A Feasibility Study Report Prepared for:

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FEASIBILITY STUDY REPORT
PANAMA CANAL LOCK WATER RECLAMATION PROJECT
PANAMA CANAL, PANAMA

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TABLE OF CONVERSIONS

Multiply	By	To Obtain
Acres	0.4047	Hectares
Cubic feet	0.02832	Cubic meters
Feet	0.3048	Meters
Gallons (U.S. liquid)	0.003785	Cubic meters
Gallons per minute	0.00006309	Cubic meters per second
Inches	0.0254	Meters
Miles (U.S. statute)	1.6093	Kilometers
Square feet	0.0929	Square meters
Square miles	2.59	Square kilometers

ACRONYMS

ACP	Panama Canal Authority
ARI	Authority of the Interoceanic Region
CND	Central Nacional de Depacho
EDECHI	EDE-Chiriqui
EDEMET	EDE-Metro Oeste
ELEKTRA	EDE-Elektra Noreste
ENSO	El Nino-Southern Oscillation
ETESA	Empressa de Transmission Electrica
GDP	gross national product
GWh	giga-watt hour
IDAAN	Instituto de Aqueductos y Alcantarilldos
INRENARE	National Institute for Renewable Resources
ITCZ	Inter-tropical Convergence Zone
kV	kilo-volts
KWh	kilo-watt hour
mgd	million gallons per day
M&I	municipal & industrial
ml	milli-litres
mm	millimeters
msl	mean sea level
MVA	milli-volt amperes
MW	mega watts
ppm	parts per million
ppt	parts per thousand
SIN	Sistema Interconectado Nacional
tds	total dissolved solids
USEPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

Traffic through the Panamá Canal has grown dramatically since it's opening in 1914. The current ship traffic average of 37 vessels per day is expected to increase approximately 15 percent to 42 lockages per day within the next several years. In response to the anticipated traffic demand, the Panamá Canal Authority (ACP) has been implementing an improvement program that will allow increasing its capacity to the equivalent of 42 lockages per day. The operation of the Panamá Canal requires approximately 52 million gallons of water per lockage. Continued increase in transit traffic through the canal has exerted a great pressure upon the watershed that supplies water to operate the canal system. Current hydrologic reliability of the Panamá Canal is approximately 99.6 percent. The hydrologic reliability with the demand increasing to 42 lockages would diminish to 98.8 percent. Further, a 20 percent increase of daily transit traffic to 44 lockages daily would diminish hydrologic reliability to 98.4 percent.

The ACP through its Canal Capacity Projects Office is in the process of developing a long-term plan to address the future needs of the Panamá Canal. The main objectives of the long-term plan is:

1. To satisfy the municipal and industrial water supply needs without adversely affecting the operation of the Panamá Canal;
2. To provide sufficient navigation waters to meet existing and future canal transit demands and maintain the historically reliability levels of 99.6 percent; and
3. To take advantage of projects by supplementing hydropower production and increase current capacity and energy production.

Wpsi, Inc. (Wpsi), a US company based in California, developed a technical concept proposing an engineering solution for which it has completed this feasibility study. This concept aims at increasing the availability of fresh water and hydroelectric power in the canal region to facilitate sustained increases in capacity growth over the next fifty years,

to enable domestic economic growth and to create beneficial environmental impacts to the region.

The proposed project consists of the design and construction of a $420 million Panama Canal Lock Water Reclamation Project (Project) that would divert a variable portion of the water discharged from the exit locks to retention reservoirs from where water would be drawn for treatment processes that would allow its reclamation and reuse. Such reclamation and reuse includes:

1. Recycling treated water to Gatun Lake to support the hydraulic needs of the canal;
2. "Flushing" Miraflores Lake with fresh water discharge from the Pedro Miguel lock system in combination with a saltwater intrusion prevention system to restore it as a fresh water body; and,
3. Providing the public water system with additional significant supplies of "potable" water needed to sustain domestic and economic growth in the region.

Further, as part of this Project, Wpsi proposes to construct parallel side-paths adjacent to lock discharge culverts and install hydroelectric power turbine generators in each that would eventually generate approximately 110 mega-watts of electricity to operate the treatment facilities and allow for excess generated electrical power to be transmitted to the power grid. Lastly, Wpsi's Project design includes a saltwater intrusion prevention system by which the advance of saltwater into the fresh water bodies of Gatun Lake and Miraflores Lake is arrested and terminated.

Panamá is the largest economic center in Central America and an important economic market that needs continued attention. Wpsi's proposal offers the opportunity for continued collaboration with the Panamá Canal Authority and the government of Panama.

Wpsi intends to enjoin a consortium of private parties in an investment and development holding company, duly incorporated according to U.S. law, to privately finance, design,

construct, operate and manage the operations of the proposed Project. Further, Wpsi proposes that such a holding company will also create a subsidiary(s) incorporated according to the laws of the Republic of Panama chartered as a waterworks and power generation entity to operate and maintain the treatment and power generation facilities of the proposed Project. Lastly, Wpsi envisions that these private project parties will enter into a concession relationship with the ACP to operate, maintain and manage the Project by which a portion of the treated water and generated electrical power pass through ACP administration and to be sold to public utilities. Wpsi envisions that when Project investment objectives are achieved the Project parties, according to an agreement to be negotiated with local and/or regional water and power authorities, will offer to transfer the Project to ACP ownership, or optionally to another private concession authorized by ACP authorities.

Implementation of this project creates the following benefits:

1. Assures current level of daily lockages for the long-term;
2. Enables the sustained growth canal capacity;
3. Enables the sustained growth of transit revenues and associated economic benefit;
4. Enables termination of saltwater intrusion in the canal's lake system and a significant improvement in the water quality of those fresh water bodies;
5. Enables the augmentation of potable water supplies to sectors of the region in need of it;
6. Enables the production of significant additional hydraulically generated "clean" electrical power to support the expansion of regional commercial activity without adverse environmental impacts; and,
7. Enhances the productive management and long-term protection of the regional watershed supporting the Panama Canal.

1.0 INTRODUCTION

The Panama Canal, constructed between 1903 and 1914 at one of the narrowest and lowest geographical saddles along the Isthmus that connects North America to South America, has facilitated almost 870,000 transits between the Pacific and Atlantic Oceans. From north to south, the principal geographical features that make-up the Panama Canal are:

1) The Gatun Locks;
2) Gatun Lake;
3) The Gaillard Cut;
4) The Pedro Miguel Locks;
5) Miraflores Lake; and,
6) The Miraflores Locks.

Using the force of gravity and water from Gatun Lake, transiting ships are raised from sea level to an elevation of approximately 85 feet and lowered again to sea level. The lockage of each ship transiting the Panama Canal requires approximately 52 million gallons of fresh water from Lake Gatun; with approximately 26 million gallons used to navigate each of two lock systems: Gatun and Miraflores/Pedro Miguel.

By constitutional authority of the sovereign government of the Republic of Panama, the Panama Canal Authority (ACP) was established as an autonomous administrative government body and given the responsibility to manage, preserve, operate, maintain, improve and modernize the canal. An eleven-member Board of Directors, whose members' appointments and service terms are staggered to ensure independence and continuity from one government administration to another, governs the ACP. By law, the Panama Canal is an inalienable patrimony of the Republic of Panama and cannot be sold transferred, mortgaged, or in any way burdened or liened. The preeminent goal of the ACP is to ensure the Canal is maintained and operated in such a manner as to ensure it is

capable of providing peaceful and uninterrupted service to the international maritime and commercial communities.

1.1 Need For Proposed Project

Given the belief that near and long term demands for fresh water in the Panama Canal region to maintain and support the growth of canal capacity, domestic consumption, and commercial and industrial expansion could exceed the natural yield of the region's watershed, and given the belief that the watershed's yield capacity could be further adversely affected by soil erosion associated with deforestation, pollutant loading from human activities, and significant and serious climatic changes; a presumption emerged that clearly indicated the presence and growth of a severe gap between the natural carrying capacity of the region's watershed and such demands for it's yield.

Given the gravity and urgency of this situation, Wpsi, Inc. initiated efforts to identify what technical remedies could be engineered and implemented to reduce the emerging gap between watershed yield and the inevitable growth in demands placed upon it from domestic, commercial, industrial and agricultural activities. These efforts revealed an engineering opportunity to recover all lock water currently discharged to the shipping channels from exit lock chambers, conveying it to treatment facilities where variable volumes of water required to support transit activity and public water demand could be reclaimed and recycled back into the watershed's lake and public water supply systems. Specific economic and environmental benefits are believed to be directly associated with this opportunity. These benefits include the following and are discussed in further detail later in this document:

1) Sustains the current level of canal transit capacity;
2) Enables the expansion of canal transit capacity to the upper physical limits of the canal system and subsequently the incremental increase of transit revenues and associated economic benefit;

3) Enables a process to arrest deterioration of lake water quality conditions in the canal region and to begin the process of long-term restoration;
4) Enables the augmentation of public potable water supplies and transportation to sectors of the region in need of it;
5) Enables the production of significant additional hydraulically generated "clean" electrical power to support the expansion of regional commercial activity without adverse environmental impacts; and
6) Enhances the productive management and long-term protection of the regional watershed.

1.2 Goals and Objectives of Proposed Project

1.2.1 Goal of the Proposed Project

The goal of the proposed Project is to provide an engineered concept that when fully designed and constructed enables the recovery of all water discharged from the exit locks of the Gatun and Miraflores locks systems and its reclamation and recycling to Gatun Lake, as well as production of significant quantities of fresh potable water and environmentally clean hydroelectric power for conveyance to public water and power utilities respectively.

