Clark County Sanitation District

Las Vegas, Nevada

April 1991

Lake Mead Eutrophication Model

Development and Provisional Calibration

Prepared by

Dan Szumski & Associates

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Clark County

Sanitation District

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June 12, 1991

TRUSTEES' BRIEFING REPORT

SUBJECT: DEVELOPMENT AND CALIBRATION OF THE LAKE MEAD EUTROPHICATION MODEL

For the past two years the District has been jointly working with the cities of Henderson and Las Vegas on Water Quality Studies in Lake Mead. The District's efforts were primarily directed at the development of a eutrophication model that would provide a better understanding of the effect of wastewater discharges on Lake Mead.

The District and its consultant, Dan Szumski, selected the U.S. Environmental Protection Agency's WASP4 modeling program after careful review of its performance in situations similar to that which exist in Lake Mead. The model program choices have been endorsed by the Nevada Division of Environmental Protection, U.S. EPA Region IX and the Water Quality Study peer review consultant Victor Bierman, Ph.S., Limno-Tech, Incorporated.

The model is similar in many ways to the WRMI model which the Water District is using as an analytical tool to predict future water demand and delivery system constraints. Planners input water demands based on housing and socioeconomic data, water conservation and total water resources. Similarly, the Las Vegas Bay Eutrophication Model is a complex set of equations that describe water volumes, water movements and various biochemical processes that take place in Las Vegas Bay.

Inputs to the eutrophication model included the flows in Las Vegas Wash and the Colorado River, treated wastewater loading from the City and District treatment plants, water storage and releases from Lake Mead, and some environmental and meteorological information. The model then computes the concentrations of pollutants, algae and nutrients that are expected from the set of inputs.

This modeling method, which has been successfully used in hundreds of locations nationwide, has proven to be a very cost-effective way to specify waste load reductions necessary to achieve compliance with water quality standards.

The end product of the work currently completed is referred to as a model calibration. It is a test of the model's credibility whereby historical data is input. The model's calculations are then compared with actual observations obtained from an extensive field and laboratory data collection effort conducted by the District during 1988 and 1989. The calibration shows that the model can effectively predict conditions in Lake Mead.

There were some important conclusions from the work completed thus far:

1. The model shows that there has been a shift in species from the 1979-80 algae blooms of phosphorus rich green algae to a species now present in the lake that appears to have very sparse nutrient requirements. This is a direct result of the City and District's phosphorus removal programs.

2. Dissolved oxygen concentrations in the lake's bottom layer (hypolimnion) are approaching zero milligrams per liter during early fall. Stabilization of ammonia from the treatment plants and the decay of phytoplankton are major contributors to this problem. Sediment study results show that additional phosphorus releases from the sediments only serve to exacerbate late summer algae blooms, which frequently exceed state water quality standards by a factor of 4.

3. Un-ionized ammonia nitrogen concentrations in Las Vegas Bay frequently exceed State standards by a factor of 10. However, the fishery study, conducted by the City of Las Vegas as part of the Water Quality Study, indicated no significant adverse impacts on fish due to the ammonia exposure. There appears to be a problem with the EPA ammonia criteria for surface waters.

The next and final step in the model development process will be its testing and validation. This will take approximately six months to complete and will cost about $110,000.00. The State recommends that the Water Quality Study group continue its modeling efforts so that a calibrated and valid analytical tool can be used for the triennial review of the water quality standard mandated by the Federal Clean Water Act. Staff anticipates submitting a request for Board consideration in August to complete the development of this modeling effort.

E. James Gans

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CHAPTER I

EXECUTIVE SUMMARY AND CONCLUSIONS

A. INTRODUCTION

The purpose of the WQS study was to develop and test a mathematical model of phytoplankton-nutrient relationships in Las Vegas Bay and the contiguous waters of Lake Mead. In this way CCSD plans to gain an understanding of cause-effect mechanisms in Las Vegas Bay, and specifically, an understanding of the extent to which the effects of existing wastewater discharges can be mitigated to achieve water quality standards, and the water uses that they protect.

Water quality attainment in Las Vegas Bay was studied early in the WQS program design, and incorporated into a work plan that can be summarized as follows:

Array applicable water quality standards and identify interferences with legitimate water uses;

Select the most appropriate water quality model for analyzing Las Vegas Bay;

Plan and conduct necessary water quality monitoring of Lake Mead;

Develop and calibrate a water quality model capable of analyzing the water quality condition in Lake Mead;

Test the model's sensitivity to inputs and assumptions;

Make assessments of allowable treated wastewater loadings to Las Vegas Bay.

This document is the final report of studies conducted in response to the fourth item of the work plan, model development and calibration. Nevada Division of Environmental Protection's (NDEP) deadline for an initial assessment of Las Vegas Bay water quality and recommended alternatives to the waste load allocation is June 30, 1991.

