COUNTY OF INYO
WATER DEPARTMENT

STAFF REPORT

Water Table Fluctuations Due to Pumping by Wells Exempt From the Well Turn-Off Provisions of the Inyo/Los Angeles Long Term Groundwater Management Agreement.

August 24, 2007

Executive Summary

The Long-Term Water Agreement between Inyo County and the City of Los Angeles (Agreement) requires that the Los Angeles Department of Water and Power (LADWP) operate its groundwater production wells in the Owens Valley according to a management protocol where the operational status of each well is determined by conditions at a specific monitoring site. If available soil water is insufficient to support the vegetation at the monitoring site, the well may not be operated. The well turn-off provisions of the Agreement were implemented in 1991. Twenty-eight wells have been exempted from the Agreement's well turn-off provisions because they are the sole source of supply water for towns, irrigation, and fish hatcheries, or their operation allegedly does not affect areas with groundwater-dependent vegetation. Exempt well pumping has comprised 61% of LADWP's pumping in the Owens Valley from 1991 through 2004; thus, greater than half of the pumping done to-date under the Agreement was exempt from the well turn-off provisions of the Agreement.

This report presents results of a groundwater modeling study undertaken to evaluate (1) the effect that exempt well pumping has had on the water table from 1991 through 2004, and (2) what would be the likely effect of exempt well pumping if it continues indefinitely. This study was motivated by the concern that modifications to the Agreement's well turn-off provisions may be insufficient to meet the Agreement's vegetation goals if exempt pumping causes unfavorable water table conditions. Baseline vegetation conditions were evaluated during the mid-1980's, and it is assumed that groundwater levels prevailing at that time were an important factor controlling the mapped vegetation conditions. Modeling of historical impacts indicated that in areas

surrounding concentrations of exempt well pumping, groundwater levels are depressed below the levels that would have prevailed had the exempt wells not been operated. Modeling of future exempt pumping impacts indicated that mean water levels at monitoring sites would be above baseline levels in the Laws and Taboose-Aberdeen wellfields; within a few feet of baseline in the Big Pine, Thibaut-Sawmill, Bishop Cone, and Bairs-Georges wellfields; and more than a few feet below baseline in the Independence and Symmes-Shepherd wellfields.

The water table in the area from Independence to Manzanar could be depressed below baseline levels by future exempt well pumping, because exempt well pumping in this area could lead to higher pumping rates than existed during the baseline period. The majority of the wells in the Independence area were exempted for "no impact to groundwater dependent vegetation," however this study indicates that the impact from these wells extends into areas of groundwater dependent vegetation. The Inyo/LADWP Technical Group should reevaluate the validity of the exemptions granted for wells that were not expected to impact the water table in areas of groundwater dependent vegetation.

Introduction

The Long-Term Water Agreement between Inyo County and the City of Los Angeles (Agreement) requires that the Los Angeles Department of Water and Power (LADWP) operate its groundwater production wells in the Owens Valley according to a management protocol where the operational status of each well is determined by conditions at a linked permanent monitoring site. Currently, twenty-two monitoring sites are linked to sixty production wells. Generally, if available soil water is insufficient to support vegetation at the monitoring site, the well may not be operated. The specific procedures for determining the operational status of wells are given in the technical appendix to the Agreement (Green Book). Green Book section I.C also provides that:

> *Pursuant to Section II.C of the Agreement, the Technical Group has designated certain pumping wells which are exempted from linkage to vegetation sites and are not subject to the well turn-off provisions. These exempt wells are specialized cases which are the sole source of supply water for towns, irrigation, and fish hatcheries, or their operation does not affect areas with groundwater-dependent vegetation. The wells exempted are 354, 341, 330, 332, 118, 351, 356, 357, 344, and 346. These exemptions will be reconsidered as appropriate.*

The Technical Group subsequently designated an additional eighteen wells as exempt from the well turn-off provisions of the Agreement, for a total of twenty-eight exempt wells as of 2004 (Table 1).

A key goal of the Agreement is to manage water resources to avoid declines in water-dependent vegetation from those conditions that prevailed during the mid-1980's. From 1984 through 1987, LADWP surveyed vegetation on Los Angeles-owned land throughout the Owens Valley. This survey was based on field visits and analysis of aerial photographs, and resulted in a map delineating areas of groundwater-dependent vegetation on LADWP lands. Vegetation cover and species composition data were collected within units of relatively homogeneous vegetation (parcels), and each parcel was assigned to a plant community and vegetation type. In the context of the Agreement, the vegetation map defines the baseline vegetation conditions that are used as a standard for evaluating whether vegetation conditions are changing due to LADWP water management practices.

During the period 1991-2004, annual exempt well pumping has averaged 46,373 acre-feet yr^{-1}, with a maximum of 54,945 acre-feet during 2003 (Table 2). Exempt well pumping has constituted the majority of LADWP's pumping under the Agreement: since the on/off management was adopted and well exemptions were first granted in 1991, exempt well pumping has comprised 61% of LADWP's pumping in the Owens Valley. The effectiveness of vegetation monitoring sites for governing operational status of production wells may be compromised if exempt wells affect water levels at monitoring sites.

The purpose of this report is to determine the effect of exempt-well pumping on the water table. Two analyses were conducted: the first evaluates the effect that exempt well pumping has had on the water table from 1991 through 2004. This retrospective evaluation examines how water tables have been affected by exempt wells over the term of the Agreement. The second analysis examines the potential long-term effect that exempt well pumping would have on water tables at selected permanent monitoring sites if such pumping continued indefinitely.

Methods

The primary tool used in this analysis is a groundwater flow model of the Owens Valley developed by the USGS for LADWP and Inyo County as part of a cooperative study (Danskin, 1998). The model was developed using the MODFLOW computer model of groundwater flow (McDonald and Harbaugh, 1988). A detailed discussion of the philosophy, conceptual basis, development, use, and limitations of USGS Owens Valley model is given in Danskin (1998). To evaluate the impacts of exempt well pumping, two analyses were done, each consisting of multiple transient model runs. In a transient model run, inputs to the model, such as groundwater recharge, groundwater pumping, and irrigation return flows, vary over time, thus causing water levels to also vary. In contrast, a steady-state model run is one where model inputs are held constant resulting in the model producing water levels that do not change over time.

Modeling historical impacts of exempt well pumping. The first set of model runs consisted of two transient runs simulating the period 1963 through 2004. One of these runs used pumping and recharge as actually occurred; the other run was identical to the first run through 1990, and then from 1991 through 2004, no exempt well pumping was input into the model. Thus, the second model run simulated conditions that would have resulted if no exempt well pumping had taken place from 1991 through 2004. The difference in water table elevations resulting from these two model runs is the impact of historical exempt well pumping on water levels from 1991 through 2004. The purpose of this analysis was to estimate the radius of influence of exempted wells.

Modeling long-term effects of exempt well pumping. The second set of model runs was performed to estimate the long-term pumping effects at permanent monitoring site locations under conditions of maximum exempt well pumping rates. These consisted of 86 simulations, each 58 years long, with constant exempt well pumping and stochastically varying recharge. In stochastic simulations, model inputs are allowed to vary randomly in order to mimic the inherent interannual variability and unpredictability in climate-driven inputs such as recharge from seasonal snowmelt. Each of these simulations is a single realization of how recharge might fluctuate over time, and the eighty-six simulations taken together provide a sample from which statistics can be calculated to estimate the probability of the water table being at any particular level at a given location. These model runs and resulting probabilities provide estimates of the frequency with which water levels that existed during the baseline vegetation mapping period would be attained if only exempt wells were operated.

Pumping. To evaluate the effect of exempt well pumping for the period 1991-2003, exempt well pumpage for the period 1991-2004 was extracted from LADWP's pumping records (Table 2). The entire pumping record was used in the first model run; exempt well pumping was removed from the pumping record in the second run.

For the stochastic simulations, a pumping rate for each well was assigned based on the purpose of its exemption (e.g., irrigation, town supply), its pumping capacity, and its historical pumping rate. If a well was exempted due to having no impact on groundwater-dependent native vegetation, it was assumed that it would pump at its full capacity. Sole-source supply wells were assigned their mean pumping rate from the period 1991-2004, on the assumption that the rate of pumping done during that time period best represents current management practice and provides the best estimate of the amount of water needed to supply the sole source use. Table 3 presents the constant pumping rates that were used in the stochastic model runs. Wells that are exempted for irrigation were assumed to pump at full capacity for the duration of a seven-month irrigation season. Deviations from historical pumping rates or from other assumptions made regarding future exempt pumping rates would result in concomitant deviations from the predicted water table conditions. The total annual pumping given in Table 3 (65,476 af yr^{-1}) is an approximation of maximum exempt well pumping.

Flowing wells. Discharge from each flowing well was held constant at its discharge rate in 1996, 7,159 af, which was the year of median total flowing well discharge for the period 1963-2004. Flowing well discharge actually varies over time in response to changes in head, ranging from from around 3,000 to 12,000 af yr^{-1}, but since flowing wells are a minor component of the water balance, holding flowing well discharge constant was an expedient simplification that imparts little error to the calculated water balance and hydraulic head. Allowing flowing well discharge to be modulated by changing aquifer pressure would result in smaller variations in water level than those simulated here.

