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TECHNICAL MEMORANDUM

Prepared For: Sonoma County Water Agency
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Subject: **Results of MODFLOW Simulations**
Proposed Wohler Collector Well No. 6
Water Supply and Transmission System Project
Sonoma County Water Agency

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1.0 INTRODUCTION

This technical memorandum presents the results of computer simulations of groundwater flow performed by PES Environmental, Inc. (PES) for the shallow aquifer system along the Russian River in Sonoma County, California. The computer simulations were performed for the Sonoma County Water Agency (Agency) in accordance with the *Agreement for Computer Modeling Services, Proposed Wohler Collector No. 6 Project, Water Supply and Transmission System Project,* dated June 2, 2000. The objectives of the modeling activities were to: (1) assess steady-state groundwater conditions with the inflatable dam on the Russian River in place, (2) evaluate changes to groundwater conditions when the inflatable dam is removed, and (3) estimate the steady-state groundwater production rate for proposed Collector No. 6 with both a conventional lateral system and an enhanced lateral system.

To perform the simulations, PES modified the Agency's existing MODFLOW groundwater flow model of the shallow aquifer system along the Russian River. Modifications made to the model as part of the modeling activities described in this report include updating aquifer geometry and hydrologic boundaries, as well as riverbed properties. The modifications to the aquifer geometry incorporated: (1) the results of a 1999 geophysical survey performed by Norcal Geophysical Consultants, Inc. (Norcal, 1999); and (2) existing boring logs and geophysical data for the Mirabel and Wohler Areas (Marliave, 1969 and SCWA, 1970). Modifications to riverbed properties were made based on the results of the model calibration process, as well as recently estimated riverbed vertical hydraulic conductivity values for the segment of the Russian River located within the northeastern portion of the modeled area (along the former Kaiser Sand & Gravel, Westside Farms, and Lazy "W" Ranch properties). These values were obtained from the results of temperature modeling performed by staff of the U.S. Geological Survey (J. Jasperse, Sonoma County Water Agency, personal communication, June 12, 2000).

1.1 Background Information

The Agency operates five radial collector wells (Wohler Collector Wells #1 and #2 and Mirabel Collector Wells #3, #4, and #5) and seven conventional wells (Mirabel Conventional Wells MPW #1 through MPW #7) adjacent to the Russian River near Wohler Bridge and Mirabel that extract water from the alluvial aquifer (Plate 1). To augment recharge to the alluvial aquifer, the Agency has constructed several infiltration ponds and an inflatable dam located on the Russian River (upstream of Mirabel Collector Well #5). The dam is operated seasonally and is generally inflated (i.e., raised) in the late spring when precipitation events and river flows decrease and is lowered in the fall when precipitation events and river flows increase. When inflated, the dam raises the water level in the river upstream of the dam, thereby submerging a larger area of the riverbed upstream of the dam near Wohler Collector Wells #1 and #2. Four infiltration ponds and one settling pond at Mirabel are also seasonally operated by diverting river water from directly behind the dam into the settling pond and infiltration ponds. The four infiltration ponds comprise a total of approximately 46 acres and are maintained on a regular basis to remove accumulations of fine-grained materials (e.g., silts)

from the pond bottoms (SCWA, 1990). Two smaller infiltration ponds (totaling approximately 1.7 acres) are located near Wohler Collector Wells #1 and #2. These ponds, however, do not receive regular maintenance to remove silts that accumulate on the pond bottoms. The location of the collector wells, conventional wells, infiltration ponds and inflatable dam are shown on Plate 1.

The Agency initially developed a numerical groundwater flow model of the shallow aquifer system along the Russian River using MODFLOW (McDonald and Harbaugh, 1988) for "use as a planning tool for future Agency pumping facilities". A description of the original model is provided in a report prepared by the Agency entitled *Sonoma County Water Agency – Russian River Aquifer Model* (SCWA, 1996). The Agency model was modified by PES in 1998 and 1999 to incorporate data from hydrogeologic evaluations performed at the former Kaiser Sand & Gravel, Westside Farms, and Lazy "W" Ranch properties and to assess the degree of surface water/aquifer interaction (PES, 1999c). In addition to changes made at the three properties mentioned above, modifications were also made to the model orientation and river stage during PES' 1998 and 1999 modeling activities.

1.2 Conceptual Understanding of Hydrogeologic Conditions

The principal source of groundwater in the modeled area is from the alluvium of recent age that underlies the alluvial plains of the Russian River and comprises the shallow aquifer. Within the modeled area, the Russian River valley ranges from about 0.1 to 1 mile wide, and is underlain by loose, permeable deposits of sand and gravel that range in thickness from approximately 25 to more than 85 feet. The alluvial aquifer is unconfined in most areas and typically highly transmissive. The shallow alluvial aquifer is underlain and laterally bounded by consolidated rocks of the Franciscan Complex and Great Valley Sequence and semi-consolidated deposits of the Glen Ellen and Wilson Grove Formations. In the northern portion of the modeled area, the presence of a thick, relatively continuous clay layer beneath the alluvium is interpreted to represent the upper sequence of the Glen Ellen and Wilson Grove Formations. The clay layer is reported to behave as a confining unit, limiting the vertical flow of groundwater between the alluvial aquifer and the deeper Glen Ellen and Wilson Grove aquifers.

The primary source of groundwater recharge to the shallow alluvial aquifer in the modeled area is through infiltration of surface water from the Russian River, infiltration ponds, and quarry ponds. Historical data indicate that prior to the extensive development of the sand and gravel quarries and water diversions, groundwater in the modeled area generally flowed toward the river and discharged as underflow during much of the year (i.e., gaining river condition) (Cardwell, 1965). The interaction between groundwater and surface water has been studied at a number of locations in and near the modeled area (PES, 1999a,b). The findings of these studies indicate that in areas where quarry ponds have been excavated near the river, the water levels in these ponds are generally higher than water levels in the adjacent river and alluvial aquifer. As a result, water flows from the ponds to the alluvial aquifer, which in turn, discharges to the river (gaining river conditions). When groundwater levels decline, often

during the summer and fall, surface water from the Russian River may recharge the alluvial aquifer (i.e., losing river condition) in areas outside of the influence of quarry ponds and the local direction of groundwater flow is away from the river. During high river stages (seasonal or as a result of controlled surface water releases to the river), and in areas of significant groundwater pumping near the river (e.g., in the vicinity of Wohler Collector Wells #1 and #2), surface water from the Russian River also recharges the alluvial aquifer.

2.0 MODEL DESCRIPTION

2.1 Model Grid and Boundary Conditions

A rectangular finite-difference grid, oriented in a north-south orientation, was superimposed on a map of the Russian River. A uniform grid size of 100 feet by 100 feet was used, resulting in 131 columns and 121 rows. The thickness of the alluvial aquifer was divided into 7 layers to enable a more accurate simulation of surface water/aquifer interactions and to better represent vertical flow components. Bottom elevations of layers 1 through 7 occur at mean sea level elevations of 10, 0, -10, -20, -30, -40, and -70 feet, respectively. The active model area in deeper layers is smaller than in upper layers reflecting the river channel's incision into underlying formations where the deeper parts of the alluvial aquifer are located. In total, the model consists of 110,950 block-centered cells or nodes (15,850 cells per layer). The number of active cells per layer ranges from approximately 4,500 in layer 1 to approximately 650 in layer 6. Layer 7, which represents underlying, low permeability, formations does not contain any active cells.

The grid geometry assigned in the Agency model was updated in the following areas: (1) Wohler Meadows area in the vicinity of proposed Collector #6; and (2) the Mirabel area in the vicinity of Collectors #3, #4, and #5. Geologic and geophysical data used to modify the grid geometry in these two areas were obtained from lithologic data compiled from approximately 80 borings and geophysical data from 4 seismic refraction surveys (Geo-Recon, 1969; Harding Lawson Associates, 1992; Norcal, 1987 and 1999). For all other portions of the modeled area, the grid geometry assigned in the Agency model was used.

No flow boundary conditions were selected to bound the bottom and lateral edges of the shallow aquifer. Aquifers within the Glen Ellen and Wilson Grove Formations which occur beneath and adjacent to the shallow alluvial aquifer at the northern portion of the model area were not simulated in the model because the hydraulic communication between these aquifers and the shallow alluvial aquifer is reportedly restricted by low permeability clay deposits and were, therefore, assumed to be insignificant relative to other flow components.

General head boundaries were used to represent the alluvial aquifer at the inflow (northern) and outflow (southwestern) boundaries of the modeled area. Head values for the general head boundaries were estimated based on observed water-level elevations near each respective boundary. Values of specified flux for the general head boundaries were assigned based on

transmissivity values of the alluvial aquifer estimated from aquifer tests performed within the modeled area.

The Russian River, recharge ponds, and gravel pits were simulated as head-dependent flux boundaries using MODFLOWs River Package. Input parameters for the Russian River, recharge ponds and quarry ponds are described below in Section 2.2. Mark West Creek and Porter Creek are not represented in the model.

2.2 Summary of Model Input Parameters

Model input parameters were obtained from a number of sources. For the portion of the model area downstream of the inflatable dam, input parameters assigned in the Agency model were generally used. For the portion of the model extending from the inflatable dam to the Lazy "W" Ranch, input parameters were obtained from hydrogeologic evaluations performed in the area (Harding Lawson and Associates, 1988 and Herzog Associates, 1992). For the northern portion of the modeled area (in the vicinity of the Lazy "W" Ranch, Westside Farms, and former Kaiser Sand and Gravel properties), geophysical, geologic and hydrologic data gathered during hydrogeologic evaluations performed by PES in 1998-99 were used to define model input parameters (PES, 1999a,b). The input parameters for the model are described below and have been grouped into the following components: aquifer properties; river properties; infiltration pond and quarry pond properties; groundwater withdrawals; and areal recharge.

2.2.1 Aquifer Properties

Aquifer physical properties that were estimated for input into the model included horizontal and vertical hydraulic conductivity values and specific storage/specific yield values. The aquifer physical properties representing each node are assumed to be constant and represent an average value over the grid block. The modeled area was divided into hydraulic conductivity zones as shown on Plate 2 so that values could be specified and adjusted for groups of cells containing similar hydrogeologic characteristics. The hydraulic conductivity values and zones assigned in the Agency model were used with the exception of the northern portion of the model area, which was updated based on the results of recent aquifer tests performed in that area (PES, 1999a,b). As shown on Plate 2, horizontal hydraulic conductivity values ranged from 10 to 1,500 feet per day. In areas where aquifer test data were not available, the hydraulic conductivity values were estimated based on the inferred depositional setting for the alluvial sediments comprising the aquifer. For example, higher conductivity values were assigned to the coarser-grained and more permeable deposits located adjacent to the Russian River and lower values were assigned to the margins of the alluvial valley further from the river channel. The vertical hydraulic conductivity of the aquifer was assigned a value of one-tenth the horizontal conductivity. Aquifer specific yield and specific storage were assigned values of 0.30 and 0.001, respectively, based on published values for sand and gravel aquifers (Morris and Johnson, 1967 and Domenico and Schwartz, 1990).

2.2.2 River Properties

As described above, the Russian River is simulated as a series of head dependent flux boundaries using MODFLOW's River Package. Flow between the river and the aquifer is simulated based on head differences between the river stage and adjacent aquifer, which are separated by a layer of lower permeability streambed sediments. The rate of flow between the aquifer and the river is controlled by the streambed conductance (C). The streambed conductance is derived according to the following formula:

$$C = \frac{K}{M}$$

where K = Hydraulic conductivity of streambed sediments [L/T]; and
M = Thickness of streambed sediments [L]

The streambed conductance value [L^2/T] assigned to each modeled river node is assigned by multiplying the streambed conductance by the length and width of the river within the appropriate cell.

As such, the input parameters for the Russian River include: measured or estimated vertical hydraulic conductivity values for streambed sediments, stream width, stream stage, and thickness of stream bottom sediments for both dam in place and dam lowered conditions.

The vertical hydraulic conductivity for streambed sediments ranged from 1.5 to 52 feet/day. These values were based on values assigned in the Agency's model and the results of temperature modeling recently performed by staff of the U.S. Geological Survey. In general, both the vertical hydraulic conductivity and thickness of streambed sediments remained the same for both steady state simulations (dam in-place and dam lowered). The only exception to this generalization occurs under dam in-place conditions for the river reach between the inflatable dam and Wohler Bridge where the streambed sediments were increased in thickness up to 2.5 feet and vertical hydraulic conductivity was decreased during model calibration. The increase of streambed thickness and decrease in vertical hydraulic conductivity along this river reach reflects the conceptual understanding of the depositional environment directly upstream of the inflated dam. When inflated, the dam serves as a barrier to the suspended sediment load carried by the river and causes the gradient of the river to flatten, which, in turn, reduces the rate of river flow and results in deposition of fine-grained sediments along the streambed upstream of the dam. It is, therefore, expected that the resultant buildup of fine-grained sediments on the streambed behind the inflated dam will increase the thickness and decrease the vertical hydraulic conductivity of the streambed sediments. For the remainder of the river, streambed sediments were assigned a thickness of 1 foot, which is consistent with the Agency's model. The Russian River within the modeled area was divided into riverbed conductance zones as shown on Plate 3 so that values could be specified and adjusted for groups of cells containing similar hydrologic characteristics. As shown on Plate 3, riverbed conductance values ranged from 0.5 to 35 day^{-1}.

The width of the river, which ranges from approximately 50 to 300 feet, was estimated from: (1) aerial photographs and maps provided by the Agency; and (2) topographic profiles of river sections surveyed for the Sonoma County Aggregate Resource Management Plan (ARM Plan) between 1996 and 1998 (SCPRMD and SCWA, 1998 and 2000). The elevation of the streambed was also estimated using the river section topographic profiles.

The stage of the Russian River was estimated from: (1) data obtained during the hydrogeologic evaluations performed in 1998 at the Lazy "W" Ranch, Westside Farms and former Kaiser Sand & Gravel Properties (PES, 1999a,b); and (2) the river section topographic profiles and aerial photographs.

