San Gorgonio Pass Water Agency

Technical Memorandum

Beaumont Storage Unit Basin Yield Update

San Gorgonio Pass Water Agency

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Objective

This investigation was authorized by the San Gorgonio Pass Water Agency (SGPWA) in support of the agency's continuing mission to understand and manage water resources within the agency's service area.

The objective of this investigation was to review current understandings of hydrologic conditions within the Beaumont Storage Unit in light of ongoing (1995 to present) work by the U. S. Geological Survey (USGS) and prepare updated estimates of basin yield. As a part of this assessment, current estimates of pumping within the basin were compared with estimates made previously, in light of recent work by the USGS and the SGPWA to develop a more complete record of historical pumping.

It is important to recognize that the analyses and conclusions reported herein are based on limited access to model files. The full set of model input and output files and the model documentation are in a formal USGS internal review process and may be subject to change as a result of that review. Official release of the model is expected within the next several months. As a consequence, results described herein must be considered "interim" until such time as the model has been formally reviewed and is officially released as a USGS product. Nonetheless, this investigation has provided valuable insights as to the current model's representation of hydrologic conditions within the basin, indications of significant differences that exist between the current model and an earlier model (Boyle Engineering Corporation, 1995), and, it provides a greater level of confidence in estimates of basin yield.

The investigation included the following tasks:

- Review of the earlier ground water model (Boyle Engineering Corporation, 1995) and material currently available on the USGS model.
- Obtain and review raw hydrologic data. This data consisted of time-series well water levels, stream flow data, precipitation, tunnel discharge, pumping, etc.
- Define specific conditions of modeling runs to be made by the USGS to identify in a general way differences between the 1995 model results and results produced by the USGS model.
- Compare results of model runs using the current model with equivalent results obtained using the earlier model. Identify apparent differences in results and probable causes for such differences. Estimate basin yield based on current model representations.

Summary

This study focused on the Beaumont Storage Unit, one of several lying within the limits of the SGPWA service area. The location of the Beaumont Storage Unit is shown in Figure 1. For purposes of this report, basin yield is defined as the maximum quantity of water that can be continuously withdrawn from