Recharge. Aquifer recharge results from infiltration of precipitation, from stream channels, mountain front interfluves, canals, groundwater recharge operations, and irrigation. Recharge from precipitation was considered to be temporally constant in both the historical and stochastic analyses. Danskin (1998) simplified the estimation of recharge from stream channels and on mountain-front interfluves by using percent of mean gauged Owens Valley runoff as an index of annual recharge, using various regressions of stream channel percolation loss against percent of mean runoff. Danskin (1998) used the period 1935-1984 to calculate mean runoff, which he reported as 469,604 af. Since Danskin's work was completed, LADWP has made various corrections and modifications to its accounting of Owens Valley runoff, and using their latest figures, the mean runoff for 1935-1984 is 433,532 af. LADWP calculates percent of mean runoff based on fifty-year means recalculated every five years, and the most recently calculated mean runoff (for 1951-2000) is 417,209 af. In this study, the mean runoff for the period 1963-2003, 423,513 af, was used to calculate percent of normal runoff for each runoff year during that period, so as to ensure that 100% of mean runoff corresponded to the mean value for the period of the model runs. These various renditions of mean runoff show the merit of Danskin's (1998) strategy of using percent of normal runoff rather than runoff volume as an index for estimating runoff-related recharge components. If runoff volume were used as an index, discrepancies and corrections to the calculation of runoff would require that the regression equations upon which recharge estimates are based be reparameterized, whereas using percent of mean runoff allows the mean runoff to change without necessitating derivation of new regression coefficients.

Time-series of Owens Valley runoff were synthesized for the stochastic model runs using the statistics of observed runoff for the period 1935-1999 and the method cited by Haan (1977, p. 295) for generating lognormal autocorrelated time-series. The coefficients for generating synthetic time-series of Owens Valley runoff were developed in Harrington (2001). These runoff time-series were then used to generate stream channel and mountain front recharge for input into the model.

The probability of water tables attaining or exceeding baseline levels at monitoring sites was evaluated by 86 model runs where pumping was held constant (Table 3) and recharge indexed to runoff was allowed to vary randomly according to a lognormal autocorrelated probability distribution. Each model run was 58 years long, but the first eight years of each run was discarded to eliminate any model initialization artifacts (e.g., where the hydrograph rises or falls rapidly during the first few years of the model run, and thereafter fluctuates around a constant mean). This resulted in 86 model outputs, each 50 years long. The model output was examined at the location of each monitoring site to determine the fraction of time that the water table was above baseline, and the median duration of time that the water table was below baseline.

In order to examine relative change over time, baseline water table elevation for each site was defined as the mean of the 1985, 1986, and 1987 modeled water levels. Baseline water levels were used as a standard for assessing exempt well pumping impacts to the water table because it is assumed that the water levels that prevailed during the mid-

1980's were related to the vegetation conditions mapped at that time. Other definitions of baseline may be preferable based on ecohydrological considerations. For example, the maximum water table elevation or the water table elevation immediately prior to mapping are probably a more relevant indicators of how much groundwater was available to plant roots when the baseline vegetation conditions were mapped. For the analysis presented here, the average modeled water level during the baseline mapping is a simple approach, which allows comparison between historical conditions and modeled future conditions, because within the model output water levels are consistent with regard to response to stresses. The median duration of time below baseline is of interest because the ecological effects of disconnecting the water table from the root zone may depend on both the length of time that the root zone is disconnected and the overall fraction of the time that the water table is disconnected.

Results

Historical impacts of exempt well pumping. The amount of water table depression attributable to exempt well pumping is the difference between the water table modeled with pumping as it actually occurred (Table 2) and the water table modeled with all exempt well pumping removed from the model input. Figures 1 through 4 show the amount of water table depression in groundwater-dependent vegetation parcels that is attributable to exempt well pumping. Figures 1 through 4 also show the locations of exempt wells and vegetation monitoring sites. These model runs show which areas have been impacted by exempt wells.

The Laws and Bishop areas (not shown in figures) have not historically been subject to large volumes of exempt well pumping (Table 2). Figure 5 shows that the hydrograph for well V001G, located at monitoring site L2, corresponds fairly well to the modeled hydrographs for both actual pumping and no exempt well pumping. A small deviation between the two modeled hydrographs begins in 2002 due to increased pumping from wells W365 and W236 to a nearby pasture that is irrigated with pumped water. Figure 5 illustrates the relatively small amount of stress imposed on the L2 monitoring site by historical exempt well pumping. Other monitoring sites in the Laws and Bishop wellfields are more distant from exempt well locations than the L2 site and show negligible impacts. The McNally canals were assumed to run every year and provide 5,325 af yr^{-1} of recharge, identical to how this recharge component was handled by Danskin (1998). It would be more accurate to allow recharge from the McNally canals to vary between years, however the relative difference between the model runs done for this study would be unaffected.

The impact of exempt wells W330 and W332 on the Big Pine area is evident in Figure 1. According to the model results, the Baker Creek area west of W341 is impacted more by wells Fish Springs Hatchery wells W330 and W332 than by Big Pine town supply well W341 due to the much larger volume of water pumped by W330 and W332 (Table 2). Faults isolate the Baker Creek area and surface water spreading buffers any actual pumping impacts to this area; hydrographs from piezometers in this area have perennially high water tables. Because these local hydrogeologic features are not represented in the model, pumping impacts on the water table in the Baker Creek area are overestimated by the model. The modeled impact in the area east of wells W330 and W332 is consistent with observed hydrographs. Figure 6 shows observed and modeled hydrographs for the vicinity of monitoring site BP4, approximately 0.8 miles east of wells W330 and W332. In Figure 6, the hydrograph for well T566 correspond closely with the hydrograph modeled using actual pumping. The modeled hydrograph without exempt well pumping recovers much faster and to a higher level than either the observed or modeled hydrograph with actual pumping. This illustrates the hydrologic stress imposed by exempt well pumping on monitoring site BP4. The spatial extent of this stress appears to be a radius of a few miles (Figure 1).

Figure 2 shows a region of impact due to exempt well pumping centered on Blackrock Hatchery wells W351 and W356. Figure 2 shows extensive water table depression extending north and east of the Blackrock Fish Hatchery. The hydrograph for well T804 located at monitoring site TS4, about 0.5 miles east of wells W351 and W356, shows much smaller interannual fluctuations than those of the modeled hydrographs (Figure 7), suggesting that monitoring site TS4 is buffered from pumping effects (either by surface water or by stratigraphic barriers) to a greater degree than rendered in the model, and that the modeled impact of exempt well pumping at site TS4 is overestimated. Differences between observed and simulated hydrographs may also be due to model discretization effects, where the monitoring well's zone of influence is not representative of the average condition of the 2000-by-2000 foot model cell. Monitoring site TS2 appears to be more affected than TS4 by exempt well pumping despite being farther away. Figure 8 shows a composite hydrograph of wells T582 and T806, both located at site TS4 (well T582 has been dry since 1988).

Exempt well pumping near Independence appears to affect the water table in areas of groundwater dependent vegetation to the north and east of the town (Figure 3). Figure 9 shows the effect of exempt well pumping on monitoring site IO1, about 1 mile north of the town of Independence. Though the hydrograph of well T809 lies about 10 feet above the historical pumping modeled hydrograph, the two hydrographs are roughly parallel, indicating that the model is responding to hydrologic stresses in a realistic manner despite being offset 10 feet too low. The offset of the observed and modeled hydrographs could be due to any of several reasons: the observed hydrograph may be influenced by nearby hydrologic features such as wells or surface water conveyances that cause the observed hydrograph to deviate from the local average water table; the model cell value may not be representative of the conditions at the monitoring well; subgrid-scale features (e.g., perched aquifers or multiple confining layers) may cause the monitoring well to deviate from the larger-scale hydrology rendered in the model; or the model may be inaccurate due to the approximation or inaccuracy of hydraulic parameters or water balance components. Although the model is inaccurate in terms of water table elevation, since it is responding to stresses in a realistic way, the relative difference between the actual pumping and no exempt well pumping hydrographs is credible. The modeled hydrograph without exempt well pumping indicates water tables recovering to about 15 feet higher than under actual pumping by 2004. A broad region of exempt well drawdown extends from Independence south into the Symmes-Shepherd wellfield to the area near well

W402 (Figure 3). At monitoring site SS3, exempt well pumping appears to have depressed the water table about 8 feet (Figure 10). The hydrograph of well T561 lies about 16 ft higher than the modeled hydrograph with historical pumping, indicating a similar situation to site IO1, where the model's water table elevations deviate from monitoring well observations, but the model's response to hydrologic stresses is similar to the monitoring well's response.