2.2.3 Pond Properties

Infiltration and quarry ponds were simulated as head dependent flux boundaries using MODFLOWs River Package. Accordingly, the required input parameters are similar to those described above for the Russian River and include: measured or estimated vertical hydraulic conductivity values for infiltration pond and quarry pond sediments, the width and length of the pond in each cell, pond stage, and the thickness of pond bottom sediments.

The bottom sediments within the four infiltration ponds located at Mirabel (Ponds 1 through 4) were assigned a vertical hydraulic conductivity of approximately 27 feet/day and a thickness of 1 foot to be consistent with values assigned in the Agency's model. The pond bottom elevations were obtained from survey data provided by the Agency (Delta Geomatics, 1997) and ranged from 37 to 40 feet above mean sea level. The depth of water within each pond was set to 3 feet to be consistent with values assigned in the Agency model. For the purpose of performing the dam in place simulations described in this report, each of the four infiltration ponds were operated continuously throughout the simulations. This represents a simplification of actual conditions, as the Agency generally alternates operation between the four ponds on a weekly basis (J. Jasperse, Sonoma County Water Agency, personal communication, August 30, 2000).

The bottom sediments of the two small infiltration ponds present along the east side of the river near Wohler Collector Wells #1 and #2 were assigned a lower hydraulic conductivity value and greater streambed thickness than those for the infiltration ponds at the Mirabel area. These ponds were assigned lower hydraulic conductivity values and a greater bottom sediment thickness because regular maintenance (i.e., removal of fine-grained sediments) is not performed for these ponds as it is with the Mirabel ponds. The pond bottom elevations were obtained from survey data provided by the Agency (Delta Geomatics, 1997) and were set at 31 and 35 feet above mean sea level. The depth of water within each pond was set to 3 feet to be consistent with values assigned in the Agency model.

Quarry ponds located along the northeastern model boundary (Benoist Pond, Wilson Pond, and McLaughlin Pond) are simulated in the model by assigning head dependent flux boundaries to

the western edges of the ponds. The depth and thickness of bottom sediments were assigned values consistent with those used in previous models of the shallow aquifer and quarry ponds (Luhdorff and Scalminini, 1997). Stage elevations within the gravel pits were based on elevations surveyed in October 1998 (PES, 1999a,b).

2.2.4 Groundwater Withdrawal

Groundwater withdrawals from the modeled area were simulated as groundwater pumping from the existing Agency collector and conventional wells using MODFLOW's Well Package. The pumping rates assigned to each well were estimated based on the cumulative pumping rates provided by the Agency for the calibration period. While the pumping rates for individual wells and collectors were not known, reasonable estimates were obtained by distributing the cumulative pumping rates according to estimates provided by the Agency of the historical yield for each well and collector (J. Jasperse, Sonoma County Water Agency, personal communication, June 12, 2000). Groundwater pumping rates were adjusted slightly during the model calibration process to achieve reasonable simulation results. Groundwater pumping from Collector #6 was assigned during the predictive simulations, as described below in Section 4.0.

2.2.5 Areal Recharge

Areal recharge (deep percolation of precipitation) was simulated using MODFLOW's Recharge Package. The average precipitation rate recorded at Warm Springs Dam for November 1999 was multiplied by 12.5 percent to obtain the areal recharge rate assigned in the model. The areal recharge rate represents the percentage of precipitation that contributes to groundwater recharge. The remaining percentage of precipitation is assumed to be lost to evapotranspiration and overland flow. The value of 12.5 percent of precipitation was used to be consistent with previous models developed for shallow aquifer system adjacent to the Russian River (Luhdorff and Scalminini, 1997).

3.0 MODEL CALIBRATION

The groundwater flow model was calibrated under steady-state and transient conditions to water-level measurements from an observation well network consisting of 11 observation wells monitored by the Agency within the modeled area during 1999. The observation well network is shown on Plate 4. November 1999 was selected as the calibration period because of the relatively large amount of water-level data available for the month of November in both 1999 and 1998 and because it was prior to the onset of significant precipitation events. Because hydrologic conditions were fairly similar for early November in 1999 and 1998, water-level data obtained for November 1998 was also considered during model calibration. In addition, because the inflatable dam was lowered on November 16, 1999, calibration to conditions in November 1999 provided the opportunity to calibrate the model to conditions when the dam is both in-place and lowered on the Russian River. Acceptability of model results was

determined by: (1) comparing simulated and observed hydraulic heads in each model layer; (2) assessing the magnitude and direction of horizontal and vertical head gradients; and (3) evaluating the water balance components. During the calibration process, changes were made to input parameters (primarily streambed conductance values) over an associated group of grid blocks rather than on a grid-by-grid basis and made within a reasonable range of parameter values.

As shown on Plate 4, observed water-level data used for the calibration process was fairly evenly distributed across the portion of the modeled area extending from the inflatable dam to the northern model boundary. Observed water-level measurements for the portion of the modeled area located downstream of the inflatable dam are limited to water levels measured within Mirabel Collectors #3 through #5 and Mirabel Conventional Wells MPW#1 through MPW#7. These water-level data are considered less reliable than from the observation well network due to the pronounced pumping effects from these wells on water levels and uncertainties regarding the accuracy of the measuring devices present in these wells. Additionally, the portion of the model downstream of the inflatable dam is strongly influenced by the four Mirabel infiltration ponds, which are the largest component of the water budget for the Mirabel area as described below in Section 3.3. The maintenance and operational activities associated with the ponds causes the pond stage and sediment-bottom thickness to vary over time. Since these parameters are not known for specific time periods, model calibration for the portion of the model present downstream of the inflatable dam was achieved by ensuring that simulations resulted in a reasonable flow field and water balance for this area.

3.1 Steady State/Dam In-Place

As discussed above, the model was calibrated under steady state conditions with the inflatable dam in-place on the Russian River using data from November 1999. Simulated hydraulic heads were compared to observed water-level elevations measured on November 15, 1999, prior to the lowering of the inflatable dam. The steady-state model included pumping from Agency Wohler Collectors #1 and #2 (at a combined rate of 21 million gallons per day [mgd]) and Mirabel Collectors #3, #4, and #5 (at a combined rate of 60 mgd or 20 mgd each). Groundwater pumping was also simulated from seven Agency Conventional Wells (MPW#1 through MPW#7) located on the west side of the river near the inflatable dam at a combined rate of 7 mgd or 1 mgd each.

Model calibration was achieved primarily by adjusting streambed conductance and groundwater pumping rates within a reasonable and observed range of values. The Russian River was divided into nine segments each containing similar streambed conductance to facilitate the calibration process. Changes to streambed conductance values made during the calibration process were applied to these segments of the river, rather than to individual nodes.

Results of model calibration indicate that the absolute value of the mean difference between simulated and observed hydraulic heads is 0.4 feet. A comparison of simulated hydraulic heads and observed hydraulic heads is provided in Table 1, along with the calculated mean and

mean of the absolute value for the residual heads. The results of model calibration indicate that the best fit between simulated and observed hydraulic heads was achieved for the portion of the model extending from the Wohler Meadows area to the northern model boundary. This portion of the model also contains the most hydrogeologic data. The simulated water budget for the Steady-State/Dam In-Place model is described below in Section 3.3 and summarized on Table 3.

3.1.1 Sensitivity Analysis

Sensitivity analyses of the steady state model were performed to assess the confidence associated with the values of input parameters used in the calibrated model and to identify model inputs that have the most influence on the simulated results. Individual input parameters were increased and decreased by a constant factor while all other parameters were unchanged. The difference between simulated and observed values of hydraulic head was used to evaluate model sensitivity to individual input parameters.

Parameters included in the sensitivity analyses were selected based on the model calibration process and evaluation of the simulated water budget. The following parameters were adjusted during the sensitivity analysis: (1) horizontal aquifer hydraulic conductivity; (2) vertical aquifer hydraulic conductivity; (3) vertical hydraulic conductivity of streambed sediments; (4) hydraulic conductivity of infiltration pond sediments; (5) hydraulic conductivity of quarry pond sediments; and (6) groundwater withdrawal rates. Each parameter was adjusted by ±20 percent, with the exception of horizontal aquifer hydraulic conductivity and groundwater withdrawal rates. Due to model convergence difficulties, horizontal aquifer hydraulic conductivity could only be decreased by 10 percent and groundwater withdrawal rates could only be increased by 15 percent. The factor by which each parameter was changed and the results of the sensitivity analyses are provided in Table 2. As indicated in Table 2, the model is relatively insensitive to changes made to vertical aquifer hydraulic conductivity and hydraulic conductivities of sediments lining quarry ponds and infiltration ponds. While the model is also not very sensitive to increases in horizontal aquifer hydraulic conductivity, it is quite sensitive to decreases made to this parameter. The model is most sensitive to changes made to the hydraulic conductivity of streambed sediments (particularly increases) and groundwater withdrawal rates (particularly increases). The findings of the sensitivity analysis are consistent with results of sensitivity analyses performed for: (1) previous models developed for shallow aquifer system adjacent to the Russian River (Luhdorff and Scalminini, 1997); and (2) numerical flow models developed for groundwater basins containing similar hydrogeologic settings and groundwater uses (Cunningham et al., 1996).

3.2 Transient/Lowering of Dam

Model calibration was extended to transient flow conditions for simulation of the lowering of the inflatable dam by including storage coefficients in the model and changing input parameters for the river. The calculated hydraulic heads for November 15, 1999 from the calibrated steady state model with the dam in-place were used as starting heads for the transient

simulation. A 14-day period beginning on November 15 (the day prior to the lowering of the inflatable dam) and ending on November 28, 1999 was selected for the transient simulation. The duration of the transient simulation was limited to 14 days due to an increase in precipitation events commencing on November 29, 1999.

The transient simulation was comprised of two stress periods. The first stress period consisted of one time step lasting one day and represented transient conditions with the dam in-place. The second stress period (consisting of 13 time steps) lasted 13 days and represented transient conditions with the dam lowered. Changes made to model input parameters for the second period of the transient simulation consisted of: (1) modifying riverbed properties and river stage values associated with the portion of the Russian River extending from the inflatable dam to the northern model boundary; (2) decreasing the pumping rate assigned to the Agency's wellfields; and (3) elimination of the Mirabel and Wohler infiltration ponds from the model.

To simulate the lowering of the inflatable dam, the river stage elevation was lowered from approximately 6 feet at the dam to approximately 0.5 feet at the northern model boundary. These values were based on estimates from 1998 river staff gauge data obtained at the Lazy "W" Ranch property and directly behind the inflatable dam. The streambed conductance value was also decreased for the second stress period to account for the decrease in stream width due to the lowering of the dam. The decrease in stream width resulting from the lowering of the dam was estimated from aerial photographs and ranged from approximately 40 percent between the dam and Wohler Bridge to less than 5 percent at the northern boundary of the model area.

The pumping rate for Wohler Collectors #1 and #2 was reduced to a combined 14 mgd during the second stress period to be consistent with the recorded pumping rate for the transient simulation period. The pumping rates for Mirabel Collectors #3, #4, and #5 were reduced to a combined 30 mgd (10 mgd each) and Mirabel Conventional Wells MPW#1 through MPW#7 were maintained at the rates used for the steady-state simulations as described above.

The results of the transient simulation indicate that hydraulic heads within the aquifer declined within the modeled area in response to the lowering of the inflatable dam. Table 1 summarizes the observed and simulated hydraulic heads at the start and end of the transient simulation. As indicated on Table 1, the magnitude of simulated hydraulic head declines within the observation well network ranged from 9.89 feet at observation well 93-18 to 0.50 feet at observation well KSG-OW-1. In comparison, the magnitude of observed hydraulic head declines measured during the transient simulation period ranged from 15.04 feet at observation well 93-18 to 0.40 feet at observation well KSG-OW-1. As shown on Table 1, simulated hydraulic head declines generally matched observed hydraulic head declines to within approximately 1.5-foot, with the exception of observation wells located closest to Wohler Collectors #1 and #2 (93-18 and TW-1). The observed water levels for these wells exhibit daily pumping influences which were not incorporated into the transient simulation from the nearby collector wells, causing the simulated hydraulic head declines to deviate from observed hydraulic head declines in the vicinity of Wohler Collectors #1 and #2. Hydrograph plots are

provided in Appendix A that illustrate the observed and simulated hydraulic heads during the transient simulation for each of the 11 observation wells. The hydrograph plots also include the daily precipitation measured at Warm Springs Dam for the transient simulation period. The comparative hydrographs indicate that the transient model realistically simulates hydraulic head changes in response to the lowering of the inflatable dam.

Based on the calibrated transient model, a steady-state model representing groundwater flow conditions when the inflatable dam is lowered and prior to the onset of significant winter precipitation was developed. This Steady-State/Dam Lowered model was developed for the purpose of performing predictive simulations of hydraulic head with operation of the proposed Wohler Collector #6, as described below in Section 4.0. The input parameters assigned to the Steady-State/Dam Lowered model were identical to those for the second stress period of the transient model with the exception of the pumping rates assigned to the Agency's wellfields. The pumping rates for the wellfields with the dam lowered were assigned as follows: 13.0 mgd from Wohler Collectors #1 and #2; 19.0 mgd from Mirabel Collectors #3, #4, and #5; and 3.0 mgd from Mirabel Conventional Wells MPW#1 through MPW#7. Evaluation of historical pumping rates and water-level data measured at the collectors for conditions when the dam is lowered and significant precipitation has not occurred, indicates that these pumping rates are appropriate pumping rates under these steady-state conditions.

3.3 Water Budget

MODFLOW Zonebudget zones were established to quantify inflow and outflow between the aquifer and: (1) specific segments of the river; (2) infiltration ponds; and (3) quarry ponds. The established zones are shown on Plate 5 and estimates of the water balance for each zone under various steady-state and transient conditions are summarized in Tables 3 and 4.

3.3.1 Dam In-Place

As indicated on Table 3, when the dam is in-place on the Russian River, the largest flux of surface water to the aquifer occurs from the recharge ponds at the Mirabel Area. During conditions with the dam in-place, the ponds contribute approximately 72 percent of the total volumetric water budget for the modeled area. Other significant inflow components include infiltration from: (1) "losing" segments of the Russian River (approximately 23 percent); and (2) quarry ponds (approximately 2.5 percent). The largest outflow component is from groundwater extraction through Agency Collectors and Conventional Wells (approximately 81 percent). The other main outflow component is through recharge to the Russian River (approximately 14 percent).

