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CALIFORNIA ENERGY COMMISSION STAFF REVIEW OF CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE'S MOJAVE RIVER ALTO TRANSITION-ZONE WATER BALANCE ANALYSIS

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Summary

In response to the directions of the Committee assigned to the petition to drought-proof the High Desert Power Project (HDPP), California Department of Fish and Wildlife (CDFW) completed a water balance analysis to determine the volume of recycled water that could be diverted to HDPP without negatively impacting riparian habitat in the Mojave River (CDFW 2016). The water balance study was designed to derive a relationship between net water balance (inflows minus outflows) in the Alto Sub-basin Transition Zone (TZ) of the Mojave River and the amount of rise or fall of the groundwater table elevation. The study used annual inflow and outflow data from the 1993/94 through 2015/16 water years.

The study concluded that diversion of 1,000 to 3,000 acre-feet per year (AFY) of recycled water from the Mojave River for use by HDPP could result in a groundwater elevation drop of 1 to 3 feet and have a negative impact on the riparian habitat in the TZ. The study also concluded that the amount of recharge needed to raise the water table by one foot is twice the amount of extraction that would result in a one-foot drop of the groundwater table.

Petitioner conducted a technical review of the water balance study (GSI 2017). The technical review concludes the water balance study lacks a sound technical basis and should not be used by the Energy Commission siting committee for decision making purposes.

Staff subsequently conducted an independent review and analysis of the data provided in the CDFW water balance study. Staff concludes that the study provides useful data, but disagrees with its conclusions because: 1) several unjustifiable assumptions were made about the data used in the water balance equation; and 2) the method of analysis used to arrive at the conclusions was incorrectly applied. The following is Staff's analysis of the CDFW study.

Water Balance Methodology

A water balance analysis for a basin is simply a solution of the mass balance equation:

Change in storage = Inflow – Outflow

The difference between inflow and outflow is sometimes referred to as net flow or net water balance. Positive net water balance indicates an increase in storage, and negative net water balance indicates a reduction in storage or that an aquifer is losing water. In unconfined aquifers (sometimes referred to as water table aquifers), change in storage is manifested as an increase or decrease in the water table elevation corresponding to positive and negative net water balance, respectively. The term “Inflow” encompasses all flows that bring water into the basin, and the term “Outflow” includes all flows out of the basin. Both inflow and outflow components are further divided into surface and subsurface components. The inflow components included in the CDFW water balance study are listed below:

INFLOW A. *Mojave River base flow at the Lower Narrows*: Obtained from the annual report of the Watermaster, who was appointed by the adjudication judgment from 2000.

INFLOW B. *Mojave River storm flow*: Taken from a USGS gauging station located at the north end of the Lower Narrows.

INFLOW C. *Victor Valley Water Reclamation Authority (VVWRA) Discharge*: Obtained from the Watermaster’s annual report.

INFLOW D. *Ungauged tributaries to the Mojave River*: Assumed constant at 320 AFY, similar to the 2003 URS study conducted to establish a hydrologic budget for the TZ (URS 2003a and 2003b). This amount was assumed constant regardless of how wet or dry a year was. For example, with storm flow of 184,574 acre-feet (AF), water year 2004-2005 was extremely wet, compared to an extremely dry water year 2007-2008, when the stormwater flow was only 267 AF. Yet the ungauged tributaries’ flows were assumed the same for both years.

INFLOW E. *Precipitation*: Assumed constant at 96 acre-feet per year (AFY), similar to what was done in the 2003 URS study. Similar to flows at ungauged tributaries, precipitation was also assumed constant regardless of how wet or dry a year was. However, inflow due to precipitation is a rather small component compared to other components.

INFLOW F. *Pumping return flows*: Two scenarios were considered. In the first scenario, return flows were assumed to be 50 percent of verified pumping for agricultural and personal use and 0 percent for industrial pumping as prescribed by the judgment in the adjudication case. In the second scenario, return flows were taken from a 2015 study conducted by the Watermaster engineer (obtained by Kit Custis from a Watermaster meeting on 2/24/2016 (CDFW 2016)).

For the subsurface component, only inter-basin flow was included. This was assumed to be a constant value of 2,000 AFY. This was based on the 2,000 AFY obligation of the Alto subarea to the Centro Subarea as established by the 2000 judgment. It should be noted here that groundwater inflow was also set at 2,000 AFY. This value was based on a 2006 study (Wagner 2006) that, according to the CDFW study, found that groundwater gradients were stable for the Alto Sub-basin. This renders a zero net groundwater flow for the sub-basin.

The outflows were divided into surface and subsurface flows. Surface outflows included the following:

OUTFLOW A. *Evaporation*: Similar to the 2003 URS study, this was assumed constant at 1,159 AFY. This estimate is based on detailed studies by USGS (USGS 1996a) where they show the range in evaporation from free water surfaces along the Mojave River is 60 to 75 inches per year. The URS study used the median value of evaporation which appears to provide a reasonable estimate.