Exempt pumping in the Bairs-Georges wellfield has not been large enough to cause significant declines in the water table (Figure 3, Table 2). Exempt well pumping in the Lone Pine area has caused depression of the water table in groundwater dependent vegetation parcels north, east, and south of the town. Though the volume of water pumped from exempt wells in Lone Pine is smaller than areas such as Big Pine, Thibaut-Sawmill, or Independence, the Lone Pine area is relatively sensitive to pumping stress due to the low permeability bedrock of the Alabama Hills shunting groundwater flow from the Sierra Nevada range front to the south or north of the Lone Pine area. This deprives Lone Pine of groundwater inflow from the alluvial fans flanking the Sierra Nevada. Additionally, most of the Lone Pine area is down-slope from the Los Angeles Aqueduct, and Lone Pine and Tuttle Creeks have relatively short runs from the Alabama Hills to where they enter the Aqueduct. The LA Aqueduct is concrete lined in the Lone Pine area. The short wetted stream reaches and aqueduct lining result in relatively little recharge from natural stream channels or the LA Aqueduct in the Lone Pine area. Recharge is primarily from irrigation return flows and percolation from ditches, rather than from stream channels as is the case in the wellfields north of the Alabama Hills. Consequently, the water table in the Lone Pine area is relatively sensitive to changes surface water management.

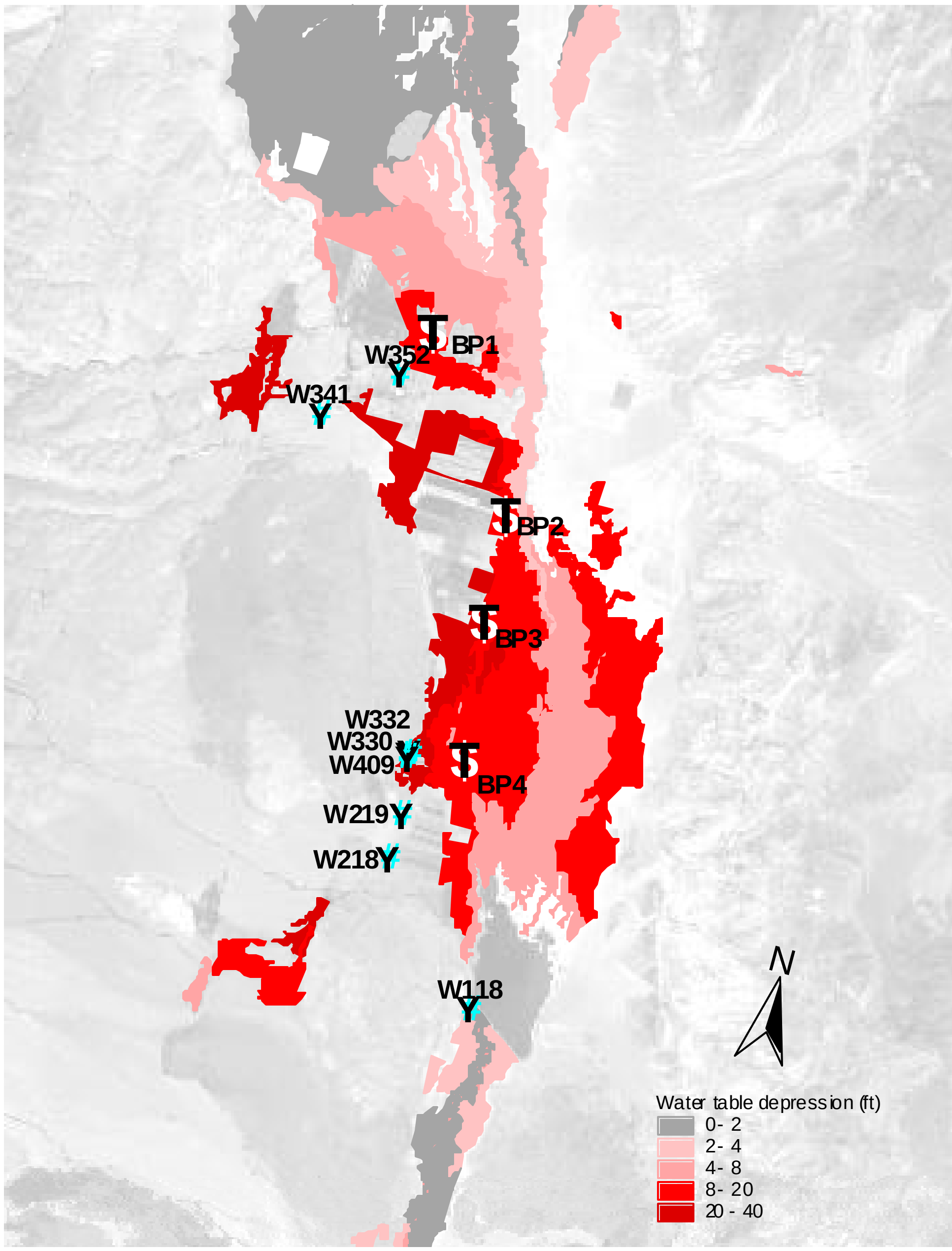

Figure 1. Water table depression due to exempt well pumping at end of runoff-year 2004 in groundwater-dependent vegetation parcels in the Big Pine area. Exempt wells (red circles) and monitoring sites (white triangles) are also shown.

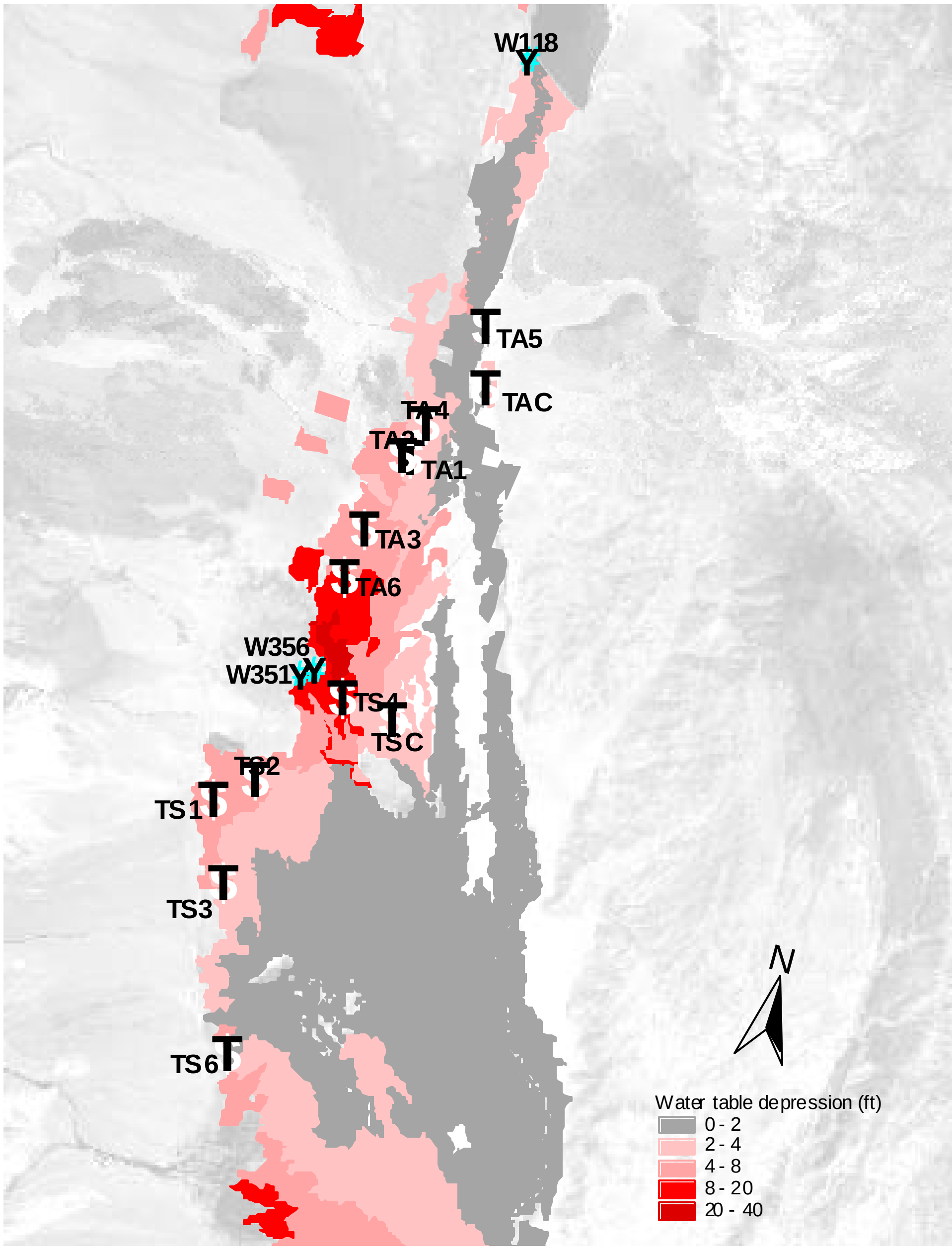

Figure 2. Water table depression due to exempt well pumping as of the end of runoff-year 2004 in groundwater-dependent vegetation parcels in the Taboose-Aberdeen and Thibaut-Sawmill areas. Exempt wells (red circles) and monitoring sites (white triangles) are also shown.