Evaluation of the river-aquifer flux for individual segments of the Russian River indicate that: (1) gaining river conditions are present for the river reach extending from the northern model boundary to the southernmost portion of the quarry ponds (upper segment); (2) losing river conditions are present from the southernmost portion of the quarry ponds to the inflatable dam (middle segment); and (3) gaining river conditions dominate the segment of the river

downstream of the inflatable dam to the southern model boundary (lower segment). The gaining river conditions simulated within the upper river segment are attributed to the presence of the quarry ponds. The quarry ponds contribute approximately 2.7 mgd to the aquifer along this reach. The losing river conditions simulated within the middle river segment are attributed to induced infiltration in the vicinity of Wohler Collectors #1 and #2 and the elevated river stage caused by the inflatable dam. The river contributes approximately 23 mgd to the aquifer within this segment via induced infiltration. The gaining river conditions simulated within the lower river segment are due to the presence of the infiltration ponds at Mirabel. These ponds contribute more water to the aquifer (approximately 78 mgd) than is removed by the collectors and conventional wells in this area (67 mgd).

3.3.2 Dam Lowered

When the dam is lowered on the Russian River and the Mirabel infiltration ponds are not in service, the largest flux of surface water to the aquifer is through induced infiltration from the Russian River. Table 4 summarizes the water budget for conditions when the dam is lowered on the Russian River. Induced infiltration from the river comprises approximately 82 percent of the total volumetric water budget during conditions when the dam is lowered. Inflow from quarry ponds represents approximately 10 percent of the total water budget. The two primary outflow components when the dam is lowered are extraction through Agency Collectors and Conventional Wells (approximately 89 percent) and recharge to gaining segments of the river (approximately 9 percent)

Evaluation of the simulated river-aquifer flux for individual segments of the Russian River indicate that: (1) gaining river conditions persist within the upper river segment; (2) losing river conditions persist within the middle river segment; and (3) the lower river segment exhibits losing conditions when the dam is lowered and the Mirabel infiltration ponds are not in service.

4.0 RESULTS OF STEADY STATE SIMULATIONS INCLUDING PROPOSED WOHLER COLLECTOR #6

The steady state groundwater flow models described above were used to estimate and compare the groundwater production rate for proposed Wohler Collector #6 with both a conventional lateral system and with an enhanced lateral system. The planned configuration for both the conventional and enhanced lateral systems for the proposed Wohler Collector #6 provided by the Agency was reviewed to select the distribution of pumping stresses for the predictive simulations. The proposed location for Wohler Collector #6 is shown on Plate 6. The pumping stresses for the conventional lateral system were assigned to 4 cells located in Layer 5 (-20 to -30 feet msl) centered beneath the proposed location for the caisson to simulate the proposed 150-foot radial lateral system. The enhanced lateral system consists of three horizontal wells (Laterals #1 through #3), which range in length from 500 to 1,000 feet.

These laterals are located in Layer 4 (-10 and -20 feet msl) and each extends from the proposed caisson location to approximately the center of the river.

The simulations for the conventional and enhanced lateral system were performed under conditions with the existing Agency Collectors and Conventional Wells operating. The pumping rate assigned to the Collectors and Conventional Wells varied for each simulation (Dam In-Place and Dam Lowered) based on: (1) the average observed pumping rates for each condition; and (2) the pumping rate sustainable for each steady state model. The sustainable steady state production rate for each well construction scenario (conventional and enhanced lateral systems) was assessed by successively increasing the pumping rate for proposed Wohler Collector #6 until excessive drawdowns caused model instability. Table 5 summarizes the results of the simulations and the pumping rates assigned to the existing collectors and conventional wells during each simulation.

4.1 Simulations with Dam In-Place

The simulations for proposed Wohler Collector #6 with the inflatable dam in-place on the Russian River were performed with: Wohler Collectors #1 and #2 pumping collectively at 21 mgd; Mirabel Collectors #3, #4, and #5 pumping collectively at 60 mgd; and Mirabel Conventional Wells pumping collectively at 7 mgd.

Results of the simulations with the conventional lateral system for proposed Wohler Collector #6 indicate that a steady state groundwater production rate of 17 mgd can be sustained when the dam is in-place on the Russian River. At pumping rates exceeding 17 mgd, simulated water-levels fall below the elevation of the laterals at Wohler Collectors #1 and #2. Comparison of the simulation results including the conventional lateral system at Wohler Collector #6 with the steady-state model results under existing pumping conditions indicates that water levels are lowered approximately 17 feet in the immediate vicinity of proposed Wohler Collector #6 when it is pumped at 17 mgd.

Results of simulations performed with an enhanced lateral system for proposed Wohler Collector #6 indicate that a steady state groundwater production rate of 23 mgd can be sustained when the inflatable dam is in-place on the Russian River. At pumping rates exceeding 23 mgd, simulated water-levels fall below the elevation of the laterals at Wohler Collector Wells #1 and #2 causing model instability. Comparison of the simulation results including the enhanced lateral system at Wohler Collector #6 with the steady-state model results under existing pumping conditions indicates that water levels are lowered approximately 11 feet in the immediate vicinity of proposed Wohler Collector #6 when it is pumped at 23 mgd. Results of the simulations indicate that drawdown in the vicinity of proposed Wohler Collector #6 is less with the enhanced lateral system with a higher pumping rate relative to the conventional lateral system due to the increased infiltration from the river (39 to 45 mgd within the middle river segment).

4.2 Simulations with Dam Lowered

The simulations for proposed Wohler Collector #6 with the inflatable dam lowered on the Russian River were performed with: Wohler Collectors #1 and #2 pumping collectively at 13 mgd; Mirabel Collectors #3, #4, and #5 pumping collectively at 19 mgd; and Mirabel Conventional Wells pumping collectively at 3.0 mgd.

Results of the simulations with the conventional lateral system for proposed Wohler Collector #6 indicate that a steady state groundwater production rate of 8.5 mgd can be sustained when the inflatable dam on the Russian River is lowered. At pumping rates exceeding 8.5 mgd, simulated water levels fall below the elevation of the laterals at Wohler Collectors #1 and #2 causing model instability. Comparison of the simulation results including the conventional lateral system at Wohler Collector #6 with the steady-state model results under existing pumping conditions indicates that water levels are lowered approximately 9 feet in the immediate vicinity of proposed Wohler Collector #6 when it is pumped at 8.5 mgd.

Results of simulations performed with an enhanced lateral system for proposed Wohler Collector #6 indicate that a steady state groundwater production rate of 12 mgd can be sustained during conditions when the inflatable dam on the Russian River is lowered. At pumping rates exceeding 12 mgd, simulated water levels fall below the elevation of the laterals at Wohler Collectors #1 and #2 causing model instability. Comparison of the simulation results including the enhanced lateral system at Wohler Collector #6 with the steady-state model results under existing pumping conditions indicates that water levels are lowered approximately 6 feet in the immediate vicinity of proposed Wohler Collector #6 when it is pumped at 12 mgd.

4.3 Summary of Simulation Results

The results of the simulations indicate that the estimated steady-state groundwater production rate for proposed Wohler Collector #6 with a conventional lateral system is approximately 17 mgd when the inflatable dam is in-place on the Russian River and 8.5 mgd when the dam is lowered. The estimated steady-state groundwater production rate for proposed Wohler Collector #6 with an enhanced lateral system is approximately 23 mgd when the inflatable dam is in-place on the Russian River and 12 mgd when the dam is lowered. These values indicate that an enhanced lateral system will result in an approximately 35 percent increase in the groundwater production rate when the dam is in-place and a 41 percent increase when the dam is lowered. Evaluation of the water budgets for the simulations (Tables 3 and 4) indicates that the increase in the estimated sustainable groundwater production rate with the enhanced lateral system at proposed Wohler Collector #6 occurs due to an increased induced infiltration rate from the Russian River. The induced infiltration rate is likely higher with the enhanced lateral system because pumping stresses are: (1) distributed over a larger area of the aquifer beneath the riverbed; and (2) located directly beneath the riverbed.

The simulations further indicate that operation of proposed Wohler Collector #6 reduces the amount of underflow contributing to the existing yield of Wohler Collectors #1 and #2. Consequently, exceeding the sustainable groundwater production rate for proposed Wohler Collector #6 resulted in dewatering the laterals associated with the downstream Wohler Collectors #1 and #2.

5.0 REFERENCES

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TABLES

Table 1
Residual Head Values From Observation Well Network
Steady State and Transient Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

	Steady-State: November 15, 1999			Transient: November 29, 1999			Water-Level Decline in Response to Dam Lowering		
Observation Well	Observed Hydraulic Head (ft. msl)	Simulated Hydraulic Head (ft. msl)	Residual Head (Simulated Minus Observed)	Observed Hydraulic Head (ft. msl)	Simulated Hydraulic Head (ft. msl)	Residual Head (Simulated Minus Observed)	Observed Water-Level Decline (feet)	Simulated Water-Level Decline (feet)	Residual Head (Simulated Minus Observed)
93-14	33.16	33.43	0.27	28.38	27.48	-0.90	4.78	5.95	1.17
93-15	34.57	33.71	-0.86	28.56	27.94	-0.62	6.01	5.77	-0.24
93-18	31.75	31.17	-0.58	16.71	21.28	4.57	15.04	9.89	-5.15
KSGOW-1	38.35	38.47	0.12	37.95	37.97	0.02	0.40	0.50	0.10
LWOW-1	37.15	37.55	0.40	35.85	35.22	-0.63	1.30	2.33	1.03
LWOW-4	37.66	37.67	0.01	36.85	35.55	-1.30	0.81	2.12	1.31
TW-1	31.22	29.90	-1.32	21.49	21.99	0.50	9.73	7.91	-1.82
TW-13	36.14	36.03	-0.11	32.26	32.70	0.44	3.88	3.33	-0.55
TW-8	37.10	36.95	-0.15	34.97	34.06	-0.91	2.13	2.89	0.76
OW-B	34.26	33.73	-0.53	28.84	27.61	-1.23	5.42	6.12	0.70
WSOW-8	38.28	38.62	0.34	37.76	37.92	0.16	0.52	0.70	0.18
Residual Mean			**-0.22**			**0.01**			**-0.23**
Absolute Value of Residual Mean			**0.43**			**1.03**			**1.18**

Notes:
ft. msl = elevation in feet above mean sea level
Residual heads represent the difference between simulated and observed hydraulic heads (positive values indicate simulated heads are higher than observed heads; negative values indicate simulated heads are lower than observed heads)

Table 2
Results of Sensitivity Analysis of Model Parameters
Steady-State Model/Dam In-Place
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

Model Parameter	Adjustment Factor	Mean Residual Head	Difference from Calibrated Model	Mean of Absolute Value of Residual Heads	Difference from Calibrated Model
Calibrated Model	**1**	**-0.22**	—	**0.43**	—
Horizontal Aquifer Hydraulic Conductivity	**1.20**	-0.18	**0.04**	0.44	**0.01**
	0.9	-1.12	**-0.90**	0.82	**0.39**
Vertical Aquifer Hydraulic Conductivity	**1.20**	-0.16	**0.06**	0.50	**0.07**
	0.8	-0.26	**-0.04**	0.44	**0.01**
Hydraulic Conductivity of Streambed Sediments	**1.20**	0.62	**0.84**	1.02	**0.59**
	0.8	-0.56	**-0.34**	0.55	**0.12**
Hydraulic Conductivity of Infiltration Pond Sediments	**1.20**	-0.17	**0.05**	0.42	**-0.01**
	0.8	-0.38	**-0.16**	0.46	**0.03**
Hydraulic Conductivity of Quarry Pond Sediments	**1.20**	-0.22	**0.00**	0.42	**-0.01**
	0.8	-0.22	**0.00**	0.42	**-0.01**
Groundwater Withdrawal Rates	**1.15**	-1.28	**-1.06**	0.92	**0.49**
	0.8	0.11	**0.33**	0.61	**0.18**

Table 3
Water Budget Analysis/Dam In-Place
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

	Steady-State/Dam In-Place			Enhanced Lateral System Operating at 23 mgd			Conventional Lateral System Operating at 17 mgd		
Source/Sink	Inflows to Aquifer	Outflows from Aquifer	Net Flux[1]	Inflows to Aquifer	Outflows from Aquifer	Net Flux	Inflows to Aquifer	Outflows from Aquifer	Net Flux
Wells	0.00	87.97	**-87.97**	0.00	110.97	**-110.97**	0.00	104.98	**-104.98**
Areal Recharge	0.16	0	**0.16**	0.16	0.00	**0.16**	0.16	0.00	**0.16**
Northern General Head Boundary	0.26	0.06	**0.19**	0.26	0.06	**0.19**	0.26	0.06	**0.19**
Southern General Head Boundary	0.03	0.14	**-0.11**	0.03	0.14	**-0.11**	0.03	0.14	**-0.11**
Quarry Ponds	2.71	0.30	**2.41**	2.71	0.30	**2.41**	2.71	0.30	**2.41**
Mirabel Infiltration Ponds	78.15	3.81	**74.34**	78.17	3.81	**74.35**	78.17	3.81	**74.35**
Wohler Infiltration Ponds	1.20	1.00	**0.20**	0.91	0.72	**0.20**	0.92	0.71	**0.20**
Upper River Segment	0.21	2.30	**-2.08**	0.38	2.28	**-1.90**	0.32	2.28	**-1.97**
Middle River Segment	22.62	1.18	**21.44**	45.20	1.21	**43.99**	39.29	1.11	**38.19**
Lower River Segment	3.09	11.72	**-8.64**	3.09	11.71	**-8.62**	3.09	11.71	**-8.62**
Total	108.4	108.5	-0.1	130.9	131.2	-0.3	124.9	125.1	-0.2

Notes:
1 = Positive value indicates flow into aquifer and negative value indicates flow out of aquifer.
All values are in millions of gallons per day (mgd)

Table 4
Water Budget Summary/Dam Lowered
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

