Tropical Lake Ecology Assessment with Emphasis on Changes in Salinity of Lakes

Evaluación Ecológica de Lagos Tropicales con Énfasis en Cambios en la Salinidad de Lagos

URS Holdings, Inc.

Abril del 2005

Resumen Ejecutivo

URS

Tropical Lake Ecology Assessment
With Emphasis on Changes in
Salinity of Lakes
Project No.SAA-140714
Executive Summary

Prepared for:
Panama Canal Authority

Prepared by:
URS Holdings, Inc.

Panama – April, 2005

TABLE OF CONTENTS

ES-1.0 INTRODUCTION 1

ES-2.0 REVIEW OF INTERNATIONAL SALINITY STANDARDS 1

ES-3.0 INVENTORY OF FLORA AND FAUNA 3

ES-4.0 PROPOSED SALINITY STANDARDS 5

ES-5.0 FLORA AND FAUNA MONITORING PLAN 5

ES-6.0 WATER QUALITY SAMPLING PLAN 6

ES-7.0 EVALUATION OF THE SALINITY INTRUSION MODEL 7

ES-8.0 DETERMINATION OF POTENTIAL IMPACT 9

ES-9.0 REVIEW OF PROPOSED MITIGATION MEASURES 11

ES-10.0 CONCLUSIONS 14

ES-1.0 INTRODUCTION

The Panama Canal Authority (ACP) is currently performing a series of studies to assess the feasibility of a new set of locks, alternative systems to raise and lower vessels, and upgrading the navigation channel to prepare a Master Plan for the Modernization and Expansion of the Canal. Part of these studies includes the analysis of risks to increase the salinity of the lakes Gatun and Miraflores. This may occur as a consequence of increased traffic and anticipated structural modifications, which include an additional set of locks to accommodate larger Post-Panamax vessels. Lake Gatun is adjacent to the locks on the Atlantic and Pacific sides of the Canal and Miraflores lake is adjacent to the locks on the Pacific side of the Canal.

Within this context, URS Holdings, Inc. (URS) was retained by ACP for the execution of the contract for the Tropical Lake Ecology Assessment with Emphasis on Changes in Salinity of Lakes. More specifically, under this agreement, URS shall recommend the maximum salinity levels, which may be tolerated in the lakes mentioned above. The salinity standards must consider the current procedures for treatment of potable water in Panama and must also maintain the biological integrity of freshwater ecosystems. The terms of reference specified the main topics to be addressed in this effort as follows:

- Review of international salinity standards;
- Compile an inventory of flora and fauna species;
- Propose salinity standards for Lakes Gatun and Miraflores;
- Propose a monitoring plan for flora and fauna;
- Propose a monitoring plan for salinity related water quality parameters;
- Evaluate the appropriateness of the salinity intrusion model;
- Determine the potential impacts that may be caused by the salinity intrusion in Lake Gatun; and
- Review of the Proposed Mitigation Measures to reduce the levels of salinity intrusion.

During the execution of the work, the procedures and results from each of these main topics were documented by independent technical memoranda (TM). This Executive Summary, presents an overview of each one of evaluated aspects.

ES-2.0 REVIEW OF INTERNATIONAL SALINITY STANDARDS

A literature review was conducted to identify existing salinity standards for potable uses and the protection of biological communities in other countries. The results are presented below.

Potable Water Standards

The parameters directly related to salinity are considered to be substances, which may lead to complaints by users, particularly due to the taste they give to the water. The World Health Organization (WHO) proposes as guideline value for chlorides 250 mg/l, and for total dissolved solids 1,000 mg/l.

The value for conductivity standards in the Latin American countries surveyed ranged between 400 and 1,600 uS/cm, with Costa Rica and Nicaragua exhibiting the lowest limits, and El Salvador the highest. Additionally, only 5 out of the 15 Latin American countries surveyed include conductivity as a parameter for potable water quality. In the case of chlorides, the values ranged between 250 and 600 mg/l, with 250 mg/L being the most common value (9 out of the 15 countries), as proposed by the WHO. Guatemala and the Dominican Republic reported the highest value (600 mg/l), and the remaining 4 countries reported values of 300, 350 and 400 mg/l. On the other hand, the value for total dissolved solids standards for Latin American countries ranged between 1,000 and 1,500 mg/l. Most countries (7 out of 11) reported a limit of 1,000 mg/l, as proposed by WHO. Three countries adopted as a limit for this parameter 1,500 mg/l, and El Salvador reported a value of 600 mg/l.

In North American countries, the European Union, and other countries of the world, the range of values for conductivity, chloride and total dissolved solids standards is similar to that listed for Latin American countries, with some exceptions. Amongst the exceptions we shall mention that conductivity standard in Germany is 2,000 uS/cm, and the total dissolved solids standard in Taiwan and Thailand is 500 mg/l.

Generally speaking, the standards evaluated for salinity-related parameters are similar throughout the world, and are consistent with guidelines set forth by the WHO. In addition, the chloride limits established by the various countries are driven mostly by a taste threshold rather than a health concern.

