Appendix L1

Estimated Evaporation from Bristol and Cadiz Dry Lakes

ESA

Estimated Evaporation From Bristol and Cadiz Dry Lakes

PREPARED FOR: Cadiz

PREPARED BY: Terry Foreman/CH2M HILL

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This memorandum summarizes findings from evaporation monitoring of Bristol and Cadiz Dry Lakes between May and November of 2011 and provides estimates of annual evaporation rates. This evaluation was undertaken for the purpose of determining whether the observed evaporative rates from the Dry Lakes are consistent with that reported in the literature and estimates of groundwater recharge at rates in excess of 30,000 acre-feet per year as reported by CH2M HILL (2010). The evaluation resulted in an estimation of evaporation rates from Bristol and Cadiz Dry Lake at approximately 7,860 and 23,730 acre-feet per year, respectively, for a total combined rate of 31,590 acre-feet per year, when the measured data are extrapolated to an area over which evaporation is expected to occur and extrapolated for a full year based on expected monthly variations, as observed from pan evaporation and measured evaporation rates from Franklin Dry Lake located to the north. This technical memorandum summarizes data collected by the Desert Research Institute, a summary of measured evaporation from Bristol and Cadiz Dry Lakes and estimates of annual evaporation. These estimated annual evaporation rates, 1) are consistent with rates reported for other dry lakes and, 2) are conservative because they do not account for the impact of groundwater production for the existing agriculture by Cadiz and by salt-mining operations.

Data Collection

Cadiz retained the Desert Research Institute (DRI) to measure evaporation from the Bristol and Cadiz Dry Lakes in order to assess the magnitude of groundwater discharge from the watershed for comparison to estimates of groundwater recharge.

DRI installed Eddy Covariance (EC) instrumentation on Bristol Dry Lake and began collecting data on May 4, 2011. The EC instrumentation is shown in Figure 1. Eddy covariance (EC) instrumentation consists of one 3-meter tall EC tower (Figure 1) that includes all necessary instrumentation to continuously measure latent heat flux (LE) (i.e., heat transferred to the air in water vapor from evaporation (E)) that is used to calculate E. The EC towers are positioned downwind of the dominant wind direction. The instruments installed on the EC towers consist of a three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc., Logan, Utah, USA) to measure the three wind direction components, and an open-path infrared gas analyzer (IRGA) to measure H2O molar density (LI-7500, LI-COR Inc., Lincoln, Nebraska, USA). All sensors on the EC towers are mounted 2.5 meters above ground surface. Weather (e.g., air temperature, relative humidity, and precipitation) and soil instruments (e.g., soil moisture and soil heat flux) at the EC sites are

Figure 1. EC Instrumentation and Meteorological Towers Installed on Bristol Dry Lake

mounted on an adjacent 3-meter tower (Figure 1). Data from all instruments were recorded with a data logger (CR5000, Campbell Scientific) at a frequency of 10 Hz (10 times per second) and stored on compact flash cards. Data were also transmitted back to the Desert Research Institute (DRI) via a cell phone modem. Data were transmitted every hour from the data logger to a data server located at DRI. DRI personnel checked the data on a daily basis for errors (DRI, 2012).

Average E parameters for each half-hour period, including sensible (H) and latent (LE) heat flux were measured using the EC method (DRI, 2012). Further details on calculation of E, uncertainty, and E footprint are provided by DRI (2012). In general, they estimate a high degree of methodological certainty and indicate that E is likely underestimated on Bristol Dry Lake by four percent and overestimated on Cadiz Dry Lake by eleven percent.

DRI installed another set of EC instrumentation on Cadiz Dry Lake and began data collection on July 20, 2011. The same instrumentation and process were used for both Bristol and Cadiz Dry Lakes. The location of the EC instrumentation is show in Figure 2.

