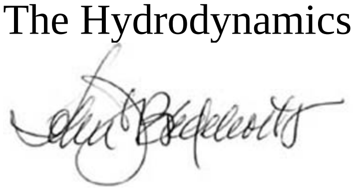
COMMENT ON THE HYDROGEOLOGY OF PROPOSED CADIZ PROJECT

Prepared on behalf of

CENTER FOR BIOLOGICAL DIVERSITY &
NATIONAL PARKS CONSERVATION ASSOCIATION

John Bredehoeft
The Hydrodynamics Group, Sausalito, CA 94965



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THE HYDROLOGY OF VALLEYS IN THE BASIN AND RANGE

Under natural conditions the alluvial aquifers that underlie the valleys of the Basin and Range are full of groundwater. These systems have existed for geologic time. There were periods of higher rainfall in the area during the Pleistocene ice ages. Under natural (undisturbed) conditions before any development, the recharge to the aquifers is balanced by the discharge from the aquifers, or:

Recharge = Discharge (under undisturbed conditions)

The discharge from the aquifers occurs in many of the closed valleys in the Basin and Range as either evaporation from the playa, or by transpiration from plants in the lower parts of the valleys that draw their water from the water table. (Plants that draw water directly from the water table are referred to as ***phreatophytes.***) Common plants that draw groundwater from the water table are creosote bush, giant sage, and rabbit brush. Very few of these plants are present in Cadiz project area; groundwater in this area is thought to discharge, before development, primarily as evaporation from the local playas.

Pumping groundwater in one of these valleys constitutes an additional withdrawal from a system that was in a natural state of balance. In order for such a groundwater system to reach a new equilibrium (a state that can be maintained indefinitely) one of two things must occur: 1) the pumping must increase the recharge, and/or 2) the pumping must decrease the discharge. Usually groundwater pumping has no impact on the recharge; recharge is determined by climatic conditions—precipitation, etc. On the other hand the pumping can decrease the discharge. For example, in Cadiz area pumping groundwater can lower the water table beneath Bristol Lake and Cadiz Lake playas and either reduce or eliminate groundwater discharge as evaporation there.

FIRST PRINCIPLES

Let me further address the question—where does water come from in the groundwater system when a well is pumped? Lohman (1972) speaking for the U.S. Geological Survey answered this question:

Water withdrawn artificially from an aquifer is derived from a decrease in storage, a reduction in the previous discharge from the aquifer, an increase in the recharge, or a combination of these changes (Theis, 1940). The decrease in discharge plus the increase in recharge is termed capture. Capture may occur in the form of decreases in groundwater discharge into streams, lakes, and the ocean, or decreases in that component of evapotranspiration derived from the saturated zone. After a new artificial withdrawal from the aquifer has begun, the head in the aquifer will continue to decline until the new withdrawal is balanced by capture.

This idea, introduced by Theis (1940), contains the essence of quantitative groundwater hydrology, and is elegant in its simplicity. Capture is concerned with the changes in the recharge and/or the discharge created by the pumping—not the initial values of recharge and/or discharge. As the definition of capture implies, water will be drawn from storage until the pumping can be fully balanced by the capture.

If the pumping exceeds the quantity of groundwater that can be captured, then water will be continually drawn from storage, and water levels within the system will continue to decline. In this situation the water drawn from storage is ***mined*** from the system.

HYDROLOGIC ANALYSIS

In assessing the perennial yield of a groundwater system, two basic tools are widely used:

1. Water budget analysis;
2. Numerical models that portray the hydrogeology of the system.

Water Budgets

The water budget, as generally applied to a hydrologic system (for example a particular valley), is a global estimate of the inflow, outflow, and rate of change in storage for the system at a point in time. Commonly, these estimates are made for the system prior to development; usually with the assumption that the system is at steady state—i.e. recharge equals discharge.

Given the undisturbed water budget, one can estimate how large a perennial yield might be—in other words how much pumping might be maintained indefinitely?

