APPENDIX D

MODEL DESCRIPTIONS

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D.1 INTRODUCTION

Potential impacts of the 10-year proposed project on groundwater levels and quality and surface water quality can be estimated using a modeling approach. Three models were developed using available data and used interactively to estimate the effects of the 10-year proposed project. The models are a groundwater flow model, groundwater quality model, and a surface water mixing model. Each of these models is discussed in detail below. The application of the models is summarized on the flow chart shown on Figure D-1. As shown on this chart, the modeling process starts with the development of a proposed Mendota Pool Group (MPG) pumping program for the first year of the project in which transfer pumping would occur. The well locations and monthly pumping rates for each well included in the pumping program are input into the groundwater flow models along with the estimated pumpage for each non-MPG well in the study area. The flow model calculates monthly drawdowns at each well in the simulation. This includes all MPG and non-MPG wells in the study area that are pumping during the simulation period. The simulated drawdowns are input into the groundwater quality model to determine the hydraulic gradient for flow of saline groundwater toward MPG and other wells near the Fresno Slough. The groundwater quality model calculates changes in total dissolved solids (TDS) at these wells on a monthly basis. The TDS calculated for each MPG well at the end of December is input into the surface water mixing model for the southern Fresno Slough. The mixing model calculates the monthly TDS at the Mendota Wildlife Area (MWA). This predicted TDS is compared against water quality targets for the MWA provided by the Department of Fish and Game. If the water quality targets are met, the pumping program is considered acceptable, and the process is repeated for the next year of the project. If water quality targets are not met, the pumping program is modified and the process repeated. This method was used to develop MPG pumping programs for the 10-year project that were predicted to meet surface water quality criteria.

The 10-year pumping program includes two wet years during which there would be no MPG transfer pumping, although MPG pumping for adjacent use would continue. Year 1 and Year 6 were simulated as wet years. The other eight years were simulated as normal years (maximum of 31,600 acre-feet of transfer pumpage). Transfer pumping greater than 31,600 acre-feet, as would be allowed in a dry year, was not simulated because the results of the surface water mixing model suggest that this level of pumping would not be possible without exceeding surface water quality criteria. This could change in the future if the actual salinity of the groundwater or the Delta-Mendota Canal (DMC) inflow are better than the assumptions used in the model. MPG pumping for adjacent use was assumed to be constant (14,000 acre-feet/year) during each of the ten years.

The proposed pumping program for Year 2 of the project, the first simulated normal year, is summarized on Table D-1. This table shows the capacity (pumping rate) and predicted TDS concentration for each MPG well at the beginning of the year. It also shows whether each well would be pumped during a given month and whether the pumpage would be used for transfer or to irrigate adjacent lands. Well use is indicated with T, A, and T/A for transfer, adjacent, and a combination of the two, respectively. A significant number of MPG wells (italicized) are not scheduled to pump due to high salinity or other factors. These wells were not simulated with the groundwater quality model. Similarly, deep wells east of the Fresno Slough are not included in the groundwater quality simulations because no water quality degradation has been observed at these wells. This includes MPG wells owned by Farmers Water District (FWD), Baker Farming, and Panoche Creek Ranch. Note that Table D-1 does not show the non-MPG wells that are simulated with the groundwater flow and quality models.

D.2 GROUNDWATER FLOW MODELS

Analytical groundwater flow models are used to estimate drawdowns caused by pumping in the Mendota area, including MPG transfer pumping. The model results are used to predict water level and subsidence impacts from proposed MPG pumping programs and to calculate the amount of compensation to be paid by the MPG to other well owners in the area for increased pumping costs. The models are also used to calculate drawdowns for the groundwater quality model discussed below.

The groundwater flow models simulate the monthly drawdown caused by pumping of all known agricultural and other large capacity wells within the study area, delineated by a 6-mile radius from the center of the MPG wells in FWD. Separate models were developed for the shallow aquifer above the A-clay and the deep aquifer below the A-clay. For the proposed project, the shallow zone model simulates pumpage from 52 MPG wells. No shallow non-MPG production wells are known to exist in the Mendota area. The deep zone model simulates pumpage from 16 MPG wells and 240 non-MPG wells.

The groundwater flow models that have been used for drawdown simulations since 2000 are based on the Hantush-Jacob (1955) equation, which calculates drawdown in a semi-confined (leaky) aquifer. The models are partially based on a computer program written by Walton (1985), which allows the Hantush-Jacob equation to be used to simulate drawdowns due to pumping of multiple wells. The models compute the drawdown for each pumping well using this equation and use the principle of superposition to calculate a total drawdown for all wells at a specified time. These models have been used to simulate impacts of previous MPG transfer pumping programs (2000-2002) and have been found to be capable of predicting drawdowns with sufficient accuracy.

Model inputs include aquifer transmissivity, storativity, and leakage factor. The leakage factor (B) is a function of the transmissivity (T), the aquitard thickness (b'), and the vertical hydraulic conductivity of the aquitard (K'):

$$B = \sqrt{\frac{Tb'}{K'}} \qquad (1)$$

The shallow zone model was calibrated against 1999 and 2000 water level data for shallow wells in the Mendota area. It uses a transmissivity of 220,000 gallons per day per foot (gpd/ft), a storage coefficient of 0.10, and a leakage factor of 25,000 feet (see Table D-2). The amount of vertical leakage simulated by the model is inversely proportional to the leakage factor. The relatively large leakage factor of 25,000 feet minimizes the amount of leakage as compared to the deep zone model because there are no overlying saturated layers to provide leakage to the shallow zone. For the shallow zone model, the leakage factor was used primarily to simulate recharge to the shallow, unconfined aquifer resulting from seepage from surface water bodies and deep percolation of applied irrigation water and precipitation. The calibration of the shallow zone model is discussed in depth in the 2000 annual report (*Mendota Pool Group Pumping and Monitoring Program: 2000 Annual Report* [LSCE and KDSA, 2001].

The deep zone model uses different parameters in the western and eastern portions of the study area due to greater aquifer confinement in the eastern area. The Fresno Slough and the San Joaquin River north of Mendota Dam are generally considered to define the dividing line between the western and eastern areas. The model used the same transmissivity (120,000 gpd/ft) for all areas. The model of the western area has a storage coefficient of 0.02 and leakage factors of 2,000 to 7,000 feet. The model of the eastern area uses a smaller storage coefficient (0.002), and larger leakage factors (5,000-10,500 feet). The model was calibrated against water level data between January 2000 and January 2002 for 38 deep wells in the MPG monitoring program. The calibration of the deep zone model is discussed in the 2001 annual report (LSCE and KDSA, 2002).

D.3 GROUNDWATER QUALITY MODELS

D.3.1 Conceptual Framework

Pumping is anticipated to increase groundwater quality degradation rates in the vicinity of the Mendota Pool. The magnitude of this change must be estimated to assess the potential impacts of the proposed project over the 10-year period. Salinity (as TDS) was used as an indicator of water quality because it is conservative, is readily measured, and sufficient data are available to conduct an analysis. The more limited data available for arsenic, boron, molybdenum, and selenium in groundwater preclude their use as indicators. The groundwater quality models calculate salinity changes measured as TDS concentrations in both shallow and deep wells above the Corcoran Clay near the Fresno Slough. They were developed to predict changes in groundwater quality that would occur with or without the 10-year MPG proposed project. The purpose of the models is to simulate long-term trends in salinity. No attempt was made to simulate the large seasonal fluctuations or other short-term TDS changes observed at some wells.

The conceptual framework of the models is primarily based upon two processes controlling water quality in the wells under investigation: (1) the horizontal flow of naturally occurring higher salinity groundwater from the west towards the Slough, and (2) seepage of better quality surface water from the Slough to the shallow zone or from the shallow to the deep zone. The former is induced by the regional hydraulic gradient, roughly to the east and northeast, and is accelerated by pumping in the Mendota area conducted by the MPG and other entities. The movement of higher salinity groundwater towards the Fresno Slough causes water quality degradation observed in a number of wells west of the Slough, and to a smaller degree in the shallow Coelho West wells just east of the Slough near Whites Bridge. The geographical distribution of salinity in the shallow and deep zones in 2001 is shown on EC contour maps (Figures 3-11 and 3-12, respectively) of the 2001 Annual Report (LSCE and KDSA, 2002). It appears from these contour maps that poor quality water is encroaching upon the Fresno Slough in the form of a wide saline front following the direction of the regional hydraulic gradient; i.e., the direction of the concentration gradients generally coincide with the regional water level gradients.

The models calculate the change in TDS in wells based on existing concentration gradients (estimated from the EC contour maps) and the differential changes of hydraulic head along the direction of concentration gradient. The other major process simulated with the models is the seepage of surface water from the Slough, which counteracts water quality degradation due to movement of the saline front (primarily in the shallow zone). As discussed in Section 3.4.2.3 and Woodward-Clyde Consultants (1994), surface water percolation from the Slough has been independent of the amount of pumpage since at least the late 1980s due to the presence of an unsaturated zone beneath the Slough.

Some shallow wells at the northern end of the Slough (Fordel M-2, M-3, and M-4 and Terra Linda TL-4C) appear to be impacted by wastewater from the City of Mendota sewage treatment ponds and Fresno County waste disposal site. In addition, three of the five Coelho West wells (CW-3, CW-4, and CW-5) are apparently impacted by high salinity groundwater originating from wastewater ponds and wastewater-irrigated pasture on the Spreckels Sugar Co. property. These additional sources of salinity are accounted for in the water quality model for the shallow zone based on the assumption that their impact and that of the saline front are additive. The discussion of the groundwater quality model provided below includes the following sections: 1) Derivation of Equations, 2) Hydraulic Gradients, 3) Concentration Gradients, 4) Model Calibration, and 5) 10-Year Simulation.

D.3.2 Derivation of Equations

The development of the equations used in the groundwater quality models is summarized below. The general equation for solute transport in groundwater calculates movement of a solute by advection with retardation due primarily to sorption as described by a linear isotherm (Domenico and Schwartz, 1998):

$$v_c = \frac{v_w}{R} \qquad (2)$$

v_c = velocity of solute
v_w = pore water velocity
R = retardation factor

For conservative (non-reactive) constituents such as salts, retardation is generally not a significant factor. Therefore, R is assumed equal to one ($v_c = v_w$). Combining this with Darcy's equation (Darcy, 1856) and the average pore water velocity:

$$v_d = Ki$$

$$v_w = \frac{v_d}{n}$$

yields: $$v_c = \frac{Ki}{n} \qquad (3)$$

v_d = Darcy velocity of groundwater
n = porosity of aquifer material

K = hydraulic conductivity
i = hydraulic gradient

Using the definition of transmissivity ($T = Kb$), K = T/b; substitution in (2) yields:

$$v_c = \frac{Ti}{nb} \tag{4}$$

T = transmissivity of the aquifer
b = thickness of aquifer

Multiplication by time yields the distance traveled by the solute:

$$d_{vc} = v_c t = \frac{Ti}{nb} t \tag{5}$$

d_{vc} = distance traveled during time t

Multiplication by the concentration gradient yields the change in salinity measured as TDS:

$$TDS_{change} = \frac{Ti}{nb} tC \tag{6}$$

TDS_{change} = change in TDS during time t
C = concentration gradient

$$\text{where: } C = \frac{TDS_{source} - TDS_{well(t_0)}}{L} \tag{7}$$

TDS_{source} = TDS at upgradient location (assumed to be constant)
$TDS_{well(t_0)}$ = initial TDS at well at beginning of simulation
L = distance between well and source location

Addition of TDS_{change} and the initial TDS yields the new TDS at the well.

$$TDS_{well} = TDS_{well(t_0)} + \frac{TDS_{source} - TDS_{well(t_0)}}{L} tT \frac{i}{nb} \tag{8}$$

The TDS at the downgradient well is calculated for successive months, where each month is denoted by p = 1,2,3…, k (k = # of months).

Units of variables used in the final equation:

TDS = mg/L
L = ft
t = days
$T = ft^2/day$ (gal/day/ft multiplied by conversion factor 0.134 ft^3/gal)
i = ft/ft
$n = ft^3/ft^3$
b = ft

D.3.3 Hydraulic Gradients

Groundwater moves in a northeasterly direction towards the Fresno Slough due to the regional hydraulic gradient, which is caused by regional (rather than local) pumping activities and other factors that affect regional groundwater conditions. The effect of deep zone pumping in western Madera County is a major factor influencing the regional gradient above the Corcoran Clay in the Mendota area. Rising water levels in WWD, after CVP water became available in 1968, have also contributed to a steeper regional gradient in the Mendota area (Section 3.4.3.1). The magnitude and direction of the regional gradient was estimated with the aid of groundwater elevation contour maps of the winter months prepared for the 2000 and 2001 annual reports (LSCE and KDSA 2001 and 2002). The dates of these contour maps are December 1999, December 2000/January 2001, January 2002 (shallow zone) and December 1999, and January 2001 and January 2002 (deep zone). The effect of the regional gradient is most obvious during the winter months, when groundwater extraction is minimal and localized recovery of water levels after the irrigation season has occurred. The magnitude of the regional gradient west of the Fresno Slough was estimated to be about 0.0015 ft/ft for the shallow zone and 0.0024 ft/ft for the deep zone based on the contour maps. The magnitude and direction of the regional gradient was assumed to be constant for all simulations.

To estimate the hydraulic gradient at individual wells, initial differences in hydraulic head between each well and an upgradient reference location were determined. Reference locations were selected along an upgradient contour line such that they aligned with the direction of the regional gradient. The initial differences in groundwater elevations in January 1999 were calculated by applying the regional gradient over the distance between wells and their respective reference locations. This was necessary because measured water level data were only available for a small subset of the calibration wells. The groundwater quality models incorporate changes in hydraulic head based on monthly drawdowns calculated using the groundwater flow models. These are used to predict changes in the hydraulic gradient caused by pumping, which are added to the regional gradient to determine the total gradient for groundwater flow. The generally easterly flow of saline groundwater is modeled along the direction of these gradients.

D.3.4 Concentration Gradients

The wells simulated with the groundwater quality models were divided into clusters for calibration purposes, and similar model parameters were used for the wells within each cluster. Water quality contour maps were used in conjunction with the water quality data from individual wells to calculate initial (1999) concentration gradients for each well. An average concentration gradient was estimated and applied to all wells in a given cluster (Tables D-3 and D-4). The calculated concentration gradients can be highly variable, because even nearby wells often have very different water quality. The phenomenon of the high variability of salinity among nearby wells is generally explained by the location of the wells relative to the saline front and the amount of surface water recharge in the vicinity of the well. The recharge is primarily related to the depth of the wells and their proximity to the Fresno Slough, although geologic conditions are also a factor. Well construction differences and casing damage in older wells are also possible causes of water quality variations among nearby wells. Shallow wells in the southern half of the MPG well field exhibit the most variability. For example, samples collected on October 17, 2002 from CGH-6B and CGH-6D showed TDS concentrations ranging from 2,110 mg/L to 1,160 mg/L, respectively. These wells are aligned in an east-west direction and are only about 200 feet apart.

To calculate concentration gradients for the shallow zone, a 1999 TDS concentration contour map was generated based on a combination of measured data and estimated values. This map is generally similar to the 2002 TDS concentration contour map shown on Figure 3-11. Deep zone concentration gradients were based on a 1999 EC contour map prepared for the Phase I report (KDSA and LSCE, 2000a) and converted to TDS using a linear regression equation (see Section 7.0). This map is generally similar to the 2002 TDS concentration contour map shown on Figure 3-12. . The general lack of water quality data upgradient (west) of the MPG wells along the Slough makes water quality contours in that area somewhat speculative, and there is considerable uncertainty attached to the estimated concentration gradients.