Biological Integrity Standards

URS performed a wide search for standards around the world in order to identify recommended limits for salinity in water, from the standpoint of protecting freshwater biological communities. Specifically, the review focused on standards that identified limits for the following parameters: conductivity, total dissolved solids, chlorides, and salinity.

Salinity or salinity-related parameters standards specifically drafted for conservation of biological integrity are very rare because different organisms respond differently to changes in

salinity. It is more common to have salinity standards for a specific body of water for which salinity intrusion is a concern. The following table summarizes the standards identified for the protection of aquatic life.

Table ES-1
Recommended Standards for the Protection of Aquatic Life

Parameters	Recommended Standards			
	ANZECC[1]	Malaysia	EPA	Florida
Conductivity (umhos/cm)	-	1000	-	1275
Total Dissolved Solids (mg/L)	-	-	-	-
Salinity (per thousand)	< 1	1	-	-
Chlorides (mg/L)	-	-	230	-

As may be seen from the table above, general salinity standards for the protection of aquatic organisms are scarce around the world. However, from these limited values certain similarities may be observed. For instance, conductivity standards for Florida and Malaysia, and salinity standards for ANZECC and Malaysia are similar. Also, the suggested value for chlorides by the EPA is lower than the typical value of 250 mg/l recommended for potable water.

ES-3.0 INVENTORY OF FLORA AND FAUNA

Published literature and consulting reports were reviewed to develop the inventory of flora and fauna. Over 90 different sources of information were identified and provided by ACP. After reviewing these and other sources of information identified by the URS team, the relevant species of flora and fauna were organized in tabular form and summarized in text and tables. In addition, the scientific names of species reported in older documents were updated to reflect changes in scientific taxonomy as a result of more recent findings.

Plant Species

The plant species identified in lakes Gatun, Miraflores and in the Panama Canal entrances were divided into three main groups: algae, aquatic macrophytes, and mangroves.

The Algae include species associated to freshwater and marine environments, which can be classified as micro-algae (freshwater and marine phytoplankton) and macro-algae that inhabit primarily marine environments. A total of 320 species of algae, distributed in 9 main taxonomic

[1] Australian and New Zealand Environment and Conservation Council

groups (Division), have been reported from the area under study (Gatun and Miraflores lakes and the Pacific and Atlantic Entrances of the canal). Most species belong to four major groups including 127 species of diatoms or Bacillariophyta, 96 species of green algae or Chlorophyta, 36 species of blue-green algae or Cyanophytas; 28 species of dinoflagellates or Dynophyta. The other five taxonomic groups are represented only by a few species, as follows: 15 species of red algae, or Rhodophytas, 8 species of golden-brown algae or Chrysophytas, 5 species of brown algae or Phaeophyta, 4 species of Euglenophyta, and only 1 species of Xanthophyta.

The aquatic macrophytes include submersed, emergent, and floating species as well as the flora associated to the border of lakes or marginal species. A total of 95 species of Macrophytes were reported for the study area, distributed in 4 main functional groups (marginal, emergent, floating, and submerged macrophytes). The largest number of species was recorded among the marginal group, which amounted to a total of 54 species. The remaining species were distributed as follows: 19 emergent species, 10 floating species , and 12 submerged species.

Finally, mangroves include the species from several taxonomic groups of plants. A total of 11 species were reported; with 4 of them found only at the Pacific entrance to the Canal. The remaining 7 species were found at both entrances to the Canal, ; with one of them also found at Lake Gatun (*Cassipourea elliptica* (Sw.) Poit.).

Animal Species

The species of fauna reported for Gatun and Miraflores lakes was made up of 114 and 44 species respectively; with 43 species being common to both lakes. At the Pacific and Atlantic Entrances of the Canal were reported 882 species, while 61 species were reported in the Gatun and Miraflores Locks.

The main groups reported for Lake Gatun included 50 species of aquatic insects of medical importance, 33 species of freshwater fish , 8 species of marine peripheral fishes, 11 species of large crustacean (shrimps and crabs) and 10 species of planktonic crustaceans, specifically three species of copepods and 7 species of cladocerans. At Lake Miraflores the main groups reported included 14 species of marine fish, 24 species of freshwater fish, 8 species of macro-crustaceans, and 10 species of planktonic crustaceans: six species of cladocerans, and 4 copepods.

ES-4.0 PROPOSED SALINITY STANDARDS

Based on the research of existing salinity standards, recommendations for Lake Gatun were made. In the case of Lake Gatun considerations were made both for maintaining this water body as high-quality source for drinking water and to protect aquatic species of flora and fauna.

The URS team considered appropriate to establish a maximum and an action level value for salinity in Lake Gatun. The action level value is the value at which a review of the entire set of control measures shall be prompted in order to make sure that the salinity levels in the system will not exceed the maximum value of the standard and will not cause significant unanticipated impacts. The maximum standard recommended is 500 mg/L for TDS, 769 uS/cm for conductivity, and 230 mg/L for Chloride ion. It should be noted that the 769-uS/cm value for conductivity corresponds to the existing conductivity-dissolved solids relationship (0.65), which was calculated from actual water quality data from Lake Gatun.