	Steady-State/Dam Lowered			Enhanced Lateral System Operating at 12 mgd			Conventional Lateral System Operating at 8.5 mgd		
Source/Sink	Inflows to Aquifer	Outflows from Aquifer	Net Flux[1]	Inflows to Aquifer	Outflows from Aquifer	Net Flux	Inflows to Aquifer	Outflows from Aquifer	Net Flux
Wells	0.00	34.96	**-34.96**	0.00	46.92	**-46.92**	0.00	43.43	**-43.43**
Areal Recharge	0.16	0.00	**0.16**	0.16	0.00	**0.16**	0.16	0.00	**0.16**
Northern General Head Boundary	0.57	0.03	**0.54**	0.57	0.03	**0.54**	0.57	0.03	**0.54**
Southern General Head Boundary	2.31	0.00	**2.31**	2.31	0.00	**2.31**	2.31	0.00	**2.31**
Quarry Ponds	3.72	0.20	**3.52**	3.73	0.20	**3.53**	3.73	0.20	**3.52**
Mirabel Infiltration Ponds	0.58	0.57	**0.01**	0.57	0.57	**0.01**	0.57	0.57	**0.01**
Wohler Infiltration Ponds	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Upper River Segment	0.20	3.38	**-3.18**	0.25	3.35	**-3.10**	0.23	3.36	**-3.14**
Middle River Segment	13.62	0.44	**13.18**	24.95	0.30	**24.65**	21.47	0.31	**21.16**
Lower River Segment	18.21	0.17	**18.04**	18.21	0.17	**18.04**	18.21	0.17	**18.04**
Total	39.4	39.7	-0.4	50.8	51.5	-0.8	47.3	48.1	-0.8

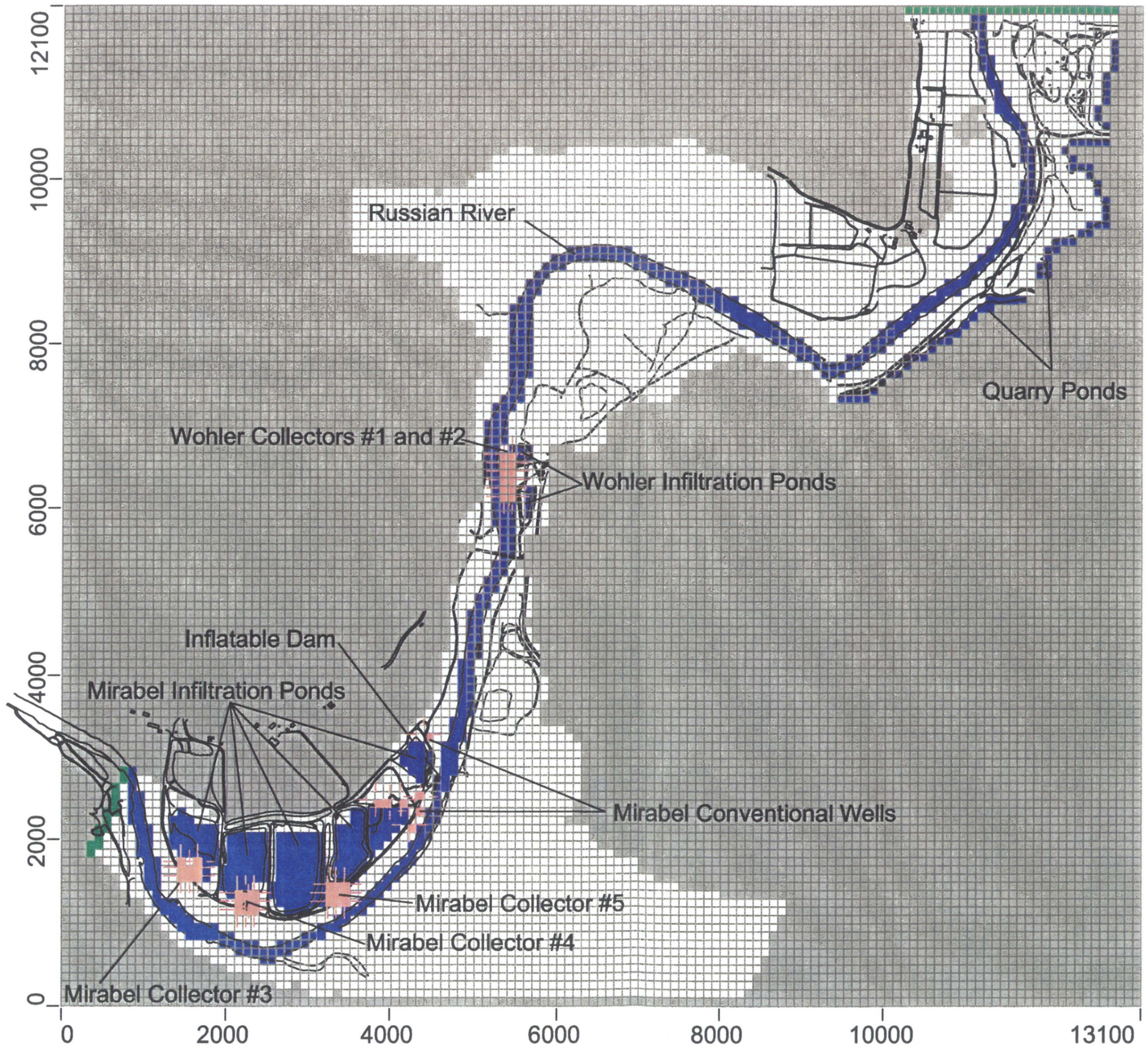
Notes:
1 = Positive value indicates flow into aquifer and negative value indicates flow out of aquifer.
All values are in millions of gallons per day (mgd)

Table 5
Results of Simulations Including
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

	Simulated Steady-State Groundwater Production Rate
Dam In-Place	
Wohler Collector Wells #1 and #2	21 mgd
Mirabel Collector Wells #3, #4, and #5	60 mgd
Mirabel Conventional Wells MPW#1 through MPW #7	7 mgd
Proposed Wohler Collector Well #6 (Conventional Lateral System)	**17 mgd**
Proposed Wohler Collector Well #6 (Enhanced Lateral System)	**23 mgd**
Dam Lowered	
Wohler Collector Wells #1 and #2	13 mgd
Mirabel Collector Wells #3, #4, and #5	19 mgd
Mirabel Conventional Wells MPW#1 through MPW #7	3.0 mgd
Proposed Wohler Collector Well #6 (Conventional Lateral System)	**8.5 mgd**
Proposed Wohler Collector Well #6 (Enhanced Lateral System)	**12 mgd**

PLATES

#190



Explanation

- Inactive (No-Flow) Cell
- Active Cell
- General Head Boundary
- River or Pond Cell
- Cell with Existing Agency Collector or Conventional Well

N

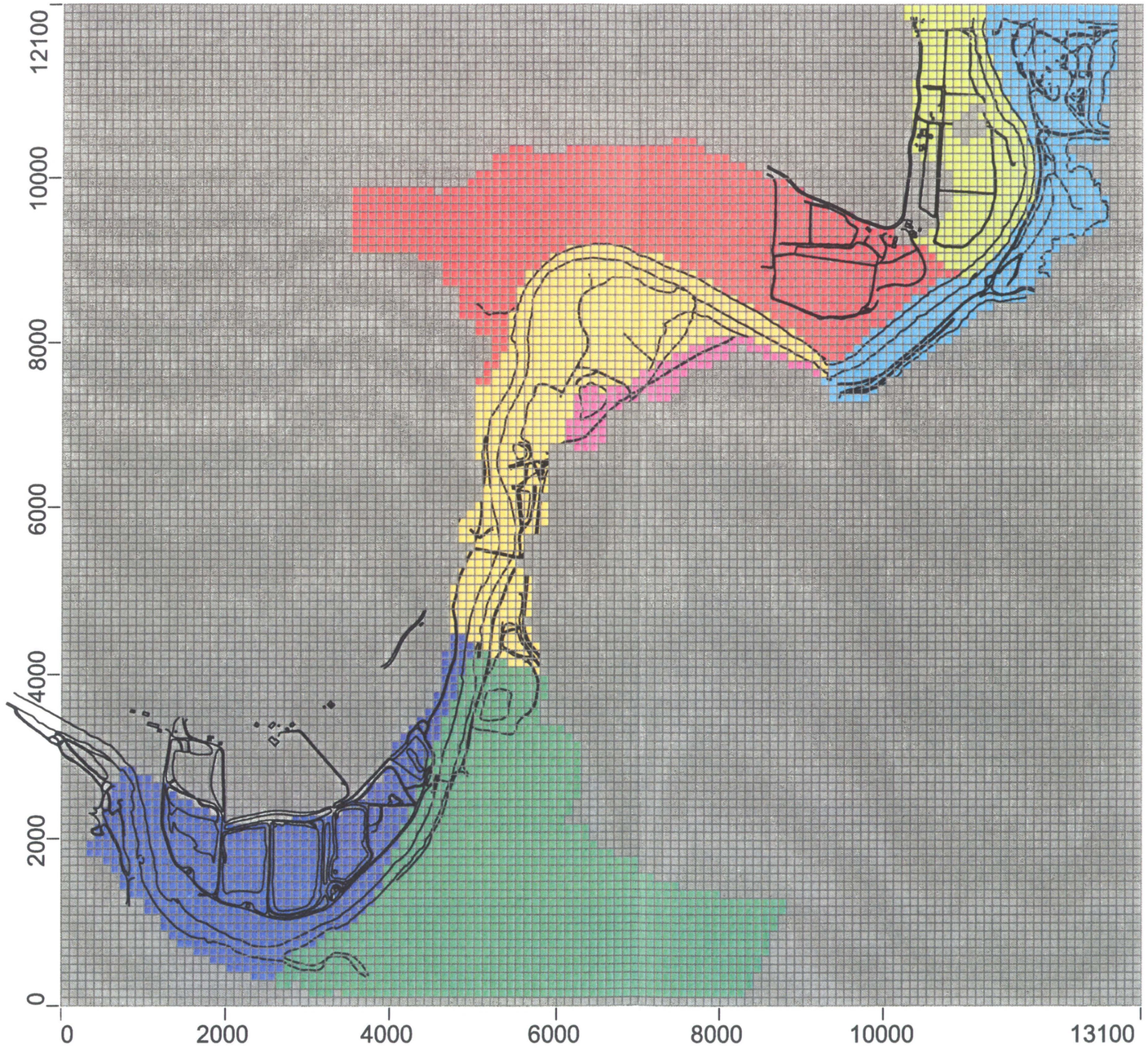
0 1500
APPROXIMATE SCALE IN FEET

PES Environmental, Inc.
Engineering & Environmental Services

Model Grid and Boundary Conditions
Results of Modflow Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

PLATE **1**

647.006.01.001	647_006_plate1		08/00
JOB NUMBER	DRAWING NUMBER	REVIEWED BY	DATE



Explanation

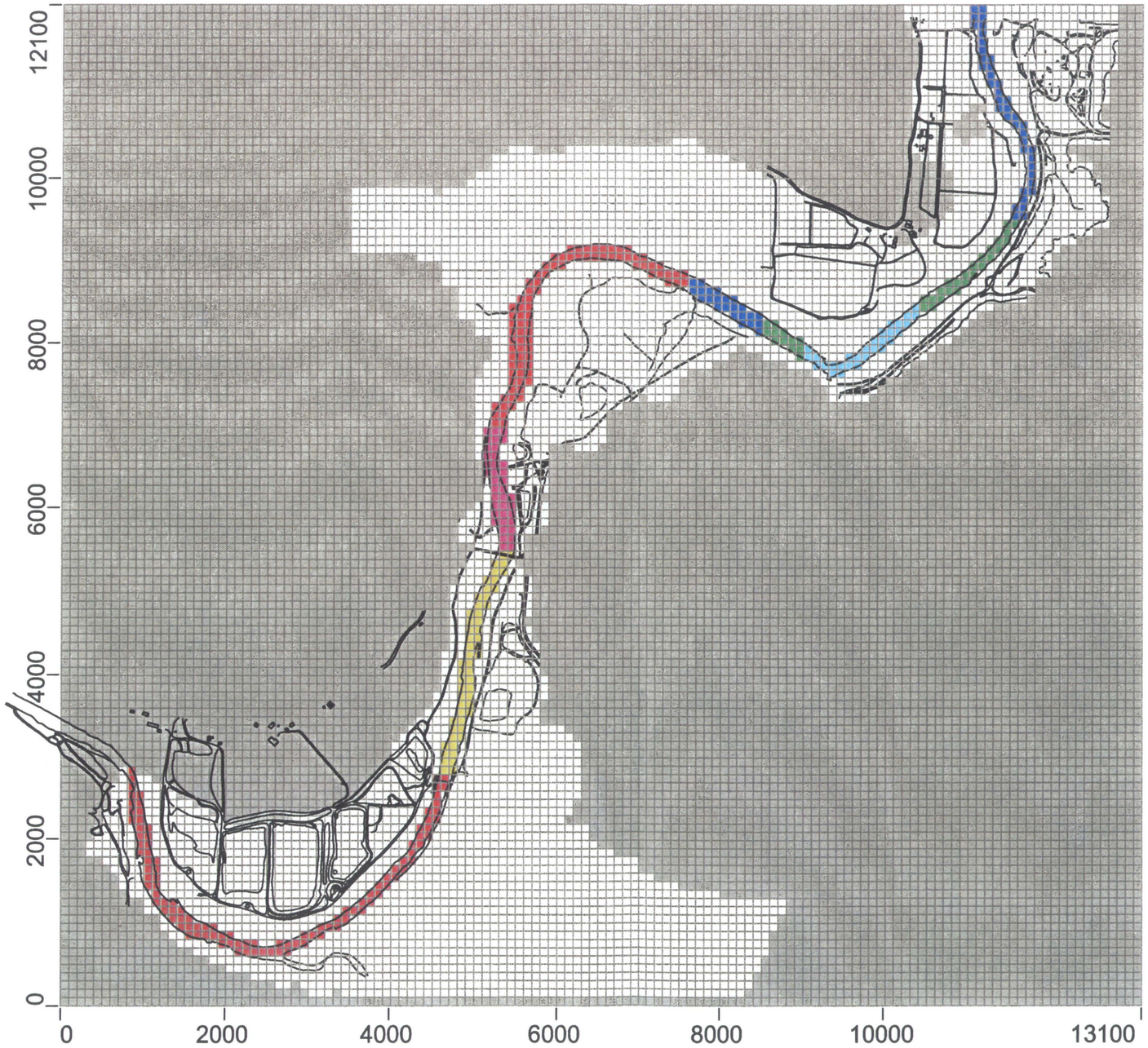
- Inactive (No Flow) Cell
- Horizontal Hydraulic Conductivity = 1,500 feet/day
- Horizontal Hydraulic Conductivity = 1,200 feet/day
- Horizontal Hydraulic Conductivity = 1,300 feet/day
- Horizontal Hydraulic Conductivity = 1,100 feet/day
- Horizontal Hydraulic Conductivity = 1,000 feet/day
- Horizontal Hydraulic Conductivity = 740 feet/day
- Horizontal Hydraulic Conductivity = 10 feet/day

PES Environmental, Inc.
Engineering & Environmental Services

Aquifer Horizontal Hydraulic Conductivity Zones
Results of Modflow Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

PLATE
2

647.006.01.001	647_006_plate2		09/00
JOB NUMBER	DRAWING NUMBER	REVIEWED BY	DATE



Inactive (No-Flow) Cell

Riverbed conductance ranges from 0.5 - 1.0 day $^{-1}$

Riverbed conductance ranges from 1.0 - 2.5 day $^{-1}$

Riverbed conductance ranges from 2.5 - 5.0 day $^{-1}$

Riverbed conductance ranges from 5.0 - 7.5 day $^{-1}$

Riverbed conductance ranges from 7.5 - 10 day $^{-1}$

Riverbed conductance ranges from 10 - 35 day $^{-1}$

Riverbed conductance values are equivalent to the vertical hydraulic conductivity of riverbed sediments divided by the thickness of riverbed sediments.

