ASSESSMENT OF WATER ADDITION SCENARIOS
LAKE MERCED

May 2002

This memorandum provides an overview of an evaluation of scenarios involving water additions to Lake Merced which has evolved in two sets of scenarios: 1) planning level estimates of the volume of water that would need to be added at a particular flow rate to induce the lake level to rise in various increments; and 2) revision of the initial estimates to reflect seasonal restrictions in the availability of water which might be added to the Lake. The results of the evaluation are presented in terms of the induced impact above the ambient lake level caused by the added water. It should be emphasized that the scenarios are not intended to reflect a final conclusion or a recommendation regarding how fast water should be added, how high the lake level should be raised, or what sources of supplemental water should be targeted; rather, they are intended to provide a general understanding of the impact of adding water to Lake Merced at a particular rate and, in turn, the volume of water required to achieve and maintain a range of water levels above current or future ambient levels.

Evaluation Method

The Geo/Resource (1993) calibrated numerical ground-water flow model was adapted to develop estimates of lake response to the direct addition of water. The following are pertinent aspects related to the use of this model:

- used calibrated aquifer parameters (conductivity, storativity, leakance, thickness);
- used same pumping as in the calibrated model (i.e., from the 1990 stress period of the calibrated model);
- used same recharge as in the calibrated model except for the area of the Lake where recharge was increased to simulate the addition of water to the Lake (here, additional recharge was added to the simulated North and South Lakes, but not to Impound Lake);
- North and South Lakes are “connected” as in the calibrated model;

- the Lake is represented by high conductivity cells and no lakebed resistance;
- ten-day time steps were used to model shorter term behavior than the calibrated model, which has annual time steps (pumping and recharge, except at the lake, remained constant during the simulation period of 360 days);

In contrast to Geo/Resource's simulation of the short-term effects of adding water to Lake Merced, which was by "instantaneously" raising the lake level by four feet, the recharge package was used in the scenarios in this analysis to continuously add water to the Lake over a period of time. This model was used to examine the magnitude of lake level impact at specified rates of water addition; it was also used to examine the rates of water addition required to maintain the lake level impact once those levels were achieved by the initial rate of water addition. For the two generalized scenarios evaluated in this memorandum, water was either added continuously for the entire prediction period (360 days) or for a shorter period (180 days), the latter to reflect potential constraints on water availability.

Model Assumptions and Limitations

Notable assumptions and limitations of the Geo/Resource model, as used for this purpose, include the following:

- North and South Lakes are completely connected in the model, so added water is spread over larger area resulting in a smaller simulated impact than would be the case if the water was all added to South Lake (as has been the case in previous actual water additions);
- The model does not reflect lake bathymetry (in the model, lake cells have vertical "walls" and constant perimeter; however, in the actual setting, the amount of water needed to raise the elevation of the lake surface will vary with its water level);
- The modeled impacts do not include seasonal fluctuations (typically 1-1/2 to 3 feet) or longer term trends (typically less than 1/ 2 ft/yr up to 2-1/2 ft/yr) in lake levels due to extended (i.e., multiple years) weather patterns and, therefore, it is necessary to consider the predicted impacts as approximately additive to fluctuations that will otherwise occur;
- There is no lakebed resistance in the model (i.e., the model does not reflect any degree of clogging of the sides or bottom of Lake Merced); this may contribute to an underestimate of lake level impact or an overestimate of how fast water leaks out at a given lake level.

While the preceding factors may limit the absolute precision of the model simulations, the results achieved under these assumptions and limitations should be sufficiently accurate in terms of rate and volume to provide the desired general reference with respect to lake level response to the direct addition of water.

Continuous Water Additions (360 days)

For the initial estimates, water was added at a rate of 5 mgd. This rate was chosen for two reasons: it corresponds to the actual rate of water addition in 1994, and it reflects the capacity limits of the existing piping infrastructure to deliver water to Lake Merced. It should be reminded that similar lake level impacts could also be achieved at higher or lower rates, depending on a number of factors including availability of water, delivery capacity of infrastructure, impacts of shoreline inundation, etc. Ultimately, however, once a particular impact is achieved, a lower sustaining rate, as described below, could be implemented to maintain that water level impact.

Multiple scenarios were simulated to examine lake level impacts of 2 feet, 4 feet, 6 feet, and 8 feet. After determination of the time required to achieve each of those lake level impacts, the rate of adding water was reduced to a rate that would approximately maintain the impact (it should be emphasized that the lake level would continue to fluctuate due to other factors, such as seasonal ground-water level fluctuations or longer term trends, while the impact of the water addition would be approximately constant at the sustaining rate). The simulation results are shown on Figure 1 of lake level impact vs. time for a 360-day period; the results are also summarized in the following table.