The value for the action level, at this time, is recommended to not exceed 50% of the maximum standard value. It is to say that the mean value for TDS shall be set at 250 mg/L, the mean value for conductivity shall be set at 385 uS/cm and the mean value for Chloride ion shall be set at 115 mg/L.

The above standards consider the multiple uses of the resource and are consistent with expected future uses as well as reviewed potable and biological standards.

ES-5.0 FLORA AND FAUNA MONITORING PLAN

Fourteen (14) sites were proposed for the monitoring of flora and fauna, 5 of these sampling points are in the main tributaries to Lake Gatun, the other 9 sampling points are located in the lake itself. Information from these sites will allow the establishment of a reliable baseline and the identification of long-term trends to facilitate the evaluation of possible changes in the diversity and structure of the biological community in response first to natural seasonal variations and second, in response to fluctuations in the salinity levels in the lake. Four (4) sites were proposed for Lake Miraflores, 2 in the main tributaries, and two in the lake itself.

The flora sampling plan was divided into two main portions, phytoplankton sampling and macrophytes sampling. For each main component the sampling and laboratory procedures, monitoring frequency, data presentation, analysis and reporting requirements were presented. The fauna sampling plan was divided into four main portions, zooplankton, benthos, fish and

macro invertebrates sampling. For each main component the sampling and laboratory procedures, monitoring frequency, data presentation and analysis and reporting requirements are presented.

A monitoring schedule was proposed as part of the plan. To understand the monitoring frequency proposed it is necessary to visualize the various stages or phases associated to the potential Panama Canal Expansion. For the purposes of the monitoring plan, the following phases were identified:

- **Baseline**. This corresponds to the start of the monitoring plan for a period of up to 2 years.
- **Pre-Construction**. This corresponds to the period after the baseline and before the start of construction activities.
- **Construction**. This corresponds to the period when construction activities would take place.
- **Operation**. This corresponds to the period following construction, when the lakes system could be influenced by an influx of saltwater.

Given that each phase of the project is unique, the required monitoring frequency may be different as the project moves forward. Two sampling events during the dry season and two during the wet season were proposed for the baseline and first year of operation. One sampling event per season was proposed for the pre-construction, construction and after the first year of operation.

ES-6.0 WATER QUALITY SAMPLING PLAN

Fourteen (14) sampling sites were proposed for Gatun Lake and two (2) for Miraflores Lake. The rationale behind the selection of these sites is to provide continuity with the data gathered in previous studies, as well as to provide sites that are representative of various geographic regions of the lakes.

To monitor water quality near the existing locks as well as near the proposed new locks, a grid system of sampling sites was suggested. A 9-point grid, spaced every 200 meters, was proposed just to the South of the existing Gatun Locks and a 7-point grid adequately spaced, was established just south of the entrance to the proposed new Post Panamax locks system in Lake Gatun. A 7-point grid, adequately spaced, was established just to the North of the existing Pedro Miguel Locks; and a 9-point grid system, spaced every 250 m, was established for the new

Pacific-side locks near Gaillard Cut. The sampling plan provides the basic requirements for sample collection, field measurements (including permanent stations and data logging requirements), laboratory analysis (included recommended parameters and analytical methods), sampling frequency, and report preparation.

A monitoring schedule was proposed as part of the plan, and the Phases of the canal expansion mentioned above were used as reference. Given that each phase of the project is unique, the required monitoring frequency may be different as the project moves forward. Two sampling events during the dry season and two during the wet season were proposed for the baseline and first year of operation. One sampling event per season was proposed for the pre-construction, construction and after the first year of operation.

ES-7.0 EVALUATION OF THE SALINITY INTRUSION MODEL

Present Conditions

URS conducted a review of seven reports, prepared by WL | Delft Hydraulics (Delft) under contract with ACP, to examine the modeling approach and results. These reports were completed between June 2003 and January 2005. In the model developed by Delft, a number of separate basins represent the lock chambers and the lakes. In addition, artificial basins have been created in the model to represent the section of the lakes and estuaries immediately adjacent to the upper and lower locks. These are called the "forebays" and "tailbays". They represent the portions of the lakes and estuaries that are so close to the locks that water discharged into them during locking operations can flow back into the adjacent lock chamber in a subsequence step of lock operation.

The selected approach included a volume-averaged Simulation Model, which allows for quantitative representation of the important aspects of lock operations during ship transits. It is not a precise tool as a more detailed three-dimensional hydrodynamic model could be. However, is the most effective approach for addressing most of questions and issues that need to be answered with respect to the present function of the locks and for predicting the effects of the envisioned Post-Panamax locks. The 3-D model would simply be enormously cumbersome to set-up and apply. It is important to point out that although this model may be appropriate to estimate the total amount of salt transported through the locks, it is not a good choice for analyzing the fate of salt water in the Gatun and Miraflores Lakes or the long approach channel that is envisioned where the third lane will bypass the Pedro Miguel Lock and Lake Miraflores.

Furthermore, it is important to understand the sources of inaccuracy associated with an analysis based on this model, even for the estimation of the total amount of salt that may be transported through the lock system. These primarily stem from the need to generalize important hydrodynamic processes and the need to ascribe patterns to the sequence of ships transiting the canal over periods of months or years.