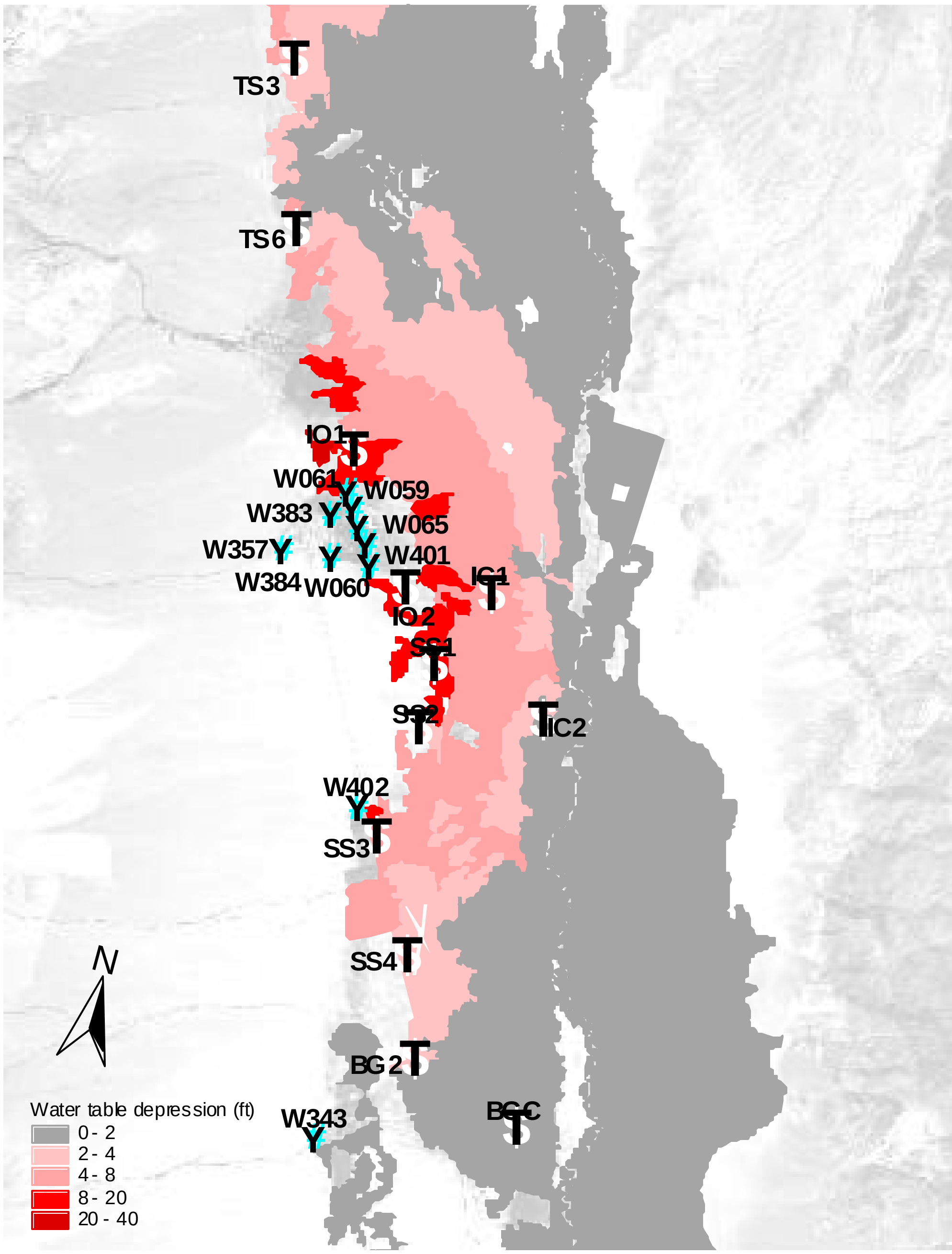

Figure 3. Water table depression due to exempt well pumping at end of runoff-year 2004 in groundwater-dependent vegetation parcels in the Independence-Oak, Symmes-Shepherd, and Bairs-Georges wellfields. Exempt wells (red circles) and monitoring sites (white triangles) are also shown.

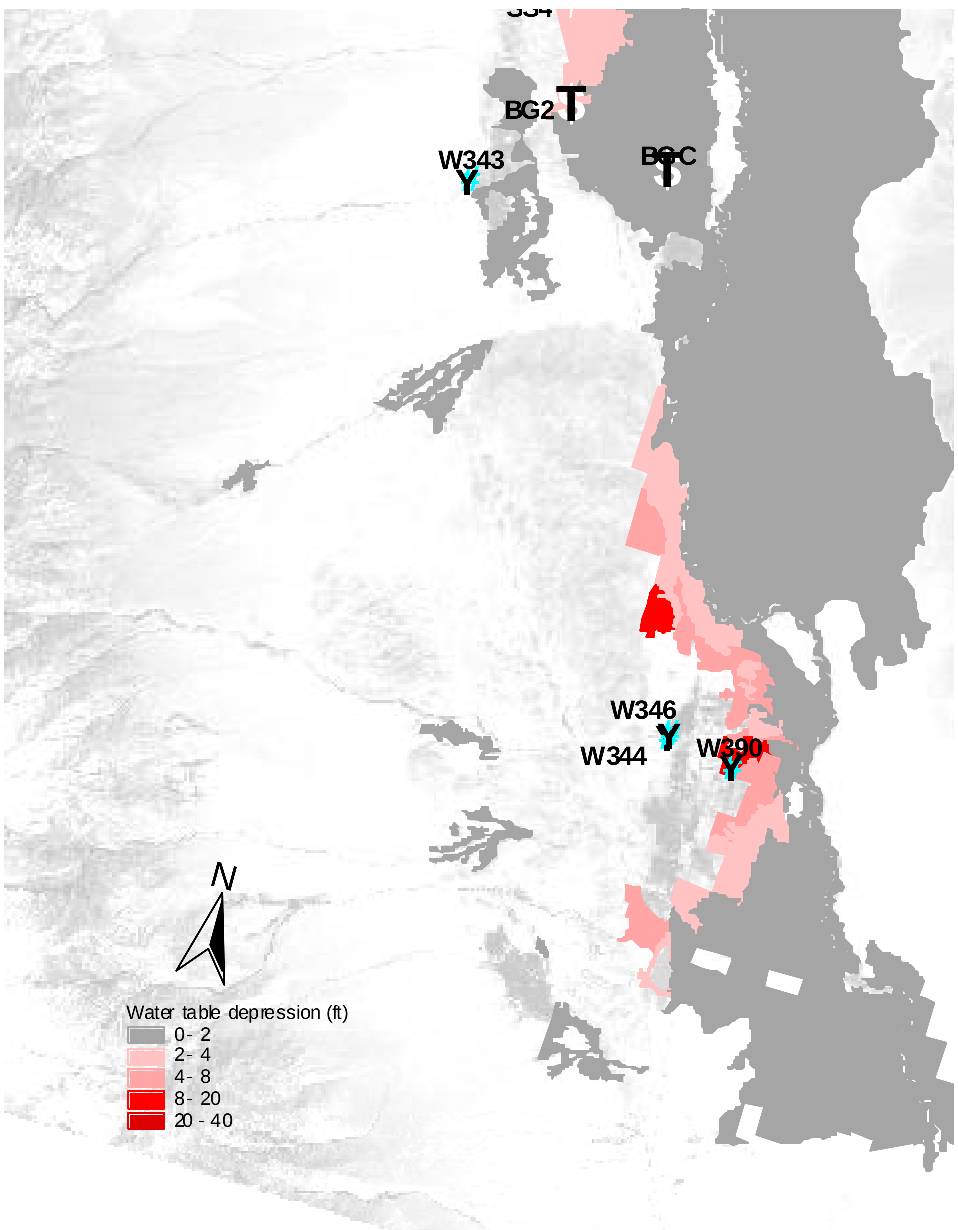

Figure 4. Water table depression due to exempt well pumping as of end of runoff-year 2004 in groundwater-dependent vegetation parcels in the Lone Pine wellfield. Exempt wells (red circles) and monitoring sites (white triangles) are also shown.