N

0 1500

APPROXIMATE SCALE IN FEET

PES Environmental, Inc.
Engineering & Environmental Services

Riverbed Conductance Zones
Results of Modflow Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

PLATE **3**

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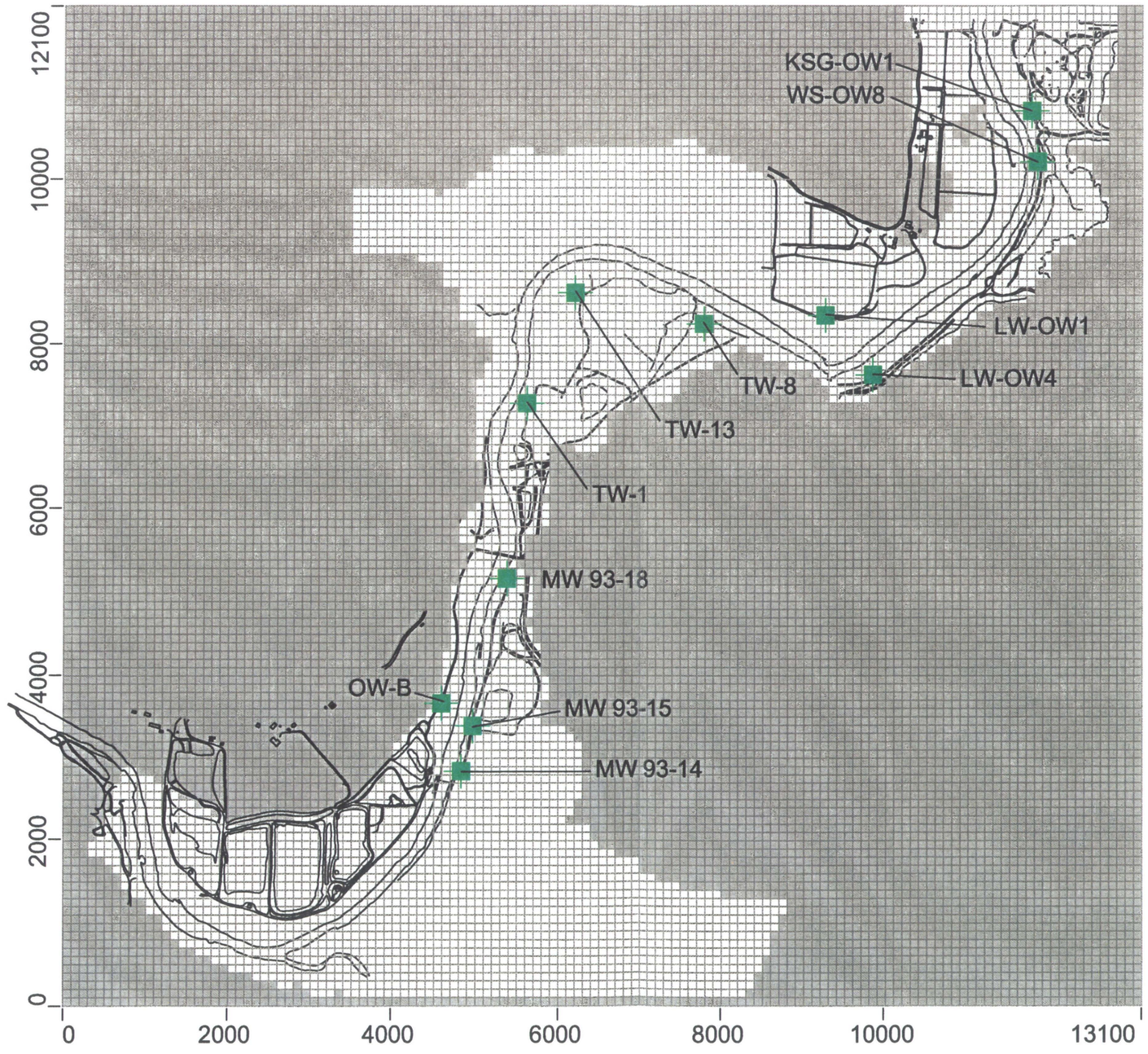

Explanation

Inactive (No-Flow) Cell

Location of Observation Well used during model calibration

N

0 1500

APPROXIMATE SCALE IN FEET

PES Environmental, Inc.
Engineering & Environmental Services

Observation Well Network
Results of Modflow Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

PLATE **4**

647.006.01.001	647_006_plate4		09/00
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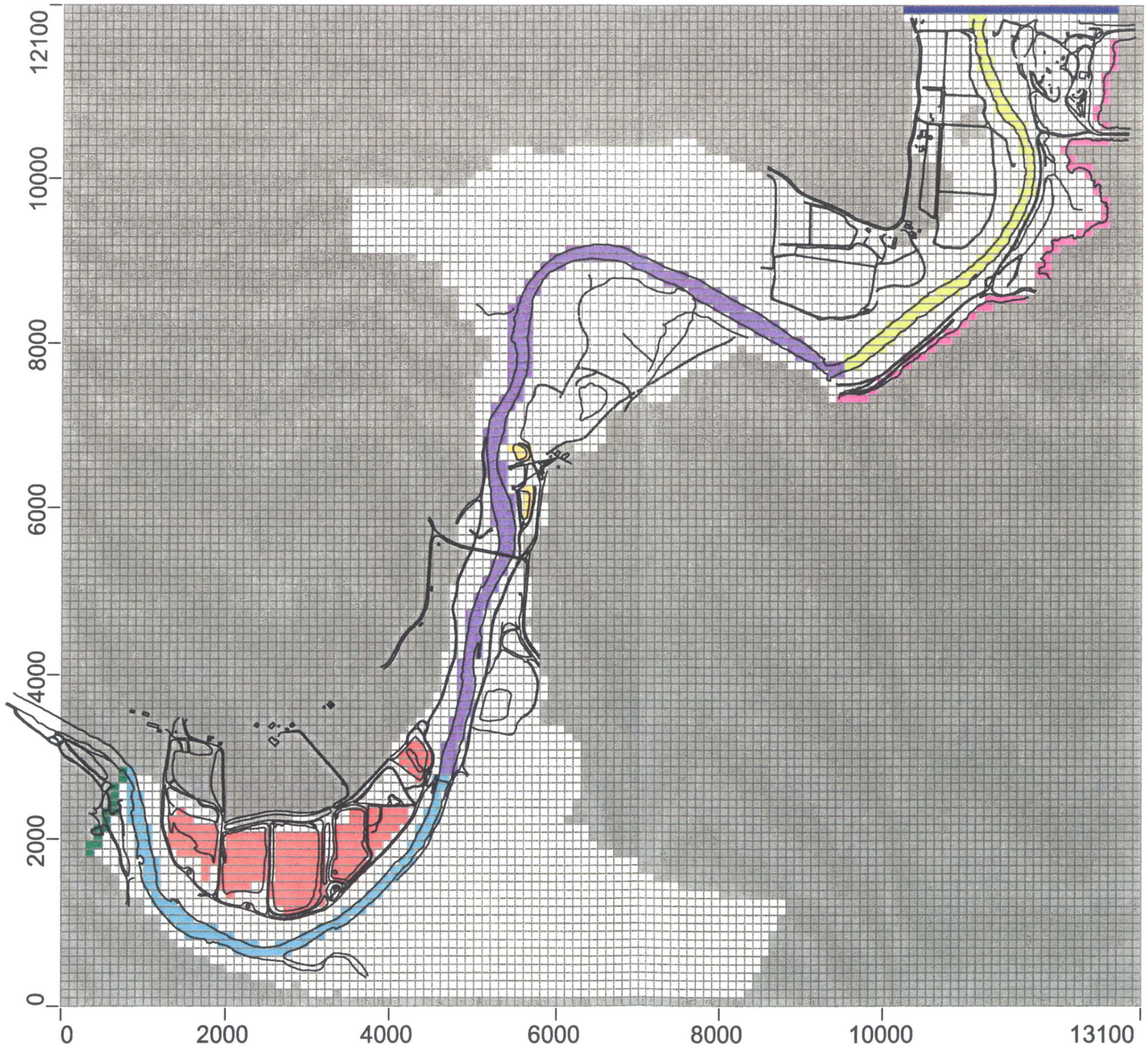

Explanation

- Inactive (No-Flow) Cell
- Northern General Head Boundary
- Southern General Head Boundary
- Quarry Ponds
- Mirabel Infiltration Ponds
- Wohler Infiltration Ponds
- Upper River Segment
- Middle River Segment
- Lower River Segment

N

0 1500
APPROXIMATE SCALE IN FEET

PES Environmental, Inc.
Engineering & Environmental Services

Water Budget Zones
Results of Modflow Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

PLATE
5

647.006.01.001	647_006_plate5		09/00
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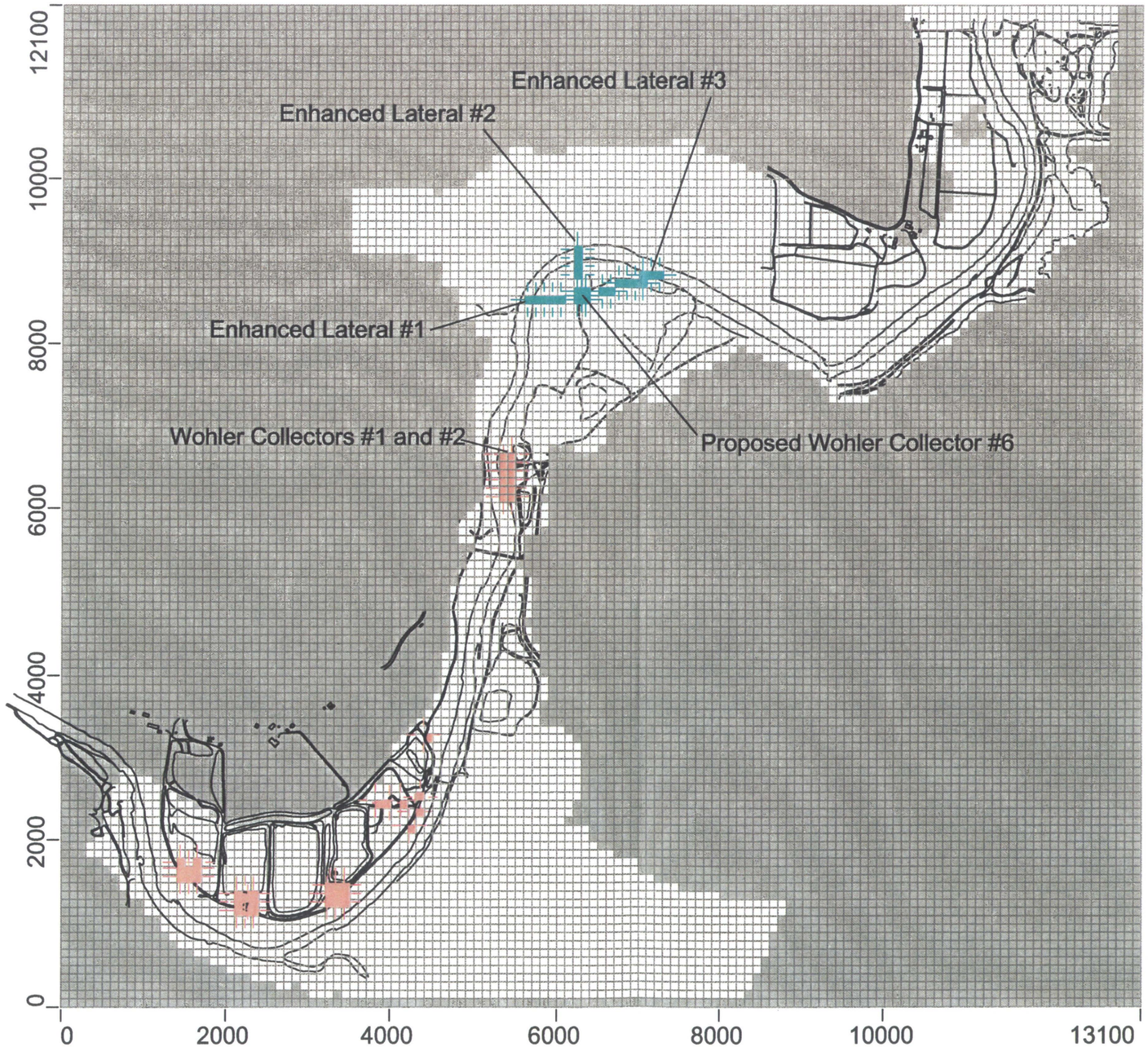


