

TECHNICAL MEMORANDUM

TO: Mid-Kaweah Groundwater Sustainability Agency, Technical Advisory Committee

FROM: John Ayres
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DATE: July 28, 2016

RE: REVIEW OF KAWEAH DELTA WATER RESOURCES INVESTIGATION
REPORTS

This Technical Memorandum (TM) discusses GEI Consultants' (GEI) review of the recently updated *Water Resources Investigation Update – Kaweah Delta Water Conservation District*, (WRI) (Fugro 2016). During review, GEI discovered that the WRI relied heavily on the previous *Water Resources Investigation of the Kaweah Delta Water Conservation District* (Fugro 2007) and also referenced the report *Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing* (Davids Engineering 2013). Because these reports are interrelated, GEI has reviewed all three reports.

The review provides an overview of the contents of each of the three documents, an assessment of the suitability of the analysis used in these documents, and a discussion regarding the ability of these documents to provide the technical foundation for the development of a Groundwater Sustainability Plan (GSP) for the Mid-Kaweah Groundwater Sustainability Agency (GSA) under the Sustainable Groundwater Management Act (SGMA).

Water Resources Investigation of the Kaweah Delta Water Conservation District (Fugro 2007)

The 2007 report is an update to the original Water Resources Investigation developed in 2003. The purpose of the 2003 effort was to conduct a detailed geologic and hydrogeologic investigation and analysis to evaluate and assess the quantity of groundwater in the Kaweah Delta Water Conservation District (KDWCD), sources and volumes of natural recharge, water budgets, trends in water levels, and determination of safe yield.

There are six major sections to the 2007 WRI:

1. Introduction, Data Summary, and Base Period
2. Descriptive Geology

3. Geohydrology
4. Surface Water
5. Water Quality
6. Water Balance and Safe Yield

GEI has reviewed each section below and provided an assessment of the suitability of the analysis conducted and has also reviewed potential applicability of the studies for use in GSP development.

Introduction, Data Summary, and Base Period

This section of the 2007 WRI provides general information about the study area, including the purpose for the report and a description of KDWCD. This section also defines where the hydrologic units used by the WRI. The hydrologic units were established “coincident with the service areas of the entitlement holders” (Fugro 2007). The hydrologic units are shown in Figure 1.

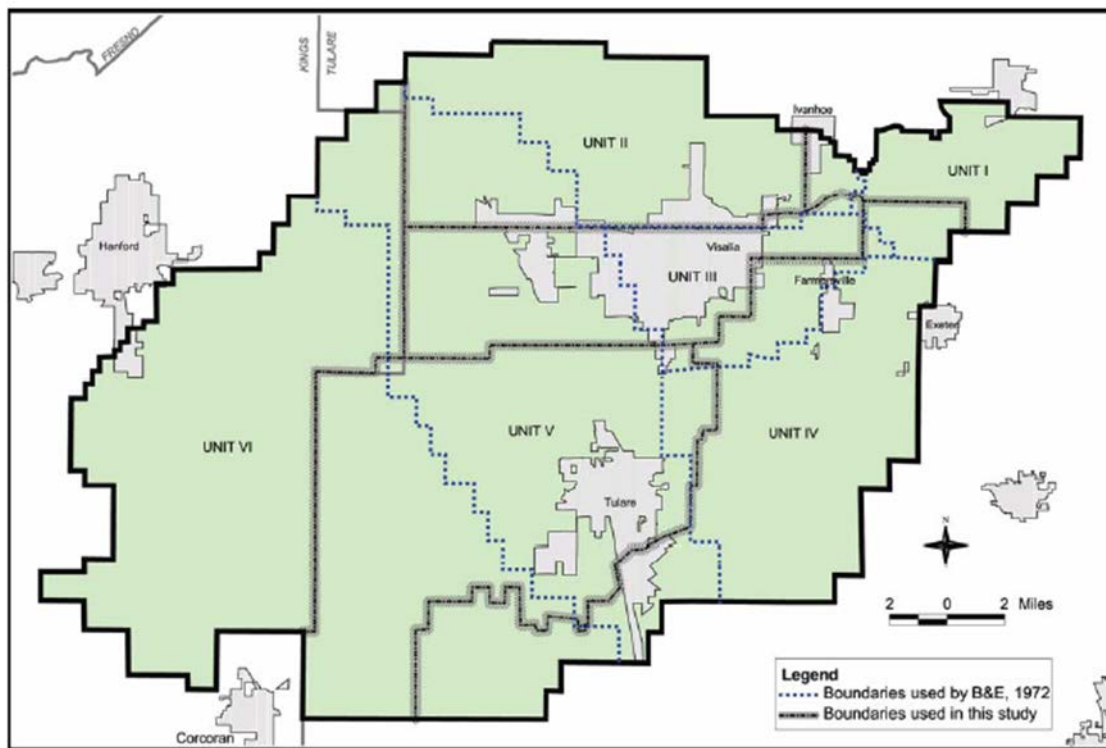


Figure 1. 2007 WRI Hydrologic Units

Data was collected from a wide variety of sources and were compiled into Microsoft Excel and Access for processing. Geospatial data was compiled from well completion reports and oil well logs into a Geographic Information Systems (GIS) database. Over 7,000 well completion reports were collected and sorted for geologic data, well design, water level, and aquifer parameter data. Geophysical electric log and pump test data were obtained for about 100 wells. Data from monitoring well data was collected from the Department of Water Resources (DWR) and

KDWCD that are dispersed throughout the study area. Other data collected includes: precipitation, surface water, imported water, water quality, artificial recharge, agricultural water demand, municipal water demand, and rural water demand.

The hydrologic base period selected for analysis in the 2007 WRI was 1981 through 1999. This period was selected because better data was available and appropriately represents historical wet-dry cycles.

Suitability of Analysis

The hydrologic units, description of data collected, and selection of a hydrologic base period were appropriate selections useful for the analysis and characterization of the KDWCD study area. Available data appeared to be limited for artificial recharge, agricultural water demand, and water quality.

GSP Applications

The hydrologic units selected in this report are not suitable for use under SGMA for GSP development, as they do not match current and proposed GSA boundaries for Mid-Kaweah, the Greater Kaweah or East Kaweah GSAs. The data collected was stored in Microsoft Access and Excel formats, and the GIS database will be useful during GSP preparation, although additional data will be needed to update the data sets to current conditions and that is representative for the yet to be selected SGMA baseline hydrologic period for the Kaweah subbasins.