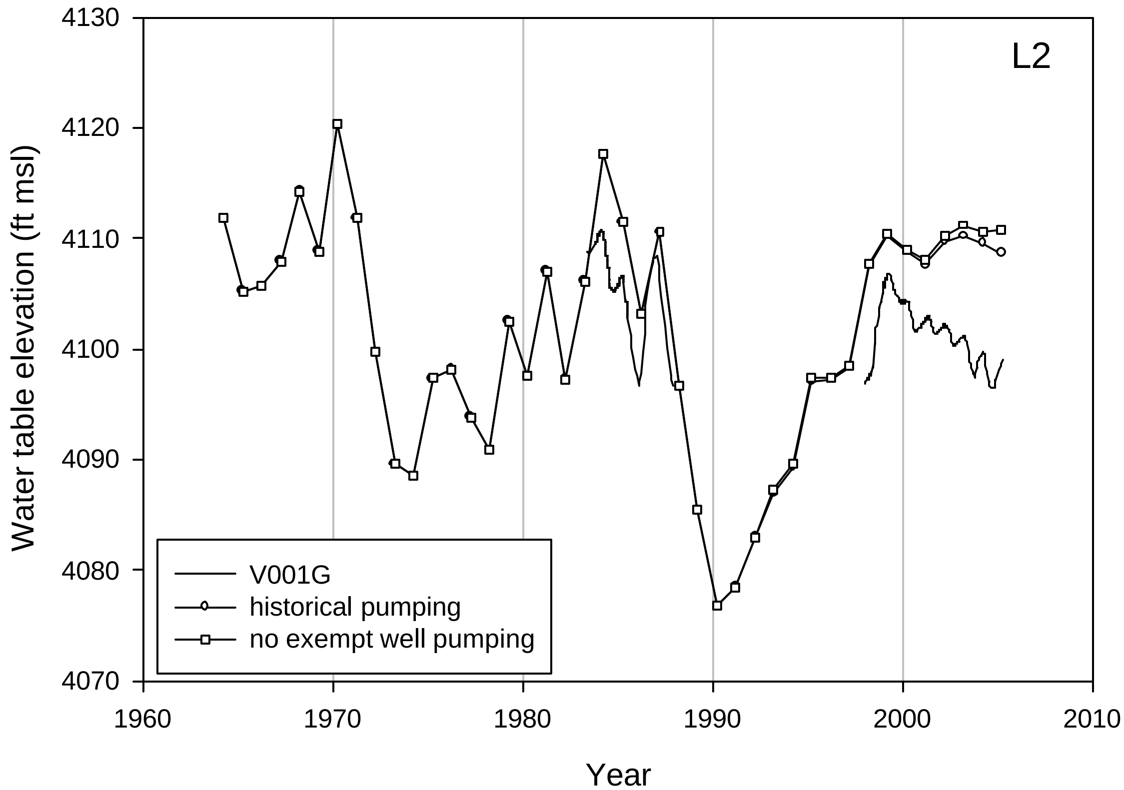

Figure 5. Observed and modeled hydrographs at monitoring site L2. Well V001G was dry from 1988 through 1997. Ground surface at V001G is 4120.9 ft amsl.

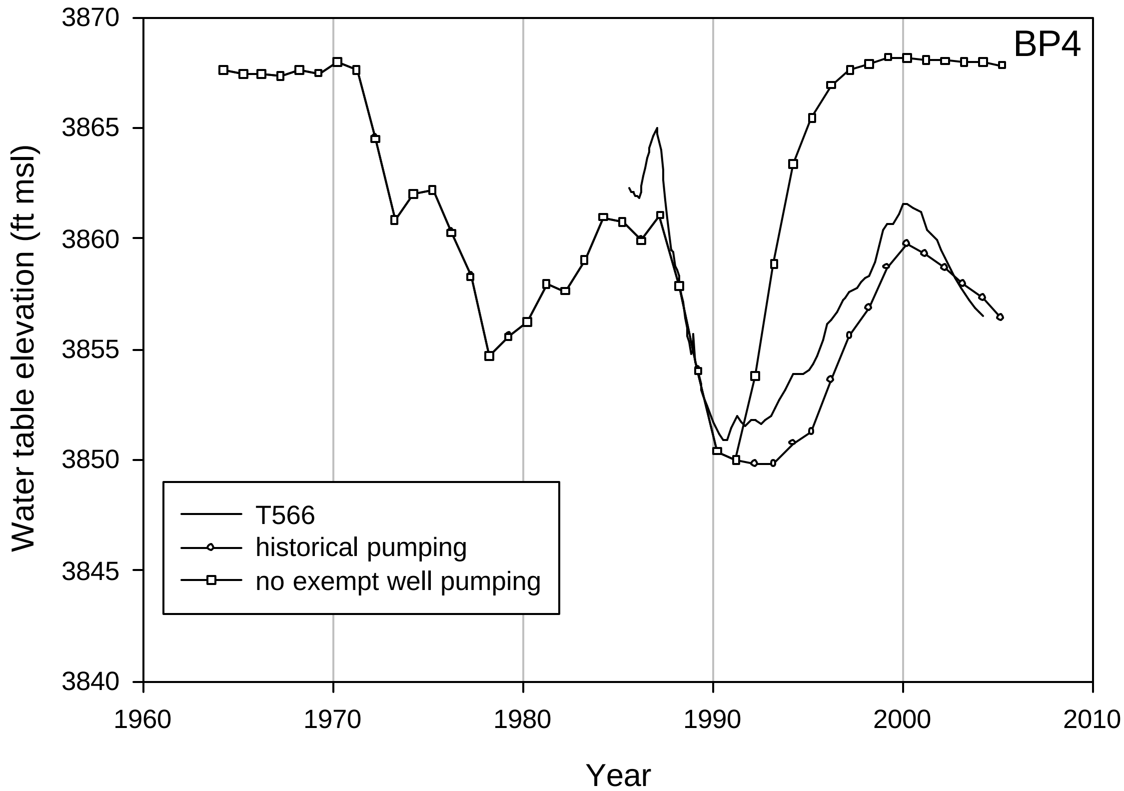

Figure 6. Observed and modeled hydrographs for monitoring site BP4. Ground surface at T566 is 3880.7 ft amsl.

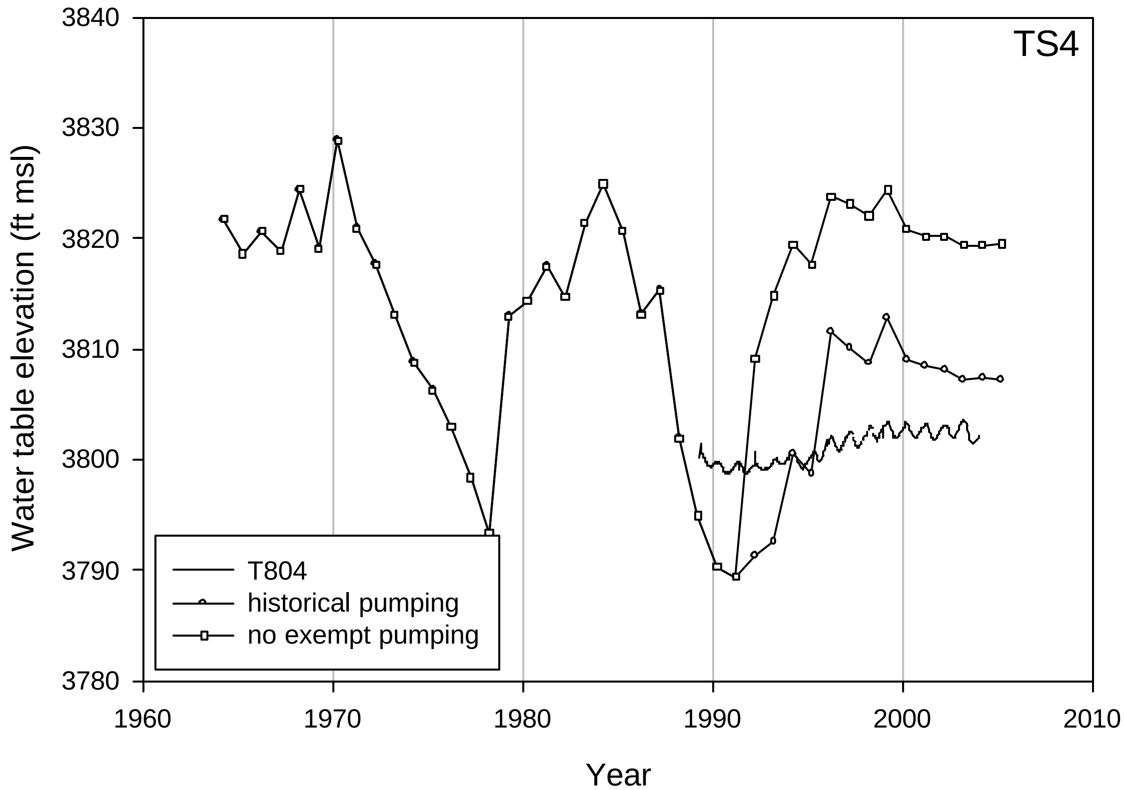

Figure 7. Observed and modeled hydrographs for monitoring site TS4. Ground surface at T804 is 3810.3 ft amsl.

