September 12, 2018

Mr. Geoff Poole
General Manager, Borrego Water District
806 Palm Canyon Drive,
Borrego Springs, CA 92004

RE: Methodology To Examine Future Groundwater Overdraft In Terms Of The Overall Hydrologic Water Balance Considering Recharge Variability And Parameter Uncertainty

Dear Geoff,

The following draft Report was produced under our existing contract to provide technical support to BWD for to the Borrego Valley Groundwater Basin Groundwater Sustainability Plan Proposition 1 Grant Project. It addresses portions of Tasks 2.1, 2.2, and 3.1 specific to water supply uncertainties related to the assessment of groundwater overdraft.

Subsequent analyses are in process that will build from this Report to examine the effect of overdraft on BWD supply well production rates and water quality.

Thank you for your time and attention.

Sincerely,

Jay W. Jones
CA PG#4106
Environmental Navigation Services Inc.

METHODOLOGY TO EXAMINE FUTURE GROUNDWATER OVERDRAFT IN TERMS OF THE OVERALL HYDROLOGIC WATER BALANCE CONSIDERING RECHARGE VARIABILITY AND PARAMETER UNCERTAINTY

OVERVIEW

The Borrego Springs Subbasin (Borrego Basin) of the Borrego Valley Groundwater Basin is currently in a state of critical overdraft. Groundwater pumping reductions will be necessary under the Sustainable Groundwater Management Act (SGMA) to achieve long-term sustainability of the water supply for the Borrego Springs community. A target pumping rate of 5700 AFY has been proposed where Borrego Basin groundwater use is balanced by the long-term average groundwater recharge inflow rate.

The purpose of this Draft Report is to present a methodology to examine the proposed target pumping rate in terms of the overall hydrologic water balance and future overdraft that will occur as groundwater production rates decrease. The analysis is based on the maximum 20-year reduction period allowable under SGMA. The 5700 AFY target is based on the average groundwater recharge rate as determined by the US Geological Survey ([USGS Report, 2015] Faunt, C.C., Stamos, C.L., Flint, L.E., Wright, M.T., Burgess, M.K., Sneed, Michelle, Brandt, Justin, Martin, Peter, and Coes, A.L., 2015, Hydrogeology, hydrologic effects of development, and simulation of groundwater flow in the Borrego Valley, San Diego County, California: U.S. Geological Survey Scientific Investigations Report 2015–5150, 135 p., http://dx.doi.org/10.3133/sir20155150).

The 5700 AFY target pumping rate is examined here in terms of the potential variability of recharge and its effects on the degree of groundwater overdraft that will occur over time. The Borrego Water District (BWD) serves a California Department of Water Resources (DWR) designated severely disadvantaged community (SDAC). Of concern are the potential impacts on the Borrego Water District's (BWD) ability to produce drinking water and related increase in water production costs should the target pumping rate fail to achieve the SGMA-mandated sustainability goals as described in the Groundwater Sustainability Plan (GSP, in process. Public Review Draft expected to be released December 2018).

This Draft Report includes the following:

- A review of the overall water balance that includes groundwater recharge, groundwater discharge, pumping, irrigation return flows, and evapotranspiration-related water demand from native phreatophytes (groundwater dependent ecosystems).

- An assessment of how the recharge rates and water balance components may vary over time during a 20-year Groundwater Sustainability Plan (GSP) as based on the results of the USGS Groundwater model for the model period of 1945 to 2016. This assessment supports consideration of the uncertainty and potential basin management risks associated with the water balance calculations.

- Comparison of the degree of overdraft to the USGS model predictions for water level decline (USGS Report Scenario 6).

- Statistically-based 'what if' simulations that use the model's time-varying recharge rates to look at what may be observed after 5 years of pumping reductions following 'wet' or 'dry' periods. The GSP includes a 5-year review cycle and an adaptive management strategy is planned to be used that may include revisions to the target pumping rate at 5-year intervals.

- Summary and Considerations

Chronic lowering of groundwater levels and reduction of groundwater storage are two of six Sustainability Indicators, if found to be significant and unreasonable, describe the undesirable results of critical overdraft to be addressed in the GSP (DWR, 2017. CA Department of Water Resources Sustainable Management Criteria Best Management Practice Guidance, November 2017). The GSP will include metrics to establish thresholds for all of the sustainability indicators.

DWR has established a maximum period of 20 years for the Borrego Basin to achieve sustainability where "the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. Sustainable yield is referenced in SGMA as part of the estimated basinwide water budget and as the outcome of avoiding undesirable results…for the six sustainability indicators" (DWR, 2017. p.32). This Report focuses on the basinwide water budget, termed here as the water balance. Potential changes in BWD supply well water quality and production rates associated with ongoing overdraft are also of concern but not directly addressed in this Draft Report.

1.0 Water Balance Components

The 5700 AFY target pumping rate is based on an analysis of the hydrologic water balance (water budget) conducted by the USGS and is a water extraction rate equal to the amount of water that replenishes the Borrego Basin as groundwater recharge. The model can be viewed as a large box that is discretized into smaller rectangular boxes to track the flow of water over time into and within the alluvial basin. The target pumping rate was set equal to the average annual groundwater recharge inflow rate and is based on a combination of groundwater inflow (into the sides of the large box) and water that enters into the basin from adjacent watersheds and flows into the aquifer system as recharge (see **Figure 1**).

As stated in the USGS Report (Summary and Conclusions, p. 128*): "The main source of recharge to the system is underflow from the upstream portions of the watershed and runoff from creeks and streams draining the upstream portions of the watershed that, with the exception of runoff generated in response to exceptionally large and infrequent storms, quickly seeps into the permeable streambeds and infiltrates through the unsaturated zone. Over the 66-year study period [ed: 1945 to 2010], on average, the natural recharge that reaches to the saturated groundwater system is approximately 5,700 acre-ft/yr, but natural recharge fluctuates in the arid climate from less than 1,000 to more than 25,000 acre-ft/yr."*

The groundwater recharge rate, as noted above, varies widely over time in contrast to the stated average. This variability is examined here by examining the amount of overdraft that will occur over a 20 year period to evaluate how effective the target pumping rate of 5700 AFY will be towards meeting the SGMA goals. To date the overall aquifer water balance has been negative in that outflows have exceeded inflows, leading to an estimated cumulative depletion (or overdraft) of 440,000 acre-feet (AF) as of 2010 with associated water declines of over 150 ft (USGS, 2015. p.129). Th overdraft was calculated to be 520,000 AF as of 2016 as described in the Groundwater Sustainability Plan (GSP, currently in process by others).

The Borrego Basin water balance calculations provide a direct measure of the effect of pumping rate reductions on a basin-wide scale by tracking how much more water will be derived from storage. The Borrego Basin aquifer water balance consists of six flow components.

- Inflows occur via groundwater flow, surface (natural) recharge, and irrigation return flows.
- Outflows occur via groundwater flow, deep-rooted groundwater dependent plant use (termed evapotranspiration), and groundwater pumping.

These six values are calculated in the USGS model and the annual values for the model analyzed in this report were obtained from Dudek's update of the USGS model update (as presented on).

1.1 INFLOWS

Groundwater.

The USGS groundwater model allows for time-varying groundwater inflow rates but in this case the inflow rate was relatively constant over the model duration, approximately 1400 AFY as stated in the USGS Report. Most of this inflow occurs along the northwestern and western edges of the valley. Please refer to the GSP for additional details.

There is no groundwater flow in or out of the northeastern side model domain where the NW-SE trending Coyote Creek Fault occurs because it is assumed to be a no-flow boundary condition. The potential impact of this assumption has not been assessed in this report.

Natural Recharge.

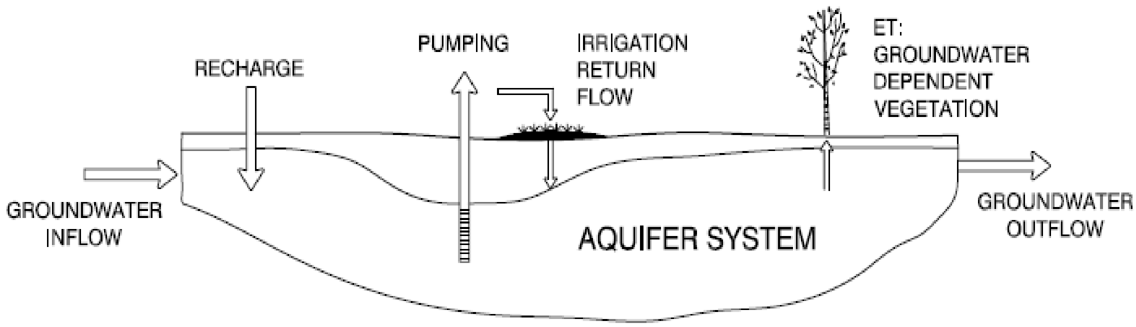
The primary source of water to the Borrego Basin is surface water (stormwater and ephemeral stream flow) that flows into the valley from adjacent mountain watersheds and then infiltrates. Direct recharge by rainfall within the valley is very low compared to surface water inflows as the annual rainfall averages 5.8 in/yr. [USGS Report, page 43].

The contributory watersheds are approximately 400 mi^2 and much larger in area than the approximately 110 mi^2 Borrego Valley (USGS Model Report). Further, because the adjacent watersheds are higher in elevation and have higher precipitation rates they provide the bulk of the water that enters the Borrego Basin. Inflows from the adjacent watersheds were not directly calculated by the USGS groundwater model, instead these were determined using the USGS' regional scale Basin Characterization Model (BCM) for the watersheds located west and north of the Borrego Basin. Per the USGS Report (p. 48) "*The BCM calculates potential in-place recharge and potential runoff and generates distributions of both components. In this study, the BCM provided estimates of the underflow from the adjacent mountains and basins and potential runoff in stream channels into the basin. Moreover, the BCM can be used to compare the potential for recharge under the current climate (2010) and that for past wetter and drier climates (Flint and Flint, 2007a). The BCM model domain includes the watersheds that surround and drain into the Borrego Valley (fig. 16).*"

The BCM calculations rely on multiple types of hydrologic data and require streamflow measurements to support model calibration. Per the report *"[h]istorical discharge data are available for 1950–83 for Coyote Creek, 1950–2004 for Borrego Palm Creek, and 1958–83 for San Felipe Creek*". The BCM is a highly complex hydrologic model that incorporates parameters such as precipitation data, runoff coefficients, multiple soils data and estimated parameters, in-channel groundwater flow rates, and soil and plant evapotranspiration estimates. As noted (USGS Report p.48) it calculates both surface water and groundwater flows wherein "*the BCM provided estimates of the underflow from the adjacent mountains and basins and potential runoff in stream channels into the basin"*. These inflow values were then re-assessed by allowing the BCM-determined inflows to vary when the Borrego Basin model was calibrated (USGS Report p.128).