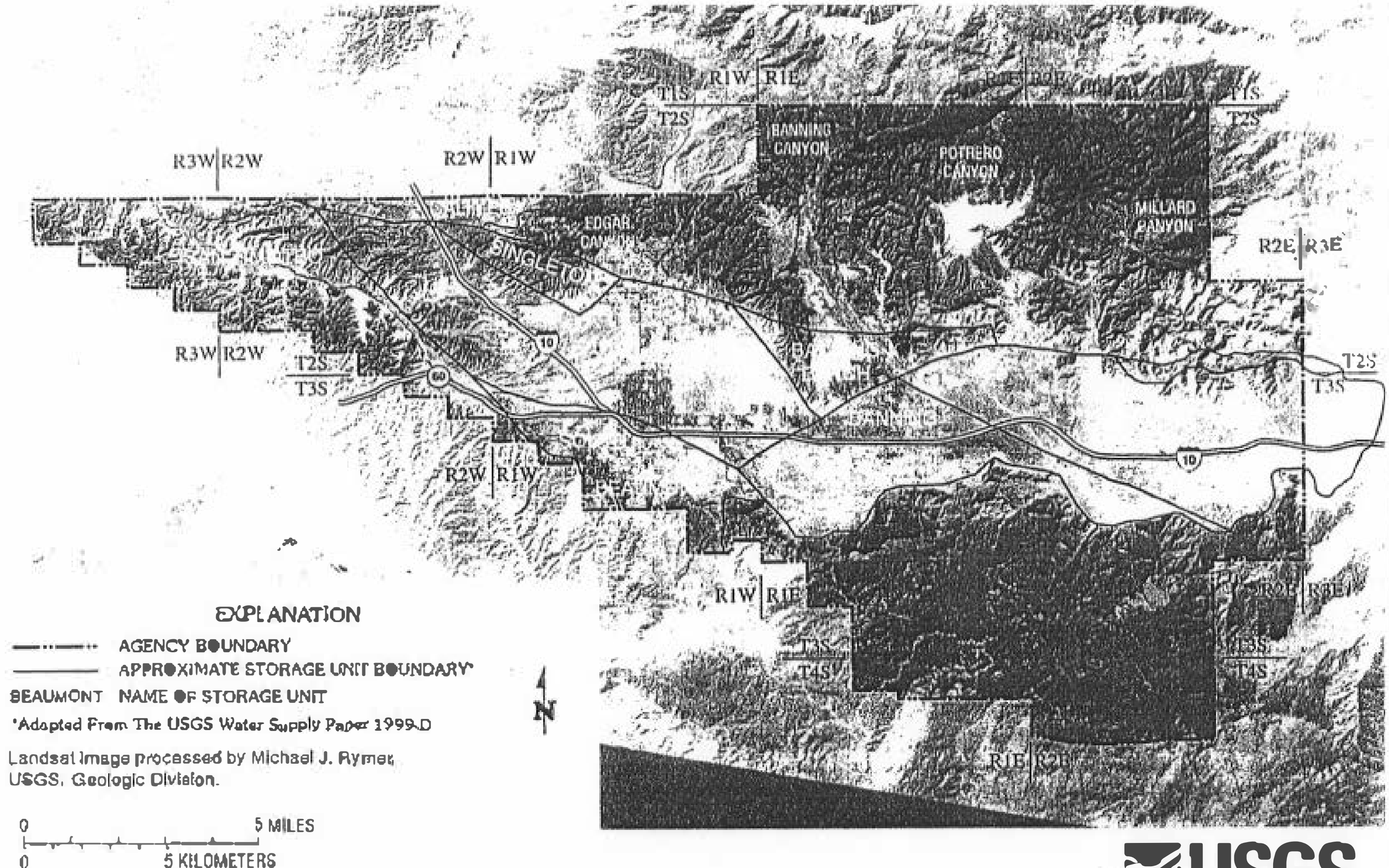


Figure 1. Location of the Beaumont Storage Unit

USGS
science for a changing world

a ground water basin without adverse effect. There are two measures of withdrawal described herein, as follows:

- Total Pumping – this is a measure of the total volume of withdrawals or extractions, without regard to the particular uses to which the water is put, and without consideration of the portion of pumping that returns to the basin as deep percolation or return flow.

- Net Pumping – for purposes of this report, net pumping represents that portion of the total pumping that is consumed, generally equal to total pumping less return flow.

In most cases, a portion of the water pumped from a well is returned to the basin. For example, a portion of the water pumped for irrigation supply is returned to the basin as deep percolation, or return flow. In the case of water pumped for municipal or residential use, a portion of the water pumped is returned to the basin through on-lot septic systems, or as a discharge from a wastewater treatment plant. In the prior analysis of basin yield (Boyle Engineering Corporation, 1995), the return flow from all uses was estimated to be about 28 percent of total pumping, meaning the consumptive use portion of pumping represented 72 percent of total pumping (100% – 28% = 72%). Work by the U.S. Geological Survey (USGS), the subject of this investigation, appears to employ a return flow fraction averaging about 22 percent. And, a recent study by Wildermuth Environmental (2002) employed a return flow fraction of 22 percent. The relationship between total pumping and net pumping requires information on the return flow fraction or the consumptive use of the water pumped. A basin yield equal to a total pumping rate of 5,000 acre feet per year (AF/Y), is equivalent to a net pumping rate of about 3,900 AF/Y (5,000 x 0.78 = 3,900) using a return flow fraction of 22 percent. These distinctions become particularly important in forecasting future basin development, where the types of uses (irrigation, municipal), the types and locations of wastewater disposal processes (on-lot septic, centralized wastewater treatment), and the levels of reuse of wastewater may change from current conditions. For purposes of this investigation, a return flow fraction of 22 percent has been adopted, unless otherwise indicated.