Chapter I is divided into two parts. Part A is an executive summary of the study's conclusions and recommendations. It provides concise descriptions of immediate and longer term modeling needs. Part B is a summary of the study's methods and results. The remaining chapters of this report provide the detailed technical backup for information contained in this chapter.

B. WQS Conclusions and Recommendations

The WQS has at this point developed and begun testing a Eutrophication Model of Lake Mead and Las Vegas Bay. From this process emerge insights into the data set and an understanding of mechanisms occurring in the Lake and in the Wash, which it becomes the modeler's responsibility to report. This section of the report presents some of this study's more significant conclusions, and highlights areas where study results suggest that the District consider taking action.

1. THE MODEL

The understanding of the physical system that encompasses Lake Mead's Boulder Basin, Las Vegas Bay, and Las Vegas Wash has advanced in several areas where the model required specific data. Most notable among these were:

studies of Lake currents,

vertical temperature and conductivity profiles

bathymetry surveys of Inner Las Vegas Bay, and

field surveys and modeling of time-of-travel
within the Wash.

This and other information is initially brought together in the transport calibration. The calibration process tests the model's ability to track the distribution of conservative substances such as chloride and Total Dissolved Solids (TDS) against field data. A review of the model's components and testing include the following:

The model consists of three vertical layers that exhibit identifiable patterns in their loadings and quality characteristics. The layers correspond to vertical temperature gradients in the Lake. The model has shown the gradient to be weak in the Inner Bay (Stations LM02 & LM03), and becoming stronger in the direction of Boulder Basin.

The model has six distinct transport fields. These appear to be fairly well represented in the model as borne out by the calibration results, particularly within Inner Las Vegas Bay. Uncertainty in the flow balance within the Inner Bay's meta- and hypoliminon layers (segments 17-10-18), appears to be causing an underestimation of conservative tracers and nutrient forms during the fall of both 1988 and 1989. While it is important to solve this problem, its presence in the model does not preclude immediate efforts to provisionally calibrate the eutrophication kinetics. This is because the anomaly only occurs following critical growth periods.

The two principal loads to the model are Las Vegas Wash and the Colorado River. Although the Wash represents only a few percent of the total TDS and chloride load, it tends to dominate concentrations in Inner and Middle Las Vegas Bay. Calibrations show that in 1979-80 the Bay is loaded in its metalimnion layer, with plume 'leakage' to the surface layer. In the 1988-89 calibration there is a combination of 'leakage' to the epilimnion and direct loading to the hypolimnion. Since the Wash is the primary source of concentrated nutrient loading to the eutrophication model, the amount of 'leakage' and the vertical loading patterns in the Bay are very important.

Computed and observed tracer profiles tend toward high initial concentrations in the metalimnion layer within the Inner Bay. These concentrations rapidly diminish in the direction of Boulder Basin reaching background concentrations in the region of Station LM06.

Stratification/de-stratification patterns, primarily within Inner and Middle Bay, appear to be responsible for sharp temporal gradients in chloride and TDS concentration. When the system is stratified, metalimnion and hypolimnion segments that receive Wash loads tend to exhibit high concentrations. These diminish rapidly in periods of destratification when the Lake mixes in its vertical dimension. From approximately November to May the Lake is completely mixed in the vertical, with very small longitudinal gradients.

The calibration has indicated most areas are within our understanding and the transport coefficients are good, yet there are at least two where our understanding is still uncertain:

> The first is the period surrounding the fall turnover when the model computes concentrations of tracer substances and effluent constituents that are unusual in each of two years. However, since the transport anomaly occurs after the peak phytoplankton growth period, it probably will not affect calibrations of the model's eutrophication kinetics.
>
> Second, the Las Vegas Wash flow distribution in the Bay's vertical dimension is still suspect. Segments 9-17 are questionable because the chloride calibration is insensitive to vertical distribution of Wash flow, even though it is expected to be sensitive to other Wash components such as nutrients and oxidizable organics. Also, the flow distribution uncertainties are possibly a contributing factor to the calibration inaccuracies during the fall overturn.

It is the recommendation of this study that solving the model's transport calibration problem during the fall be deferred pending completion of the more important tasks:

1) further calibration and testing the 1988-89 calibration, and

2) at least one more calibration of the model's transport and eutrophication kinetics.

If the transport anomaly in Inner Bay meta- and hypolimnion (segments 10 and 18) are not satisfactorily resolved within the next year or two, then the best method for determining the hydrodynamic changes occurring in Las Vegas Bay during the fall turnover is to measure them directly. To accomplish this, a dense local array consisting of 3 or 4 moorings should be placed to measure the phenomenon. The study should also include chloride measurements, continuous temperature and conductivity measurements, and wind data. Data analysis should focus on calculating vector averages at several time intervals to approximate average 1, 2, 3, 6, 12, 24 hours current vectors.

