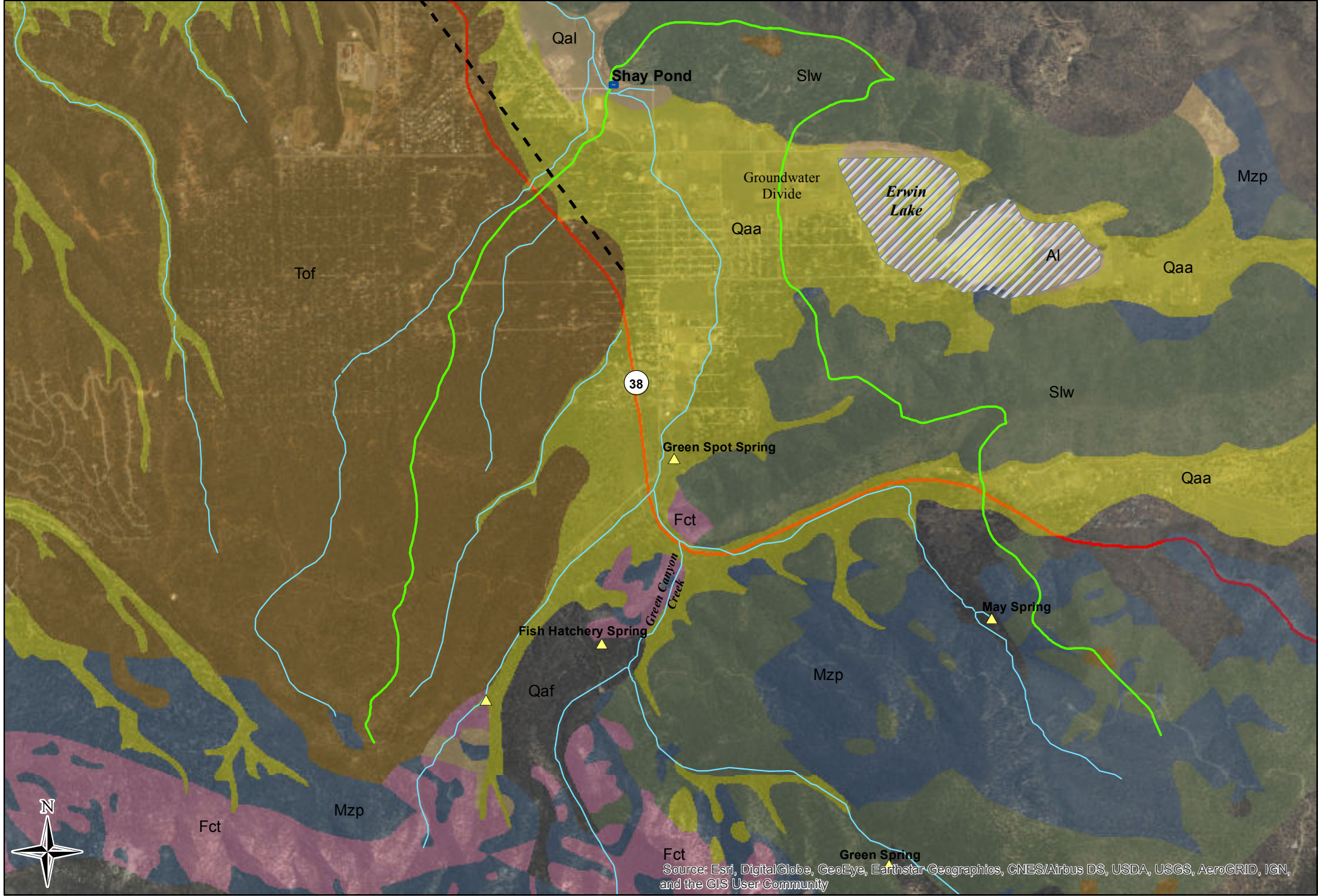
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Site Map

Figure 2



31-Aug-17



Map Features

Al

Lake and Meadow Deposits (Quaternary)

Qal

Very young alluvial fan deposits (Late Holocene)

Qaa

Young alluvial fan deposits (Holocene and late Pleistocene)

Tof

Sedimentary rocks south of Big Bear Lake (Possibly Miocene)

Fct

Undifferentiated Granitic Rocks (Mesozoic)

Mzp

Baldwin Gniess (Middle Proterozoic)

Slw

Quartzite of Wildhorse Meadows (Late Proterozoic)

Spring

Stream / Creek

Shay Pond Drainage Basin Boundary

Fault (approximate)