There have been several prior investigations of basin yield. A 1988 investigation (Boyle Engineering Corporation, 1988) estimated basin "dependable" yield at 3,000 AF/Y net pumping (about **3,800 AF/Y total pumping** using a return flow fraction of 22 percent). In that study, dependable yield represented the sum of the natural inflows (recharge from precipitation and streamflow) to the Beaumont Storage Unit. A second term, defined as "usable" yield, was estimated by reducing the dependable yield by subsurface outflow from the basin, estimated at 750 AF/Y. The study conclusions were based on relatively sparse hydrologic data. A subsequent study (Boyle Engineering Corporation, 1995) attempted to improve on the estimate of basin yield. The 1995 study benefited from significantly improved data on basin hydrologic conditions, and a significantly improved understanding of the basin's hydrogeologic setting. That study relied on a ground water flow model (MODFLOW) in its investigation and testing of basin hydrology and concluded that yield of the basin was about **6,100 AF/Y total pumping** (about 4,400 AF/Y net pumping, wherein a return flow fraction of 28 percent was estimated).

The subject of the current investigation is a model developed by the USGS. The model has benefited from several years of additional investigation of basin geology and hydrology and many years of data collection. The model also takes advantage of many additional years of data on water levels and improved, more accurate reporting of basin extractions. Using the USGS model, basin yield was evaluated using two somewhat independent lines of inquiry. First, analysis of the water budget components of the USGS model for the period 1970 – 1979, a time of relatively stable water levels, suggests a basin yield of about 4,600 AF/Y total pumping (about 3,600 AF/Y net pumping). Yield of the basin could be as much as about 5,200 AF/Y when return flows from water imported from adjacent basins (Banning Bench, Banning Canyon, Edgar Canyon) are considered. Yield is estimated to be nearer the higher end of this range (about **5,000 AF/Y**). Second, analysis of ground water level response to a range of pumping suggests basin yield lies in the range of about 2,500 to 5,000 AF/Y total pumping (2,000 to 3,900 AF/Y net pumping, assuming a return flow fraction of 22 percent. Yield is estimated to be at the higher end of this range (about **5,000 AF/Y** total pumping).

These estimates are summarized as follows:

Summary of Recent Estimates of Beaumont Storage Unit Yield (Total Pumping, AF/Y)	
Source/Method	**Estimated Yield (AF/Y)**
Boyle Engineering Corporation, 1988: Water Budget	3,800
Boyle Engineering Corporation, 1995: Model Water Budget/Water Level Response	6,100
This Study: USGS Model Water Budget	5,000
This Study: USGS Model Water Level Response	5,000

On the basis of the prior investigations combined with findings from use of the USGS model, basin yield is estimated to be in the range of **5,000 to 6,000 AF/Y total** pumping. This estimate may be modified as additional water level history and extraction history become available.

Geologic and hydrologic conditions within the Beaumont Storage Unit are highly complex. While there have been major advances in understanding these conditions, there continues to be significant uncertainty in predicting basin yield and basin response to pumping. This is particularly evident in the broad range of estimates of boundary inflows and outflows. Predictions are further complicated by the extremely long response time of basin water levels to changes in pumping and recharge. Prior studies by Boyle (1995) suggested that it could take as long as 50 years for basin water levels to adjust and reach equilibrium in response to changes in pumping. The USGS has tentatively concluded that return flows from applied water may require from 10 to 30 years to actually reach the water table. Therefore, current water level behavior may not be a reliable indication of basin yield. Reliability of estimates of basin yield will increase, as will the confidence in these estimates, as the length of the record of water levels and extractions is extended. The Agency is encouraged to continue their aggressive program of measuring and recording this information.

Methodology

Yield of the Beaumont Storage Unit was investigated using the following information:

1. Assignments of boundary conditions (e.g. precipitation recharge, subsurface inflow and outflow, stream recharge) used in the development of the USGS model provide direct information on sources of recharge to the basin. The sum of all inflows to the basin may be considered one measure of basin yield.

2. Use of the USGS model to test the hydrologic response of the basin to a range of hypothetical rates of extraction. This testing yielded information on changes in water levels and boundary inflows and outflows in response to a range in pumping, and provided an indirect measure of basin yield. For example, in the case where water levels are predicted to decline rapidly without sign of stabilizing, it may be concluded that yield of the basin has been exceeded.

The USGS model is based on MODFLOW, a finite difference, three-dimensional numerical ground water flow model. The model includes all of the Beaumont Storage Unit, as well as portions of adjacent storage units. The model represents the ground water system using 2 layers. The model grid contains 50 rows and 130 columns. Model cells are a uniform 1,000 feet x 1,000 feet.