Descriptive Geology

This section describes the geologic units that underlie the KDWCD. Major work in this section included the preparation of a GIS database that included data from 600 well logs and geophysical electric logs. The GIS database also included water level data, which was put into the GIS database from existing data sources. Interpretations of existing data are documented in Table 11 in the 2007 WRI. Lithologic data entered into the database was limited to sediment classifications to identify permeable and non-permeable areas. Cross sections were then created automatically using GIS functionality. Review of the cross sections indicates that they were refined by professional staff.

The geology underlying the District is comprised of the following generalized units:

- **Basement Rocks:** Non-water-bearing granitic and metamorphic rocks.
- **Marine Rocks:** Non-water-bearing marine sediments including the San Joaquin Formation.
- **Unconsolidated Deposits:** Non-marine, water-bearing material comprised of the Tulare Formation and equivalent units.
- **Alluvial Deposits:** Coarse-grained, water-bearing alluvial fan and stream deposits including older oxidized and reduced units and younger alluvium.
- **Lacustrine and Marsh Deposits:** Fine-grained sediments representing a lake and marsh phase of equivalent continental and alluvial fan deposition.

The location, thickness, and depth of the Corcoran E Clay is also identified and mapped. Specific yield was estimated using a publication from the 1957, which was contoured showing the distribution of specific yield across the District and reinforced by review of well logs collected during the WRI.

Suitability of Analysis

The analysis conducted in this section was largely appropriate. Verification that the cross-sections developed in this section were created under the supervision and review of a Professional Geologist is needed, as the report is unclear. The geologic unit descriptions are reasonable and appropriate. The mapping of the Corcoran E Clay is thorough and appropriate. The specific yield relies on a 60 year old report which was generally checked with well completion reports that were available at the time. A more detailed review of specific yield using more recent well completion logs may be useful.

GSP Applications

The GIS database developed for the 2007 WRI will be extremely useful for GSP development. The description of geologic units will be valuable for the Basin Setting portion of the GSP, the identification of the Corcoran E Clay and specific yield information is critical for development of change in storage calculations, basin setting descriptions, and determining management actions in the GSP.

Geohydrology

This section describes the aquifer characteristics, water level conditions, storage, subsurface flow, and subsidence within KDWCD. Analysis was conducted using water level data from DWR and KDWCD, as well as the GIS database created during the geologic analysis.

Aquifer characteristics were determined by reviewing previous reports. Horizontal permeability was estimated for each hydrologic unit and varies from 70 gallons per day per foot squared to 750 gallons per day per foot squared.

The water level analysis included an effort to correlate wells monitored by DWR and KDWCD to well construction, and it was determined that no well construction information was available for any of the monitored wells, making it impossible to determine whether monitoring was representative of confined or unconfined aquifer systems. Water levels were contoured in the WRI for the period of 1981 to 1999.

Groundwater in storage was calculated in this section by multiplying spatial changes in groundwater levels with spatial specific yields throughout KDWCD for the 1981 through 1999 period. Specific yield numbers were not concrete and the 2007 WRI authors shared calculations using multiple specific yields.

Subsurface flows were calculated and mapped with flows generally towards the southwest. Significant approximation is likely to have occurred in the western portion of KDWCD due to the presence of Corcoran E Clay, and the lack of well construction information for the monitoring wells combining to obfuscate conditions in the confined aquifers. Subsurface flows

between hydrologic units were calculated. Subsidence was not significantly addressed.

The most significant subsurface feature in the District affecting the occurrence and movement of groundwater is the Corcoran E Clay, a relatively impervious stratum, the eastern edge of which follows generally a north-south line about 2 to 3 miles east of U.S. Highway 99. The Corcoran E Clay dips to the west and usable groundwater is found both above and below this stratum. The areas between the easterly edge of the Corcoran E Clay and the Rocky Hill fault have been designated as Hydrologic Units II, III, and IV, and groundwater in these units is found in unconfined alluvium and semi-confined continental deposits underlying the alluvium.

Suitability of Analysis

The analysis conducted in this section was appropriate and used the best data available at the time.

GSP Applications

Information provided in this section is useful for GSP development, both in the basin setting portion and the water budget portion of the GSP. Aquifer characteristics information will be useful for updating calculations to current water levels and change in storage. The information in the 2007 WRI will be useful for establishing historical water budgets. Subsurface flows calculated in this report can provide a starting point for developing subsurface flow calculations.

GSP regulations require that monitoring wells include well construction information and identify which aquifers are monitored by each well. Because of this, during GSP implementation the monitoring grid will need to be updated and improved, which will improve the accuracy of change in storage calculations and subsurface flows.

Surface Water

This section reviewed the surface water hydrology within the KCWCD, calculated conveyance losses, artificial recharge, and crop deliveries. Annual runoff of the Kaweah River was provided and imports were identified. Conveyance losses were calculated using flow gauge data of a daily timestep to account for reaches that are not continuously filled with water, with adjustments for riparian diversions and constructed channels, which was then aggregated by hydrologic unit.

Artificial recharge basins were inventoried and identified in Table 28 of the 2007 WRI, with acreage, capacity, and rate of percolation where available. Recharge basin inflow was calculated by estimating the number of days a basin received water based on river flows and when its supplier received water through its headgate. Crop deliveries were derived from headgate diversions and conveyance losses and is presented by hydrologic units. Any flows outside the District were also calculated.

Suitability of Analysis

The analysis conducted in this section was appropriate and used the best data available at the time.

GSP Applications

Information provided in this section will be useful for GSP water budget calculations.

Water Quality

This chapter discusses groundwater and surface water quality, including sources of data, general water quality issues, conditions and discussions. Data was collected from a wide variety of sources including state agencies, federal agencies, and county and city water departments.

The groundwater quality discussion is largely generalized, although representative constituents are identified for each hydrologic unit. It appears that limited groundwater or surface water quality data was available and data used in the report was identified as insufficient in the discussion.

Suitability of Analysis

The analysis conducted in this section was appropriate, but did not have enough data to be meaningful.

GSP Applications

Data collected could be used as part of a data collection effort needed to document water quality for a GSP, however, significantly more data and future monitoring will be needed for SGMA compliance.

Water Balance and Safe Yield

This section includes development of a hydrologic budget, groundwater in storage, and development of a water balance and safe yield estimate.