From the point of view of hydrodynamic generalization, it is important to point out that empirical 'exchange coefficients' were estimated from data collected for this purpose and the modeler's understanding of the existing locks operation. Those coefficients were used to evaluate the fraction of the salt content of one lock basin that is transferred to the adjoining basin as the lock gates open and close. In actuality, the processes that cause this salt flux are a complex combination of individual mechanism and effects and the exchange coefficient quantifies the overall effect. However, the data show that there are different coefficients for different size ships and other variables such as the length of time the lock gates remain open. To avoid developing a huge population of exchange coefficients to cover all possible situations it is necessary to group the situations into general classes, with each coefficient being merely the best estimate of an average value with an inherent error. Because the ships do not neatly divide into discrete displacement intervals these coefficients are probably more in error for vessels with sizes close to the vessel classification boundaries. When simulations are conducted for 72 lock system transits per day over a period of simulated years the individual inaccuracies tend to accumulate into significant uncertainties. This is not necessarily a linear process wherein the inaccuracies add directly one upon the other. Instead, some add while others subtract leading to an increasing spread in the possible results. Such effects are best quantified with a formal error and sensitivity analysis.

The exchange coefficient issue becomes of even more concern when the Simulation Model is applied to predicting the salt-water intrusion in the envisioned Post-Panamax lock systems. This is because these locks will be unique in their scale and operation. There is no opportunity to take measurement of the salt fluxes that can be used to derive the exchange coefficients. Delft is well aware of this difficulty. In the reports covering the Post-Panamax situations they point out that the most reasonable analogs to these envisioned larger locks are the present ones. They recognize that there are significant differences such as the geometry of the approach sections, locations of the inlets and outlets within the lock chambers, etc. These could cause an unknown amount of difference between the present and future locks

Future Conditions

The analysis of the future conditions is subject to other assumptions as well. For example, it is assumed that the operation of the Post-Panamax locks will not change the discharges of freshwater at the Miraflores and Gatun dam spillways. Again, in the context of the present reports this is a reasonable assumption. Users of the model study reports need to be aware of these assumptions and how different the results would be if they prove to be unwarranted.

Another source of potential inaccuracy lies in the development of the ship traffic model scenarios and day patterns. Although these were provided by ACP on the basis of historical data and projected demand, in practice during the modeling, very little variability was introduced in the day-to-day (or simulated day-to-day) traffic. The day pattern that was used to validate the Simulation Model analysis of current conditions was fixed for a 'typical' day while the model simulated durations of years (ie. many hundreds of days). Exchange coefficients and other model parameters were changed during the validation of the model for current conditions until the observed and measured salinity patterns in the lakes were in reasonable agreement. There appears to have been no attempt to determine whether some of the differences between initial model results and the measurements could have been better explained by differences between the ship traffic as it was input into the model and the actual ship traffic.

However, it appears that the exchange coefficients for the lock operations were part of these adjustments during the validation phase of the analysis of current conditions. These may have been unknowingly passed along to the analyses of future conditions when the existing situation exchange coefficients were adopted for the future condition modeling. Considering all of the uncertainties associated with the modeling analyses of the future conditions this may, or may not have been a significant difficulty. Certainly users of the results should be aware of these concerns and this may be a subject that is worth revisiting in the future.

ES-8.0 DETERMINATION OF POTENTIAL IMPACT

A deterministic ecological model was used to identify and quantify the potential impacts from a possible increase in salinity levels in Gatun Lake. This model was based on the information developed in previous tasks of the project, primarily the inventory of flora and fauna.

The Model

The conceptual model was used to summarize what we know about the reservoir and to identify the main information gaps. The ecosystem diagram was prepared using the energy circuit language symbols (Figure ES-1), which have been used extensively for ecosystem diagramming

and modeling. The conceptual diagram of Gatun Lake (Figure ES-2) shows a somewhat aggregated food-web influenced by the flows of water and salt introduced as a result of the operation of the locks system.

This diagram indicates the main relationships of the ecosystem with the rest of the world, and between its main components. The diagram frame establishes the limit between the reservoir and the outside world. On the outside there are several forces, flows and switches, which directly affect what goes on in the ecosystem. Between the forcing functions we can mention solar radiation, atmospheric gases, wind, rain, runoff, the oceans, birds, and fishing. In addition the diagram depicts the decisions made by ACP, which control fluxes of water to pass ships, produce potable water, generate electricity, and maintain the water level in the lake under safe conditions.

Inside the reservoir we can see a complex matrix of physical and biological elements represented by the several energy circuit language symbols. Two big tanks represent the water and the sediments in Lake Gatun, with several sub-compartments. The big bullet shaped symbol represents the primary producers, the organisms that are able to take the energy of sunlight and convert and store it in the form of chemical energy in biomass. The hexagon shaped symbols represent several levels of consumers, which depend for their survival from the energy incorporated into the food web by producers upstream, classified according to their feeding habits.