Water budgets, in desert basins, require that two quantities be estimated: 1) recharge, and 2) discharge. As indicated above, one of the first principles is that the recharge is equal to the discharge in these basins before they were disturbed. These systems have existed for sufficiently long periods such that the long-term average discharge is balanced by the long-term average recharge.

Even though it is sometimes possible to make observations of either the discharge or the recharge at specific locations, the data must be extrapolated to large systems, inevitably this extrapolation results in both the recharge and the discharge becoming estimates made by the hydrologists. In this situation it is important that the recharge estimates be compared to the discharge estimates, and that they are balanced. Commonly, this requires adjusting the values of the recharge or the discharge, or both. Mistakes are made when either the recharge or the discharge is examined alone, without considering the constraint placed by the other quantity—more on this below.

Groundwater impacts depend upon the hydrogeology of the system. The impacts can be quite different depending upon where the pumping is located within the system. Usually budgets provide no information on the place and timing of impacts (Bredehoeft, 2002).

Models

Groundwater models were invented in an attempt to estimate the timing and location of groundwater impacts. They evolved, as our computer technology has exploded over the past 60 years into sophisticated analytical tools. With present technology, anyone hoping to project potential future impacts in both time and place almost certainly uses a model to make a credible analysis. Currently there are two models that are relevant to the analysis of the proposed Cadiz Development—more on this below.

THE CADIZ PROJECT

Conceptually the project is quite simple. The Cadiz Company proposes to pump an average of 50,000 acre-feet annually (ac-ft/yr) from property they own in Cadiz Valley for a period of 50 years. The water will be put into a pipeline that is approximately 43 miles long built of the right of way of the ARZC railroad to a point where the pipe reaches the Colorado River Aqueduct. Once that water reaches the aqueduct it can be delivered to the cities of southern California. Cadiz has arranged participation with a number of water agencies in southern California, presumably to receive water from the project.

Cadiz Project Water Budget

The Draft Environmental Impact Statement (DEIR) for the project includes three scenarios of recharge for Cadiz/Fenner Valley: 1) 5,000 ac-ft/yr; 2) 16,000 ac-ft/yr; and 3) 32,000 ac-ft/yr. Immediately we recognize that all of these estimates of recharge are less than the proposed average annual pumping of 50,000 ac-ft/yr. This indicates that given any of these estimates of recharge, pumping 50,000 ac-ft/yr will require that groundwater be continually drawn from storage; this system cannot be sustained indefinitely. This follows directly from our discussion of first principles above.

Our budget analysis informs us that the proposed development will mine groundwater—remove groundwater from storage as long as the pumping continues. In fairness, the proponents of the project do not pretend otherwise. The magnitude of the quantity of groundwater mined during the life of the project depends upon which of the recharge scenarios more nearly represents reality.

CONCLUSION 1: The Cadiz Project is designed to mine groundwater (this fact is undisputed by the proponents).

Cadiz Recharge

In a 20-01 comment on the cadiz project, I summarized a number of previous estimates of recharge to the project area; table 1 is taken from that report (Bredehoeft, 2001);

Table 1. A summary of the recharge estimates.

Methodology/Author	Estimate (ac-ft/yr)
Watershed Runoff Model—MWD & BLM (1999)	20,000-70,000
(GeoScience Groundwater Model)	(50,000)
Maxey/Eakin Method	
USGS (2000)	2,550-11,200
Durbin (2000)	5,000
Fenner Gap Groundwater Flow	
Friewald (1984—USGS)	270
LaMoreaux (1995)	3,700
USGS (2000)	2,600-4,300
Chloride Method (correctly applied)	
USGS (2000)	1,700-9,000
Durbin (2000)	2,000
Drawdown Associated with Cadiz Land Co. pumping	
Boyle Engineering (1996)	4,000

The point of the table was that recharge methods vary widely, and give widely differing results. CH2MHill (2010) acknowledged a wide range of recharge estimates.

