Panama Lakes Water Quality Modeling Study

Estudio del Modelo de Calidad de Agua de Lagos de Panamá

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Abstracto, Resumen y Recomendaciones

ABSTRACT: The Panama Canal Authority operates the Panama Canal that connects the Atlantic and Pacific Oceans across the isthmus of Panama allowing for the passage of ocean-going vessels. The canal has a length of 80 km and is capable of traversing vessels up to 294 m long with maximum drafts of 12 m. Most portions of the canal are above sea level in a man-made reservoir, Gatun lake. The Canal, its associated reservoirs, and the lands adjacent to them are administered by the Panama Canal Authority (ACP). ACP is currently investigating the feasibility of expanding the canal system by constructing additional reservoirs to increase water availability for navigation. Currently, Gatun Lake and Lake Madden produce adequate quantities of water for navigation, power generation, and water supply. However, there is concern that an increase in the number of ships using the Canal in the future, coupled with drier conditions, could result in situations where there is inadequate water for canal operations. ACP is studying up to three new reservoirs to the west of Gatun Lake. The reservoirs of the western watershed are Río Indio, Caňo Sucio, and Coclé del Norte (or Toabré). Waters from these reservoirs would be transferred via channel and tunnel to Gatun Lake. The purpose of this study was to assess what the expected water quality would be in the proposed reservoirs of the western watershed and what might occur due to interbasin water transfers from the proposed reservoirs to Gatun Lake with respect to the existing water quality. This report discusses the modeling results and offers conclusions and recommendations on the various scenarios simulated.

8 Summary and Recommendations

Summary

Three reservoirs of the Panama Canal system, two existing and one proposed, were simulated using CE-QUAL-W2 for the purpose of assessing water quality impacts resulting from inter-basin transfers. Of specific concern was the impact that waters removed from the proposed Rio Indio reservoir via a tunnel would have upon water intakes when released into Gatun Lake.

CE-QUAL-W2, a two-dimensional, laterally averaged hydrodynamic and water quality model was selected as the model for performing this study based upon its capabilities for simulating reservoir operations. W2 allowed for representation of variations in water quality and currents in the longitudinal and vertical directions. A separate application of W2 was required for each reservoir. W2 was also set up for the proposed Coclé del Norte and Caño Sucio reservoirs but no simulation made. Although W2 utilizes a laterally averaged approach to modeling, it was the best choice for this study. W2 has features required to accurately simulate reservoir operations (intakes, density placed inflows, selective withdrawal) that are not found in three dimensional models developed for use in estuarine systems. Additional effort would be required to attempt to incorporate these features when there is currently no evidence that a three dimensional model is justified. In addition, a three dimensional model developed for this system based on the same data used for this W2 study would likely have produced no better results. W2 has been applied in approximately 400 water quality studies of reservoirs, lakes and estuaries. While Gatun Lake would be one of the larger reservoirs in areal extent simulated with W2, the irregular shape of Gatun Lake was captured by dividing the system into a number of branches which were similar in size to previous W2 applications.

Both Gatun Lake and Lake Madden were calibrated using a non-synoptic data set compiled from various sources and time periods. Seasonal averages of observed water column concentration data from a sampling study conducted for the years 1972-1974 were used to “calibrate” the model. Attempts to locate the original data were unsuccessful as the records of the original data had been destroyed. Separate calibrations for Gatun Lake and Lake Madden were accomplished using the previously mentioned seasonal observed data and a set of collection (seasonal, monthly, daily, synthetic) of flow and meteorological data. Model results were not perfect but, considering the lack of input information and the inconsistency between the forcing functions (meteorology and inflows) and the summary nature of the observations, the model calibration was deemed adequate for scenario testing.

A total of six W2 scenario simulations were made based upon the HEC-5 reservoir operation simulation results supplied by ACP. Four W2 simulations were made for the proposed Rio Indio reservoir and two for Gatun Lake. HEC-5 simulation results supplied by ACP provided the inflow, discharge, and water demand requirements for these scenarios. A four-year period selected from the HEC-5 simulation results supplied by ACP for use in these scenarios runs. The "lumped" information supplied by the HEC-5 output required some interpretation to assign it to appropriate inflows and discharges in W2. For example, HEC-5 reported inflows only as "local inflow" without regard to the source of the inflow. For W2, the "local inflow" had to be assigned to individual tributaries based upon relationships developed in this study.

Results of these scenarios indicated that water quality in the proposed Rio Indio reservoir as expressed by dissolved oxygen varied with the processes occurring in the reservoir. When the reservoir was being drawn down, either via inter-basin transfer or downstream discharge, the dissolved oxygen levels were higher. When the reservoir was being filled, undesirable low dissolved oxygen levels occurred in the bottom portions of the reservoir. These low dissolved oxygen episodes ended as soon as the reservoir started drawing down again. The reason for these low bottom water dissolved oxygen level was the sediment oxygen demand. Under filling conditions, there is less movement in the lower layers than there is when the reservoir is being drawn down. Consequently, there is less mixing and dilution of the lower dissolved oxygen water when the reservoirs are filling.

Single port and multi-port discharges were simulated for the proposed Rio Indio reservoir. These simulations were conducted to serve as a screening level assessment of the need for selective withdrawal. Single port withdrawals, whether for downstream discharge or inter-basin transfer, resulted in more water being withdrawn from the lower levels which aided in the mixing and dilution of the low dissolved oxygen by entrainment of waters from overlying layers that had higher dissolved oxygen levels. The cause of the low dissolved oxygen water in the lower layers was the sediment oxygen demand. When multi-port withdrawals were used, there was less mixing of the low dissolved oxygen waters. This resulted in the dissolved oxygen levels in the lower layers of the reservoir decreasing.