OUTFLOW B. *Riparian transpiration*: Assumed constant at 6,000 AFY as per the 2003 URS study. This assumption is based on data from a study conducted by USGS (USGS 1996b). The USGS study shows that although this is a good approximation, the actual year to year variation could be on the order of plus or minus 50 percent of this estimate. Also if there have been changes in the riparian habitat since the time of the study, such as expansion due to increased recycled water discharge since 1996, this value could be higher.

OUTFLOW C. *Surface outflow across the Helendale Fault*: Assumed to be a fixed percentage (105 percent) of the surface inflow measured at the Lower Narrows, similar to the 2003 URS study. For example, for water year 2013-2014, the surface inflow was measured at 563 AFY, so the outflow at Helendale Fault was calculated to be 591 AFY (1.05 x 563).

OUTFLOW D. *Groundwater outflow*: Including only the inter-basin flow and well pumping. As mentioned above, inter-basin flow was assumed to be a constant 2,000 AFY. Well pumping was the sum of the pumping done by major pumpers, taken from verified well pumping information, and pumping by minor pumpers. Pumping by minor pumpers was assumed to be fixed at 177 AFY as was done by the 2003 URS study.

Discussion of the Water Balance Study

The CDFW used the results of the basin water balance and compared them to shallow groundwater level data for the same 22-year period to determine if there is a relationship that can be used to evaluate the effects of diversion of recycled water on water levels supporting riparian habitat in the TZ. The groundwater level data comes from a groundwater well known as H2-1 which is used for evaluating whether adequate depth is maintained for preservation of riparian habitat in the TZ in accordance with the terms of the judgement. The CDFW Study presents plots of the TZ groundwater depth for both the winter and summer periods against the 10-foot maximum depth requirement. For winter the depth used for the water balance is the seasonal shallowest, whereas for summer the depth is the seasonal deepest.

Linear Regression Analysis

The CDFW study then plots the year-to-year changes in groundwater depth relative to the corresponding net water balance and applies a simple linear regression as a method of analysis to determine if there is a correlation between the data. In statistics, linear regression is an approach for modeling the relationship between a scalar dependent variable (in this case the change in groundwater elevation) and one or more explanatory variables (or independent variables - in this case - net water balance).

Two of the most sensitive components to weather conditions are evaporation and riparian evapotranspiration, the sum of which constitutes somewhere between 10 and 25 percent of the total outflows from the TZ. CDFW's assumption that those two components remained constant over time could have significantly affected calculations. The plots of data in Figures 4 through 6 of the CDFW water balance study show there is significant scatter in the data and there is no apparent linear relationship. The poor correlation is also quantitatively indicated by the low values of the coefficient of determination, or the R^2 values, shown on the CDFW figures.[1] The lack of correlation could be due to the fact that many of the inflow and outflow components of the water balance equation were assumed to be constant throughout the 22 years analyzed. As discussed above those terms likely would not have been constant on an annual basis considering the pronounced variability of precipitation in the 22-year record considered. There would have been variations of different magnitudes in those components from year to year, which may be more or less significant depending on weather conditions and subsequent changes in storm flows.

Two of the most sensitive components to weather conditions are evaporation and riparian evapotranspiration, the sum of which constitutes somewhere between 10 and 25 percent of the total outflows from the TZ. CDFW's assumption that transpiration remained constant in all years when the actual value could range from 50 percent greater or less than that assumed could have significantly affected the calculations. Similarly, although a smaller part of the balance, inflows from ungauged stream flows and precipitation could compound lack of correlation. Staff believes this is a possible reason for poor linear correlation in the plots.

Another reason why no coherent relationship might have been found is that some inflow or outflow components might have not been accounted for. That may explain why for several years the change in water table elevation was negative (falling water table) when the net water balance was positive, and vice versa. The water balance study also

[1] The coefficient of determination is a measure between 0.0 and 1.0 of how close the data can be fitted to a straight line. A value of 1.0 indicates a perfect linear relationship, and a value of 0.0 indicates that a linear relationship between the variables analyzed does not exist. Typically, any value of R^2 below 0.5 is considered to be poor correlation.

tested to see if the correlation would improve by lagging the water table response by one year relative to the water balance difference, but there was virtually no improvement.

The 2003 URS study summarizes information from various USGS water resource studies that show the gradients between upper and lower aquifers in the TZ change during seasons and at different locations in the TZ. It also appears there may be a significant change in TZ aquifer characteristics just downstream of Well H2-1. These conditions could also add to the variability of the data plots. The most likely explanation for the lack of a linear relationship could be that the hydrogeologic conditions in the TZ are complex and cannot be approximated by simple linear solutions. If groundwater levels measured at well H2-1 are truly representative of unconfined conditions then non-linear methods would better approximate basin changes over time.

Overall, the results of the CDFW linear regression analysis appear to show there is limited to little correlation between the change in groundwater elevation and the net TZ basin balance. If all components of the inflows and outflows to the basin were measured on an annual basis rather than assumed constant it may have been possible to establish a better correlation with annual changes in groundwater depth. Even then there may still have been no linear correlation in which case other methods would have to be considered.