The water budget was prepared using inflows and outflows, much of which were identified in earlier portions of the report. The water budget considered water on the land surface, the soil root zone, the deep vadose zone, and the saturated zone. Subsurface inflows were calculated using groundwater elevation contour maps and aquifer properties. Precipitation percolation was calculated with consideration of evaporation and evapotranspiration (ET), with an assumption that all rainfall within KDWCD did not runoff. Percolation of irrigation return water and wastewater was also calculated. Subsurface outflow and between hydrologic units was calculated, as well as evaporation and surface runoff. Surface water runoff was determined to only happen during extremely wet years. The ET was developed using reference data and crop coefficients combined with land use data which were then translated into monthly crop coefficients for the study area. Municipal use was documented from pumping records, and additional data was collected for small water systems and dairies. Agricultural pumping was calculated by summing agricultural demand and subtracting surface water deliveries. Figure 2 shows the conceptual water budget model used in the report.

The water budget estimated 412,000 acre-feet of deficit over the base period of 1981-1999 groundwater monitoring and specific yield indicated 685,000 acre-feet of reduction in groundwater storage over the base period. The differences in the two methods were thoroughly compared and generally correlate well.

Safe or perennial yield was calculated using ‘considerable assumptions’ and an understanding that the confined aquifer is not accurately represented in this report. The report estimated safe yield using two methods. The first method assumed that safe yield is equal to long-term recharge,

which is calculated to be 600,000 acre-feet per year. The second method compares annual extractions over the base period to net changes of groundwater in storage as identified by monitoring and specific yield indicates that safe yield is approximately 583,000 acre-feet per year.

Suitability of Analysis

The water budget created in this section utilizes robust methodologies and is a comprehensive and appropriate analysis, with the exception of ET. ET calculations have dramatically improved since 2007, and modern satellite calculation techniques should be used (and later were used) to update water budget information.

Safe yield calculations were conducted using appropriate analysis, and include caveats and assumptions identifying potential improvements to the calculation.

GSP Applications

The water budget and safe yield calculations are a strong starting point for the water budget portion of the GSP. They will need to be updated to the present, and ET calculations may be updated to use modern satellite methods, but are otherwise a strong base and should withstand critical review.

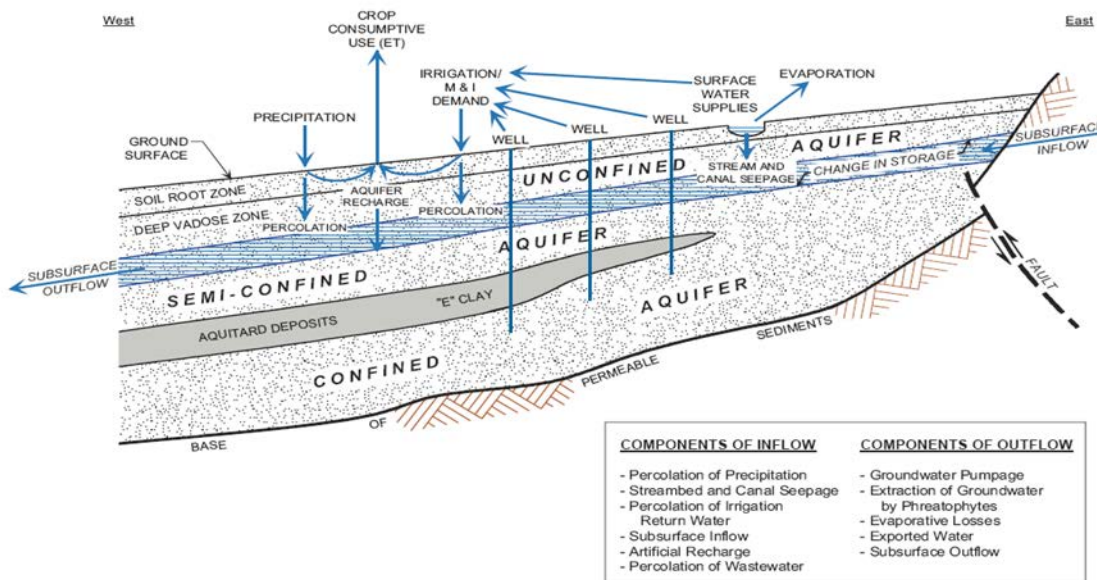


Figure 2. Components of a Water Budget

Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing (Davids Engineering 2013)

The Davids Engineering report was developed to support the 2016 WRI update to improve evaluations of ET within the District. It includes sections on identifying field boundaries, Normalized Difference Vegetation Index (NDVI) analysis, model development, calibration, and a comparison to the 2007 WRI estimates.

The purpose of this report was to develop improved time series estimates of agricultural water demands for KDWCD service area from 1999 through 2010. Demand was quantified at the field scale using a daily root zone water balance model, allowing aggregation to time steps on a monthly basis by hydrologic unit or other spatial scale to support ongoing groundwater modeling and conjunctive management of available surface water and groundwater supplies. ET was quantified using a combination of remote sensing and simulation of irrigation events using a daily root zone water balance model driven by remotely-sensed estimates of crop ET. Total applied irrigation water was then calculated based on estimates of the crop consumptive use fraction, by crop type and irrigation method. Finally, downward fluxes to the groundwater system from deep percolation of precipitation and deep percolation of applied water were estimated.

Development of Field boundaries and Cropping

This chapter describes development of spatial coverage of field boundaries including field polygons, which form the basis of the analysis. Each polygon included daily water balance and irrigation calculations. Field boundaries were delineated by combining existing coverages from the United States Department of Agriculture and DWR. Figure 3 shows the level of detail of the field polygons.

