AUTORIDAD DEL CANAL DE PANAMA
Division de Proyectos de Capacidad del Canal

Preliminary Assessment of the Water Quality Data Collection Program

THE PANAMA CANAL

ENGINEERING SERVICES

Work Order No. 6
Reservoir Water Quality Model
For Three Proposed Reservoirs in Panama
Contract No. 20075 [CC-3-536]

MWH

December 2003

Preliminary Assessment
of the
Water Quality Data Collection Program

INTRODUCTION

The US Army Corps of Engineers (USACE) and Harza Engineering, Inc. (now MWH), under contract with the Panama Canal Authority (ACP), developed a CE-QUAL-W2 water quality model for Gatun and Madden Lakes. CEQUAL-W2 is a state-of –the-art, two-dimensional laterally averaged water quality model. It is well suited to simulating reservoir water quality, incorporating all pertinent hydrodynamic and water quality processes. The initial modeling effort calibrated the model based on available data, and identified additional data needs in order to more accurately calibrate the model. Recently, salinity intrusion through the locks was identified as an issue of concern related to potential Canal expansion. This issue is expected to require additional data collection and at least two-dimensional modeling. Thus, data are needed, at a minimum, for these anticipated tasks: model calibration and salinity modeling.

A recent preliminary review of ACP water quality data indicated that the data collection program may need modification to provide data adequate to support water quality modeling. Therefore, MWH was tasked to review the water quality monitoring program. This review was intended to address not only model-related issues, but broader programmatic issues as well, including:

- Evaluate the goals of the ACP water quality monitoring program(s);
- Evaluate water quality aspects of the (draft) Master Plan;
- Assess current monitoring efforts and capabilities relative to the goals;
- Assess current monitoring with respect to the needs of potential future modeling efforts; and
- Assess current monitoring with respect to Master Plan requirements.

The focus of this report is on the type of water quality data being collected (parameters, locations, frequencies, etc.), and thus does not address issues such as laboratory methods, quality assurance, field sampling methods, etc. These "procedural" issues were addressed in a recent review (Fraser and Stoker, 2002).

To gather information needed for this review, meetings were held with ACP staff involved in water resource policy and monitoring (Table 1). Prior to and during those meetings, efforts were made to obtain relevant documents such as:

- ACP ESM watershed management plan and Master Plan sections that address water quality data collection and modeling;
- Documentation of water quality and modeling objectives;
- Documentation of past or planned water quality studies; and
- Maps showing locations of water quality sampling.

Information and data were then reviewed in order to determine the adequacy of the sampling program to meet modeling needs and overall water resources management needs. Thus, this report documents the assessment of current water quality monitoring efforts and capabilities relative to the goals of ACP's environmental and modeling programs, and provides recommendations to ensure a continued high level of excellence and service.

Table 1. Meeting attendance

Meeting	Attendance
Kick-off	Daniel Muschett, José Maturell, Guadalupe Ortega
Water Quality Unit	Marylin Dieguez, Cecilio Puga, Alejandro Veces
Operations (under Watershed Management)	Jaime Massot, Alberto Bourdett
Drinking Water Plant	Santiago Torrijos, Marieta Ng
Met & Hyd Section	Carlos Vargas,
Debrief/presentation of preliminary findings	Daniel Muschett, Santiago Torrijos, Marieta Ng, José Maturell

STATUS

Water Quality Unit

Constitutional law provides the Panama Canal Authority (ACP) with the mandate and responsibility for managing water resources (that is, quantity and quality) within their jurisdictional boundary:

> "The Panama Canal Authority, in coordination with other government agencies as established by the Law shall be responsible for the administration, maintenance, use and conservation of the water resources of the Panama Canal watershed, which includes the waters of the lakes and their tributary streams."
> Political Constitution of the Republic of Panama
> Title XIV – The Panama Canal, Article 310

> "The regulations adopted by the Authority shall consider… the supervision of quantity and quality of water in the Canal watershed and its areas of impact."
> Panama Legislative Assembly, Law No. 19
> Organic Law of the Panama Canal Authority
> Chapter VII, Environment and Canal Watershed
> Article 121, Number 4, 1997.

In 1999, the area of ACP's responsibility for water resources was extended to include three additional sub-watersheds to the west (Legislative Assembly, 44th Law, August 31, 1999).

Meteorological and flow monitoring is performed by the Met and Hyd Section (Figure 1). Management of water resources is the responsibility of the Department of Safety, Environment and Security, through its Environmental Management Division. Within the Environmental Management Division, the Watershed Management section is responsible for monitoring program design, implementation and control. These functions are carried out by the Water Quality Unit (Figure 1). Thus, the ACP Water Quality Unit is responsible for maintaining a continuing program of monitoring and control of the water quality within the Canal and Western watersheds, and ensuring high quality water for human activities and canal operations. The Water Quality Unit was organized in 1999, and by 2001 had established a routine monitoring program. The basic approach of the Water Quality Unit is to collect baseline water quality data in the Canal watershed, and to conduct monitoring for specific projects as needs arise. Collecting data to support water quality modeling efforts could be considered one such special project. There does not seem to be a sampling plan or policy document that takes the overall goal of managing water resources and lays out specific objectives for the program (although it is possible that one exists and we simply did not locate it during the short series of meetings). Similarly, ACP seems to have no numeric water quality criteria.