The model employs several of the standard MODFLOW packages to represent various elements of the basin's hydrology. Boundary conditions are represented using a specified flow condition, a no-flow condition or the general-head boundary condition. Deep percolation of rainfall is introduced using the recharge package. Basin outflows along the southwestern boundary of the Beaumont Storage Unit where it abuts the San Timoteo Storage Unit are represented using the drain package. Infiltration from streams entering the basin is represented using the well package. Pumping for municipal, industrial, and irrigation supply, and deep percolation of irrigation and municipal and domestic return flows are also represented using the well package.

The USGS model was constructed as a transient model, covering a 75-year period. Two types of simulations were carried out by the USGS to support this investigation of basin yield. The historic simulation covers the years 1926 through 2000, and contains estimates of historic hydrologic conditions, including pumping and return flows. Return flows are lagged in the model by either 10 years or 30 years, depending on where in the basin the return flows are occurring. On average, a return flow fraction of about 22 percent appears to have been used.

Additional simulations were developed to test the basin's hydrologic response to a range of hypothetical extraction rates, as follows: 2,500 AF/Y; 5,000 AF/Y; 7,000 AF/Y; 9,000 AF/Y; and 12,000 AF/Y. These simulations all represented pumping as a constant value over time. Starting water levels for these simulations were the same as those used in the historical simulation. For expediency, return flows from pumping were constant for all simulations. Return flows were set equal to between 22 percent and 23 percent of pumping within the basin, as shown in the following table:

Return Flows Associated with Hypothetical Extraction Rates			
Scenario	Extraction Rate (AF/Y)	Return Flows (AF/Y)	Return Flow as Percentage of Extraction Rate
1	2,500	580	23%
2	5,000	1,130	23%
	7,000	1,570	22%
	9,000	2,000	22%
	12,000	2,260	22%

Currently, there is water pumped from areas outside the basin, principally in the Edgar Canyon and Banning Bench/Banning Canyon storage units that is imported for use within the basin. Return flows from this water were not explicitly included in the simulations of future hypothetical extraction rates, but were considered in evaluating results of the modeling and in forming estimates of basin yield

Findings

Estimates of basin yield were developed using several somewhat independent approaches, as follows:

Water Budget

Previous work by Boyle (1995) identified the period 1970 – 1979 as one in which water levels appeared to be relatively stable, suggesting an approximate balance between basin recharge and basin discharge. Water budget values extracted from that analysis were based on a steady-state simulation using average values for the 1970 through 1979 period

Results from the USGS transient historic simulation were extracted and compared to the results of Boyle's steady-state simulation Basin inflows and outflows were tabulated from the USGS model for the same 1970 – 1979 period. Differences resulting from a comparison between a steady-state simulation and a transient simulation are not expected to be significant, since the period is one of relative stability. Further, as noted earlier, several of the modeled parameters, e.g. precipitation recharge, streamflow recharge, are modeled by the USGS as constant over time.

For ease of comparison, several of the terms of the water budget have been combined in the following table.

Water Budget Comparison – Beaumont Storage Unit
(all units of AF/Y unless otherwise indicated, rounded, for years 1970 - 1979)

	Component	Boyle (1995)	USGS (2002)
Inflow Components	Stream infiltration	0[a]	3,000
	Boundary inflows	3,400	0
	Precipitation recharge[a]	4,000	2,100
	Precipitation, streams and subsurface inflow, total	7,400	5,100
	Return flow from pumping	1,700	1,100
	Total Inflow	**9,100**	**6,200**
Outflow Components	Pumping	6,100	5,500
	Subsurface Outflow[b]	3,000	1,500
	Total Outflow	**9,100**	**7,000**
Storage Change	**Basin Outflow – Basin Inflow**	**0**	**800**

Notes:
a) Value for stream infiltration reported by Boyle was included in estimate for precipitation recharge (Boyle, 1995, p. 28.). Precipitation recharge represents the portion of total precipitation that recharges the ground water. Methodology as described in Boyle (1995).
b) Quantities of subsurface outflows at model boundaries differ to some extent because of differences in placement of model boundaries.