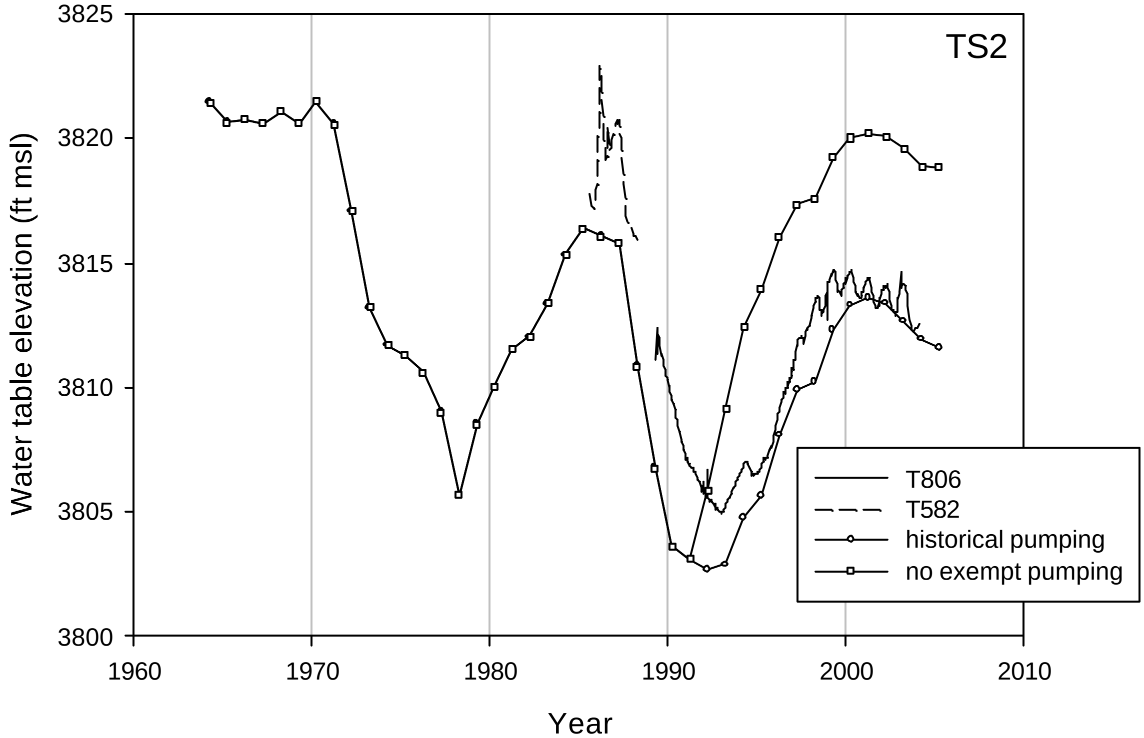

Figure 8. Observed and modeled hydrographs for monitoring site TS2. Well T582 has been dry since 1988. Ground surface elevation at T582 is 3826.4 ft amsl and at T806 it is 3825.6 ft amsl.

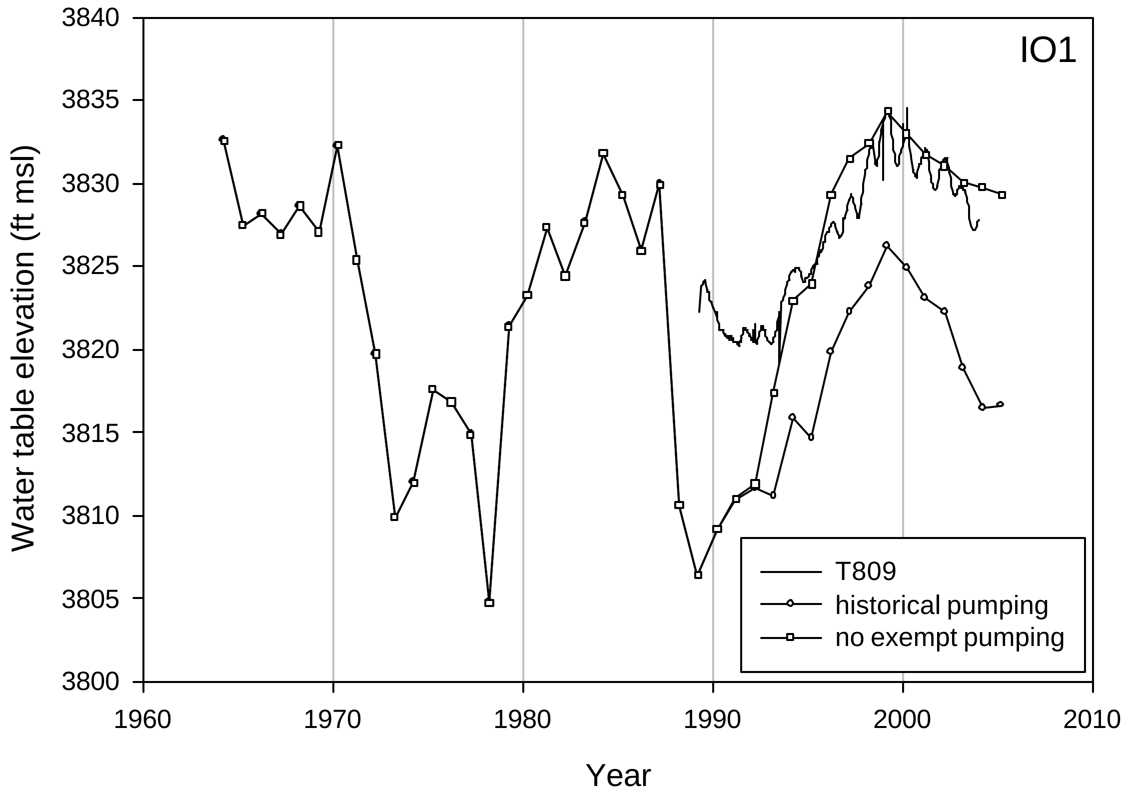

Figure 9. Observed and modeled hydrographs for monitoring site IO1. Ground surface at T809 is 3841.6 ft amsl.

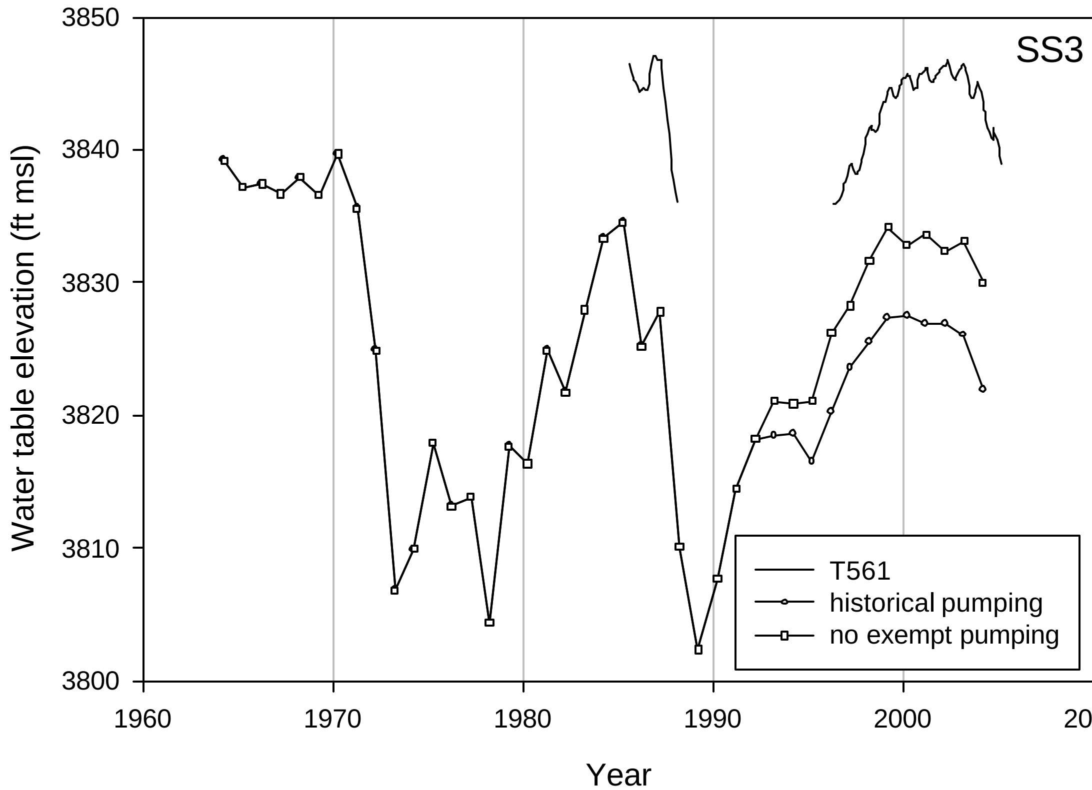

Figure 10. Observed and modeled hydrographs for monitoring site SS3. Well T561 was dry from 1988 through 1992. Ground surface elevation at T561 is 3853.0 ft amsl.

Probability of water tables attaining baseline. For each vegetation monitoring site linked to LADWP production wells, the modeled baseline water level, mean water level throughout the stochastic model runs, percent of time that the water table was above baseline, and median duration for which water levels were below baseline are given in Table 4. Overall, the frequency with which any particular site attains baseline depends on two factors: (1) the amount of hydrologic stress that the site was subjected to during the baseline period, and (2) the level of hydrologic stress that exempt well pumping exerts on the site presently and in the future.

The results for Laws indicate little impact from exempt well pumping. In Bishop, though the results indicate that the water table will infrequently attain baseline levels, this is not due to exempt well pumping; rather, it is due to runoff and irrigation induced high water table conditions during the baseline period. The Big Pine area also rarely attains baseline levels due to sustained exempt well pumping for the Fish Springs hatchery. However, because the baseline water table were already affected by pumping from wells W330 and W332, the deviation from baseline levels is less than 5 ft at BP1 and less than 3 ft at other Big Pine monitoring sites. The Taboose-Aberdeen area was predicted to be above baseline due high levels of pumping during baseline which depressed baseline water levels and low amounts of exempt well pumping (Table 3). Results for site TA6 are similar to sites in the Thibaut-Sawmill wellfield because TA6 is affected by pumping at Blackrock Hatchery. The Thibaut-Sawmill wellfield is predicted to attain baseline levels less than half the time, but more frequently than farther south in the Independence-Oak wellfield. Similar to the area near the Fish Springs hatchery, the area around the Blackrock hatchery was pumped heavily during the baseline period, so the model results show that those pumping-impacted water levels can be attained with some regularity. The Independence-Oak and Symmes-Shepherd wellfields are predicted to rarely if ever attain baseline levels. This is because the potential exempt well pumpage in the Independence-Oak wellfield (17,052 af, Table 3) is substantially higher than the pumping that occurred in the Independence-Oak wellfield during the baseline period. Potential exempt well pumping is presently low in the Bairs-Georges wellfield and located in the western part of the wellfield, which results in little potential impact due to exempt well pumping. The Lone Pine wellfield has no permanent vegetation monitoring sites in the wellfield, so no Lone Pine sites are listed in Table 4; however, based on the relative magnitudes of potential exempt well pumping (2,674 af) and average pumping during the baseline period (1984-1986 mean: 2,202 af), some impact would be expected in Lone Pine. Additionally, most pumping that presently occurs in the Lone Pine wellfield is exempt, so management of exempt well pumping is critical in Lone Pine.