FIGURE 1

WATER BALANCE



INFLOWS: RECHARGE (SURROUNDING WATERSHED INFLOW)

LATERAL GROUNDWATER

IRRIGATION RETURN FLOWS

OUTFLOWS: PUMPING

LATERAL GROUNDWATER

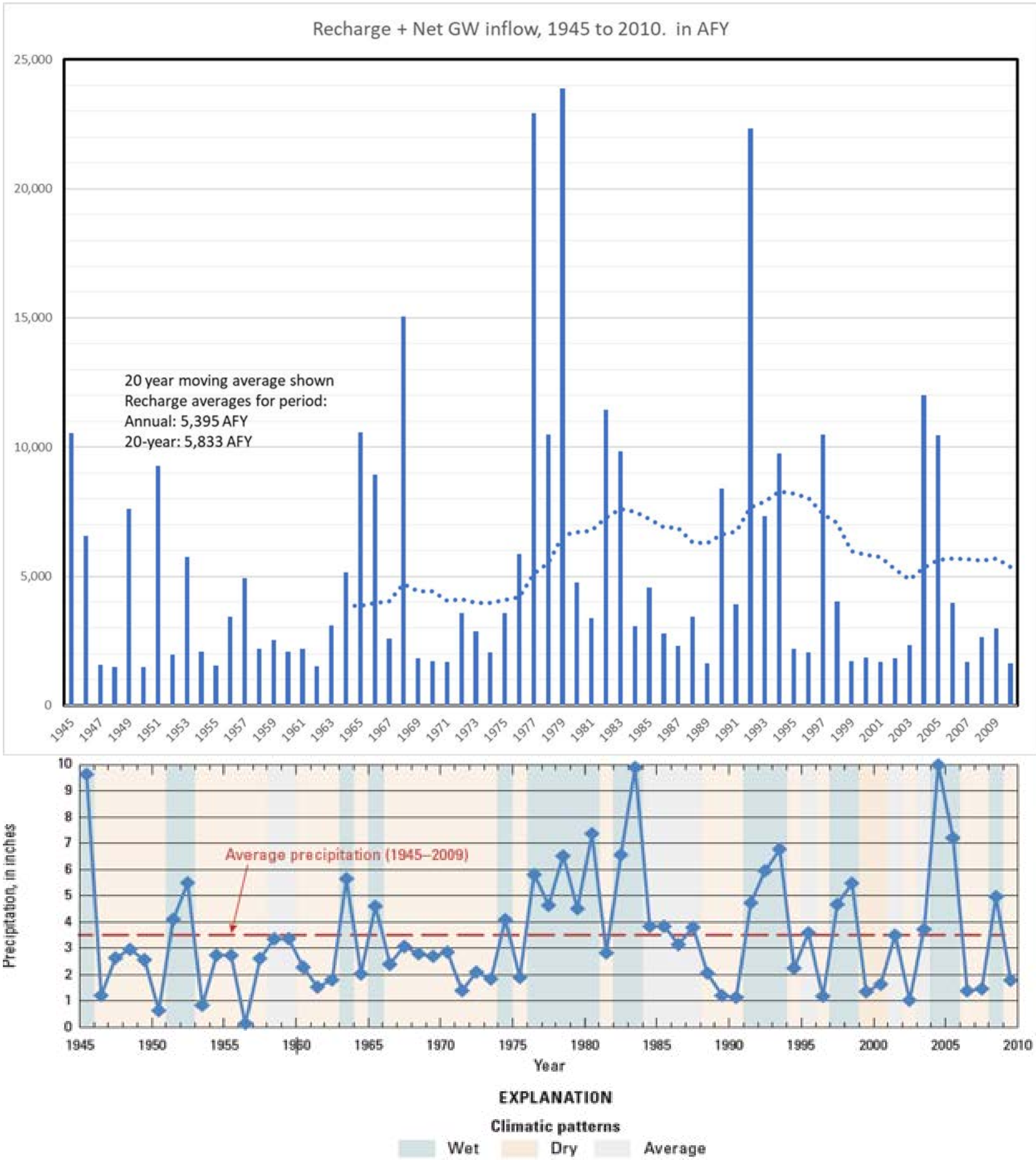
EVAPORATION - NATIVE PLANTS

	Current		Target	
	Inflows	Outflows	Inflows	Outflows
Groundwater	1400	525	1400	525
Natural Recharge	4300		4300	
GW-Dependent ET		400		400
Irrigation Return Flow (10%)	2204		570	
Pumping		**22,044**		**5,700**
totals	7904	22969	6270	6625
net		-15065		-355

The basinwide water balance is based on the USGS Model and uses the current baseline pumping allocation of 22,044 AFY.

The USGS model's annual recharge rates calculated for the 1945 to 2010 model period of 66 years are shown in **Figure 2**.   Also shown is the rainfall record for Borrego Desert State Park (station 040983) presented as Figure 3 in the USGS Model Report.

FIGURE 2



The recharge rates shown in **Figure 2** include groundwater inflow and the water that enters from adjacent watersheds- a value that varies over time. As noted above, the watershed inflows were calculated independently of the groundwater model by the USGS' BCM. Review of the recharge values shows that the inflows have a wide range of values, that high recharge events occur on a decadal scale, and there is some periodicity to the time series. The average value for the 1945 to 2010 period generally cited as the model period was 5,395 AFY. The 20-year average, a period equal to that described under SGMA, is also shown in **Figure 2** to also illustrate how the average recharge rate varies over time when viewed over the 20-year time GSP planning period. The years with high recharge, though infrequent, cause the 20-year averages to generally be higher than the annual recharge rates.

Figure 2 also includes a graph of the rainfall record included in the USGS Report for Borrego Valley. Visually there is a good correlation between precipitation and recharge events. Recharge predominantly occurs as a result of inflows along the basin margins so the correlation indicates that the inflows are readily recharged as they occur.

The USGS groundwater model focused on the 1945 to 2010 period and was updated through 2016 by Dudek (as described in a). The target pumping rate of 5700 AFY was established based on a recharge inflow rate that consists of 1400 AFY of groundwater inflow and 4300 AFY of surficial recharge per the USGS Report. **Table 1** summarizes the statistics of the recharge values.

Table 1. Recharge Values (Inflow) from USGS Model (1945 to 2016)

Year Ending	GW Inflow AFY	Recharge AFY	Total Recharge AFY	20-yr Average AFY		Year Ending	GW Inflow AFY	Recharge AFY	Total Recharge AFY	20-yr Average AFY
1945	1,366	9,182	10,548			1981	1,366	2,011	3,377	6,771
1946	1,366	5,201	6,568			1982	1,366	10,071	11,437	7,266
1947	1,366	196	1,562			1983	1,366	8,443	9,809	7,601
1948	1,370	112	1,482			1984	1,370	1,679	3,049	7,496
1949	1,366	6,232	7,599			1985	1,366	3,183	4,549	7,195
1950	1,366	127	1,493			1986	1,366	1,402	2,769	6,888
1951	1,366	7,915	9,282			1987	1,366	926	2,293	6,872
1952	1,370	594	1,964			1988	1,370	2,039	3,409	6,291
1953	1,366	4,375	5,741			1989	1,366	233	1,600	6,280
1954	1,366	725	2,091			1990	1,366	7,016	8,382	6,614
1955	1,366	174	1,540			1991	1,366	2,515	3,882	6,723
1956	1,370	2,067	3,437			1992	1,370	20,913	22,283	7,659
1957	1,366	3,566	4,932			1993	1,366	5,915	7,282	7,879
1958	1,366	828	2,195			1994	1,366	8,348	9,714	8,263
1959	1,366	1,151	2,517			1995	1,366	787	2,153	8,191
1960	1,370	696	2,066			1996	1,370	656	2,026	8,000
1961	1,366	835	2,202			1997	1,366	9,088	10,454	7,377
1962	1,366	163	1,529			1998	1,366	2,625	3,992	7,054
1963	1,366	1,741	3,108			1999	1,366	318	1,684	5,944
1964	1,370	3,785	5,155	3,851		2000	1,370	450	1,820	5,798
1965	1,366	9,204	10,570	3,852		2001	1,366	283	1,650	5,712
1966	1,366	7,548	8,915	3,969		2002	1,366	428	1,795	5,230
1967	1,366	1,231	2,597	4,021		2003	1,366	932	2,298	4,854
1968	1,370	13,666	15,036	4,698		2004	1,370	10,615	11,985	5,301
1969	1,366	459	1,825	4,410		2005	1,366	9,034	10,401	5,593
1970	1,366	337	1,704	4,420		2006	1,366	2,563	3,929	5,652
1971	1,366	330	1,697	4,041		2007	1,366	292	1,658	5,620
1972	1,370	2,193	3,563	4,121		2008	1,370	1,229	2,599	5,579
1973	1,366	1,512	2,878	3,978		2009	1,366	1,572	2,938	5,646
1974	1,366	671	2,037	3,975		2010	1,366	234	1,601	5,307
1975	1,366	2,215	3,581	4,077		2011 (update)	1,366	1,182	2,548	5,240
1976	1,370	4,482	5,852	4,198		2012 (update)	1,370	6,493	7,863	4,519
1977	1,366	21,545	22,912	5,097		2013 (update)	1,366	1,948	3,314	4,321
1978	1,366	9,100	10,467	5,510		2014 (update)	1,366	1,617	2,983	3,985
1979	1,366	22,504	23,871	6,578		2015 (update)	1,366	2,313	3,679	4,061
1980	1,370	3,372	4,742	6,712		2016 (update)	1,370	1,768	3,138	4,116
						Averages: 1945 to 2010	1,367	3,905	5,395	5,833
						1945 to 2016				
						Average	1,367	3,905	5,272	5,668
						Median	1,366	1,858	3,226	5,593
						Maximum	1,370	22,504	23,871	8,263
						Minimum	1,366	112	1,482	3,851
						Range	4	22,392	22,388	4,412

Review of the model recharge values in **Table 1** emphasizes how much the recharge varies over time and the relative impact of infrequent 'wet' years. The annual recharge rate (1945 to 2016) has a wide range of 1,482 to 23,871 AFY with an average of 5272 AFY (versus the USGS' stated average of 5700 AFY for the 1945 to 2010 period). The median, the midpoint of all of the values, is 3226 AFY. This statistic indicates that half of the time the recharge rate was 3226 AFY or less.

The 20-year averages provide time intervals in the context of the 20-year GSP planning period. Due to the occurrence of a few years with very high recharge rates the 20-year values are, on average, greater than the annual values. Especially noteworthy is comparison of two 'back to back' periods- 1955 to 1974, and 1975 to 1994 where the 20-year averages were 3,975 AFY and 8,263 AFY, respectively (refer to the 20-year values for 1974 and 1994). The effect of pumping reductions over a 20-year GSP would be very different during these two 'dry' and 'wet' periods.

Irrigation Return Flows

The bulk of current groundwater use is for farm and golf course irrigation. A portion of this water returns to the aquifer as a 'return flow'. The rate and timing of irrigation return flows to the aquifer depend on multiple factors. Among these include:

1. How much the application rate exceeds plant and crop demand. For example, irrigation may be applied at a rate that exceeds crop or turf demand to manage the soil so as to reduce soil salinity for plant health. Overwatering and system leakage may also occur.

2. Surface soil moisture conditions. Soils have a 'soil moisture capacity' and can retain a significant quantity of water that will not pass downward when the moisture levels are less than the moisture capacity. Water will then be lost as evaporation from wet soils.

3. Plant root depth. Crops and plants will have varying root depths and thus varying ability to extract water from soil after it is applied.