Double Mass Curve Analysis

The CDFW study also employs another method of analysis, which is used to determine if there is a strong "linear" relationship between two observed quantities. This is done by performing a Double Mass Curve (DMC) analysis (Searcy and Hardinson 1960). The DMC analysis is performed by plotting the cumulative sums of the two observed quantities that are expected to be correlated with each other. In the CDFW study, correlation between the net balance in the TZ and the depth to the groundwater table was analyzed. However, as the water balance equation above shows, the quantity affected by the net water balance to a basin is the change in storage, expressed in terms of a change in water table elevation (or depth, not the depth to the groundwater table. Besides, the water table elevation (or depth) is a relative quantity that depends on the reference elevation it is measured relative to. Using a higher or lower reference elevation (datum) affects the magnitude of the water table elevation, and thus the slope of any perceived relationship. Thus the appropriate quantity to use in a DMC analysis is the change in the groundwater table elevation, whose magnitude is not dependent on the location of an arbitrarily chosen reference datum.

In addition to using the relative quantity of the depth to the groundwater table, the CDFW analysis also added a rather large constant value of 10,000 AF to the net balance values in order to get rid of any negative values so that the cumulative sum is always ascending. The author justifies adding the constant of 10,000 AF to all net water balance values as follows: "This shifts the zero point of the horizontal axis but not the slope of the regression line." However, adding a constant value to a variable shifts the plotted data without changing the slope of the relationship only if the raw data were plotted against each other. This is not true when the cumulative sums are the quantities plotted as is done in the DMC analysis. Furthermore, a negative water balance is normal in hydrologic analyses; it means that there is a deficit in the water balance or loss in storage.

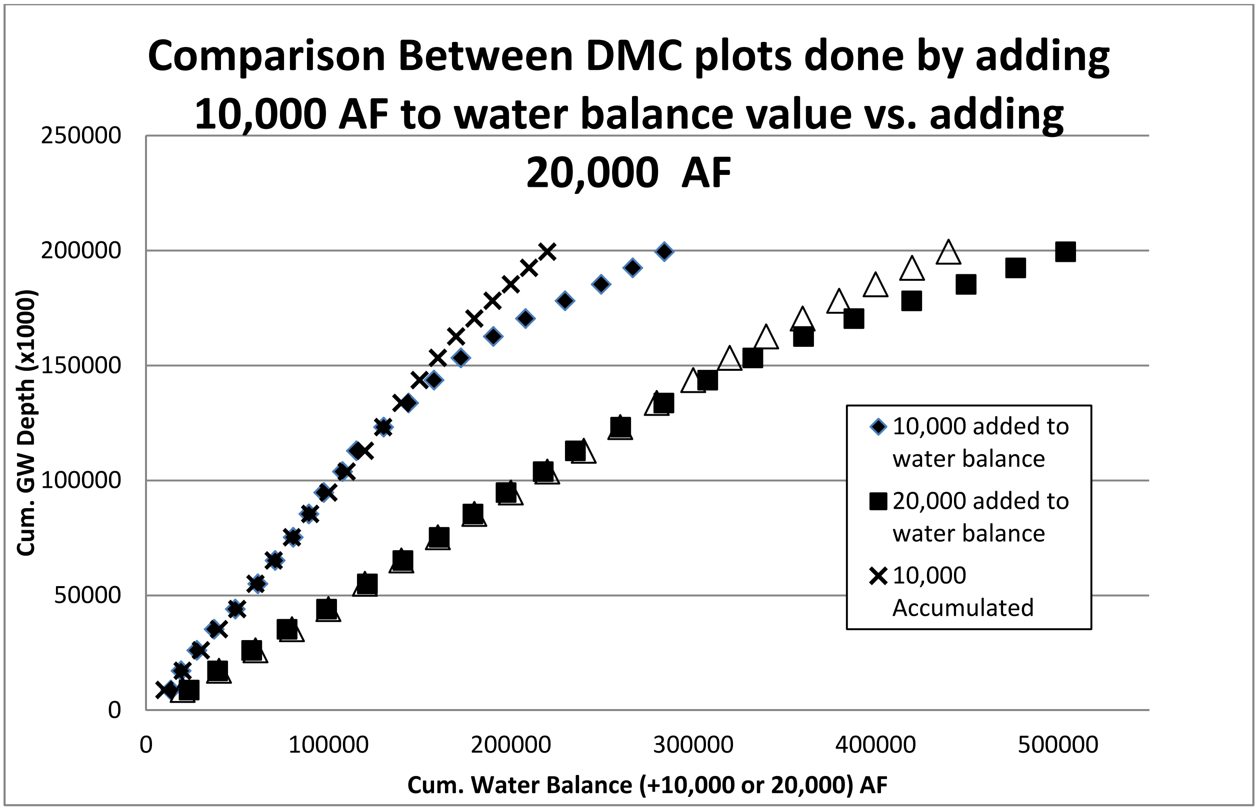
Contrary to what was stated in the water balance study, adding a constant value to either of the variables in a DMC analysis does change the slope of the relationship because the constant added to each value keeps growing as those values are consecutively accumulated. For example, the 10,000 AF added to each water balance value becomes 20,000 AF in the second cumulative sum, 30,000 AF in the third, and so on, up to 220,000 AF in the last sum since there are 22 data points in the record analyzed. To illustrate that adding a constant value to the variables used does affect the slope of the relationship, Staff performed the same analysis done in the water balance study, but added 20,000 AF to each water balance point instead of 10,000 AF, as was done in the CDFW study. A comparison between the plot obtained by Staff and the plot shown in Figure 13A of the water balance study is shown in **Figure 1** below to illustrate Staff's concerns with CDFW's statistical methodology. The relationship between the cumulative values is significantly changed when 20,000 AF was added compared to the case where 10,000 AF was added. By adding the larger value it had the effect of making the relationship more linear and the slope much flatter (almost half the slope of the plot for the DMC analysis in CDFW's water balance study).