Discussion and Conclusions

Modification of the Agreement's on-off provisions must account for the effects of exempt well pumping. Exempt pumping has comprised 61% of LADWP's pumping in the Owens Valley 1991-2004. Additionally, 17% of the pumping 1991-2004 has been from the Bishop Cone, where pumping is managed according to the Hillside Decree, or from wells in Laws that are not linked to an on-off monitoring site; thus, greater than three-quarters of the pumping done to-date under the Agreement has not been subject to the well turn-off provisions of the Agreement.

The results presented here largely agree with those of Danskin (1998) in his evaluation of water management alternatives in the Owens Valley. He concluded (p. 140) that the intensive groundwater management in place in the Owens Valley would result in areas of thriving vegetation near enhancement/mitigation projects and areas of stressed vegetation near concentrations of pumping. Figures 1 through 4 show such a pattern of drawdown centered on loci of exempt well pumping, which potentially stressed groundwater dependent vegetation. Danskin (1998) used steady-state modeling to examine water management alternatives concluding, "…to maintain the water table at an altitude similar to 1984, total pumpage needs to be about 75,000 acre-feet/yr…." Danskin (1998) defined pumpage as including discharge from flowing wells, which amounted to about 8,400 af yr^{-1} of the 75,000 af yr^{-1} estimated by Danskin (1998); therefore, Danskin's (1998) 75,000 af yr^{-1} and the total exempt well pumping given in Table 3 of 65,476 af yr^{-1} happen to be similar amounts of valley-wide pumping. The deviations from baseline given in Table 4 are small throughout much of the valley, except in the Independence-Oak and Symmes-Shepherd wellfields, where the mean water table is below baseline, and in Laws and the northern part of the Taboose-Aberdeen wellfield, where the mean water table is above baseline. In a broad regional sense, Danskin's result and the results presented here are corroborative.

There are some noteworthy discrepancies between model results and test well observations. Ideally, the modeled hydrograph would closely match test well observations (e.g., Figure 6), however, often the modeled hydrographs are either offset from the observed, or fluctuations are of different magnitudes. In development and application of the model, Danskin (1998) deemed that precise tracking of observed and simulated hydrographs was not necessary, or in some cases not even desirable, depending on the characteristics of the well, surrounding aquifer, and model cell containing the well. He placed more importance on reproducing the general shape and trend of observed hydrographs. In the Baker Creek area (Figure 1) and at monitoring site TS4 (Figure 7), the model predicted greater fluctuations in the water table than were observed in monitoring wells. In these areas, surface water conveyances and irrigation or geologic structures buffer the water table against pumping induced fluctuations, and the model is not useful for assessing the impact of exempt wells in those areas. In other areas, the modeled water table is offset from the observed hydrograph (e.g., Figures 9 and 10), but the timing and magnitude of modeled and observed fluctuations coincide. In these cases, the model does not reproduce observed water levels, but responds to hydrologic stresses in the same manner as observations. In this case, the model can be used to assess changes in water levels by comparing modeled prior conditions to modeled future conditions, e.g., prediction of changes from baseline conditions.

Table 4 indicates that many of the vegetation monitoring sites would rarely reach their baseline levels under the amount of pumping given in Table 3. However, at many of these sites, the mean water levels given in Table 4 within a foot or two of the baseline levels (BC1, BC2, BC3, BP2, BP3, BP4, TA6, TS1, TS2, TS3, SS4, and BG2). Despite being only a few feet below baseline, these monitoring sites are predicted to rarely attain baseline levels because fluctuations due to variations in runoff are relatively small; even though the mean water levels are within a few feet of baseline, variations in runoff are rarely large enough to raise the water table above the baseline elevation. This result is consistent with Danskin's (1998, p. 139) conclusion that long-term variations in recharge have relatively modest effects in comparison with historical variations in pumping. Runoff preceding the baseline period was unusually high: the five-year average runoff-year Owens Valley runoff for 1982-1986 was 609,775 af yr^{-1}, which has a <1% probability of exceedence for any five-year period. Recharge from the high levels of snowmelt runoff during this period are at least partly responsible for the baseline water tables being above the modeled mean levels.

Modeling of the historical impacts of exempt well pumping indicates that in areas surrounding concentrations of exempt well pumping, groundwater levels are depressed below the levels that would have prevailed had the exempt wells not been operated (Figures 1–4). Despite these depressed water levels, the stochastic modeling indicates that mean water levels would be above or within a few feet of baseline levels at most of the monitoring sites that were examined if exempt well pumping continued indefinitely (Table 4). These two results are reconcilable because many of the exempt wells (primarily fish hatchery and town supply wells) were operated continuously through the baseline period of the mid-1980's, so the water table had already been drawn down in the manner shown in the historical model runs.

By the mid-1980's, the water table had been affected by ongoing operation of fish hatchery and town supply wells, and continued operation of these wells causes little additional effect beyond what was present during the baseline period. The wells supplying the Fish Springs hatchery have actually pumped a few thousand af yr^{-1} less since they were exempted in the Green Book than they did in the late-1970's and 1980's.

Even through drawdown due to hatchery pumping was present during the baseline period, groundwater dependent vegetation may not have fully responded to such drawdown when it was mapped. Before revisions to the Agreement's on-off provisions are undertaken, the impacts on groundwater dependent vegetation of exempt well pumping should be examined. In areas where maximizing exempt well pumping results in pumping above baseline pumping rates, exempt well pumping could result in significant water level declines below baseline levels. The region between Thibaut Springs and Manzanar is such an area.

Potential for water table declines below baseline levels due to exempt well pumping exists in the Independence-Oak and Symmes-Shepherd wellfields, where the stochastic model runs indicated that exempt well pumping from wells in the Independence-Oak wellfield could prevent water levels from ever recovering to near baseline at vegetation monitoring sites. It is apparent from Tables 3 and 4 that exempt wells in the Independence-Oak wellfield can influence the water table in the Symmes-Shepherd wellfield. Without consideration of pumping from the Indepence-Oak wellfield, permanent monitoring sites in the Symmes-Shepherd wellfield are problematic for managing pumping.

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Table 1. Exempt wells. The pumping rate is the constant rate at which wells were assumed to pump in the stochastic model runs.

Well	Well Field	Duration	Reason	Capacity (cfs)	Notes
59	IO	Annual	No impact on areas with groundwater dependent vegetation	2.9	Exempted 12/11/1991.
60	IO	Annual	No impact on areas with groundwater dependent vegetation	4.4	Exempted 12/11/1991.
61	IO	Irrigation season	Sole source of irrigation water	2.3	Exempted 12/11/1991.
65	IO	Annual	No impact on areas with groundwater dependent vegetation	4.6	Exempted 12/11/1991.
118	TA	Annual	No impact on areas with groundwater dependent vegetation	2.9	Exempted in Green Book.
218	BP	Annual	No impact on areas with groundwater dependent vegetation	3.5	Exempted 12/11/1991.
219	BP	Annual	No impact on areas with groundwater dependent vegetation	4.1	Exempted 12/11/1991.
236	L	Irrigation season	Irrigation supply when 365 is insufficient	4.6	Exempted 2003.
330	BP	Annual	Sole source- fish hatcheries; 330,332, and 409 may only be operated two at a time	16.1	Exempted in Green Book; revised 10/1/1999.
332	BP	Annual	Sole source- fish hatcheries; 330,332, and 409 may only be operated two at a time	16.1	Exempted in Green Book; revised 10/1/1999.
341	BP	Annual	Sole source primary town supply	1.1	Exempted in Green Book.
343	BG	Irrigation season in below average runoff years	Sole source of irrigation water in below average runoff years	1.5	Exempted 12/11/1991.
344	LP	Annual	Sole source primary town supply	1.4	Exempted in Green Book.
346	LP	Annual	Sole source backup town supply	3.0	Exempted in Green Book.
351	TS	Annual	Sole source- fish hatcheries	17.4	Exempted in Green Book.
352	BP	Annual	Sole source backup town supply	3.0	Exempted 12/11/1991.