2. Segmentation

One of the more difficult problems encountered during model development was the shifting locations of sampling stations as Lake levels dropped in 1989. Stations LM02 and LM03 are identified by specific sounding depths. The way that the Lake Mead Eutrophication Model is constructed, the epilimnion and metalimnion ride on top of a hypolimnion that responds to changes in reservoir storage. There is a tendency to try to correct this aberration and "fix" the station locations, as is normally done. After considering arguments in favor of both positions, it is not clear that fixed station locations for LM02 and LM03 are preferable to the present Lagrangian locations. For example, it is difficult to imagine significant quantities of epilimnion or metalimnion waters crossing through the strong summer density gradient to the hypolimnion from which the Hoover Dam discharge occurs. Consider, for instance, that the early summer lake levels in 1989 fell at an average rate of 1.4 inches/day or 12 feet in five months. Fixed segments also have drawbacks such as disappearing segments and uncertain transport fields. At this time, the conceptual framework consisting of a floating upper two layers seems preferable to the fixed boundaries modelers normally deal with.

An analysis of Inner Bay geometry presently being conducted by the City's consultants may lend insights into continuity relationships as lake levels change. The existing sampling locations should be maintained until this issue is resolved. It is recommended that HDR's analysis of the bathymetry in Inner Las Vegas Bay should be completed. Particular attention should be given to changes in model volumes as lake levels drop between 1205.00 and 1190.00 feet above sea level.

3. Current Monitoring

The 1988-89 model calibration and preliminary modeling of 1979-80 conditions found that the Lake stratifies rapidly during the end of March and mid-April. Recurring periods of high vertical mixing appear in June of the three years where the measurements have been studied. This event appears to bring large quantities of inorganic nutrients to the surface just as water temperatures begin an approach to annual maximums, so it is an important influence on chlorophyll production. This is also the period during which the current monitoring contractor deployed and maintained the meters in Las Vegas Bay at his cost. The District should consider previewing this data to see if it provides insight into the recurring June mixing phenomena.

4. Statistical Tests

Statistical tests of the transport calibration indicate that our understanding of relevant advective and dispersive processes is good, particularly during the phytoplankton growth periods. The model scores well in both a Student 't' comparison of computed and observed monthly means and a weighted least squares regression of those quantities.

There is, however, one region in space-time where the calibration is poor by several standards. This occurs in both 1988 and 1989 from September through November in the meta- and hypo- limnion layers of model which are near the campgrounds on Las Vegas Bay (segments 10 and 18). The problem appears to be associated with the way that the model calculates the Lake's fall turnover, and more specifically, the mass and flow balance specifications around hypolimnion segment 18. This localization of the problem in segment 18 was recognized from a weighted least squares analysis of the calibration. It will be important to solve this problem once the transport and kinetic calibrations are farther advanced. For present purposes of getting the model fully tested and into preliminary planning projections, the 1988-89 transport calibration should be provisionally accepted with the understanding that the eutrophication calculation's sensitivity to this apparent problem must be continually assessed. In the present case, changing the January 1 boundary condition to the observed January values and rerunning the program has to be checked to insure that there are no significant impacts on the eutrophication calculations.

5. The Wetlands

The Wash and its contiguous wetlands were historically a significant portion of the Las Vegas Valley's wastewater treatment system. The Wash wetlands removed some phosphorous and more than half of the total nitrogen from the City and County secondary treated effluent during the 1970's. Headcutting during the 1980's has channelized and drained wetlands, eliminating between 5,000 and 8,000 pounds per day of total nitrogen removal capacity. Detention time was reduced from approximately 18 hours in 1979 to approximately 6 hours in 1985, and 5 hours during the WQS dye study.

As water supplies and waste load allocations become scarce in the Southwest, the potential for development of the Wash's treatment capacity provides the District with flexibility in the coming decades. With the possibility that funds may become available to address hydraulic capacity and flood control issues in the Wash, it seems prudent to review and comment on these and other project proposals, and discourage developments that reduce future off-line treatment capacity potential. Furthermore, the District might consider collecting quantitative information on the Wash for planning purposes. Over the next few years, this could include:

Summarize a best estimate of the Wash's present water budget.

Develop a deterministic temperature balance and adjusted water budget for the Wash.

Quantify a projected flow budget with and without the hydraulic capacity of off-channel marshes (realistic, pessimistic, and optimistic projections).

Estimate the marshes safe seasonal treatment capacities, its seasonally adjusted atmospheric losses (with methods for loss reductions), and its riparian flow requirements.

These are quantities that preliminary modeling of the Wash indicates are undetermined in any quantitative planning analysis of issues in Las Vegas Wash.