4. Movement and potential storage of water in the unsaturated zone above the aquifer. Unsaturated flow is highly dependent on soil moisture (or residual moisture- water that is retained in soil following a wetting event). As noted by the USGS Report (p. 3), *"[D]epending on the thickness, permeability, and residual moisture content in the relatively thick unsaturated zone, it takes tens to hundreds of years for the bulk of return flow to reach the water table. In addition, not all water that reaches the root zone reaches the water table because some water is lost through evapotranspiration or goes into storage in the unsaturated zone. Therefore, in many areas, water that is applied to previously unirrigated land arrives at the underlying water table decades or longer after it is applied."*

A distinction needs to be made here between recharge that occurs as a result of surface water inflows versus infiltration of irrigation return flows. Comparison of the annual precipitation record and the recharge calculated by the model (**Figure 2**) suggests that groundwater recharge may be occurring fairly rapidly. The typical conceptual model for infiltration is that of piston flow where infiltration is transmitted rapidly through the vadose zone. Most of this type of recharge occurs along the edges of the basin as a result of surface water flows entering stream channels and floodplains in the valley. In contrast the volume of recharge that occurs within the valley by direct infiltration of rainfall and irrigation return flow is relatively low and has the potential to occur more slowly as discussed above. The USGS model included a 16 year 'spin up' period (prior to 1945) to allow for the delay associated with vadose zone recharge (see page 86 of the USGS Report).

Irrigation return flows are determined in the groundwater model using the Farm Process Package, or FMP. As described in the USGS Model Report (Table 9) the FMP is used to *"Setup and solve equations simulating use and movement of water on the landscape as irrigated agriculture, municipal landscape,* *and natural vegetation."* In turn it supports the time-dependent calculation of water flow within the unsaturated zone using the unsaturated zone flow package, or UZF, that *"Simulates the infiltration and exfiltration of water below the root zone through the unsaturated zone in combination with FMP."* The calculations are used in the model to determine the volume of irrigation that flows below the root zone and enters the unsaturated zone. The UZF simulates the downward flow of water from beneath the root zone to the water table and thus incorporates a time delay.

The vadose zone flow rate (UZF flow) is compared here to the total pumping rate based on review of Dudek's model update report (as presented to the Borrego Advisory Committee 11/2017). Appendix B of the report tabulates, by year, the UZF flows and total pumping rates. Over the last 10 years of the model the UZF flows are approximately 10% of total pumping, and range from 7 to 13%. Combined agricultural and golf course irrigation represent approximately 80% of total pumping so these rates correspond to irrigation-specific return flow rates of approximately 9 to 16%.

The return flow values used here are derived from the model output and may appear lower than what is stated in the USGS report introduction (p.2) where: "*Since agricultural, recreational, and municipal land uses have been developed, a relatively small amount of recharge also occurs from excess irrigation water and septic-tank effluent. Recharge from irrigation return flows, as indicated by the model results, was about 10–30 percent of agricultural and recreational pumpages*". Review of the model results do show irrigation return flow (UZF) rates historically occurred in the range of 10 to 30 percent; however, the rates have decreased over time and are now approximately 10 percent (see, for example, Figure 6 of the model update report). The current model-determined irrigation return flow rate of 10 percent (of total pumping, roughly 13% of irrigation-related pumping) is used in this Draft Report.

For reference a 15% excess water application rate for soil management is stated without basis to be necessary for irrigation done in the Coachella Valley per RWQCB-Colorado Region Order R9-2014-0046 [https://www.waterboards.ca.gov/coloradoriver/board_decisions/adopted_orders/orders/2014/0046cv_ag_waiver.pdf]. The UZF-calculated rates are similar given that not all of the water can be assumed to pass through the relatively deep vadose zone that occurs in the Borrego Valley. The amount of water required for soil management will vary with irrigation method, soil type, season, and crop type.

These water balance calculations do not address water quality impacts due to irrigation return flows. Irrigation return flows will contain elevated levels of dissolved salts due to the evaporation of applied water and water in excess of crop demand is necessary to manage soil salinity and maintain soils for cultivation. Return flows also have the potential to mobilize minerals such as naturally-occurring evaporites from the vadose zone. In addition, contaminants such as nitrates and pesticides can accumulate in the vadose zone and subsequent transport may indeed take years. As a result, irrigation water applied at the start of the 20-year GSP planning period has the potential to contaminate the aquifer both during and possibly after the planning period.

1.2 OUTFLOWS

Per the USGS model description (p.115): *"Groundwater discharge occurs from three primary sources - (1) evapotranspiration in areas where the water table is shallow and direct uptake from plants (mostly in and around the Borrego Sink) can occur; (2) a small amount of seepage from the southern end of the basin; and (3) groundwater pumpage for agricultural, recreational, and municipal uses."*

Evapotranspiration (ET).

Consumptive use of groundwater by native plants (phreatophytes) within the Borrego Basin is primarily associated with mesquite trees located mostly in and around the Borrego Sink where shallow groundwater condition historically occurred. The current ET rate is estimated to be 400 AFY. Historically it is estimated that ET was 7,100 AFY prior to development-related groundwater extraction (USGS Report, p. 129). It has declined over time and was estimated to be approximately 1,220 AFY in 1980 (Moyle, 1982). The decrease is due to the loss of phreatophytes due to the long-term groundwater level decline.

Groundwater Outflow.

Similar to groundwater inflow, while the USGS model can allow for time-varying groundwater outflow rates, the outflow rate was relatively constant over the model duration, approximately 525 AFY. Note that since groundwater outflow is less than groundwater inflow (1400 AFY) there is a net accumulation of groundwater in the Borrego Basin at an approximate rate of 875 AFY.

Total Pumping

A starting value of 22,044 AFY is used in this draft report that corresponds to the currently-estimated baseline pumping allocation. The water balance calculations assume for demonstration purposes that pumping rates decline at a constant annual rate over a 20-year period until the rate is reduced to 5700 AFY. This methodology can assume various pumping schedules to examine overdraft over time.

1.3 Current Water Balance

The current water balance is shown in **Figure 1**. The rate of overdraft is approximately 15,000 AFY. As previously described, this is based on the overall water balance parameters established by the USGS groundwater model and the currently-estimated baseline pumping allocation.

Note that when the target pumping rate of 5700 AFY is applied there is a net negative balance of 355 AFY equal to approximately 6% of the target pumping rate. Given the overall uncertainties in the water balance, future refinements of the water balance parameters may be required should this methodology be used to assess cumulative overdraft under the GSP.

2.0 Sustainable Pumping Rate: Baseline Rate and Reductions

SGMA describes a maximum 20-year attainment period starting in 2020 with 5-year assessment periods (refer to the GSP for further details). SGMA does not mandate a 20-year period and therefore does not preclude using shorter timeframes for attainment. Calculations are presented here for a baseline case that includes:

- A baseline pumping allocation of 22,044 AFY
- An average annual groundwater recharge (inflow) rate of 5700 AFY (The stated value in the USGS Model Report. **Table 1** includes the annual values and summary statistics.)
- Evapotranspiration (native plant ET) rate of 400 AFY
- Groundwater outflow rate of 525 AFY
- Irrigation return flow rate of 10% pf total pumping.

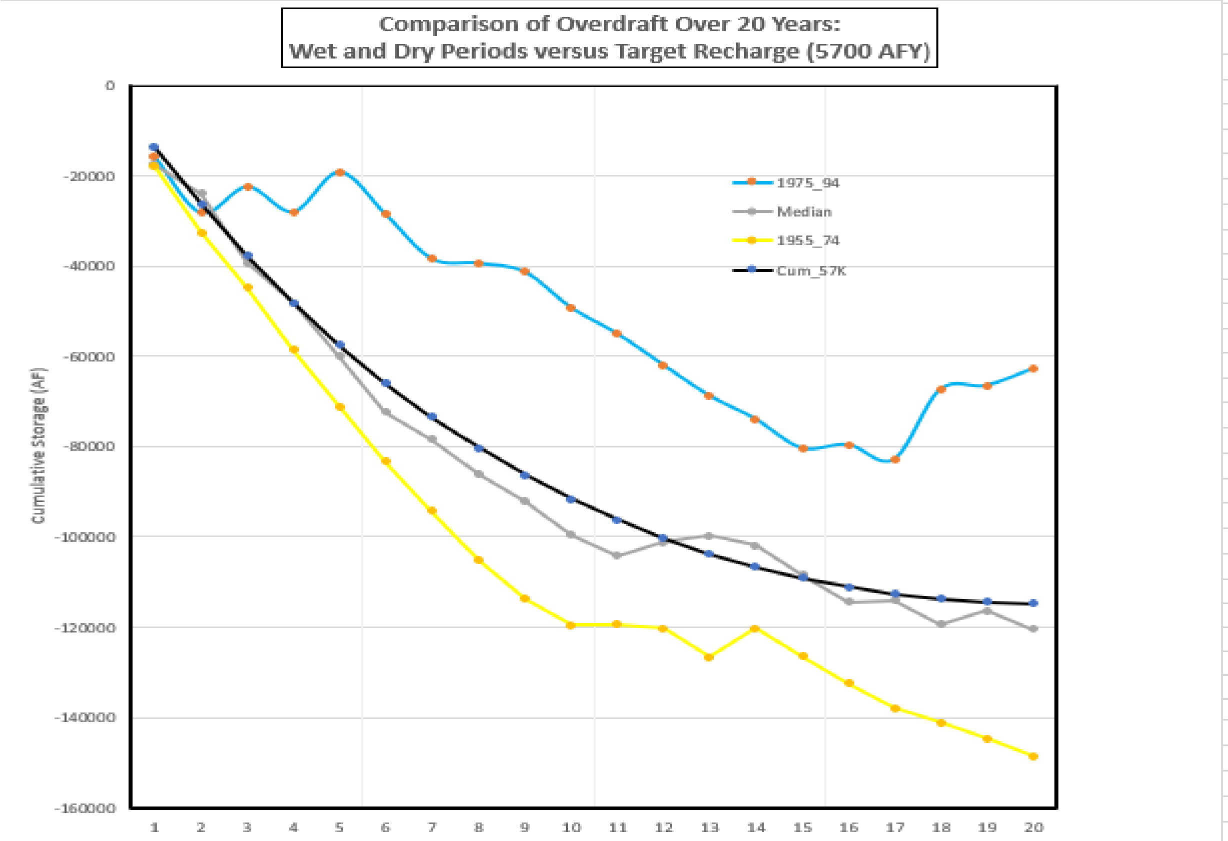
An Excel spreadsheet was used to calculate the water balance where the pumping rate is reduced by a fixed percentage each year until the pumping rate is reduced from 22,044 to 5700 AFY at the end of the 20-year period. This requires an annual reduction of approximately 6.5% per year. The cumulative volume of net groundwater removal from storage, or groundwater overdraft, is calculated over the 20-year SGMA planning timeframe.

Figure 3 shows the results. Four groundwater recharge rates are used to calculate overdraft over the 20 year period using the same pumping rate reductions. The calculates the effect of using recharge values from the USGS Model for low, median, and high recharge periods. Here the periods of 1955 to 1974 (low), and 1975 to 1994 (high), are used to illustrate how the range of recharge rates compare to the rate used to set the target pumping rate. The median recharge rate is also shown.