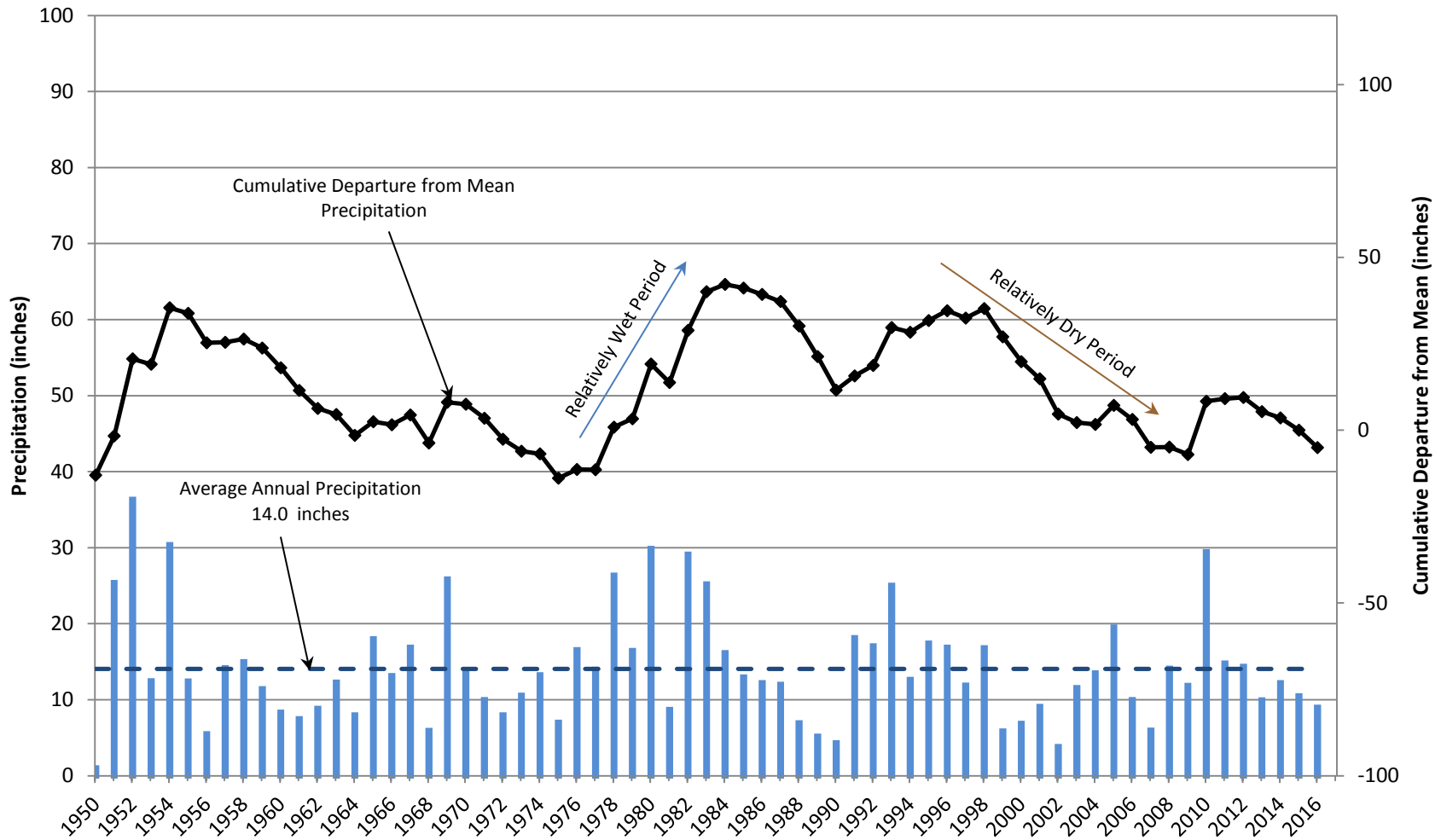
Highway

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Geology

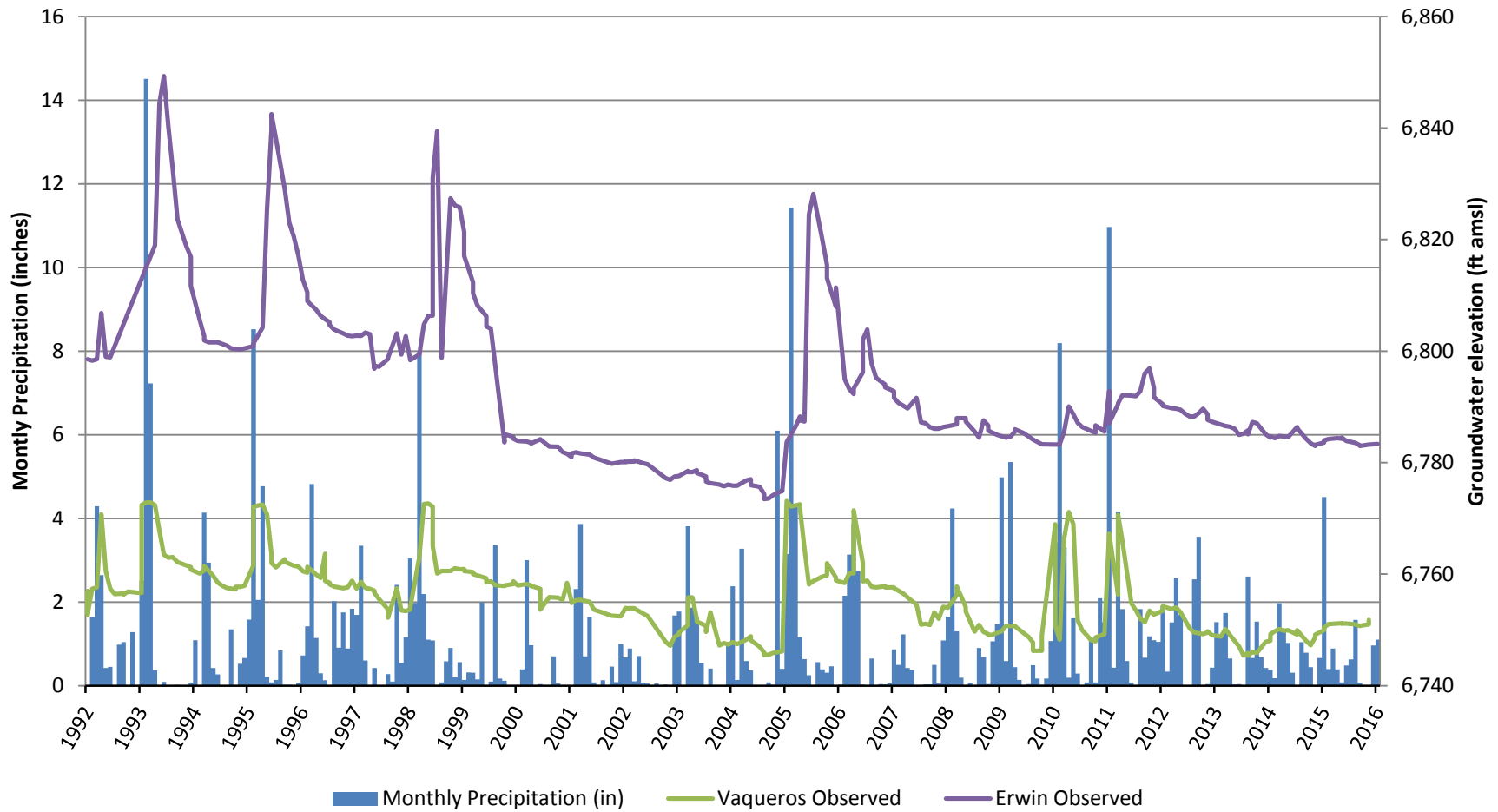
Figure 3

Big Bear Annual Precipitation 1950 to 2016



All data are reported as calendar years.

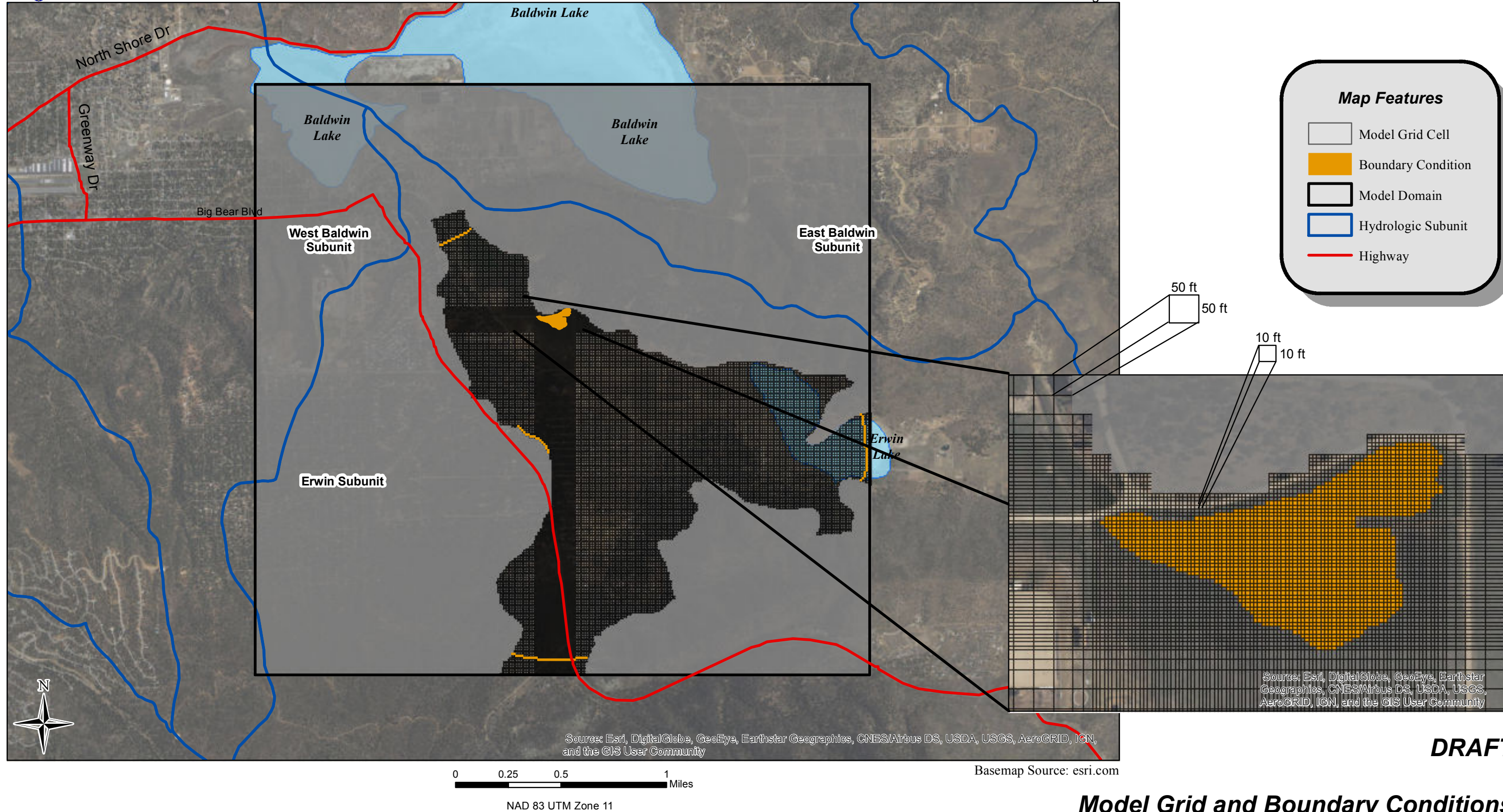
Vaqueros and Erwin Monitoring Wells with Big Bear Precipitation 1992 to 2016