Figure 1 also shows a plot of the added 10,000 AF and 20,000 AF constants accumulated on their own without the accumulated water balance values. As stated above, and as illustrated in **Figure 1**, the reason a more linear plot was obtained when a constant value was added to the water balance data is that the cumulative sums of the actual data are much smaller compared to the cumulative sum of the artificially added constant, such that variations in the actual cumulative sums of the data became too small to be detected by the naked eye. It is clear in the figure that for the most part, the plots of just the sums of the added constants cannot be distinguished from the plots of the cumulative sums of the water balance data with the constants added.

In light of the foregoing, Staff concludes that the results of the DMC analysis presented in the CDFW water balance study are erroneous and cannot be relied upon.

Even without the errors in the DMC analysis discussed above, the quantity used for the analysis is not appropriate. The appropriate variable to use in the DMC analysis is the change in water table elevation, because this is the variable affected by the net water balance of the groundwater basin. Thus, the DMC analysis should be performed using those two quantities.

Figure 1 - Comparison between DMC plots when 10,000 AF or 20,000 AF is added to the net water balance



Independent Staff Analysis

Staff performed an independent analysis using the data given in Table 1A of the CDFW water balance study to determine whether using the appropriate application of the same methods used in the CDFW analysis would show some correlation in the data. In the analysis, Staff used the same data and assumptions as CDFW regarding the major inflow and outflow components for the basin balance described above. Staff performed the DMC analysis on the net water balance against the change in groundwater table elevation. **Figure 2** below shows the DMC plot for the water balance and the change in groundwater table elevation using the winter groundwater elevation data assumed to be caused by the previous year's flows.

Staff also performed the DMC analysis for the net basin balance and the change in groundwater table elevation using the summer groundwater elevation data listed in Table 1B of the CDFW study. The DMC plot for this case is shown in **Figure 3** below. As can be seen from both **Figure 2** and **Figure 3**, the data prior to 2006 do not exhibit any discernible relationship. This is likely due to the assumption that many of the values for the basin balance variables are constant. This also could have been caused by the presence of some inflow or outflow components that have not been accounted for in the CDFW analysis. As discussed above, USGS water resource studies show the gradients between upper and lower aquifers in the TZ change during seasons and at different locations in the TZ. This would suggest there could be significant vertical flow components into or out of the TZ that may not be accounted for.

Both **Figures 2** and **3** show a pronounced correlation for the data starting in 2006 through 2011. Also, both figures show that the correlation for the data beyond 2011 is not as strong, but still much better than the pre-2006 portion of the plots. The behavior beyond 2011 might have been due to the severe drought period that the state of California experienced. Because of the drought, reliance on groundwater was heavier and resulted in faster declines in water table levels (MWA 2017). Therefore, if the first half of the data are excluded because there is no correlation between the data sets, and if the last part of the graph corresponding to the drought years is ignored because it deviates from the trend exhibited by the middle portion, one is left with the linear portion from 2006 through 2011.

Figure 2 - **DMC plot using winter groundwater elevations and net water balance**