Review of the results demonstrates

- Total overdraft is approximately 115,000 AF when an annual average recharge rate of 5700 AFY is assumed.
- Overdraft is as high as 149,000 AF under the low recharge conditions (29% more than for the average recharge rate of 5700 AFY).
- An overdraft of 63,000 AF occurs even under the ‘wettest’ recharge conditions

FIGURE 3

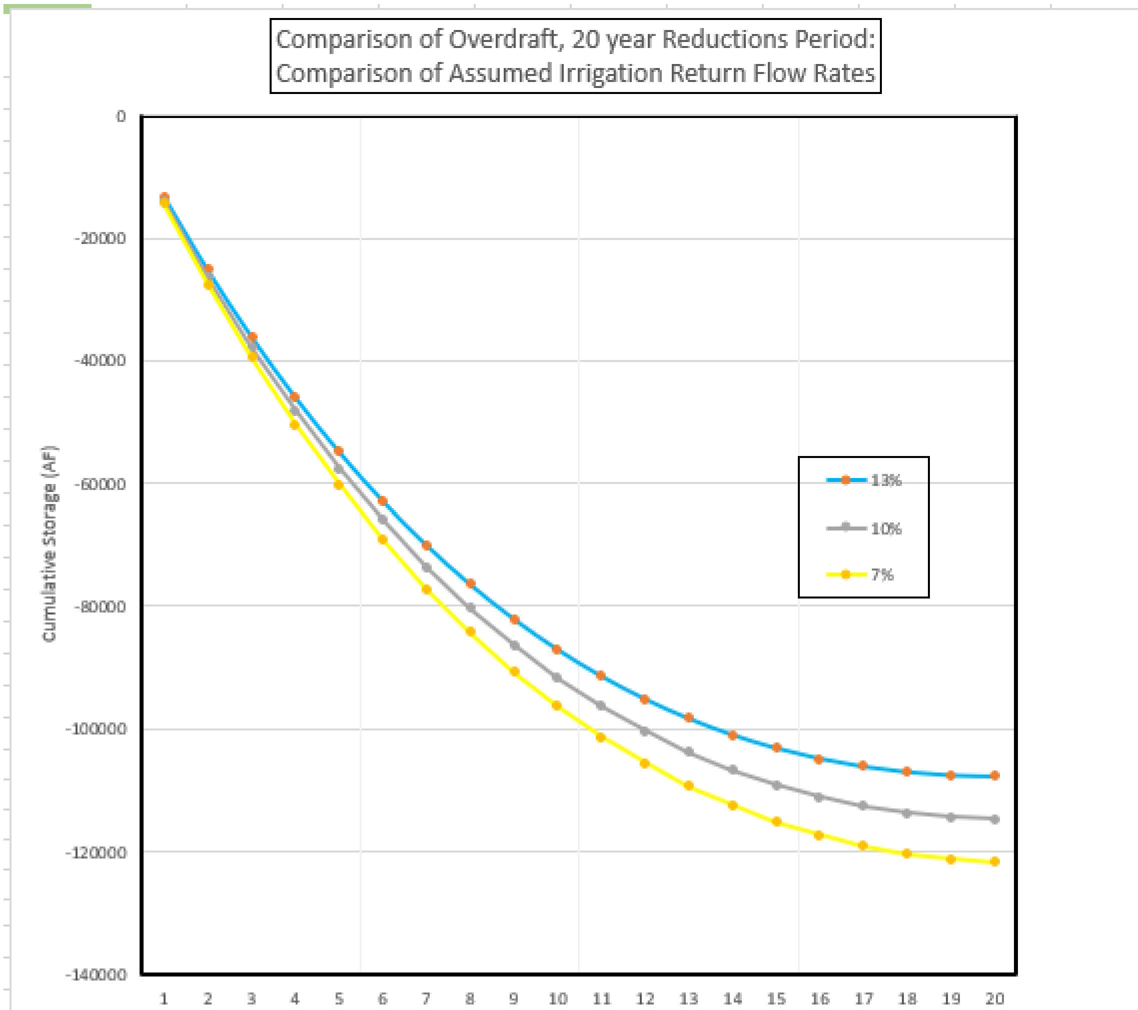


	INFLOW (AFY)					OUTFLOW (AFY)				NET: INFLOW-OUTFLOW (AFY)							
	GW-in	Natural Recharge			Irrigation Return	GW_out	ET	Q_total		Cumulative storage				Annual Change in Storage			
year	(GW BC)	1975_95	Median	1955_75				22044	yr	1975_94	5700 AFY	Median	1955_74	1975_94	5700 AFY	Median	1955_74
1	1400	2215	470	174	2060	525	400	20603	1	-15852	-13767	-17597	-17893	-15852	-13767	-17597	-17893
2	1400	4482	10540	2067	1926	525	400	19255	2	-28225	-26322	-23912	-32681	-12373	-12555	-6315	-14787
3	1400	21545	259	3566	1800	525	400	17996	3	-22401	-37744	-39374	-44836	5824	-11422	-15462	-12156
4	1400	9100	5894	828	1682	525	400	16819	4	-27963	-48106	-48143	-58671	-5562	-10363	-8769	-13834
5	1400	22504	1803	1151	1572	525	400	15720	5	-19131	-57479	-60013	-71193	8832	-9373	-11870	-12522
6	1400	3372	467	696	1469	525	400	14692	6	-28507	-65926	-72294	-83244	-9375	-8448	-12281	-12052
7	1400	2011	5808	835	1373	525	400	13731	7	-38379	-73509	-78369	-94292	-9872	-7583	-6075	-11048
8	1400	10071	3291	163	1283	525	400	12833	8	-39383	-80284	-86152	-105204	-1004	-6775	-7783	-10912
9	1400	8443	4380	1741	1199	525	400	11994	9	-41260	-86304	-92092	-113782	-1877	-6020	-5940	-8578
10	1400	1679	2223	3785	1121	525	400	11210	10	-49195	-91618	-99483	-119611	-7935	-5314	-7391	-5828
11	1400	3183	4325	9204	1048	525	400	10477	11	-54966	-96272	-104112	-119360	-5771	-4654	-4629	250
12	1400	1402	11249	7548	979	525	400	9792	12	-61901	-100309	-101200	-120150	-6935	-4037	2912	-789
13	1400	926	9182	1231	915	525	400	9151	13	-68736	-103770	-99780	-126680	-6835	-3461	1420	-6531
14	1400	2039	5201	13666	855	525	400	8553	14	-73920	-106693	-101801	-120237	-5184	-2923	-2021	6443
15	1400	233	196	459	799	525	400	7994	15	-80406	-109112	-108325	-126498	-6486	-2419	-6523	-6260
16	1400	7016	112	337	747	525	400	7471	16	-79639	-111061	-114461	-132409	767	-1949	-6137	-5912
17	1400	2515	6232	330	698	525	400	6982	17	-82933	-112570	-114038	-137888	-3294	-1509	423	-5479
18	1400	20913	127	2193	653	525	400	6526	18	-67418	-113669	-119310	-141093	15515	-1098	-5272	-3205
19	1400	5915	7915	1512	610	525	400	6099	19	-66517	-114383	-116409	-144596	901	-714	2901	-3502
20	1400	8348	594	671	570	525	400	5700	20	-62824	-114738	-120469	-148580	3692	-355	-4061	-3984
	avg:	6896	4013	2608									chk sum:	-62824	-114738	-120469	-148580
	yr end	1995	1952	1975													

Irrigation return flows represent a portion of the water balance that also has a degree of variability. A range of 7 to 13% (of total pumping, roughly 9 to 16% of irrigation pumping) is shown in **Figure 4** using the same parameters used in **Figure 3** to assess the relative impact of irrigation return flows on the water balance. The overdraft after 20 years is within 6 percent of the baseline case.

Overall the results demonstrate that the primary uncertainty associated with the overdraft calculations is due to the variability of the historically-observed recharge rates.

FIGURE 4

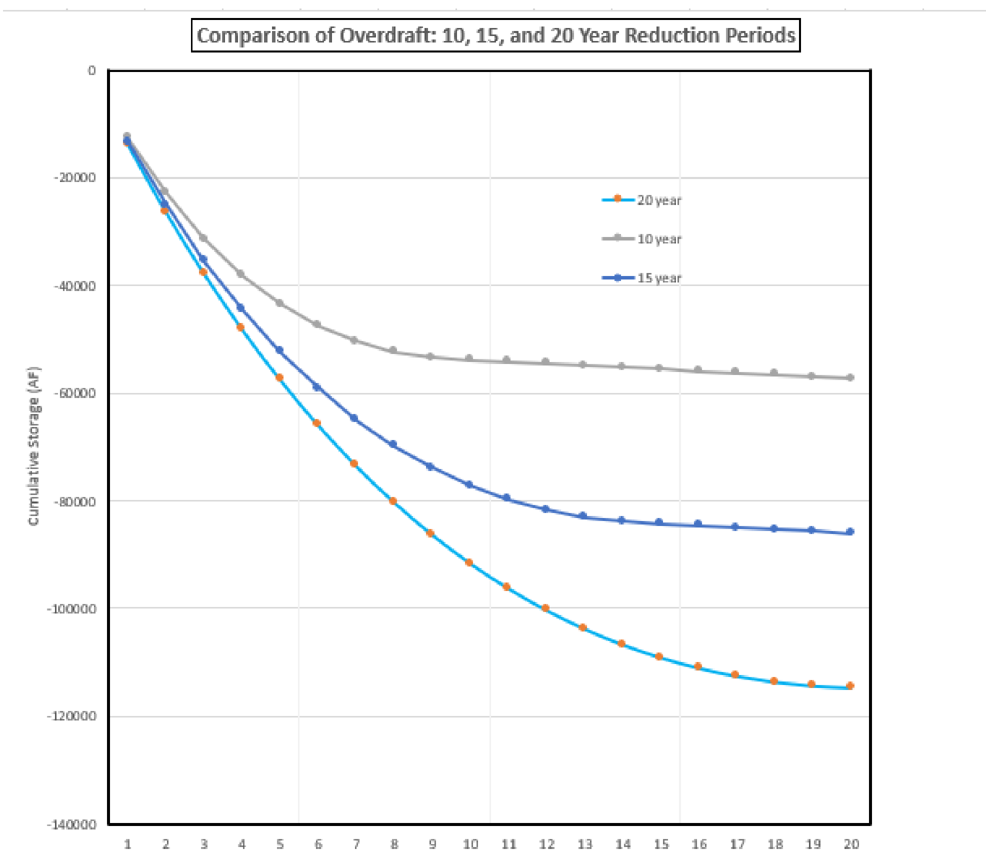


2.1 Effect of Reduction Periods Less Than 20 years

A maximum 20-year groundwater pumping reduction period is described in SGMA (DWR, 2017). The water balance calculations can be used to generally illustrate how overdraft will be affected by changing the reduction period. In this case the pumping reductions are done over 10, 15, and 20 years. Annual pumping rates are reduced for these cases by approximately 6.5, 8.6, and 12.7 % per year. The same water balance values are used as done for **Figure 3** with a target pumping rate of 5700 AFY.

The result of varying the reduction periods is that overdraft is substantially reduced. Since constant reduction rates were used the corresponding overdraft after 20 years went from approximately 115,000 AF to 86,000 AF for the 15-year period. Overdraft reduces to 58,000 AF for the 10-year period. These correspond to 75% and 50%, respectively, of the overdraft that would be experienced after 20 years. A shorter reduction period provides for less uncertainty because overdraft and its associated uncertainty increase cumulatively over the reduction period.

FIGURE 5



The calculations are summarized in the following table. A 10% irrigation return flow (of total pumping) is assumed and the total amount of recharge entering the basin is held constant at 5700 AFY. Outflows are also held at average annual values of 525 AFY for groundwater and 400 AFY for native plant consumptive use (evapotranspiration, or ET).

Based on these values there is a net negative balance of 355 AFY using the target pumping rate. The relative impact of the negative balance is small compared to the magnitude of the cumulative overdraft for the 10, 15, and 20 year periods.