*Note: Big Bear Precipitation from Big Bear Community Services District Station

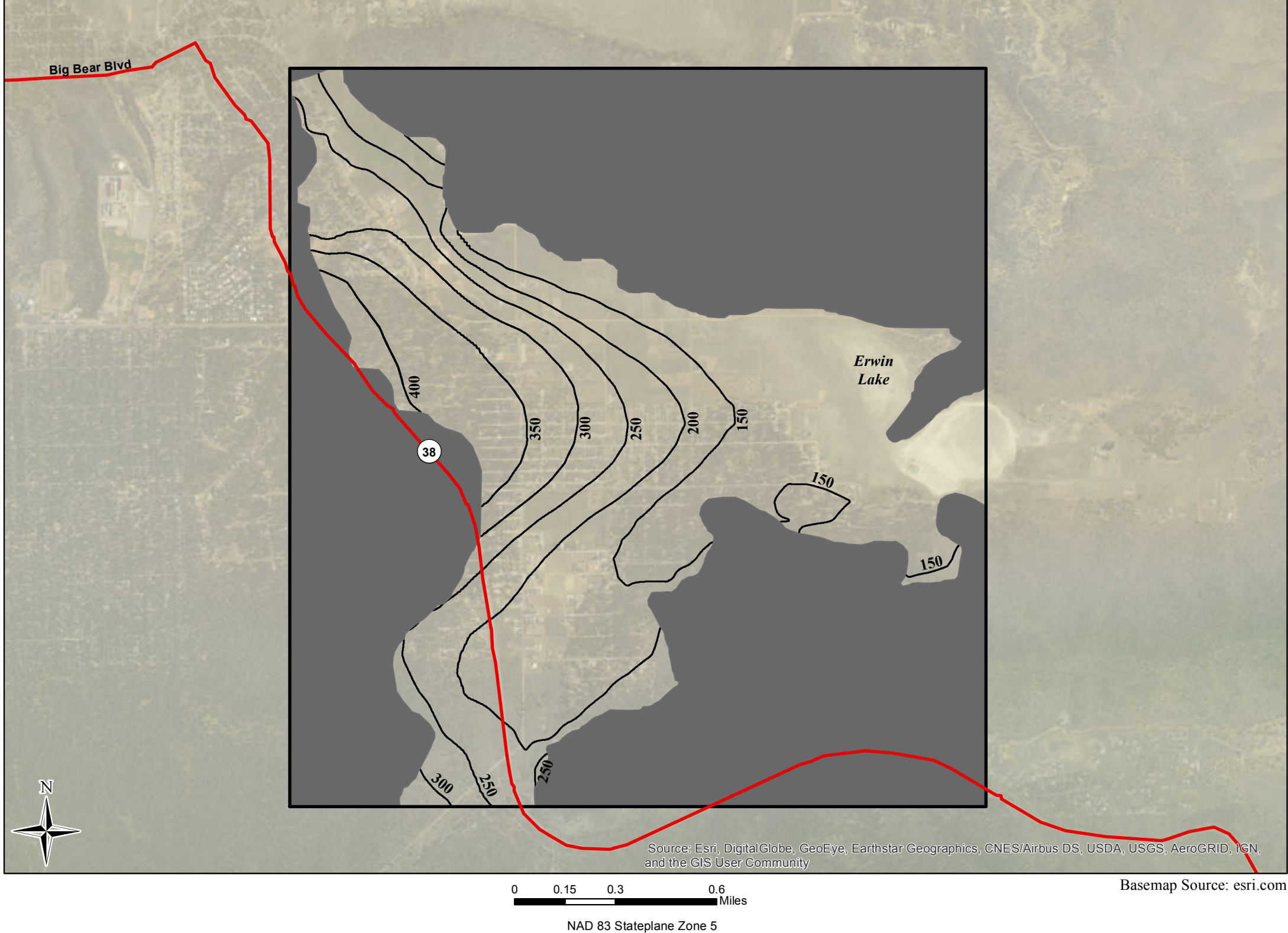


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Map Features

- Layer Thickness (ft)
- No Flow Zone
- Model Domain
- Highway

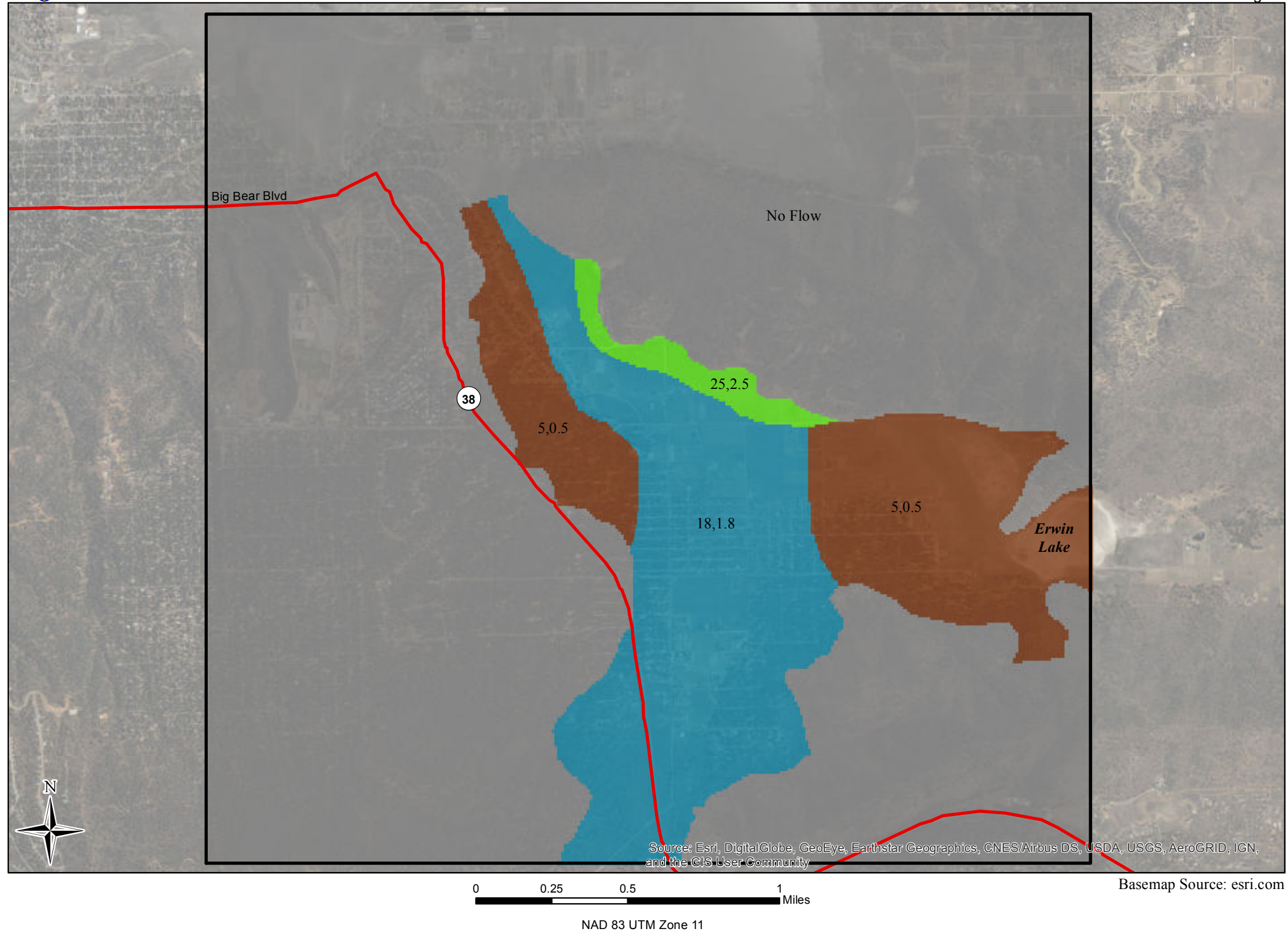
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Model Layer Thickness

Figure 7



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Map Features

Hydraulic Conductivity (ft/day)

Kx

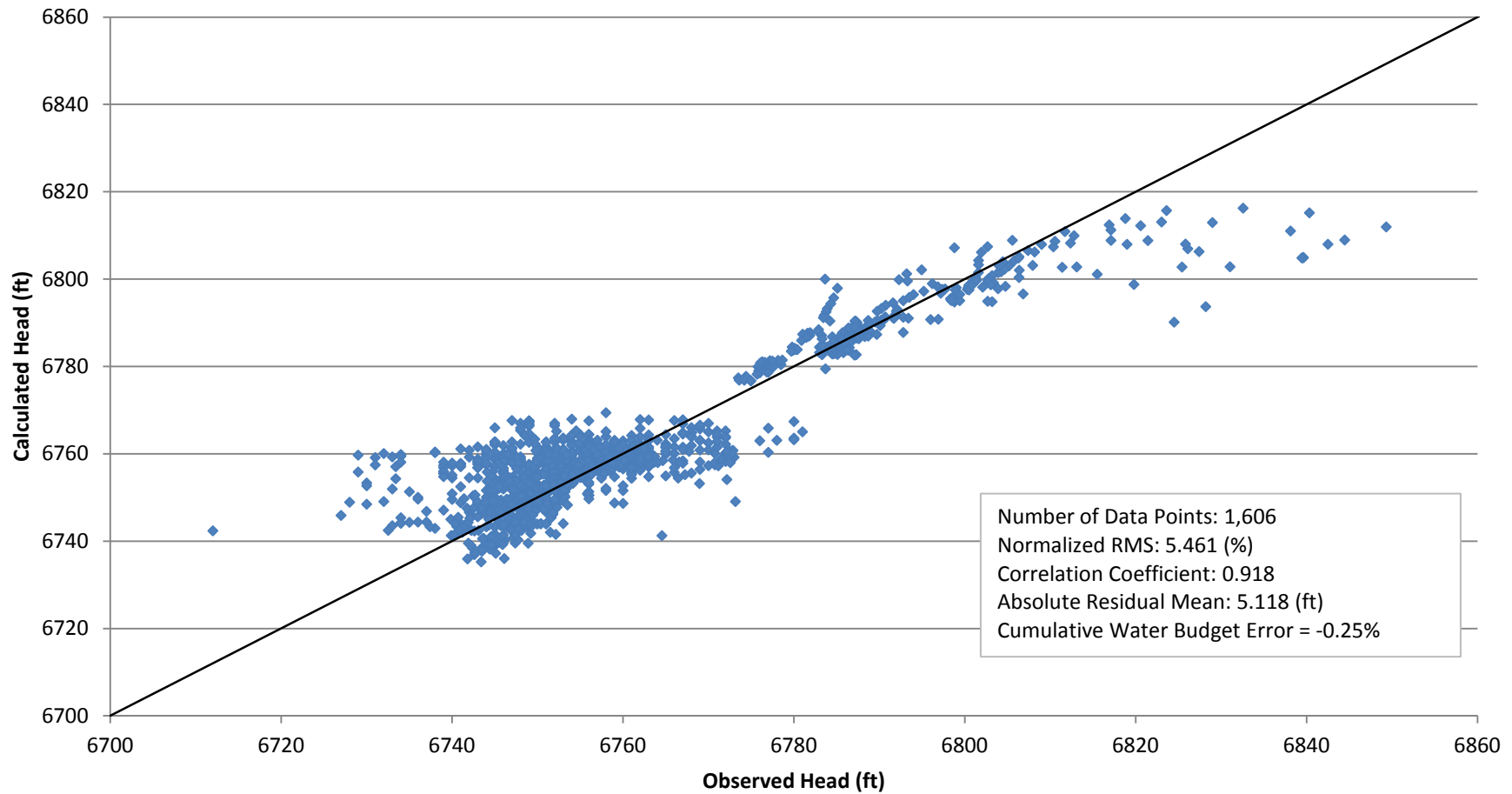
- 5
- 18
- 25
- No Flow
- Study Area
- Highway