Supplemental Water Requirements
to Achieve Discrete Lake Level Impacts
With Continuous Water Addition

Lake Level Impact (feet)	Time to Complete Lake Impact at 5 mgd (days)	Sustaining Rate to Maintain Lake Level Impact (mgd)	Total Volume Added to Lake in First Year (acre-feet)
2	40	0.25	860
4	80	0.50	1,655
6	130	0.75	2,525
8	190	1.00	3,435

The preceding table is organized to show, for selected impacts in lake level (e.g., 2 feet, 4 feet, etc.), the time required to fill Lake Merced and increase its level by each selected amount, at an assumed rate of 5 mgd. At the end of that time period, assuming that it is then desirable to maintain whatever lake impact increase has been achieved, the table also shows the rate of supplemental water addition that would be required to sustain the increased level. The total volume of added water over the first year of supplemental water addition is then presented at the end of the preceding table. For example, assuming that water is added at a rate of 5 mgd, it would take about 80 days to achieve a four-foot impact in lake level; once that impact was achieved, it could be maintained by reducing the rate of supplemental water addition to about 0.5 mgd. Under such a scenario, the total water added to Lake Merced at the end of the first year would be about 1,655 acre-feet (5 mgd for 80 days, followed by 0.5 mgd for 280 days).

For any subsequent year, less water would need to be added on an annual basis since there is a residual impact from the preceding year. That amount can be estimated from the sustaining rate multiplied by 360 days; so, for the scenario where a four-foot impact is being maintained through a second year, the additional water required in the second year would be about 0.5 mgd for 360 days, or about 550 acre-feet. Though there are greater uncertainties for the longer time periods, the analysis points to an important principle regarding a diminished rate and volume needed to sustain the lake impacts once an initial impact is created (here, the initial impact is created by adding water initially at 5 mgd).

As noted earlier, the predictions of impacts on Lake Merced from water additions do not take into account seasonal fluctuations or long-term trends in lake levels due to other factors such as variations in precipitation, evaporation, or other flows into or out of the Lakes, which will occur to somewhat independently of any impact of water additions. Thus, it is important to note that the water addition scenarios represent impacts that would be superimposed onto a fluctuating lake system. If that system is exhibiting a trend of either rising or falling water level elevations, the amount of water added may need to be adjusted if the objective is to maintain a target level.

Intermittent Water Additions (180 Days)

Subsequent to completion of the preceding initial estimates, and after some further consideration of possible supplemental water availability, at least in the short term, a second set of scenarios was crafted to examine the potential benefit to the lake level under a constrained supplemental water supply. In this case, based on general expectations that supplemental water availability could be limited at certain times, the conditions and scenarios described above were re-analyzed with the constraint that supplemental water would only be available for six months during the year; e.g., from October through March, inclusive.

For runs using the six-month water addition constraint, the model was extended an additional six full months after water addition was halted. In other words, water was added at 5 mgd, for periods up to six months duration, to achieve the same two, four, six, or eight feet of lake level impact described under the previous scenarios. After achieving the target lake level impact (e.g. 2 feet, 4 feet, etc.), the rate of water addition was reduced to a sustaining rate that would maintain the achieved impact; however, in contrast to the initial estimates described above where supplemental water was assumed to be continuously available, water additions for scenarios in this case were completely stopped after six months, and the lake system was allowed to decline without addition of water over the next six months.

The simulation results for intermittent water addition are shown on Figure 2 of lake level impact versus time for a 360 day period that includes both the 180 day addition of supplemental water and the subsequent 180 day period of no water addition. The results are also summarized in the following table:

Supplemental Water Requirements to Achieve Discrete Lake Level Impacts with Intermittent Water Addition

Time (days)	Lake Level Impact at 5 mgd (feet)	Sustaining Rate to Maintain Lake Level Impact [1] (mgd)	Total Volume Added to Lake in First Year [2] (acre-feet)
40	2	0.25	720
80	4	0.50	1,380
130	6	0.75	2,110
180	7.5	n/a [3]	2,765

Notes: 1. Rate to sustain lake level impact over balance of 180 day period.
2. Volume added over 180 day period of available water.
3. Lake would continuously fill over 180 day period of available water; consequently, no sustaining period.