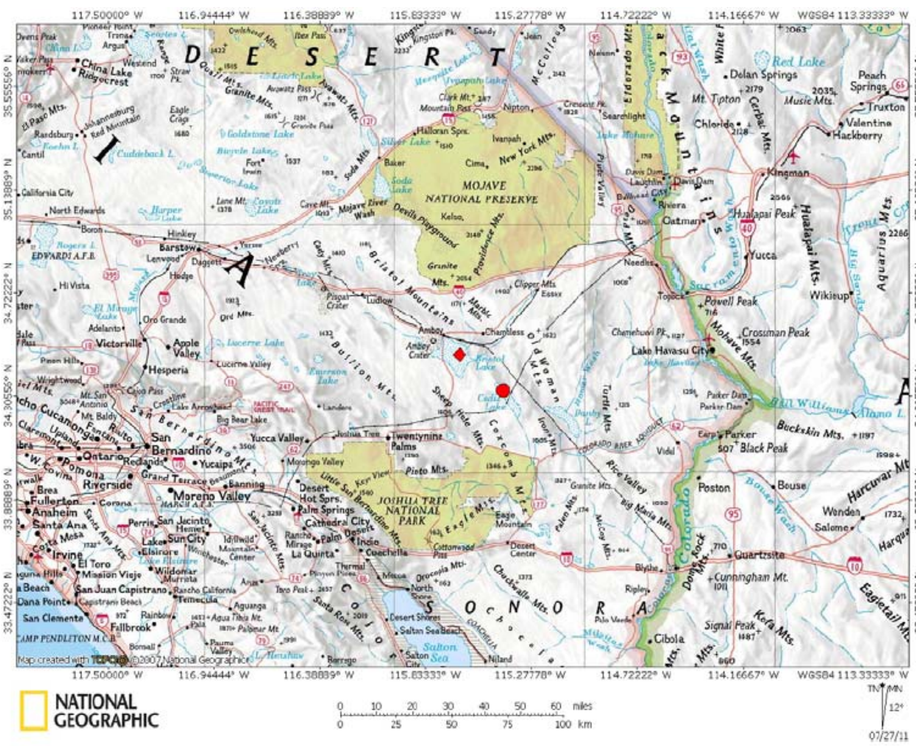

Figure 2. Location of EC Instrumentation Installed on Bristol and Cadiz Dry Lakes.

Monitoring Results

DRI collected data from May 4, 2011 through November 15, 2011 on Bristol Dry Lake and from July 20, 2011 through November 15, 2011 on Cadiz Dry Lake. The EC footprint (the area sampled by the EC tower) is shown in Figures 3 and 4 for Bristol and Cadiz Dry Lakes, respectively. The Bristol Dry Lake footprint is 33,038.85 acres. The Cadiz Dry Lake EC footprint area is 43,537.41 acres.

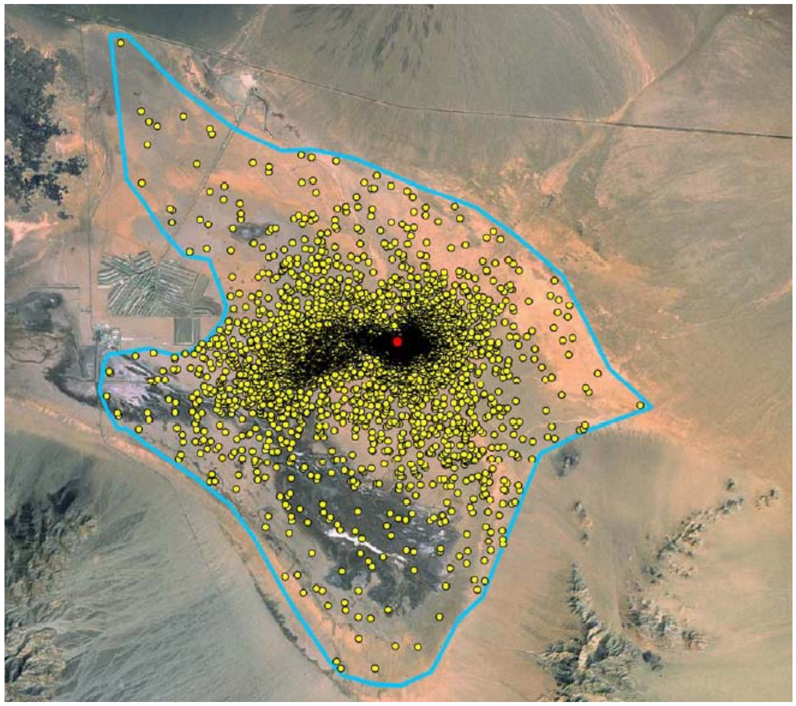

Figure 3. Bristol Dry Lake EC Footprint. The yellow dots represent the 30-min flux values measured by the EC tower (red dot). The light blue line is the EC footprint area.