The main biological processes occurring in the reservoir are primary production and respiration. **Primary producers** take a portion of the energy in solar radiation, transform it into chemical energy, and store it in the form of biomass through the process of photosynthesis. Primary producers present in the reservoir include phytoplankton species (large and small), periphyton species, submerged macrophytes (hydrilla), as well as floating and emergent aquatic plants. The biomass produced by these organisms is grazed directly by herbivores or the dead plant material flows as detritus.

Results

The Lake Gatun model was simulated using an EXCEL spreadsheet. The model was run for 2 years to make sure transient behaviors that are not seen in a single year simulation, are identified. The salinity effects were then simulated as an additional respiration or metabolic cost for dealing with the altered osmotic balance that increases linearly. Affected most by the increased salinity are the green algae and diatoms. The respiration of green algae was modeled to increase by 75% when the salinity is at 500 mg/l, while that of diatoms was increased by 72%. On the other hand, respiration of blue-green algae was increased only by 5%. Other organisms affected by the

increased salinity are cladocerans (22% higher respiration), copepods (9%) and primary consumers (5%). Benthic organisms and secondary and tertiary consumers are not affected by salinity in the model.

The results from these simulations show that the dominance from diatoms decreases and they become similar in importance to blue-green algae as salinity increases. Blue-green algae show marked increases in total biomass over the 2 year simulation both, at the 250 mg/l and the 500 mg/l model runs. All components of the ecosystem are affected by the increased salinity including those whose respiration is not directly augmented. Zooplankon compartments have higher amplitudes of fluctuation and there is a shift from cladocerans to copepods.

Primary consumers and benthic organisms decrease in total biomass primarily as a consequence of less production and food being available to them. Their decrease seems to be more dramatic than one would expect, but this is probably due to the fact that only the pelagic portion of the ecosystem is being modeled. Secondary and tertiary consumers are also affected but do not show the extreme changes seen in the lower trophic levels.

Even non living elements of the system show a change. Particularly interesting is the observed increase in phosphorus in the water column, which will have significant implications in the water quality in the lake. Although the change at the intermediate salinity level (250 mg/l) is not noticeable, when the salinity reaches 500 mg/l there is a significant trend to increased levels of phosphorous in the water column.

ES-9.0 REVIEW OF PROPOSED MITIGATION MEASURES

Delft also investigated the use of various saltwater intrusion mitigation measures, evaluated their individual effectiveness and cost, and made recommendations to the ACP for their inclusion into the numerical models. Potential mitigation systems were grouped in three categories:

Group A – Systems that would prevent the upward migration of salt water:

- System 1: Stepwise flushing of all lock chambers (dummy lockage)
- System 2: Flushing of the middle and upper lock chambers
- System 3: Flushing of the upper and lower lock chambers
- System 4: Enhanced flushing of the upper and lower lock chambers
- System 5: Intensive flushing of the upper lock chamber
- System 6: Exchange of salt water with fresh water in the lower lock chamber

Group B – Remove salt water that has passed the locks from the forebay or lake

System 7: Drainage of salt tongue through slit in the floor

System 8: Drainage of salt water from a salt water collecting pit

System 9: Drainage of salt water from a pit with perforated floor

Group C – Systems that prevent the upward migration of salt water or reduce the salt content of the lock chambers

System 10: Pneumatic barrier

A gradual review and screening process that involved ACP, Delft, and the Ministry of Public Works of Holland reduced the systems under consideration to four:

Mitigation System I – stepwise flushing of all lock chambers (dummy lock)
Mitigation System II – flushing of middle and upper lock chamber
Mitigation System III – flushing of salt water from pit
Mitigation System IV – pneumatic barrier at the entrance to the lower and upper lock chamber.

System I – Step-wise flushing of all lock chambers (dummy lockage).
This System consists of drawing water from Gatun Lake and progressively passing the lockage water downward through the upper, middle and lower lock levels, as in a normal downlockage. This introduces fresh water into the System and lowers the volume averaged salinity levels.

This system is the easiest and most straight forward to utilize. It does not require any additional costs. It would be used as a dummy lockage without the operation of water saving basins. Using the water savings basins increases the volume averaged salt water concentration and effectiveness in an individual chamber but reduces the amount of non-efficient water, water not used to transit a ship, required to perform the dummy lockage. Non-operation of the water saving basins increases the fresh water required to perform the dummy lockage but reduces the volume averaged level of salt water in each lock chamber. This would be sensitive to the water available in the Canal watershed and in wet years, with high fresh water availability, and low transit levels, would be the preferred option. No additional construction costs are involved; however this system may delay Canal transits especially at high levels of usage. This system would reduce the volume averaged salinity levels in each chamber by about one-third, being most effective in the lower chamber.

System II – Flushing of middle and upper lock chamber.

This System consists of lowering the level of the middle chamber to the low level of the lower chamber by passing the water through an additional valve to the tailbay. The upper chamber is then leveled to the low level of the middle chamber and fresh water is drawn in from Gatun Lake to establish the high level of the upper chamber.