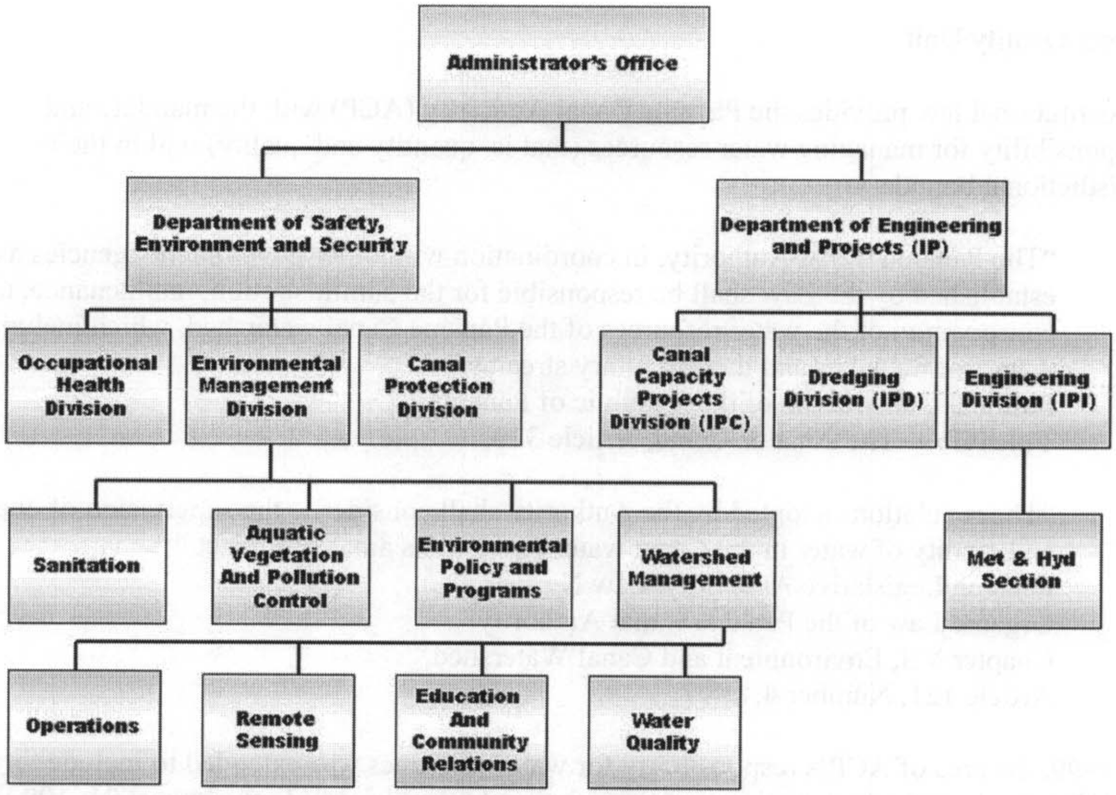

Figure 1. Organizational chart for environmental and water quality aspects of ACP.

The Water Quality Unit began monitoring quarterly in 2001 and has increased the frequency to monthly. Ten locations are monitored in Lake Gatun, five in Miraflores Lake, and five in Madden Lake (Figure 2). Monitoring is conducted 3 feet from the surface and 5 feet from the bottom. No profiling of the key water quality and related parameters has been performed. In addition, surface monitoring is conducted at all major tributaries (Table 2 and Figure 2). A continuous (15-minute) flow monitor is installed at each of these tributaries. A Hydrolab model 4a is used to collect the measurements listed in Table 3 in lakes. In tributaries, samples are collected for laboratory analysis of these parameters.

Table 2. River monitoring stations

Chico (*Rio Chagres*)
Candelaria (*Rio Penqueni*)
Peluca (*Rio Boquerón*)
Ciento (*Rio Gatún*)
Canones (*Rio Cirí Grande*)
Chorro (*Rio Trinidad*)

Table 3. Routine sampling - hydrolab measurements

Parameter	Unit	Range	Accuracy	Resolution
pH	Units	0-14	±0.2	0.01
specific conductance	ms/cm	0-100	±1%,±0.001	4 digits
temperature	˚C	-5-50	±0.10	0.01
resistivity				
dissolved oxygen	mg/L	0-20	±0.2	0.01
salinity	ppt	0-70	±0.2	0.01
total dissolved solids				
turbidity	NTU	0-100	±2.6	0.1
depth	m	0.1 m	±0.08	0.01

In addition to field measurements, reservoir and tributary samples are collected for laboratory analysis of the parameters in Table 4.