FIGURE 5, continued

	INFLOW (AFY)						OUTFLOW (AFY)						NET: INFLOW-OUTFLOW (AFY)						
	GW-in	Recharge	Irrigation Return				GW_out	ET	Q_20	Q_15	Q_10		Cumulative storage				Annual Change in Storage		
year	(GW BC)		20 year	15 year	10 year				22044	22044	22044	yr	20 year	15 year	10 year		20 year	15 year	10 year
1	1400	4300	2060	2014	1926		525	400	20603	20143	19255	1	-13767	-13354	-12555		-13767	-13354	-12555
2	1400	4300	1926	1841	1682		525	400	19255	18406	16819	2	-26322	-25144	-22917		-12555	-11791	-10362
3	1400	4300	1800	1682	1469		525	400	17996	16819	14691	3	-37744	-35507	-31364		-11422	-10362	-8447
4	1400	4300	1682	1537	1283		525	400	16819	15369	12833	4	-48106	-44563	-38139		-10363	-9057	-6775
5	1400	4300	1572	1404	1121		525	400	15720	14043	11209	5	-57479	-52428	-43452		-9373	-7864	-5313
6	1400	4300	1469	1283	979		525	400	14692	12833	9791	6	-65926	-59202	-47489		-8448	-6774	-4037
7	1400	4300	1373	1173	855		525	400	13731	11726	8553	7	-73509	-64980	-50412		-7583	-5778	-2922
8	1400	4300	1283	1071	747		525	400	12833	10715	7471	8	-80284	-69849	-52360		-6775	-4868	-1949
9	1400	4300	1199	979	653		525	400	11994	9791	6525	9	-86304	-73885	-53458		-6020	-4037	-1098
10	1400	4300	1121	895	570		525	400	11210	8947	5700	10	-91618	-77162	-53813		-5314	-3277	-355
11	1400	4300	1048	818	570		525	400	10477	8175	5700	11	-96272	-79745	-54168		-4654	-2583	-355
12	1400	4300	979	747	570		525	400	9792	7470	5700	12	-100309	-81693	-54523		-4037	-1948	-355
13	1400	4300	915	683	570		525	400	9151	6826	5700	13	-103770	-83062	-54878		-3461	-1368	-355
14	1400	4300	855	624	570		525	400	8553	6237	5700	14	-106693	-83900	-55233		-2923	-839	-355
15	1400	4300	799	570	570		525	400	7994	5700	5700	15	-109112	-84255	-55588		-2419	-355	-355
16	1400	4300	747	570	570		525	400	7471	5700	5700	16	-111061	-84610	-55943		-1949	-355	-355
17	1400	4300	698	570	570		525	400	6982	5700	5700	17	-112570	-84965	-56298		-1509	-355	-355
18	1400	4300	653	570	570		525	400	6526	5700	5700	18	-113669	-85320	-56653		-1098	-355	-355
19	1400	4300	610	570	570		525	400	6099	5700	5700	19	-114383	-85675	-57008		-714	-355	-355
20	1400	4300	570	570	570		525	400	5700	5700	5700	20	-114738	-86030	-57363		-355	-355	-355
avg:															chk sum:		-114738	-86030	-57363
																		75%	50%

3.0 Relationship Between Overdraft and Water Levels

Overdraft is measured as the net amount of water pumped from the aquifer. The water balance calculations provide a broad overview of hydrologic conditions within the Borrego Basin and directly relate to the effect of pumping restrictions specific to groundwater sustainability. Water level declines within the Borrego Basin will vary within the aquifer depending on localized pumping rates, localized aquifer response to pumping and overdraft, site-specific aquifer conditions, and recharge.

3.1 Calculating Water Level Decline in Response to Overdraft

Overdraft has caused and continues to cause water levels in the aquifer system to decline fairl rapidly over time. The water is coming from water stored in the aquifer. Here the aquifer is comprised of sand, silt, and clay- materials that have open pore space that contains water. When the water level is lowered most of the water drains from the aquifer with some of the water being retained.

A hydrologic parameter known as the specific yield (Sy) expresses how much water will freely drain from an unconfined aquifer, as a percentage of the aquifer volume, as water levels drop. For example, a Sy value of 10% means that a 1 cubic foot of aquifer will yield one 0.1 cubic foot of water for a water level drop of 1 foot[1]. However, locally under pumping, water levels at specific wells would also depend on the hydraulic conductivity (K) of the particular aquifer materials intersected by the well and on the well characteristics. For a well being pumped the drawdown (drop in water level in the well) is approximately proportional to pumping rates, and inversely proportional to hydraulic conductivity; hence an order of magnitude reduction in K would increase drawdown approximately by an order of magnitude. In addition to the general consideration of overdraft and storage depletion this has implications on the choice of well location, well construction (screen interval, etc.), and potential energy costs.

The USGS model uses three sets of Sy values for the upper, middle, and lower aquifers. Review of Table 18 of the USGS model report indicates that Sy varies spatially for each of the aquifers. The average Sy values for these three aquifers in the model are:

Upper Aquifer: 0.13
Middle Aquifer: 0.11
Lower Aquifer: 0.04

[1] In terms of acre-feet (AF), an acre-wide area of the aquifer will yield 0.1 acre-feet of water when the water level drops one foot for a Sy = 0.10. Under these conditions a ten-foot drop in water level is required to release one AF of water from an acre of the aquifer. However, locally, water levels in production wells will also depend on the hydraulic conductivity (K) of the aquifer. Drawdown at a well will increase as K decreases in order to maintain a constant production rate.

The model Sy values for the upper and middle aquifers are roughly similar and mean that the water level in the aquifer will drop at roughly the same rate as water is extracted from these aquifers. This is important because it means that current water level decreases are roughly proportional to the amount of overdraft. In contrast the rate of water decline due to removal of water from storage will accelerate approximately 3-fold should the middle aquifer be dewatered. This comparison assumes that the middle and lower aquifers are unconfined- an assumption made in the model construction that may not be valid across the Borrego Basin.

The USGS Report examined six future pumping scenarios. Scenario 6 assumed that agricultural pumping would be reduced to 40% of the 2010 rates and that municipal and recreational pumping would be reduced by 50% (USGS report Table 20). After 20 years the pumping rates are held constant for another 30 years. The starting pumping rate was 18,271 AFY and total pumping in year 20 decreases to 7824 AFY. This Scenario does not comply with SGMA sustainability requirements but is used here to show how water levels relate to overdraft. The reduced pumping rate of 7824 AFY is 37% above the 5700 AFY target and is too high to prevent long-term overdraft and achieve sustainability.

Cumulative overdraft after 50 years, as shown in **Figure 6**, is approximately 200,000 AF for Scenario 6. Prior water balance calculations to achieve sustainability after 20 years under SGMA projected an overdraft of approximately 115,000 AF – a point that is reached after 14 years of pumping in Scenario 6.

Figure 7 (Figure 56 from the USGS Report) shows that water level drawdown calculated by Scenario 6 ranges from 26 to 75 feet in the northern half of the BGVB. The scenario does not specifically show where water levels occur relative to the upper and middle aquifer systems but it noted in the report that “the levels do not decline to the middle aquifer in most of the basin” (p. 124).

If the specific yields of the upper and middle aquifers are similar where overdraft occurs, then the change in water levels due to loss of water in storage will be directly proportional to the degree of overdraft. Under these assumptions the water levels associated with an overdraft of 115,000 AF will be roughly be just more than half of the drawdown indicated in **Figure 7**.

In summary, Scenario 6 is presented as an example of how overdraft as a total volume of water pumped from the aquifer can be related to water level decline. It is important to note that the USGS scenarios provide a large-scale depiction of groundwater conditions and may not represent conditions observed at individual wells or subareas of the Borrego Basin. While local trends may be able to be correlated to local pumping rates, the assessment of localized groundwater conditions under varying pumping conditions will require use of the model.

FIGURE 6

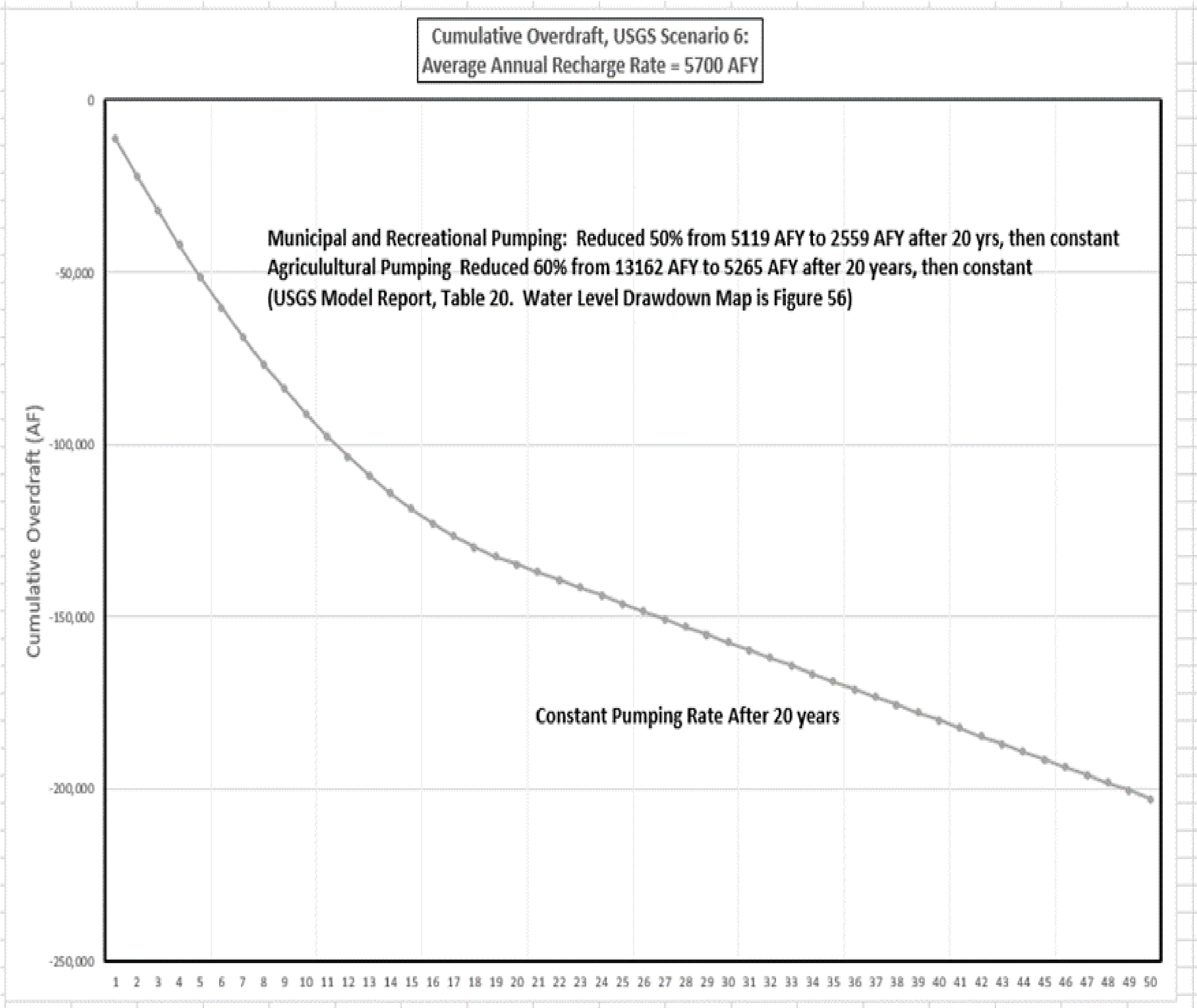

Cumulative Overdraft, USGS Scenario 6:
Average Annual Recharge Rate = 5700 AFY
Municipal and Recreational Pumping: Reduced 50% from 5119 AFY to 2559 AFY after 20 yrs, then constant
Agricululture Pumping Reduced 60% from 13162 AFY to 5265 AFY after 20 years, then constant
(USGS Model Report, Table 20. Water Level Drawdown Map is Figure 56)
Constant Pumping Rate After 20 years
Cumulative Overdraft (AF)
0
-50,000
-100,000
-150,000
-200,000
-250,000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