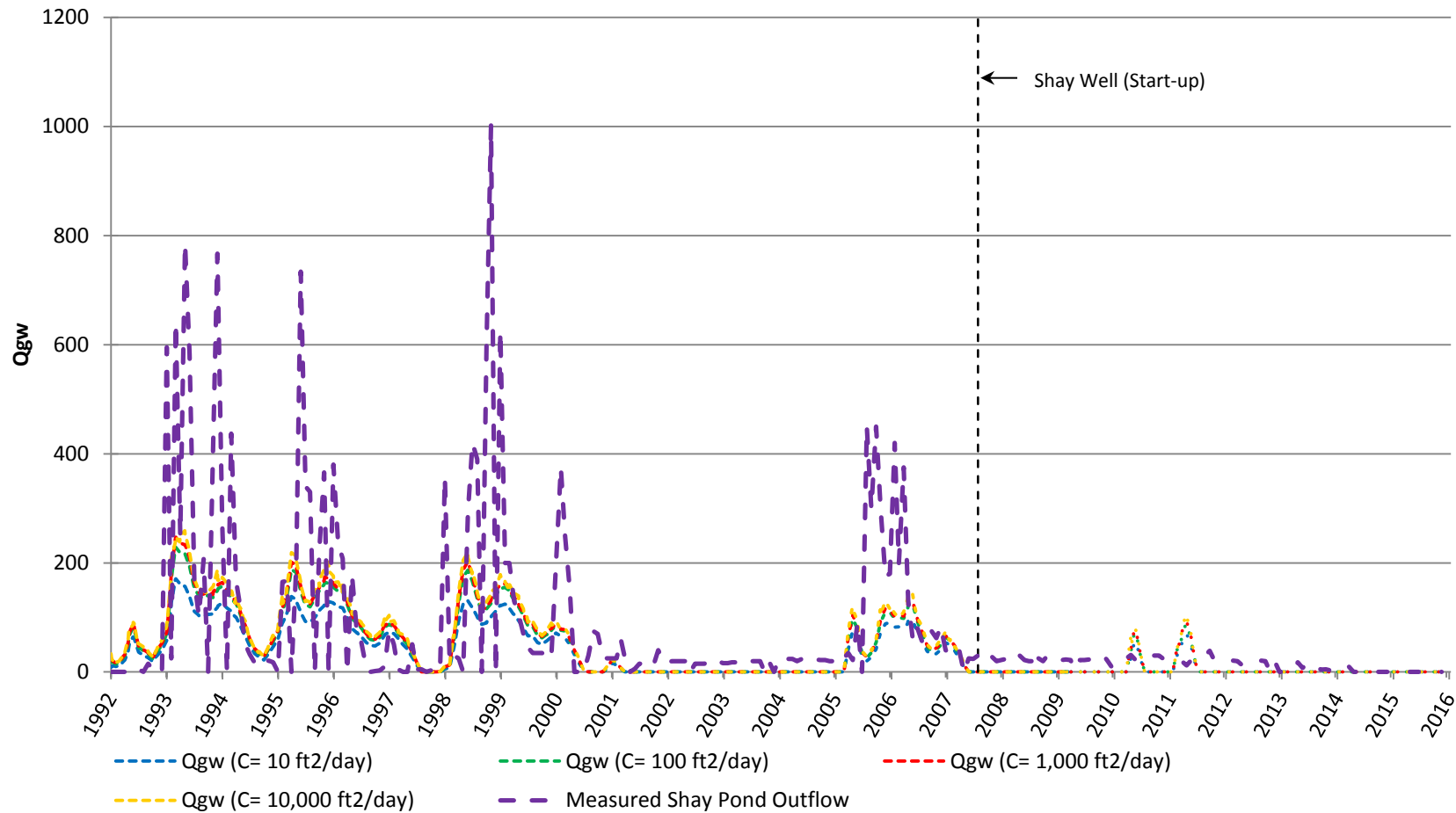
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Hydraulic Conductivity Zones