This system is a variation of System I and is effective in reducing the volume averaged salt levels in the middle and upper chambers. The water with the lowest salt content is withdrawn and passed downward to the middle chamber. This System would not have an overall effectiveness as good as System I. The effect would be to reduce the level of salt concentration in the top two chambers by about one-third but have minimal effect on the highest concentration of salt water in the lowest chamber. The subsequent use of the water saving basins would reduce the effectiveness of this system.

System III – Flushing of salt water from pit

In this System, a pit would be constructed just outside of the upper lock and catch the salt water that has accumulated in the upper chamber when the gates are opened. The pit would then be drained through the floor using an auxiliary outlet system that would pass across the length of the lock chambers and discharge into the tailbay.

The pit would require an expensive structure on three sides, at depth, and ancillary facilities to discharge the water. Special attention would need to be made to possible navigation delays as the salt wedge would need to be almost completely drained out of the lock and pit prior to a ship moving over the pit and into the lock. The salt water would also have to be drained from the pit before a ship is passed over it in order to avoid the mixing action of the ship's propeller to have maximum effectiveness. This removes salt that has passed the three lock levels and does not have an overall significant effect on all three lock levels because of the low levels of accumulated salinity. This is more of a system safeguard and can be operated only when concentration of salt intruded water exceeds the permissible limits. Monitoring would be required.

System IV – Pneumatic barrier at the entrance to the lower lock.

This System consists of providing a pneumatic barrier (air curtain) at the entrance to the lower lock in the tailbay. Its function is to provide a medium that prevents the upstream movement of heavily laden salt (sea) water into the tailbay and lower lock chamber by setting up a circulating current. This current moves the water from the bottom to near the top of the surface and away from the lock. It also keeps the lesser laden salt water in the tailbay and lower lock chamber. The

discharge from the lock operation moves lesser laden salt water into the tailbay and ocean channel.

This is a system that is expensive to operate and maintain but in combination with another correctly chosen system, may have a very high degree of effectiveness. The Canal locks have a benefit in that they pass the water downward. The discharge from the bottom lock chamber empties into the tailbay and drives the salt laden sea water to a distance from the bottom lock entrance depending on the intensity of the transit operations. As long as the discharge is regular, the sea water is kept at a distance from the entrance. A pneumatic curtain would be beneficial in maintaining the sea water at a distance from the lock entrance and could possibly be operated part time. The barrier needs to be correctly located to take advantage of the discharge from the lower lock chamber and to minimize the transfer of salt water due to ship passage through the barrier. The effectives of this system is considered to have a reduction in the salt concentration in the lower chamber of about up to one-half .

At the entrance to the upper lock chamber, the situation is different. Water intake into the locks for lock operations has an effect of sucking-out some of the salt water that intrudes into the Lake and passes it down through the locks. A pneumatic curtain may be effective in confining some of the salt water that may intrude into the Lake but it will also dilute the bottom salt water from the upper chamber by the mixing action of the pneumatic curtain and ship movements. This system may be more effective with a design that contains the salt water at the bottom of the channel as with the pit, and then with proper location of the lock intakes, can withdraw the bottom salt water for lock operations.

ES-10.0 CONCLUSIONS

Based on the data reviewed and the analyses conducted for the various Technical Memoranda, the following conclusions, organized into the corresponding subject matter, may be presented.

Research of Standards

- Salinity-related parameters standards for potable water are very well established throughout the world and generally follow the guidelines of the WHO (500 mg/L for TDS and 250 mg/L of Chloride).
- Although a limit of 250 mg/L for chlorides seems to be accepted as a threshold for taste detection, the effects that increased chloride and dissolved solids concentrations may have on the coagulation and flocculation processes at the water treatment plants must be determined through jar tests or pilot plants.

- General salinity standards established for the protection of biological resources are not very common. Where present, the values were similar, typically 1 part per thousand for salinity and in the range of 1,000 umhos/cm for conductivity. USEPA considers 230 mg/L of Chloride as the permanent toxicity level for freshwater organism.

Inventory of Flora and Fauna

- A total of 417 aquatic plant species have been reported from the Panama Canal system. These include 311 species of algae, 95 species of aquatic macrophytes, and 11 species of mangroves.
- A total of 1061 species of animals have been reported for the Panama Canal Area. They are distributed in 21 groups, with prevalence of mollusks (244), marine and fresh water fish (377 ssp), Crustacean (182), Antozoa Corals (98), Insects (64) and Echinoderms (44).
- Available information indicates a greater number of species reported for Gatun Lake than for Lake Miraflores. On the other hand, a slightly higher number of species have been reported for the Pacific side of the Canal than for the Atlantic. The same inventories report a significantly greater number of marine animal species than freshwater species.
- Although a clear difference may be observed between lakes, there is a degree of uncertainty as to the exact salinity level that would bring about the disappearance of species present in Gatun Lake.

Proposed Salinity Standards

- The URS team considered appropriate to recommend a set of maximum and action level values for salinity standards in Lake Gatun.
- The maximum standards shall not be exceeded at any time and it shall be established at 500 mg/L for TDS, 769 uS/cm for conductivity and 230 mg/L for Chloride.
- The action level standards shall be revised periodically. URS suggests every five years. The initial recommended value for the action level standard is 50% of the maximum standard value; it is to say 250 mg/L for TDS, 385 uS/cm for conductivity and 115 mg/L for Chloride.