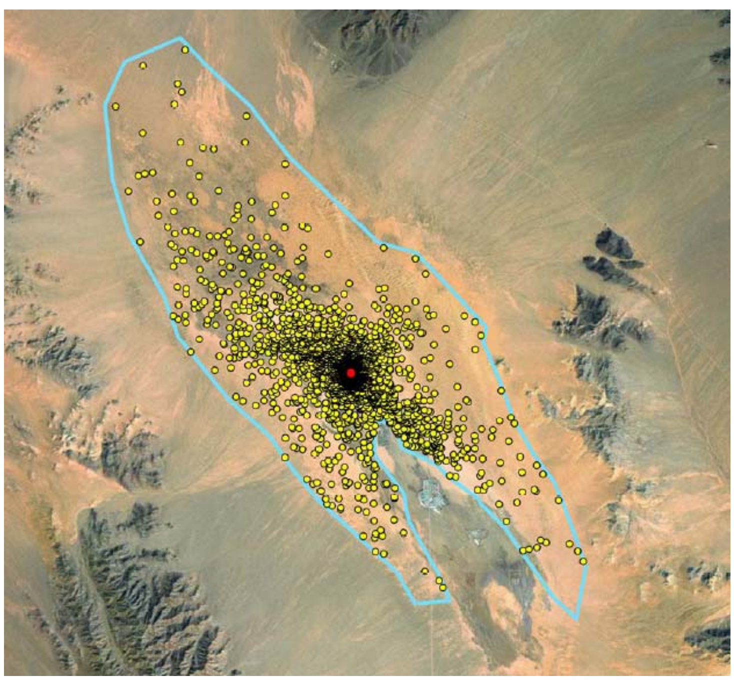

Figure 4. Cadiz Dry Lake EC Footprint. The yellow dots represent the 30-min flux values measured by the EC tower (red dot). The light blue line is the EC footprint area.

Data collected between May 4 and November 15, 2011 on Bristol Dry Lake indicate that 49.75 millimeters (mm) of evaporation occurred from within its EC footprint. Data collected between July 20 and November 15, 2011 on Cadiz Dry Lake indicate that 57.06 mm of evaporation occurred from within its EC footprint. Precipitation occurred at the Bristol Dry Lake EC site on July 30, September 10, September 13, November 4, and November 12. Precipitation occurred at Cadiz Dry Lake EC site on July 30, September 5, September 10, September 13, November 4, and November 6. Evaporation values measured on days where precipitation occurred were significantly higher than on days without precipitation. Higher rates of E also were observed for several days after precipitation occurred. Table 1 shows the net monthly E, which accounts for precipitation, in that the monthly E values have been adjusted for precipitation (net monthly total E is total measured monthly E – total precipitation for the month).

TABLE 1
Net Monthly E for Bristol and Cadiz Dry Lakes

Month	Bristol Dry Lake E (mm)		Cadiz Dry Lake E (mm)	
	Gross	Net	Gross	Net
May (4-31)	5.94	5.94		NA
June	6.41	6.41		NA
July [1]	7.32	6.82	6.57	0.98
August [2]	8.67	8.67	14.97	14.97
September	13.76	-3.51	21.61	18.32
October	5.37	5.37	8.65	8.65
November (1-15)	2.28	1.78	5.26	2.98

[1] Cadiz Dry Lake EC tower data collection began on July 20
[2] Data were not collected from August 9 through 15 due to data logger failure on Cadiz Dry Lake

Using the EC footprint areas given in Figures 3 and 4, and evaporation rates given in Table 1, the cumulative volume of net evaporation measured during the data collection period is 11,392 acre-feet. This net evaporation accounts for precipitation that occurred during the period but it does not account for about a week of missing data due to data logger failure at Cadiz Dry Lake from August 8 through 15, 2011, so the net volume of evaporation is somewhat higher than 11,392 acre-feet.