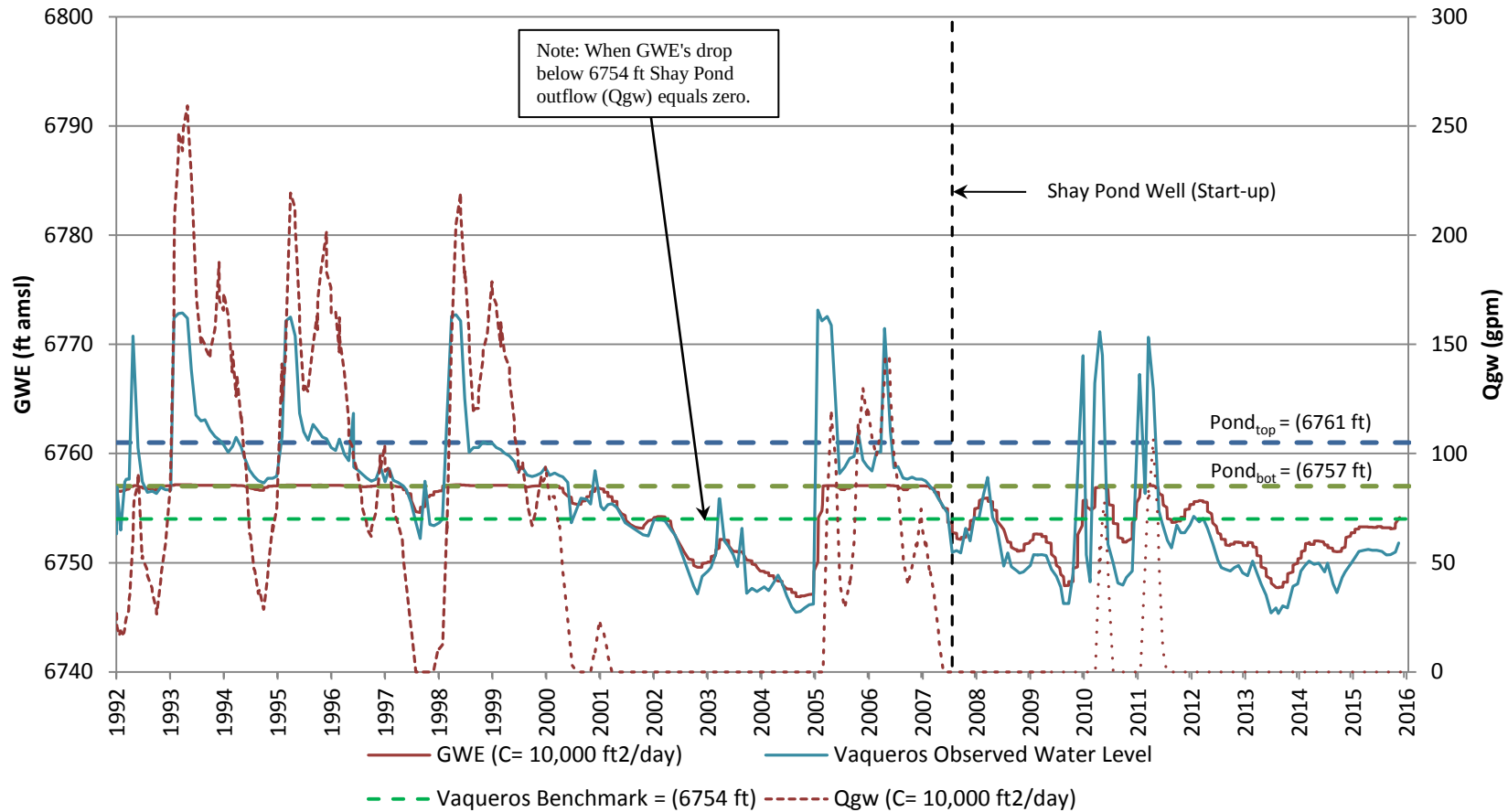
Figure 8

Measured vs. Model-Generated Groundwater Elevations
Transient Model Calibration

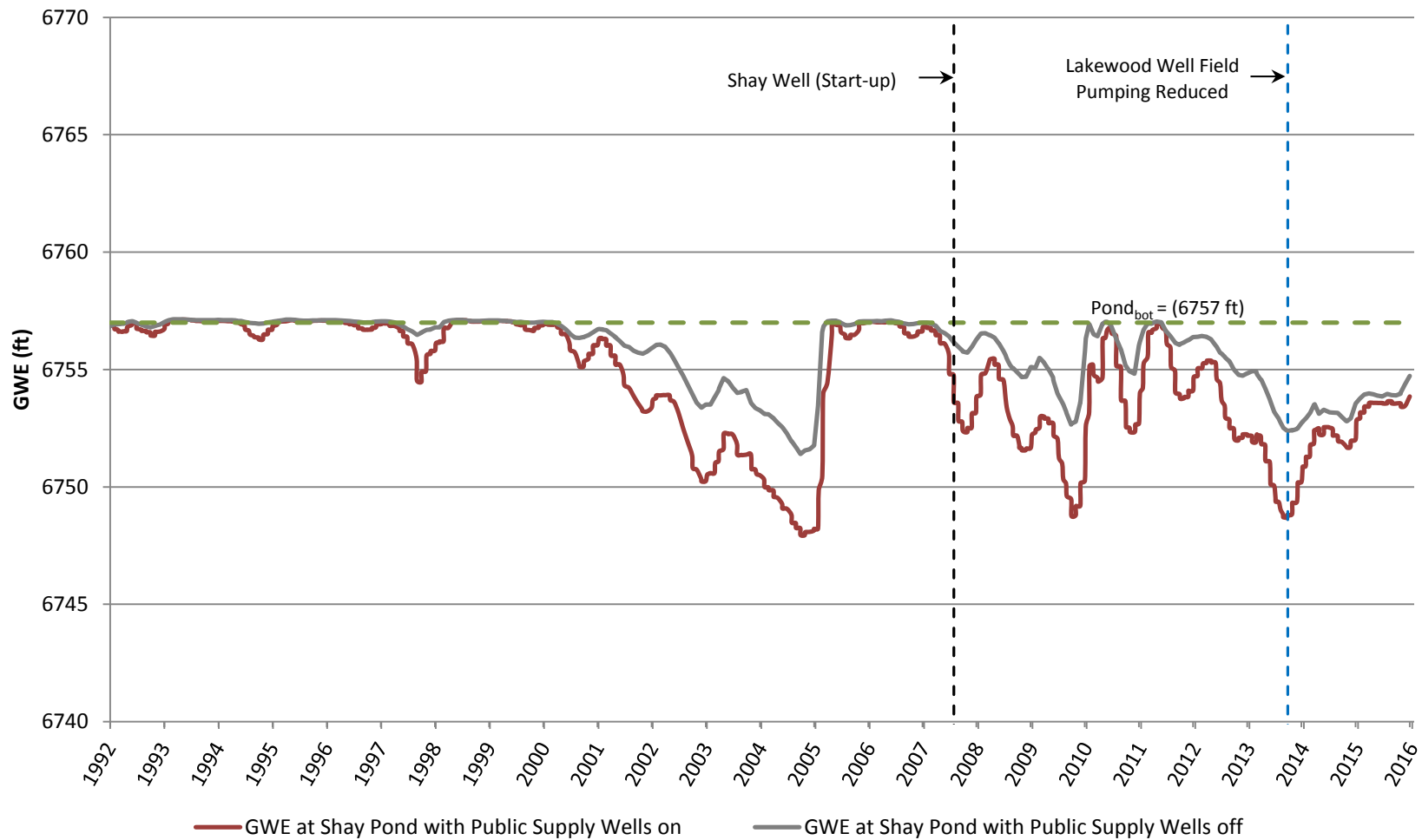


Model-Predicted Groundwater Discharge into Shay Pond (Q_{gw}) vs. Time

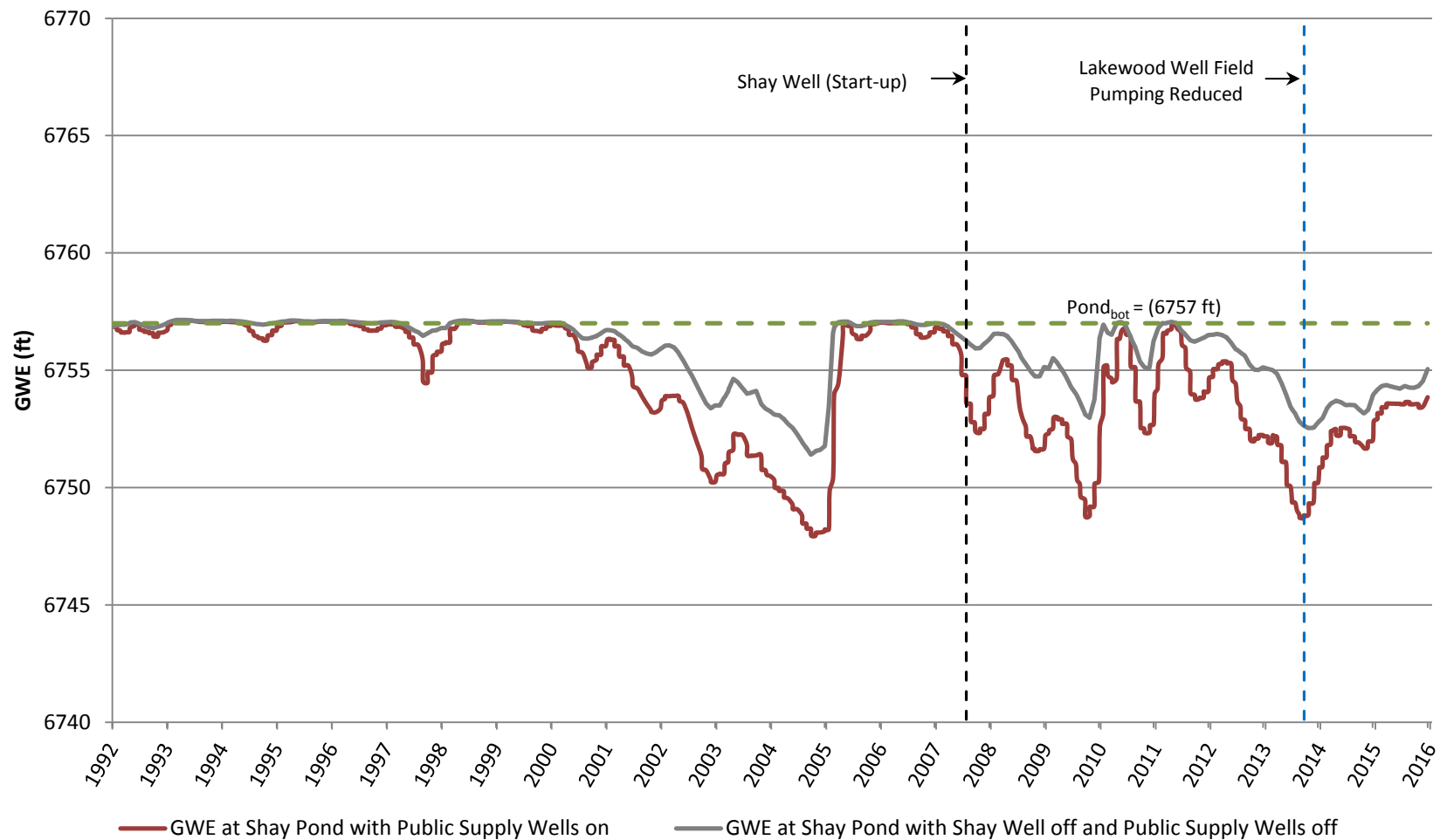
Model-Predicted Groundwater Elevation (GWE) and Groundwater Discharge into
Shay Pond (Qgw) vs. Time