Explanation

Inactive (No-Flow) Cell

Cell with Existing Agency Collector or Conventional Well

Cell with Proposed Agency Collector Well

N

0 1500

APPROXIMATE SCALE IN FEET

PES Environmental, Inc.
Engineering & Environmental Services

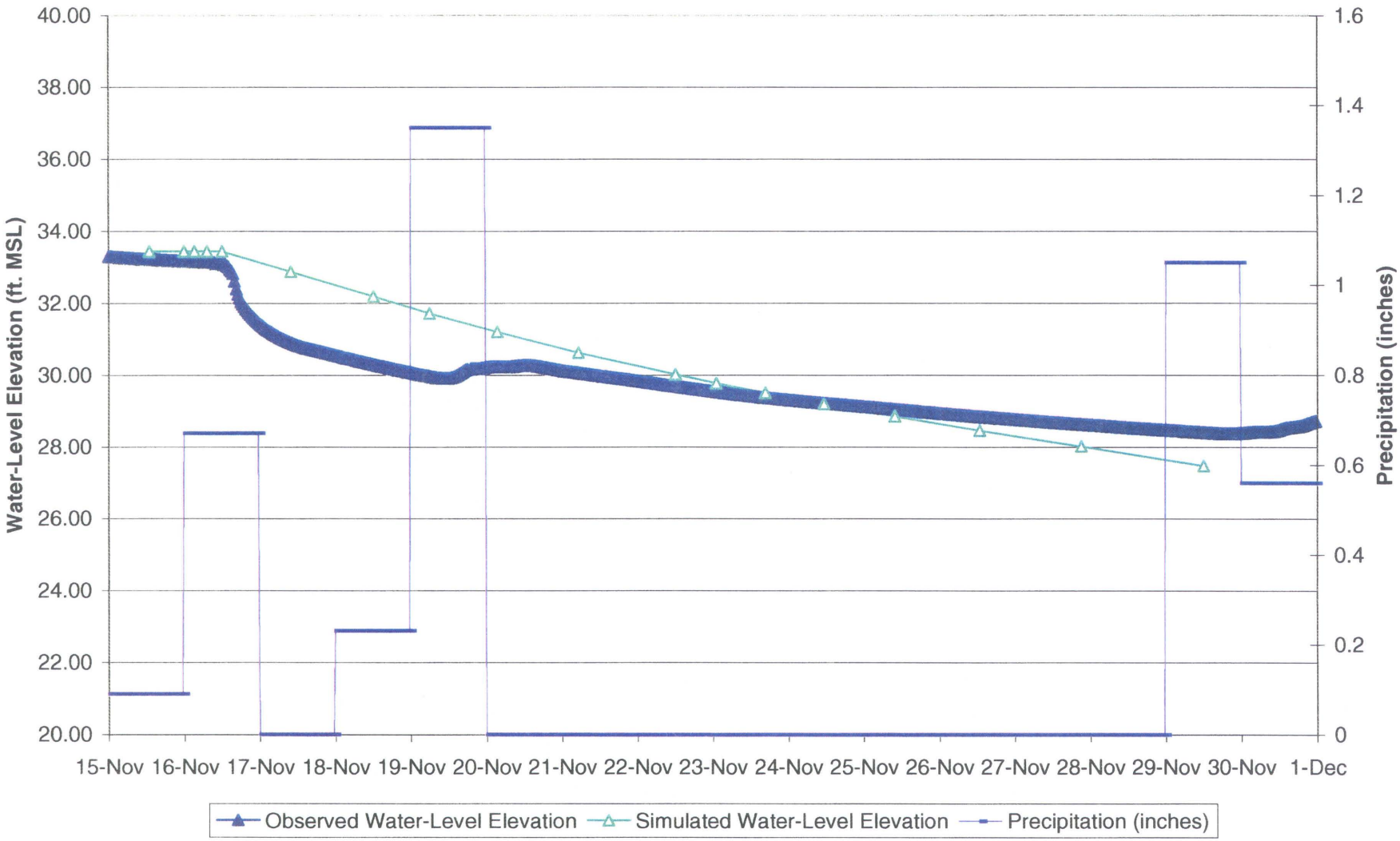
Location of Proposed Wohler Collector #6
Results of Modflow Simulations
Proposed Wohler Collector Well #6
Water Supply and Transmission System Project
Sonoma County Water Agency

PLATE **6**

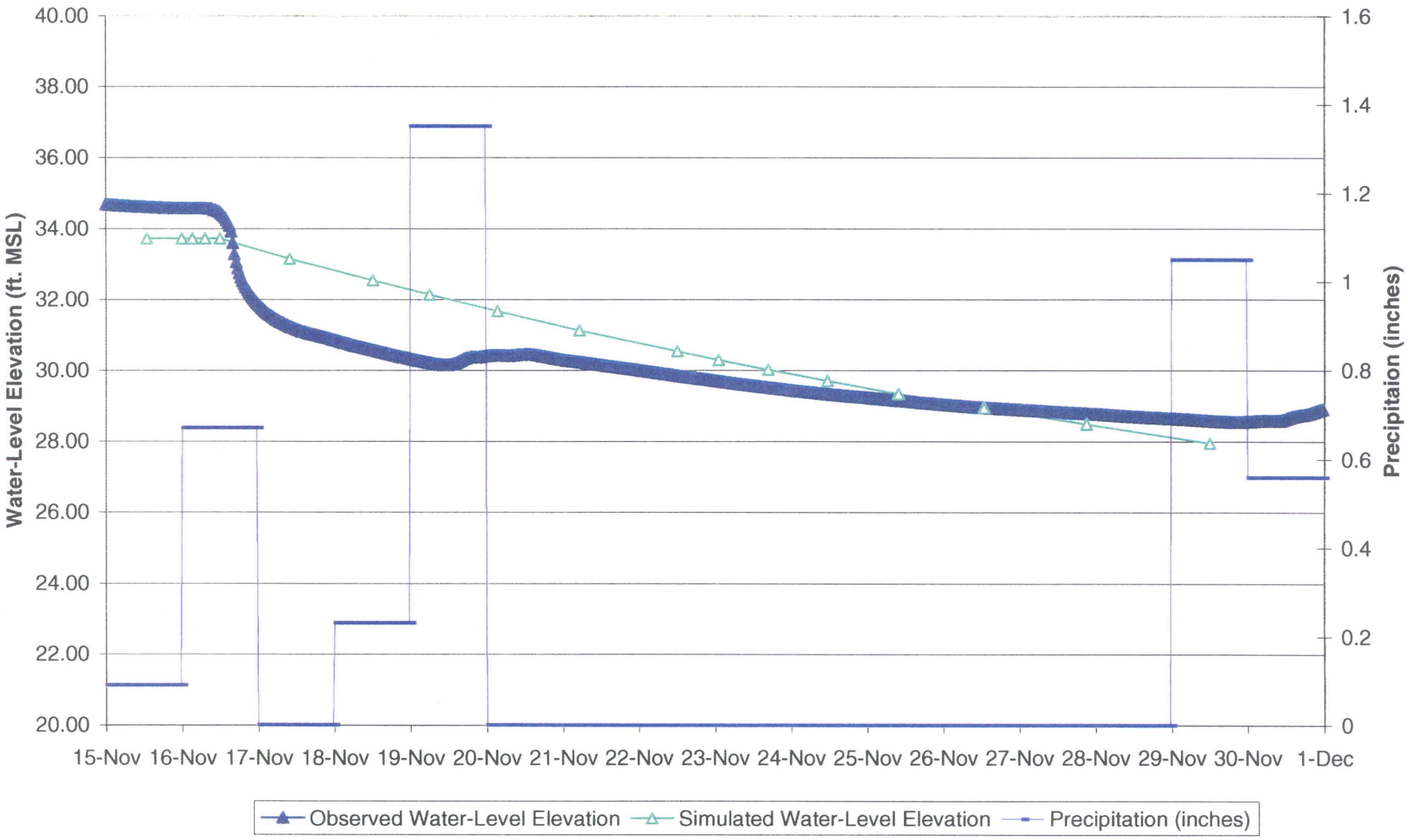
647.006.01.001	647_006_plate6		08/00
JOB NUMBER	DRAWING NUMBER	REVIEWED BY	DATE

APPENDIX A

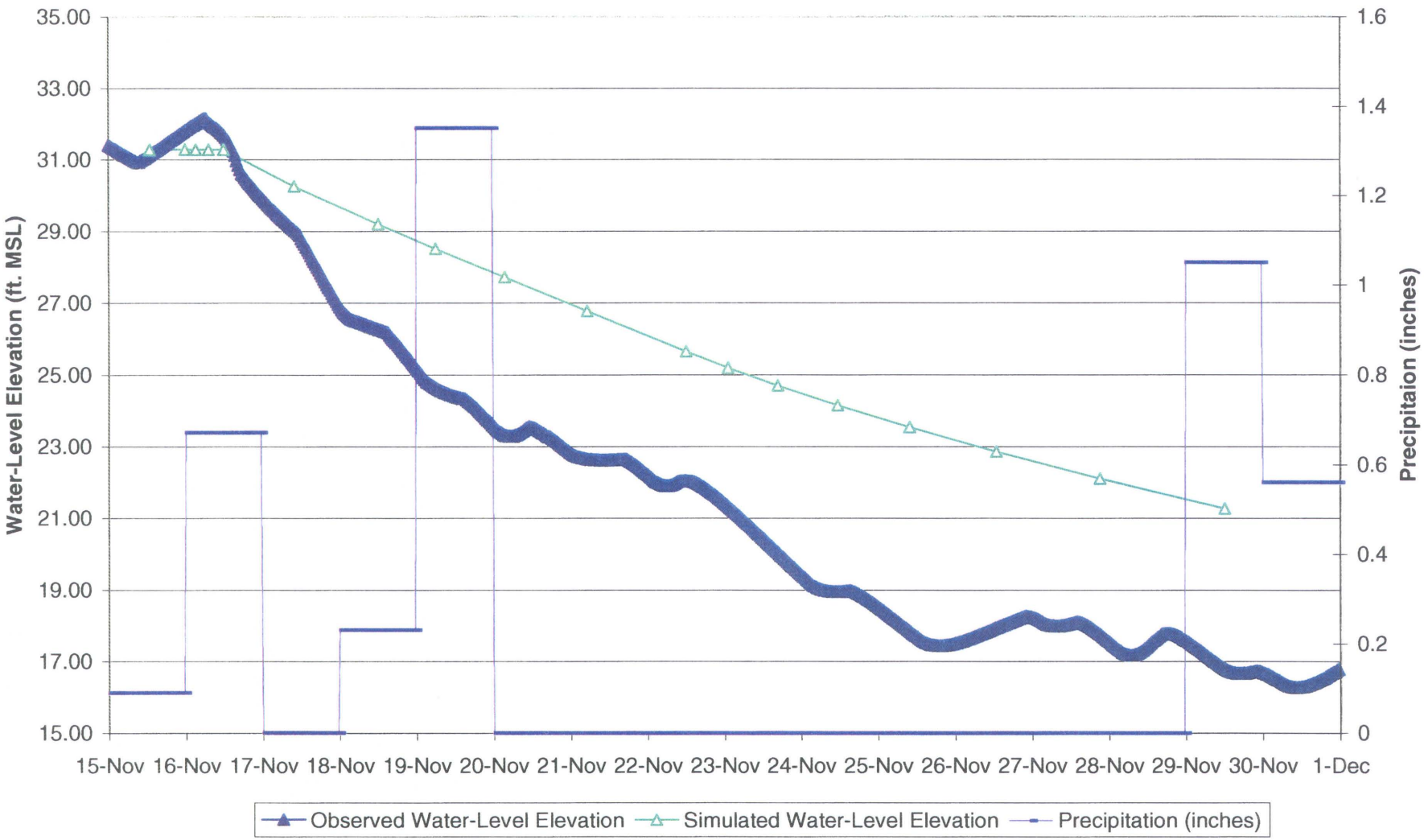
Well MW-93-14: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



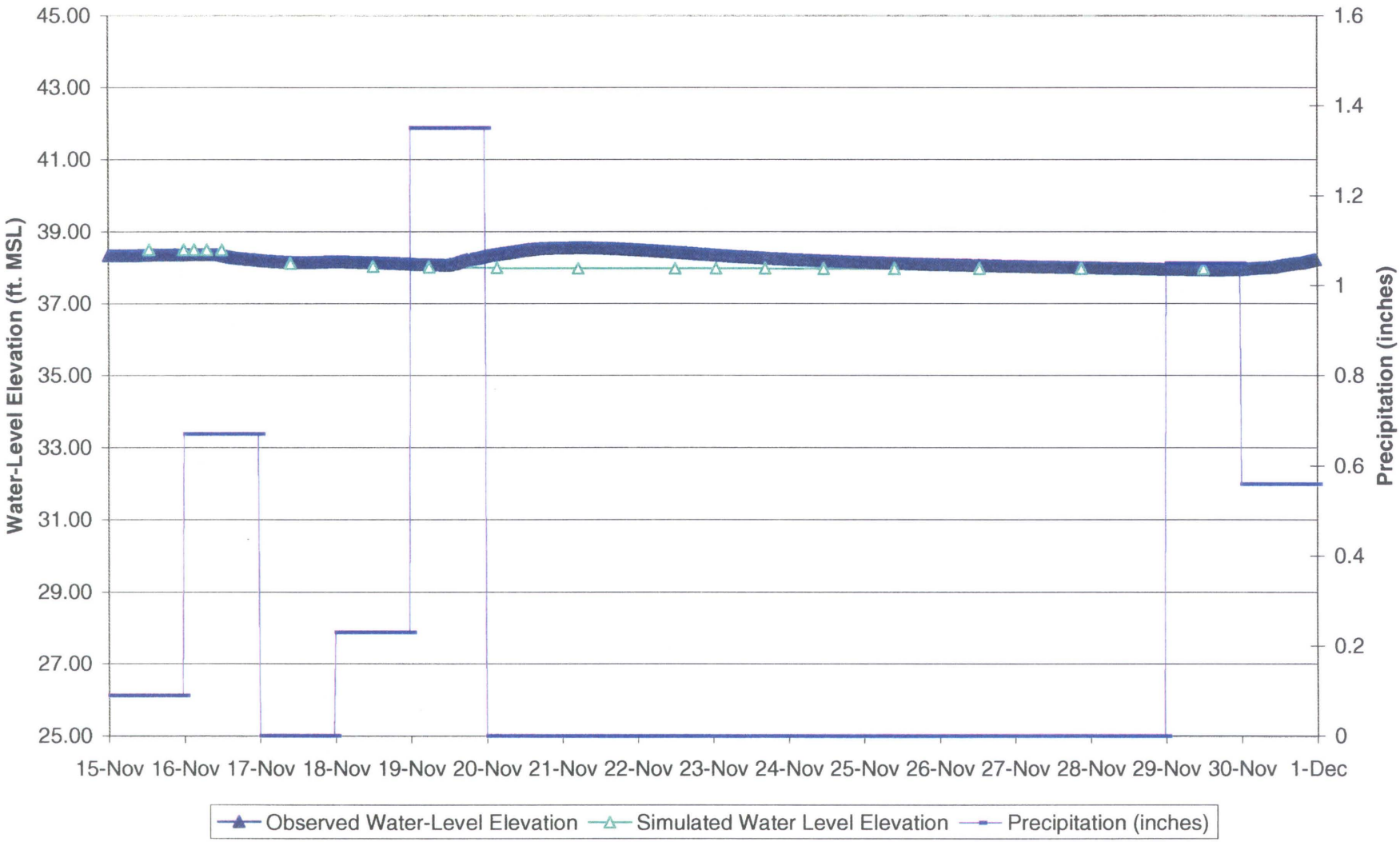
Well MW-93-15: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