1.2.2 Objectives of the Proposed Project

The proposed project has five principal objectives:

1) Enable the sustainment of current canal capacity and facilitate long-term canal capacity increases through the transportation of variable volumes of treated lock water recovered from the Gatun and Miraflores exit locks to Gatun Lake that are necessary to support canal operations;

2) Install a proprietary saltwater intrusion prevention system that curtails future intrusion of saltwater through the Gatun and Miraflores lock systems into Gatun Lake and Miraflores Lakes;
3) Enable, over a relatively short period of time, the natural flushing of Miraflores Lake and its recovery to a fresh water habitat condition;
4) Produce and convey to public water authorities treated reclaimed lock water that meets safe drinking standards for public consumption; and
5) Generate and convey environmentally clean hydroelectric power to the public electrical power grid that will allow for the reduction of higher cost and environmentally adverse fossil-fuel generated electrical power and boost the level of electrical power reserves throughout the region to a favorable posture.

1.3 Description of Proposed Project

The proposed Project is envisioned to be developed in two phases, generally described as follows:

Phase I

Water Recovery and Treatment

Phase I of the proposed Project, as shown in Plate 1.3a and planned to be initiated in year 2006, incorporates the diversion of all discharge lock water from the Gatun and Miraflores exit locks to treatment facilities. When Phase I of the proposed Project is initiated it is assumed that initial transit capacity will be approximately 37 lockages per day. At both Gatun and Miraflores treatment facilities approximately 30 percent (577 million gallons per day total) of the influent to the facilities will be treated with the balance of influent (approximately 1,346 million gallons per day total) being released through the saltwater intrusion prevention system into the ship channel draining to the Atlantic and Pacific Oceans. Approximately 30 percent of the influent being treated at each facility (approximately 175 million gallons per day total) will be conditioned to

Panamanian and World Bank safe drinking water standards (see Appendix D) and purveyed through ACP facilities and into the public water supply system of the Instituto de Acueductos y Alcantarilldos Nacionales (IDAAN). The remaining 70 percent of influent being treated at each facility (approximately 402 million gallons per day total) will be conditioned to beneficial reuse standards in accordance with the prevailing laws of the Republic of Panama (see Appendix D) and conveyed for discharge in Gatun Lake. Initially, as a result of the "brackish" condition of Miraflores Lake water, a desalinization process will be incorporated into the treatment facility at Miraflores as the primary treatment process to enable achieving the necessary water quality to allow for discharge at Gatun Lake and purveyance of potable water to IDAAN. When the water quality of Miraflores Lake returns to a fresh water condition, as a result of saltwater intrusion prevention system operations and the natural "flushing" of the lake water with higher quality water from Gatun Lake, the desalinization process will be decommissioned and a conventional treatment process capable of achieving the drinking water and beneficial use standards provided in Appendix D will be installed in its place.

Saltwater Intrusion Barrier System

Immediately downstream of each set of exit locks of the Gatun and Miraflores lock systems, a proprietary saltwater intrusion prevention system will be constructed and operated to curtail the intrusion of saltwater through the respective systems of locks into Gatun Lake and Miraflores Lake.

Hydroelectric Power Generation

High-volume, low-head water turbine electric power generators will be installed in parallel pathways constructed adjacent to and interconnected with existing culvert drains for each of the three sets of locks (Gatun, Pedro Miguel and Miraflores) that convey the drainage of lock water from each lock to the next succeeding lock. Electrical power generation substations will be constructed at the Gatun and Miraflores treatment facilities. The Miraflores Substation will receive and handle electric power generated at the Pedro Miguel Locks. Project facility operations will draw from these substations

what power is needed to sustain treatment, pump and process control operations. Each of the hydroelectric power generation substations will be tied into existing inter-connection facilities and be capable of conveying approximately 90 MW to the public utility electrical power grid for region-wide use.

Waste Treatment

Solid wastes generated from water treatment processes will be conveyed to a waste treatment process at each of the two treatment facilities. Generally, solid waste material, in a largely saturated form, is collected and conveyed to a sludge filter press operation where it is compressed and de-watered. Water recovered from the filter press operation is recycled upstream to the pump station that moves water from the retention reservoir to the pre-treatment process. De-watered sludge is conveyed from the filter press operation to sludge holding basins where composite sampling of the material would be conducted. That which is determined to be environmentally clean can be recycled for processing as soil amendments to be used to support agricultural or forestation projects; that which is not will be processed for proper disposal according to the laws of the Republic of Panama.

Phase II

Water Treatment

Phase II of the proposed Project, as shown in Plate 1.3b, is anticipated to be initiated during the period of 2016 to 2020 and continues with the conveyance of all discharge lock water from the Gatun and Miraflores exit locks to treatment facilities. When Phase II of the proposed Project is initiated it is assumed that transit capacity will be approximately 45 lockages per day. At both treatment facilities approximately 60 percent of the influent at each facility (approximately 1,404 million gallons per day total) will be treated with the balance of facility influent (approximately 936 million gallons per day total) being released through the saltwater intrusion prevention system into the ship channels draining to the Atlantic and Pacific Oceans. Approximately 15 percent of the

influent to each facility (approximately 210 million gallons per day total) will be conditioned to safe drinking water standards and purveyed to the ACP and/or the IDAAN. The remaining 85 percent of facility influent (approximately 1,194 million gallons per day total) will be treated to beneficial reuse standards in accordance with the prevailing laws of the Republic of Panama and the World Bank and conveyed for discharge in Gatun Lake. When Phase II is initiated, it is assumed that Miraflores Lake has been "flushed" and returned to a fresh water condition no longer requiring the use of the desalinization process. This would allow for decommissioning of the desalinization plant and replacement with a conventional treatment process capable of achieving the drinking water and beneficial use standards provided in Appendix D.

Saltwater Intrusion Barrier System

The proprietary saltwater intrusion barrier system will continued to be operated throughout Phase II as it was in Phase I.

Hydroelectric Power Generation

As shown in Plate 1.3b, existing electrical power generation substations will be modified to handle approximately 110 MW of hydroelectric generated power for transmission to existing inter-connection facilities.

2.0 DEFINITION OF BASELINE CONDITIONS

The region for which the following baseline conditions are identified and discussed relative to the proposed Project, as well as the area of influence to be impacted by the proposed Project is defined as the watershed region providing hydraulic support for Panama Canal operations and the specific provinces of Panama and Colon as generally shown in Plate 2.1a. While the Project's area of influence is likely to be the two provinces in which it is located, and through which the Panama Canal passes, many of the impacts and benefits discussed in this study are likely to impact the entire region and to some extent the entire country.

2.1 Canal Operations

The Panama Canal is a 50-mile, man-made hydraulic structure that connects the Pacific Ocean (to the south) to the Atlantic Ocean (to the north) and consists of three sets of locks structures as shown in Plate 2.1a and Plate 2.1b. Passage through the canal from either direction, as shown in Plate 2.1b, requires transiting Miraflores Lake and Gatun Lake for which water levels are maintained at 54 feet above mean sea level (msl) and 85 feet above msl (87.5 feet above msl during wet season), respectively to accommodate navigation through the canal[1]. The channel that connects these lakes to one another is known as the Gaillard Cut. Both lakes are considered to be fresh water lakes, although Miraflores Lake has progressively become brackish over the many years of canal operations due to saltwater intrusion from the saltwater ship channel at the exit locks. Gatun Lake, having an estimated storage capacity of approximately 183 billion ft^3 at a lake level of 85 feet above msl (or 196 billion ft^3 at 87.5 feet above msl), was created by constructing Gatun Dam across the Chagres River[2]. Other dams along the Chagres River upstream of drainage to Gatun Lake were constructed to capture and provide storage of

[1] *Saltwater Intrusion in the Panama* Canal; T.M. Parchure, Steven C. Wihelms, Soraya Sarnuff, William H. McAnally; February, 2000.
[2] Ibid. 1.

storm water runoff to enhance long-term operability of the canal. Water from Gatun Lake is used to operate the Gatun and Pedro Miguel lock systems while water from Miraflores Lake; having an available active storage capacity of approximately 88 million ft^3 (total storage capacity of 670 million ft^3) at a mean lake level of 54 feet above msl is used to operate the Miraflores lock system[3]. Ships entering the canal from either ocean create a condition known as saltwater intrusion whereby saltwater migrates into Gatun and Miraflores lakes, while approximately 26 million gallons of the fresh water used to operate the navigational locks is lost per lockage (56 million gallons total) through each set of exit locks to ship channels draining to the Pacific and Atlantic oceans.

2.1.1 Current Operations

The Panama Canal lock system, as shown in Plate 2.1a and Plate 2.1b, consists of six-twin locks that are grouped in three sets. These sets are, transiting from the Atlantic Ocean to the Pacific Ocean: 1) Gatun Locks (see Plate 2.1c) with two lifts; 2) Pedro Miguel Locks (see Plate 2.1d) with one lift; and 3) Miraflores Locks (see Plate 2.1e) with three lifts. Shown at Table 2.1.1 are the physical characteristics of these locks. This system of locks lift ships transiting from one ocean across Gatun Lake to the other ocean, a height of approximately 85 feet above msl, and then lowers them back to sea level. The twin-lock system serves two purposes: 1) they act as a stand-by in the event of closure of one side of the lock system; and, 2) they act as an alternate system of locks for multiple small ships transiting at one time.