D.3.5 Model Calibration

The approach to model calibration was constrained by the availability of data of sufficient duration. The focus of the calibration was on prediction of long-term water quality trends rather than short-term fluctuations. The models were calibrated against observed TDS data from January 1999 through October 2002. The model for the shallow zone was calibrated using only data from MPG wells because these are the only shallow production wells in the model area. As discussed above, data from upgradient shallow monitoring wells were used to determine the concentration gradients. The model for the deep zone was calibrated using data from CCID wells, City of Mendota wells, and the Mendota Biomass well, in addition to the MPG wells. Multiple water quality samples were available for a number of deep wells during the calibration period, but only a few shallow wells had sufficient data to be used as calibration wells. This problem is compounded by the fact that some shallow MPG wells have been abandoned since 1999, and others have been drilled as recently as 2002. As a result, initial (1999) TDS concentrations for many wells had to be estimated either on the basis of available data from nearby wells of similar depths, or extrapolated using observed data for a shorter period (one or two years), along with estimated degradation rates. Although some wells were not included in the 10-year pumping plan due to poor water quality, they were used as calibration wells due to the availability of historical data. Some wells were included in the model calibration even though they were drilled after 1999. For these cases, the 1999 TDS concentrations were based on water quality estimates for a particular location and depth, rather than data from a specific well. As further discussed below, almost all shallow and deep wells used to calibrate the models showed water quality degradation during the calibration period.

D.3.5.1 Shallow Zone

The well locations and clustering used for calibration of the shallow zone model are shown on Figure D-2. The calibration parameters, annual TDS changes calculated for December 1999 through December 2002, and the mean degradation rates are summarized on Table D-3. As mentioned above, concentration gradients were applied uniformly within each cluster of wells. Concentrations gradients estimated for shallow wells range from 0.15 to 0.92 mg/L/ft. They generally increase from north to south and were found to be the highest in the vicinity of the wells in the central and southern portion of the MPG well field. Seepage factors were generally held constant within clusters. However, some adjustments were made as necessary, particularly in areas where large TDS differences occur in wells of close proximity.

The focus of the calibration was on simulation of the overall salinity trend that was observed during the 1999-2002 period. No attempt was made to simulate the sudden TDS changes or large seasonal fluctuations observed at some wells. These may be caused by seasonal factors, the amount of time that the well had been pumping prior to collecting the samples, or the laboratory that analyzed the results. In many cases a compromise had to be found such that the selected parameters generated degradation rates that could reasonably approximate the most recent sample results. For example, Terra Linda wells TL-4C and TL-17 experienced a much larger increase in TDS between June 2001 and June 2002 than other wells in this cluster, which the model did not adequately simulate. Matching of both the 2001 and 2002 sample results could only have been achieved by drastically changing the calibration parameters including the use of an unrealistically low initial TDS. The simulated TDS values are thus to be viewed as averages representing long-term trends. Due to the lack of data and greater variability for the shallow wells, there is more uncertainty in the calibration for the shallow zone than for the deep zone. Overall, the calibration was considered acceptable for predicting salinity changes during the 10-year proposed project.

The shallow-zone calibration is shown on Figures D-3 through D-9. On these plots, the same color code was used for sample data (symbols) and modeled TDS concentrations (solid lines) for each well. Figures D-3 and D-4 show the calibration for cluster S1, which includes the Fordel wells and the northernmost Terra Linda wells. The lack of historical data is very apparent on these figures; only two wells in this cluster (Fordel M-2 and Terra Linda TL-4A) were sampled in 1999. For wells without 1999 data, a decision regarding the starting concentration was made as part of the calibration process. Because well TL-4A does not yet appear to be impacted by wastewater from the City of Mendota sewage treatment plant or the Fresno County disposal site, it is believed to be more representative of water quality degradation due to movement of the saline front and was used as the primary calibration well for this cluster. Similar calibration parameters were used for other wells in the cluster (M-5 and M-6 have slightly smaller incremental seepage factors), and different starting concentrations were estimated for each well. The concentration plots illustrate slightly higher degradation rates in the summer months, when pumping activity is high, and reduced water quality degradation (or, in the case of Fordel M-2, even slight water quality improvement) in the winter, when extraction is minimal. For Fordel M-2, emphasis was placed on matching the most recent data points and the apparent degradation rate in 2001-2002, which could only be achieved by disregarding some of the earlier data. Fordel wells M-3 and M-6 experienced some short-term water quality improvements between June and October 2001. A later sample (June 2002) revealed that this trend has not continued at well M-6. Since there is no reason to expect continued water quality improvements in well M-3, it was modeled similarly to other wells in the cluster.

The comparison of complete water quality analyses from monitoring wells near the City of Mendota sewage ponds and the Fresno County disposal site with water quality at MPG wells indicates that four MPG wells have been impacted by saline wastewater from these facilities: Fordel M-2, M-3, and M-4 and Terra Linda TL-4C. These wells have significantly higher measured TDS concentrations than other wells in the cluster (Figure D-3) and have slightly higher degradation rates than other nearby wells (Table D-3). However, they are not the most westerly wells, as would be expected if the saline front was the only source of poor quality water. Water quality changes in these wells were modeled as the sum of the effect of the saline front and the influence of percolated wastewater. The most recent data from TL-17 indicate that it may also be impacted by wastewater, but this was not simulated with the model.

Figure D-4 shows the calibration plots of four Terra Linda wells, also in cluster S1, which have no 1999 or 2000 data. One of these wells (TL-10C) showed water quality improvement between 2001 and 2002, but it was assumed that degradation would occur at this well over the long term. Calibration parameters for these wells were based primarily on the wells plotted on Figure D-3.

Figure D-5 shows calibration plots of three Terra Linda wells (TL-13, 14, and 15) in cluster S2, all of which were constructed in 2001. Degradation has occurred at one of these wells (TL-14) since it was first sampled in July 2001. Calibration parameters for these wells were similar to those used for cluster S1.

Calibration plots of the wells in cluster S3 in the Central Fresno Slough group are shown on Figure D-6. This cluster includes one Terra Linda well (TL-12), two Silver Creek wells (SC-3B and 4B), and five CGH wells or well clusters (CGH –1, 2, 6, 9, and 10). The northernmost wells in this cluster (SC-3B and 4B and TL-12) have the best water quality but limited data because they were not drilled until 2000 (TL-12) or 2002 (SC-3B and CS-4B). These wells were modeled using the same calibration parameters as the CGH wells, which have more water quality data.

The CGH-1 cluster includes three individual wells (CGH-1A, CGH-B, and CGH-C) connected to a common introduction point. These were modeled as one well because only composite samples were taken at the introduction point in 1999 and 2000 (round symbols). Individual sampling of the wells did not start until June 2001, when CGH-1C (diamond symbols) was initially sampled, and CGH-1A and CGH-1B (square and triangular symbols, respectively) were not sampled until 2002. CGH-6C and CGH-6D (round and square marker, respectively) were also modeled as one well for similar reasons. CGH-6A and CGH-6B have been removed from the pumping program due to poor water quality and are not shown on Figure D-6.

CGH-9 and CGH-10 were drilled in November 2000 but were not used until early summer of 2001. Data from these wells showed a TDS increase of more than 200 mg/L during the first few months of pumping, but degradation slowed considerably during the following year. For these and other wells, priority was given to matching the most recent water quality data. Figure D-6 also illustrates another source of uncertainty not related to modeling, which was highlighted in 2002 when split samples were sent to three different laboratories; reported TDS concentrations in

October 2002 differed by as much as 100 mg/L for split samples from CGH-2 and 10 that were analyzed by different laboratories. Overall, the wells in this cluster required the most adjustments to the overall seepage factor, which ranged from 0.966 at TL-12 (the well with the lowest TDS in the cluster) to 0.990 at CGH-2 (the well with the highest TDS).

Figure D-7 shows three shallow Meyers Farming wells in cluster S4. MS-3 is the only well with water quality data in 1999 and served as the primary calibration well, even though it is no longer part of the pumping program. MS-6 and 7 were completed in May and June 2002, but MS-6 has been abandoned due to its elevated TDS.

Figure D-8 shows the calibration of the ten Five Star wells in cluster S5. The discharge of these wells is combined into one introduction point, but the wells are modeled separately because the water quality is quite variable and each of the individual wells were sampled in 2001. Water quality in these wells ranged from 590 mg/L in FS-1 to 1,600 mg/L in FS-7. FS-5 is the only well in this cluster that was sampled in 1999; it was used as the primary calibration well.

The calibration of the Coelho West wells (cluster S6) is shown on Figure D-9. The comparison of water quality data from nearby Spreckels Sugar Co. monitoring well MW-1 with water quality from the Coelho West wells indicates that CW-3, CW-4, and CW-5 are impacted by wastewater used to irrigate permanent pasture in the western portion of the Spreckels' property. Samples from CW-5, the well closest to Spreckels MW-1, had the highest TDS concentrations in this cluster. TDS concentrations measured in the southernmost wells (CW-1 and CW-2) were lower and are probably indicative of water quality that would be expected in this area without the influence of Spreckels' wastewater.

All samples collected from the Coelho West wells in 2002 had lower TDS concentrations than samples collected in 2001, especially at wells CW-4 and CW-5. This variability is probably not due to any long-term water quality improvements in this area. The fall 2002 sample from CW-5 had a much higher TDS concentration (similar to the fall 2001 sample). Such large fluctuations are poorly understood, and no attempt was made to simulate them with the water quality model. The impact of the saline front is relatively small in this cluster due to its location on the eastern side of the Fresno Slough. Water quality changes in CW-3, CW-4, and CW-5 were modeled as the sum of the effect of the saline front and the influence from Spreckels Sugar Co. wastewater.

D.3.5.2 Deep Zone

The well locations and clustering used for calibration of the deep-zone model are shown on Figure D-10. The deep-zone calibration for individual wells is shown on Figures D-11 through D-15. In general, considerably more data were available for deep zone wells, reducing the uncertainty associated with the calibrated model parameters. Water quality data for the deep zone indicates that salinity in this zone generally increases at a more constant rate. Seasonal fluctuations and other short-term changes are much less apparent in the data. Concentration gradients estimated for deep wells exhibit less variability and range from 0.4 to 0.56 mg/L/ft (Table D-4) indicating a more uniform advance of the saline front than in the shallow zone. Less influence from good quality recharge (in this case from the shallow zone) is reflected by larger incremental seepage factors (0.3 to 0.59 for the deep zone compared to 0.16 to 0.29 for the shallow zone). The minimum overall seepage factor for the deep zone (0.995) equals the maximum overall seepage factor used in the shallow zone.

Figure D-11 shows the calibration graphs of non-MPG wells north of the City Mendota (cluster D1). Relatively frequent data are available for City of Mendota wells No. 3 and No. 5. Fewer data were available for City of Mendota well No. 4 and the CCID wells, but all wells had 1999 sample results. Unlike most of the MPG wells, these wells all have water quality data prior to 1999. The historical data generally show higher degradation rates during the late 1980s and early 1990s, followed by a leveling off after 1995. Only the 1999 through 2002 data are used for calibration purposes because the recent degradation rates are considered to be more representative of degradation rates that would be likely to occur in the future.

Calibration plots for the deep MPG wells in the northern portion of the Pool (cluster D2) are shown on Figure D-12. Fordel M-1 and Terra Linda well TL-3 had 1999, 2000, and 2001 data and were used as the primary calibration wells in this cluster. TL-2 had only one measured TDS value in 2000, and the same calibration parameters used for TL-1 were also assigned to TL-2.

Figure D-13 shows the calibration plot for cluster D3, which includes two Terra Linda wells (TL-8 and TL-9), the Conejo West well, and CCF-1. TL-8 had the most complete data, with at least one sample from each year of the calibration period, and was used as the primary calibration well. Data from this well indicate a relatively linear rate of degradation during this period.

Figure D-14 shows the calibration plot for cluster D4, which includes two Terra Linda wells (TL-5 and TL-7), in the central portion of the MPG well field and the Mendota Biomass well. Well TL-7 and the Mendota Biomass well had data from each year of the calibration period, and TL-5 had data for every year except 2002. The 1999-2002 data from TL-7 and the 2000-2002 data from the Mendota Biomass well indicate a relatively linear rate of degradation.

Figure D-15 shows the calibration plot for cluster D5, which includes deep wells in the southern half of the MPG well field (SC-5, CGH-7, and MS-5). The calibration of CGH-7, which has only been sampled twice, was partly based on data from SC-5. A total of 15 samples (the most for any MPG well) was available for MS-5. This well shows some seasonal fluctuations, but the overall degradation rate is also relatively linear.

D.3.6 10-Year Simulation

The groundwater quality models were used to simulate the 10-year period of the proposed project (from January 2003 to December 2012). The starting concentrations for the 10-year model run were based on simulated concentrations at the end of the calibration period (December 2002). Annual summaries of simulation results for shallow and deep wells are provided in Tables D-5 and D-6, respectively. Simulated TDS concentrations are listed for each well at the end of each year of the project. Also shown are the initial concentrations and the average annual degradation rates. Note that some wells used to calibrate the models are not shown on these tables because they have been abandoned or are not included in the MPG 10-year pumping program due to poor water quality.

The model results for shallow wells indicate that the salinity in all wells is predicted to increase non-linearly during the 10-year period. During wet years, the degradation rate would decrease considerably and, in some cases, result in water quality improvements. The degree of water quality improvement during wet years is primarily due to the amount of seepage from the Slough, which is controlled by the seepage factors in the model. The predicted water quality improvements during wet years are greatest at shallow wells owned by Silver Creek, CGH, and Five Star. Meyers well MS-7 also shows significant water quality improvement in wet years. According to the model results, MS-7 would exceed the 2,000 mg/L limit in Year 5 of the 10-year project and, thus, would be removed from the pumping program. Removal of MS-7 from the transfer pumping program results in a decreased rate of degradation during the second half of the project. Results for most other shallow wells also indicate that the degradation rate would decrease slightly toward the end of the simulation period as pumpage reductions occur and the salinity in some wells approaches that of the upgradient source.

An annual summary of simulation results for shallow wells is provided in Table D-5. A comparison between the predicted average annual degradation rates and those calculated for the calibration phase (Table D-3) shows that the future degradation rate for well clusters S3 through S6 is predicted to be significantly less than was estimated during the calibration period. This is primarily the result of planned pumping reductions in the southern half of the MPG well field and the effect of suspending transfer pumping during the wet years.

The results of the 10-year simulation for the deep zone are summarized in Table D-6. The predicted rates of water quality degradation in the deep zone are much more linear than in the shallow zone. Degradation rates decrease only slightly during wet years, and no water quality improvements are predicted, because the amount of seepage from the Slough is insufficient to counteract water quality degradation caused by movement of the saline front. Deep zone pumpage along the Fresno Slough would be only slightly less during wet years because most deep wells in this area are pumped for adjacent use rather than transfer. The total proposed volume of deep zone pumpage during normal years is much less than the shallow zone pumpage, and the majority of the deep zone pumpage would occur in FWD wells. Deep zone pumpage during normal years does not change during the 10-year simulation because planned pumping reductions made to meet water quality targets would occur from shallow wells. Degradation rates predicted for the deep zone are generally higher than for the shallow zone and are much less dependent on MPG and other local pumpage because the regional gradient in the deep zone is steeper and is responsible for much more of the movement of the saline front (see Table 4-3). The predicted deep zone degradation rates during the 10-year project (Table D-6) are more similar to degradation rates calculated during the calibration period (Table D-4).

D.4 SURFACE WATER MIXING MODELS

Two surface water mixing models were developed, one for the southern portion of the Fresno Slough and one for the San Joaquin River branch of the Pool. The models are used to predict concentrations of chemical constituents in the Pool at the MWA and at Mendota Dam (southern and northern mixing models, respectively). The models are used primarily to estimate salinity (as TDS) but have also been used to estimate boron concentrations. These models do not require calibration since they merely blend water of varying quality and quantity using flow averaging. Implicit in this approach is the assumption of instantaneous and complete mixing. The flow volumes used in the models are based on water demands (outflows) calculated from the water budget, which is discussed in Section 3.3.1 and the 2000 and 2001 annual reports (LSCE and KDSA 2001 and 2002). The inflows and outflows used for the water budget are tracked on a daily basis by SLDMWA.

The models do not account for evaporation and seepage losses. Inclusion of these variables would make the models less conservative by adding to the net demand, which would result in a larger DMC contribution to the volume of water available for mixing. Since there is no meaningful way to predict stage changes in the Pool, variations in monthly inflow due to storage change were also omitted from the models.