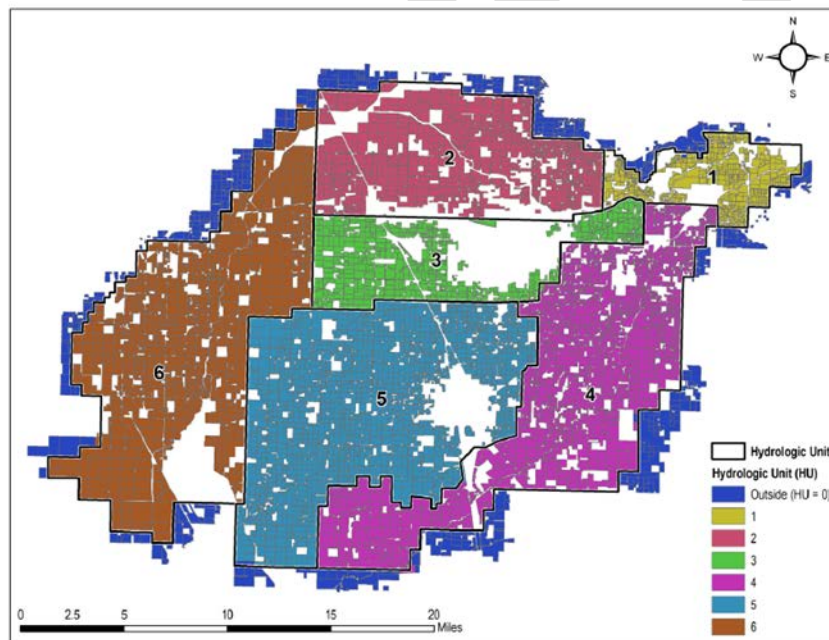


Figure 3. Field Boundaries and Hydrologic Units

ET was calculated by using remote sensing data and simulation of irrigation using a daily root zone model. Crop types and irrigation methods were updated and assigned by DWR to land use surveys from 2003, 2007 and 2010, depending on location.

Normalized Difference Vegetation Index Analysis

Normalized Difference Vegetation Index (NDVI) analysis was used to identify the amount of green vegetation present over time in each field polygon. The NDVI analysis used landsat images covering dates from 1998 through 2011. When landsat images were covered by clouds or not

available, data was filled in using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. MODIS imagery was adjusted for differences and filled in pixel by pixel. NDVI values were then interpolated across the full analysis period to provide daily time series of NDVI values for each polygon. NDVI was then used to improve the basal crop coefficient portion of the ET calculation.

Model Development

The model developed during this analysis is a root zone water balance model, consistent with those typically developed for irrigation scheduling purposes. Figure 4 shows the fluxes used in the model. The model used nearby California Irrigation Management Information System (CIMIS) data and correlated the data using linear regression to estimate ET. Precipitation data was selected from the Visalia CIMIS station with supplemental data from the Hanford and Porterville stations. Precipitation data was not spatially distributed.

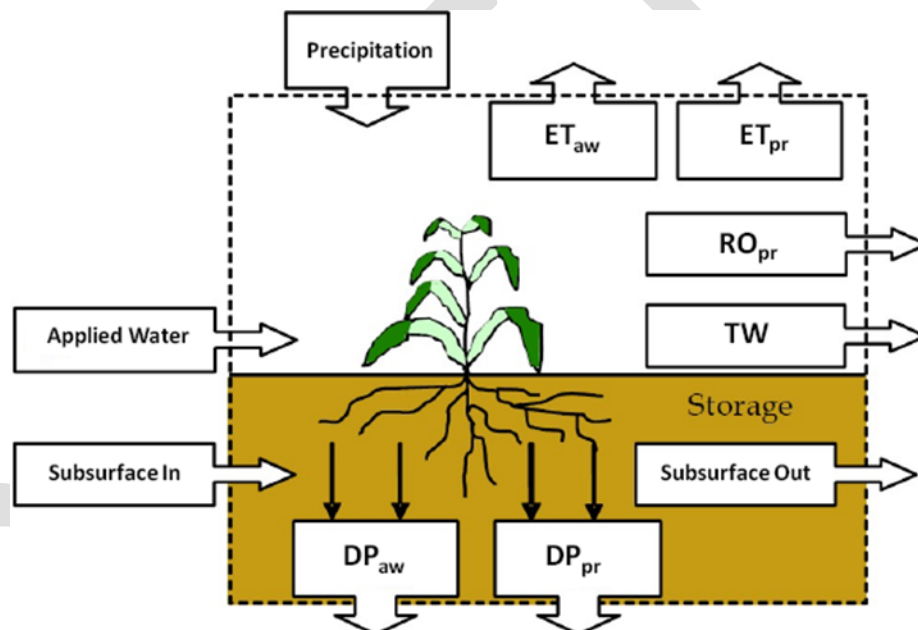


Figure 4. Fluxes Used in Model

Root zone water balance transfers were estimated by crop group based on published values and soil hydraulic parameters. Crop consumptive use was estimated by use of published irrigation efficiencies, with an assumption of no tailwater runoff from the service area.

Calibration, Validation, and Application of Field-Scale Root Zone Water Balance Model

This chapter described the calibration, validation and application of the root zone water balance model. ET estimated by the model was compared to Surface Energy Balance Algorithm for Land (SEBAL) data and adjustments were made. The daily root zone model was also calibrated using CCUF data and soil parameters were adjusted based on SEBAL results. Roughly half the fields were calibrated, and the other half of the fields were used for model validation.

Validation was accomplished through comparisons of ET and SEBAL using weighted averages over a three year period. Over the compared range, the model and SEBAL correlated closely. ET estimates from the model were also compared by individual crop irrigation method to SEBAL, and also correlated well.

Comparison to Water Resources Investigation Estimates

This section compared the estimates of crop coefficients and ET from the study to the results of the 2007 WRI by crop type. Comparisons showed that the 2007 WRI estimates were significantly different than the model's estimates. Further, the model showed monthly changes in ET, and the 2007 WRI estimates did not in a number of cases. The 2007 WRI estimates overestimated ET in some cases and underestimated in others. Figure 5 shows the results of comparisons for select crops during 1999. The 2007 WRI estimated a crop ET that is roughly half a foot of water per acre less than reported in this study.

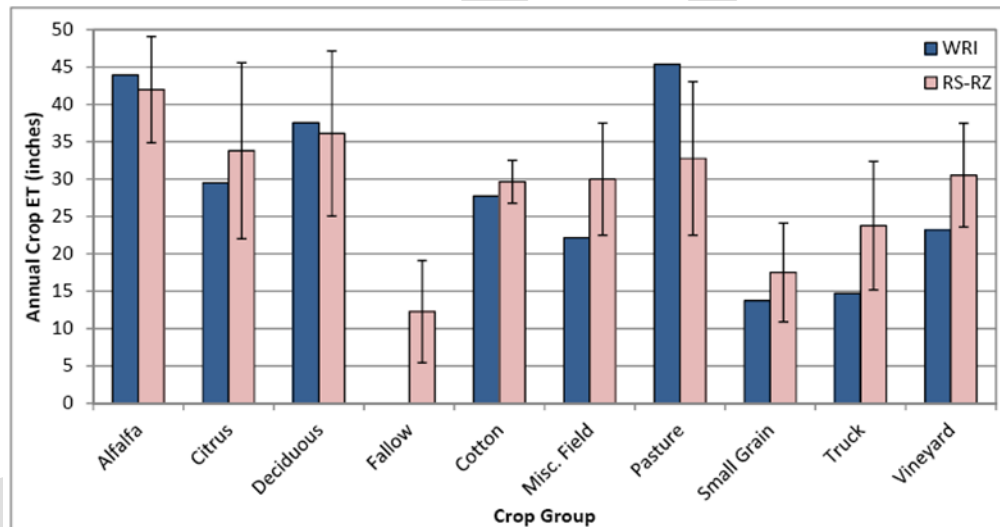


Figure 5. Comparison of 1999 Annual Crop ET

Other compared results indicate significant differences as well. Comparison indicates substantial differences in estimated acreages, where the 2007 WRI estimated significantly more cropped acreage. The 2007 WRI also estimated 3 more inches of precipitation in the study area than did this report. The 2007 WRI estimated applied irrigation water in 1999 to be 100,000 acre-feet less, and deep percolation of applied water at double what is reported in this report.