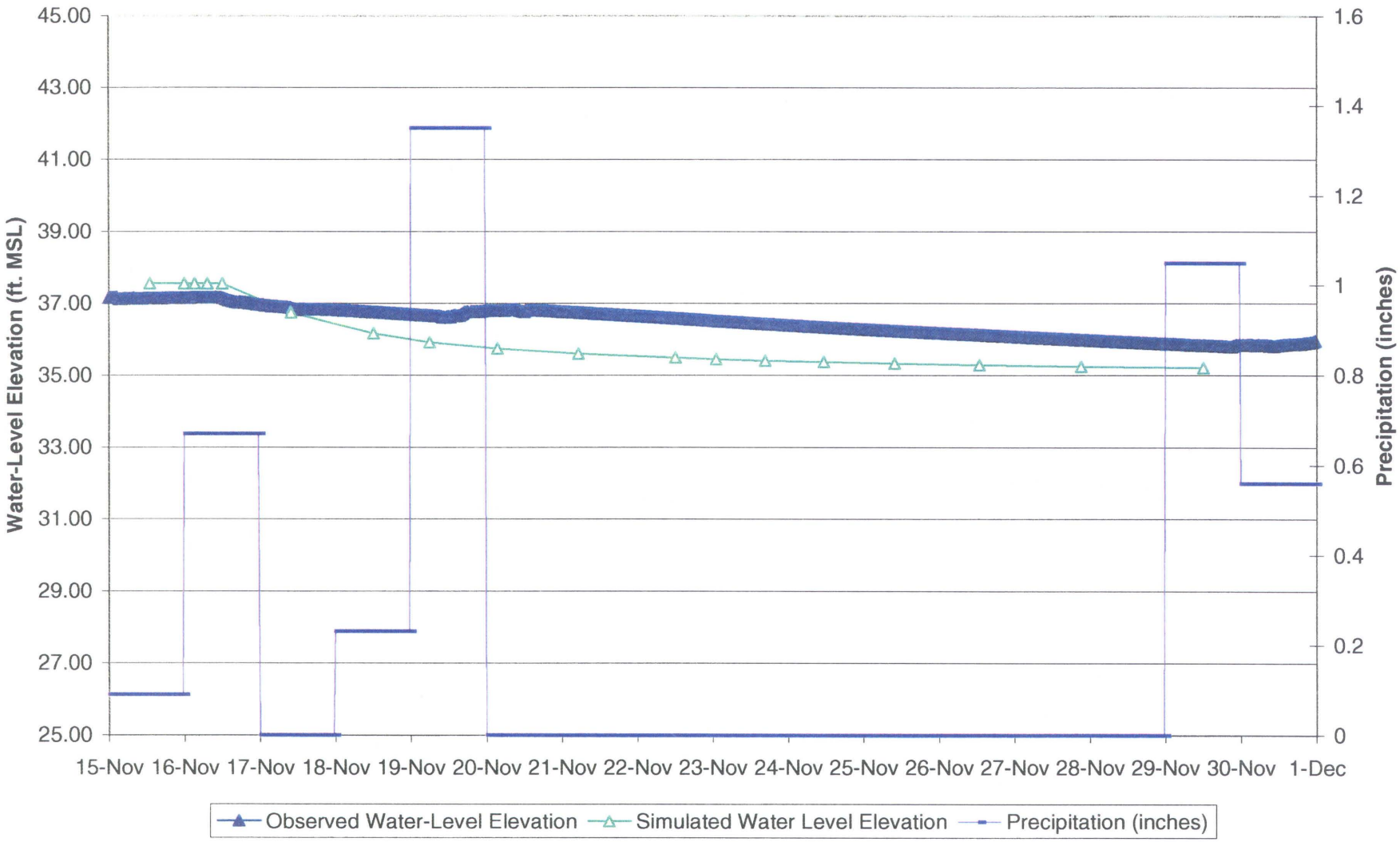
Well MW-93-18: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



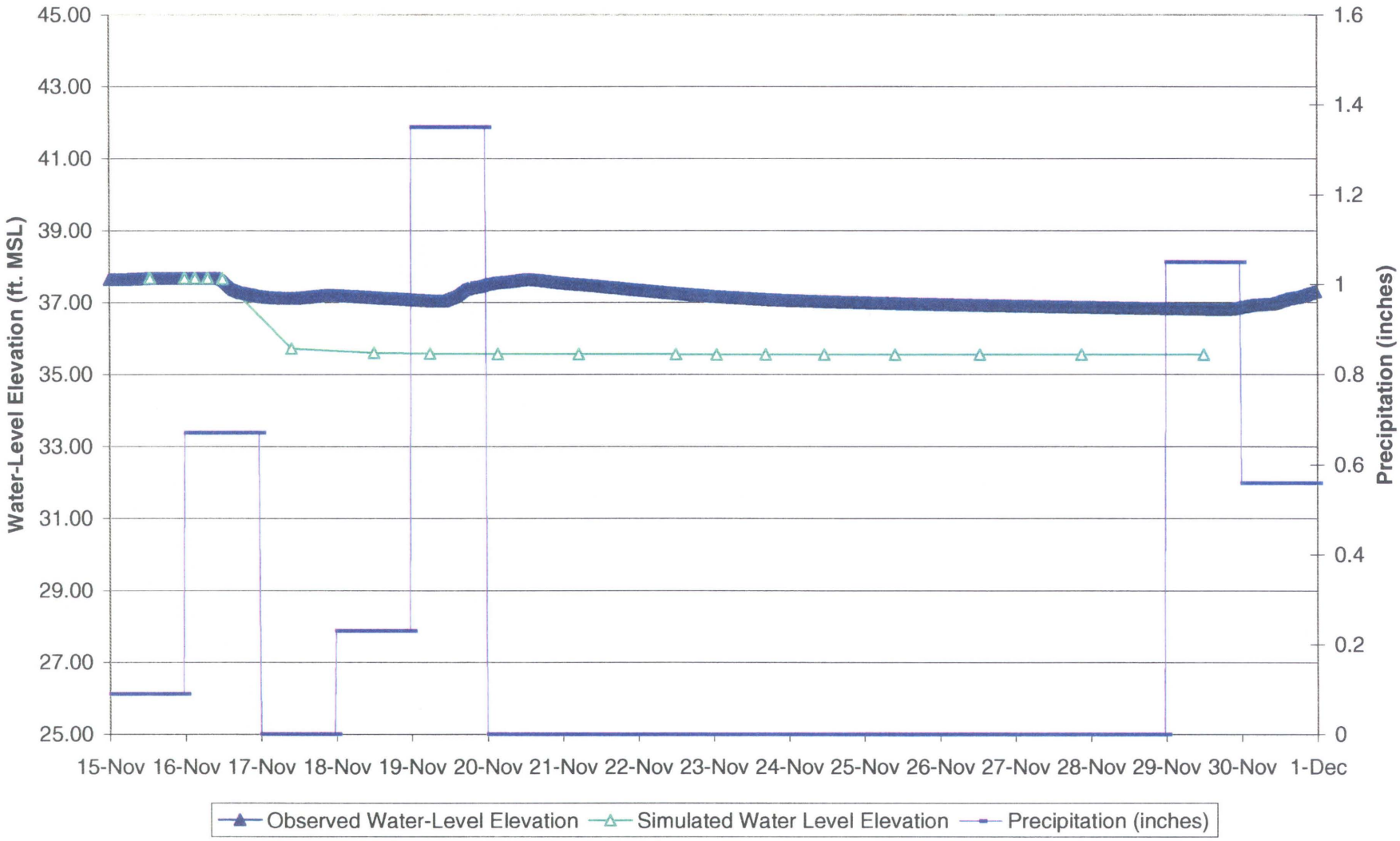
Well KSG-OW-1: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



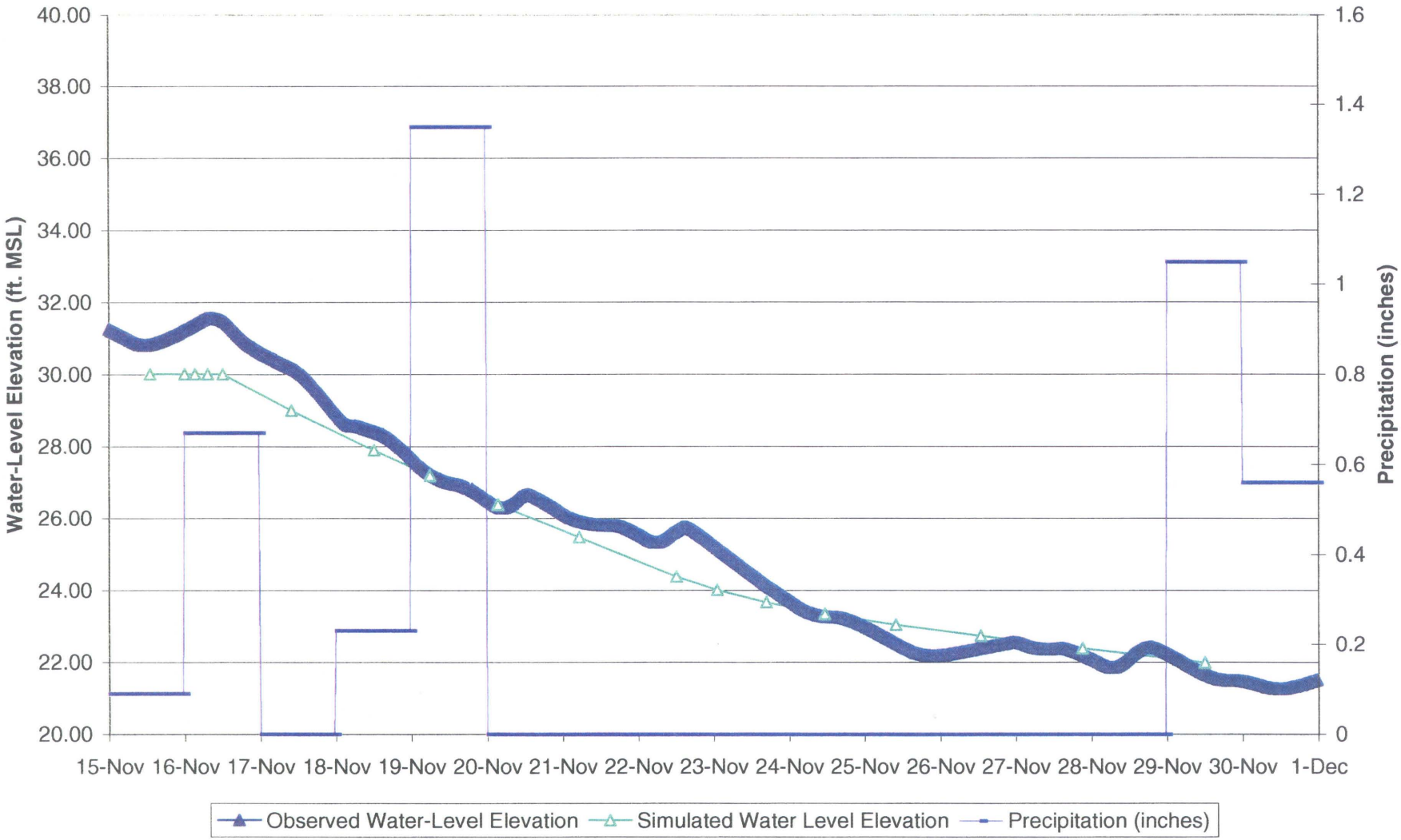
Well LW-OW-1: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