Presently, the lockage operation of transiting a ship through the canal simply consists of hydraulically lifting and lowering ships in the lock chambers by the gravity flow of water. Water from Gatun Lake is released through a system of culverts into the upper Gatun Lock and Pedro Miguel Lock chambers for lifting ships in these locks. Likewise, water from Miraflores Lake is also released through a system of culverts into the upper Miraflores Lock chamber. From the upper lock chambers, water is released through a

[3] Ibid. 1.

system of culverts to lower chambers to lift a ship from a lower level. The established maximum safe rate of water flowing from one lock chamber to another is controlled at 7.5 feet per minute enabling raising or lowering of a ship in approximately 8 minutes[4]. Each ship transiting the canal must negotiate six locks and travel the 50-mile ship channel across Gatun Lake, Gaillard Cut and Miraflores Lake. A typical canal transit time is approximately nine hours. The Panama Canal operates 24 hours day, 365 days a year. Typically, larger ships conduct lockage operations during daylight hours, whereas the smaller ships transit the canal at any time convenient to the ACP.

2.1.2 Projected Operations

The Panama Canal system described in section 2.1.1 above has reached its maximum operational capacity. In order to satisfy customer demand for increased capacity, the ACP is in the process of evaluating a number of alternatives that would enable it to increase canal capacity. Such alternatives are categorized as follows: 1) water resource alternatives; and, 2) engineered systems alternatives.

2.1.2.1 Water Resource Alternatives.

Water resource alternatives being evaluated by the ACP to increase water supply and conveyance to support an increase in capacity include:

a) Developing the 823 mi^2 (526,720 acres) "Occidental Region" watershed (also known as the Western Watershed, see Plate 2.1f) into two large reservoirs by constructing dam structures in the watershed basin to capture drainage from the Rio Indio, Toabre and Cocle del Norte river basins and flooding it. These reservoirs would be inter-connected with one another and with the Gatun Lake by a system of control-flow tunnels[5].

[4] *Hydraulics of the Locks of the Panama Canal*; R.H. Whitehead; October, 1915.
[5] *The Panama Canal*; The Panama Canal Authority; 2001.

b) Deepening the navigational channel in Gatun Lake and Gaillard Cut to 34 feet PLD[6].

c) Improving water capture in the lower Trinidad and upper Charges river drainage basins[7].

Implementation of these water resource alternatives is expected generate enough yield in the watershed basins to enable a canal capacity increase of between 40 to 44 lockages per day[8].

2.1.2.2 Engineered Systems Alternatives.

Engineering studies being conducted to increase canal capacity include:

a) Construction of additional "third" set of locks incorporating the installation of water saving systems such as multiple-level locks, lateral basins, and water recycling.

b) Navigational channel improvements that included the widening of Gaillard Cut.

c) Implementation of modernization programs that include new and improved operations equipment designs, procurement of new tugboats and locomotives, installation of a hydraulic miter gate system, operations equipment overhauls, the replacement of the marine traffic control system with an enhanced satellite-based vessel traffic management system, and telecommunications network modernization.

[6] Ibid. 5.

[7] Ibid. 5.

[8] Ibid. 5.

2.2 Canal Transit Activity

At the present time, approximately 13,400 ships transit the Panama Canal annually. This transit activity equates to approximately 37 ships per day[9]. By the year 2010 the level of ship transit activity through the Panama Canal is expected to increase by 15 percent to approximately 15,330 ships per year or approximately 42 ships per day[10]. Completion of modernization and improvement programs in progress that include the widening of the Gaillard Cut, an increase in the towboat fleet, purchase of new and more powerful lock locomotives, the modernization of the marine traffic management and lock control systems and replacement of 50,000 feet of lock tow track will enable the increase of transit activity by 20 percent from current levels to 16,080 ships per year or approximately 44 ships per day[11]. Further, a recent long term traffic demand forecast indicated that over the next 50 years the number of ship transits could increase to approximately 26,800 or approximately 73 ships per day[12].

Each ship transiting the Panama Canal requires the total use of approximately 52 million gallons of fresh water from Gatun Lake and the Alhajuela Lake watershed[13]. Currently, this water is discharged from the lock systems to the ship channels that drain to the Bay of Panama or the Caribbean Sea. Shown in Table 2.2 are estimates of the volumes of fresh water required to operate the Panama Canal to meet current and forecasted transit activity using the current transit activity of approximately 13,400 ships as the base year. As shown in Table 2.2, the estimated annual requirements for fresh water needed to operate the Panama Canal and successfully satisfy forecasted ship transit activity is expected to increase by approximately 139 billion gallons (382 million gallons per day)

[9] www.pancanal.com; General Information; Canal News; September 9, 1999.
[10] Ibid. 9.

[11] www.pancanal.com; Programs and Projects; Canal Improvement Program.
[12] www.pancanal.com; Programs and Projects; Canal Capacity.

[13] www.encarta.com; Panama Canal; Section III.

in ten years (2010) and 697 billion gallons (1.9 billion gallons per day) in fifty years (2050).

2.3 Fresh Water Demand in the Canal Region

The raw water resources of the Alhajuela Lake watershed that drain to Gatun Lake are an essential supply source for municipal and industrial (M&I) systems serving the Panama Canal Region and its more than 1.5 million inhabitants[14]. The quantity and quality of raw water drawn from the Alhajuela watershed and treated by IDAAN to be made available by it to residential, commercial, industrial and public customers has a significant and direct impact of the region's quality of life and capacity to accommodate economic growth. In the past, the availability and quality of water resources and water supply drawn from it has been abundant and reliable; however, as articulated in Sections 2.4, 2.5 and 2.7 of this report, a variety of current and forecasted circumstances, conditions and activities present the potential for significant differences between what the existing water supply system can provide and the quantity and quality of water required to meet forecasted demands associated with domestic and economic growth.

2.3.1 Existing Fresh Water Infrastructure

The Republic of Panama has assigned to IDAAN the lawful responsibility to supply potable water service to public communities of 500 people or more throughout Panama. For those communities having less than 500 people, the Panamanian Ministry of Health has oversight responsibility to ensure potable water is provided in sufficient supply. In addition to these two public entities, the ACP and other private concessions provide supplemental supplies of potable water to IDAAN. Presently, more than an estimated 1.5 million people, representing over 90% of the population of the Panama Canal region, are supplied potable fresh water by IDAAN[15]. The balance of the population in the region

[14] *Long-term Forecast for M&I Water Demand (Draft)*; Harza; January, 2001.
[15] Ibid. 14.

acquires fresh potable water from a variety of sources that include small, non-centralized water systems, extractions from drainage courses in the watershed, and individual water supply wells. Presently, the fresh potable water production capacity in the Panama Canal region is approximately 233.6 million gallons per day (mgd). This regional water production capacity is derived from a variety of facilities as shown in Table 2.3.1.

2.3.2 Current Fresh Water Demand

M&I water demand derives from the needs of quantifiable residential and non-residential use customers. Baseline quantifiable demand for both customer categories was estimated using historical metered data and established historical base demand rates of consumption[16]. Non-residential customers were stratified into ten subcategories representing the breadth of economic activities in the region. The quantification of current baseline M&I fresh water demand for residential and nonresidential customers for the region, as shown in Table 2.3.2a, are approximately 113.2 mgd and 40.6 mgd, respectively; totaling approximately 153.8 mgd.

In assessing current demand and forecasting projected fresh water demand, previous water demand surveys and studies took into account the loss of water in the system as a result of distribution system leakage and non-metered withdrawals from the water distribution system. According to IDAAN data and previous consultant studies, water distribution system withdrawals by non-metered customers, whose billing is based on factored estimates, are typically much greater than metered customers[17]. Historically, IDAAN data indicates that between 35% and 50% of the water produced from its production facilities cannot be accounted for[18]. A recent consultant study corroborated this data in establishing that reported levels of estimated water losses in the system attributed to distribution system leakage and excessive use by non-metered customers is

[16] Ibid. 14.
[17] Ibid. 14.
[18] Ibid. 14.

approximately 36% of the water produced[19]. Further, this same study assumed, on the basis of IDAAN's limited success in curtailing system losses, that this level of loss would likely remain relatively steady over time. Taking in account data and information developed in previous studies, baseline water system losses attributed to water distribution system losses and excessive use by non-metered withdrawals are, as shown in Table 2.3.2b, approximately 61.1 mgd and 24.5 mgd, respectively. Further, normal water use by non-metered customers, who according to IDAAN are registered by IDAAN and regularly billed, but whose water use is not metered, account for a significant portion of the total water requirement; estimated to be 55.7 mgd. As also shown in Table 2.3.2b, total unaccounted for water requirements are presently estimated to be 141.3 mgd.

Combining current estimated water demand totals from Tables 2.3.2a and 2.3.2b, the cumulative total baseline M&I water demand in the Panama Canal Region is approximately 295.1 mgd, as shown in Table 2.3.2c. Comparison to the total water production capacity of 233.6 mgd of the existing fresh water system in Table 2.3.1 to the current total estimated demand of 295.1 mgd as shown in Table 2.3.2c, shows that there presently exists an estimated shortfall of approximately 61.5 mgd.

2.3.3 Projected Fresh Water Demand

Fresh water demand studies have clearly demonstrated that demand for fresh water in the Panama Canal region will grow as a result of domestic population growth, changes in land use, and economic expansion[20]. Year 2000 census data indicates that approximately 57% of the entire population of the Republic of Panama is located in the Panama Canal Region[21]. Approximately 80% of the Panama Canal region population is largely concentrated in the urban areas of Arraijan, Colon, La Chorrera and Panama City[22]. The

[19] Ibid. 14.
[20] Ibid. 14.
[21] Ibid. 14.
[22] Ibid. 14.

most recent census tract data reflects a population migration trend to these urban areas in the Panama Canal region[23]. Given some variation in past population growth projections developed by the Contraloria, the U.S. Army Corps of Engineers, and outside consultants, the population growth projection trend lines that emerge from each are relatively consistent with one another and generally reflect a projected annual growth rate estimate of approximately 0.9%[24]. As such the population in the Panama Canal region is projected to increase from a current population of approximately 1.5 million to a population of approximately 2.6 million in year 2050 as shown in Table 2.3.3a. Concurrently, using the base water demand rate for residential customers provided in Table 2.3.2a, the estimated demand for fresh water from residential customers is projected to increase from a current demand of 113.2 mgd to approximately 188.2 mgd in year 2050 as shown in Table 2.3.3a.