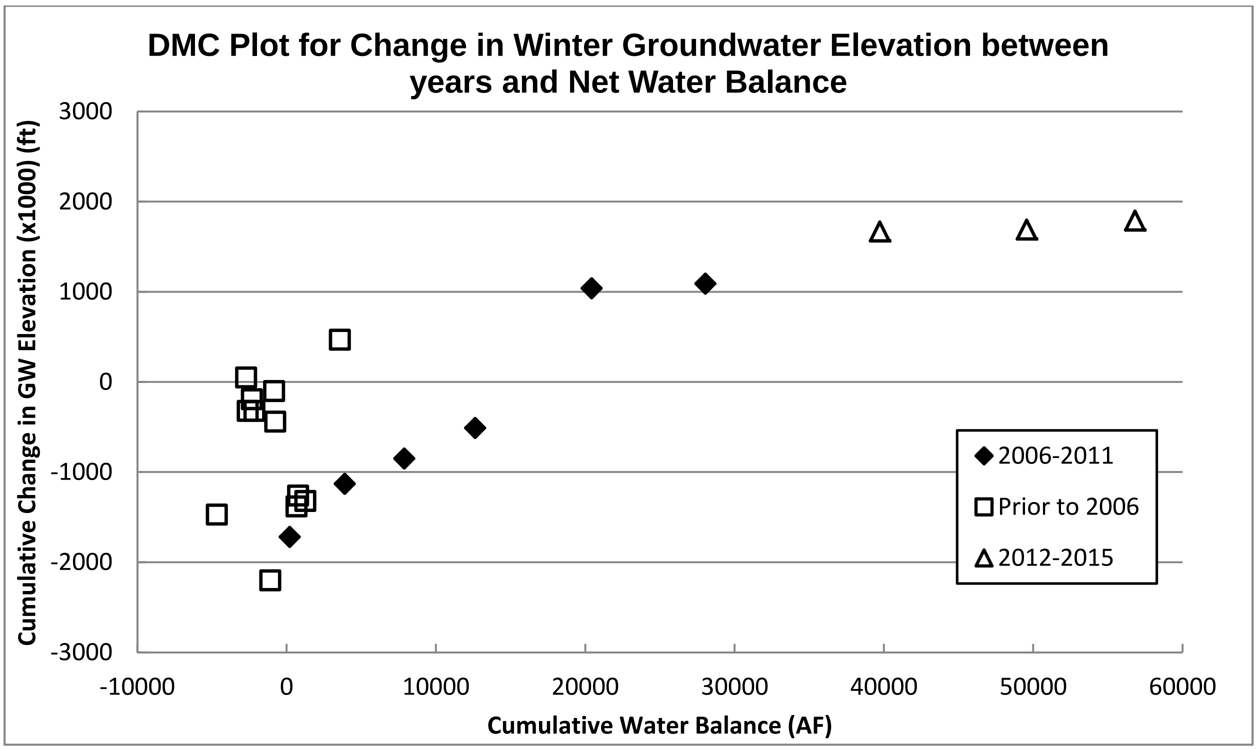
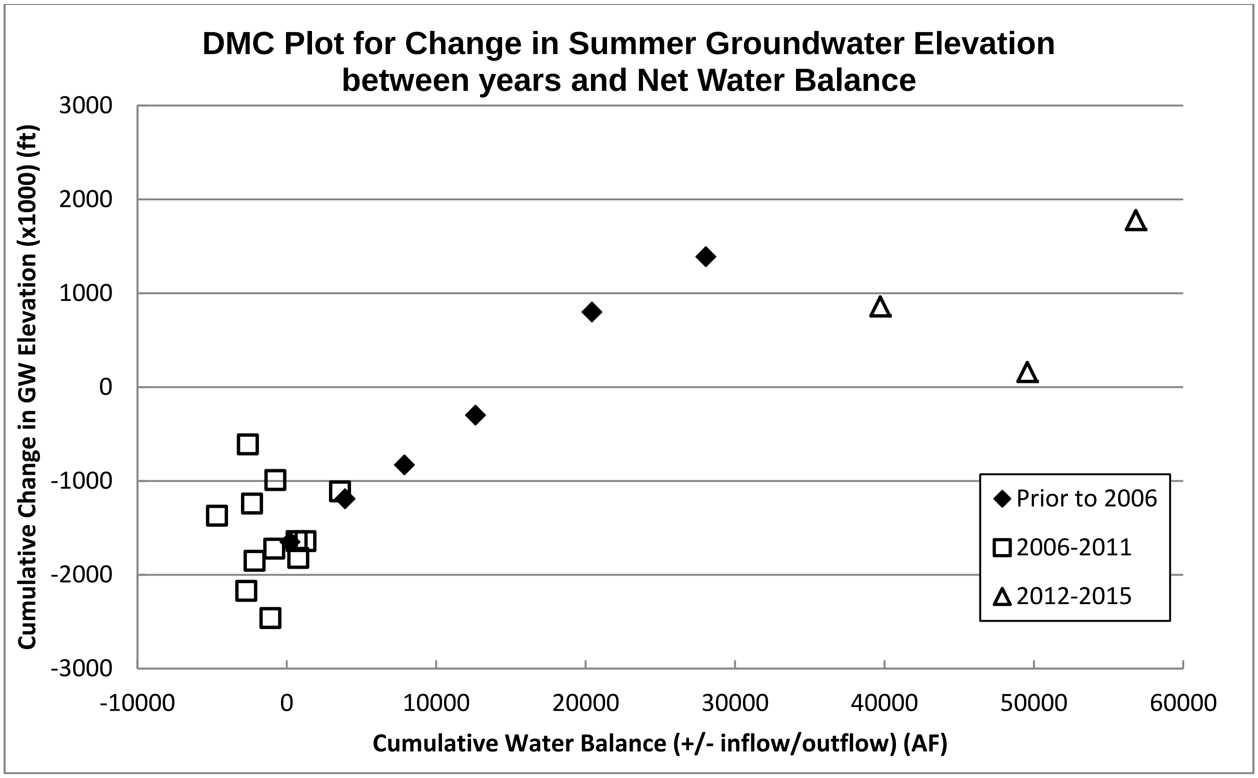


Figure 3 - DMC plot using summer groundwater elevations and net water balance



The linear portion of both graphs has been fitted with a linear regression line as shown in **Figures 4** and **5**. The coefficient of determination was 0.94 for the plot using winter groundwater elevation changes, and 0.99 for the one using the summer water elevations. Both coefficients of determination indicate a very good fit between the data and the fitted linear relationship.