There are several significant differences between the USGS model representation and prior estimates of specific components of the water budget. Estimates of pumping in the Beaumont Storage Unit have been refined since 1995, as part of an ongoing effort on the part of the Agency to improve the accuracy of these estimates. Careful review of historic records of extractions, combined with increased reporting in recent years has improved the overall reliability of these estimates.

The locations of the lateral boundaries of the Beaumont Storage Unit as contained in the USGS model differ somewhat from those in earlier modeling As a result of this, refinements in the estimates of pumping, and differences in the way in which boundary conditions are represented, values of pumping supplied to the USGS model differ from those supplied to the earlier, Boyle model.

Recharge from deep percolation of rainfall is treated in the USGS model as a constant value over the simulation period. Recharge from rainfall is modeled as a constant value of 2,100 AF/Y. This represents about 8% of the total rainfall over the approximately 28 square mile basin. Recharge from streambed infiltration is estimated at about 3,000 AF/Y. The USGS estimates combined recharge from precipitation and streams at a constant 5,100 AF/Y. Boyle estimated this volume to be about 4,000 AF/Y. The USGS water budget estimates no subsurface boundary inflow, whereas Boyle estimated subsurface boundary inflow at about 3,400 AF/Y. Accordingly, Boyle's earlier estimate of natural inflow terms totaled about 7,400 AF/Y (4,000 AF/Y + 3,400 AF/Y).

Differences in estimated subsurface outflow are smaller: whereas Boyle estimates subsurface outflow at 3,000 AF/Y, the USGS model represents this at about 1,500 AF/Y. In both cases, subsurface outflow is exclusively across the southeast boundary of the Beaumont Storage Unit to the adjacent Banning Storage Unit.

A portion of the pumping returns to the aquifer (return flow) while the remaining amount is consumed. The Boyle analysis used a return flow of about 28 percent of total pumping, while the USGS model suggests a return flow of about 22 percent of total pumping. The USGS model includes a significant lag in time between the time water is applied and the time it effectively returns to the water table. Return flows are lagged between 10 years and 30 years, depending on where in the basin they occur. No such lag was included in the Boyle model.

The water budget analyses described above may be used to infer yield of the basin. Based upon the water budget analysis by Boyle, yield of the basin is estimated at about 6,100 AF/Y of total pumping, or about 4,400 AF/Y net pumping, using a return flow fraction of 28 percent. By contrast, the USGS model suggests a basin yield of about 4,600 AF/Y (total pumping) for a balanced water budget, where inflow = outflow. In the case of a balanced budget, inflow terms would include recharge from precipitation and streams (5,100 AF/Y) and return flows from pumping (22% of 4,600 = 1,000 AF/Y), while outflow terms would include pumping (4,600 AF/Y) and subsurface outflow (1,500 AF/Y).

The USGS model includes a significant delay in the timing of return flows. Return flows associated with a particular water use are lagged by as much as 30 years. As a result, the water budget constructed for the 1970 – 1979 period reflects return flows from pumping that occurred as much as 30 years prior. And, while basin-wide pumping has increased significantly since the earlier period, the 1970 - 1979 period model does not include the full amount of return flows resulting from those increases, principally water imported from pumping in the Banning Bench, Banning Canyon, and Edgar Canyon areas. It is estimated that an additional 500 AF/Y of return flows, over and above those estimated for the 1970 – 1979 period, will eventually accrue to the ground water. Assuming a return flow fraction of about 22 percent, this component of the water budget has the potential for increasing basin yield by about 600 AF/Y. Accordingly, basin yield may be in the range of 4,600 AF/Y to 5,200 AF/Y. Yield is estimated to be nearer the high end of this range (about 5,000 AF/Y) measured in terms of *total pumping*.