6. Phytoplankton and Nutrients

A comparison of historical phytoplankton data from 1979-80 with that collected as part of the WQS suggests that species shifts might have occurred over the period 1979-89 which could impact the direction of near term model calibration. The Lake Mead Eutrophication Model contains simulations of two phytoplankton groups:

First, a mixed phytoplankton population is responsible for the spring and early summer blooms that are light limited and are probably dominated by cryptophytes.

A second episode that this report calls a dinoflagellate bloom occurs in late summer. This bloom is characterized by large numbers of green algae, but has a biomass peak dominated by dinoflagellates. The model and data indicate that the bloom is phosphorous limited.

This contrasts with the 1979-80 condition where the summer biomass peak was dominated by green algae and cryptophytes.

There are several questions that must be asked at this juncture that could best be answered by an expert in Lake Mead algal populations or, more generally, a phytoplankton physiologist; someone who could look at the available reductions of the data and explain exactly what the model calibration is, or is not, telling us. For example, the dinoflagellates in the model have a nonexistent settling velocity Const(29)); also the ratios P:Chl-'a' and N:Chl-'a' (Const(64,101)) look low, and it may not be realistic to set the fraction particulate (Const(13)) to zero, etc.

This study recommends that the District take steps to arrange for perhaps a week of initial consultation by a qualified expert, with a brief letter report summarizing the conclusion of the meetings and data review.

7. Provisional Calibration

Two portions of the provisional calibration presented in this report are not well calibrated within the metalimnion and hypolimnion layers of the model: nitrate nitrogen and dissolved ortho-phosphate. In both cases, the model computes too much nutrient, presumably due to a combination of factors including the absence of a dissolved oxygen correction for denitrification rates. These are presumed to be due to the way that organics are segregated, settled, and mineralized in the model. These issues should be resolved prior to any allocation analysis with the model because it directly impacts inorganic nutrient concentrations, and thus, phytoplankton growth potential.

8. Dissolved Oxygen

The State has found that a low dissolved oxygen condition, frequently below 2.0 mg/l at stations LM04(h) and LM05(m,h) just prior to the fall turnover, is restricting a safe zone of passage between Inner Las Vegas Bay and Boulder Basin. If the conditions in the Bay restrict the zone of passage and it becomes necessary for the fish to migrate out of the area, then some of the fish will suffer the adverse consequences.

The WQS review of historical data found that dissolved oxygen conditions at station LM05 meta- and hypolimnions are dropping below 1.0 mg/l with the historical frequency in the metalimnion of approximately 1 week/3 years and in the hypolimnion of approximately 1 week/2 years). The dissolved oxygen calibration will explore the causes of this condition, and estimate the mg/l increment over background conditions caused by the Wash loads of carbonaceous and nitrogenous BOD_{ult}.

Studies being completed now suggest that there is a large difference in Las Vegas Bay sediment phosphorous release rates depending upon whether the overlying waters are aerobic or anaerobic. These results should be carefully checked and reviewed because of the implication that any future reductions in hypolimnion dissolved oxygen could have on phytoplankton and fishery populations. Scheduled reductions in oxidizable nitrogen at the District's facility to meet present NPDES permit requirements appear to be a constructive step toward minimizing the discharge of oxidizable loadings to this potentially productive region although the controls are being implemented to satisfy a waste load allocation for ammonia nitrogen.

9. UN-IONIZED AMMONIA

The WQS has not yet reached any conclusions regarding un-ionized ammonia issues in Las Vegas Bay. However, results of the WQS fishery studies find no significant adverse impacts coincident with concentrations of un-ionized ammonia, frequently exceeding the standard by a factor of 10 and suggest that there is a problem with the criteria, not the fish. The District should consider supporting continuing efforts by the City to have EPA conduct a thorough technical review of the 'water effect' in ammonia toxicity testing.

10 PEER REVIEW

The independent peer review element of the present study has been and continues to be an asset to the model development task. The District should continue to consider this an integral part of the modeling process. In addition, it is recommended that the District make it a policy that contractors and others who provide research data for use in the model publish their data and conclusions in a peer review journal or other peer review forum. This will document the peer review process for our successors.

11 The Final Word

The Lake Mead Eutrophication Model is a process, and as you read this you are potentially a part of that process. Every effort has been made during its planning, development, and review to keep information as up to date and as public as possible in the hope that this atmosphere would maximize the opportunity for constructive technical inputs. It has. Now the maintenance and refinement of the model must be planned and attended to. Periodically, the model has to have its calibration updated or extended, using both historical and recent data sets.

Everyone's best interests are ultimately served by a better model and a better allocation. The ongoing modeling process involving the District, the City, and the regulatory agencies in the calibration efforts has been successful so far and is still believed to be the best way to achieve water quality goals for Las Vegas Bay. This cooperative effort should be continued.