It is unclear why the 6-year portion of the 22-year data set demonstrates a strong linear relationship. Even the extended plot of data from 2006 to 2015 suggests there may still be some correlation. These correlations may only indicate that whatever errors were introduced by the various assumptions made for the analysis were consistent, but not necessarily that the water balance components were accurately represented. However, it may also be possible that assumed values for the basin balance variables may have actually approximated basin conditions during these periods. If this is the case then there may be value in presenting the relationship and discussing what it tells us about groundwater elevation changes that could be related to recycled water diversion.

Both of the fitted regression lines have very close slopes of about 0.11. The slope indicates that withdrawal of 1,000 acre-feet from the TZ results in 0.11 ft. of groundwater table drawdown, or 9,000 acre-feet for a 1-ft drop in the water table elevation. The fact that the linear portions of both graphs were fitted with two lines having very similar slopes gives confidence that this may be closer to the true relationship for the data analyzed, given all the questionable assumptions about the components of the water balance equation.

Using the slope of the fitted linear regression lines, Staff concludes that diversion of 3,000 AFY or so of recycled water for HDPP might cause a fraction of a foot (0.33 ft) of a drop in the water table. It can be said with confidence that this is within the margin of error of the input data, whether they were individually measured or due to the assumptions that several of the major water balance components were assumed constant throughout the 22 years used in the analysis. Staff also understands that use of such a small data set may not demonstrate significant statistical significance. Overall the data set suggest there is no significant linear relationship between changes in groundwater elevation and the net basin balance. Using a simple linear regression is not appropriate for this data. The groundwater system in the TZ appears to be complex and changes in groundwater elevation are likely governed by non-linear relationships. Also, use of fixed value assumptions for many important variables in the basin balance is likely not appropriate for anything other than the simple basin accounting system used for the groundwater basin adjudication for which it was designed.

<u>Wetted Channel Length Analysis</u>

In addition to the DMC analysis, the CDFW water balance study also looked at the relationship of the wetted length of the Mojave River channel as a function of the net water balance. Again, this analysis also assumed a constant infiltration rate which was the same as that assumed in the 2003 URS analysis. Since the wetted length is strongly dependent on the river flow, infiltration rate, and vegetation density, assuming that such a critical variable is constant throughout the record cannot be justified.

Figure 4 - DMC plot for winter groundwater elevation changes beyond 2006, with a linear regression fit for data points between 2006 and 2011