CH2MHill (2010) used the USGS program INFIL3.0 which is a soil moisture budget program to estimate the recharge in the Fenner Valley. Fenner valley provides approximately 70 percent of the groundwater recharge to the project area. Using INFIL3.0 the group calculated a recharge to Fenner Valley of 30,000 ac-ft/yr. They considered this estimate reasonable.

The application of soil moisture accounting programs often leads to overestimates of recharge. The USGS (Heilwell and Brooks, 2010) in a recent reanalysis of recharge for a large area of the Basin and Range in eastern Nevada and western Utah used the Basin Characteristic Model (BCM). BCM is also a soil moisture accounting program, very similar to INFIL3.0, created by the same team at the USGS. When the calculated recharge was compared with the discharge; the recharge values calculated by the BCM were revised. Figure 1 is a map showing the revisions to the BCM calculated values (Heilwell and Brooks, 2010):

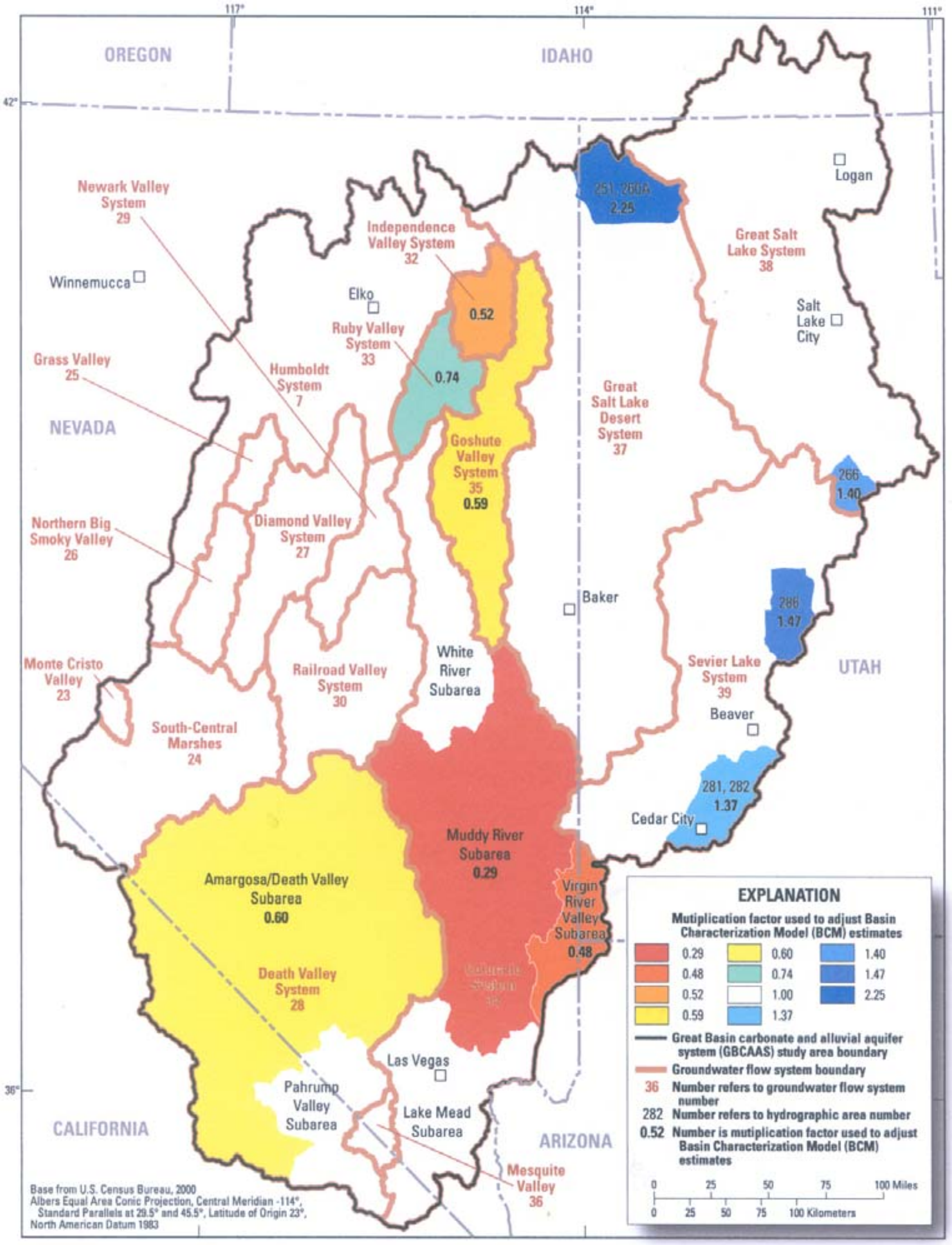

Figure D–8. Multiplication factors used for adjusting Basin Characterization Model (BCM) in-place recharge and runoff for the Great Basin carbonate and alluvial aquifer system study area.

Figure 1. Adjustments to BCM recharge estimates (Heilwell and Brooks, 2010--USGS).

One sees in this figure that in many of the Nevada/Utah basins that the BCM calculated recharge values were reduced significantly. This emphasizes the importance of comparing recharge with discharge estimates, and their need to be reconciled.

Model of Groundwater Flow through Fenner Gap

Fenner Gap is both a topographic and hydrogeologic gap that separates the Fenner Valley from the Cadiz Valley. As suggested above, approximately 70 percent of the groundwater recharge to the project area occurs in the Fenner Valley. This recharge moves as groundwater flow through the gap. A question arises: given our observations of water levels in the vicinity