Similar to Figure 1, which illustrates the impacts of continuous water addition, Figure 2 illustrates that water level impacts up to about 7.5 feet can be achieved within 180 days at a supplemental water addition rate of 5 mgd. Smaller impacts, e.g. 2 feet, 4 feet, 6 feet, can be achieved in less than 180 days at a 5 mgd rate; and a smaller sustaining rate can be used to keep the Lake at one of those levels for the remaining part of the 180-day period. Note that the full 8-foot impact cannot quite be achieved in 180 days at a 5 mgd water addition rate; the lake would increase nearly 8 feet by the end of 180 days and therefore no sustaining rate of water addition would be applicable for this scenario.

Figure 2 also shows the rate and result of the decline in lake level as a result of no water additions for the balance of the year after adding water for 180 days (i.e., no sustaining additions after 180 days). For example, 2 feet of impact, achieved in 40 days at 5 mgd and sustained for 140 days at 0.25 mgd, would decline by about 0.5 feet over the subsequent 180-day period of no water addition. Similarly, the 4-foot impact would decline by about 1 foot; the 6-foot impact would decline by about 1.5 feet; and the 7.5-foot impact would decline nearly 2 feet. For all scenarios, however, the Lake would experience a net positive level impact at the end of a full year, despite the restriction of supplemental water addition to the first half of the year.

Possible Future Refinements

Further refinement of the short-term model, such as calibration against previous water additions to Lake Merced, does not appear to be justified due the inability to simulate seasonal fluctuations. If, in the future, improved short-term estimates and longer-term (i.e., multiple year) simulations are needed, it is recommended that data be collected during and after a "pilot" addition of water to Lake Merced using the existing water level monitoring network (Lakes and wells). This data could then be used to calibrate an appropriate model. However, such as a modeling tool might be desired for some purpose at that time, it should be developed with the following features:

- ability to simulate seasonal fluctuations;
- the Lake as part of a basin-wide model;
- incorporate lakebed resistance;
- incorporate lake bathymetry.

As a final point, predictions using the Geo/Resource model beyond a period of about one year were not performed due to uncertainty regarding model boundary conditions. While there is confidence that the estimated impacts to Lake Merced during the initial water addition are useful for planning purposes, the model may be somewhat limited at longer times, especially as impacts propagate to the model boundaries.

It should be apparent from the two cases presented above that there is a residual benefit of water addition in the form of increased lake elevation after 360 days. For the case where water additions occur year-round, it would follow that the rate and total volume of water added in the second year would be significantly less than the first year, which had a period in which water was initially added at 5 mgd. For the second case, where water is assumed to be available for only 180 days during a given year, the lake system is higher at the start of the second year (at the time when water can be added again), meaning that the period during which water would need to be added at 5 mgd, in order to reach a target elevation, would be shorter than the preceding year.

As stated earlier, the simulation runs do not consider other hydrological factors, such as variations in evaporation and precipitation, which also affect the level in Lake Merced. In short, it is felt that the Geo/Resource model provides a general estimate of the magnitude of potential benefits from direct water additions to Lake Merced. Lending confidence to the predictions and the approach is the approximate agreement in the results with observations of lake level impacts for past water additions (1978 and 1994). Furthermore, because the quantities of water added under the scenarios evaluated here represent a significant fraction of reported water budgets for the ground-water system (e.g., as estimated by Geo/Resource, 1993 and CH2MHILL, 1997), the use of direct water addition is seen as an effective means to creating change in the lake-aquifer system in the short term. The fate of that water and the long-term changes in the lake-aquifer system can only be assessed from careful field observations. Long-term management and actions related to Lake Merced and ground-water would be best addressed through a basin-wide model, as discussed in LSCE's March 2002 report, **Conceptualization of the Lake-Aquifer System, Westside Ground-Water Basins, San Francisco and San Mateo Counties**.

Conclusion

The preceding discussion of two general cases of supplemental water addition to Lake Merced, including several scenarios to examine a range of lake level impacts, is intended to provide a frame of reference for consideration of a potential mitigation measure; that is, direct supplemental water addition. The various parameters used in this evaluation (i.e., rates and periods of water addition, increments of lake level impact) are not intended to be interpreted as specific targets or recommendations. Rather, they are intended to illustrate that various lake level impacts, which are significant in magnitude, can be achieved and continuously, or intermittently, sustained. Variations from the parameters employed herein could be considered as well. Obviously, higher or lower rates of initial supplemental water addition would increase or decrease the rate and magnitude of lake level impact. However, once some desired impact is achieved, the rate of water addition to sustain it will be something less than the amount required to create the initial impact as in the scenarios discussed herein, i.e., up to 1.0 mgd to sustain as much as an 8-foot lake level impact. Ultimately, if water could be made available from a supplemental source at a rate up to 5 mgd, intermittent or continuous water additions could create an impact on the lake level that corresponded to some target level or range of lake levels up to about 8 feet above its ambient condition. At the same time, the rate of water addition could be varied, higher or lower, to offset natural variations in that ambient condition.