Well	Well Field	Duration	Reason	Capacity (cfs)	Notes
354	L	Annual	Sole source primary town supply	2.0	Exempted in Green Book.
356	TS	Annual	Sole source- fish hatcheries	9.3	Exempted in Green Book.
357	IO	Annual	Sole source primary town supply	0.8	Exempted in Green Book.
365	L	Annual	Sole source of irrigation water and no impact on areas with groundwater dependent vegetation	1.6	Exempted 12/11/1991.
383	IO	Annual	No impact on areas with groundwater dependent vegetation	2.4	Exempted 12/11/1991.
384	IO	Annual	Sole source backup town supply and no impact on areas with groundwater dependent vegetation	1.7	Exempted 12/11/1991.
390	LP	Irrigation season	Sole source of irrigation water and no impact on areas with groundwater dependent vegetation	4.1	Exempted 12/11/1991.
401	IO	Annual	No impact on areas with groundwater dependent vegetation	5.5	Exempted 12/11/1991.
402	SS	Irrigation season	Sole source of irrigation water and no impact on areas with groundwater dependent vegetation	3.4	Exempted 12/11/1991.
409	BP	Annual	Sole source hatcheries; 330,332, and 409 may only be operated two at a time	--	Exempted 10/1/1999.
413	L	Irrigation season	Sole source backup town supply, backup fire flow supply, and E/M museum irrigation	--	Exempted 2002.
415	BP	Annual	Sole source backup town supply	--	Exempted 2002.

Table 2. Historical pumpage from exempt wells, by runoff-year (April-March).

Well	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Laws wellfield														
W236	—	—	—	—	—	—	—	—	—	—	—	—	—	1293
W354	35	22	27	27	27	34	45	34	33	37	38	40	32	33
W365	739	502	2	1	87	0	0	0	0	597	236	1,624	836	512
W413	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Laws Total	774	524	29	28	114	34	45	34	33	634	274	1664	868	1838
Big Pine wellfield														
W218	—	790	1	1	756	70	0	0	0	1,536	2,029	2,465	2,480	657
W219	—	1,769	1	1	1,188	837	0	0	0	2,231	2,894	3,381	3,332	907
W330	8,413	8,010	7,730	7,376	6,678	8,512	7,831	7,775	7,858	7,862	7,392	6,998	6,694	6,507
W332	12,015	11,747	11,848	11,804	11,702	11,990	12,935	13,261	9,943	13,252	13,338	12,996	12,848	12,326
W341	391	475	412	460	402	414	441	393	457	495	462	452	441	448
W352	?—	0	74	7	1	239	46	203	1	2	41	2	6	15
W409	—	—	?—	—?	—	—	—	—	1,253	0	238	24	0	0
W415	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Big Pine Total	20,819	22,791	20,066	19,649	20,727	22,062	21,253	21,632	19,512	25,378	26,394	26,318	25,801	20,860
Taboose-Aberdeen wellfield														
W118	?	699	0	0	973	47	0	0	1,497	797	1,683	1,712	2,060	1,714
Thibaut-Sawmill wellfield														
W351	12,485	12,454	12,625	12,572	9,488	13,048	12,698	12,426	12,520	12,286	12,421	11,651	11,201	9,668
W356	26	37	15	7	2,024	30	26	2	5	32	11	818	5	2
Total	12,511	12,491	12,640	12,579	11,512	13,078	12,724	12,428	12,525	12,318	12,432	12,469	11,206	9,670
Independence-Oak wellfield														
W59	—	1,221	66	154	0	0	39	79	0	30	0	979	1,807	384
W60	—	2,023	2,514	3,085	2,392	1,721	1,709	1,681	1,615	1,748	1,654	1,897	1,935	2,490
W61	—	1,182	940	1,434	1,146	1,256	1,239	1,195	1,237	1,311	1,061	1,063	1,087	1,019
W65	—	1,681	1,060	1,827	1,315	1,529	1,458	1,387	1,167	1,166	1,372	1,005	923	1,429
W357	422	441	508	504	477	510	477	445	1,195	705	567	534	563	485
W383	—	1,345	967	1,215	1,693	1,784	1,004	936	1,152	1,135	1,189	1,340	1,005	997
W384	—	501	505	878	1,337	1,178	669	554	615	1,117	1,021	723	1,084	696
W401	—	2,406	0	343	823	0	78	171	0	57	0	3,009	3,355	2,443
Indep.-Oak Total	422	10,800	6,560	9,440	9,183	7,978	6,673	6,448	6,981	7,269	6,864	10,550	11,759	9,943
Symmes-Shepherd wellfield														
W402	—	1,188	1,242	1,305	1,235	1,532	1,247	1,163	1,167	1,257	1,084	1,132	1,138	1,189
Bairs-Georges wellfield														
W343	?	203	79	246	73	0	0	0	1	157	737	43	73	331
Lone Pine wellfield														
W344	989	981	1,097	836	821	839	742	1,392	943	667	387	214	193	117
W346	138	264	8	3	88	2	3	642	8	1014	598	508	588	642
W390	—	333	360	318	212	248	253	233	287	308	273	335	395	337
Lone Pine Total	1127	1578	1465	1157	1121	1089	998	2267	1238	1989	1258	1057	1176	1096
Valley-wide Total	35,653	50,274	42,081	44,404	44,938	45,820	42,940	43,972	42,954	49,799	50,726	54,945	54,081	46,641

Table 3. Pumping rates for stochastic model runs.

Well	Constant pumping rate (af yr^{-1})	Notes
Laws		
W236	1951	Pumping rate is full capacity for seven months.
W354	72	Pumping rate is mean rate for 1991-2003.
W365	1156	Pumping rate is full capacity.
W413	145	145 af yr^{-1} to supply Museum E/M project.
Laws Total	3324	
Big Pine		
W218	2529	Pumping rate is full capacity.
W219	2963	Pumping rate is full capacity
W330	7661	Pumping rate is mean rate for 1991-2003.
W332	12286	Pumping rate is mean rate for 1991-2003.
W341	434	Pumping rate is mean rate for 1991-2003.
W352	72	Pumping rate is mean rate for 1991-2003.
W409	217	Pumping rate is mean rate for 1991-2003.
W415	–––––	Presently not pump equipped; replaces W341.
Big Pine Total	26162	
Taboose-Aberdeen		
W118	2096	Pumping rate is full capacity.
Thibaut-Sawmill		
W351	12141	Pumping rate is mean rate for 1991-2003.
W356	217	Pumping rate is mean rate for 1991-2003.
Total	12358	
Independence-Oak		
W59	2096	Pumping rate is full capacity.
W60	3180	Pumping rate is full capacity.
W61	940	Pumping rate is full capacity for seven months.
W65	3324	Pumping rate is full capacity.
W357	578	Pumping rate is mean rate for 1991-2003.
W383	1734	Pumping rate is full capacity.
W384	1229	Pumping rate is full capacity.
W401	3975	Pumping rate is full capacity.
Indep.-Oak Total	17052	
Symmes-Shepherd		
W402	1445	Pumping rate is full capacity for seven months.
Bairs-Georges		
W343	361	Pumping rate is mean rate for 1991-2003.
Lone Pine		
W344	723	Pumping rate is mean rate for 1991-2003.
W346	217	Pumping rate is mean rate for 1992-2003.
W390	1734	Pumping rate is full capacity for seven months.
Lone Pine Total	2674	
Valley-wide Total	65476	

Table 4. Results from stochastic model runs simulating conditions of maximum exempt well pumping. All values are derived from modeled values. Deviation of mean water table elevation from baseline is positive when mean is above baseline.

Site	Baseline water table elevation (ft msl)	Mean water table elevation (ft msl)	Percent of time above baseline	Deviation of mean water table from baseline (ft)	Median duration of periods below baseline (years)
L1	4126.02	4135.88	100.0	9.86	———
L2	4107.94	4115.71	100.0	7.77	———
L3	4082.17	4098.47	100.0	16.30	———
BC1	4007.69	4007.49	16.0	-0.20	9
BC2	4018.07	4017.63	0.7	-0.44	>50
BC3	4015.11	4014.09	8.3	-1.02	6
BP1	3916.44	3911.93	6.9	-4.51	6
BP2	3881.20	3880.10	12.2	-1.10	9
BP3	3857.70	3855.35	14.9	-2.35	7
BP4	3870.61	3869.93	5.5	-0.68	6
TA1	3830.42	3835.12	100.0	4.70	———
TA2	3834.82	3841.80	100.0	6.98	———
TA3	3827.37	3830.29	98.0	2.92	2
TA4	3833.77	3839.03	100.0	5.26	———
TA5	3826.17	3827.26	100.0	1.09	———
TA6	3819.25	3818.27	36.0	-0.98	4
TS1	3820.93	3820.32	39.3	-0.61	6
TS2	3815.99	3815.71	43.0	-0.28	6
TS3	3819.31	3819.14	45.9	-0.17	7
TS4	3816.17	3811.92	12.4	-4.25	6
TS6	3855.27	3840.88	0.7	-14.39	>50
IO1	3828.70	3807.12	0.0	-21.58	>50
IO2	3809.66	3780.04	0.0	-29.62	>50
SS1	3812.09	3795.25	0.0	-16.84	>50
SS2	3799.13	3795.77	0.0	-3.36	>50
SS3	3829.34	3821.75	0.6	-7.59	>50
SS4	3796.61	3794.49	19.4	-2.12	6
BG2	3776.86	3776.48	40.8	-0.38	4