Multi-port discharges at the dam would be of benefit during period when the reservoir is being filled and the only discharge are the regulatory flows. Dissolved oxygen levels at the 12 m port for downstream releases tended to be very low during this period. Without the ability to with draw from other layers or some form of mechanical reaeration, this situation could result in the release of low dissolved oxygen water which could have detriment effects downstream. During the four year simulation, dissolved oxygen levels dropped to near 0 mg/l during the first year and below 2 mg/l for periods of the remaining years. Under such conditions, sediment releases of reduced metals could occur. Waters containing these metals, when oxygenated by passage through the dam, would precipitate metals in the channels downstream of the dam

The need of multi-port intakes for the inter-basin transfer tunnel is less dramatic. Results indicate little variation between the conditions at the tunnel intake site for the four scenarios performed. In actuality, the worse dissolved oxygen conditions occurred when the transfer flow was split between the three ports. Again this was due to there being less flow in the bottom layers which resulted in less vertical mixing. The anoxic conditions remained beneath the elevation of the lower tunnel intake. Dissolved oxygen levels increased when inter-basin transfers occurred due to the increased vertical mixing and movement of the waters. From this it appears that the critical condition will be when inter-basin transfers are commencing. After that initial "flush," the large flows will mix the reservoir and improve dissolved oxygen levels throughout the layers used for withdrawal.

Two scenarios were run for Gatun Lake, one in which a single port was used for the transfer flow intake and another in which three ports were used for the transfer tunnel intake, simulating the receipt of inter-basin transfers from Rio Indio reservoir. Results indicated little difference in the dissolved oxygen levels for the water intakes. This was expected for two reasons. One, the water quality of the tunnel discharge was similar whether single port or multi-port withdrawal was used at the tunnel intake. Second, all major intakes are far removed from the tunnel discharge site and are negligibly impacted by it. Only the intake at Escobal is on the same branch as the tunnel discharge site. It is located approximately 14 miles from the discharge site. Dissolved oxygen levels at the Escobal intake were high in both scenarios. No allowances were made in the Gatun scenarios for reaeration resulting from energy dissipation devices such as baffle blocks.

Recommendations

The following recommendations have been developed during the course of this study and are presented here as aids for further studies of the Panama Canal system.

a. Observed data. The data set used for this study was the best that was available at the time. Creation of an up to date database consisting of water column observations, tributary concentrations, and tributary inflows should be a top priority. Such a database would allow refinement of the models developed and increase the belief in the model's relevance. Observation of currents and collection of current/flow data in selected locations of Gatun Lake would aid in determining the occurrence and assessing the impact of non-uniform flows. The data base generated by this effort would enable ACP to improve the hydrodynamic and water quality simulation model developed in this task.

b. Watershed loads and conditions. ACP has indicated that the population along the Transithmian Highway has increased substantially in the years since the 1972-1974 water quality sampling study. Consequently, it is also felt that there is also an increase in loadings associated with this growth. Estimation of the impact of this growth upon the water of Gatun Lake, Lake Madden, and the proposed reservoir at Rio Indio requires a comprehensive approach consisting of sampling, hydrology, and application of watershed models to assess the loads reaching the tributaries and lakes.

c. Sediment processes. Scenarios for Rio Indio indicated the significance of good estimates for sediment oxygen demand. In the Rio Indio scenarios, anoxic and hypoxic bottom water conditions were observed. These conditions in the model are a result of the specified SOD rate and have a direct impact on the requirement for inter-basin selective withdrawal capability. The rate used was a conservative value. However, there is no information as to what the appropriate SOD ate should be. Soil samples should be collected at the proposed Rio Indio reservoir site and analyzed for SOD and sediment releases. Based upon these results, the scenarios for Rio Indio should be reassessed using the revised SOD rates.

d. Ongoing monitoring. A limited continuing sampling effort at key locations in the system will enable earlier detection of changes in water quality. The data collected would serve a "first warning" for water quality degradation. It would aid in the analysis of "cause and effect" of water quality problems. Development of a monitoring program would enable ACP to be pro-active when dealing with water quality problems instead of reactive.

e. Dam site selective withdrawal capability. The Rio Indio Reservoir simulations indicate the need for selective withdrawal at the dam site. During periods where only minimum flows were simulated, low dissolved oxygen conditions existed near the lower port simulated (12m). The ability to draw waters from different levels would enable waters of different qualities to be mixed thereby increasing the quality (as indicated by dissolved oxygen) in the receiving waters.

f. Tunnel intake selective withdrawal capability. The requirement for a multi-port structure to support selective withdrawal is less clear for the tunnel intake. In the simulation where the multi-port facility was tested, dissolved oxygen levels were higher in the tunnel water during certain periods of tunnel operation, generally when the first transfers occurred. The lowest DO level predicted at the tunnel intakes was 2.33 g/m^3 for the simulation using only one intake port for the tunnel inlet. For the simulation performed with the tunnel flow split between three inlets, the dissolved oxygen was 3.11 at that same time. This dissolved oxygen level value is heavily dependent upon sensitivity of the SOD value used. It can be said that the dissolved oxygen levels were higher during the first portion of inter-basin transfer for simulations using a multi-port tunnel intake. After the initial portion of inter-basin transfer, the additional mixing in Rio Indio resulting from the inter-basin transfer flows resulted in tunnel intake dissolved oxygen levels being similar for the single port and multi-port intake cases. No allowance was made in the simulations for reaeration at the tunnel outlet. These simulations should be revisited once better information on SOD rates are obtained.

g. Additional scenarios. Two sets of conditions were tested during this study for inter-basin transfer flow and those only differed in the type of tunnel intake used (single or multi-level). It would be desirable to simulate other periods than the 1951-1954 period to see the impact that differing water levels in Rio Indio Reservoir had on transfer flow water quality.