Figure 1

Lake Merced Elevation Impact
Direct Addition of Supplemental Water

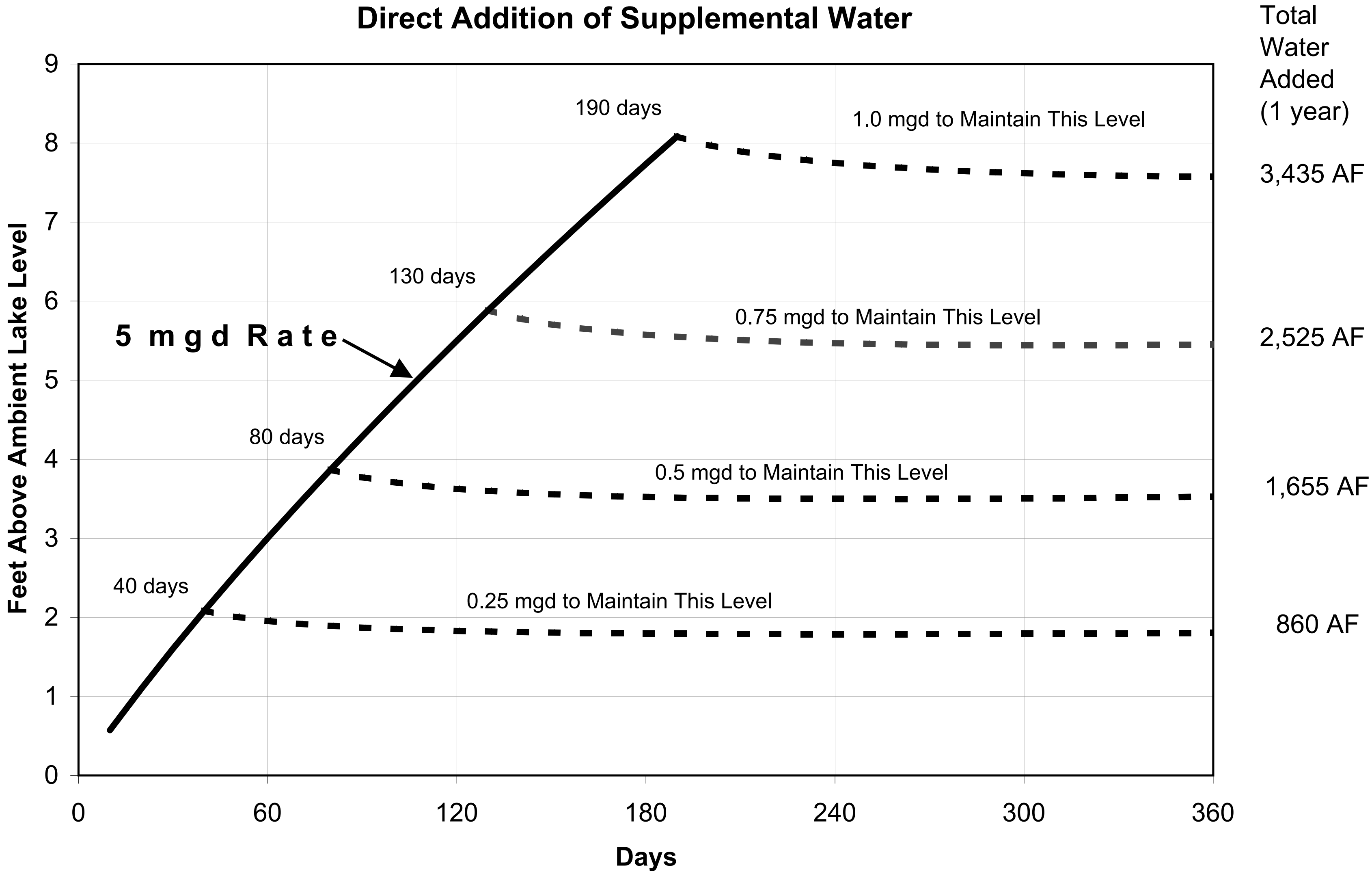

Figure 2

Lake Merced Elevation Impact
Direct Addition of Water - 180 Days