D.4.1 Southern Fresno Slough Model

The model for the southern portion of the Fresno Slough calculates average monthly concentrations in the Fresno Slough at the MWA south of Whitesbridge Road. Flow volumes are based on a simplified monthly water budget that calculates the monthly net water demand in the southern portion of the Slough. This demand is based on diversions by the MWA, James and Tranquillity Irrigation Districts, Westlands and Fresno Slough Water Districts, and several smaller users. This demand is mostly met by inflow from the DMC, and to a much smaller degree by MPG pumpage for transfer and adjacent use. The portion of the DMC inflow that flows south to the MWA is calculated as the difference between the net demand at the south and the inflow from MPG wells along the Slough. Therefore, a southerly flow direction is implicit in the calculations. The quantity and quality of MPG pumpage into the Slough is accounted for on a well-by-well basis using the most recent well capacities and measured or predicted water quality.

Application of the model requires assumptions regarding the net demand in the southern portion of the Slough, the water quality of DMC inflow, and the changing water quality of MPG wells. The monthly demand was based on averages between January 1999 and July 2002 calculated from the water budget, excluding months when the Mendota Pool was drained. The water quality of the DMC inflow is based on the daily EC measurements made at the DMC terminus from January 1993 through October 2002. This period was selected because: 1) implementation of the CVPIA, which began in 1993, has resulted in major changes in the quantity and quality of the DMC inflow; and 2) measurement of EC at Bass Avenue near the DMC terminus (Check 21) began in January 1993. Earlier DMC water quality data are from Check 20, located 6 miles upstream.

The 10-year record of the daily average EC (µmhos/cm) at the DMC terminus was used to calculate monthly average EC values, which were subsequently converted to TDS (mg/L) using a linear regression equation based on 2000-2001 surface water grab sample data:

$TDS = 0.6426*EC - 14.46, n = 108.$

Boron data for the DMC are obtained from grab samples collected by the MPG from June through November 2002. These concentrations ranged from 0.13 to 0.24 mg/L. The January through May concentrations were based on the average of the June and November results (0.17 mg/L).

The effect of MPG pumpage on boron concentrations at the MWA is discussed in Section 4.4.1.5. In general, boron concentrations in the MPG wells along the Fresno Slough are low, but on average they are slightly higher than the concentrations in the DMC inflow. The model results indicate that under the proposed project, MPG transfer pumpage in 2004 would result in boron concentrations at the MWA that would be 0.03 to 0.06 mg/L higher (0.04 mg/L average) than without transfer pumpage during the months that the pumpage would occur (Table 4-5). Since the effect of MPG pumpage on boron concentrations at the MWA is presently very small, no 10-year simulations were conducted.

To check the accuracy of the mixing model, TDS results for 2001 and 2002 were compared against grab sample data collected from the MWA during those years. The model results corresponded reasonably well to observed concentrations for both years. The 2001 comparison is discussed in the 2002 EA (Reclamation 2002).

After each year of the 10-year period, the simulated monthly water quality at the MWA was checked, and adjustments to the pumping program were made as necessary to prevent exceedance of water quality targets. Compliance was achieved by reducing transfer pumpage and, to a smaller degree, by redistributing pumpage for adjacent use. During the summer months, demand at the south is sufficiently high that most MPG wells would be able to pump without causing water quality impacts. Pumpage reductions were necessary during the spring and fall because the relative impact of MPG pumpage increases when the net demand is low. Transfer pumpage had to be reduced in the months of March and April beginning in year five to prevent predicted TDS concentrations in excess of 600 mg/L. The TDS target of 450 mg/L during the fall period (September, October and November) was the most difficult to meet, and the largest transfer pumping reductions were necessary in these months. The impact of the proposed project on the water quality at the MWA is summarized on Table D-7. Model results indicate that the predicted TDS concentrations will not exceed 450 mg/L during the fall or 600 mg/L in any month. The annual TDS ranged from 376 to 475 mg/L for the 10-year period. The mean annual TDS for the period is 447 mg/L.

D.4.2 San Joaquin River Branch Model

The model for the San Joaquin River branch of the Pool calculates TDS and boron concentrations at Mendota Dam based on a simplified water budget for the area north and east of the CCID Main Canal. Flow volumes are based on the monthly net water demand in this portion of the Pool. Flow over the dam to the lower San Joaquin River constitutes by far the largest outflow component. Smaller outflow components are diversions to the Columbia Canal and NLF. These demands are primarily met by inflow from the DMC, with much smaller components from the MPG wells and the San Joaquin River. The San Joaquin River inflow, which has varied greatly in recent years, is discussed below.

The net demand (difference between the total outflows and the San Joaquin River inflow) is primarily met by inflow from the DMC and to a much smaller degree by MPG transfer pumpage. The DMC contribution is calculated as the difference between the net demand at the north and the inflow from MPG wells in FWD.

Magnitudes of outflow past Mendota Dam to the Columbia Canal and NLF are average values based on monthly 1999-2002 data (excluding months when the Pool was drained). Inflow from the San Joaquin River depends mainly on reservoir operations at Friant Dam and varies greatly from year to year. For example, 1999 and 2000 summer releases from Friant Dam to restore riparian habitat along the San Joaquin River resulted in flow in this reach of the River during most of the irrigation season and a westerly flow direction in this branch of the Pool. In contrast, flow to the Pool from the San Joaquin River was minimal in 2001 and 2002. Therefore, two scenarios (one for moderate and one for low flow conditions of the San Joaquin River) were simulated.

The estimation of water quality of the DMC is based on the same assumptions as the southern mixing model. Water quality of the San Joaquin River was estimated based on grab sample analyses from the Columbia Canal intake collected during times of significant inflow from the River.

The model incorporates individual pumpage and TDS or boron contributions from the MPG wells in FWD. Wells in FWD use the Pool to convey water for transfer purposes only. Water for adjacent uses does not enter the Pool. Therefore, there is no potential during wet years, and the water quality was not simulated with the model.

The mixing model results for the San Joaquin River branch of the Pool indicate that MPG transfer pumpage would have virtually no effect on TDS and boron concentrations in this area (Tables 4-6 and 4-7). This is primarily due to the fact that the water quality of the FWD wells is generally similar to that of the DMC. Furthermore, the volume of water introduced by the MPG (about 10,000 af) constitutes less than 5 percent of the total volume of water conveyed through this portion of the Pool. Because water quality degradation has not been observed in samples from the FWD wells, the predicted TDS concentrations are assumed to be constant during the remainder of the 10-year proposed project. Further discussion is provided in Section 4.4.1.5.

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Table D-1
Proposed Pumping Schedule for Second Year of 10-Year Project (2004)

Well ID[1]	Depth Zone	Capacity (gpm)	Predicted TDS[2] (mg/L)	Well Usage[3] Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep. 1-15	Sep. 16-30	Oct	Nov	Dec
Fordel, Inc.																
M-1	D	1,100	829													
M-2	S	494	746				T	T	T	T	T	T	T	T		
M-3	S	898	836				T	T	T	T	T	T	T	T		
M-4	S	800	825				T	T	T	T	T	T	T	T		
M-5	S	850	540			T	T	T	T	T	T	T	T	T	T	
M-6	S	650	465			T	T	T	T	T	T	T	T	T	T	
Fordel/Bio	*D*	*2,962*														
Terra Linda Farms																
TL-1	D	800	835						A	A	A					
TL-2	D	800	1,077						A	A	A					
TL-3	D	1,271	609	A	A	T	T	T	A	A	A	A	T	A	A	
TL-4A	S	700	621				T	T	T	T	T	T	T	T	T	
TL-4C	S	700	793					T	T	T	T	T				
TL-5	D	2,800	1,086						A	A	A					
TL-6	*D*	*1,661*														
TL-7	D	1,600	880						A	A	A	A	A	A		
TL-8	D	1,616	885					A	A	A	A			A		
TL-9	*D*	*1,071*														
TL-10A	S	550	612			T	T	T	T	T	T	T	T	T	T	
TL-10B	S	450	626			T	T	T	T	T	T	T	T	T	T	
TL-10C	S	300	535	A	A	T	T	T	T	T	T	T	T	T	T	
TL-11	S	200	510	A	A	A	T	T	T	T	T	T	T	T	T	
TL-12	S	700	558			A	A	T	T	T	T	T	T	T	T	
TL-13	S	1,000	559			A	A	T	T	T	T	T	T	T	T	
TL-14	S	800	670			T	T	T	T	A	A	T	T	T	T	
TL-15	S	600	598			T	T	T	T	T	A	T	T	T	T	
TL-16	S	600	629			T	A	T	T	T	T	T	T	T	T	
TL-17	S	900	611			T	T	A	T	T	T	T	T	T	T	
Coelho/Coelho																
Conejo West	*D*	*3,032*														
Coelho/Coehlho/Fordel																
CCF-1	*D*	*3,366*														
CCF-2	*D*	*3,800*														
Silver Creek Packing																
SC-3	*D*	*898*														
SC-3B	S	1,300	876			T	T	T	T	T	T	T	T	T		
SC-4	*D*	*898*														
SC-4B	S	1,000	850				T	T	T	T	T	T		T		
SC-5	*D*	*1,800*														
SC-6	D	1,500	1,560													
SC-7	*D*	*763*														
Coelho/Gardner/Hanson																
CGH-1	S	1,100	1,066		A	A	A	T	T/A	T/A	T/A	T/A				
CGH-2	S	1,000	1,505						A	A	A					
CGH-3	*S*	*494*														
CGH-4	*S*	*269*														
CGH-5	*S*	*449*														
CGH-6C, D	S	382	1,314					A	A	A	A	A				
CGH-7	D	718	1,322					A	A	A	A	A		A		
CGH-8	*S*	*763*														
CGH-9	S	550	1,290						A	A	A	A				
CGH-10	S	800	1,004		A	A	A	T	T	T	T	T	T	T	A	
CGH-11	*S*	*600*														

Table D-1
Proposed Pumping Schedule for Second Year of 10-Year Project (2004)

Well ID[1]	Depth Zone	Capacity (gpm)	Predicted TDS[2] (mg/L)	Well Usage[3] Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep. 1-15	Sep. 16-30	Oct	Nov	Dec
Meyers Farming																
MS-5	D	1,800	1,929				A	A	A	A	A	A	A	A		
MS-6	*S*	*1,000*														
MS-7	S	1,000	1,897						T	T	T					
Five Star/Conejo Farms																
FS-1	S	359	664			T	T	T	T	T	T	T	T	T	T	
FS-2	S	359	838				T	T	T	T	T	T	T	T		
FS-3	S	359	1,237					T	T	T	T					
FS-4	S	359	1,177					T	T	T	T	T				
FS-5	S	359	671			T	T	T	T	T	T	T	T	T	T	
FS-6	S	359	1,473						T	T	T					
FS-7	S	359	1,692						T	T	T					
FS-8	S	359	1,418					T	T	T	T					
FS-9	S	359	1,367					T	T	T	T					
FS-10	S	359	977					T	T	T	T					
Coelho West																
CW-1	S	425	710			T	T	T	T	T	T	T	T	T		
CW-2	S	425	713			T	T	T	T	T	T	T	T	T		
CW-3	S	425	1,019					T	T	T	T	T				
CW-4	S	425	1,004					T	T	T	T	T		T		
CW-5	S	425	1,348					T	T	T	T					
Farmers Water District																
R-1	D	1,100	217					A					A	A		
R-2	D	1,800	330				A	T					T	T		
R-3	D	1,100	495					T								
R-4	D	1,500	150			T	T	T	A	A	A	A	T	T	T	
R-6	D	1,400	290			A	A	T	A	A	A	A	A	A	A	
R-7	D	2,700	280			T	T	T	A	A	A	A	T	T	T	
R-8	D	2,100	285			A	A	T		A			T	T		
R-9	D	1,700	440			T	T	A					T	T		
R-10	D	1,500	490					T					A	A		
R-11	D	1,400	400													
E-Loop-2	*D*	*600*														
E-Loop-3	*D*	*800*														
W Loop-1	*D*	*1,000*														
W Loop-2	*D*	*1,000*														
W Loop-3	*D*	*900*														
Baker Farming Co.																
BF-1	D	1,800	380				T	T					T	T		
BF-2	D	750	310			T	T	T					T	T		
BF-3	D	1,600	310			T	T	T					T	T	T	
BF-4	D	1,500	310				T	T					T	T	T	
BF-5	D	1,885	300			T	T	T					T	T	T	
Panoche Creek Farms																
PCF-1	D	1,700	390				T	T					T	T		

1. Italicized wells were not included in the proposed pumping program due to high TDS or other factors. Their TDS was not simulated for the 10-year project.
2. Simulated at end of year 1 of project (2003).
3. T = pumping for transfer; A = pumping for adjacent use, Blank = well not used

Table D-2. Parameters Used in Groundwater Flow Model Calibration

Parameter	Deep Zone			Shallow Zone
	Western Area	Eastern Area		
		Shallower Wells	Deeper Wells	
Aquifer Transmissivity (gpd/ft)	120,000	120,000	120,000	220,000
Aquifer Storage Coefficient (unitless)	0.02	0.002	0.002	0.10
Leakage Factor (ft)	7,000[1]	7,500[2]	10,500	25,000

1. CCID wells have a leakage factor of 2,000 ft.
2. NLF W-32, W-42, W-89, and W-91 have a leakage factor of 5,000 ft.

Table D-3. Simulated TDS in Shallow MPG Wells (1991-2002)

Well Owner & Cluster Number		Well ID[1]	Initial Concentration Gradient (mg/L/ft)	Incremental Seepage Factor	Overall Seepage Factor	TDS Concentration (mg/L) Initial 1999	Simulated at End of Year 1999	2000	2001	2002	Mean Deg. Rate 1999-2002 (mg/L/yr)
Northern Fresno Slough											
Fordel, Inc.	(S1)	**M-2**	0.15	0.20	0.995	620	641	662	696	684	16
	(S1)	**M-3**	0.15	0.29	0.995	690	717	742	774	782	23
	(S1)	**M-4**	0.15	0.29	0.995	670	699	726	760	769	25
	(S1)	M-5	0.15	0.25	0.995	430	447	464	485	501	18
	(S1)	M-6	0.15	0.25	0.995	330	352	374	399	420	22
Terra Linda	(S1)	TL-4A	0.15	0.29	0.995	480	506	528	555	582	25
Farms	(S1)	**TL-4C**	0.15	0.25	0.995	655	680	700	732	737	20
	(S1)	TL-10A	0.15	0.29	0.995	500	515	531	553	578	19
	(S1)	TL-10B	0.15	0.29	0.995	510	526	545	567	595	21
	(S1)	TL-10C	0.15	0.29	0.995	400	420	441	466	493	23
	(S1)	TL-11	0.15	0.29	0.995	370	392	415	441	468	24
	(S1)	TL-16	0.15	0.29	0.995	510	528	544	567	592	21
	(S1)	TL-17	0.15	0.29	0.995	480	498	515	542	568	22
Central Fresno Slough											
Terra Linda	(S2)	TL-13	0.15	0.29	0.995	400	420	441	474	508	27
Farms	(S2)	TL-14	0.15	0.29	0.995	570	580	590	612	636	17
	(S2)	TL-15	0.15	0.29	0.995	480	494	509	534	561	20
	(S3)	TL-12	0.73	0.22	0.966	280	355	411	486	537	64
Silver Creek	(S3)	SC-3B	0.73	0.23	0.980	550	607	659	726	785	59
Packing Co.	(S3)	SC-4B	0.73	0.23	0.980	520	579	632	699	767	62
Coelho/Gardner/	(S3)	CGH-1	0.73	0.20	0.984	700	783	857	950	1,014	78
Hanson	(S3)	CGH-2	0.73	0.20	0.990	1,100	1,184	1,261	1,359	1,437	84
	(S3)	CGH-6	0.73	0.23	0.986	980	1,065	1,149	1,232	1,296	79
	(S3)	CGH-9	0.73	0.20	0.988	900	969	1,037	1,138	1,222	80
	(S3)	CGH-10	0.73	0.20	0.984	650	714	774	868	943	73
Meyers Farming	(S4)	MS-3	0.92	0.23	0.991	1,950	2,035	2,109	2,199	2,256	77
	(S4)	MS-6	0.92	0.23	0.991	1,710	1,812	1,905	2,008	2,092	95
	(S4)	MS-7	0.92	0.23	0.990	1,520	1,613	1,700	1,791	1,860	85
Southern Fresno Slough											
Five Star	(S5)	FS-1	0.78	0.18	0.980	470	512	554	614	638	42
	(S5)	FS-2	0.78	0.18	0.985	570	624	679	754	792	55
	(S5)	FS-3	0.78	0.19	0.990	970	1,016	1,069	1,145	1,187	54
	(S5)	FS-4	0.78	0.18	0.990	890	941	998	1,075	1,121	58
	(S5)	FS-5	0.78	0.20	0.978	420	479	536	609	639	55
	(S5)	FS-6	0.78	0.20	0.990	1,300	1,324	1,358	1,421	1,450	37
	(S5)	FS-7	0.78	0.21	0.991	1,500	1,526	1,564	1,632	1,665	41
	(S5)	FS-8	0.78	0.20	0.990	1,190	1,226	1,270	1,343	1,379	47
	(S5)	FS-9	0.78	0.19	0.990	1,180	1,208	1,245	1,309	1,340	40
	(S5)	FS-10	0.78	0.16	0.990	700	751	806	877	922	56