Table 4. Routine sampling – laboratory measurements

Parameter	Sensitivity/Range (mg/L)
total alkalinity	
total suspended solids (TSS)	
sulfate	
potassium	0.2 – 2.0
calcium	1.0 – 4.
sodium	0.1 –1.00
magnesium	0.1 – 0.5
hardness	(sum of hardness of Ca + Mg)
sulfate	10 - 60

In order to evaluate the ability of ACP methods to address water quality concerns, ACP routine monitoring sensitivities were compared to United States Environmental Protection Agency (USEPA) drinking water Maximum Contaminant Levels (MCLs) and Ambient Water Quality Criteria (AWQC) for the protection of freshwater organisms (Table 5). All sensitivities were adequate. However, because Gatun Lake salinities are in the range of 0.1 to 1.0 ppt, more sensitive methods are needed to accurately measure these levels, particularly for modeling purposes.

Table 5. USEPA drinking water and aquatic organism water quality criteria (mg/L unless stated otherwise).

Parameter	Drinking Water Maximum Contaminant Level (MCL)		Ambient Water Quality Criteria (AWQC)	
	Value	**Description**	**Value**	**Description**
Alkalinity	None		⩾20	4-day average
Biological Oxygen Demand (BOD)	None		None	
Calcium	None		None	None
Chloride	250	Secondary MCL; recommended level	230	4-day average; for dissolved chloride associated with sodium; criterion probably will not be adequately protective when chloride is associated with potassium, calcium or magnesium
	500	Secondary MCL; upper level	860	1-hour average; for dissolved chloride associated with sodium; criterion probably will not be adequately protective when chloride is associated with potassium, calcium or magnesium
	600	Secondary MCL; short-term level		
Conductivity	None		None	None
Copper*	1.3	Primary MCL; value to be exceeded in no more than 10% of samples at the tap.	0.0025	Dissolved, 4-day average
	1.0	Secondary MCL	0.065	Dissolved, 1-hour average
			0.0032	Total, 4-day average
			0.0082	Total, 1-hour average
Dissolved oxygen	None		6.0	Warmwater, early life stages, 7-day mean
			5.0	Warmwater, early life stages, 1-day mininum
			5.5	Warmwater, other life stages, 30-day mean
			4.0	Warmwater, other life stages, 7-day mean minimum
			3.0	Warmwater, other life stages, 1-day minimum
Dissolved Phosphate	None		None	

Iron	0.3	Secondary MCL	1.0	4-day average
Lead*	0.015	Primary MCL; value to be exceeded in no more than 10% of samples at the tap.	0.0025	Dissolved, 4-day average
			0.065	Dissolved, 1-hour average
			0.0032	Total, 4-day average
			0.0082	Total, 1-hour average
Magnesium	None		None	
Manganese	0.05	Secondary MCL	None	
Nitrate	10	Primary MCL; as N; in addition, limit for total nitrate + nitrite as N is 10	None	
Nitrite	1.0	Primary MCL; as N; in addition, limit for total nitrate + nitrite as N is 10	None	
pH (units)	6.5-8.5	Secondary MCL; within range is acceptable	6.5-9	Instantaneous value must be within range
Potassium	None		None	
Salinity	See chloride, sodium, specific conductance and total dissolved solids			
Sodium	None		None	
Specific conductance (µmhos/cm)	900	Secondary MCL; recommended level	None	
	1,000	Secondary MCL; upper level		
	1,500	Secondary MCL; short-term level		
Sulfate	250	Primary MCL		
	500	Secondary MCL	None	
Total Dissolved Solids (TDS)	500	Secondary MCL; recommended level		
	1,000	Secondary MCL; upper level		
	1,500	Secondary MCL; short-term level		
Total Suspended Solids (TSS)	None		None	
Turbidity (NTU)	1 or 5	Primary MCL; value depends on type of filtration system		Phrased in terms of percentage change

* AWQC is hardness dependent; values listed are for hardness of 100 mg/L as $CaCO_3$