Suitability of Analysis

The analysis conducted was appropriate, robust, and used the best available data. This analysis dramatically improves land use analysis from the 2007 WRI and is suitable for use in SGMA.

GSP Applications

Land use, precipitation, deep percolation, and ET are critical components of water budget calculations. The data collected and analyzed in this report can be used as the foundation for these water budget components in future GSP water budget calculations.

As recommended in the report, this data and analysis will benefit from being updated to the present day with the latest information available.

Water Resources Investigation Update, Kaweah Delta Water Conservation District (Fugro 2016)

The 2016 WRI update investigated and quantified water resources of KDWCD for the study period of 1981 to 2012, which provides an update from the original 1981 to 1999 period in the 2007 WRI. The 2016 WRI is an updated technical investigation intended to provide answers to questions related to the quantity of groundwater, the hydraulic movement of groundwater, sources and volumes of natural recharge, and trends of groundwater levels in the KDWCD study area.

Introduction, Data Summary, and Study Period Definition

This section provides the introduction, summarizes data collected, and defines the study period. The purpose of the 2016 WRI was to update the WRI by extending the study period through 2012, and includes the period from 1981 to 2012. Data collected for the 2016 WRI included: artificial recharge, water level, precipitation, municipal and community water demand, surface water, rural water demand, imported surface water, and wastewater data. Collected data was input to a GIS database.

The hydrologic base period of 1981 to 1999 was not revisited in the 2016 WRI update. The 2016 WRI update compares the extended period (2000 through 2012) to the original study period to investigate how conditions in KDWCD changed during long term climatic cycles.

Suitability of Analysis

The data collected were appropriate selections and useful for analysis. Data for artificial recharge was significantly better than what was available during the 2007 WRI. Water quality data does not appear to have been collected for this update.

GSP Applications

The hydrologic units used in the 2007 and 2016 WRI update are not suitable for use under SGMA during GSP development, as they do not match GSA boundaries. The data collected was stored in Microsoft Access and Excel format, and the GIS database, and can be extracted and reconfigured to match the Mid-Kaweah GSA. The data will be useful during GSP preparation and additional data will need to be collected to update the data sets to current conditions.

Geohydrology

This section of the 2016 WRI update is focused on updating groundwater levels, potentiometric surfaces and development of groundwater contour maps. This analysis was used to estimate annual changes of groundwater in storage and to identify subsurface inflow and outflow across KDWCD boundaries.

Groundwater moves generally in a southwesterly direction along the principal axis of KDWCD. Outflow of groundwater from KDWCD occurs to the west from Hydrologic Unit VI. Outflow

also occurs from Unit IV to the south. Inflow of groundwater to the District occurs both from the north and from the south into Unit VI in response to a pumping depression in aquifers above the Corcoran Clay. Large areas of lowered groundwater levels were present in 2012 in hydrologic unit number VI, near the cities of Corcoran and Hanford, shown in Figure 6. Changes in groundwater storage were calculated for each year in the study period, and indicate that over the 32 year study period, there has been a reduction of 2,403,000 acre-feet of water in groundwater storage.

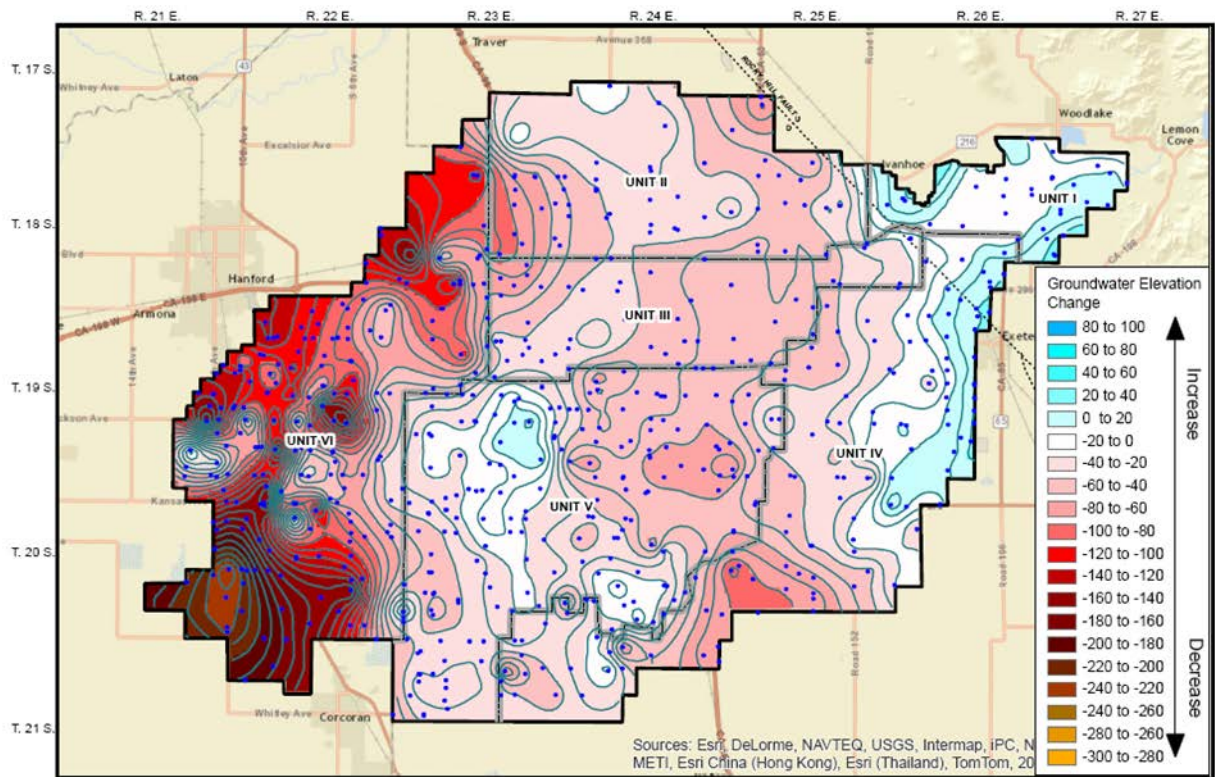


Figure 6. Contours of Change in Groundwater Levels, 1952 to 2012

Subsurface flow rates were calculated along KDWCD and hydrologic unit boundaries. The inflow to KDWCD perimeter is between 8,700 and 23,100 acre-feet per year, depending on water year type. Net inflow and outflow for each hydrologic unit were also calculated.