Table D-3. Simulated TDS in Shallow MPG Wells (1991-2002)

Well Owner & Cluster Number		Well ID[1]	Initial Concentration Gradient (mg/L/ft)	Incremental Seepage Factor	Overall Seepage Factor	TDS Concentration (mg/L) Initial 1999	Simulated at End of Year 1999	2000	2001	2002	Mean Deg. Rate 1999-2002 (mg/L/yr)
Coelho West	(S6)	CW-1	0.48	0.25	0.984	620	634	653	686	698	20
	(S6)	CW-2	0.48	0.25	0.984	640	650	665	695	705	16
	(S6)	**CW-3**	0.48	0.25	0.984	870	893	921	969	990	30
	(S6)	**CW-4**	0.48	0.25	0.984	840	865	896	948	971	33
	(S6)	**CW-5**	0.48	0.25	0.984	1,180	1,206	1,238	1,291	1,316	34

1. Wells impacted by additional sources other than the saline front are depicted in bold print. CGH-1 is a well cluster of three wells. CGH-6 is a well cluster of four wells, of which only CGH-6C and 6D were modeled.

Table D-4. Simulated TDS in Deep Wells Near Fresno Slough (1999-2002)

Well Owner & Cluster Number		Well ID	Initial Concentration Gradient (mg/L/ft)	Incremental Seepage Factor	Overall Seepage Factor	TDS Concentration (mg/L) Initial 1999	Simulated at End of Year 1999	2000	2001	2002	Mean Deg. Rate 1999-2002 (mg/L/yr)
North of Mendota											
Central Calif.	(D1)	CCID 5A	0.54	0.30	0.998	380	412	450	487	521	**35**
Irrigation Dist.	(D1)	CCID 32B	0.54	0.50	0.999	1,420	1,477	1,539	1,612	1,681	**65**
City of	(D1)	City No.3	0.54	0.45	0.999	1,500	1,580	1,667	1,739	1,799	**75**
Mendota	(D1)	City No.4	0.54	0.45	0.999	1,550	1,608	1,686	1,761	1,824	**69**
	(D1)	City No.5	0.54	0.45	0.998	1,200	1,260	1,316	1,382	1,438	**59**
Northern Fresno Slough											
Fordel, Inc.	(D2)	M-1	0.53	0.40	0.997	580	626	681	741	772	**48**
Terra Linda	(D2)	TL-1	0.53	0.40	0.998	557	601	666	714	752	**49**
Farms	(D2)	TL-2	0.53	0.40	0.998	840	878	929	971	1,009	**42**
	(D2)	TL-3	0.53	0.37	0.995	320	372	434	494	530	**52**
	(D4)	TL-7	0.56	0.35	0.998	570	624	687	748	794	**56**
	(D3)	TL-8	0.55	0.34	0.998	588	636	694	756	803	**54**
	(D3)	TL-9	0.55	0.34	0.999	798	850	904	957	996	**49**
Conejo West	(D3)	ConejoWest	0.55	0.34	0.999	885	945	1,001	1,050	1,090	**51**
Coelho/Coelho/ Fordel	(D3)	CCF-1	0.55	0.34	0.999	875	920	988	1,059	1,097	**56**
Central Fresno Slough											
Terra Linda Farms	(D4)	TL-5	0.56	0.35	0.998	770	827	894	960	1,008	**60**
AES Mendota	(D4)	Men/Biomass	0.56	0.35	0.998	700	755	813	857	893	**48**
Silver Creek Packing Co.	(D5)	SC-5	0.38	0.50	0.999	2,040	2,079	2,120	2,151	2,171	**33**
Coelho/Gardner/ Hanson	(D5)	CGH-7	0.40	0.50	0.999	1,100	1,148	1,193	1,224	1,252	**38**
Meyers Farming	(D5)	MS-5	0.42	0.59	0.999	1,650	1,717	1,764	1,816	1,858	**52**

Table D-5. Simulated TDS in Shallow MPG Wells (2003-2012)

Well Owner & Cluster Number		Well ID[1]	TDS Concentration (mg/L)											Mean Deg. Rate[3] 2003-2012 (mg/L/yr)
			Initial 2003[2]	Simulated at End of Year										
				Year 1 (wet)	Year 2 (normal)	Year 3 (normal)	Year 4 (normal)	Year 5 (normal)	Year 6 (wet)	Year 7 (normal)	Year 8 (normal)	Year 9 (normal)	Year 10 (normal)	
Northern Fresno Slough														
Fordel, Inc.	(S1)	**M-2**	684	679	746	805	857	900	867	909	942	972	996	31 (10)
	(S1)	**M-3**	782	781	836	885	929	968	949	985	1,013	1,040	1,062	28 (6)
	(S1)	**M-4**	769	769	825	876	921	961	942	979	1,009	1,037	1,060	29 (7)
	(S1)	M-5	501	505	540	574	607	637	634	662	687	711	733	23
	(S1)	M-6	420	428	465	500	534	565	566	595	621	646	669	25
Terra Linda	(S1)	TL-4A	582	586	621	654	686	715	713	739	763	786	807	23
Farms	(S1)	**TL-4C**	737	736	793	844	889	928	906	941	972	999	1,023	29 (8)
	(S1)	TL-10A	578	583	612	641	669	694	695	717	739	760	780	20
	(S1)	TL-10B	595	599	626	654	680	704	704	726	746	766	784	19
	(S1)	TL-10C	493	504	535	565	594	622	627	651	674	695	716	22
	(S1)	TL-11	468	480	510	541	570	597	603	627	650	671	691	22
	(S1)	TL-16	592	596	629	661	691	719	717	742	766	788	808	22
	(S1)	TL-17	568	573	611	648	683	715	713	742	768	793	816	25
Central Fresno Slough														
Terra Linda	(S2)	TL-13	508	522	559	595	629	660	668	696	722	747	771	26
Farms	(S2)	TL-14	636	642	670	697	722	745	747	767	786	805	822	19
	(S2)	TL-15	561	570	598	627	653	678	683	704	725	745	763	20
	(S3)	TL-12	537	502	558	598	623	638	580	604	621	634	642	11
Silver Creek	(S3)	SC-3B	785	773	876	957	1,017	1,058	1,001	1,037	1,061	1,082	1,098	31
Packing Co.	(S3)	SC-4B	767	756	850	929	987	1,028	975	1,010	1,035	1,058	1,074	31
Coelho/Gardner/	(S3)	CGH-1	1,014	1,002	1,066	1,122	1,167	1,202	1,170	1,197	1,223	1,244	1,263	25
Hanson	(S3)	CGH-2	1,437	1,437	1,505	1,570	1,626	1,674	1,660	1,697	1,732	1,765	1,793	36
	(S3)	CGH-6	1,296	1,270	1,314	1,356	1,389	1,415	1,384	1,402	1,422	1,440	1,455	16
	(S3)	CGH-9	1,222	1,221	1,290	1,353	1,406	1,450	1,432	1,465	1,497	1,526	1,551	33
	(S3)	CGH-10	943	935	1,004	1,063	1,112	1,152	1,122	1,153	1,181	1,206	1,226	28
Meyers Farming	(S4)	MS-7	1,860	1,837	1,897	1,956	1,985	2,009	1,982	1,999	2,018	2,035	2,051	19
Southern Fresno Slough														

Table D-5. Simulated TDS in Shallow MPG Wells (2003-2012)

Well Owner & Cluster Number		Well ID[1]	TDS Concentration (mg/L)											Mean Deg. Rate[3] 2003-2012 (mg/L/yr)
			Initial 2003[2]	Simulated at End of Year										
				Year 1 (wet)	Year 2 (normal)	Year 3 (normal)	Year 4 (normal)	Year 5 (normal)	Year 6 (wet)	Year 7 (normal)	Year 8 (normal)	Year 9 (normal)	Year 10 (normal)	
Five Star	(S5)	FS-1	638	615	664	705	736	760	718	741	762	779	791	15
	(S5)	FS-2	792	779	838	889	931	966	931	961	989	1,013	1,031	24
	(S5)	FS-3	1,187	1,177	1,237	1,293	1,343	1,386	1,361	1,397	1,432	1,463	1,491	30
	(S5)	FS-4	1,121	1,117	1,177	1,234	1,283	1,327	1,307	1,342	1,377	1,408	1,435	31
	(S5)	FS-5	639	616	671	716	749	774	727	752	774	792	805	17
	(S5)	FS-6	1,450	1,422	1,473	1,521	1,564	1,601	1,564	1,595	1,627	1,655	1,679	23
	(S5)	FS-7	1,665	1,638	1,692	1,745	1,791	1,832	1,798	1,832	1,867	1,898	1,926	26
	(S5)	FS-8	1,379	1,359	1,418	1,473	1,522	1,565	1,532	1,568	1,603	1,635	1,662	28
	(S5)	FS-9	1,340	1,317	1,367	1,415	1,457	1,493	1,462	1,493	1,523	1,551	1,575	23
	(S5)	FS-10	922	923	977	1,029	1,074	1,113	1,100	1,131	1,163	1,191	1,215	29
Coelho West	(S6)	CW-1	698	674	710	742	767	788	754	773	791	806	818	12
	(S6)	CW-2	705	680	713	743	767	786	753	771	788	802	814	11
	(S6)	**CW-3**	990	969	1,019	1,065	1,106	1,141	1,112	1,145	1,178	1,208	1,236	25 (14)
	(S6)	**CW-4**	971	950	1,004	1,053	1,097	1,135	1,105	1,140	1,174	1,206	1,235	26 (16)
	(S6)	**CW-5**	1,316	1,298	1,348	1,396	1,438	1,476	1,450	1,486	1,522	1,555	1,586	27 (18)

1. Wells impacted by additional sources other than the saline front are depicted in bold print. CGH-1 is a well cluster of three wells. CGH-6 is a well cluster of four wells, of which only CGH-6C and 6D were modeled.

2. The initial concentration at each well is based on model results at the end of the 1999-2002 year calibration period.

3. Values in parenthesis indicate the amount of degradation attributed to sources other than the saline front.

Table D-6. Simulated TDS in Deep Wells near Fresno Slough (2003-2012).

Well Owner & Cluster Number		Well ID	Initial 2003[1]	TDS Concentration (mg/L) Simulated at End of Year										Mean Deg. Rate 2003-2012 (mg/L/yr)
				Year 1 (wet)	Year 2 (normal)	Year 3 (normal)	Year 4 (normal)	Year 5 (normal)	Year 6 (wet)	Year 7 (normal)	Year 8 (normal)	Year 9 (normal)	Year 10 (normal)	
North of Mendota														
Central Calif.	(D1)	CCID 5A	521	553	586	618	649	680	709	738	766	794	821	30
Irrigation Dist.	(D1)	CCID 32B	1,681	1,748	1,817	1,885	1,952	2,018	2,082	2,147	2,211	2,274	2,336	66
City of	(D1)	City No.3	1,799	1,856	1,917	1,978	2,038	2,097	2,152	2,209	2,266	2,323	2,378	58
Mendota	(D1)	City No.4	1,824	1,885	1,949	2,013	2,076	2,139	2,196	2,257	2,317	2,376	2,435	61
	(D1)	City No.5	1,438	1,490	1,547	1,602	1,655	1,707	1,755	1,804	1,853	1,901	1,947	51
Northern Fresno Slough														
Fordel, Inc.	(D2)	M-1	772	798	829	859	888	915	935	961	985	1,009	1,031	26
Terra Linda	(D2)	TL-1	752	791	835	878	920	961	996	1,035	1,073	1,111	1,147	39
Farms	(D2)	TL-2	1,009	1,041	1,077	1,112	1,147	1,180	1,209	1,241	1,273	1,303	1,333	32
	(D2)	TL-3	530	564	609	651	691	729	752	786	818	848	875	35
	(D4)	TL-7	794	836	880	924	966	1,007	1,045	1,084	1,123	1,160	1,197	40
	(D3)	TL-8	803	843	885	926	966	1,005	1,040	1,077	1,114	1,150	1,184	38
	(D3)	TL-9	996	1,032	1,071	1,109	1,147	1,185	1,219	1,256	1,292	1,328	1,364	37
Conejo West	(D3)	ConejoWest	1,090	1,126	1,166	1,206	1,244	1,283	1,318	1,355	1,392	1,429	1,465	38
Coelho/Coelho/ Fordel	(D3)	CCF-1	1,097	1,132	1,170	1,207	1,245	1,281	1,314	1,350	1,386	1,421	1,455	36
Central Fresno Slough														
Terra Linda Farms	(D4)	TL-5	1,008	1,046	1,086	1,126	1,164	1,202	1,236	1,271	1,306	1,340	1,374	37
AES Mendota	(D4)	Men/Biomass	893	925	959	993	1,026	1,058	1,086	1,117	1,146	1,175	1,204	31
Silver Creek Packing	(D5)	SC-5	2,171	2,189	2,209	2,230	2,250	2,269	2,286	2,306	2,325	2,343	2,362	19
Coelho/Gardner/ Hanson	(D5)	CGH-7	1,252	1,286	1,322	1,357	1,391	1,424	1,455	1,487	1,518	1,550	1,581	33
Meyers Farming	(D5)	MS-5	1,858	1,893	1,929	1,966	2,001	2,036	2,069	2,103	2,137	2,170	2,203	34

1. The initial concentration at each well is based on model results at the end of the 1999-2002 year calibration period.

Table D-7. Predicted TDS (mg/L) at Mendota Wildlife Area (2003-2012)

Month	Year 1 2003	Year 2 2004	Year 3 2005	Year 4 2006	Year 5 2007	Year 6 2008	Year 7 2009	Year 8 2010	Year 9 2011	Year 10 2012	Mean
January	451	455	460	464	468	470	474	477	481	483	**468**
February	416	418	420	422	423	423	424	425	426	427	**423**
March	464	539	557	573	587	483	594	590	599	598	**558**
April	414	541	564	583	586	432	592	581	592	598	**548**
May	375	465	476	485	493	381	497	504	509	515	**470**
June	350	424	433	431	438	364	443	448	454	458	**424**
July	298	377	386	383	390	312	395	400	406	410	**376**
August	326	426	438	435	443	345	450	457	464	470	**425**
September	327	448	444	446	448	335	449	441	448	446	**423**
October	343	446	447	445	447	357	450	441	448	448	**427**
November	355	446	448	450	450	365	449	444	450	449	**431**
December	391	391	391	391	391	391	391	391	391	391	**391**
Mean	**376**	**448**	**455**	**459**	**464**	**388**	**467**	**467**	**472**	**475**	**447**

Thus, the equation takes the general form

$$TDS_{well(p)} = TDS_{well(p-1)} + \frac{TDS_{source} - TDS_{well(t_0)}}{L} tT \frac{i}{nb} \tag{9}$$

$TDS_{well(p)}$ = TDS at well for the p[th] month
$TDS_{well(p\text{-}1)}$ = TDS at well for the preceding month
(equal to $TDS_{well(t_0)}$ for the first month)

Seasonally collected data from a number of wells indicate that water quality improves during times of minimal extraction in the winter months, especially in the shallow zone. This suggests that dilution of the saline groundwater flowing from upgradient areas is occurring, due to two primary factors:

1) Good quality surface water percolates from the Fresno Slough to the shallow aquifer, resulting in groundwater quality improvement. Similarly, there is some vertical flow of groundwater from the shallow to the deep zone. Near the Slough, this water is lower in salinity than the deep zone groundwater and has a beneficial effect on water quality.