FIGURE 7

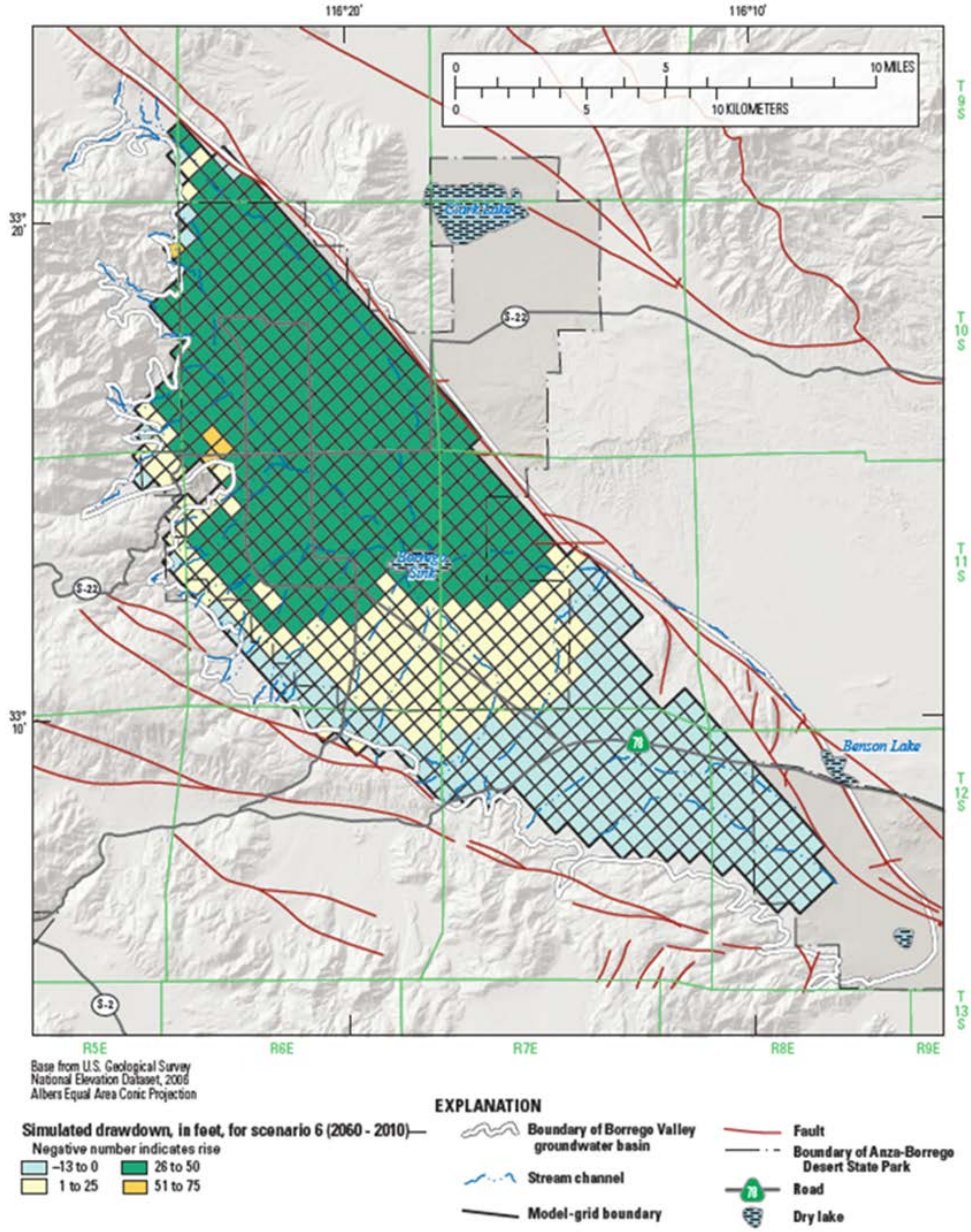


Figure 56. Simulated drawdown projected for Scenario 6, 2060 minus 2010, Borrego Valley Hydrologic Model, Borrego Valley, California.

3.2 Water Level Decline in BWD Production Wells

The BWD currently operates eight production wells located in all three groundwater management areas (north, central, and south). The current rate of water level decline in the basin is on the order of 1 to 3 feet per year (refer to the GSP for additional information).

Conceptually groundwater occurs in three aquifers denoted as the upper, middle, and lower aquifers. Long-term overdraft has effectively led to the loss of much of the upper aquifer as a viable water source across much of the valley. Wells completed in the middle aquifer to date, while not as prolific as wells that were originally installed in the upper aquifer, have been observed to have good water production rates. Of concern is that the once water levels drop into the deeper aquifers with finer-grained materials and lower permeability, water level declines at BWD production wells have the potential to increase in response to pumping.

A well-by-well analysis is not included here and will be subject of further analysis in the GSP.

4.0 Monte Carlo Simulation (MCS) Uncertainty Analysis: Constant Recharge Rate Case (5700 AFY)

All of the water balance inflow and outflow parameters are subject to uncertainty. One way to explicitly incorporate uncertainty into the calculations is using a methodology known as Monte Carlo Simulation (MCS). Each of the parameters is assigned a range of values. The water balance calculations presented in **Figure 3** are then done multiple times by repeated random sampling within the parameter ranges to obtain numerical results. The calculations provide a range of values, rather than a single value.

The essential idea is to create a set of randomly-generated values to examine how the overall water balance is affected by parameter uncertainty. The results are then examined statistically and can be used to assess a plausible range of outcomes and support decision making. In other words, the range of potential overdraft shown in **Figure 3** can be expressed statistically instead of being shown as two extremes. The following constant recharge case assumes that recharge occurs at the stated average of 5700 AFY and pumping is reduced from 22,044 AFY to 5700 AFY over a 20-year simulation period. The following are used for the constant recharge rate case MCS:

Inflow:
Groundwater Inflow: A value of 1400 AFY that ranges +/- 10 percent. A normal distribution ("bell curve") is used for the range as the USGS model had little flow variation.

Natural Recharge: Held for this first example at the target value of 4300 AFY to assess the effect of uncertainty related to the other water balance parameters independent of recharge. (Recall that total recharge is groundwater inflow + surficial recharge, and totals 5700 AFY as stated in the USGS Model Report)

Irrigation Return Flow: An irrigation return flow rate of 10% is used, with a range of 5 to 15% based on a normal distribution to fully capture the range of 7 to 10%.

Outflow:
Groundwater Outflow: A value of 525 AFY that ranges +/- 10 percent. A normal distribution is used for the range as the USGS model had little flow variation.

Evapotranspiration: 400 AFY with a range of +/- 100. A Uniform Distribution is used where the ET rate varies from 300 to 500 AFY.

Pumping Rate: Reduced over the 20-year period from 22,044 to 5700 AFY, as done in **Figures 5 and 6**. It is a time dependent variable- no uncertainty or range of values has been assigned.

Here the MCS was repeated 10,000 times to develop a range of values for the cumulative overdraft as shown in **Figure 8**. Since irrigation return flows have the highest uncertainty in the MCS simulation the figure appears very similar to **Figure 3**, with the except that the range of values can now be expressed in terms of a probability distribution function (PDF) as shown as a histogram in **Figure 9**.

FIGURE 8

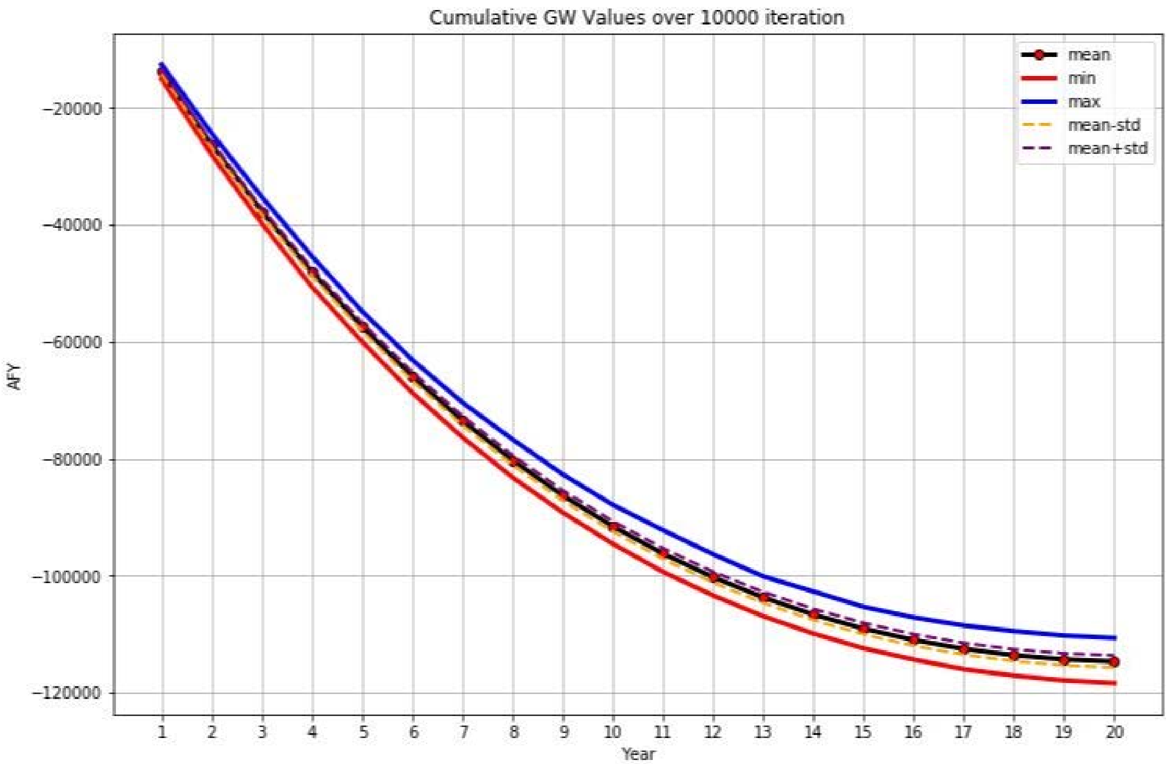
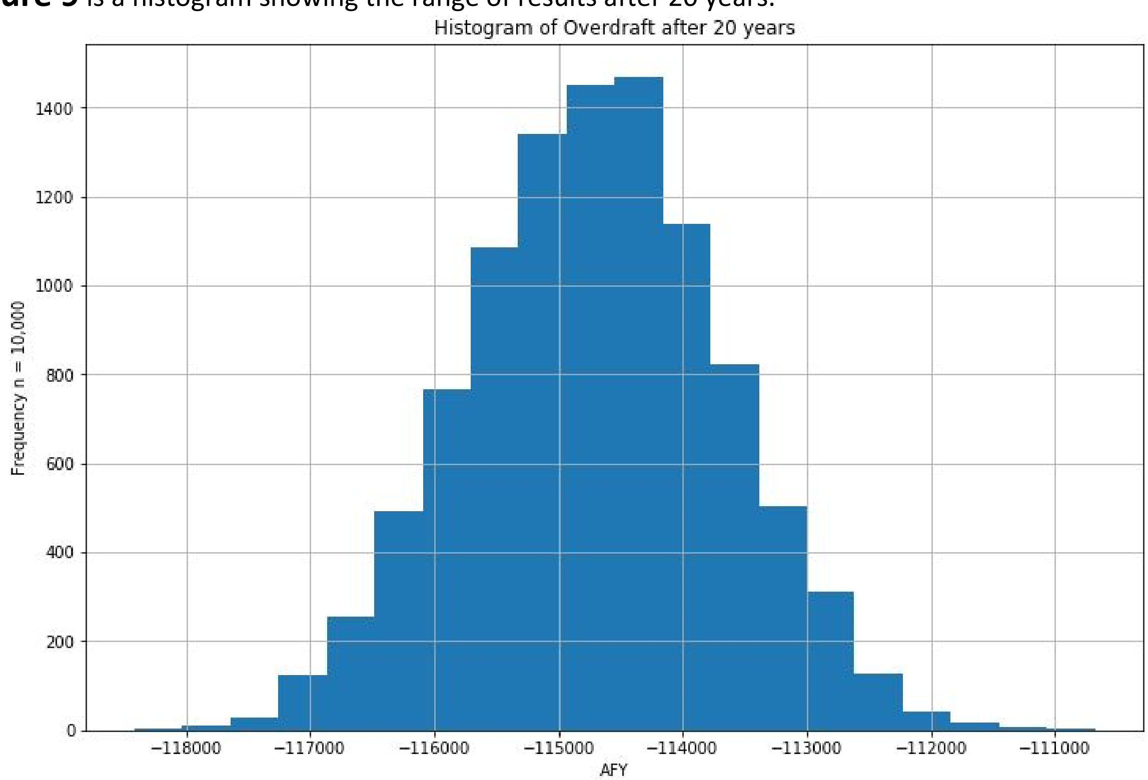


Figure 9 is a histogram showing the range of results after 20 years.