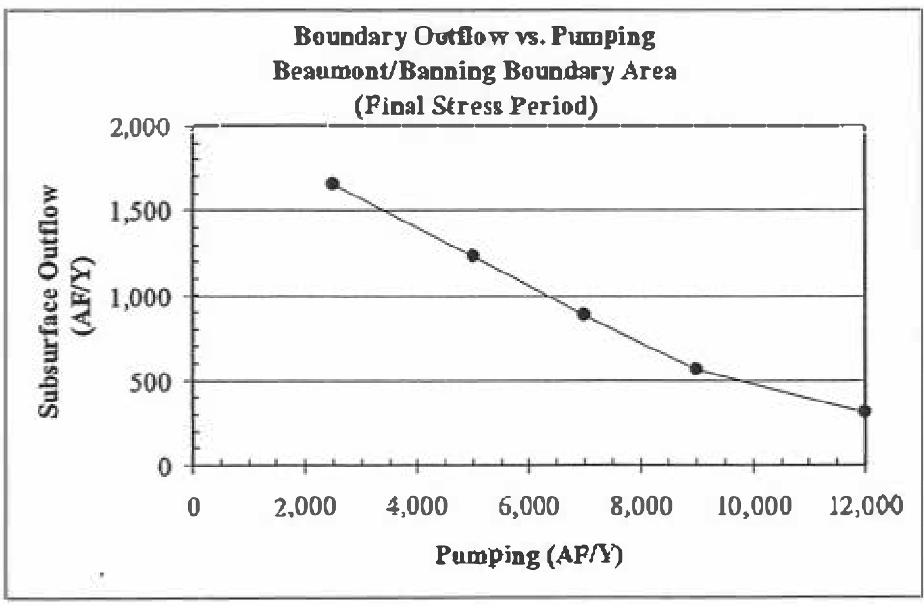
Modeling Results

The model was initially constructed as a two-layer model, and included the capability to "rewet" model cells. Cells can be "dried up" as a result of excessive pumping. With the rewetting capability activated, these cells are restored to active status once certain predefined water level conditions are satisfied. With the rewetting capability "turned off", once a cell dries up it remains so for the duration of the simulation.

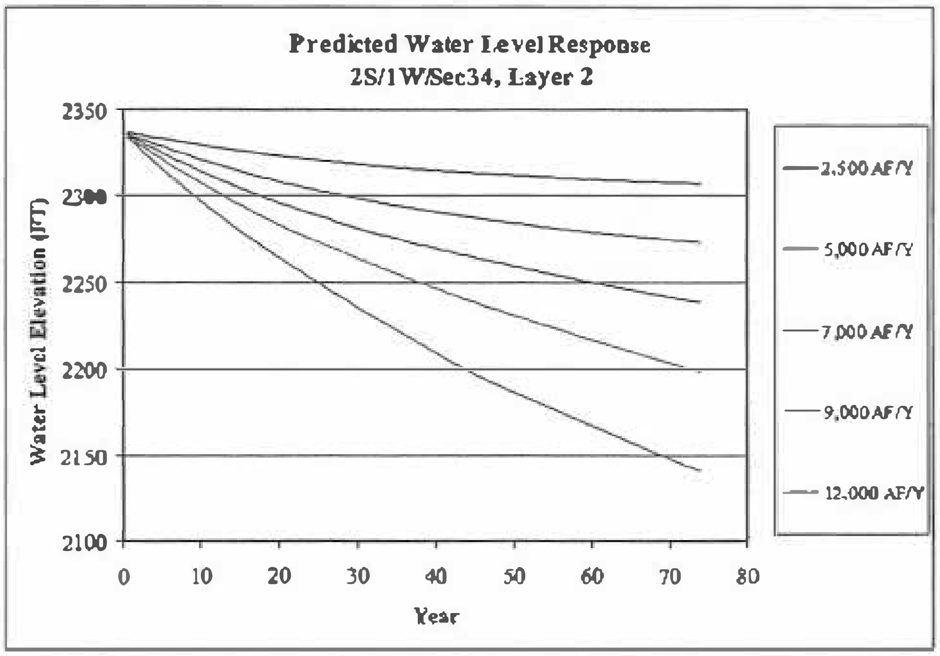
One consequence of this is that any pumping that was represented in that cell is "turned off" for the duration of the simulation.