2) Groundwater flows to the cone of depression created by pumping wells from all directions. Therefore, the higher salinity groundwater flowing from the upgradient (westerly) direction is partially offset by better quality water flowing into the cone of depression from cross-gradient and downgradient directions.

Since vertical seepage is considered to be the primary factor in groundwater quality improvements near the Slough, terms used to simulate these processes are labeled “seepage factors” in the models. An incremental seepage factor acts upon the calculated monthly TDS increment and, thus, controls the amplitude of the seasonal fluctuations. An overall seepage factor acts on the sum of the TDS increment and the TDS of the previous month, i.e., the simulated TDS in the well, and thus controls the overall degradation rate. For both seepage factors, smaller values simulate more dilution, and a value of one indicates no dilution. Both the incremental term and the overall equation are multiplied by seepage factors to yield:

$$TDS_{well(p)} = \left[TDS_{well(p-1)} + \left(\frac{TDS_{source} - TDS_{well(t_0)}}{L} tT \frac{i}{n * b} \right) S_{inc} \right] S_{oa} \tag{10}$$

S_{inc} = incremental seepage factor (acts on the monthly calculated change in TDS). This factor controls the seasonal and year-to-year fluctuations in TDS concentrations.

S_{oa} = overall seepage factor (acts on the monthly calculated total TDS). This factor controls the overall degradation rate.

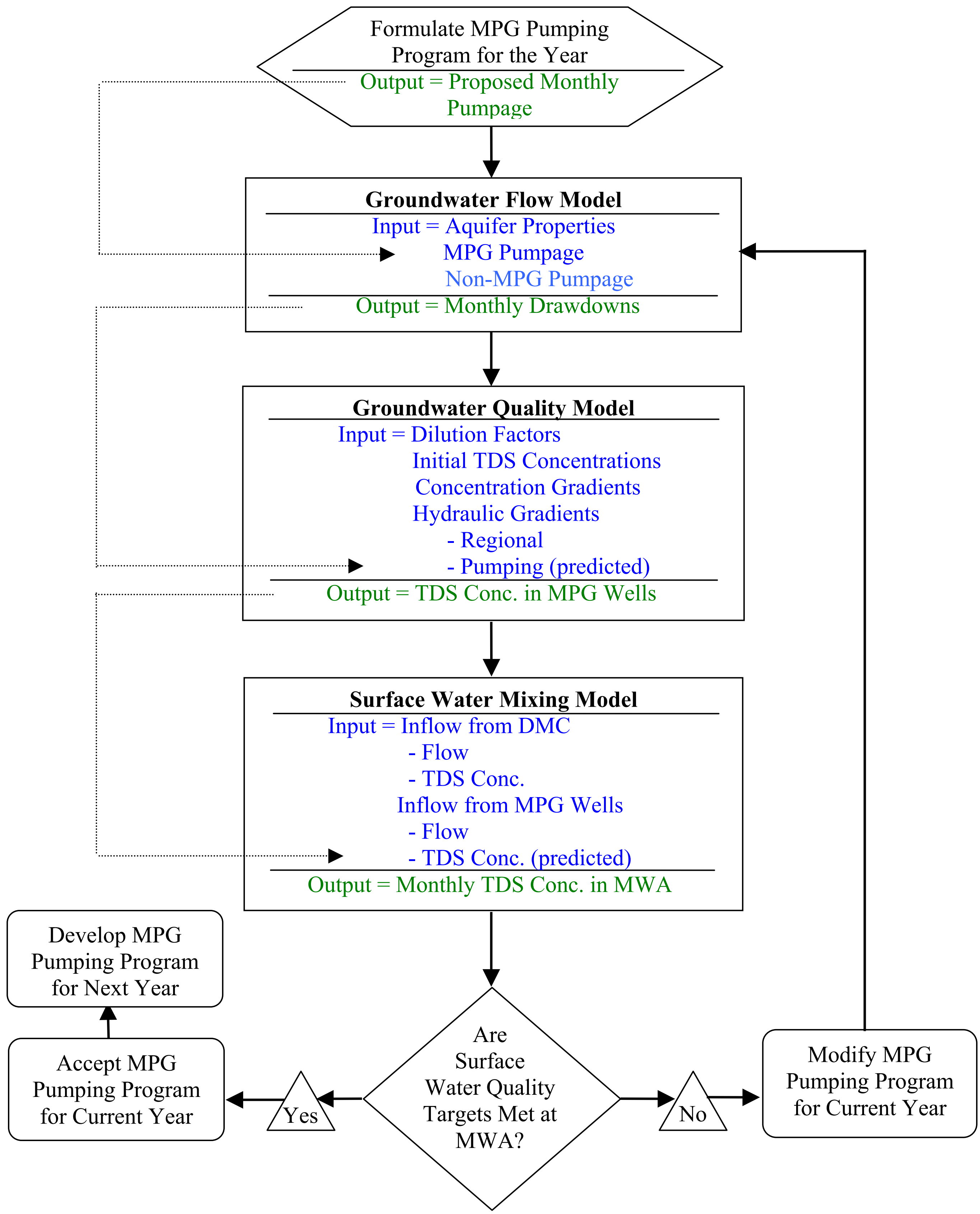

Figure D-1. Flow Chart Showing Application of Groundwater and Surface Water Models

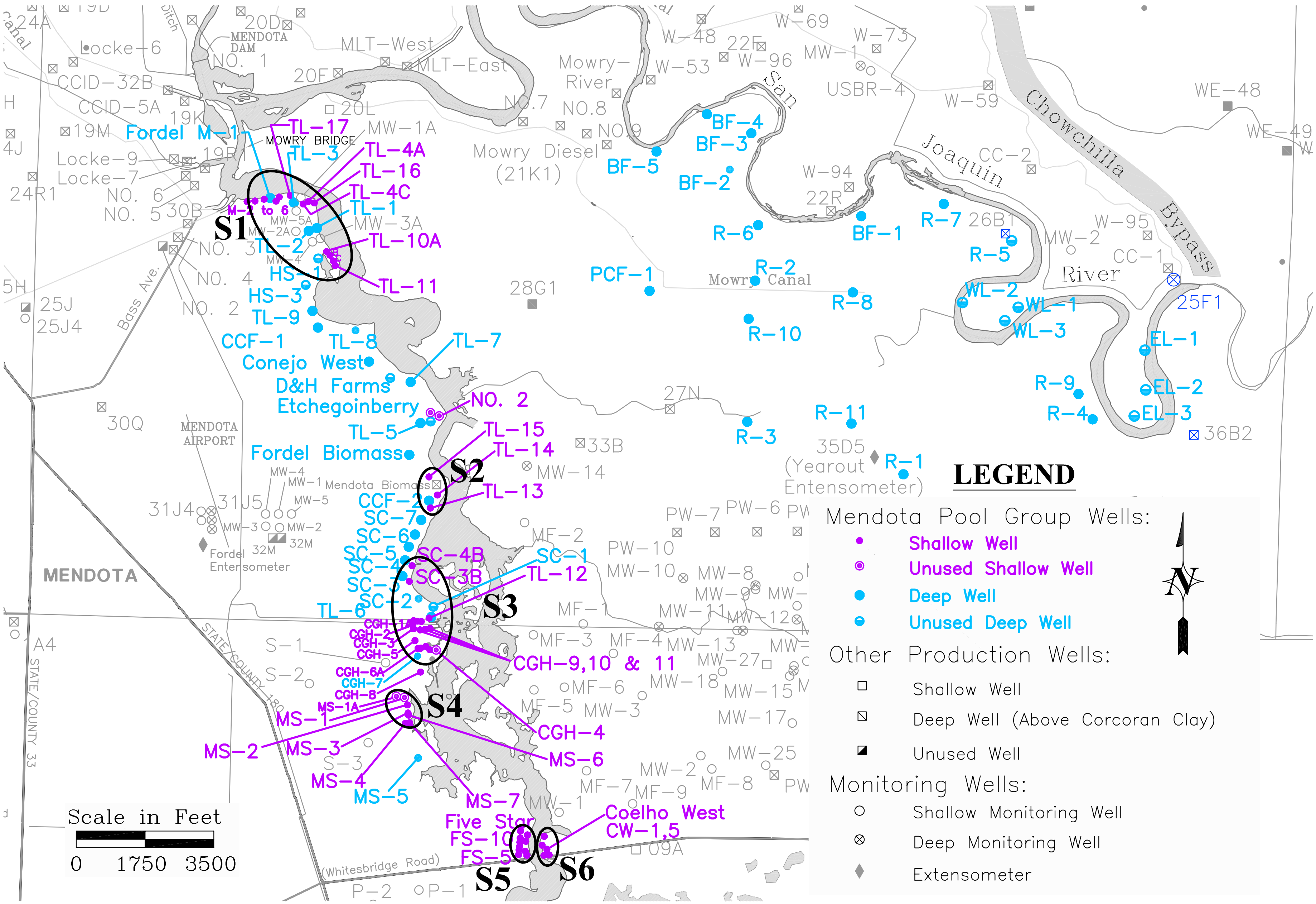

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Figure D-2
Well Clusters Used for Shallow Zone Groundwater Quality Model

Figure D-3: Simulated and Measured TDS at Shallow Wells in Cluster S1 (North)

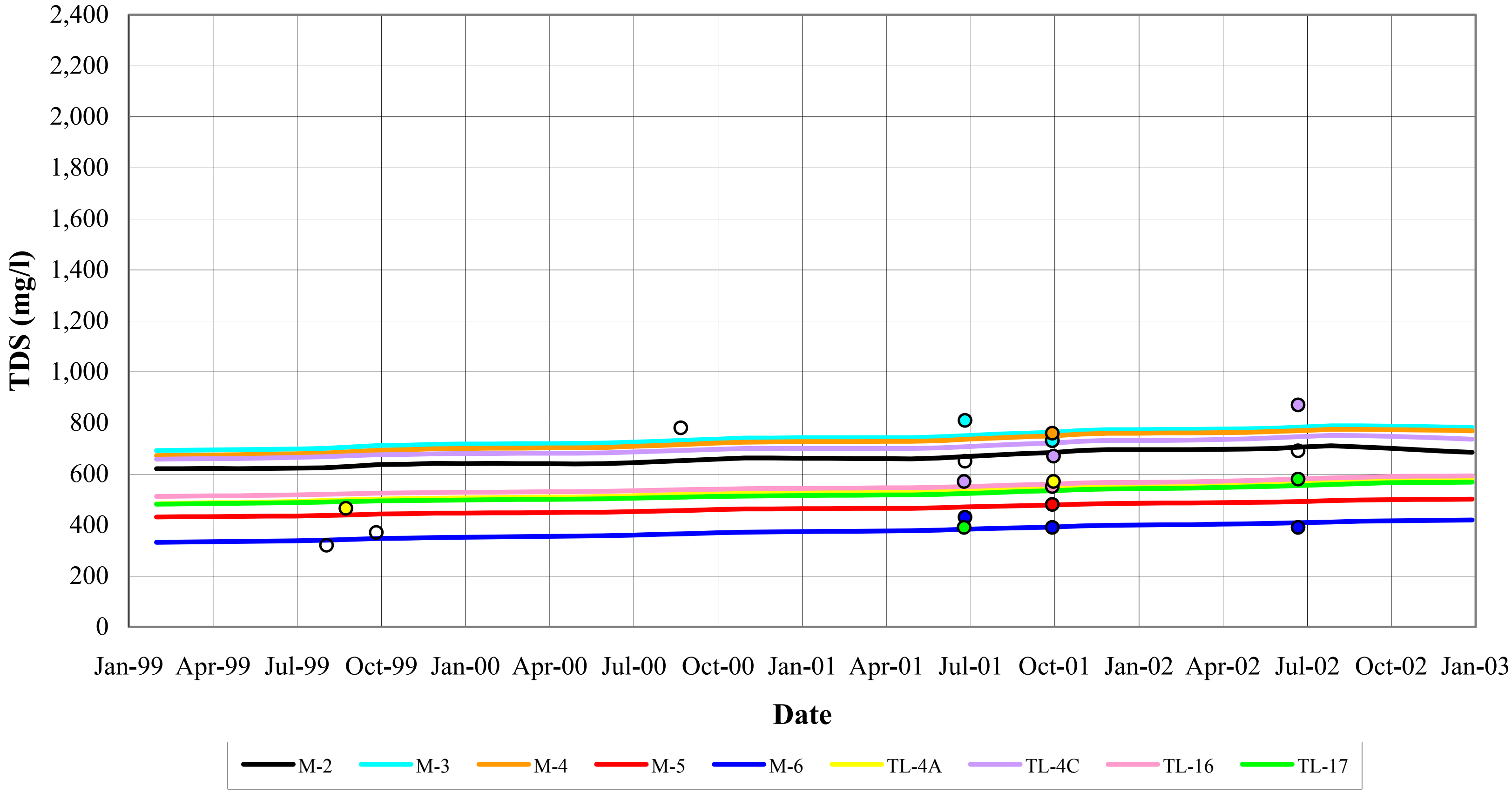


Figure D-4: Simulated and Measured TDS at Shallow Wells in Cluster S1 (South)