Review of the results show that when recharge is held constant the other parameters have relatively minor influence. The overdraft after 20 years in the MCS had a range of from approximately 110,500 to 118,500 AF, or +/- 4,000 AFY (3.5 percent), and has a Normal Distribution.

When **Figure 8** is compared to the extremes shown in **Figure 3** it is clear that the primary consideration for groundwater management is the potential variability in the recharge rate as driven by rainfall variability.

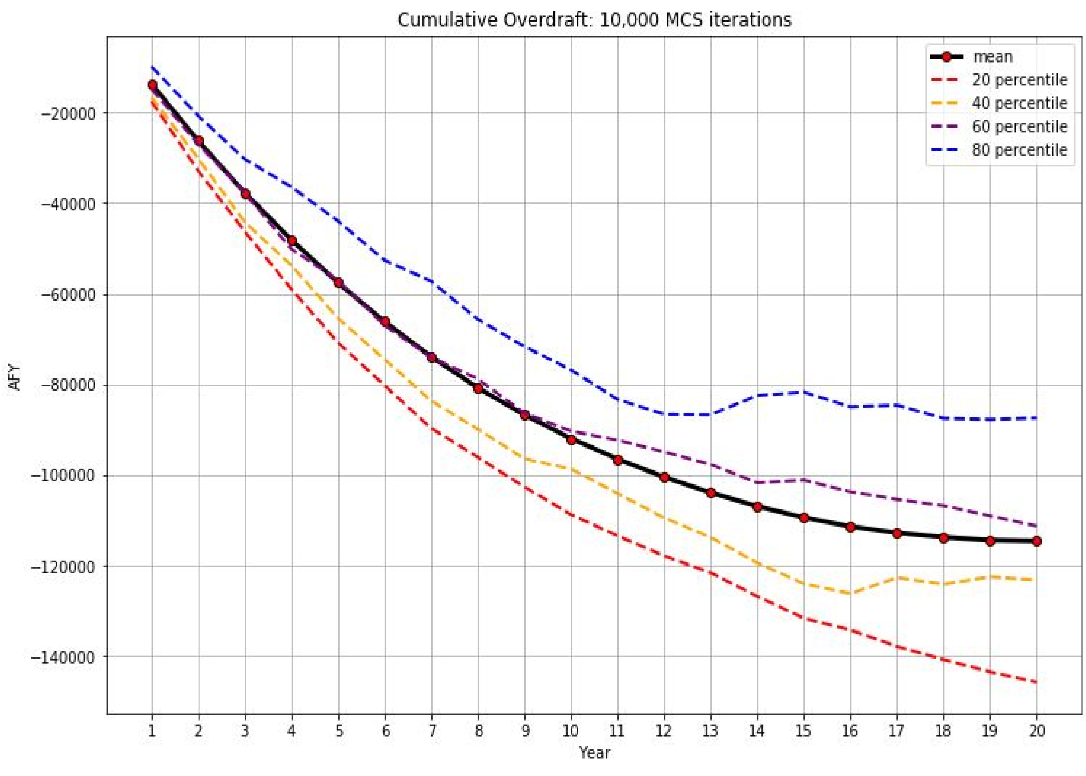
The next section expands the MCS calculation to include a range of recharge rates based on the USGS model results.

5.0 MCS Uncertainty Analysis: Time-varying Recharge Based on USGG Model History

The effect of time-varying recharge is evaluated using the MCS methodology based on the recharge values produced over the model period (as shown in **Figure 3)**. All of the simulations are based on the target pumping rate of 5700 AFY being achieved by year 20. Here, 20-year periods are selected at random from the time series. Alternatively, annual data could be randomly selected based on the distribution of values, but this was not done because review of the recharge values shows that there is periodicity within the time series. In effect the MCS provides for a series of 'what if' analyses where the 20-year SGMA attainment period could occur for any historical 20-year period and thus examine the potential variability in the water balance as exhibited by the model.

Fifty-three 20-year periods (from 1945 to 2016) are used in the MCS, together with the parameters presented in the previous section. **Figure 10** shows the MCS simulations in terms of the average and percentiles. Shown are the 20th through 80th percentiles. Percentiles group the data in order- a 20th percentile means that 20% of the values fall below the 20th percentile and 80% are above the 20th percentile. Since the simulations are looking at different time periods the values translate to rate of occurrence. For example, values below the 20th percentile occur 20% of the time.[2]

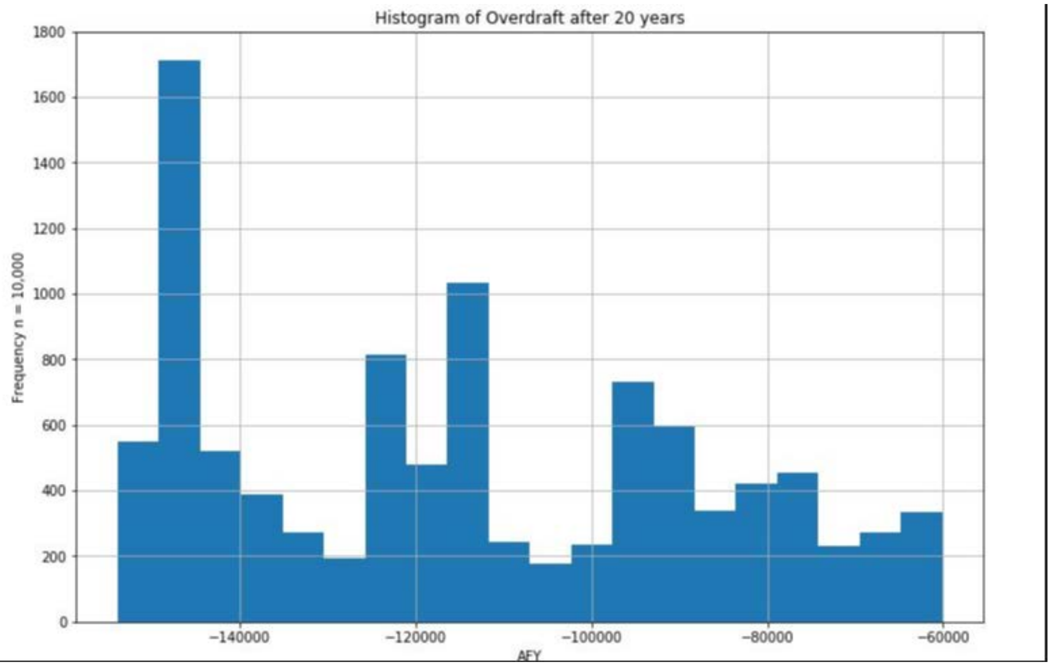
FIGURE 10



[2] Percentiles are used here to describe the results. Figure 11 shows that the results are not well described by simple statistics. For example, the average value is much different than the median since the values are 'skewed' towards lower recharge values.

The simulated overdraft at 20 years ranges between approximately 60,000 and 152,000 AF within the percentiles shown in **Figure 10**. The overdraft 'curve' that assumes a 5700 AFY average annual recharge is approximately equal to the 55^{th} percentile- meaning sustainability occurs for 45% of the simulations. For reference calculations that use a constant annual recharge rate of 5700 AFY leads to an overdraft of 114,500 AF (approximately 115,000 AFY).

FIGURE 11



The recharge variability is quite significant compared to the baseline case where a constant annual recharge rate is assumed. As calculated the cumulative groundwater extraction and degree of overdraft after 20 years is 54,000 to 37,000 AF above or below the mean of 114,500 AF. **Figure 10** shows the range of values at the end of the 20-year MCS period.

In contrast to the results shown in **Figure 8** where recharge uncertainty is not assessed, the histogram is asymmetric and shows that high recharge periods occur much less frequently than low recharge periods. This can also be seen in **Figure 2** by the 'spikes' in the annual data corresponding to high recharge years.

In essence the use of random 20-year periods to develop the MCS is equivalent to saying that the 20-year GSP period could begin any time from 1945 to 1996. Recharge is highly variable over the model period. It is noteworthy that an extreme low recharge period (1955 to 1974) was immediately followed by an extreme high recharge period (1975 to 1994). The MCS allows for additional analysis of the recharge variability between these extremes over the model period (1945 to 2016).