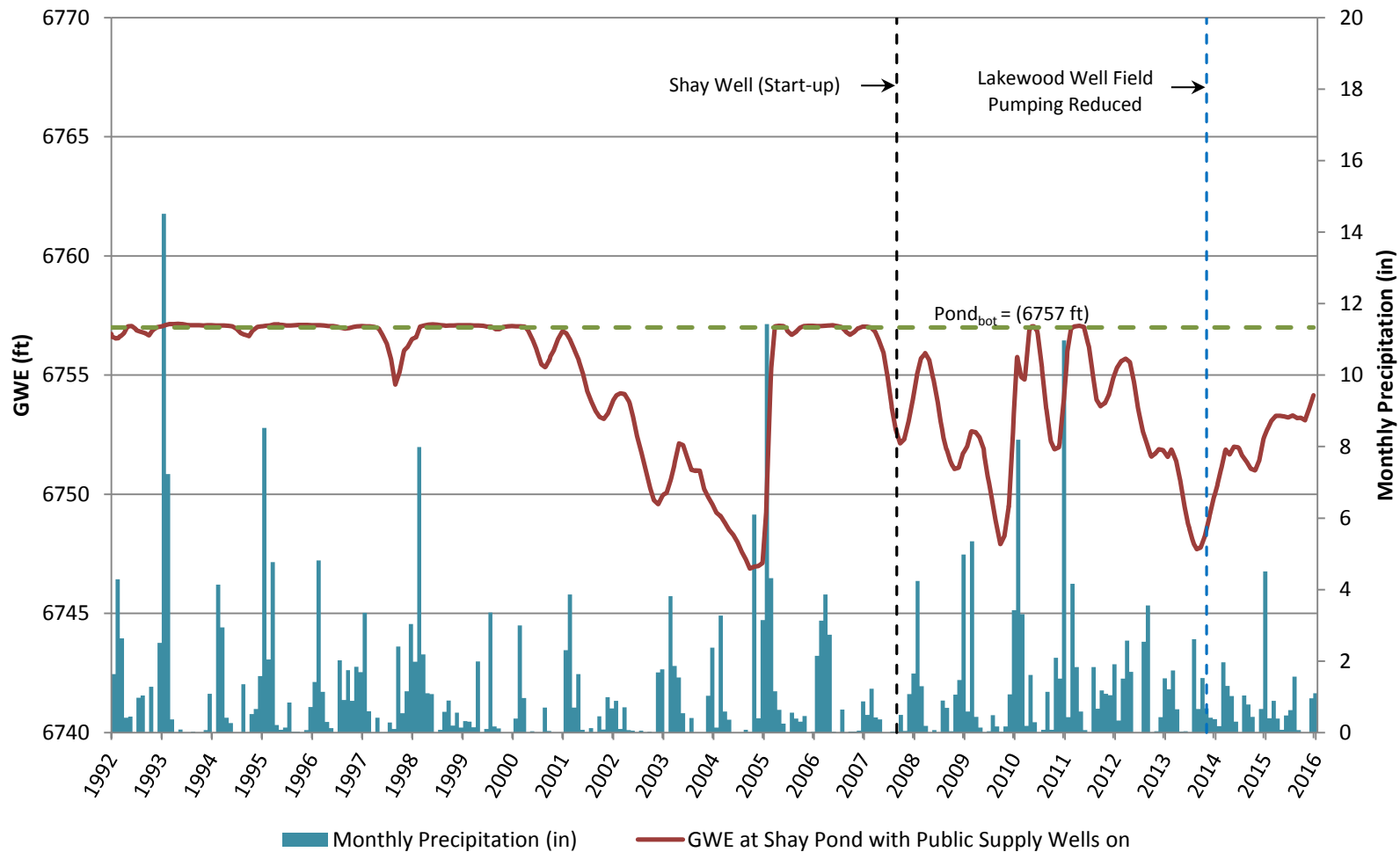
**Model-Predicted Groundwater Elevation (GWE) at Shay Pond with
Shay Pond Well on and Public Supply Wells off vs. Time**



**Model-Predicted Groundwater Elevation (GWE) at Shay Pond
with Shay Pond Well and Public Supply Wells off vs. Time**



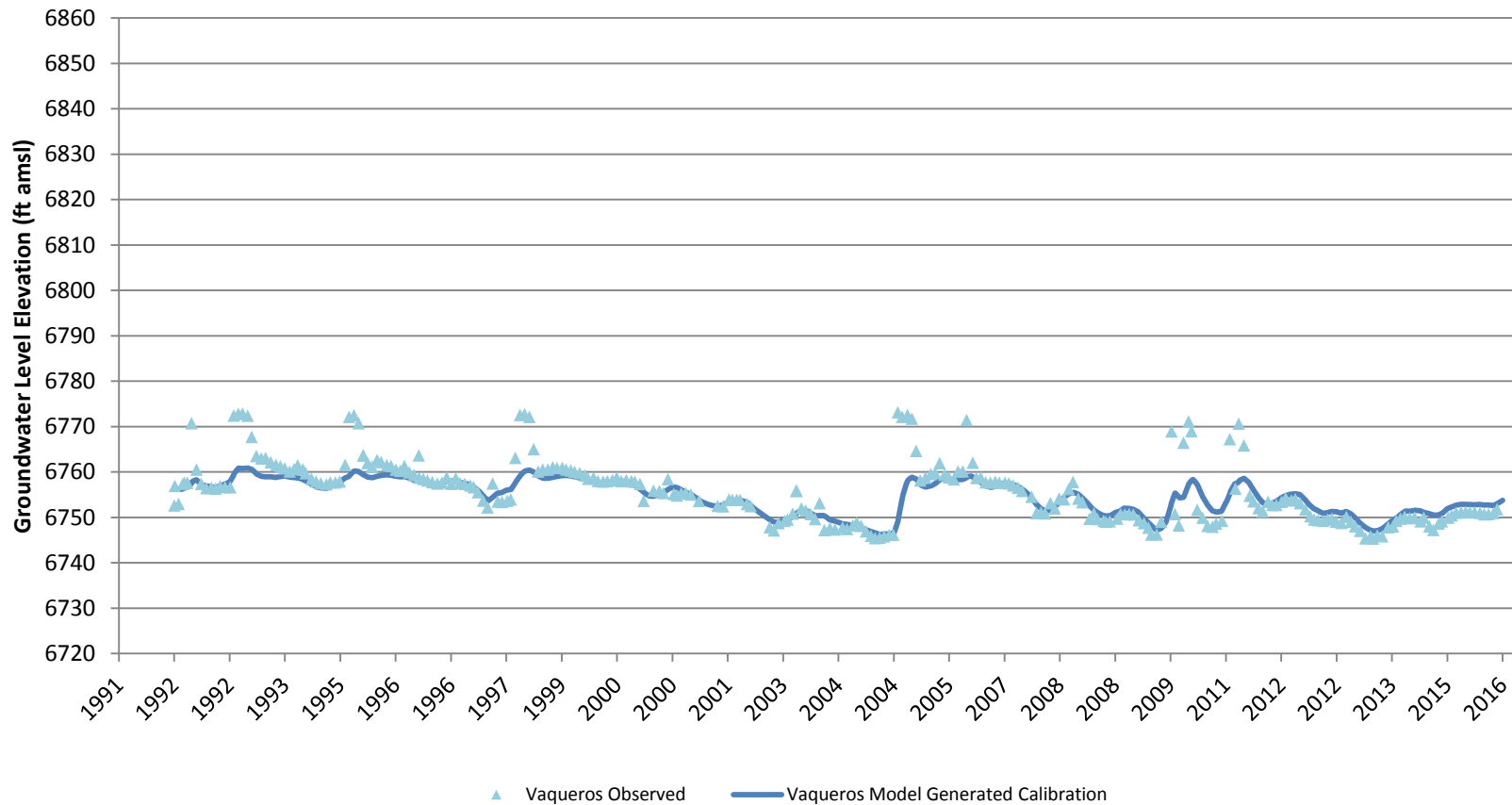
**Model-Predicted Groundwater Elevation (GWE) at Shay Pond with Project Wells
Compared to Precipitation vs. Time**