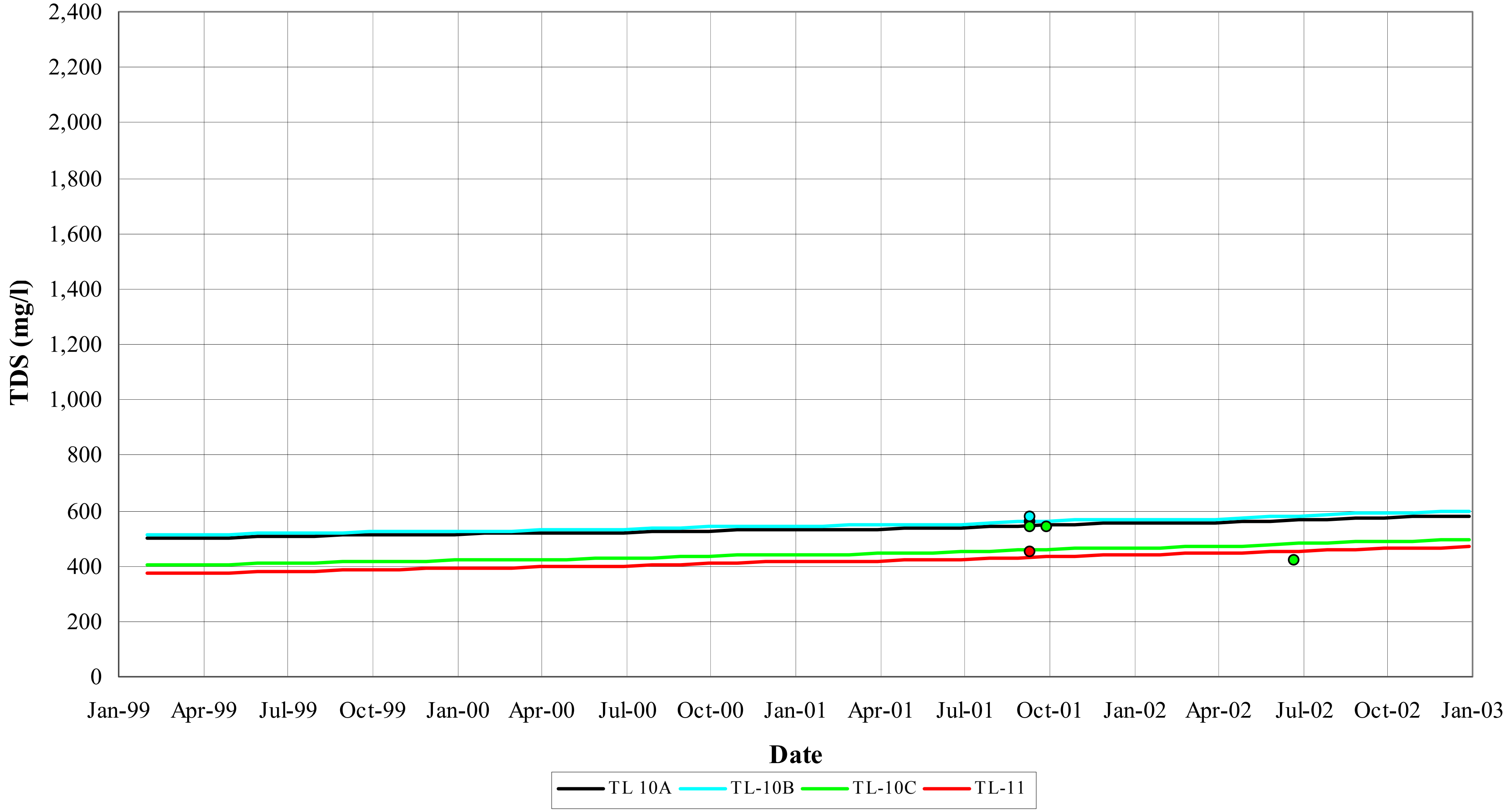


Figure D-5: Simulated and Measured TDS at Shallow Wells in Cluster S2

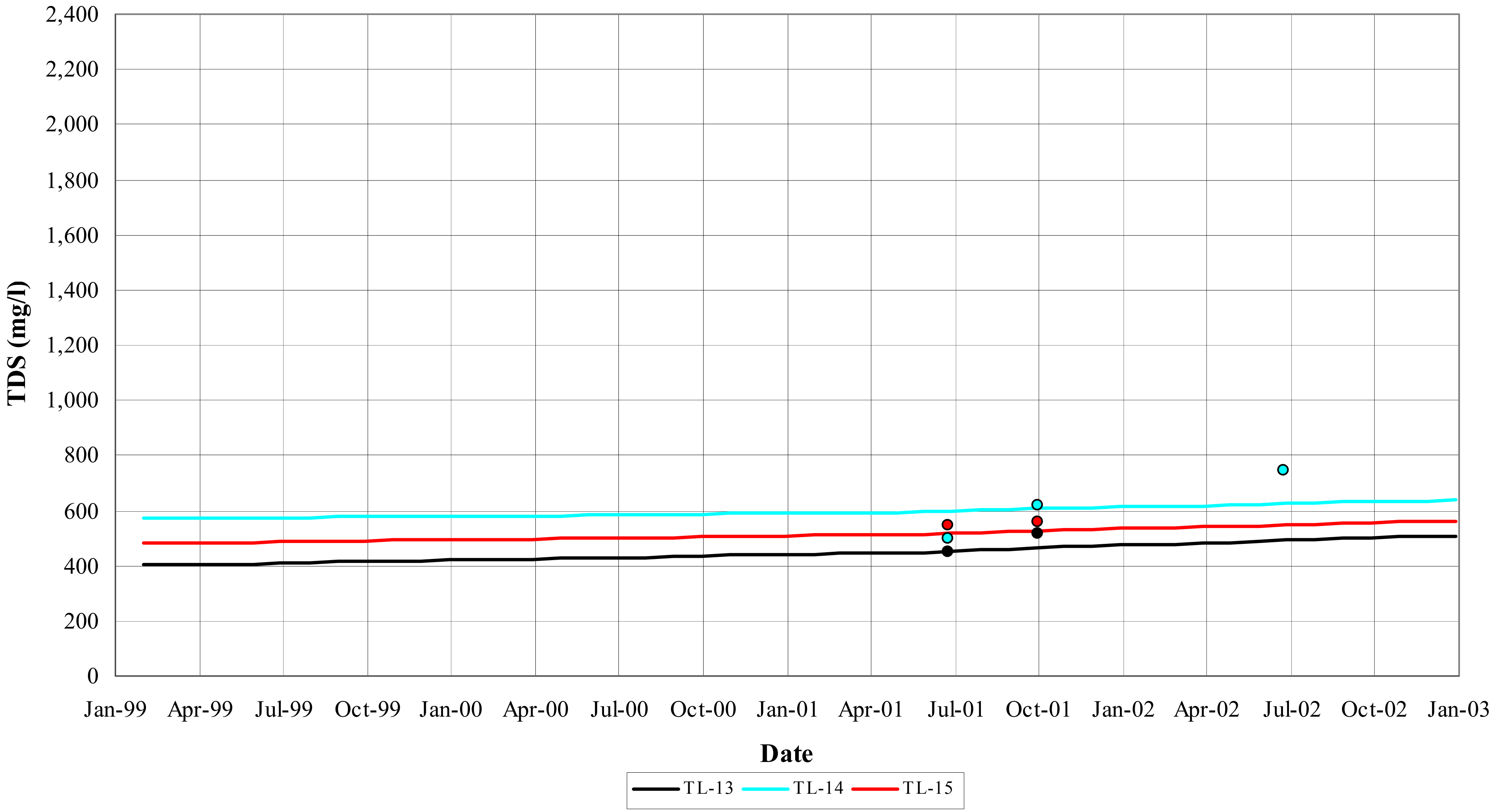


Figure D-6: Simulated and Measured TDS at Shallow Wells in Cluster S3

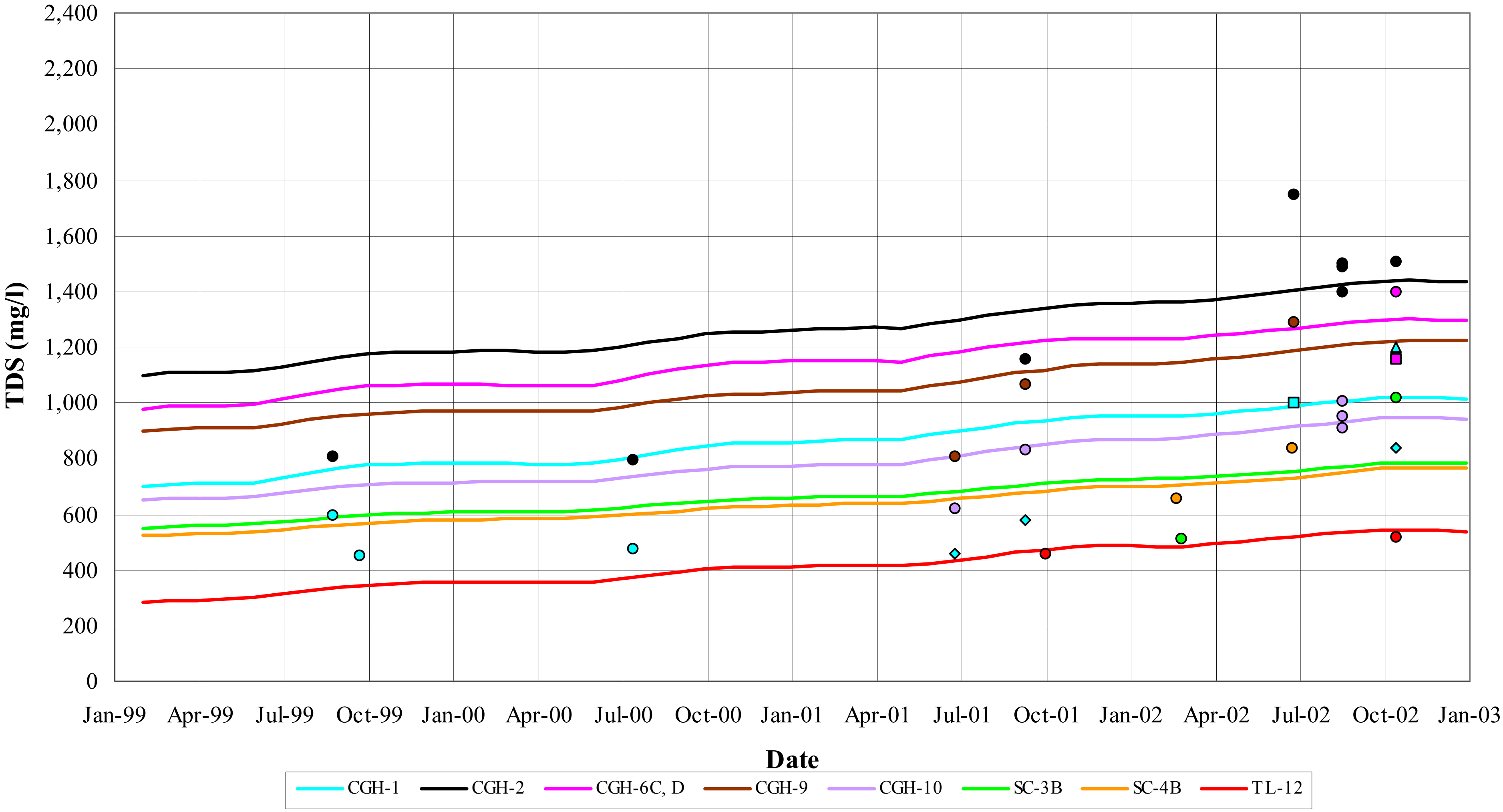


Figure D-7: Simulated and Measured TDS at Shallow Wells in Cluster S4

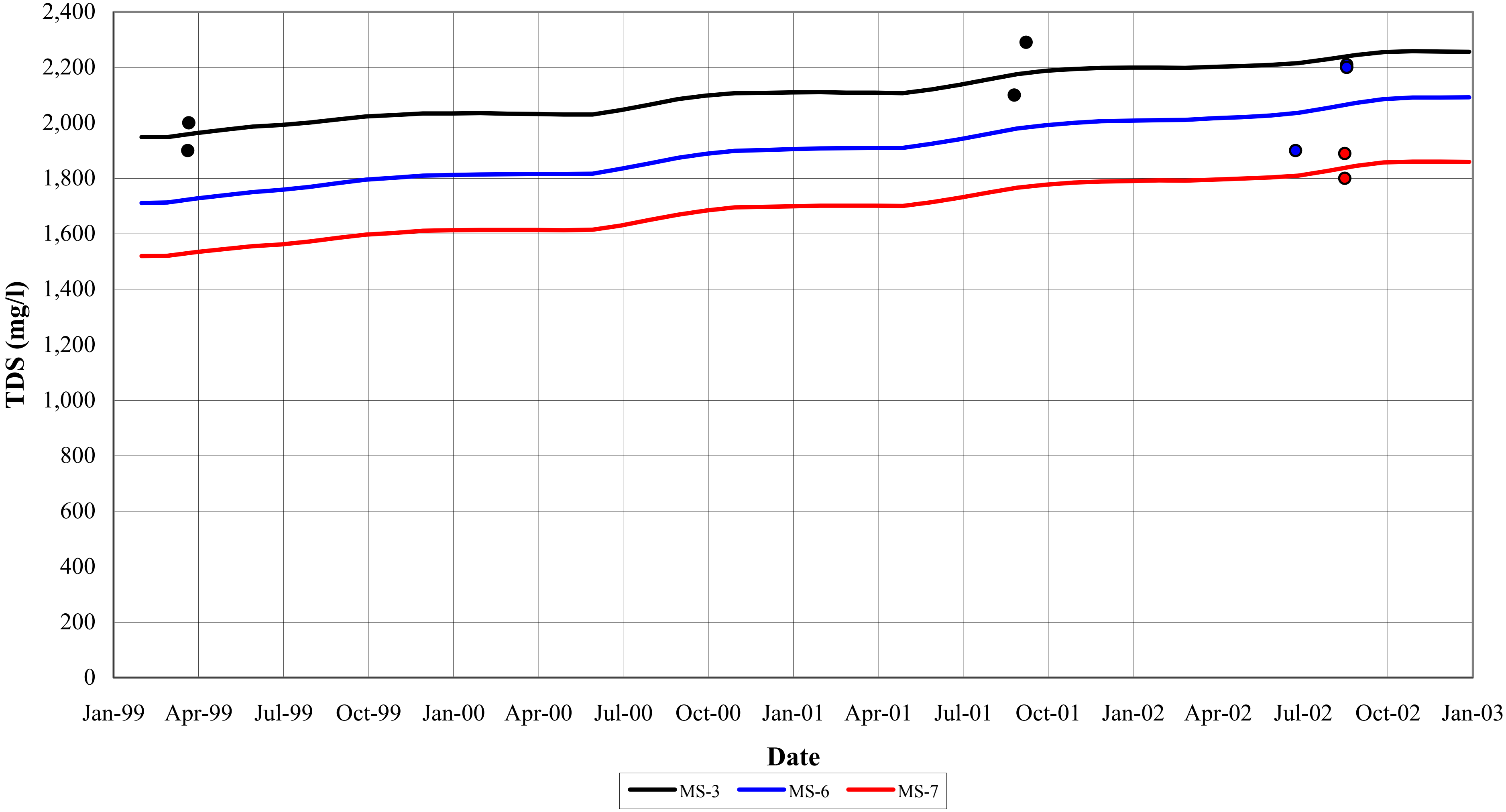