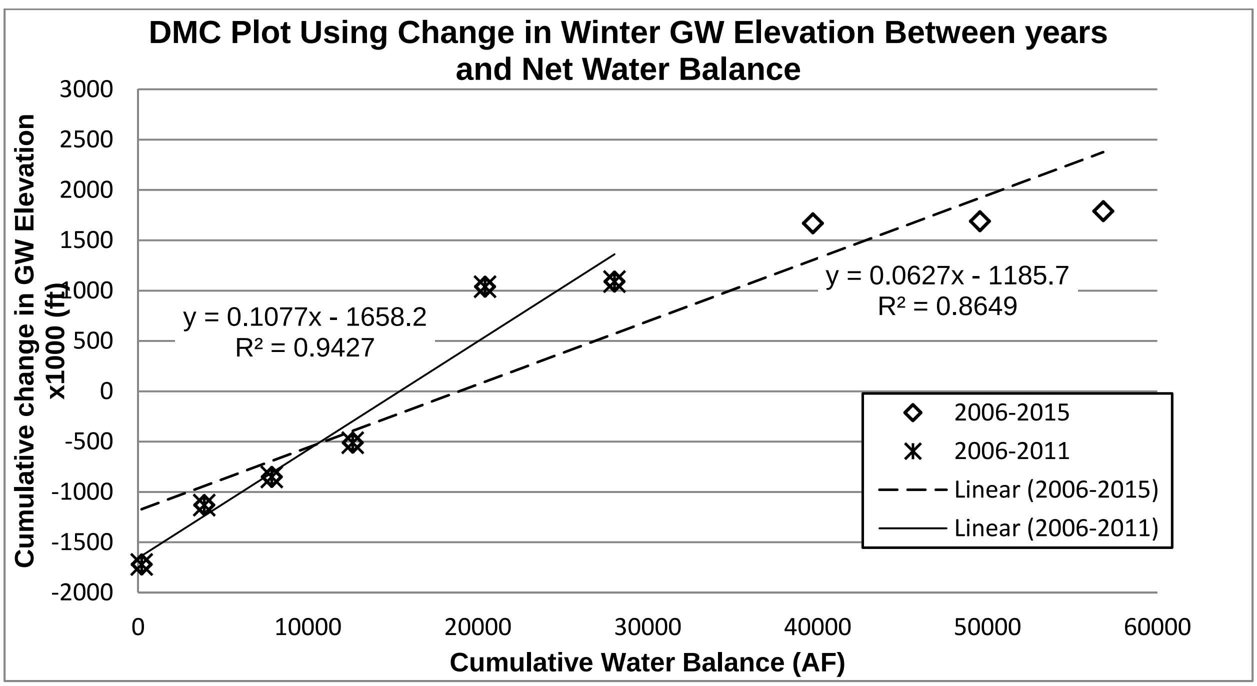
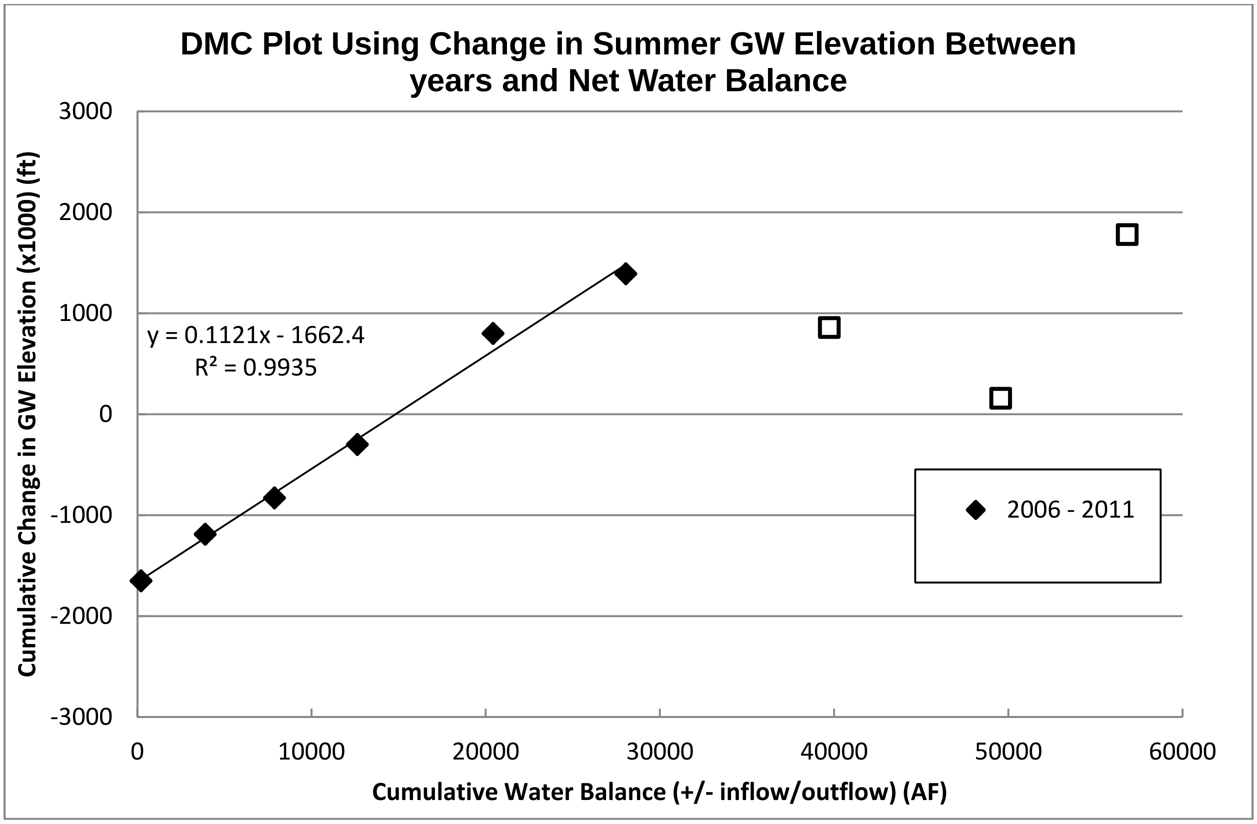


Figure 5 - DMC plot for summer groundwater elevation changes beyond 2006, with a straight line fit for data points between 2006 and 2011



The CDFW water balance study also concluded that the volume of net inflow needed to produce a one-foot rise in groundwater table elevation is twice the extraction volume that would be needed to produce a one-foot drop in the groundwater table elevation (2000 acre-feet per 1.0 foot of rise, versus 1000 acre-feet per 1.0 foot of drop). This finding defies hydrologic principles because the water level in a "container" normally falls or rises by the same amount if the same volume of water is removed or added to it, respectively.