Attachment A

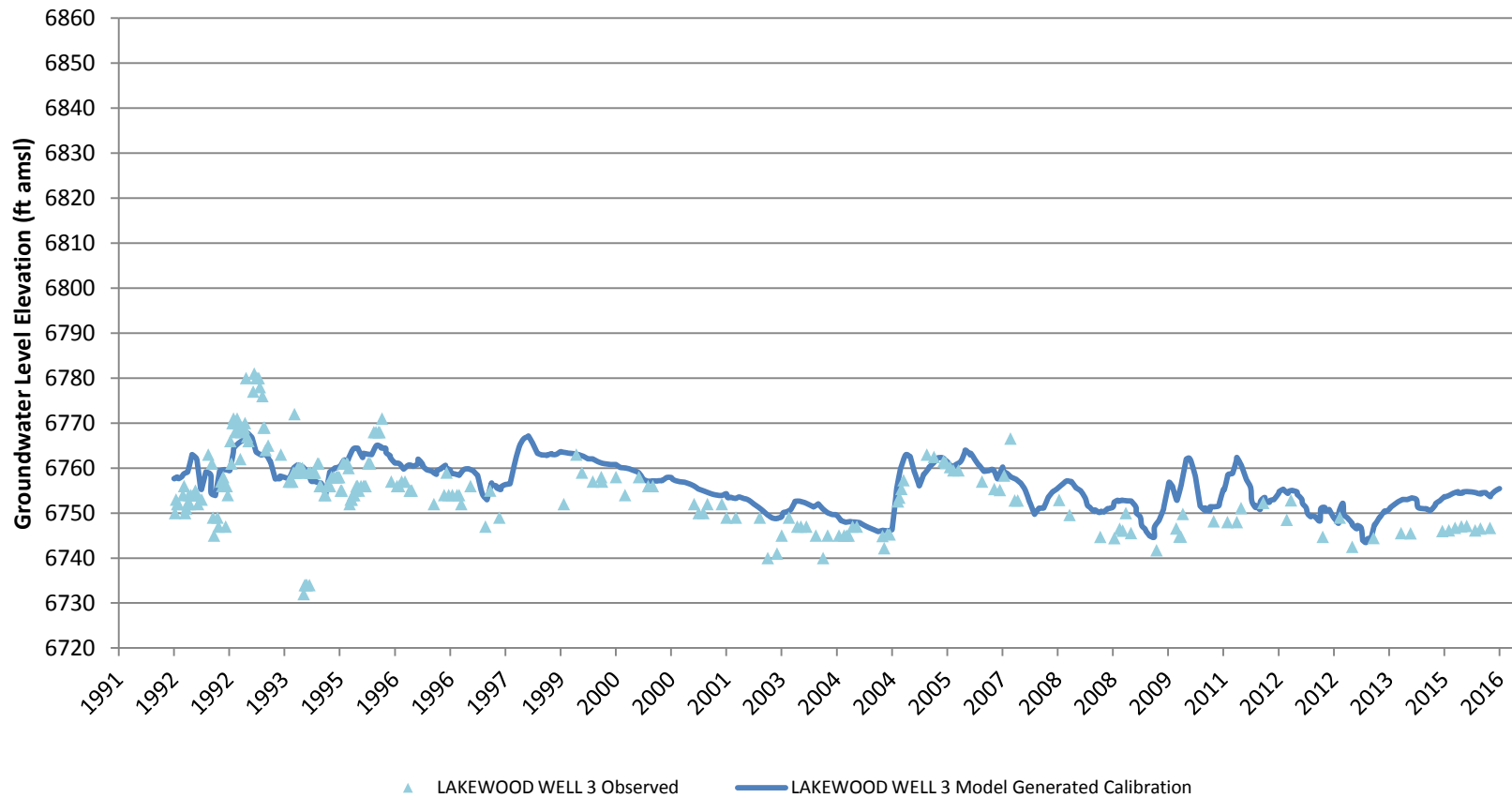


Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" $C = 10,000 \text{ ft}^2/\text{d}$
Vaqueros Monitoring Well



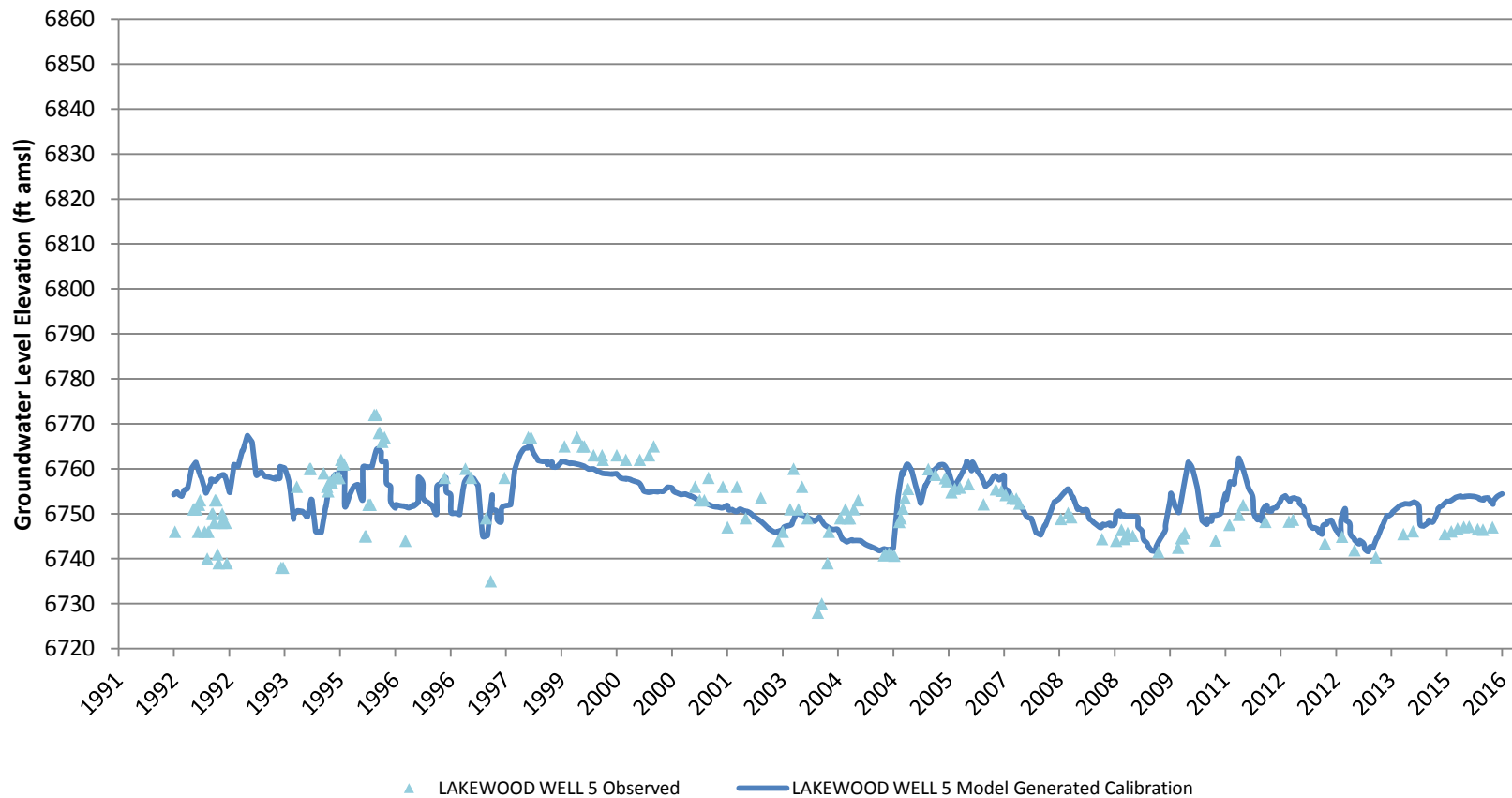
Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" $C = 10,000 \text{ ft}^2/\text{d}$

Lakewood Well 3



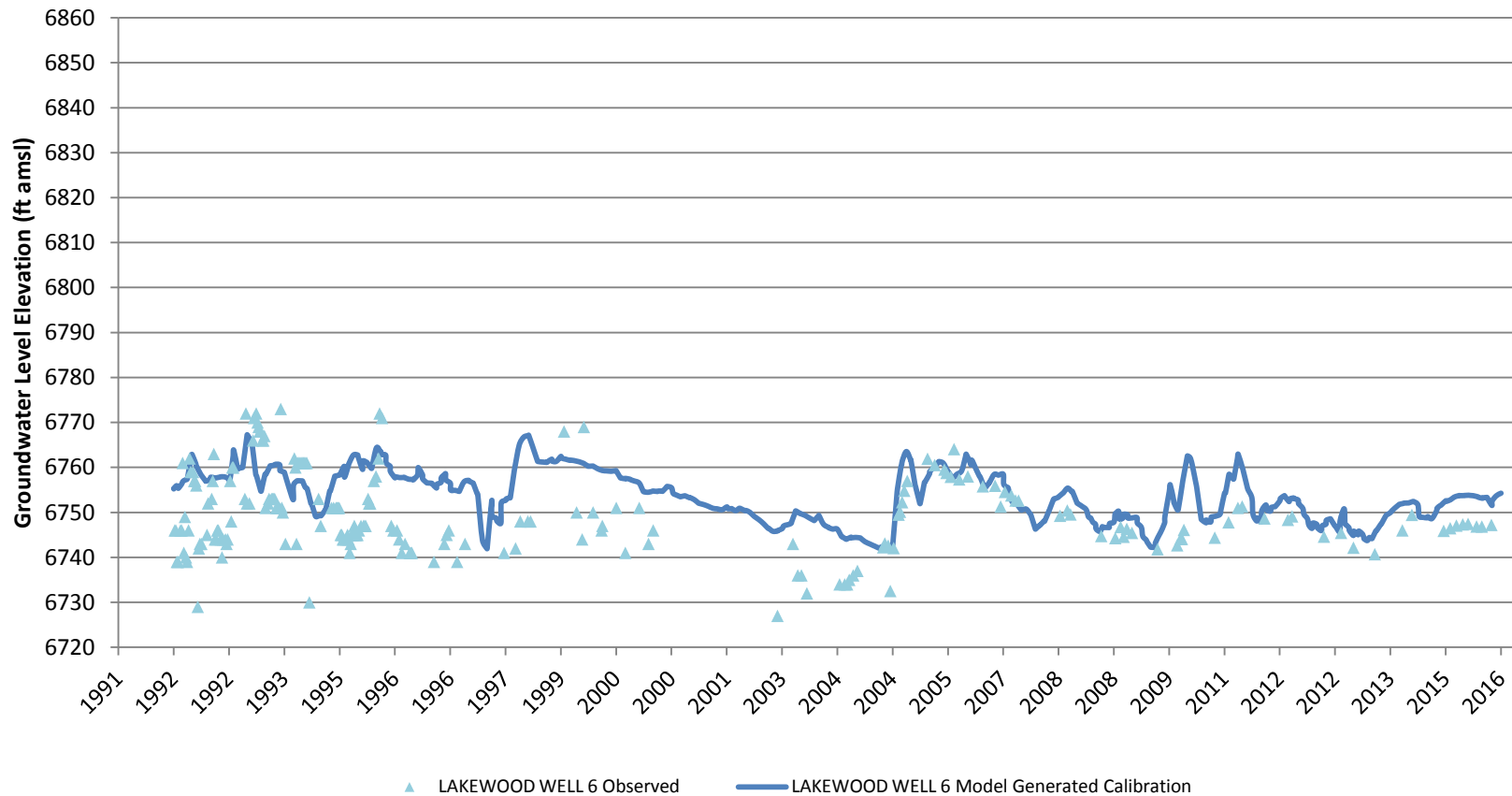
Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" C = 10,000 ft²/d