Changes in land use and corresponding property development that are emerging from the planning activities of the Authority of the Interoceanic Region (ARI) and the Ministry of Housing (MIVI), as well as projected economic expansion in the Panama Canal region are expected to have a collective significant impact on future fresh water demand. Recent studies estimate an annual growth in the gross domestic product (GDP) of 4.4% through year 2020 and 2.3% through year 2050[25]. Further, growth in consumer purchasing, export activities and investments in the Panama Canal region are estimated to increase at average annual rates of 1.5%, 1.6% and 3.2%, respectively[26]. These economic conditions are expected to have a positive impact to the extent that by year 2050:

1) Metric tonnage handled at port facilities is estimated to increase more than 400%;
2) Manufacturing and construction activities are estimated to increase more than 180%;
3) Hospitality industry related activities are estimated to increase almost 270%; and,

[23] Ibid. 14.
[24] Ibid. 14.
[25] Ibid. 14.
[26] Ibid. 14.

4) Commercial and retail activities are estimated to increase almost 200%[27].

Economic expansion will translate into increased demands for fresh water. Factoring these projected levels of growth activity and using the base water demand rate for non-residential customers provided in Table 2.3.2a, the estimated demand for fresh water from non-residential customers is projected to increase from a current demand of 40.6 mgd to approximately 78.0 mgd in year 2050 as shown in Table 2.3.3b.

Taking into account the loss of water in the system as a result of distribution system leakage and non-metered withdrawals from the water distribution system, as previously discussed in establishing baseline water demand levels, and given the assumption that this level of loss would likely remain relatively steady over time on the basis of IDAAN's past limited success in curtailing system losses, values of unaccounted for water quantities are provided in Table 2.3.3c. As shown, losses are projected to increase from approximately 169.0 mgd in year 2010 to approximately 247.0 mgd in year 2050.

Combining current estimated water demand totals from Tables 2.3.3a, 2.3.3b and 2.3.3c the cumulative total projected M&I water demand in the Panama Canal Region increases from approximately 353.1 mgd in year 2010 to approximately 514.1 mgd in year 2050, as shown in Table 2.3.3d. In comparison to the existing total fresh water production capacity of 233.6 mgd shown in Table 2.3.1 to the projected estimated demand for fresh water in years 2010 through 2050, as shown in Table 2.3.3d, significant projected estimated shortfalls in supply to meet corresponding levels of demand may occur as shown in Table 2.3.3e that increase from 119.5 mgd in year 2010 to 280.5 mgd in year 2050.

[27] Ibid. 14.

2.4 Water Quality Conditions in the Canal Watershed

Lake Gatun is the hydraulic reservoir for Panama Canal operations, as well as the primary source of potable water for fresh water customers in the Panama Canal region. Having a surface area of approximately 167 square miles and a dry-year storage capacity of approximately 1,440 billion gallons, Lake Gatun receives drainage from a watershed area of approximately 1,290 square miles in size[28]. Such drainage flows from tributaries and watercourses throughout the region, the principal one being the Chagres River-Alhajuela Lake system having a drainage area of approximately 396 square miles[29]. Alhajuela Lake, having a surface area of approximately 19 square miles has a storage capacity of approximately 212 billion gallons[30]. Numerous water quality studies of the canal watershed have been conducted and monitoring of water quality in the region continues as a high priority today. Typically, monitoring program activities (data collection and analysis) are divided into the following five geographical areas: Marine Atlantic Region, Gatun Lake, Alhajuela Lake, Chagres-Gamboa-Gaillard Cut Region, and the Marine Pacific Bay Region (Miraflores Lake). For the purpose of the feasibility study, data and information was reviewed in regard to the Alhajuela Lake, Gatun Lake, and Chagres-Gamboa-Gaillard Cut regions, as well as Miraflores Lake of the Marine Pacific Bay Region. Data from the Marine Atlantic Region were not included in this section because the data largely represents the degree of saltwater quality in natural marine habitats to include that of the channel approach to Gatun Locks, but the data were used in developing saltwater intrusion prevention options discussed later in Section 3.0. Tables 2.4a through 2.4d represent the ranges of data values for selected water quality parameters for the Alhajuela Lake, Gatun Lake, Chagres-Gamboa-Gaaillard Cut and Miraflores Lake regions, respectively.

[28] *La Cuenca del Canal de Panama*; Jaime Espinoza Gonzalez, Luis Carlos Barrow, Elizabeth Castillo; 1986.
[29] Ibid. 28.
[30] Ibid. 28.

2.4.1 Current Conditions

Historical data value ranges for selected water quality monitoring parameters for each of the four monitoring areas with respect to ranges of high and low values, as well as average dry and wet season values are provided in Tables 2.4a, 2.4b, 2.4c and 2.4d. Generally, water quality fluctuates seasonally between wet and dry cycles. Further, elevated levels of contaminants and adverse water quality parameter indications typically occur during the wet season cycle as a result of excessive storm water runoff from the watershed and contaminant source points located therein.

Historically, the Gatun Lake region has been sub-divided in to the following areas for water quality monitoring and assessment purposes: Monte Lirio, Gatun Lake North, Escobal, Vino Tinto, Ciricito, Barro Colorado and La Laguna. Shown in Table 2.4b are historical data value ranges for selected water quality monitoring parameters for each of the seven monitoring areas. Water quality typically fluctuates seasonally between wet and dry cycles. Although water quality data for water within the locks was not available, water quality within the locks can be anticipated to be similar to the closest water body.

Alhajuela Lake

Alhajuela Lake is a stratified body of water with a 4°C temperature difference between the top and bottom. Stratification is a result of density gradient currents from the Penequi and Chagres Rivers flowing into the lake. As shown in Table 2.4a, the total coliforms bacteria range form 6 to 8,000 count/100ml of which 1,700 are identified as faecal coliforms. That historical data collected in 1975 show a coliforms level of less than 200 counts/100ml suggest the increase in coliforms levels may be attributed to the increase in human settlements and farming activities along the shorelines of Alhajuela Lake, which has occurred since 1975[31]. Recently, *Cryptosporidium spp* and *Giardia lamblia*, protozoans associated with feacal matter and which infect humans, were also detected in

[31] *Canal Zone Water Quality*; Alfred Gonzalez, Alvarado-Durfee, C.T. Diaz; June, 1975.

the water from Alhajuela Lake[32]. These findings suggest that water in Alhajuela Lake can no longer be used as a source of potable water without rigorous disinfection. The water quality in Alhajuela Lake does not meet the Beneficial Use Water Standards shown in Table 2.4h, as defined in Appendix D.

Consistent with the sediment deposited in the lake through run off from the deforested areas around the lake, the total solids level range of 74-ppm to144 ppm is high. The amount of dissolved oxygen in surface waters greatly impacts aquatic ecosystems. Surface waters in a tropical climate reach 100 percent saturation. Reduction in the dissolved oxygen levels may result in eutrophication, algal blooms, adverse taste and odor, and a less suitable environment for sustaining fish and wildlife. Dissolved oxygen levels are near saturation in the upper water levels, but reduced at depths.

Gatun Lake Region

Historical studies of Gatun Lake show that waters in the Gatun Locks north entrance and Limon Bay are of excellent quality with dissolved oxygen levels near saturation and low faecal coliforms counts[33]. As shown in Table 2.4b, the water quality has been maintained for Gatun Locks north and the Vino Tono region. Elsewhere, and most markedly in the Monte Lirio region, faecal coliforms levels reach 600 counts/100ml and beneficial water use criteria are not met. The diminution of water quality in the Monte Lirio, Escobal, Cirito and Barro Colorado regions may be attributed to increased surface runoff from deforested lands, and increased human settlement with a concomitant increase in the discharge of untreated sanitary wastes.

[32] www.pancanalsociety.org/Articles.

[33] Ibid. 31.

Chagres-Gamboa-Gaillard Cut

The water in this region has the poorest water quality of the Canal Zone and does not meet the beneficial use water criteria presented in Table 2.4h. Gaillard Cut water quality is influenced by water flowing from the Chagres River. The Chagres River receives a chemical and biological load from the Chilibre River and thus has high maximum levels of faecal and total coliforms bacteria, 13,000 and 6,000counts/100 ml, respectively. As shown in Table 2.4c, all waters in this region have high coliforms levels, with the Gamboa outfall region showing the highest maximum levels, 89,700 and 34,000 counts/100 ml for total coliforms and faecal coliforms, respectively. Dissolved oxygen levels are at reduced levels compared with Gatun Lake and total solids reach a high level of 950 ppm at the Gamboa outfall.

Miraflores Lake

The water quality in Miraflores Lake is reduced by influxes of water from the Gaillard Cut and the intrusion of saltwater from the Miraflores lock system. As shown in Table 2.4d, the Miraflores Lake has a high maximum total coliforms count of 21,500 counts/100ml, of which 5,900 counts/100ml are faecal coliforms. Dissolved oxygen levels are diminished and total solids elevated at a maximum level of 1,233 ppm. Water in Miraflores Lake does not meet beneficial use water criteria presented in Table 2.4h.