Even if one considers the effect of hysteresis in the soil moisture characteristic curve, as applied in the study, the expected trends would be opposite to what the study concluded. The effect of hysteresis would be the opposite of what was stated because soil retains more water during the drying phase than it does during the wetting phase, and therefore it takes more time to observe a drop in the water table as a result of pumping than a rise of the same amount in response to addition of water. This is known among hydrogeologists as the "delayed effect" of pumping.

Lastly, the water balance study attempted to do a rough analysis of the wetted channel length of the Mojave River to see if a relationship could be established between the net water balance and the length of the wetted channel. However, the analysis again assumed that the filtration rate of the river bed are constant, regardless of how wet or dry a water year or how close the water table is to the ground surface. Since the infiltration rate is the most critical variable in such an analysis, which is definitely a function of weather conditions as well as the moisture content of the underlying soil, any results of such an analysis cannot have any meaningful value.

CDFW Conclusions

The study concluded that diversion of 1,000 to 3,000 acre-feet per year (AFY) of recycled water from the Mojave River for use by HDPP could result in groundwater elevation changes that would have a negative impact on the riparian habitat in the TZ. CDFW emphasized the need to place triggers that would limit the diversion of recycled water from VVWRA's Shay Road plant to HDPP based on changes in groundwater elevation at a key well (H2-1). As was stated in the CDFW study, if the groundwater table is lower than 5 feet below ground surface at the beginning of the summer, or if it falls below 7 feet below ground surface for more than three consecutive months, excluding the early summer months, it could be harmful for the health of TZ vegetation.

However, this is not supported by the information presented in the CDFW water balance study. For example, **Figure 3**, as well as Figure 8A, shows that the water table has remained below the 7-ft trigger throughout the whole record analyzed. Yet, in a previous submittal by CDFW, it was stated that the TZ vegetation has been improving and the density of the vegetation has been increasing for the most part of the record (CDFW 2016). Additionally, requiring that the groundwater table elevation be maintained above the 5-8 ft. depth below ground surface is in conflict with the adjudication judgment that required the water table in the key well to be no more than 10 ft. below ground surface.

The proposed triggers limiting diversions of recycled water do not appear to be tied to current or past conditions. Based on Staff's review of the basin balance study estimated changes do not appear to be representative of TZ conditions and tying them to triggers does not appear to be appropriate at this time. The triggers are also proposed to be more restrictive than that identified in the basin adjudication. Given Staff's analysis it would appear that if the correlation described above were valid then the diversion of a significantly greater volume of recycled water should be possible before any change in water levels in the TZ would be observed and no triggers would be needed.

Staff Conclusions and Recommendations

Staff disagrees with the methodology of the CDFW study and provides the following conclusions and recommendations:

1. The study used data from the Mojave River groundwater basin adjudication as a basis for demonstrating a relationship between depths to groundwater and the groundwater basin balance. The data showed poor to non-existent linear relationship between groundwater depths and net water balance in the TZ.

2. It is likely there is no linear relationship because there are multiple components or variables in the water balance equation that were assumed constant. This introduces significant repeatable errors when attempting to quantify changes in

any of the other variables. In addition, there are likely other inflow or outflow components, such as vertical flow, that have not been accounted for in the water balance calculations. If the groundwater system supporting riparian vegetation in the TZ is unconfined then changes in groundwater depth are generally defined by non-linear relationships and it could be expected that there is no linear correlation.

3. The DMC analysis performed in the CDFW study incorrectly added a constant value to net water values before accumulating them, thereby affecting the slope of any relationship that might exist between the analyzed variables. Additionally, the DMC analysis used the groundwater depth which is a relative quantity, rather than the change in water table elevation or depth, which is the quantity affected by the net water balance.

4. The water balance study concluded the volume of net inflow needed to produce a one foot rise in groundwater table elevation is twice the extraction volume that would be needed to produce a one-foot drop in the groundwater table elevation. This conclusion goes against physical principles and field observations. Due to the phenomenon of delayed response of a groundwater table to pumping, in the short term it often takes a slightly larger volume of extraction to cause the same amount of drop as the recharge amount that would cause the same amount of rise in groundwater table elevation.

5. Results of DMC analysis performed by Staff on the same data given in the CDFW study, despite the potential errors incurred by assuming most of the water balance equation components constant, suggest that it would take much more water to cause a drop or a rise in the water table elevation. Staff found that it would take somewhere between 10,000 and 15,000 acre-feet to produce a 1-ft drop (or rise) in the groundwater elevation. This is much greater than the amount of water proposed for diversion to HDPP.

6. The channel wetted length analysis done in the water balance study was also flawed because it assumed a significant variable to be constant regardless of how wet or dry a water year was.

7. The triggers are based on flawed analysis and are not appropriate for use in limiting diversions at this time.

8. CDFW presents data that may be useful in conducting analysis of potential impacts from diversion of recycled water from the riparian habitat in the TZ.

9. Staff recommends a workshop be conducted which would allow the parties to discuss the result of the study and Staff and Petitioner comments, to determine if there is a way the CDFW data and/or other data or methods can be used to conduct an analysis agreeable to all parties.

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