Salinity Intrusion Model Review

- Overall, the Delft reports reviewed cover work that has been competently and well done. The results are well supported and meaningful. However, engineers and managers who are to use these results need to be aware of the limitations of the modeling work.
- In spite of the data that was collected in support of the Delft modeling studies and the additional data that has been previously collected, there is a need for additional

measurements. One form of measurements would be with recording instruments so that the time-varying hydrodynamic parameters can be assessed. These are primarily temperature and salinity. The measurements are needed in the area just above the locks in Lake Miraflores and Lake Gatun.

- URS also recommends that the Simulation Model be retained and strengthened for future applications. There is always the need for more data to support such modeling and surely WL|Delft could list measurements that are needed in, and near, the locks to better support the exchange coefficients or to expand the range of conditions that are parameterized.
- There appears to be an immediate need for additional sensitivity analyses to bind the reliability of the results of the modeling given in the present series of reports. These analyses should include both the model parameters, such as the exchange coefficients, as well as the representations of vessel traffic.
- A modeling effort that combines the Simulation Model for saltwater intrusion through the locks needs to be combined with a more detailed representation of the flow in the approach channels above the locks using a three-dimensional time-varying model. Such an effort is well within the state-of-the-art. It would profit from the additional field measurements recommended above. This effort would result in a much more detailed and valid prediction of future conditions once it had been verified for the present situation.

Determination of Potential Impacts

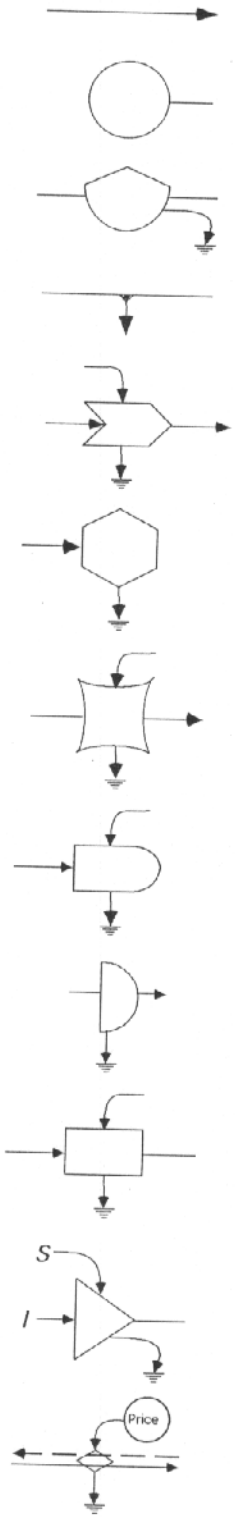
- Very little quantitative data are available to properly evaluate the changes that may occur in Lake Gatun as a consequence of the small increases in salinity anticipated. General biological theory suggest that changes in the relative abundance of species are most likely to occur at the lower trophic levels.
- Even small salinity increases may negatively affect the smaller algae in the phytoplankton community. Although not well documented the role of these small algae may be important to maintain low levels of nutrients (phosphorous), and high levels of dissolved oxygen and light penetration in the ecosystem. Consequently, changes will tend to move the reservoir water towards a more euthrophic-like condition.
- An effect associated with the above described changes could be a shift towards and even more detritus dominated food chain in the ecosystem, favoring the harvesting of freshwater shrimp and mollusks over fish. The net flow of oxygen from and to the atmosphere and the net reduction in light penetration, if any, will play a very important role in the magnitude of that shift.
- Small salinity changes may negatively affect the relative abundance of rotifers and cladocerans, while increasing the relative abundance of calanoids and cyclopoids

copepods. The impact of this switch on species dominance in the entire ecosystem is unpredictable at this time.

- The changes in other biological components of the ecosystem are even less predictable.
- A research and monitoring program could fill the information for more precise evaluations in the future.

Review of Mitigation Measures to Reduce Salinity Intrusion

- The systems that have been identified as the four preferred systems should be considered for use in the Canal.
- The use of the salt pit may prove to be costly and provide limited benefit as it only has an effect of salt water with a low concentration and is basically a system safeguard. Other methodologies that address blocks of salt water with higher levels of salt concentration are more beneficial in reducing the level of intrusion.
- It is convenient to keep in mind that the Panama Canal Lock system is a unique system and although existing mitigation measures can be adapted for use in the Canal, the uniqueness and much larger scale of the proposed new locks requires special and additional design and model testing to provide an efficient system.
- The new Canal locks will initially open for use with a limited number of transits, probably about 5 Panamax-Plus and Post-Panamax ships. Also, ship beam and length will be smaller for the ships initially than in later years. During this early period, salt water intrusion is not expected to be a problem and the system should have minimum salt water intrusion levels through the new locks into Gatun Lake, with salt concentration levels similar to the existing locks.
- During this early period measurements of salt water intrusion level shall be taken at various traffic and seasonal patterns in the lock entrances, through the locks, water savings basins, and Gatun Lake and additional modeling efforts conducted. Pumping of water to simulate scenarios for testing or other methods could be used to exchange water to investigate various salt water mitigation configurations that were not placed in the original construction. Experiments could also be performed with a pneumatic curtain or water barrier to test their effectiveness.
- Based on these prototype investigations, the ACP could select the salt water mitigation method or combination of methods that best serve the new Canal. This may be an extremely important consideration in satisfying the environmental community, i.e., perform field tests and making adjustments in the new locks to provide the best operating procedures.