Potential Annual Evaporation From Dry Lakes

The potential annual evaporation from Bristol and Cadiz Dry Lakes is extrapolated by, 1) extending the area over which evaporation likely occurs and, 2) estimating evaporation rates from the dry lakes for those periods not measured by DRI in order to cover an entire year. In addition, pumping of brine and brackish water, and use of trenches by salt mining companies lowers the water surface beneath the surface of the dry lakes, which likely reduces water available for evaporation that would otherwise be measured by the EC towers, if these operations did not exist.

The EC towers on the two dry lakes were located to avoid salt mining operations, including the open pits used to evaporate brine to recover salt minerals. The EC footprint is not expected to cover the entire area over which evaporation is or has occurred from the dry lakes. For example, the EC tower on Bristol Dry Lake is located in the far northeastern corner of the dry lake, where the depth to groundwater is expected to be high compared to the southern and western extents of the dry lake. The EC footprint on Cadiz Dry Lake was limited to areas not disturbed by salt mining operations (as shown by the two lobes of the southeastern footprint). Therefore, there is expected to be significant evaporation from the dry lakes that is not measured by the two EC towers.

The footprint of each dry lake was extended to areas that are expected to or have contributed to evaporation from the dry lakes. The footprint was simply extrapolated by extending the footprint area over areas of the dry lakes that are similar in elevation to the surface from which evaporation was measured by the EC tower. These extended areas are shown in Figures 5 and 6, for Bristol and Cadiz Dry Lakes, respectively. The extended area for Bristol Dry Lake is 42,164 acres (versus 33,038.85 acres for the EC footprint area) and 55,180 acres for Cadiz Dry Lake (compared to 43,537.41 acres for the EC footprint area). These extended areas also extend into areas of salt mining operations in order to account for areas that would contribute to evaporation under undisturbed conditions.

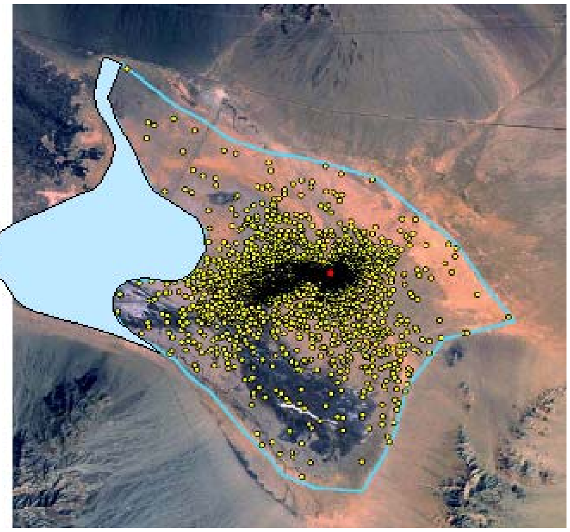

Figure 5. Estimated Extended Area Over Which Evaporation Is Expected To Occur From Bristol Dry Lake

Estimates of evaporation rates for the periods not measured by DRI are made in a two-step process. First, data sets for those months with incomplete data for the month are extended by using the average daily rate of the measured values in a given month to those days for which measurements were not made by DRI (or where the data logger failed in August at Cadiz Dry Lake). Then, these measured and limited filled data sets were used to extrapolate evaporation rates to other months using an average of pan evaporation rates for Amboy (GSSI, 1999) and evaporation rates reported for Franklin Dry Lake to the north (Czarnecki, 1997). Given that solar radiation drives evaporation rates, this is a reasonable approach to estimating evaporation rates for other months, which have reduced daylight hours and possible cloud cover. The pan evaporation rates and actual dry lake evaporation measurements account for this variability.

Figure 7 shows the monthly percentages of total annual evaporation measured at Franklin Dry Lake, pan evaporation for Amboy, and average percent of annual evaporation for each month as average between these pan evaporation and lakebed evaporation rates.