Salinity

Fresh water from Gatun Lake and "brackish" water from Miraflores Lake are used for filling the navigation locks while transiting ships in and out of the lakes as the ships pass from the Pacific Ocean to the Atlantic Ocean or vice versa. Saltwater from the ocean and ship channels courses though the lock chambers into to the lakes by density currents. Typically, the salinity of the oceans is approximately 35 parts per thousand (ppt) and fresh water is at 0 ppt. The salinity of Gatun Lake is at or near 0 ppt. However, salinity

levels in Miraflores Lake have progressively increased reaching a steady state of less than one ppt within a year of commissioning of the canal (see Appendix A)[34].

There is a paucity of data for salinity levels within the locks. Discrete data gathered in May and November 1999 for Gatun Lake and Gatun Locks East and North are shown in Table 2.4e. These data confirm the fresh water quality of Gatun Lake with all samples in Gatun Lake at 0.0 ppt. Salinity is also less than 1.0 ppt in Gatun Locks East except for one set of samples taken in November 1999 where the levels are about 4.0 ppt. The Lower Gatun Lock, which is adjacent to the Atlantic, shows salinity levels closer to that of seawater. Table 2.4f shows discrete data from observations made in October 1999. These data show somewhat higher salinity levels in the lower lock chamber (ca. 20 ppm) and in the middle lock chamber (ca. 2.0 ppm). Within the Miraflores Locks recent observed salinities are reported as shown in Table 2.4g

2.4.2 Projected Conditions

As described in section 4.2, discharge of untreated sewage throughout the Panama Canal watershed has resulted in higher than acceptable levels of faecal bacteria in the water. *Cryptosporidium spp* and *Giardia lamblia* have also been recently detected in Alhajuela Lake, where the water is essentially not potable. Stanley Heckadon of the Smithsonian Tropical Research Institute has predicted that, if left unmitigated, soon only bottled water will be safe to drink in the Panama City-Colon regions[35].

2.5 Climatic Conditions in the Canal Region

Generally, the climate of Panama is tropical with wet and dry seasons. Annual movement of the Inter-tropical Convergence Zone (ITCZ) induces seasonal change. The dry season typically occurs during the period of February through April and is typically

[34] Ibid. 1.
[35] Ibid. 32.

characterized as less humid and having moderate to strong northerly winds. During this period of time the ITCZ is generally located south of Panama near the equator. Sometime in March or April the ITCZ begins to move northward, arriving in the vicinity of Panama in late May or early June. The passage of the ITCZ across Panama marks the beginning of the wet season and typically results in heavy rainfall over much of the country. The wet season is typically characterized by mild humid southerly winds. Historically, the magnitude of the wet season and rainstorm events begins to dissipate when the ITCZ has moved well north of Panama during the period of June through July.

Generally, a second dry season begins in August once the ITCZ has moved well north of Panama. This entire process begins to reverse itself in late summer or early fall during which the ITCZ begins to move southward passing over Panama in late October or early November. The period of October through early January is associated with heavy rainfall throughout Panama. The dry season returns to Panama when the ITCZ has moved well south of Panama. This oscillating movement of the ITCZ is illustrated in Plate 2.5[36].

2.5.1 Temperature, Relative Humidity and Winds

Variations of air temperature throughout the year in the Panama Canal region are typically moderate with the highest mean temperature occurring in April (approximate range of 83°F to 86°F) and the lowest mean temperature occurring in November (approximate range of 75°F to 78°F). The highest levels of relative humidity, approximately 90%, in the region typically occur during the wet season in November. The lowest levels of relative humidity, approximately 75%, in the region typically occur during the dry season in March. The strongest winds in the region typically occur during the dry season. During this period trade winds typically blow from the north and northwest at an approximate average sustained velocity of 15 miles per hour 90 percent

[36] *Study of Variations and Trends in the Historical Rainfall and Runoff Data in the Gatun Lake Watershed*; Montgomery Watson Harza; December 2001.

of the time, while the strongest winds called "northers" that occur along the Atlantic coast of the region reach sustained velocities of in the range of 30 to 60 miles per hour.

2.5.2 Historical Watershed Rainfall Trend

A recent report calculated annual average rainfall amounts for the Panama Canal watershed for drainage areas of: 1) Alhajuela Lake and the drainage area upstream of it known as *Madden Lake - Upstream* (~398 mi^2); 2) downstream of Alhajuela Lake and Gatun Lake known as *Gatun Lake - Downstream* (884 mi^2); and 3) the total drainage area above Gatun Lake known as *Gatun Lake Total* (1,282 mi^2) for the period from 1911 to 2000. The calculated annual average rainfall values for these drainage areas were 2837mm, 2576mm and 2663mm, respectively[37]. Plates 2.5.2a, 2.5.2b and 2.5.2c provide summaries of average annual basin rainfall and 5-year moving average basin rainfall values, respectively[38]. These data and a linear trend line for the three drainage areas were shown graphically by the author of the referenced report and are reproduced on Plates 2.5.2a, 2.5.2b and 2.5.2c. As shown in Plate 2.5.2a, the slope of the linear trend line for annual average rainfall in the *Madden Lake – Upstream* drainage basin is slightly positive; approximately +1.04 mm per year. However, as shown in Plate 2.5.2b, the slope of the linear trend line for annual average rainfall in the *Gatun Lake – Downstream* drainage basin is clearly negative; approximately -2.8 mm per year. Plate 2.5.2c, *Gatun Total*, representing a composite of the preceding two shows a linear trend line for annual average rainfall for the entire basin as slightly negative, approximately -1.6 mm per year. Given a total watershed basin area of approximately 1,282 mi^2 and the data presented above, the trend line reduction in annual average rainfall for the entire drainage basin is approximately 1.4 billion gallons per year; equivalent to approximately 27 transits per year.

[37] Ibid. 36.
[38] Ibid. 37

2.5.3 Impact of El Nino-Southern Oscillation Events

The El Nino-Southern Oscillation (ENSO) is a large-scale coupled ocean-atmosphere oscillation in the Pacific Ocean. An ENSO event is the warming of the eastern equatorial Pacific Ocean that influence global climate on a time scale of years or decades. Further, it is generally recognized that ocean water temperature changes associated with an ENSO event diffuse throughout the entire tropical belt. Given the interrelationships between ocean temperature and atmospheric conditions, the emergence of an ENSO event affects the movement of the ICTZ that generally result in below normal rainfall in some parts of Panama and above normal rainfall in others[39]. The most recent ENSO events occurred in 1976/77, 1982/83, 1991/92, 1993/94 and 1997/98. A study conducted in the recent past listed thirteen historical ENSO events during the period of 1920 and 1983 and conducted a comparison of long-term mean annual rainfall and that associated with an ENSO event[40]. This study found that an ENSO event produces below normal rainfall in most regions of Panama, the general exception being the drainage basin located north of the Cordillera on the Atlantic coast. Table 2.5.3 presents a reproduction of data recently developed in a study of variations and trends in the historical rainfall and runoff that shows the percent decrease in annual rainfall for the most recent and significant ENSO events[41]. As shown in Table 2.5.3, decreases of record rainfall and runoff in the watershed were significant during ENSO events. Further the study demonstrated that the most affected months during these events were the dry and transitional periods between seasons[42].

2.6 Electrical Power Demand in the Canal Region

Access to abundant and reliable electrical power from Empressa de Transmision Electrica (ETESA) and the Central Nacional de Despacho (CND) of the Sistema Interconectado

[39] Ibid. 36.
[40] Estoque, M.A., et. al.; 1985
[41] Ibid. 36.
[42] Ibid 36.

Nacional (SIN), as made available by private and public electrical power generators, is essential for the support of domestic growth and the public's well-being, as well as for supporting the expansion and vitality of commercial and industrial activities in the Panama Canal region.

Presently, more than an estimated 2.8 million people inhabit the Republic of Panama; of which more than 1.5 million inhabit the Panama Canal region. As previously discussed in Section 2.3.2, the projected annual growth rate between the present and year 2050 is estimated to be approximately 0.9%. Assuming this projected rate of growth is consistent nationwide, the population of Panama and the Panama Canal region will increase from approximately 2.8 million and 1.5 million, respectively, to a population in year 2050 of approximately 4.4 million and 2.6 million, respectively[43]. Given, residential customer demand for electrical power presently accounts for approximately 30% of total electrical power grid demand, future population growth throughout Panama plays an important factor in power demand forecasting to meet future electrical power requirements[44].

Historically, the Panamanian economy experienced annual GDP growth rates of 6.7% during the period between 1989 and 1994 and 3.3% during the period of 1994 and 1999[45]. Recent studies estimate an annual growth in the GDP of 4.4% through year 2020 and 2.3% through year 2050[46]. Further, growth in consumer purchasing, export activities and investments in the Panama Canal region are estimated to increase at average annual rates of 1.5%, 1.6% and 3.2%, respectively[47]. Economic expansion translates into increased demand for electrical power and will necessitate consideration when forecasting future electrical power requirements.

[43] www.populationaction.org/why-pop/water/water-table6.htm; *Sustaining Water, Easing Scarcity.*
[44] *Report on Power Market Study (draft)*; Harza Engineering Company, LLC; November, 2000.
[45] Ibid. 44.
[46] Ibid. 14.
[47] Ibid. 14.