Figure D-8: Simulated and Measured TDS at Shallow Wells in Cluster S5

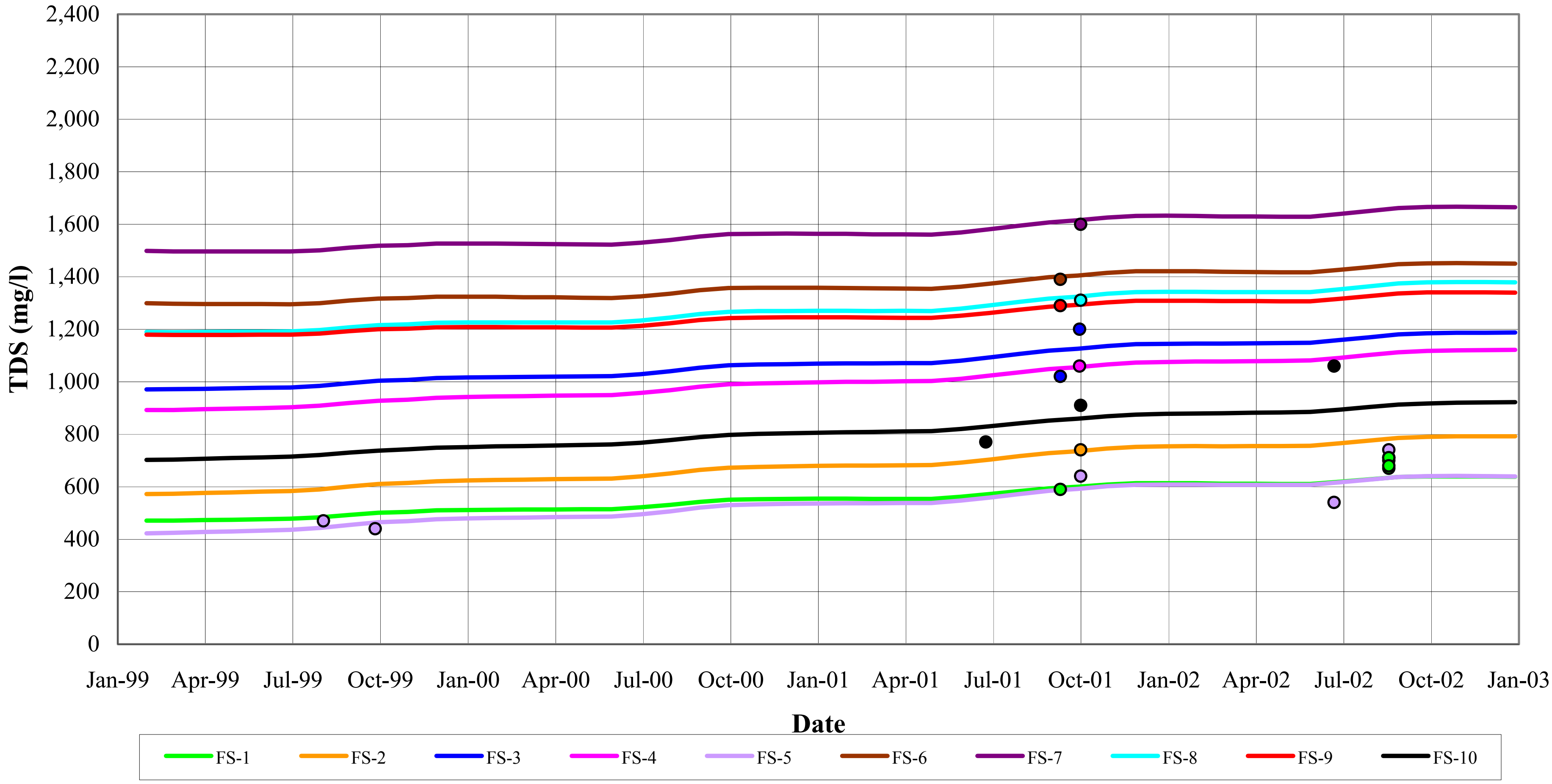
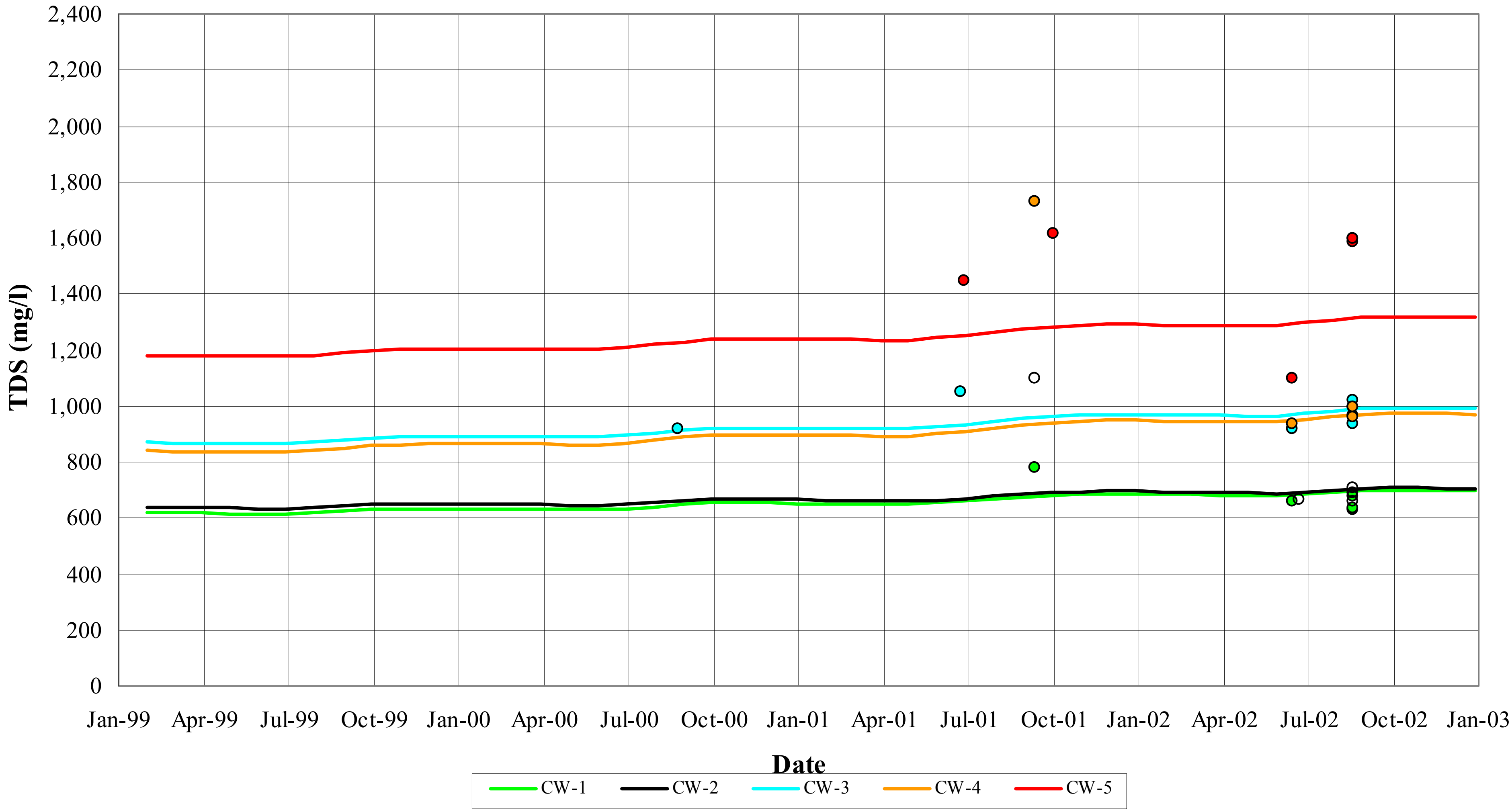


Figure D-9: Simulated and Measured TDS at Shallow Wells in Cluster S6



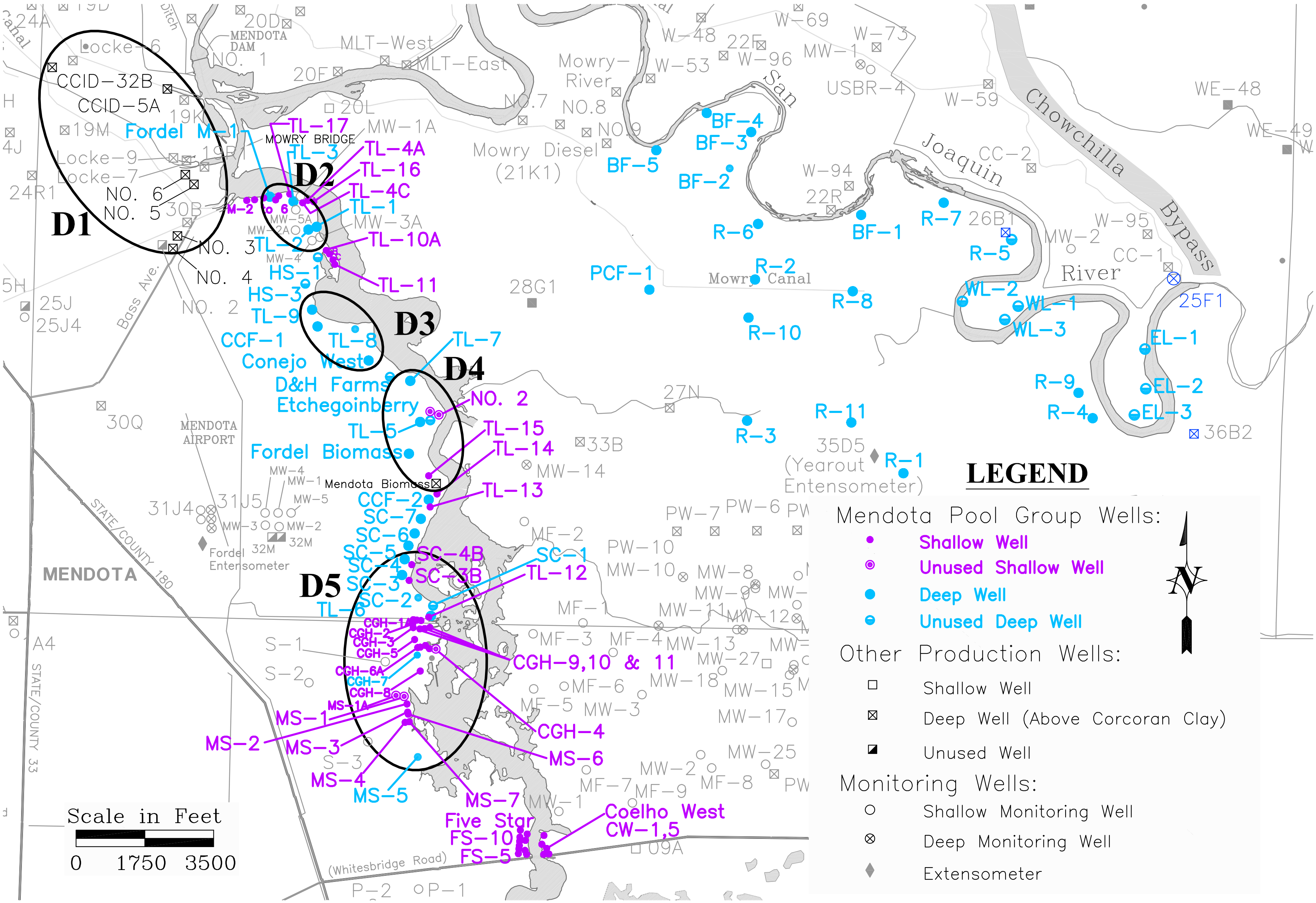


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Figure D-10
Well Clusters Used for Deep Zone Groundwater Quality Model