Lakewood Well 5



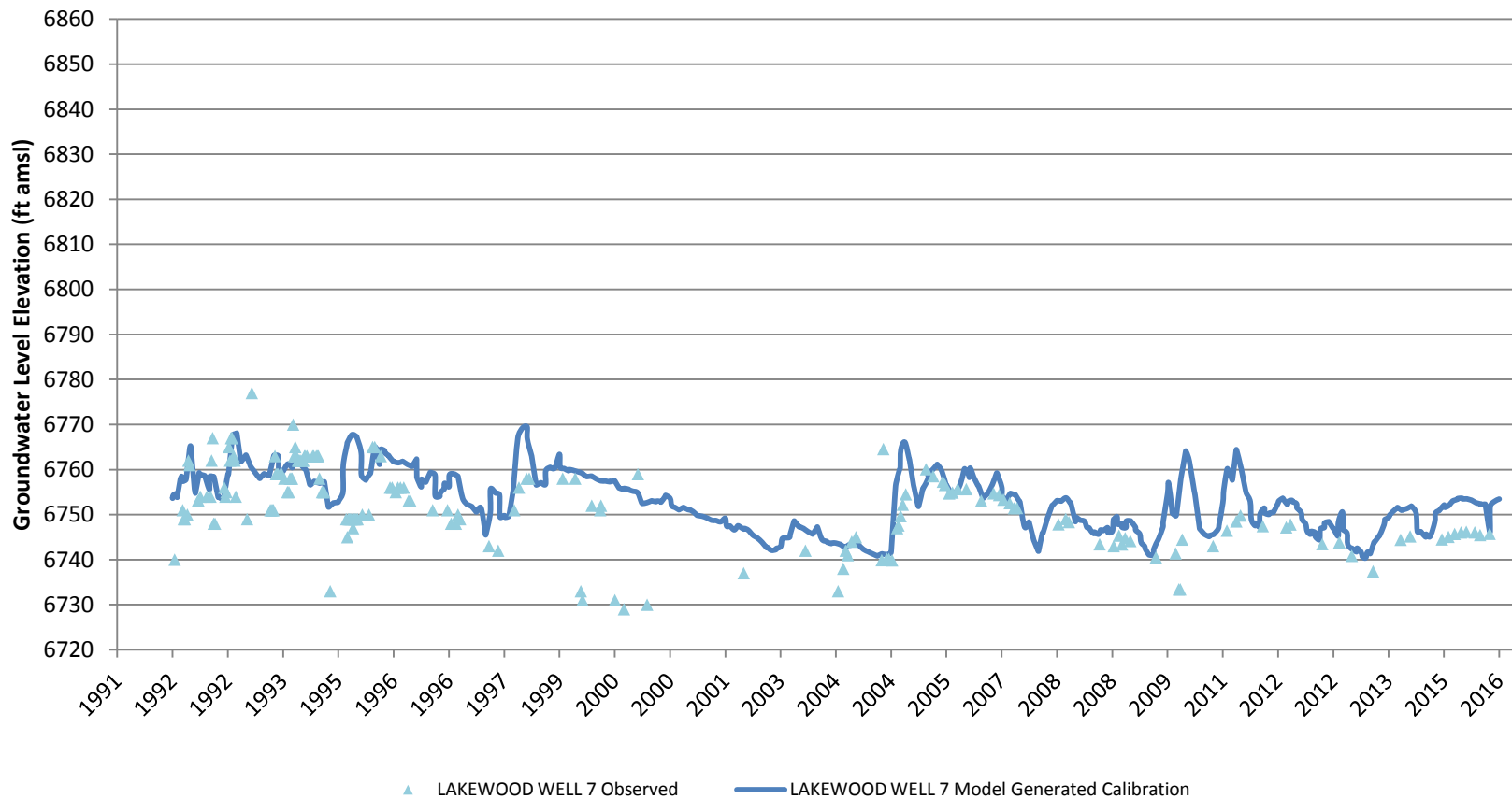
Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" $C = 10,000 \text{ ft}^2/\text{d}$

Lakewood Well 6

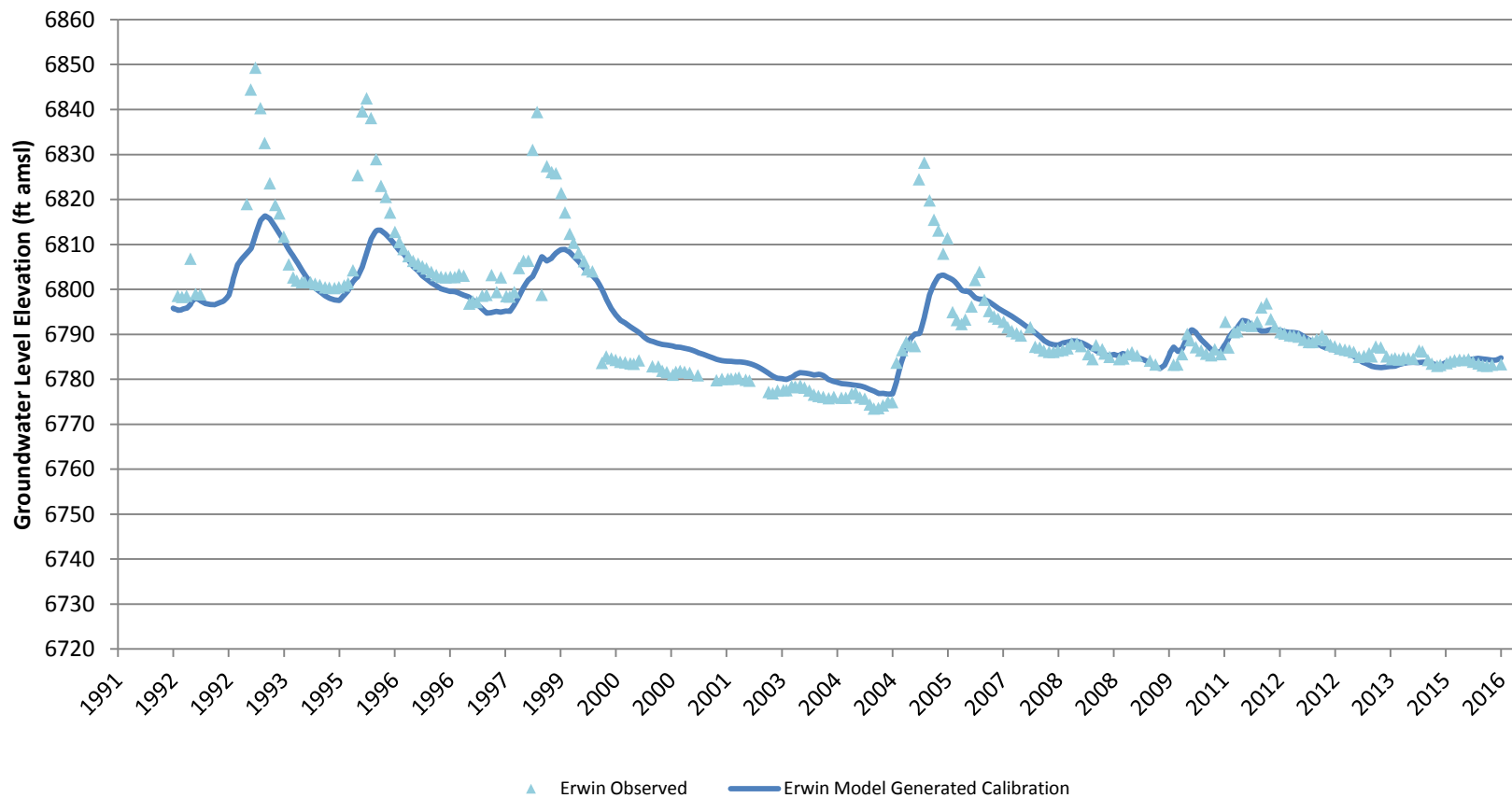


Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" C = 10,000 ft²/d

Lakewood Well 7



Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" C = 10,000 ft²/d
Erwin Monitoring Well



Comparison of Model-Generated Calibration and Observed Water Levels
"With Project" $C = 10,000 \text{ ft}^2/\text{d}$

Big Bear Community Services District Well 2