Suitability of Analysis

The analysis conducted in this section was appropriate and used the best data available.

GSP Applications

Information provided in this section is useful for GSP development, both in the basin setting portion and the water budget portion of the GSP. Water level and change in storage information will be useful for establishing historical water budgets. Subsurface flows calculated in this report can provide a starting point for developing subsurface flow calculations for GSPs.

Water quality is not discussed in the 2016 WRI update, and will need to be included in development of a GSP.

Surface Water

This section reviewed and tabulated the availability, conveyance, and delivery of surface water in KDWCD. It also evaluated accounting for conveyance losses and compiled artificial recharge activities.

Recharge basin calculations were changed from the 2007 WRI to estimate percolation more accurately, and was based on individual daily and monthly diversion to facilities, the number of wetted days in each basin, and the known infiltration rate during those days. The change in calculation indicates a six percent change in artificial recharge estimates, from 65,700 to 70,000 acre-feet per year.

Runoff for major rivers and streams was documented, including: the Kaweah, St. Johns, and the Lower Kaweah river systems. Distributaries and canals were not updated. CVP deliveries for the extended study period were documented, and deliveries from the Tulare Irrigation District main canal system, as well as Kings River water were documented.

Conveyance loss calculations were also updated in this report. The changes in calculations did not create large differences in calculated conveyance losses, which were similar to the original study period. Spills of surface water discharge outside of KDWCD were also documented, though spills were limited to very wet years.

Suitability of Analysis

The analysis conducted in this section was appropriate and used the best data available at the time.

GSP Applications

Information provided in this section will be useful for GSP water budget calculations.

Water Balance and Safe Yield

A water budget was calculated for the study period of 1981 to 2012 by assessing the components of inflow and outflow of water within KDWCD, and calculating the change in groundwater storage. The water budget was performed by calculating components of water inflow and outflow for each year of the study period for the entire study area and for each of the six hydrologic units, and comparing the totals to the annual change in groundwater in storage, as determined by the specific yield and change in groundwater elevation method.

Water balance calculations in the 2016 WRI were performed in a similar manner to the 2007 WRI, and were updated to include components from the Davids Engineering report. Total calculated demand exceeded components of inflow during the 32 year study period, resulting in an accumulated deficit of about 1,947,500 acre-feet during the study period, with a corresponding decrease of groundwater in storage. Water balance components included:

- Subsurface inflow
- Precipitation
- Streambed percolation and delivered water conveyance losses
- Artificial recharge
- Percolation of irrigation return water
- Percolation of wastewater
- Subsurface outflow
- Agricultural water demand and consumptive use
- Municipal pumpage
- Agricultural pumpage
- Consumptive use by phreatophytes
- Evaporative losses
- Exported water

Safe yield for the groundwater basin within KDWCD was calculated using two different methodologies. The first method assumed safe yield was equal to long term recharge, which using the same methodology as the 2007 WRI report, resulted in a safe yield estimate of 570,000 acre-feet per year. The second method compares annual extractions over the study period to the net changes in groundwater storage, calculated a safe yield of 635,900 acre-feet per year. Both methods indicate that KDWCD study area is in a condition of overdraft.

The 2016 WRI calculates that the sum of all the components of outflow from the entire KDWCD exceeded the sum of all the components of inflow by an estimated 60,900 acre feet per year, for an accumulated storage depletion of about 1,947,500 acre feet over the study period of 1981 to 2012. For KDWCD as a whole, irrigation water return flow (deep percolation of irrigation water) was the greatest component of groundwater recharge (37 percent), followed by streambed percolation and conveyance loss at about 31 percent and percolation of precipitation at 12 percent.

The 2016 WRI indicates that the KDWCD study area as a whole is in a severe overdraft. The magnitude of the overdraft is in the range of about 60,900 to 75,100 acre feet per year and occurs predominantly in the west side of the study area. To the extent that groundwater is exported out of the study area from Hydrologic Unit No. VI, this overdraft would increase.

Suitability of Analysis

The analysis conducted in this section was appropriate and used the best data available.

GSP Applications

The water budget calculations are useful for development of a GSP, and can be used as the basis for future water budget calculations for SGMA compliance. The water budget study area would

need to be changed for SGMA, either to a Kaweah Subbasin wide coverage, or to a Mid-Kaweah GSA area coverage, depending on coordination agreement decisions.

Conclusions

Review of the three reports that comprise the analysis performed to develop the 2016 WRI indicates that the work performed was technically appropriate, comprehensive, defensible, and should be sufficient as a base for development of a GSP.

The 2007 WRI relied upon reference ET for calculating water balance. Reference ET's are too general to be relied upon for detailed water budgets. To remedy this, KDWCD completed a thorough analysis of ET performed by Davids Engineering in 2013, and that updated ET information was used during development of the 2016 WRI. The 2016 WRI updated water budget information using the improved ET information, and is suitable for use in GSP development.

The 2016 WRI provides water budget information for the KDWCD and the six identified Hydrologic Units. Tables 1 and 2 show the results of water budget calculations from the 2016 WRI for Hydrologic Units III and V, respectively. The Mid-Kaweah GSA falls within the boundaries of these two units. The tables show calculated values for each year from 1981 through 2012, and the maximum, minimum, and average values for each component. Components are grouped into inflow and outflow components, and change in storage by analysis method. The water budgets for Hydrologic Units III and V show that both units have been in a general condition of overdraft over the study period.