2.6.1 Existing Electrical Power Infrastructure

Presently, as shown in Table 2.6.1 and on Plate 2.6.1, the total installed electrical power generation capacity in Panama is approximately 1,388.4 MW. The net amount of this production capacity connected to SIN is approximately 1,374.2 MW, of which the ACP generates approximately 153 Mw or 11% of the total installed capacity. Approximately 44% of this electrical power production capacity is hydroelectric power generation. The balance of electrical power generation is accomplished by means of fossil fuel fired facilities; namely gas turbines, fired steam generators and internal combustion units. As shown in Table 2.6.1, there are nine private and public electrical power generators that include the ACP. There are three electrical power distribution companies in Panama (EDE – Chiriqui (EDECHI), EDE – Elektra Noreste (ELEKTRA) and EDE – Metro Oeste (EDEMET), two of which also operate electrical power generation facilities, as shown in Table 2.6.1. Electrical power generated at the ACP's Gatun and Madden Dam facilities are used to support canal operations, commercial, residential and public requirements in the Panama Canal region. The ACP's electrical power generation facility at Miraflores typically serves as a backup for the hydroelectric power generation plants during conditions of high lake water levels and provides electrical power during times of low lake water levels.

ETESA is responsible for the operation and maintenance of the SIN electrical power transmission system, CND operations and development of SIN generation and transmission expansion plans. Currently, the transmission system, as shown on Plate 2.6.1, consists of approximately: 1) 580 kilometers of 230kV transmission lines; 2) 175 kilometers of 115kV transmission lines; and 3) 10 – 230kV electrical power substations having a capacity of 885 MVA[48].

[48] Ibid. 44.

2.6.2 Current Electrical Power Demand

Total electrical power consumption in Panama accounting for system distribution to metered customers, large clients and power exports has, as shown in Table 2.6.2a increased from approximately 3,997 GWh in 1998 to an estimated consumption level of approximately 4,774 GWh for year 2001; representing annual increases during this period of 7.8%, 4.7% and 5.8% for years 1999, 2000 and 2001, respectively[49]. Shown in Table 2.6.2b are recent data of monthly and annual maximum electrical power demand in Panama for years 1999, 2000 and 2001. As shown in this table, average corresponding monthly electrical power demand maximums between years 1999-2000 and 2000-2001 increased at rates of 3% and 6%, respectively[50]. In assessing current and forecasting projected demands for electrical power, previous electrical power demand surveys and studies have taken into account the loss of electrical power transmission and distribution system as a result of: 1) systemic resistance; 2) voltage steps; 3) climatic conditions; 4) insulation factors; and 5) non-metered withdrawals from the electrical power distribution system. According to recent ETESA historical data as shown in Table 2.6.2c, that portion of total electrical power consumption attributed to electrical power transmission system losses for years 1999, 2000 and 2001 has amounted to 3.5%, 3.6% and 2.7%, respectively[51]. Distribution system loses have historically been more significant; on the order of approximately 18%[52].

2.6.3 Projected Electrical Power Demand

Shown in Table 2.6.2d are electrical power demand, peak load, load factors and rates of growth for the SIN from 1990 to the present[53]. As shown in this table, the recent historical average annual growth rates for electrical power demand and in peak loads are

[49] www.etesa.com.pa; CND; Historical Data.
[50] Ibid. 49.
[51] Ibid. 49.
[52] Ibid. 44.
[53] Ibid. 44. & 49.

approximately 5.6% and 5.7%, respectively. For the same recent historical period the SIN annual system load factor averaged approximately 67.5%; however, the load factor value increased in year 2000 to 70.1% reflecting a sudden increase in systemic stress[54]. As shown in Table 2.6.2b, monthly peak loads and energy demands on SIN vary throughout the year. However, the trends remain relatively the same; increasing steadily through the first quarter of the calendar year and reaching peaks levels April through August, then tapering with some fluctuation to a low level in January. Typically, on a daily basis, peak loads of the SIN occur between the hours of 1100 and 1500 Monday through Saturday and between the hours of 0700 and 2000 on Sunday[55].

In a recent effort to develop an SIN demand forecast, the three electrical power distribution companies identified a medium and a high electrical power demand scenario for each of their customer markets, and then combined them into a total SIN demand forecast provided in Table 2.6.2e[56]. Electrical power demand values were calculated on the basis of total estimated energy consumption and estimated energy losses in the transmission and distribution systems. SIN peak load demands were developed on the basis of the electrical power demand forecast and an estimated annual system load factor of 69.5%. Estimated electrical power losses in the transmission and distribution systems as a percentage of total energy consumption was estimated to decrease from approximately 20% in year 2001 to approximately 14% in year 2015. As shown in Table 2.6.2e, the average annual growth rates of forecasted electrical power demand of SIN and peak load for the medium and high scenarios are approximately 5.6% and 7.0%, respectively.

In consideration of: 1) the current total electrical power production capacity of 1,374.2 MW, 2) ETESA's 15-year plan to install additional electrical power production capacity, 3) an optimistic reliability factor of 95%, 4) the above discussion of current and projected electrical power system losses, and 5) the projected demand scenario in Table 2.6.2e;

[54] Ibid. 44. & 49.
[55] Ibid. 44. & 49.
[56] Ibid. 44.

Table 2.6.2f presents a comparison of projected net electrical power production available for consumption with the projected high power demand scenario from the present to year 2015 to assess the projected levels of reserve electrical power capacity or the shortage of it[57]. As shown in Table 2.6.2f, an initial annual average reserve of approximately 14% of net available power is projected through year 2005; however, this level of reserve diminishes to an annual average of approximately 3.5% of net available power during the period of year 2006 through year 2015. The combined annual average reserve for the entire period is approximately 7% of the net available power. The high power demand was used for this comparison to balance-off an optimistic reliability factor 95% used in previous studies. In consideration of the variety of economic variables that impact electrical power demand, as well as demand forecasts from ETESA's present planning cycle, the reserve margin range of 14% to 3.5% could be too narrow. Considering: 1) the loss of a production facility for turn-around maintenance or mechanical upgrades, 2) an annual average rate of domestic and economic growth outside the ranges of 0.9% and 4.4%, respectively, 3) an increase in canal capacity, 4) implementation of ARI's general development plan for the canal region and modestly exceeding initial development goals and objectives, and 5) emerging power export opportunities outside the Republic of Panama; a reduction of the reserve margin from the range of 14% in the near term to 3.5% in the long term could easily evolve into a negative attribute that adversely affects pursuit of growth opportunities and diminish expectations of prosperity.

2.7 Environmental and Ecological Baseline Conditions in the Canal Region

2.7.1 Environmental Baseline Conditions

Physical Setting

The evolution and formation of earthen material (rock, soil and sediments) in the Panama Canal watershed region are principally the result of the dynamic interaction between all

[57] Ibid. 44.

environmental elements that affect weathering. Soils throughout the areas of Ciricito, Escobal and Cuipo north of Gatun Lake derive principally from the Gatun Formation (half-Miocene) and are characterized as a gritty, sandy, clayey conglomerate that are lightly resistant to erosion. Igneous rock is prevalent in the Panama Canal basin, indicating a slow rate of soil and sediment evolution. Transformation of rock structure to soil medium is affected by specific chemical composition and the extent of environmental exposure rendering area specific characteristics to soil and sediments. In this manner, igneous rock formations bear a similarity to lower-Miocene basalts in the areas of Camoano and Cacao. As a result, soils in these areas are not well developed, are prone to be acidic and tend to be highly erosive in the absence live vegetation and organic matter. Soils along the Chagres River extending to Madden Lake are primarily calcareous and characterized generally as a gritty, clayey, fine grain tertiary agglomerate formation composed of pyroclastic rock, clay basaltic tufts and andecite. As a result, these soils lack loamy-colloidal adhesive components and are very erosive. Generally, at the 656-foot elevation mark in the Rio Indio, Gatun Boqueron, Pequeni, San Miguel and Chagres sub-basins soils derive from primarily the cretaceous period and are characterized as an agglomerate of lavas, tufas andesitics and altered basaltic. Steep slopes (>45°) are generally absent of stable soil, however some vegetation has taken root over time enhancing slope stability. Despite the variations throughout the watershed region, the physical setting can be generally described as loamy with shallow textured basin floors containing a high percentage of silica that are highly susceptible to erosion.

Water Quality

Please refer to Section 2.4 above.

Air Quality

Air quality in the Panama Canal region is good, based on the low levels of suspended particulates and sulfur and nitrogen dioxides that meet USEPA and World Bank

benchmark air quality standards. Emissions from transiting ships and other Canal operations are minimal in relation to the overall air quality in the air basin. Air quality is impaired during the slash and burn activities which occur at the beginning of the dry season in March or April when areas of forests and secondary growth are burned to prepare the land for cultivation[58].

Solid and Hazardous Waste Generation

Sanitary wastes from communities within the Panama Canal region, discharged into water bodies in the watershed, are a significant source of hazardous waste generation as only an estimated 14 per cent of the discharge is treated, and that receives only primary treatment. It is estimated that there are at least 62 sanitary waste outfalls discharging untreated wastes directly in the canal region waterways[59]. The impact of this discharge on bacterial levels in the Panama Canal, Gatun Lake, and Alhajuela Lake is discussed in Section 2.4 and 4.2.

Runoff from deforested areas contributes to erosion and accumulation of sediment, potentially contaminated from pesticides and fertilizers used in agricultural operations. Increased sedimentation with a concomitant increase nutrient content stimulates the growth of aquatic weeds and algae with an overall reduction in water quality.

2.7.2 Ecological Baseline Conditions

An extraordinary diversity of plant and animal species is associated with the Canal Zone area that extends five miles at each side of the canal channel (see Appendix B). With the exception of urbanized areas, dense tropical forests extend up to the former boundary of the Panama Canal Zone. The tropical forest comprises semi deciduous disturbed forest,

[58] *Environmental Report: Panama Canal Gaillard Cut Widening Feasibility Study*; Panama Canal Commission; March, 1987.
[59] Ibid. 31.

semi deciduous primary forest, evergreen primary and disturbed forest, shrubland, grassland, and mangrove forest, the latter primarily in the Colon area[60].