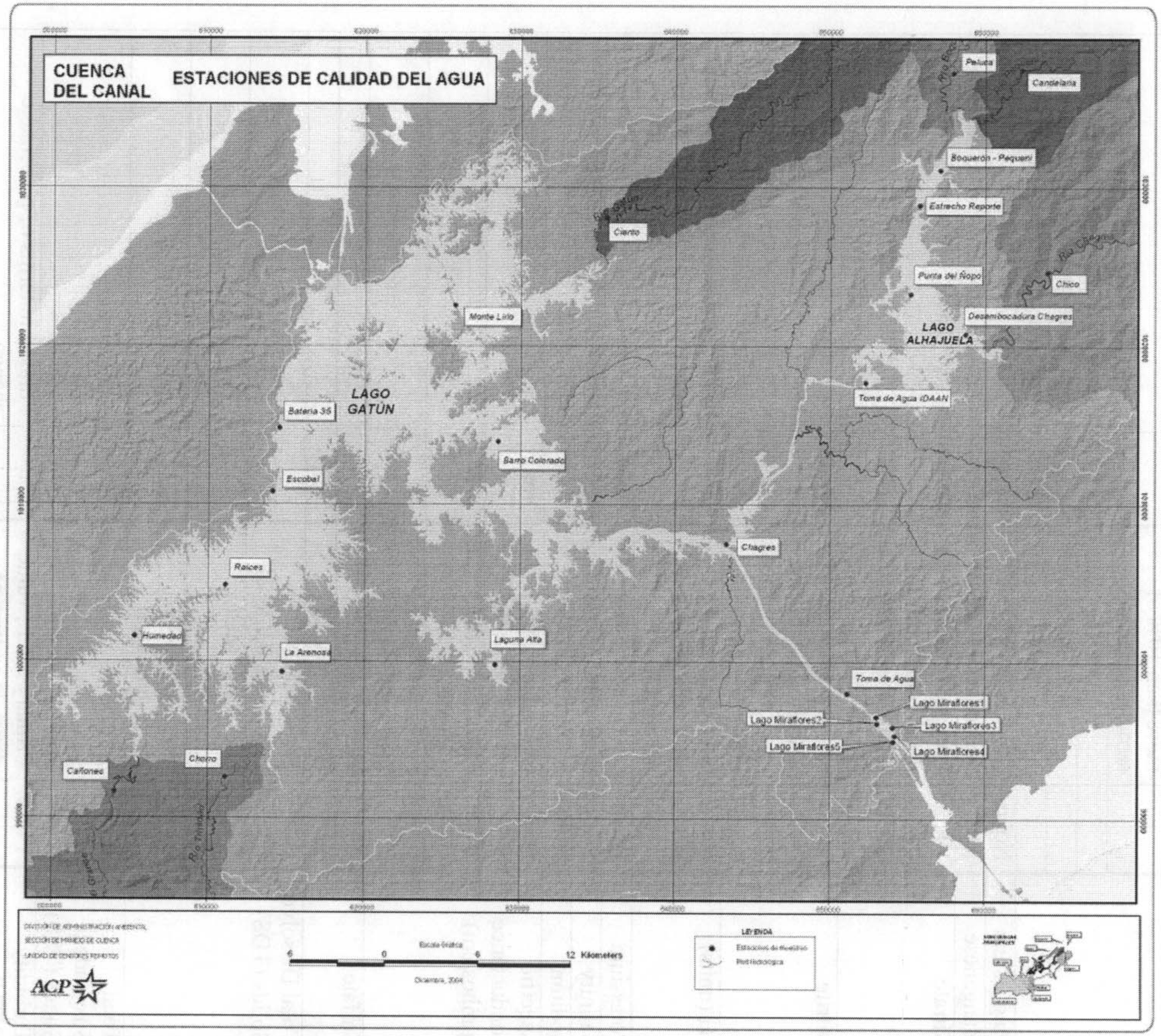

Figure 2: Routine water quality sampling locations.

The Water Quality Unit's analytical laboratory capabilities are summarized in Table 6.

Table 6. Water quality unit laboratory capabilities.

Method No.	Test Method	Reference Method	Comments
1	pH	SM 4500-H B	Field & Lab
2	Alkalinity	SM 2320 B	Titration
3	Hardness	SM 2340 B	Calculation
4	Conductivity	SM 2510	Conductivity electrode, Field & Lab
5	Total Dissolved Solids (TDS)	SM 2540 C	
6	Total Suspended Solids (TSS)	SM 2540 D	
7	Turbidity	EPA 180.1	Nephelometric – Field
8	Dissolved Metals	SM 3110	Atomic Absorbtion Ca, Mg, Na, K, Fe, Cu, Pb, Mn
9	Nitrite	SM 4500-NO2 B	Colormetric
10	Nitrate	SM 4500-NO3 E	Cadmium reduction method (N-NO3 + N-NO2)
11	Dissolved Oxygen (Lab)	SM 4500-O	Winkler iodometric method
12	Dissolved Oxygen (Field)	SM4500-O G	Membrane Electrode
13	Dissolved Phosphate	SM 4500-P E	Ascorbic Acid method
14	Sulfate	SM 4500-SO4	Turbidimetric method
15	Biological Oxygen Demand (BOD5)	SM 5210 B	5-day BOD test
16	Total Coliforms	SM 9223 B	Colilert
17	Faecal Coliforms	SM 9223 B	Colilert
18	Temperature	(probe)	*in situ* field measurement
19	Salinity	(probe)	*in situ* field measurement

The Water Quality Unit also responds to specific issues with non-routine sampling efforts. For example, in early December of 2003 monitoring was conducted to measure parameters to duplicate some of the monitoring conducted by DELFT in their development of their salinity intrusion model. Purposes of this effort included verification of DELFT data, collection of data with more sensitive equipment, and support for potential future modeling.