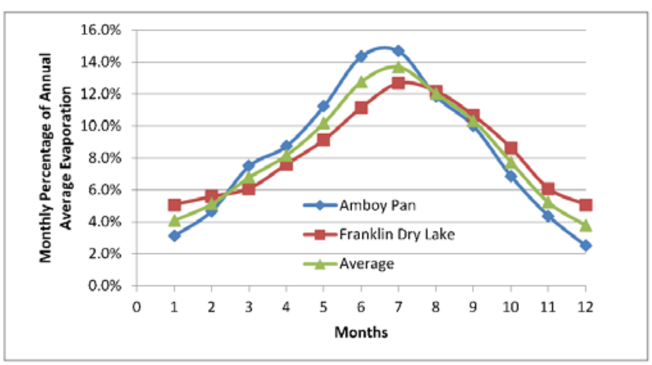

Figure 7. Monthly Percentage of Annual Evaporation Rates.

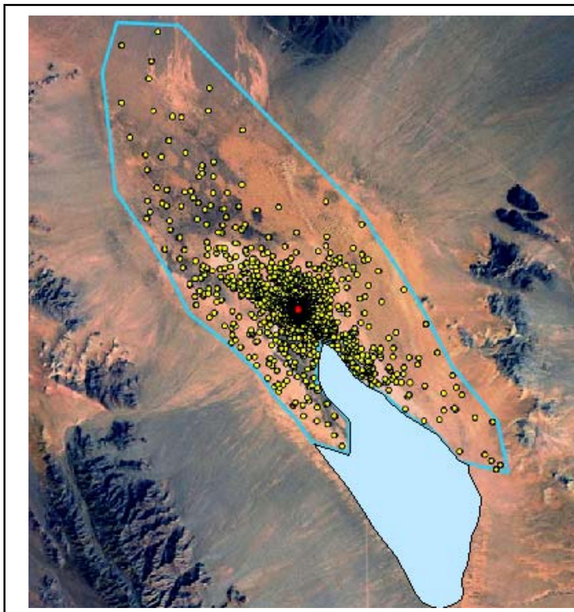

Figure 6. Estimated Extended Area Over Which Evaporation Is Expected to Occur From Cadiz Dry Lake

Table 2 shows the estimated evaporation rates for Bristol and Cadiz Dry Lakes for an entire year using the average evaporation rate curve from Figure 7.

TABLE 2
Estimated[1] Monthly Evaporation for Bristol and Cadiz Dry Lakes

Month	Bristol Dry Lake E (mm)	Cadiz Dry Lake E (mm)
January	2.90	6.42
February	3.70	8.04
March	4.90	10.63
April	5.90	12.80
May	6.58	15.95
June	6.41	19.98
July	6.82	11.43
August	8.67	18.82
September	-3.51	18.32
October	5.37	8.65
November	4.03	8.53
December	2.73	5.93
Totals	54.5 (0.18 feet)	145.49 (0.48 feet)

[1] Actual measured values provided for those months in which measurements are available

Using these estimates annual evaporation rates and the extended areas over which evaporation is expected to occur, the annual evaporation from Bristol and Cadiz Dry Lakes is 7,546 and 26,339 acre-feet, respectively. The total annual evaporation combined from both dry lakes is 33,885 acre-feet per year. If these values are adjusted for the underestimate of four percent for Bristol and eleven percent overestimate value for Cadiz as described above, then the combined total annual evaporation rate is adjusted to 31,590 acre-feet per year.

The evaporative flux estimates for Bristol and Cadiz Dry Lakes of 0.18 and 0.48 feet per year, respectively, are within the range of evaporative fluxes of 0.1 to 0.7 feet/year from dry lakes in the Death Valley regional flow system as reported by Laczniak et. al., (2001). It is important to point out that these estimates of evaporation rates do not account for consumptive pumping that occurs by Cadiz and the salt mining operations. Therefore, these estimates are likely conservative estimates of the long-term evaporation rates from the two dry lakes.

References

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