Table 1 shows water budget information for Hydrologic Unit III. Subsurface inflow, streambed percolation and conveyance losses, and irrigation water percolation are the primary sources of inflow, and direct precipitation contributes a much smaller amount of inflow in Hydrologic Unit III. Most outflow in Hydrologic Unit III is the net extraction from pumping. Water was removed from storage during most years of the study period, and the average reduction in storage per year was 21,500 acre-feet per year using the inventory method, or 4,900 acre-feet per year using the specific yield method. Using the inventory method, the safe yield was estimated to be 69,500 acre-feet per year. Using the specific yield method, the safe yield was estimated at 78,500 acre-feet per year.

Table 2 shows water budget information for Hydrologic Unit V. Subsurface inflow, streambed percolation and conveyance losses, and irrigation water percolation are the primary sources of inflow, and direct precipitation contributes a much smaller amount of inflow in Hydrologic Unit V. Most outflow in Hydrologic Unit V is the net extraction from pumping. Water was removed from storage during most years of the study period, and the average reduction in storage per year was 1,700 acre-feet per year using the inventory method, and 18,900 acre-feet per year using the specific yield method. Using the inventory method, the safe yield was estimated to be 147,900 acre-feet per year. Using the specific yield method, the safe yield is 133,700 acre-feet per year.

Change in groundwater storage was calculated using two different methods in the 2016 WRI. The inventory method calculates the change in storage as the amount that recharged or was extracted from groundwater supplies based on accounting of all inflows and outflows components. The

specific yield method calculates change in storage by comparing groundwater elevation contours developed from monitoring with the specific yield of the aquifer. Both methods were also used to calculate safe yield.

The two methods of calculating change in groundwater storage generate differing results, yet are both necessary for the best understanding of water budgets. The inventory method can be used to identify when water use is exceeding available annual supply, even when groundwater levels remain stable. Likewise the specific yield method is useful for identifying changes in groundwater in storage in the study area when the inventory method shows that inflows and outflows are even, which can be useful to identify neighboring areas that may be affecting conditions in the study area.

References

- Dauids Engineering, 2013. Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing, consultants unpublished report prepared for the Kaweah Delta Water Conservation District, March.
- Fugro West, Inc., 2007. Water Resources Investigation of the Kaweah Delta Water Conservation District, consultant's unpublished revised report prepared for the Kaweah Delta Water Conservation District, July.
- Fugro West, Inc., 2016. Water Resources Investigation Update, Kaweah Delta Water Conservation District, consultant's unpublished report prepared for the Kaweah Delta Water Conservation District, January.

Table 1. Estimated Components of Inflow and Outflow, Change in Storage, and Safe Yield, Hydrologic Unit III (Values in 1,000s of Acre-Feet)

Calendar Year	Precipitation (inches)	Components of Inflow							Components of Outflow			Change in Storage	
		Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Recharge Basin Percolation	Irrigation Water Percolation	Precipitation Percolation	Total Inflow	Total Net Extraction from Pumping	Subsurface Outflow	Total Outflow	Inventory Method	Specific Yield Method
1981	11.2	18.7	4.7	10.6	0	23.2	5.9	63.2	78.3	1.6	80.2	(17.10)	(17.90)
1982	13	20.7	4.9	32.4	4.4	21.5	7.1	91.1	51.6	9.3	61.2	29.90	47.10
1983	18.1	23.5	5.1	32.9	7.5	19.5	15	103.3	49	4.5	53.8	49.60	13.50
1984	6.6	33.7	5.3	18.6	2.4	26.6	1.2	87.8	86.5	5.2	91.9	(4.10)	0.30
1985	8.4	15.3	5.5	13.3	0.6	23.6	5.3	63.6	81.8	2.4	84.4	(20.80)	(11.60)
1986	10.9	20.4	5.7	26.3	4.4	19.2	11.9	87.9	66	0.7	66.9	21.00	27.60
1987	11.1	14.1	5.9	8.4	0.1	20.8	8.5	57.8	84.1	2.4	86.8	(29.00)	(27.60)
1988	9.2	9.4	6.1	8.9	0.1	21.1	4	49.5	83.5	8.3	92	(42.50)	(28.40)
1989	5	16.4	6.2	8.4	0	20.8	4.9	56.7	84.1	5	89.3	(32.60)	(26.60)
1990	5.6	12.9	6.3	7.1	0	21.4	5.6	53.2	89	9.2	98.4	(45.20)	(51.30)
1991	11.3	12.1	6.4	8.5	0	19	7.4	53.4	84	7.9	92.2	(38.80)	6.20
1992	10	7.8	6.3	7	0.1	18	4.8	44	85.2	15.5	100.9	(57.00)	(40.90)
1993	12.3	13.4	6.6	18.2	1.7	17.6	12.8	70.2	72.1	8.2	80.6	(10.30)	11.30
1994	9.4	9.2	6.9	10.3	0	17.8	5	49.2	83.5	10.2	94	(44.80)	(6.00)
1995	16.7	7.4	7	23.5	5.9	15.8	15.4	75.1	62.8	12	75.1	(0.10)	23.00
1996	16.2	17.1	7	17.8	3.4	15.4	9.5	70.2	77.2	8.6	86	(15.90)	(9.20)
1997	9.7	33.8	7.3	17	3.8	15.7	7.8	85.3	78.6	6.1	84.9	0.40	18.20
1998	19.9	21.9	7.4	23.8	7.4	11.4	23.1	95	47.7	5	52.9	42.00	47.00
1999	8.5	13.3	7.7	11.1	0.2	14.4	11.6	58.3	75.7	5.5	81.5	(23.20)	(32.90)
2000	12.8	27.9	8	10.6	0.3	24.4	5.9	77.1	88.9	6.7	95.8	(18.70)	(2.00)
2001	15.3	21.8	8.2	7.4	0.1	23	3.6	64.1	95.4	2.7	98.3	(34.30)	(8.20)
2002	6.4	16.6	8.2	12.8	0.4	23.9	3.2	65	96.5	8.6	105.2	(40.30)	(33.80)
2003	8.4	16.6	8.1	10.1	0.7	22.1	2.7	60.3	96.1	2.6	99	(38.60)	(16.00)
2004	8.4	23.4	8.1	9.1	0	21.3	2.9	64.9	97.8	5.8	103.7	(38.80)	(42.30)
2005	10.5	24.6	8.1	19.1	0.8	19.8	5.7	78.1	79.8	5.1	85.1	(6.90)	62.50
2006	14.8	14.3	8.3	17.2	3.4	21.3	7.1	71.5	80.1	6.3	86.6	(15.20)	(10.70)
2007	5	23.7	8.1	7.9	0	20	1.8	61.5	97	18.6	115.9	(54.30)	(37.50)
2008	5.8	12.5	8.3	11	0.2	21.9	2.6	56.3	98.8	11	110	(53.70)	(29.40)
2009	6.6	20.4	8	9.6	0.1	22.1	2.5	62.7	103.6	15.1	118.9	(56.10)	5.90
2010	16	19.9	8.4	17	1.1	25.3	8.5	80.1	91.7	19	110.9	(30.80)	22.20
2011	5.7	28.3	8	26.1	3.5	17.6	4.2	87.7	81.3	19.5	101	(13.30)	25.80
2012	5.9	24	7.9	8.8	0	21	3.9	65.6	95.3	17.5	113	(47.40)	(35.00)
Maximum	19.9	33.8	8.4	32.9	7.5	26.6	23.1	103.3	103.6	19.5	118.9	49.60	62.50
Minimum	5	7.4	4.7	7	0	11.4	1.2	44	47.7	0.7	52.9	(57.00)	(51.30)
Average	10.5	18.6	7	14.7	1.6	20.2	6.9	69.1	82	8.3	90.5	(21.50)	(4.90)