The Water Quality Unit is also working to identify biological indicators for early warning signs of pollution or salinity impacts. They are also beginning to look at watershed issues. Another effort, known as "pilot watersheds" is looking at Gatuncillo in detail; 16 locations have been selected for monitoring. Plans are underway to study all watersheds in the area under ACP's jurisdiction on a rotating basis during the course of the next ten years. Three priority watersheds have been identified for the next phase of this effort.

Drinking Water Plant Sampling

The drinking water plants (Miraflores Filtration Plant and Mount Hope Filtration Plant) primarily monitor their treated water to ensure high quality drinking water. However, some monitoring is conducted at the intakes, and it is possible that this data may be useful for modeling and for general evaluation of Gatun Lake water quality. Alkalinity, turbidity and pH data are collected daily at the Miraflores intake (Paraiso), and five times per week at the Mount Hope intake (Gatun). At the Paraiso intake, there is an online volatile organic compound (VOC) monitor that measures 61 VOC components. In addition, samples are collected annually at both intakes and analyzed for all AWWA (American Waterworks Association) and USEPA (United States Environmental Protection Agency) water quality parameters. Personnel at the plant were very cooperative regarding sharing this data, so this will be an added benefit to the Water Quality Unit monitoring.

Master Plan

At this writing, the Master Plan has not addressed water quality monitoring. Therefore, no review of the Master Plan was included.

Meteorologia e Hidrologia (Met and Hyd)

Met and Hyd is responsible for meteorological and hydrological data, and has a long history in the Canal watershed; many of their data stations were established in the early 1970's. Stream flow data are collected on all major tributaries at 15-minute intervals. They maintain a large network of meteorological stations that include wind direction and speed, temperature, humidity and solar radiation. Stream flow and meteorological stations are connected to telemetry, so real-time data are available. There are several lake-level meteorological stations along the Canal and Gatun Lake. Met and Hyd also maintains the data for flows over spillways and for hydropower generation.

RECOMMENDATIONS

Program Purpose.

It is not clear if a written sampling plan exists for routine monitoring. Perhaps the most important aspect of the sampling plan is that it should detail the purpose of each data collection effort. Some of the general purposes include collecting baseline data, supporting and meeting requirements of the Master Plan, and supporting modeling efforts. However, the purpose should be described in enough depth to justify the technical aspects of the sampling program. The description of the purpose should also include a summary of reporting requirements, and the basis for evaluating the data (such as acceptance standards or water quality criteria). It is not clear if ACP is expected or authorized to set water quality standards, or if standards are to be developed in another agency. If it is necessary to wait for another agency to take action on this issue, ACP should define "internal standards" or "interim standards." These would be temporary standards that would be used in the analysis of the data, but would not have any regulatory authority.

Documentation

"Institutional" aspects that the sampling plan should cover include documenting all water quality data collection programs with responsible organization, contact, etc. The sampling plan should name the responsible party for evaluation and development of an action plan if one is required, and the circumstances that would trigger a need for an action plan. If possible, approximate budgets should be included in the sampling plan. Technical specifications for water quality sampling that should be in the sampling plan include locations, frequencies, constituents, field and laboratory procedures, detection limits, and the data requirements for modeling and other efforts (such as master planning) that the data collection effort will support.

Currently, water quality results are not routinely evaluated to determine if there are significant findings. We recommend that an annual report be produced to summarize, evaluate, and document the data. The first annual report should address all data collected through the end of 2003. Components of this report should include:

- Objectives of the monitoring, including data requirements for model development.
- Summary tables of the data for each parameter (minimum, median, and maximum at each location; or perhaps for each waterbody).
- For documentation and future reference purposes, put all data into an appendix.
- Comparison to relevant water quality criteria. For example, the United States Environmental Protection Agency drinking water levels and aquatic life criteria could be used, although ACP may wish to utilize international standards. For each waterbody, provide a summary table listing for each parameter the number of measurements, the number of times each criterion was exceeded, and the percent of measurements that exceeded each criterion.
- Include Gatun Lake water quality data collected by the drinking water plants in the data summaries, analyses and appendices.

- For critical parameters (such as salinity, which is critical due to concerns related to canal expansion), and parameters that are frequently near or above criteria (once criteria are established), perform a graphical trend analysis. The approach to this is not an exact science, but needs to be evaluated to provide the most useful summary information yet without over-aggregating to the point where important information is not apparent. For example:
    - Plots for every location/depth vs. time (probably not enough aggregation).
    - Plots with one line each aggregating all surface locations and all depth locations within each water body.
    - Plots that aggregate all locations/depths within a waterbody (probably too much aggregation).
    - Plots that aggregate specific portions of a waterbody (for example, navigation channels).