Energy circuit: A pathway whose flow is proportional to the quantity in the storage or source upstream.

Source: Outside source of energy delivering forces according to a program controlled from outside; a forcing function.

Tank: A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.

Heat sink: Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.

Interaction: Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.

Consumer: Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.

Switching action: A symbol that indicates one or more switching actions.

Producer: Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Self-limiting energy receiver: A unit that has a self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circular pathway within.

Box: Miscellaneous symbol to use for whatever unit or function is labeled.

Constant-gain amplifier: A unit that delivers an output in proportion to the input *I* but is changed by a constant factor as long as the energy source *S* is sufficient.

Transaction: A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.

Figure ES-1: Symbols of the Energy Circuit Language and their meaning

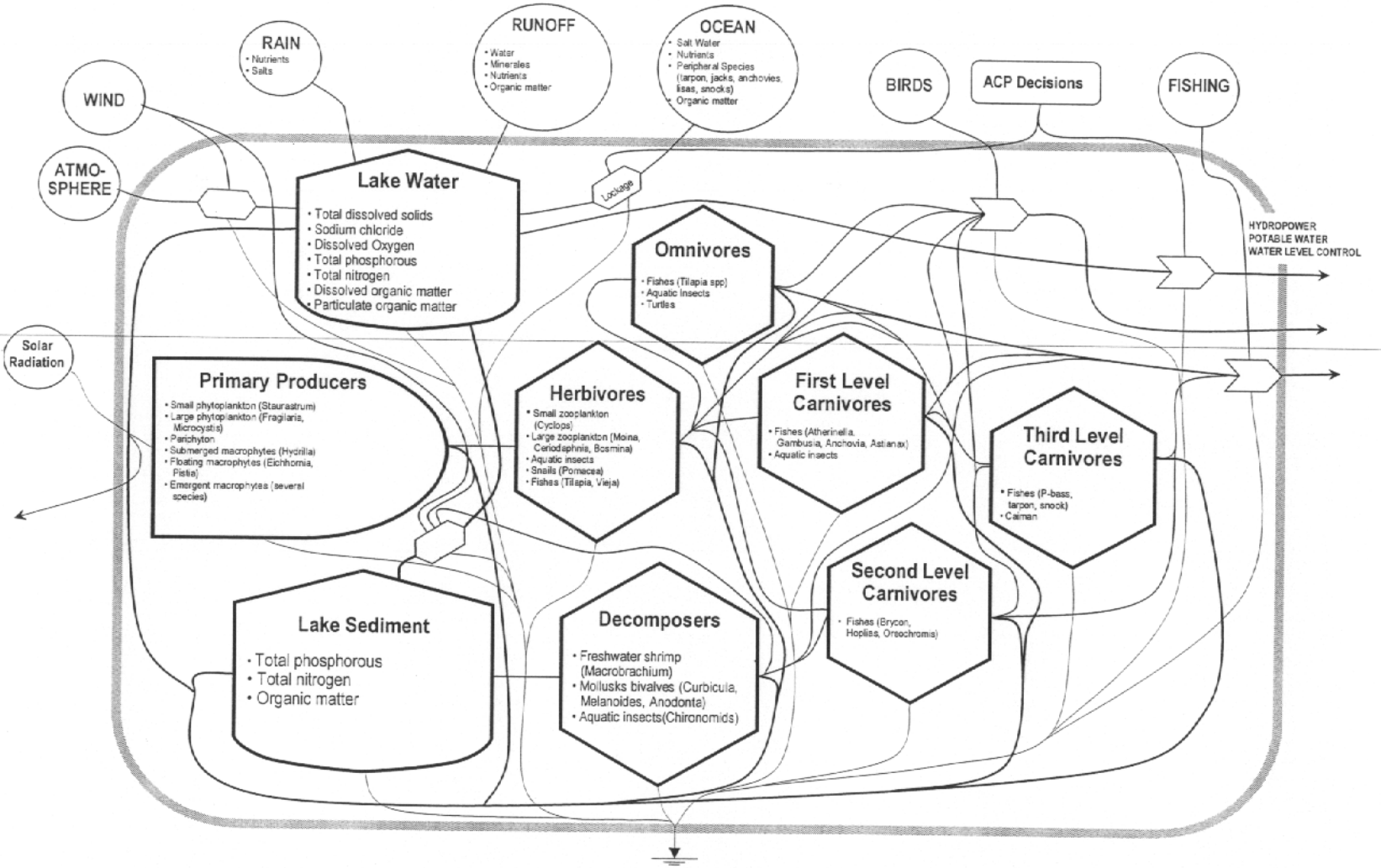


Figure 2: Conceptual Model Diagram of Lake Gatun.