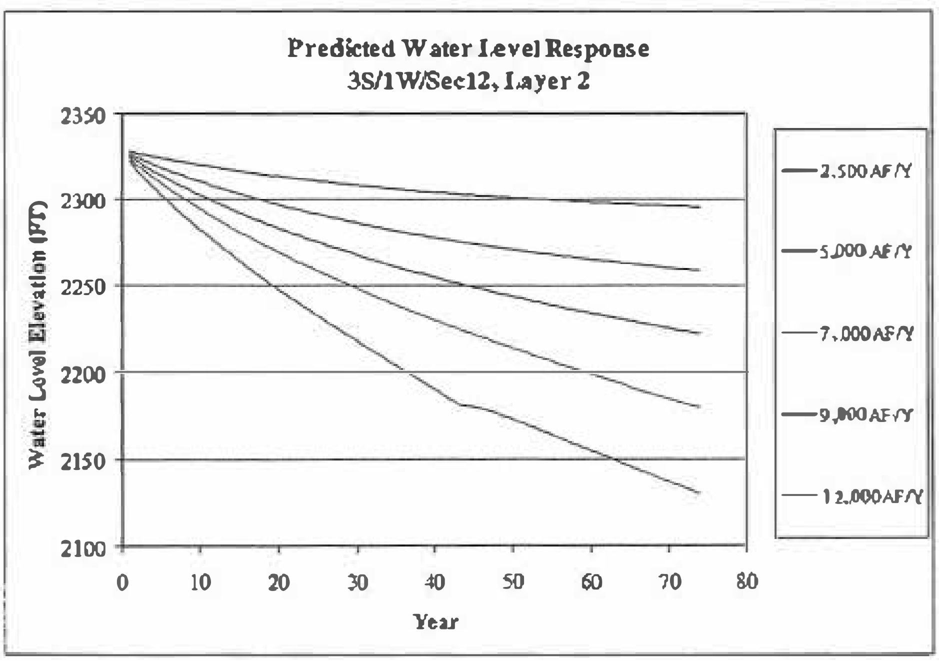
In the simulations listed above, the model's rewetting capability was activated at all rates with the exception of the 12,000 AF/Y extraction rate. The model failed to converge at the 12,000 AF/Y rate with the rewetting capability active, therefore this aspect of the modeling solution was deactivated. Although, there was some attempt at redistributing pumping to prevent drying up of cells, there was no attempt to optimize the distribution of pumping, to eliminate cells drying up. It was felt that such an attempt would impose unrealistic demands on how and where pumping would need to be distributed in the future. The instability in pumping at a rate of 12,000 AF/Y is interpreted as an indication that the basin is unable to support this level of extraction over an extended period.

The following graph shows the relationship between subsurface outflow from the Beaumont Storage Unit and the rate of pumping within the unit. As expected, subsurface outflow declines as the rate of pumping increases. The figure below also suggests that subsurface outflows cannot be effectively captured without pumping at rates that significantly exceed the yield of the basin. While it might be theoretically possible to strategically locate wells in such a way that much of the subsurface outflow is captured, there may be physical and legal access constraints that prevent this.



Ground water level response to the range of simulated extraction rates was taken as a measure of the balance between inflows and outflows. Relative long-term stability of water levels was viewed as an indication that basin inflows and outflows were approximately balanced. Long-term, persistent declines in water levels were taken as evidence that the sustainable yield of the basin had been exceeded. The following graphs illustrate model-predicted water levels for the range of extraction rates imposed on the basin at two locations, considered to be representative of water levels throughout the basin.





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Water level responses at an extraction rate of 12,000 AF/Y are influenced by a falloff in pumping as a consequence of model cells drying up. This is evident in the second graph (3S/1W/Sec12) just beyond the 40^{th} year of the simulation.

Ground water levels appear to be approaching a stable condition at extraction rates of 2,500 AF/Y. There is a slight continuing decline at 5,000 AF/Y. Water levels are declining rapidly at extraction rates of 7,000, 9,000 and 12,000 AF/Y. On the basis of water level response to the range of hypothetical extraction rates, basin yield is estimated at less than 5,000 AF/Y. However, as indicated earlier, water imported from Edgar Canyon, Banning Bench, and Banning Canyon for use within the Beaumont Storage Unit is not explicitly modeled in these simulations. Water from these sources is estimated to have averaged over 6,000 AF/Y since 1988. Assuming this trend continues, and assuming a return flow fraction of 22 percent, this represents an additional yield of about 1,400 AF/Y. Accordingly, basin yield is interpreted to be at or near about 5,000 AF/Y.

References

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