Vegetation closest to the canal comprises grasses, both native and introduced and the diversity of plant species is well documented. For example, the environmental report prepared to support the Panama Canal Gaillard Cut Widening Feasibility Study provides a thorough inventory of vegetation in the Panama Canal region[61].

Since the 1950's peasant agriculture and ranching has contributed greatly to deforestation in areas outside the protected former Panama Canal Zone and protected areas around Alhajuela Lake. During the past five decades over 70 per cent of the flora in the Panama Canal watershed region has been destroyed. The areas that remain in the watershed are: 1) Primary Forest (215 acres); 2) Secondary Forests (116 acres); 3) Stubble, where primary and secondary forest have been eliminated (138 acres); and, 4) Grasses to include pasture lands (264 acres). These areas, no longer protected military areas, are undergoing deforestation[62].

Aquatic Vegetation

Steep slopes at the canal margins, the limited light penetration at depth, and constant disturbance of transiting ships limits the development of aquatic vegetation in the lock areas. Within Lake Gatun there are at least 28 species of aquatic plants with the dominant species, *Hydrilla verticellata* an introduced species from India[63]. Because of its dense foliage it is considered a weed and its growth is closely monitored and controlled to prevent clogging of lakes and lagoons. Other aquatic plants that are systematically

[60] *Environmental Impact Report, Initial Phase, Construction and Operation of Panama Railroad*; Radian International, LLC; May 1998.
[61] Ibid. 58.
[62] *Panama Canal Watershed Monitoring Program Report, Forests*; Smithsonian Tropical Research Institute; 2000.
[63] Ibid. 58.

controlled are the water hyacinth (*Eichornia crassipes*) and water cucumber *(Ceratophyllum demersum)*[64].

Wetlands

Wetlands occur in seasonally flooded areas along the margins of the lakes and lagoons. Trees occurring in wetlands include red and white mangroves in the Colon area. A commonly found flowering plants species is palo bobo *(Erythrinia fusca)* around Gatun Lake. Other vegetation typical of these seasonal wetlands includes water hyacinth, ferns, and sedges[65].

Fauna

Panama's National Institute for Renewable Resources (INRENARE) lists the variety of animals that may be found within watershed areas extending throughout the Panama Canal region. A relative complete listing of fauna in the Panama Canal region can be found in the environmental report prepared to support the Panama Canal Gaillard Cut Feasibility Study (see Appendix B). The major taxonomic groups include mammals, reptiles, amphibians and birds that are generally discussed as follows:

Mammals

Long ago widespread hunting led to the near disappearance of large animals such as the jaguar, tapir, and capybaras. The most commonly seen mammals in the area adjacent to the canal are small mammals such as opossums, armadillos, sloths, rabbits, bats, raccoons and various rodents. Uncommon aquatic mammals include the long-tailed otter in Gatun Lake and the West Indian Manatee, which has been observed also in Miraflores Lake[66].

[64] Ibid. 60.
[65] Ibid. 60.
[66] Ibid. 62.

Reptiles and Amphibians

The green iguana, a protected species, is abundant in the canal area along the canal bank and shores of Lake Gatun. The American crocodile, considered endangered throughout Central and South America, is found in limited numbers in Gatun Lake. Snakes are numerous in Panama with over 130 different species, including the commonly encountered boa constrictor. Venomous snakes occurring in the canal areas include corals and vipers. Other common reptiles are turtles, lizards, frogs, toads and salamanders[67].

Birds

Panama is rich in bird species and over half are found in the Panama Canal region. Before protective controls were instituted, hunting reduced the native population of game birds such as wild turkeys, eagles, quail and ducks. Tertiary consumers such as gulls and herons dependent on small fish are less frequently seen because of the reduction in small fish by the accidental introduction of the sergeant fish (see below). In the areas of the project, buzzards, hummingbirds, kingbirds, finches, and flycatchers are anticipated to be amongst the birds commonly encountered[68].

Zooplankton

Virtually all zooplankton communities consist of crustaceans, principally cladocerans and copepode, and rotifers[69].

Fish

Historically, fish found in Gatun Lake, the locks and adjacent drainage courses are listed in Appendix B. The most common freshwater fish recorded from Gatun Lake include the

[67] Ibid. 58.
[68] Ibid. 58.
[69] Ibid. 58.

families Atherinidae, Characidae, Cichlidae, Goeidae, Eleotridae, Pimelodellidae, and Poecilidae. Several marine species also enter via the locks. The accidental introduction of the predatory South American fish, sergeant fish (*Cichla ocellaris*) reduced many of the native species[70].

Bethnic Organisms

Fresh water organisms dwelling on the bottom of water bodies in the Panama Canal region principally comprise mollusks (clams and snails), annelids (worms) and arthropods. Establishment of such communities in the relatively turbulent environment of the locks is difficult. In contrast, the conditions of water quality and accumulated sediment in Gutan Lake favor bethnic organisms. A study of areas near Barro Colorado Island showed that that clams and snails comprised the greatest biomass[71].

2.8 Socio-Economic Baseline Conditions in the Canal Region

2.8.1 Population Trends and Forecasts

According to the United Nations Population Division, the population of Panama was 2,855,694 in the year 2000. This was up 22 percent from the 1990 population of 2,329,329 persons (an average annual growth rate of 2.06 percent). The country's population is forecast to grow to 3,451,379 by year 2015 (1.27 percent average annual growth from 2000 to 2015); to 3,779,091 by year 2025 (0.91 percent average annual growth from 2015 to 2025) and to 4,262,033 by year 2050 (0.48 percent average annual growth from 2025 to 2050). Shown in Table 2.8.1a are present population projections for the Republic of Panama.

[70] Ibid. 58.
[71] Ibid. 58.

According to the "Long-Term Forecast for M& I Water Demand" study completed in January 2001 by Harza (an engineering firm engaged by the ACP to perform several studies in support of ACP expansion activities), the combined population of the Panama and Colon provinces was approximately 1,548,260 in year 2000. This region's population was expected to grow to 1,867,746 by year 2010 (3.82 percent average annual growth from 2000 to 2010); to 2,108,456 by year 2020 (2.45 percent average annual growth from year 2010 to year 2020); to 2,310,036 by year 2030 (1.84 percent average annual growth from year 2020 to year 2030); to 2,462,974 by year 2040 (1.29 percent average annual growth from year 2030 to year 2040); to 2,571,481 by year 2050 (0.87 percent average annual growth from year 2040 to year 2050) and to 2,643,151 by year 2060 (0.55 percent average annual growth from 2050 to 2060). Shown in Table 2.8.1b are present population projections for the provinces of Panama and Colon. Additional population trend data is provided in Appendix C-1.

2.8.2 Demographic Trends

The country of Panama's population is very young. Roughly 50 percent of the population is under the age of 25, according to the United Nations Population Division. Approximately 17 percent of the population is aged 25 to 34, and approximately 13 percent of the population is aged 35 to 44. Roughly 9 percent of the population is aged 45 to 54, with the balance of approximately 11 percent of the population aged 55 and above. By year 2050, Panama is projected to have 19 percent of its population aged 14 and under, 57 percent aged 15-59 and 24% aged 60 and above.

Currently, the life expectancy in Panama is 73.6 years. This is projected to increase to 74.5 years by year 2005, 75.9 years by year 2015, 76.5 years by year 2025 and 79.2 years by year 2050.

Literacy in Panama has been improving dramatically. The aggregate illiterate population has decreased 29 percent, from roughly 256,000 illiterate persons in year 1990 to 183,000

illiterate persons in year 1999. The illiteracy rate has dropped over the same time period from 11 percent to 7 percent. Additional demographic trend data is presented in Appendices C-2 and C-3.

2.8.3 Economic Trends

In year 1999, the GDP of Panama was estimated at $9,576,000,000 (in current US Dollars) by the American Chamber of Commerce and Industry of Panama. In constant year 1990 US Dollars, this figure equates to $7,979,000,000, which is an average annual increase of 5.5 percent over the 1990 GDP of $5,315,000,000. The growth in GDP has led to a significant reduction in unemployment over the past ten years. The unemployment rate decreased 3.6 percent annually, or 28 percent in total, from 1990 to 1999. The unemployment rate was 16.2 percent in year 1990 and had declined to reach a level of 11.6 percent by year 1999. Wholesale and retail trade made up the largest component of GDP in year 1999, at 15.7 percent. The second largest component was transportation, storage and communications, at 12.5 percent. These two sectors are largely fueled by operations of the Panama Canal and the Colon Free Trade Zone.

The Panama Canal has seen a slight decrease in activity over the past two years. Total canal transits decreased 5.9 percent from a level in year 1999 of 14,336 transits to 13,492 transits in year 2001. Total cargo decreased over this same time frame, from 195.98 million tons to 193.15 million tons, a decrease of 1.4 percent. Tolls assessed on Panama Canal traffic increased 1.2 percent from year 1999 to year 2001, from US$568,853,491 to US$579,514,220.

At the individual level, per capita income has increased an average of 4.9 percent annually from year 1990 to year 1999, from US$2,217 in 1990 to US$3,419 in year 1999. For the provinces of Panama and Colon, average annual wages were US$3,045.12 in year 1999. Additional economic trend data is presented in Appendices C-4 through C-8.