  These types of plots are important, because they enable visualization of trends and comparisons that are often not apparent in tabular data. When producing these plots, as much as possible, use a consistent system to denote locations/depths, and use the same scale, so that plots can be compared to one another. Another detail to watch is to use color, but to use it in such a way that if the images are converted to black and white it is still usable. Different types of dashed lines may be used. An example plot using Water Quality Unit data is provided below (Figure 2). Note that in this example open symbols represent surface locations and solid symbols depth locations. From this plot it can easily be observed that Escobal has the highest conductivity (salinity), and that while surface conductivity is generally less than depth conductivity at Escobal, the reverse is true at Raices.

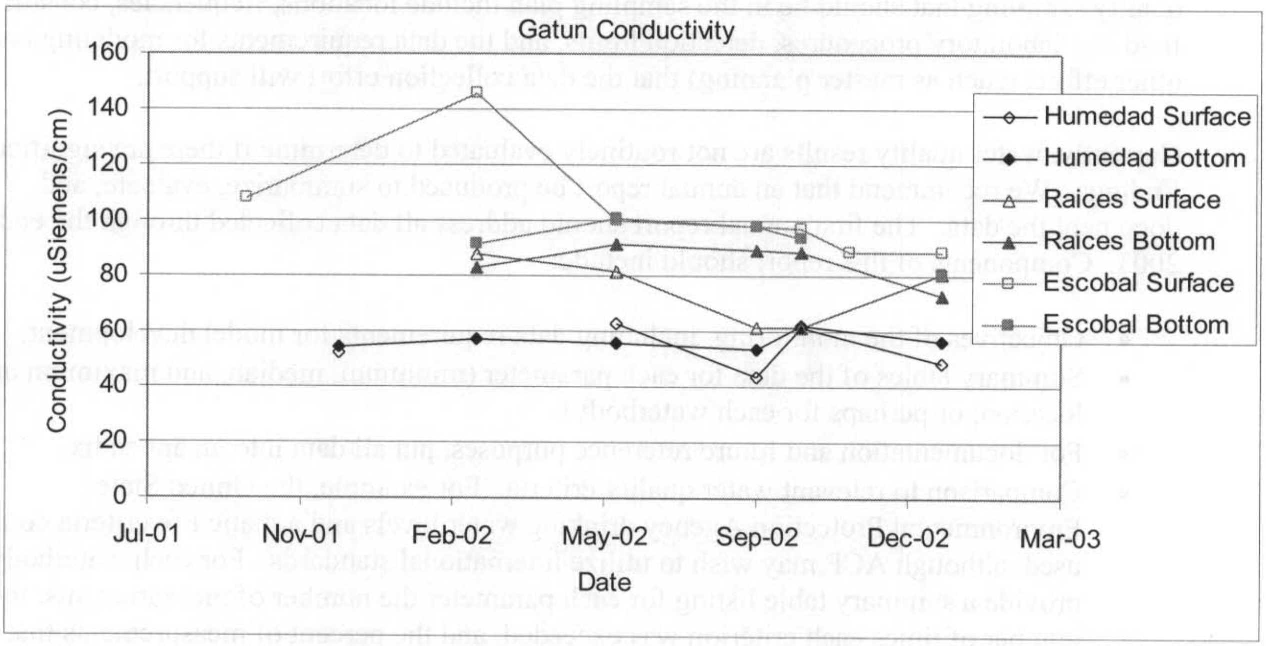

Figure 2. Conductivity in Gatun Lake.

Sampling

ACP generally collects reservoir samples around the edges of the reservoirs. To support additional modeling, we recommend adding locations in the deepest portions and/or mid-sections (lateral) of each reservoir, such as near the dams and in the navigation channels. These additional locations should include Hydrolab measurements at 1-meter intervals. At a minimum, these measurements should include temperature, turbidity and dissolved oxygen. We also recommend establishing locations upstream of the locks on both the Pacific and Atlantic side to monitor salinity intrusion. At a minimum, one location near the locks and one location sufficiently distant that salinities are less than 0.1 ppt should be selected. The latter location will provide valuable baseline data for salinity intrusion and will provide the first warning if salinity levels are increasing. In addition, it would be useful to have a station intermediate between these two stations. Locations should be established downstream as well, in order to determine if downstream/ocean salinities vary (for example salinity may vary with wet/dry season).

Salinity in Gatun Lake has been measured in the range of 0.02 to 0.08 ppt, but with precision of ±0.2 ppt. Accurate modeling requires that salinity at these low levels be known with a high degree of confidence. Therefore, we recommend investigating if a probe is on the market capable of accurately measuring salinity levels to 0.01 ppt or less. Salinity at river locations should be monitored with the same salinity sensitivity as at reservoir locations. We also recommended that chloride and turbidity sensors be added to the Hydrolab sonde. The sensitivity of the chloride probe (0.5 mg/L, or 0.0005 ppt) would be sufficient for monitoring freshwater chloride levels.