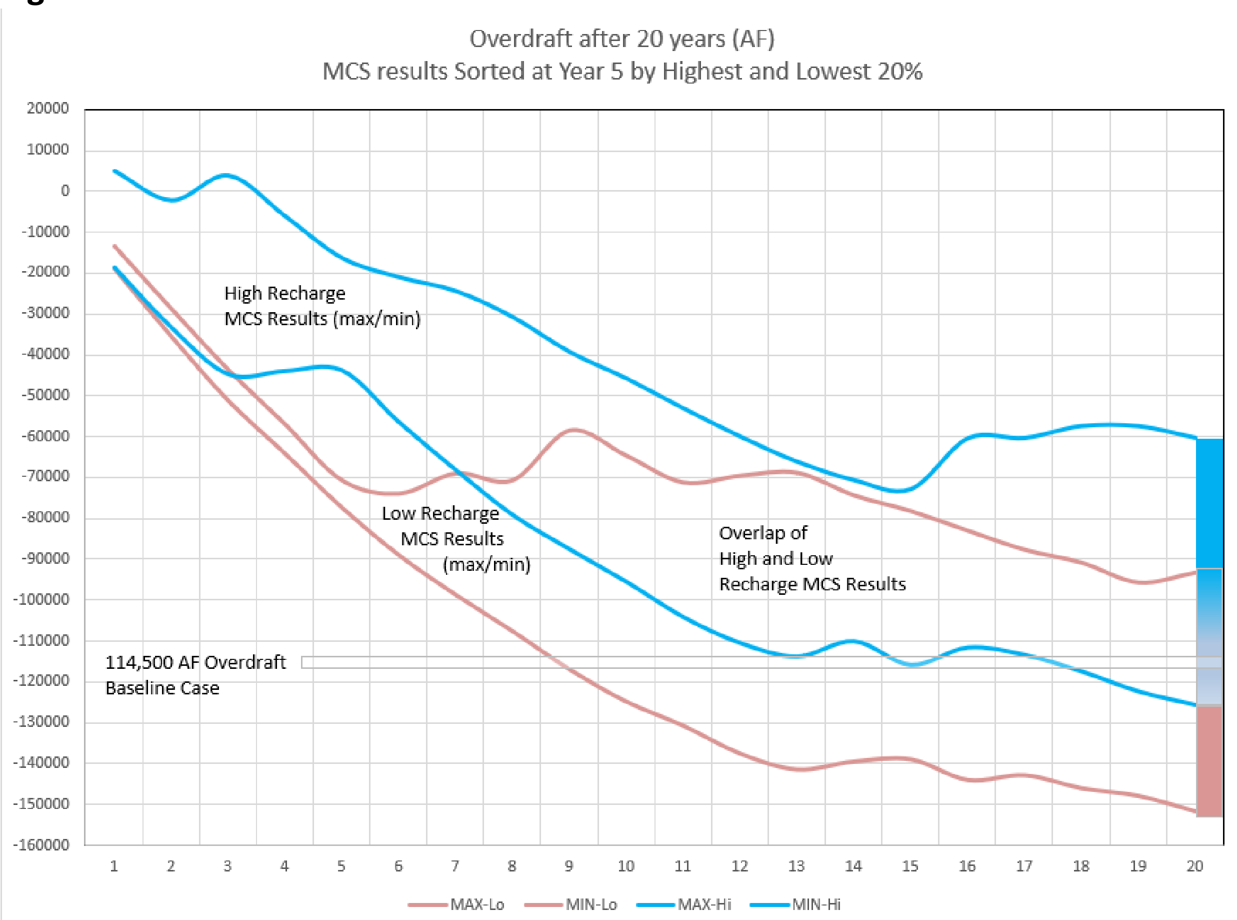
6.0 MCS-based Analysis: What happens after 5 years of low or high rainfall?

The MCS results can be used to examine 'what if' scenarios. In this case since the GSP is being proposed to be reviewed at 5-year intervals, the MCS is used to examine whether having 5 years of observations can allow for a prediction of the next 15 years. In other words, if there is an initial 5-year 'wet' or 'dry' period do the MCS results support revision to the target pumping rate? A 5-year period was used to correspond with the GSP review period.

For this example, the MCS results shown in Figure 9 were sorted in terms of 'wet' and 'dry' periods where the cumulative overdraft values after 5 years were sorted from high to low. The upper and lower 20% portions of the values were then separated for analysis.

The cumulative overdraft for the two sets of recharge values that correspond to initially 'wet' or 'dry' periods. Here the maximum and minimum values are used to show the range of values for the two cases in **Figure 12**. For reference the baseline sustainable pumping case results in an overdraft of approximately 115,000 AF after 20 years.

Figure 12



The values were sorted into two sets corresponding to the highest and lowest 20% of recharge after five years. Shown in the Figure are the full ranges of the two data sets described here as 'wet' and 'dry'. Review of the MCS results shows that

- The 5700 AF target pumping rate will have a high likelihood of achieving sustainability after an initial 'wet' 5-year period. The lowest recharge rate after 20 years for this data set leads to an overdraft of approximately 126,000 AF (9% more than the baseline case).

- If 'dry' conditions occur over the initial 5-year period overdraft will not exceed the sustainability threshold approximately 40% of the time. However, an initial 'dry' period does not preclude the Borrego Basin from being sustainable after 20 years as 40% of the time there is sufficient recharge to meet the sustainability threshold.

- The MCS indicate that overdraft could range from approximately 60,000 AF to 152,000 AF due to the high level of variability in recharge rates over the 1945 to 2016 model period. This wide range creates a high level of uncertainty as indicated by the overlap between the two sets of data.

- Having 5 years of observations that demonstrate that 'dry' conditions occur does not substantially improve the MCS outcome of potential overdraft after 20 years. Here the range of outcomes after 5 'dry' years is very wide and in years 12 to 14 can result in high recharge rates that are similar to the 'wet' data set. Comparison of the MCS results for all of the data shown in **Figure 9** shows that the threshold is met approximately 45% of the time versus 40% of the time after 5 years of 'dry' conditions.

7.0 Summary

The 5700 AFY pumping target has been evaluated based on water balance calculations for the Borrego Basin.

- Ongoing overdraft can be substantially controlled using the 5700 AFY pumping target. The water balance calculations include groundwater recharge, groundwater discharge, pumping, irrigation return flows, and evapotranspiration-related water demand from native vegetation (groundwater dependent ecosystems). An additional 115,000 AF of overdraft occurs over a 20-yr period as calculated in this Draft Report. For comparison the amount of overdraft was 520,000 AF as of 2016 (as reported in Chapters 2 and 3 of the Draft GSP).

- Projected overdraft over a 20-year period is greatly affected by variability in recharge rates. Instead of assuming an average annual recharge rate of 5700 AFY, the recharge rates are based on the results of the USGS Groundwater model for the period of 1945 to 2016. The long-term groundwater supply highly depends on 'wet' years with high recharge rates; however, these occur on a decadal scale and may not coincide with the 20-year GSP planning period.

  A clear example of the variability inherent in the recharge values is that the 20-year period from 1955 to 1974 was one of the 'driest' and it immediately preceded one of the 'wettest' periods from 1975 to 1994. The average annual recharge rates for these two periods of 'dry' and 'wet' precipitation were 3,975 and 11,907 AFY, respectively.

- Accelerated reduction periods, for example 10 to 15 years versus 20 years, can provide significant and proportional decreases in total overdraft (storage loss) and related water level decline. Because overdraft occurs cumulatively over the reduction period, the relative uncertainty associated with the overdraft also increases with time. Thus, uncertainty is reduced with shorter reduction periods and a longer time is also available to confirm that sustainability has been achieved within the 20-year GSP planning period.

- Uncertainty associated with the overdraft calculations is dominated by the historical variability of recharge rates. The other water balance components such as groundwater demand of native vegetation and irrigation return flows are of lesser importance. Additional uncertainty is associated with the time required for irrigation return flows to travel from the land surface to the underlying aquifer, the amount of return flows to application rates that may actually ever reach the water table, and the potential contaminants in such return flows.

- Overdraft, expressed as the total volume of water that is extracted from the aquifer, can be generally related to water levels when drawdown occurs within the upper and middle aquifers given the Sy and K values used in the USGS model. Here the USGS model predictions for water level decline (USGS Scenario 6) are reviewed for comparison to the calculated overdraft. Note that the USGS' scenario does not attain sustainable groundwater conditions and is not acceptable under SGMA.

With decreasing water levels water supply wells will necessarily be pumping relatively more water from the middle and lower aquifers. Because aquifer storage and permeability decreases with depth well yields are expected to decrease. Water level drawdown at the wells will also increase in order to extract similar amounts of water compared to wells screened in the upper aquifer.

- Statistically-based ‘what if’ Monte Carlo Simulations were used to look at what may be observed after 5 years of pumping reductions following ‘wet’ or ‘dry’ periods. A 5-year period was used that corresponds to the proposed GSP review cycle. Having 5 years of additional observations that demonstrate that ‘dry’ conditions occur does not substantially improve the projection of potential overdraft after 20 years. The percentage of the time that the simulations showed that percentage of time that sustainability was achieved decreased from 45% (for all of the data) to 40% after a 5-year ‘dry’ period, if this period was used to ‘adjust’ the target sustainable yield amount.

The draft report is limited to assessment of the volume of water associated with ongoing overdraft and pumping reduction necessary to balance groundwater use with groundwater replenishment by recharge. While the calculations presented in this report can provide insights towards quantification of overdraft and related changes in water levels calculations, it cannot replace ongoing observations and continued efforts to reduce groundwater pumping. Considerations going forward include:

- Are there changes in Water Quality related to overdraft that would necessitate additional pumping restrictions? The Borrego Basin is a relatively ‘closed’ groundwater system where minerals and contaminants will accumulate as water is used. The water balance analyses do not consider or account for changes in water quality related to natural or anthropogenic sources.

- The USGS model includes three layers for the upper, middle, and lower aquifers. Model-based projections of water level decline do not account for depth-dependent variations that may occur in the aquifer systems. It also assumes that unconfined conditions occur- should locally confined aquifer conditions occur more rapid drawdown is expected to occur in production wells than would be projected by the model.

- How to incorporate the effect of decadal recharge events given the 20-year SGMA planning period? Recharge variability occurs at a time scale greater than 20 years. A clear example is the two consecutive ‘dry’ and ‘wet’ periods- 1955 to 1974, and 1975 to 1994 as noted in the summary.

- How much of a ‘miss’ can be allowed during and after the 20-yr GSP planning and management period? Based on the MCS calculations (**Figure 10**) if overdraft is allowed to exceed by 20% (20% above the 114,500 AF mark or 137,400 AF) the MCS calculations support that the target pumping rate will succeed approximately 70 percent of the time.

- The MCS is based on recharge values from the model for the historical period of 1945 to 2016. The analysis assumes that the time series can be projected into the future and that the statistics (such as the mean and variance) don’t change and can also be projected forward in time and are described as ‘stationary’. The reasonability of this assumption must be considered by BWD when managing financial risk. One factor to consider is the potential for future recharge rates to decrease due to climate change. It is understood that the GSP will incorporate climate change projections when using the groundwater model to examine future overdraft conditions (CA DWR, April 2018. Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development).

The uncertainty associated with the magnitude of Irrigation return flows and time required for water to transit the vadose zone affects the water balance. While recharge variability is the dominant factor specific to the water balance, and inflow from adjacent watersheds provides the bulk of the water being recharged, irrigation return flows are a significant component of the current water balance during 'dry years'. This has the greatest impact early in the GSP process as the relative contribution of irrigation flows will decrease over time as pumping will be required to be reduced on the order of 70% to achieve sustainability.

- Should a factor of safety be applied to the target pumping rate or can revisions to the pumping rate be adaptively managed during a 20-year GSP period? Or should both be considered together? Or should a more aggressive reduction schedule be used to reduce the attainment period?

- Of concern is the relatively low resilience of BWD and its SDAC customer base to recover from miscalculations of initial GSP policy decisions. BWD is a relatively small municipal water district with limited borrowing capacity and small amount of cash reserves. Failure to include an adequate factor of safely into starting GSP policies could potentially place undue financial risk on the BWD and unrecoverable economic risk on its SDAC customer base. Based on the present analysis, an assumption that adaptive management by making policy changes every 5-year period, does not assure a means to recover from mistakes in initial GSP policy decisions based on 'better' future data.

Recommendations

- Additional analysis is needed as to the potential financial risk for the BWD and economic risk to the Borrego community from policy and starting assumptions in the GSP. Among the considerations include the impact of potential water quality changes and overdraft impacts on BWD production wells, potentially unexpected cost impacts to BWD, and the potential impact of costs and water reductions to the severely disadvantaged Borrego Springs community.

- Additional analysis and contingency planning is needed to determine how adaptive management will be used during implementation of the GSP to correct or modify initial policy assumptions, should the ongoing decrease in water levels exceed expectations either due to exceptionally low rainfall or other unexpected conditions. Among the factors necessary to implement effective adaptive management practices include sustainability agency governance, and enforcement, identification of potential funding methods, ongoing evaluation of pumping and water quality data, and ongoing review of monitoring and water quality standards.