of the gap, and our understanding of the subsurface geology and hydrology, is it reasonable to think that 30,000 ac-ft/yr can flow through the gap? The analyses listed in Table 1 indicate that previous investigators suggested that the groundwater flow through the gap might range from 270 to 4,300 ac-ft/yr. CH2MHill created a groundwater model to address this question; in the words of CH2MHill (2010):

The purpose of the Fenner Gap groundwater flow model in this study is to assess whether it is likely that 30,000 AFY of groundwater is flowing through Fenner Gap, which is the expected long-term average recoverable water estimated to occur in the Fenner Watershed. Therefore, the numerical model is being used to test the hypothesis that 30,000 AFY is flowing through the gap. The model is used to solve the inverse problem, that is, given a boundary inflow of groundwater at the north end of the gap of 30,000 AFY, and measured steady-state groundwater levels, what distribution of aquifer properties (specifically hydraulic conductivity) is required to allow for this flow and is this distribution likely given available information on aquifer properties?

The model adjusts the hydraulic conductivity values of the rock units being simulated, until a good match to the observed water levels is achieved. One can then ask as CH2MHill suggests: are the model generated hydraulic conductivity values reasonable? In this instance the model included both the alluvial fill and the underlying carbonate rocks. The model indicated hydraulic conductivity values for the carbonate rocks beneath of the Fenner Gap of 600 feet/day. Only one test was performed in the carbonate rocks in the area; that well yielded a hydraulic conductivity for the carbonate of 1150 ft/day. Figure 2 is a plot of the distribution of hydraulic conductivity values for the carbonate rock province of eastern Nevada and western Utah, the area shown in Figure 1:

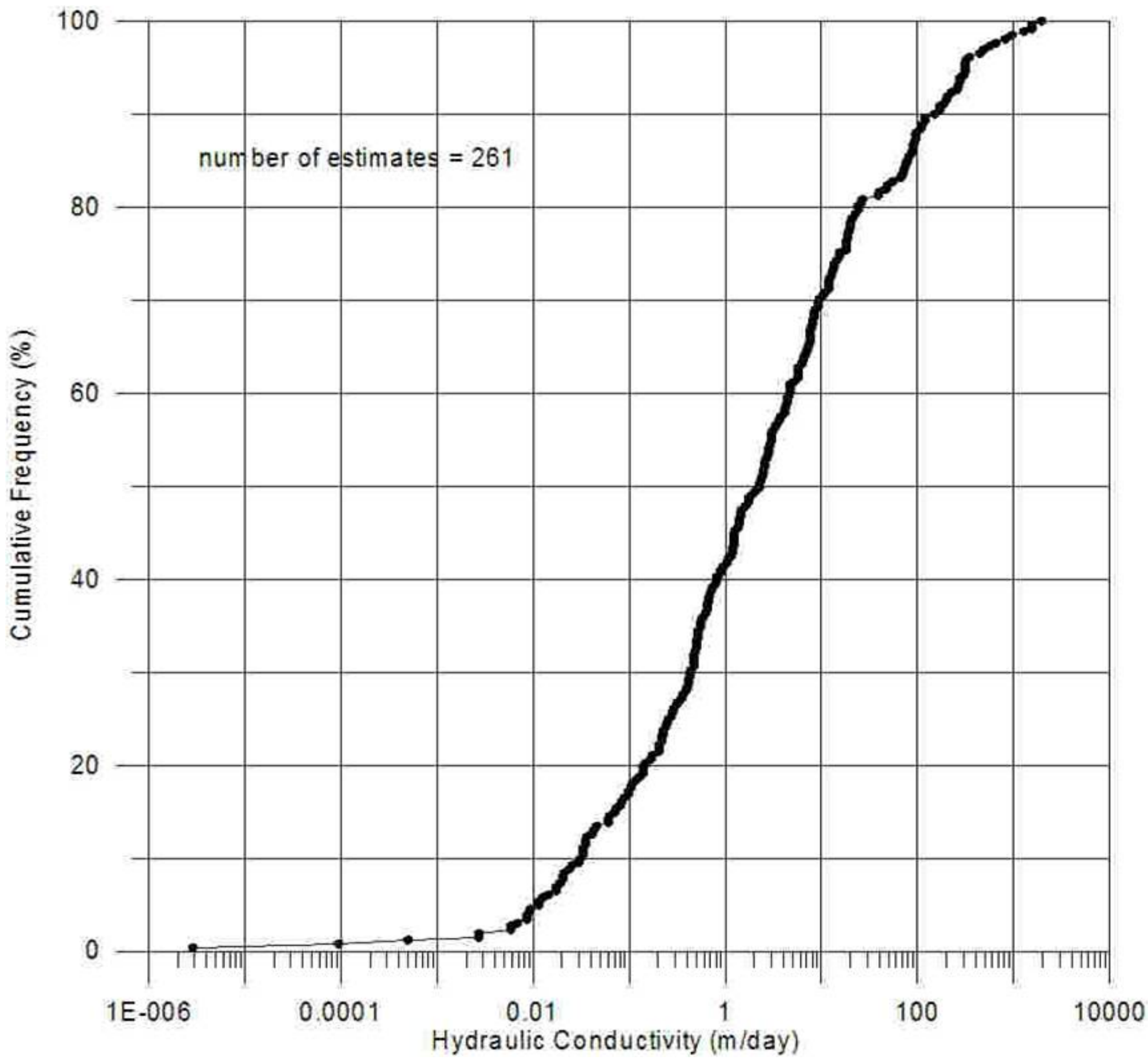

Figure 2. Plot of the cumulative distribution of hydraulic conductivity values for the Carbonate Aquifer of eastern Nevada and western Utah (Bredehoeft and King, 2010)

One sees in Figure 2 that a hydraulic conductivity value of 350 m/day (1150 ft/day) only occurs in wells in the Carbonate Aquifer of Nevada and Utah approximately 9 percent of the time—it is a high value. The CH2MHill model suggests that values in the range of 600 ft/day (approximately 180 m/day) are required for the carbonate rocks to achieve a good fit to the observed water levels. These values only occur approximately 10 percent of the time in the Nevada/Utah Carbonate Aquifer.

While the carbonate hydraulic conductivity values required by the CH2MHill model are possible, they are high.