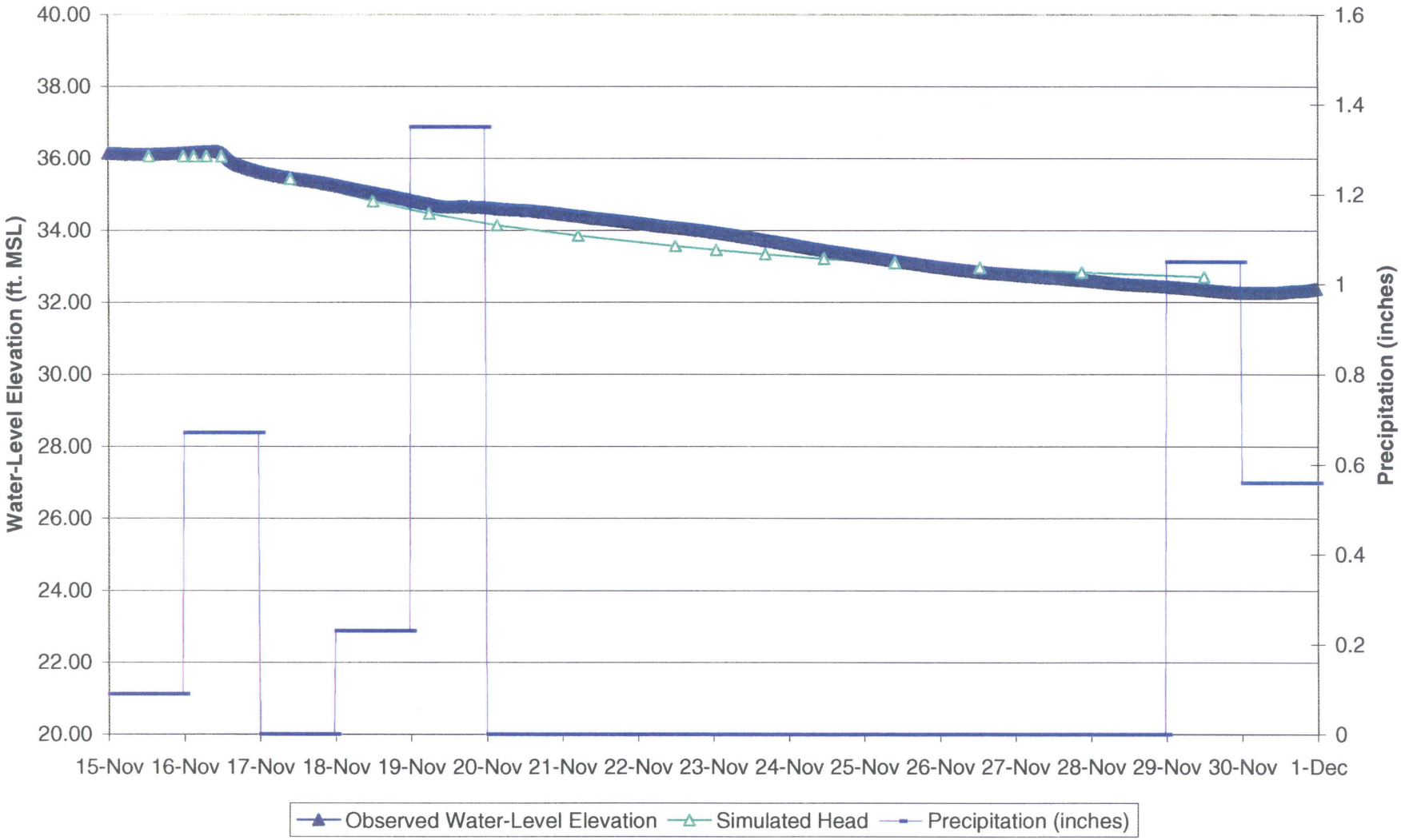
Well LW-OW-4: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



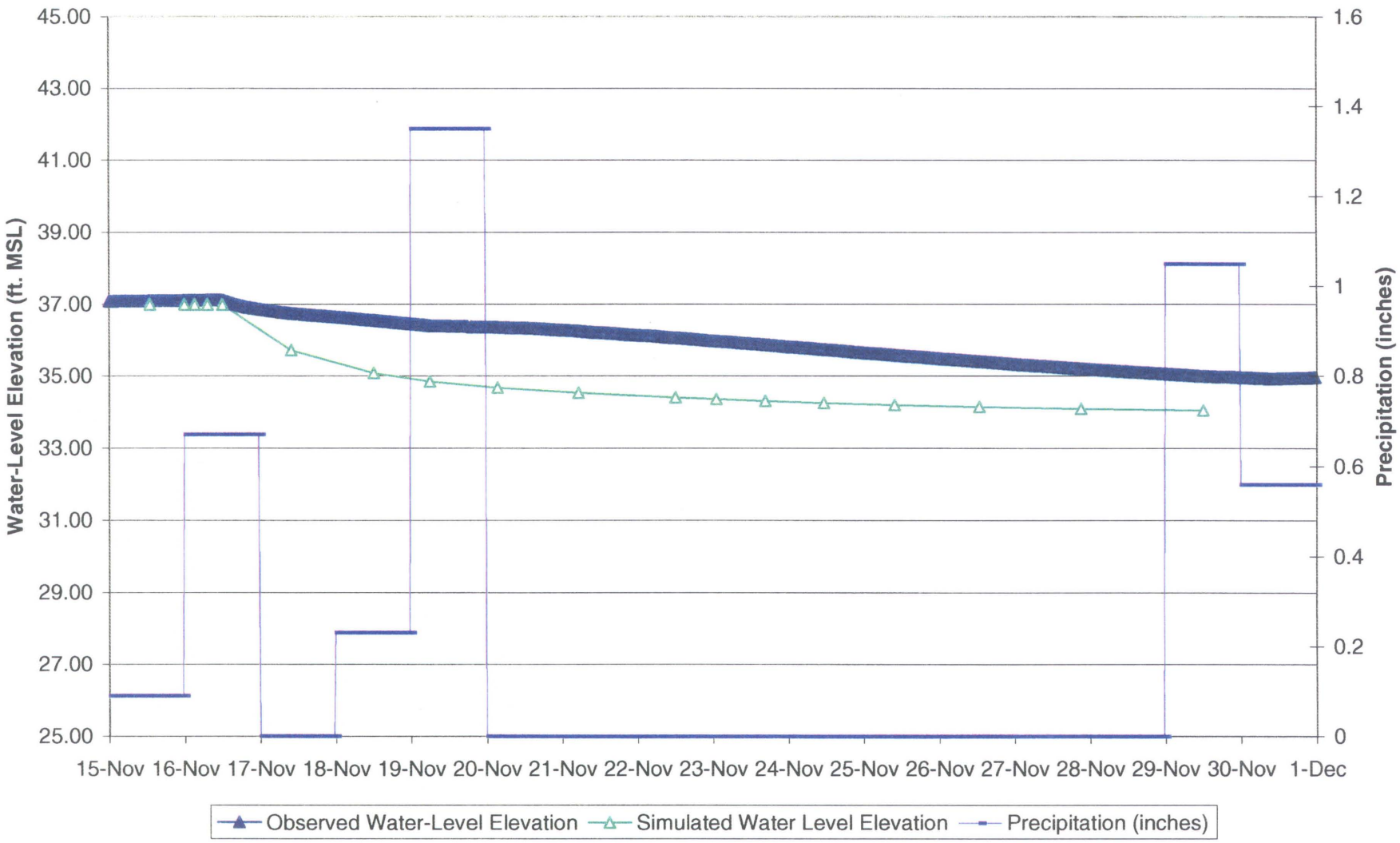
Well TW-1: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



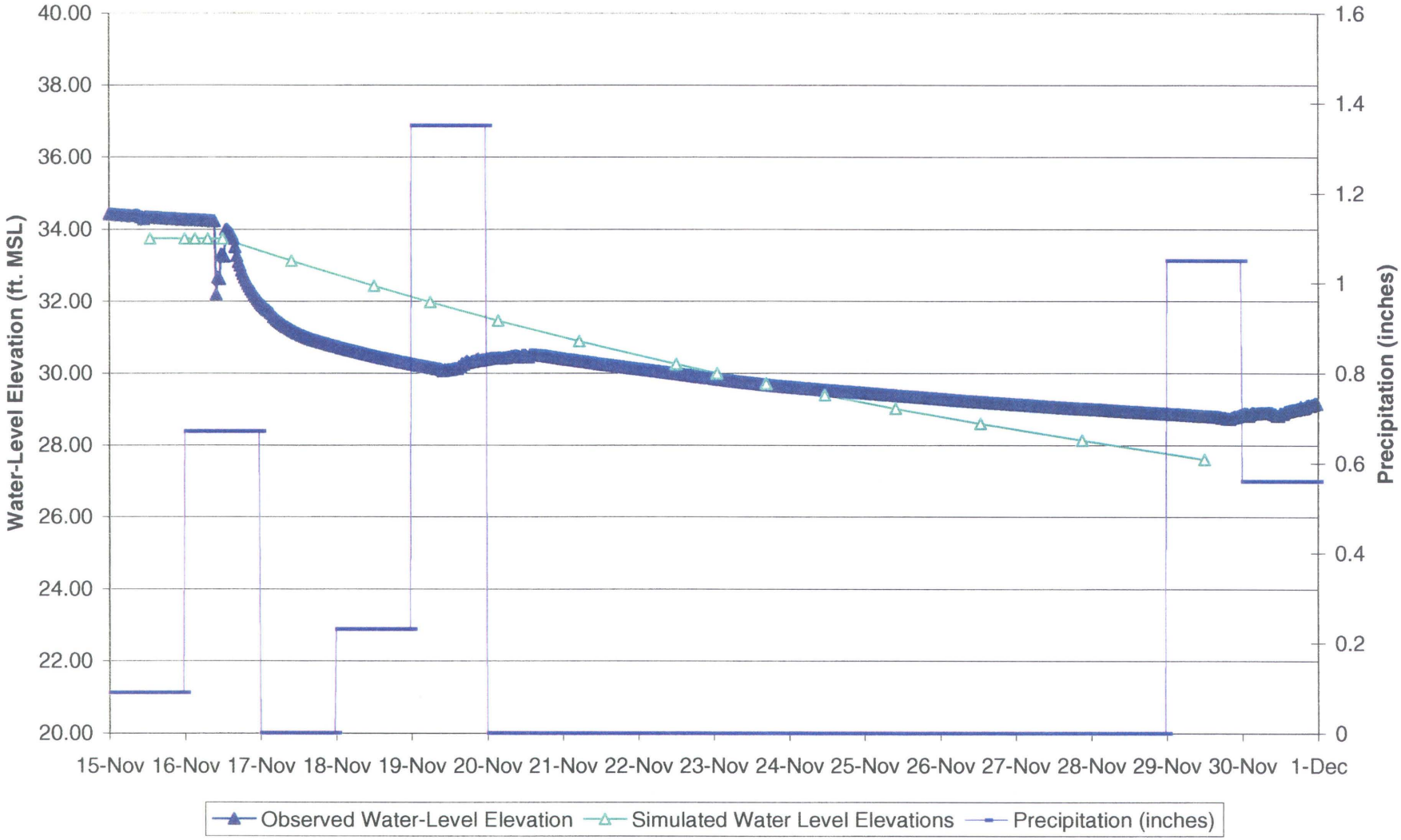
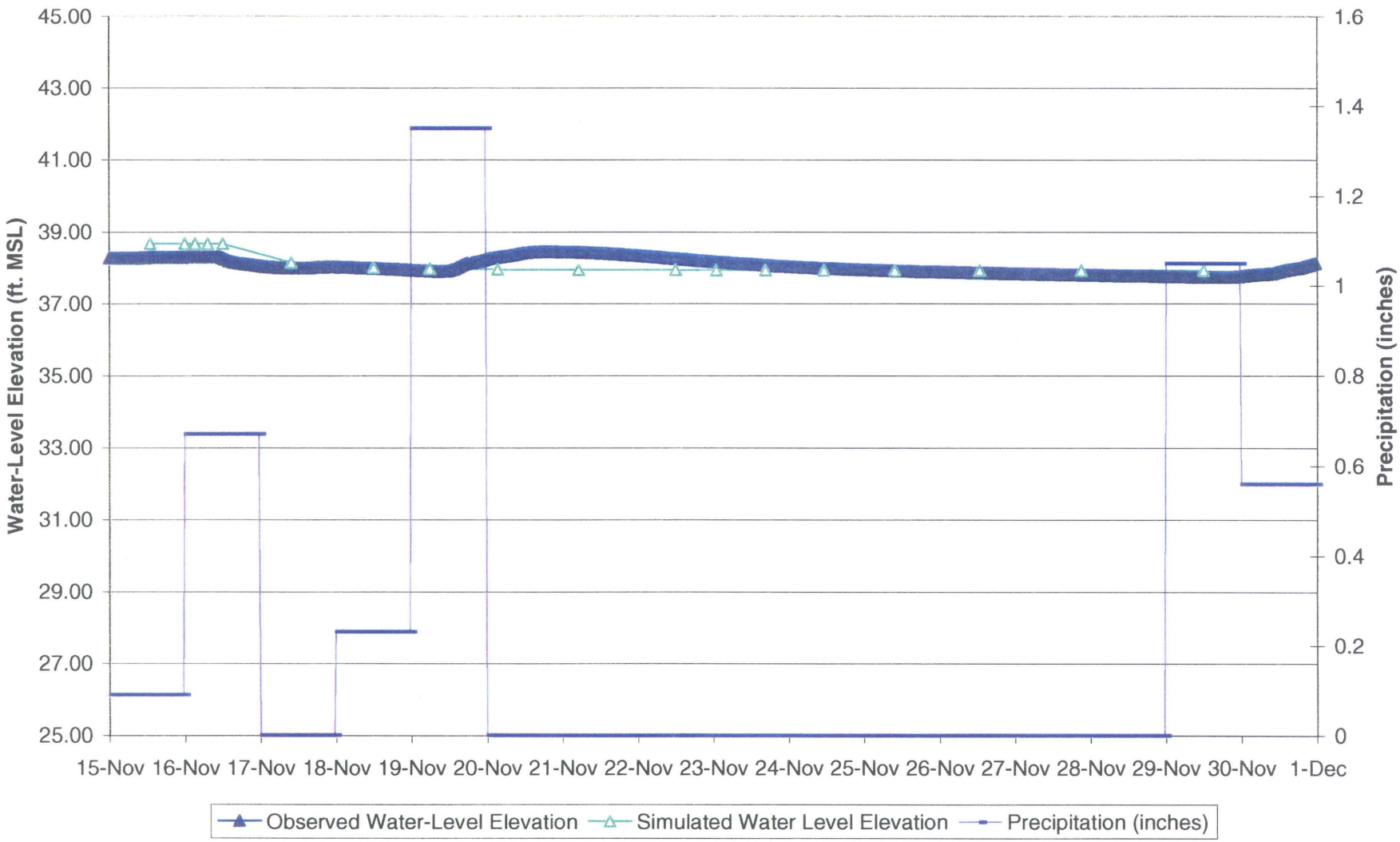
Well TW-13: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



Well TW-8: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



Well OW-B: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)



Well WS-OW-8: Simulated and Observed Water-Level Elevation & Recorded Precipitation (November 15-29, 1999)