Salinity is currently measured indirectly, by measuring conductivity, then converting to equivalent salinity. However, at low salinities such as occur in Gatun Lake, other factors, such as bicarbonate, may contribute to conductivity. These interferences are not incorporated in the conversion from conductivity to salinity and may result in an over-estimate of salinity. Therefore, concurrent with some of the measurements, we recommend collecting samples for laboratory analysis of constituents related to salinity, such as chloride ion and bicarbonate. Doing this will provide both a direct measure of salinity (chloride), and a measure of other factors that contribute to salinity. Initially, at a minimum, this monitoring should be done quarterly and include five of the current Gatun Lake stations, two each of the Miraflores and Madden stations, and all tributaries. After a year of collection, the results should be evaluated to assess whether monitoring could be decreased or needs to be increased. Monitoring could be decreased if there is little variability in concentrations and a reasonable relationship can be developed between conductivity-based salinity and chloride ion concentration. Conversely, monitoring may need to be increased if there is high variability or if the data are not sufficient to establish the above relationship. The Water Quality Unit does not currently have the capability to analyze chloride ion or bicarbonate and therefore will require appropriate equipment and training. Furthermore, added monitoring may require additional staff. Historical sampling has indicated that alkalinity is due almost completely to bicarbonate, so for the present alkalinity can be used as a surrogate for bicarbonate. Investigating the conductivity-salinity-bicarbonate relationship is an important effort. The literature should be searched to determine if there is an existing theoretical foundation describing this relationship. In addition, available data should be used to determine if there is a statistical relationship between Gatun Lake conductivity and bicarbonate/alkalinity. It may be helpful to use alkalinity data collected at drinking water intakes for this investigation.

We also recommend continuous monitoring of at least some locations. This will "connect the dots" provided by discrete sampling, and be extremely useful both for general understanding of water quality dynamics and for model development. Concerns were expressed regarding theft and vandalism of any permanent installation. Met and Hyd replaces equipment at one or two locations each year due to theft and vandalism, and the Water Quality Unit does not currently have the budget to risk losing equipment. It may be possible to place equipment at secure, yet important locations to minimize the likelihood of loss. Locations that may be sufficiently secure include near the locks, in the locks, or from buoys in the lake.

The Pilot Watershed program is an excellent effort to gain understanding of the status of watersheds and what potential water quality concerns exist at a watershed and sub-watershed level. However, because minimal data currently exist, the current 10-year schedule for completion of this program should be accelerated. After the data have been evaluated, it may be possible to select some watersheds for monitoring on a 10-year basis, but at this point in time, there may be significant risks to waiting 10 years before finding out what problems exist.

It is not clear what, if any, water quality monitoring has been conducted to evaluate the proposed reservoirs. Particularly as it becomes clearer what reservoir(s) is (are) more likely to be built, monitoring of source streams will be critical for future modeling efforts. As with any stream monitoring, measuring flows is a crucial element for model inputs. Previous modeling (Bunch *et al.*, 2003) for Rio Indio indicated the significance of good estimates for sediment oxygen demand (SOD). 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 rate 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.

No flow monitoring in the reservoir has been conducted. ADCP (Acoustic Doppler Current Profiler) devices with bottom tracking capability are available which are capable of measuring flow in three dimensions. The ADCP data are extremely useful in determination of modeling approach and the subsequent model developments. It is recommended that at least one of these devices be purchased. Implementation of this monitoring could be performed by either the Water Quality Unit or Met and Hyd.

Although there are several meteorological stations along the Canal and near Gatun Lake, for a waterbody the size of Gatun Lake, accurate, detailed water quality modeling of the lake may require that additional stations be established. After calibration of the model, it may be possible to decommission these stations, but that determination would be made based on the variability of the meteorological variables, the impact that variability has on model results, and the degree of detail and accuracy needed for future modeling.

Coordination

The water quality monitoring program should be closely coordinated with modeling efforts to ensure that data are collected of sufficient quality, at low enough detection limits, and at appropriate locations and frequencies. In addition, the monitoring will need to address requirements to be included in the Master Plan. Water quality monitoring staff should work with those developing the Master Plan and developing water quality models to ensure that capabilities and staff are adequate to meet anticipated needs. Furthermore, there seems to be some coordination between Water Quality staff and the Aquatic Vegetation and Pollution Control department. However, during the initial visit, there was not an opportunity to follow up on the nature of that coordination. Coordination between the two organizations should include identification of potential threats to water quality, so that monitoring can be implemented to quantify the threats and determine if steps need to be taken to mitigate or minimize the threats. The 2002 review of water quality (Fraser and Stokker, 2002) identified eleven potential water quality issues (Table 6). Investigation of these issues may have been part of the site selection criteria for the current monitoring locations. Regardless, these issues should be investigated by the Water Quality Unit in association with Aquatic Vegetation and Pollution Control, in order to ensure that appropriate sample locations are included in monitoring. cs

Table 6. Potential Water Quality Issues of Concern (Fraser and Stokes, 2002)