Playa Discharge

Geoscience (2011) conducted a second modeling analysis for the project: *Cadiz Groundwater modeling and Impact Analysis.* This included an analysis of the larger area that included the Bristal and Cadiz Playas. It is interest to examine the calculated discharge on the playas associated with the recharge estimate of 32,000 ac-ft/yr. This table taken from the Geoscience (2011) report summarizes the model generated evaporation rates:

Location	Maximum Evapotranspiration Rate [in/year]		
	Natural Recharge of 32,000 acre-ft/yr	Natural Recharge of 16,000 acre-ft/yr	Natural Recharge of 5,000 acre-ft/yr
Bristol Dry Lake	240	120	18
Cadiz Dry Lake	613	307	44

Geoscience (2011) commented on this table:

It is important to note that the maximum evapotranspiration rates used were based on model calibration results in order to obtain more reasonable evaporation from dry lakes and a better match between model-calculated and observed water levels. It may exceed the pan evaporation rate of 158 in/yr at the Amboy weather station (US Ecology, 1989). For example, a maximum evaporation rate of 240 in/yr was used for the Bristal dry lake for the calibration run with natural recharge of 32,000 acre-ft/yr. This is due to the fact that groundwater levels were not simulated to the accuracy required to calculate the evaporation across the entire dry lake surface. Result show an average of 19 in/yr over those cells where evaporation is occurring in the run, which is a reasonable average.

While Geoscience (2011) asserts that 19 in/yr of evaporation from the playa is reasonable, most hydrogeologists would find this value too high. The USGS (Laczniak et al., 2001) estimated evapotranspiration for a number of areas in the Death Valley regional flow system, which includes estimates for open playas similar to the Bristol and Cadiz dry lakes. The USGS estimated evapotranspiration rates range from 0.1 to 0.7 ft/yr. In a recent publication that summarizes water budgets for the large area shown above in Figure 1, the USGS indicated that an appropriate rate of evaporation from playas is 0.1 ft/yr (Heilwell and Brooks, 2010)..

CONCLUSION: The recharge estimate of 32,000 ac-ft/yr appears to be too high, especially when one considers the evaporation rates on the Bristol and Cadiz dry lake playas must equal the recharge. A recharge rate in the range of the other two considered in the DEIR, 16,000 and 5,000 ac-ft/yr, seems much more likely.

HOW MUCH GROUNDWATER WILL BE MINED?

The Geoscience (2011) modeling produces a graph of groundwater removed from storage, Figure 4:

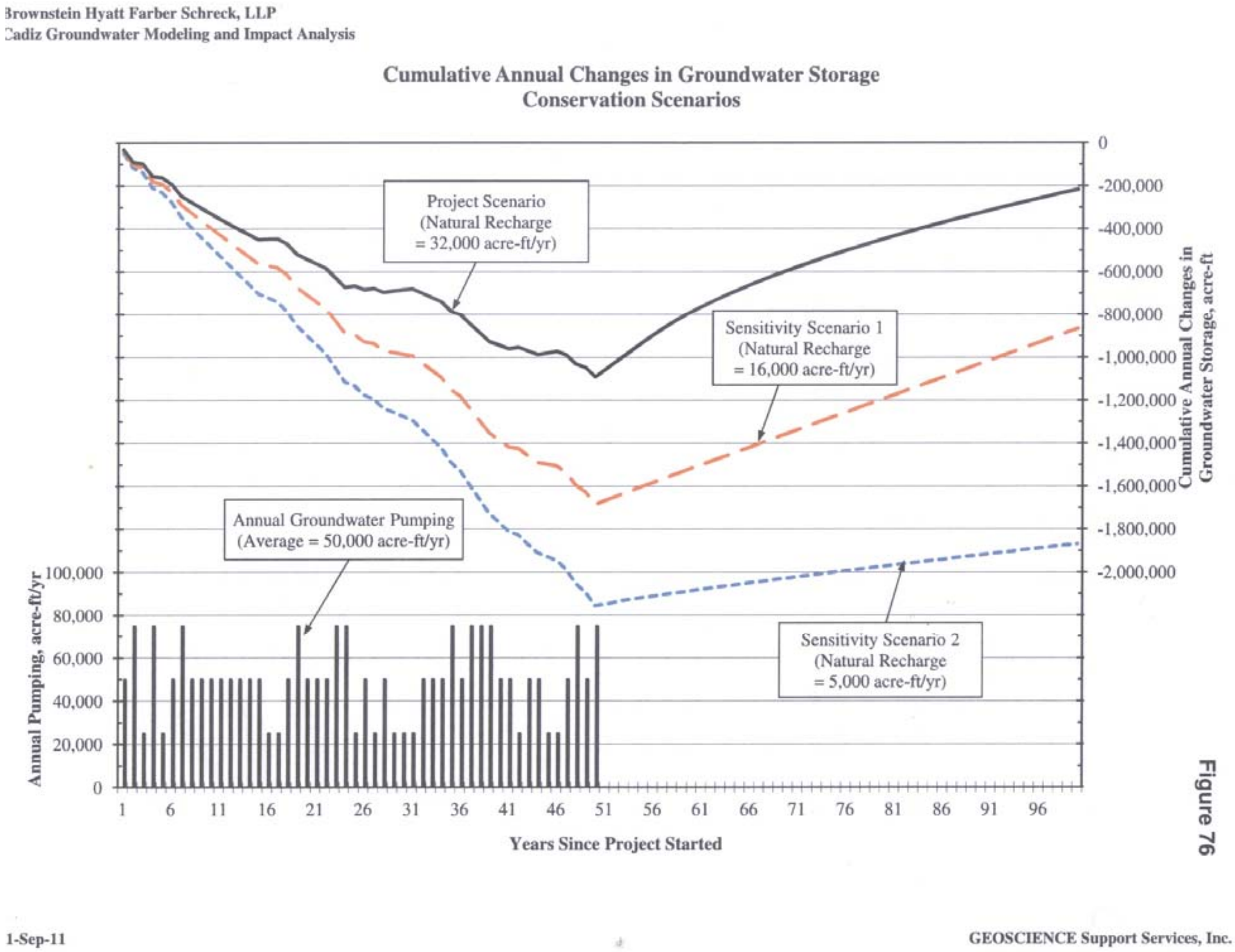

Figure 4. Cumulative amount of groundwater removed from storage; from Geoscience (2011).

In Figure 4 the graph of the cumulate change in storage is a graph of the groundwater removed from storage needed to balance the pumping. As the recharge rate decreases the amount of water removed from storage must be larger to balance the pumping. This water removed from storage is groundwater that is mined from the system—it continues to declines as long as the pumping continues. In fairness, the Cadiz Project makes no pretense that it will not remove a large quantity from groundwater storage—i.e. ***mine groundwater.***

My analysis suggests that the red or the blue curve (recharge of 16,000 or 5,000 ac-ft/yr) are probably more likely. This indicates that after 50 years of pumping between 1, 600,000 and 2,300,000 ac-ft of groundwater will be mined by the Cadiz project.

Once pumping stops the basin will recover, but at the lower rates of recharge it recovers slowly. With a recharge rate of 16,000 ac-ft/yr the basin is still depleted by 800,000 ac-ft 50 years after the pumping ceases; at a recharge rate of 5,000 ac-ft/yr the basin is depleted by 1,800,000 ac-ft 50 years after the pumping ceases.

CONCLUSION: Pumping mines groundwater and leaves the basin with impacts that persist long after the pumping ceases.

CONCLUDING REMARKS

Clearly the Cadiz Project is a project designed to mine groundwater in the Cadiz Valley; the proponents of the project do not claim otherwise. The estimate of recharge of 32,000 ac-ft/yr, especially when one examines the discharge necessary to balance the recharge, is too high. A recharge estimate in the range of 16,000 ac-ft/yr, or perhaps lower, seems much more likely. Finally the project will mine somewhere between 1 and 2 million ac-ft during 50 years of pumping. The basin recovers once pumping ceases, but even the most optimistic scenarios indicate a substantial groundwater storage deficit will remain 50 years after pumping ceases. If the recharge is low, as I believe it is, the storage in the system will take several hundred years after pumping ceases to fully recover—water levels in the basin will take several hundred years to fully recover.

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