Figure D-11: Simulated and Measured TDS at Deep Wells in Cluster D1

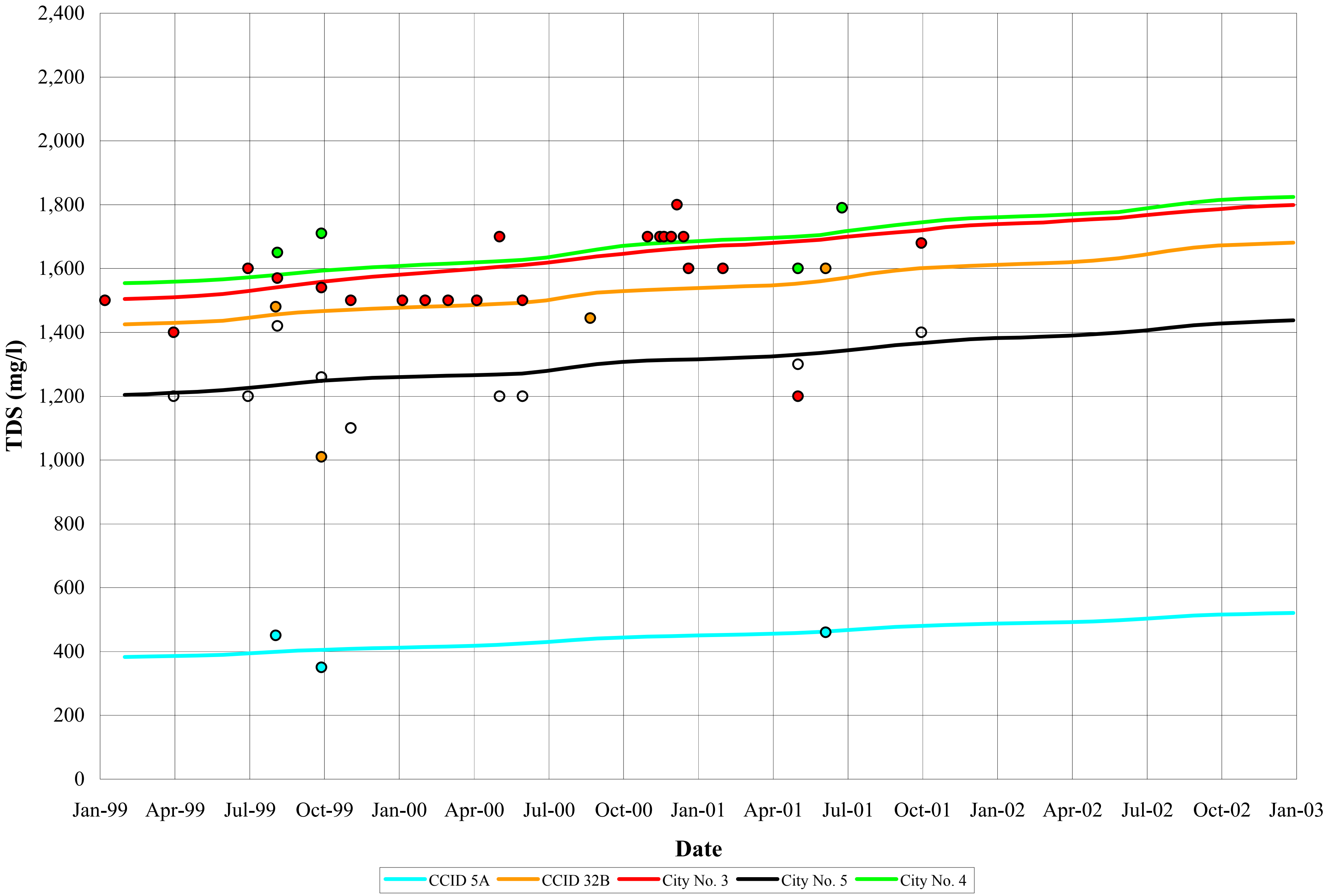


Figure D-12: Simulated and Measured TDS at Deep Wells in Cluster D2

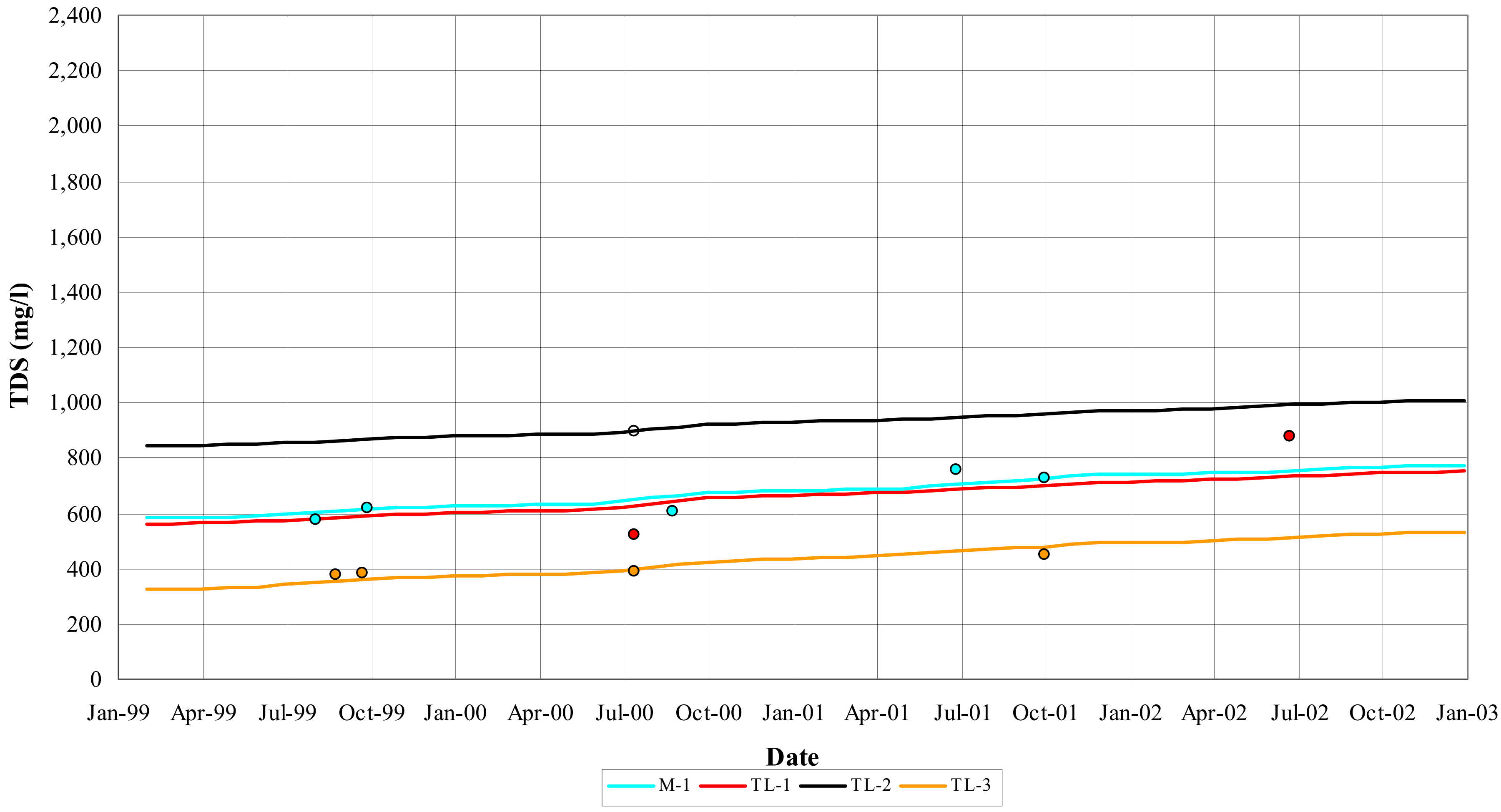


Figure D-13: Simulated and Measured TDS at Deep Wells in Cluster D3

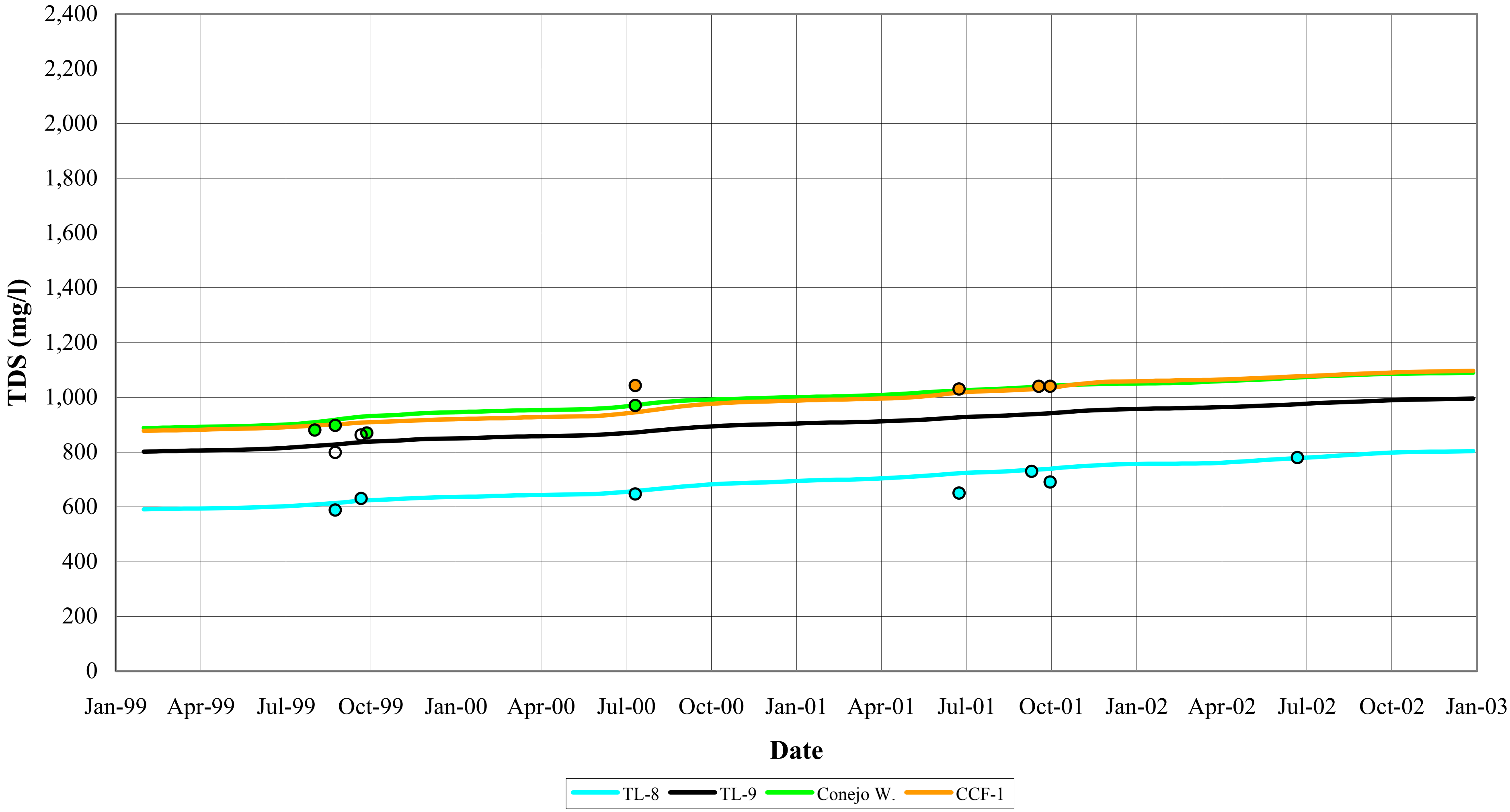


Figure D-14: Simulated and Measured TDS at Deep Wells in Cluster D4

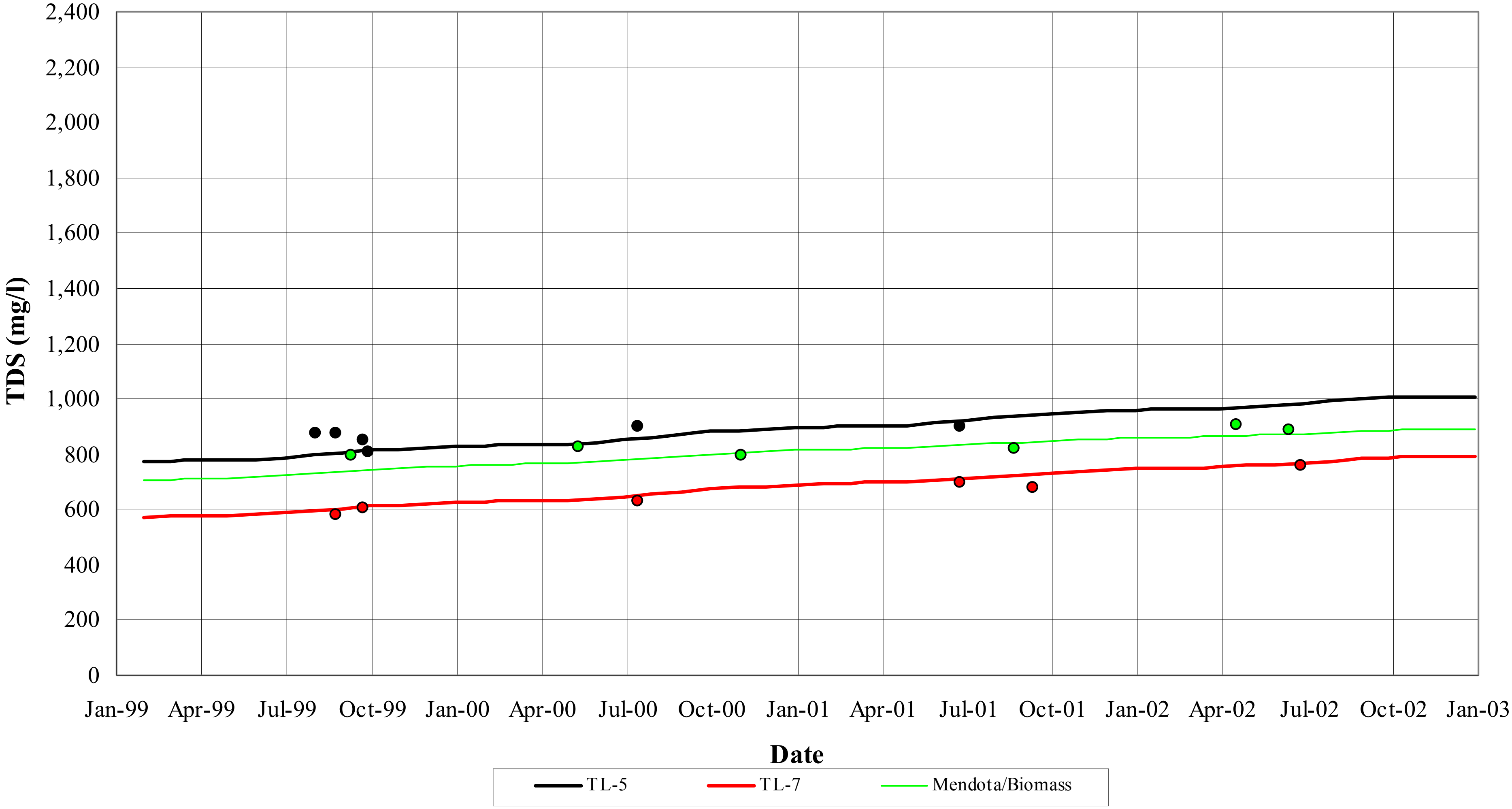
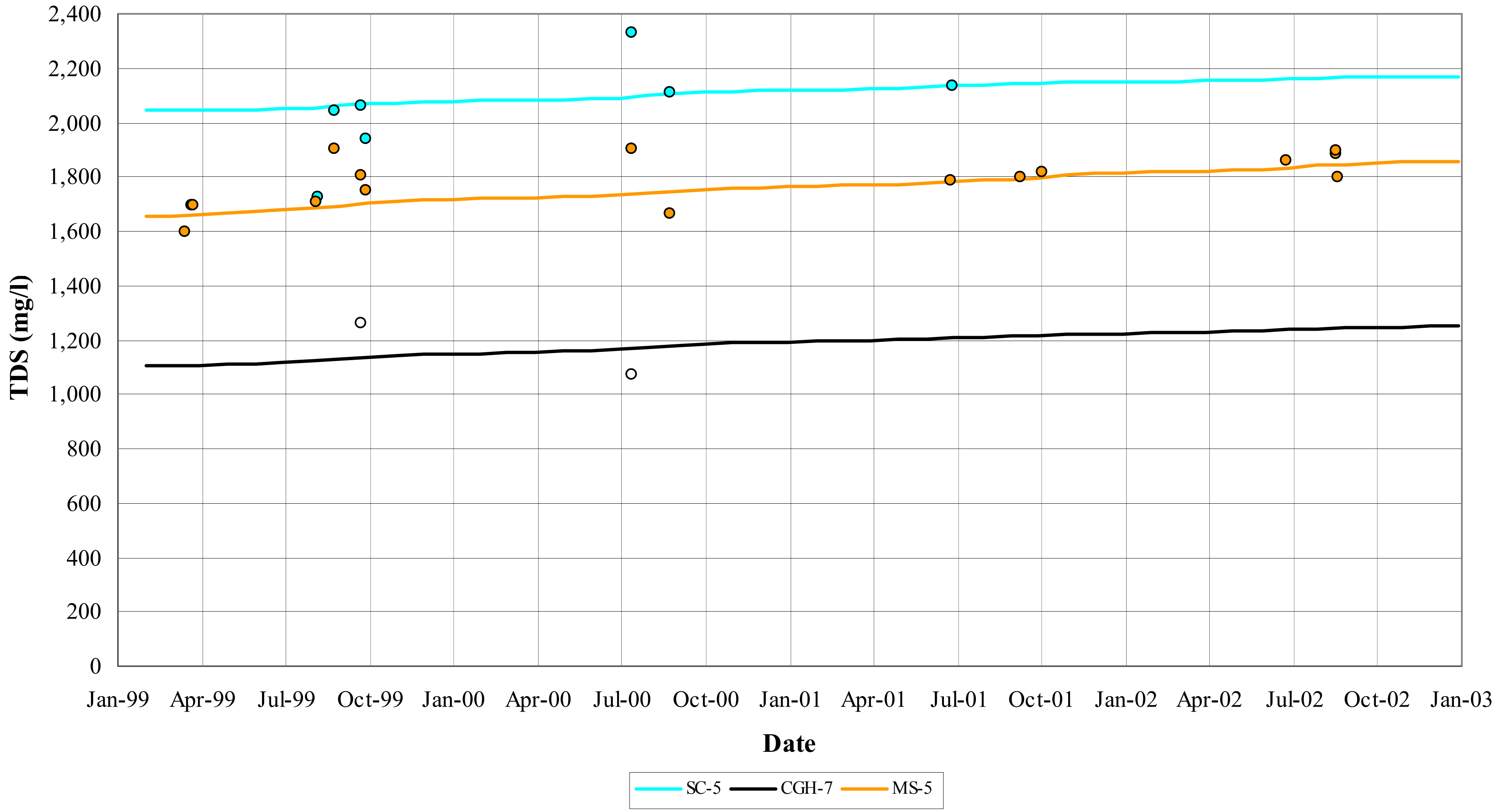


Figure D-15: Simulated and Measured TDS at Deep Wells in Cluster D5



APPENDIX E

COST OF WATER CALCULATIONS

Table E-1. PROPOSED ACTION

Cost Estimation	Pumping Costs (per af)
Groundwater extraction costs	$ 38.63
Reclamation charges	$ 6.50
SLDMWA charges	$ 15.00
Westland Water District Charges	$ 12.00
Monitoring, Instrumentation, and reporting	$ 10.50
Environmental documentation and permits	$ 1.75
Other expenses	$ 1.20
Total cost per acre - foot	**$ 85.58**

	# years	**Total Pumping (af)**	**Exchange w/ USBR (af)**	**Local Exchange**
Normal year	**6**	**31600**	**25000**	**6600**
Dry year	**2**	**40000**	**25000**	**15000**
Wet year	**2**	**0**	**0**	***0***

Total cost over 10 years : $19,804,648.00

Total cost per af exchanged: $ 99.02 (= Total cost over 10 years/200,000)

Table E-2 NEW WELL CONSTRUCTION

Number of wells needed:		75				
One time costs:						
Well Cost:		$250,000				
Loan taken - Number of years:		15				
Interest (%):		0.06				
Monthly Payment:		$2,109.64				
Total Well Cost:		**$379,735.57**				
Infrastructure Costs: *- Cost Piping ($/ft):*	*$*	*40.00*				
- Pipe needed (ft):		*297000*	=1.5 miles * 75 wells			
Total Infrastructure cost:	**$**	**11,880,000.00**				
Pumping Cost per af:						
Groundwater extraction costs	$	50.00				
Reclamation charges	$	-				
SLDMWA charges	$	-				
EIS Preparation	$	1.75				
Westland Water District Charges	$	12.00				
Other expenses	$	1.20				
Total Pumping Costs per af:	**$**	**64.95**				
Boosting Cost per af:						
Boosting Rate:	$	14.00				
Acre-feet boosted:	$	8,333.33				
Boosting Cost per af:	**$**	**4.67**				

POOL		**# years**	**Total Pumping (af)**	**Exchange w/ USBR (af)**	**Local Exchange**
Normal year		**6**	**9,000**	**0**	**9,000**
Dry year		**2**	**9,000**	**0**	**9,000**
Wet year		**2**	**9,000**	**0**	**9,000**
Pumping		**8**	**25,000**		
GW Extr costs (Pool Wells):	**$**	**38.63**			

Total cost over 10 years:	**$**	**57,760,201.28**	=# Wells*Cost+ ***Infr Costs*** +(Boosting/Pumping Costs)*200,000+(GW Extr costs)*10*9,000
Total cost per af exchanged:	**$**	**289**	(= Total cost over 10 years/(8*25,000)

Table E-3 LAND FALLOWING

Crop Value (/acre /year)	$	2,003	
Water required (af per acre per year)		2.5	
Number of acres for 1 employee		90	
Minimum Wage (per hour)	$	6.75	
Annual wage	$	14,040.00	(=Min wage *2080)
EIS Preparation: Cost for 10 years:	$	350,000.00	
Other Expenses (per af):	$	1.20	

	# years	Acres Fallowed	Employees Reduction	Total Pumping (af)	Exchange w/ USBR (af)	Local Exchange
Normal year	**6**	**10000.00**	**111**	**9,000**	**0**	**9,000**
Dry year	**2**	**10000.00**	**111**	**9,000**	**0**	**9,000**
Wet year	**2**	**0**	**0**	**9,000**	**0**	**9,000**
Pumping	**8**	**0**	**0**	**25,000**		

Total Crop Loss for 10 years :	**$**	**160,278,089.20**	=8*10,000 *Crop Value
Total Labor Loss for 10 years:		$12,480,000.00	=8*111 * Annual Wages
Crop Loss (per af of water)	$	801.39	=Crop Loss / (8*25,000)
Labor Loss (per af of water)	$	62.40	= Labor Loss / (8*25,000)