1	Microbiological contamination of drinking water supplies: a) Influences from agricultural practices b) Influences from human settlement practices
2	Suspended sediment transport and siltation
3	Nutrient enrichment
4	Humic decay, sediment resuspension, and dissolved organic carbon
5	Dissolved oxygen deficit in the bottom waters of Gatun and Alhajuela Lakes
6	Effects of pesticide and herbicide use from crop management practices and aquatic vegetation control
7	Heavy metals in suspended sediment, particularly in the shipping channels
8	Oil and grease, particularly in the shipping channels
9	Phytoplankton species diversity and occurrence; and frequency and duration of blooms
10	Biological indicators
11	Presence and effects of invasive and non-native species

When drinking water plant personnel were asked what their water quality concerns were, they replied that "traditional" pollutants are not a current or anticipated issue. From an operational standpoint, however, they were very concerned about turbidity. Turbidity above 200-300 NTU requires increased treatment and other operational costs, and thus the impact of extended periods of high turbidity would be significant. However, turbidity is not routinely monitored, and is also difficult to model (because it can be caused by a variety of biotic and abiotic factors). We suggest that Water Quality Unit staff work with drinking water plant staff to "translate" turbidity concerns into TSS levels, so that drinking water plant staff can utilize environmental monitoring data in their operations and planning. In addition, Gatun Lake water quality data collected at the intakes should be utilized by Water Quality Unit staff, as discussed in the Documentation section.

Conclusions

The recommendation section of this report is summarized below into 26 items. The first seven items are high priority and should be addressed as soon as possible. The remaining recommendations have been sorted approximately by priority, from highest to lowest. Clearly, adopting these recommendations comes at a cost, both in equipment and staff time. Equipment would be needed for new laboratory capabilities, for field capabilities, and for continuous monitoring; and staff would be needed for additional monitoring, analysis and reporting. The Water Quality Unit has established an excellent baseline monitoring program. However, as population, industry, agriculture, and Canal traffic continue to increase, continued expansion of the Water Quality Unit will be required in order to ensure that high-quality drinking water is available for the people of Panama.

Summary of Recommendations

1. Develop a written purpose for sampling (Sampling Plan component)
2. Develop written technical specifications for sampling (Sampling Plan component)
3. If available, purchase probe that can measure salinity to 0.01 ppt or less
4. Purchase chloride probe for existing Hydrolab
5. Coordinate water quality monitoring with modeling efforts
6. Coordinate water quality monitoring with Master Plan
7. Coordinate water quality monitoring with Aquatic Vegetation and Pollution Control, particularly with regard to 2002 review water quality issues
8. Conduct additional monitoring, including profiles, at deep reservoir locations
9. Conduct additional monitoring at locations near locks
10. Create a list and description of water quality data collection programs (Sampling Plan component)
11. Collect samples for laboratory analysis of salinity-related parameters
12. Develop numerical criteria (Annual Report component)
13. Document a comparison of results to criteria (Annual Report component)
14. Purchase turbidity probe for existing Hydrolab
15. Produce summary tables of data (Annual Report component)
16. Coordinate sampling with drinking water plants
17. Accelerate Pilot Watershed schedule
18. Conduct and document trend analyses (Annual Report component)
19. Perform flow monitoring in reservoirs and channels
20. Establish continuous water quality monitoring stations
21. Create data appendices of all data (Annual Report component)
22. Develop action plans for when criteria are exceeded (Sampling Plan component)
23. Include drinking water plant data in Annual Report
24. Add additional meteorological stations
25. Perform monitoring to evaluate proposed reservoirs
26. Document budgets (Sampling Plan component)

REFERENCES

Bunch B.W., B.E. Johnson, and M.S. Sarruff, 2003. Panama Lakes Water Quality Modeling Study. U.S. Army Corps of Engineers, Engineer Research and Development Center, ERDC/EL TR-03-XX.

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Appendix – Hydrolab Sensitivity Technical Details

In Table 3, resolution indicates the level of detail that the equipment will display; accuracy indicates the range within which the "real" value is expected to exist. The following examples are given to clarify the meanings of Accuracy and Resolution: A salinity measurement of 6.47 would mean that salinity was between 6.67 and 6.27. A salinity measurement of 0.07 would mean that the salinity was between 0.27 and 0.00 (since negative salinity is not possible, the minimum of the range would be zero in this case). Because of the importance of salinity, we contacted the manufacturer of Hydrolab (specifically, Bill Jones, 800-949-377, ext. 2544) in order to gain a better understanding of monitoring at these low salinities. There are two settings for converting conductivity to salinity; the default setting is for a range of 30-40 ppt, but there is also a setting for a range of 2-40 ppt. The algorithm for the conversion is based on a range of 2-42 ppt; thus, measurements below 2 ppt may be suspect. If the probe is calibrated to a salinity standard rather than a conductivity standard, it may be possible to more reasonably extend the algorithm below 2 ppt. However, the limitation of the accuracy of ±0.2 ppt means that even though the equipment may produce values as low as 0.01 ppt, these low results may not be reliable.