Table 2. Estimated Components of Inflow and Outflow, Change in Storage, and Safe Yield, Hydrologic Unit V (Values in 1,000s of Acre-Feet)

Calendar Year	Precipitation (inches)	Components of Inflow							Components of Outflow			Change in Storage	
		Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Recharge Basin Percolation	Irrigation Water Percolation	Precipitation Percolation	Total Inflow	Total Net Extraction from Pumping	Subsurface Outflow	Total Outflow	Inventory Method	Specific Yield Method
1981	11.2	29.3	3	22.7	3.7	63.9	13.1	135.7	165.3	16.3	181.8	(46.10)	(43.90)
1982	13	25.5	3.1	96.7	84.6	60	16.8	286.6	62.6	14.6	77.5	209.10	157.60
1983	18.1	24.8	3.2	97.6	141.8	51.8	33	352.1	154.2	33.9	188.3	163.80	107.60
1984	6.6	22.5	3.3	51.2	33	73.9	4	187.8	162	35.3	197.6	(9.80)	(23.60)
1985	8.4	15.5	3.4	30.5	14.3	67.2	11.1	141.9	166.8	26.7	193.7	(51.80)	(34.00)
1986	10.9	15.4	3.5	84	51.4	53.9	22.2	230.3	50.4	31.3	82	148.30	86.40
1987	11.1	14.1	3.6	4.8	2	59.3	15.8	99.6	213.7	24.4	238.4	(138.80)	(114.10)
1988	9.2	19.5	3.7	24.3	2.5	60.6	10.9	121.4	166.2	5.1	171.5	(50.10)	(80.50)
1989	5	18.1	3.8	13.4	0.2	60.4	13.3	109	192.6	6.7	199.5	(90.40)	(123.50)
1990	5.6	17.5	3.9	0.2	0	62	13.9	97.4	235	7.8	243	(145.60)	(160.30)
1991	11.3	25.2	4	18.1	0.4	54.4	18.3	120.3	174.1	6.5	180.8	(60.40)	(80.60)
1992	10	30.6	3.7	7.9	0.2	52.1	13.5	108	194	2.6	196.8	(88.80)	(84.00)
1993	12.3	20.1	4.1	67.5	27.7	49.2	29.5	198.1	46.4	10.2	56.9	141.20	59.50
1994	9.4	31.5	4.5	13.2	0	51.9	13.6	114.7	179.9	17.9	198	(83.30)	(66.30)
1995	16.7	32.6	4.6	72.4	68.2	45.2	36.3	259.3	62.5	9.3	72	187.30	94.60
1996	16.2	17	4.6	66.7	45.2	45.5	20.7	199.7	69.7	9.6	79.5	120.20	8.00
1997	9.7	9.8	4.7	59.5	42	46.1	17.1	179.1	104.8	8.5	113.6	65.50	66.00
1998	19.9	22.2	4.7	78.7	91.3	33	60.2	290.2	34.6	23.4	58.3	231.90	108.10
1999	8.5	29.8	5.2	34.8	4.9	41.8	27.9	144.3	103.1	17.4	120.7	23.60	(11.70)
2000	12.8	28.7	5.4	44.3	8.6	76.3	18.9	182.2	137.5	34.9	172.6	9.60	(22.10)
2001	15.3	26.3	5.4	17.9	2.5	68.5	11.3	131.9	201.8	20.4	222.5	(90.60)	(74.20)
2002	6.4	15.5	6.1	25	11.8	70.7	9.8	138.9	213	19.2	232.4	(93.50)	(78.10)
2003	8.4	9.8	6.8	38	11	66.7	8.6	140.9	170.8	29.9	201	(60.10)	(41.90)
2004	8.4	19.2	7	17.7	2	65.3	9.2	120.4	217.5	41.8	259.5	(139.10)	(62.90)
2005	10.5	21.8	7.4	75.8	23	61.7	17.3	206.9	58.1	25.3	83.6	123.30	86.70
2006	14.8	28.7	7.6	69.8	40.7	71.2	22.6	240.5	110.2	44.8	155.2	85.30	29.60
2007	5	23.1	7.8	11.5	1.1	70.9	6	120.3	246.7	60.8	307.7	(187.30)	(149.20)
2008	5.8	65.8	7.7	20.8	4.2	74.1	7.9	180.5	234.3	50.4	284.9	(104.40)	(118.80)
2009	6.6	7.4	7.4	35.7	5.9	70.2	7.9	134.4	190.8	51.9	242.9	(108.50)	(23.80)
2010	16	9.6	7.5	63.8	31.6	81.1	26.7	220.2	114.3	46.6	161.1	59.20	102.30
2011	5.7	9.8	7.6	82.7	55	60.5	14.5	230	88	36.7	124.9	105.20	65.70
2012	5.9	5	8.1	12.4	2.1	73.1	13.6	114.2	241.5	50.4	292.2	(177.90)	(182.50)
Maximum	19.9	65.8	8.1	97.6	141.8	81.1	60.2	352.1	246.7	60.8	307.7	231.90	157.60
Minimum	5	5	3	0.2	0	33	4	97.4	34.6	2.6	56.9	(187.30)	(182.50)
Average	10.5	21.6	5.2	42.5	25.4	60.7	17.7	173	148.8	25.6	174.7	(1.70)	(18.90)