3.0 TECHNICAL ANALYSIS

3.1 Identification and Discussion of Technical Alternatives

The proposed project, as described in Section 1.3 and as generally illustrated in Plates 1.3a and 1.3c, involves the following nine processes:

1) Lock water recovery;
2) Saltwater intrusion prevention;
3) Lock water retention;
4) Water treatment;
5) Water transportation;
6) Water discharge;
7) Hydroelectric power generation;
8) Electrical power interconnection and transmission; and
9) Solid waste disposal.

A general description of each of the above nine processes and various alternatives identified to implement each are provided in the following subsections.

3.1.1 Lock Water Recovery

On the basis of canal capacity projections, a range of volumes to be recovered, treated and recycled was considered. As such and in consideration of: water demand forecasts; ship lockage projections articulated in sections 2.1 through 2.5; and future operational flexibility; the following three technical approaches were identified and considered:

1) Recovery of 100 percent of the volume of the exit lock chamber;
2) The discrete recovery of 60 percent of the volume of the exit lock chamber; and,
3) The discrete recovery of 30 percent of the volume of the exit lock chamber.

The recovery of 100 percent of the lock water discharged from the exit lock chambers of the Gatun and Miraflores lock systems would involve the physical tie-in to existing discharge culverts with new underground discharge culverts. These discharge culverts will be constructed in tunnels bored beneath the canal structure as described in detail in Section 3.2 and will be designed to divert, by gravitational force, the flow of discharged lock water to an onshore retention reservoir at a flow rate of sufficient magnitude as to not interrupt canal capacity throughput maintaining the 8 minute drain window specified by the ACP. Further,

The discrete recovery of 60 or 30 percent of the volume of lock water discharged from the exit lock chamber the Gatun and Miraflores lock systems would involve the construction of wet well structures and the installation of turbine pumps as described in greater detail in Section 3.2.

3.1.2 Saltwater Intrusion

Saltwater intrusion into the lake systems of the Panama Canal is a process in which seawater migrates up stream through the lock systems into the freshwater lakes as a result of the high density of saltwater. This process occurs when lower lock chamber doors open to the ocean and the denser seawater current displaces the lighter freshwater as it flows into the lock chamber where it is trapped upon closure of the lock chamber doors. This process repeats itself as successive lock chambers are opened and closed during a lockage until the seawater has reached the freshwater lake system. As a result of this process, Miraflores Lake has become "brackish" causing significant changes in the ecosystem and creating a threat to the fresh water quality of Gatun Lake by the migration of this "brackish" water through the Pedro Miguel lock system and Gaillard Cut to Gatun Lake. Likewise, saltwater intrusion from the Atlantic Ocean ship channel presents a consistent threat of migrating through the Gatun Lock system directly to Gatun Lake.

An integral component and important aspect of the proposed Project is the process of arresting and preventing future saltwater intrusion. This can be accomplished by

employing a proprietary process developed by Wpsi that increases the density (or pressure) of the freshwater water in respect to that of seawater at the point of interface between the freshwater and seawater. This proprietary process, shown conceptually at Plate 3.1.2a, Plate 3.1.2b and Plate 3.1.2c, applies the three concepts that are generally described below. These concepts were evaluated for application, in part and collectively, at the exits of Gatun and Miraflores lock systems to significantly reduce or eliminate saltwater intrusion:

1) **Pneumatic Curtain**. The pneumatic curtain involves the use of compressed air pumped into a fine air bubbler system installed at the bottom of the channel in close proximity to the freshwater – seawater interface at the mouth of each exit lock chamber and in such a manner as not to interfere with ship channel navigation. As compressed air is pumped through the fine air bubbler system, air bubbles rise to the water surface causing the water level to rise in displacement inside the bubbling zone. The second phenomenon that occurs is the mixing of lower and upper water zones in the ship channel. This mixing phenomenon equalizes the density from the bottom of the ship channel to the surface and in turn creates a density barrier. This barrier in conjunction with the increase in pressure offsets that of saltwater and thus prevents intrusion. Similar pneumatic curtains have been used throughout the world in fresh water lock systems to successfully prevent saltwater intrusion. Such systems have demonstrated an intrusion reduction from 50% to 80%[72].
2) **Hydraulic Mounding**. Hydraulic mounding involves the same basic principle as "pneumatic mounding" created by the pneumatic curtain. Water in large volumes is introduced vertically upward into the ship channel in close proximity to the freshwater – seawater interface at the mouth of each exit lock chamber in such a manner as not to interfere with ship channel navigation. The flow friction created by the "up-welling" of water creates the phenomenon of "hydraulic mounding." "Hydraulic mounding" increases the pressure within the mounding zone. Increasing the pressure in the mounding zone also increases the local

[72] Ibid. 1.

weight/density of the freshwater. This increase in pressure offsets that of saltwater and thus arrests intrusion. Hydraulic mounding barriers have demonstrated an intrusion reduction from 50% to 80%[73].

3) **Retention Reservoir**. Use of a retention reservoir designed to receive 100% of the exit lock chamber water volume and having a water level within it marginally above that of sea level to prevent the backflow of seawater, enables the application of the hydraulic mounding. Further, the retention reservoir acts as a separation barrier between the fresh water from the lake systems and saltwater from the ocean.

Plates 3.1.2.a through c (Saltwater Intrusion Prevention System) show all three conceptual approaches in relation to each other; the exit lock chamber, and the freshwater – saltwater interface, as well as the slight change in elevation between the two surfaces of fresh- and saltwater. This increase in freshwater elevation resulting from the implementation of any one or combination of intrusion prevention concepts, concurrent with the processes of recovering, reclaiming and recycling discharge lock water from the canal exit lock chambers, sufficiently increases the pressure in the freshwater region such that it exceeds the density pressure of the seawater, thereby creating a barrier to saltwater density current intrusion into the exit lock chambers and subsequently the lake systems.

3.1.3 Lock Water Retention and Storage

Upon recovery and conveyance, the process of retaining discharged lock water in a retention reservoir serves several functions:

1) The retention reservoir accomplishes the process of first stage treatment by allowing for:
   a) the removal of debris and suspended matter from the influent at the reservoir inlet,

[73] Ibid. 1.

b) sufficient time for settling and removal of denser materials present in the influent,
c) aeration to: i) agglomerate and float suspended particles to the surface for separation, ii) initiate the process of removal of biological mass from the influent, iii) accomplish removal of oils and greases, and iv) flash hydrocarbons that may be present in the influent;
d) accommodating the addition of chemical reagent, and
e) separation of suspended matter;

2) The retention reservoir acts as a mechanical barrier between fresh lake water and the ocean saltwater; and,
3) The retention reservoir provides the means to implement hydraulic mounding.

Two technical approaches were identified and considered for accomplishing the above process functions:

1) **Multi-chamber Retention Reservoir**. Use of a multi-chamber retention reservoir would accomplish all the above process functions in one structural facility.
2) **Single-chamber Retention Reservoir**. Use of a single-chamber retention reservoir would accomplish the process functions noted in items 1) a., b., 2) and 3) above. Additional facilities external to the reservoir would be required to process functions 1) c., d. and e..

The process of retaining exit lock water discharged to the reservoir is a function of canal operations. The size of the retention reservoir must accommodate present and future discharge water volumes as a function of present and forecasted canal capacity, the phased approach to project implementation as described in Section 1.3, as well as influent holding time needed to best facilitate water treatment processes (separation, settling and removal of matter from the influent). As such and consistent with Section 3.1.1 above, the following three approaches were identified and considered:

1) a below grade retention reservoir design to accept 100 percent of the volume of the exit lock chamber;
2) a below grade retention reservoir designed for accepting 60 percent of the volume of the exit lock chamber; and
3) a below grade retention reservoir designed for accepting 30 percent of the volume of the exit lock chamber.

3.1.4 Water Treatment

The levels of water treatment associated with the proposed project fall in two quality categories:

1) Treatment of retention reservoir influent received from the exit lock chamber to a beneficial use standard enabling it to be recycled to the lake system; and,
2) Treatment of a portion of the retention reservoir influent received from the exit lock chamber to a "potable" safe drinking water standard for human consumption.

Treatment of retention reservoir influent to a beneficial use standard according to Panamanian Regulation 24-99 (see Appendix D) and World Bank standards, and as such suitable for recycling to the canal lake system, would require first stage treatment whereby debris, suspended organic and inorganic particle matter, oils and grease, and volatile hydrocarbons would be removed. First stage treatment at both Gatun and Miraflores treatment facilities during Phase I of the proposed Project would be accomplished through the processes of sedimentation (screening and settling), clarification (the addition of chemical reagent, flocculation, settling and skimming) and aeration. Further, the treatment process at the Miraflores Treatment Facility that is necessary to achieve the water quality standards that allow for discharge to the canal lake system will require incorporation of a desalinization plant to remediate the "brackish" condition of retention reservoir influent during Phase I of the proposed Project.

Following first stage treatment at the Gatun Treatment Facility during Phase I of the proposed Project, advanced treatment of a portion of the water is required to achieve "potable" fresh water drinking standards (see Appendix D) for human consumption in accordance with Panamanian law and World Bank standards. This is accomplished by conveying a portion of the first stage treatment effluent through advanced treatment processes where filtration, demineralization and detoxification are accomplished. The process of filtration incorporates blending of chemical reagent in the water to precipitate dissolved solids, the agglomeration of precipitate, clarification/settling, sludge removal, and mixed media filtration (gravel, sand and anthracite coal). The process of demineralization will employ ultra- and hyper-filtration (reverse osmosis) to remove extremely fine particles from the water. This advanced treatment stage at the Miraflores Treatment Facility during Phase I of the proposed Project is accomplished in desalinization plant. Lastly, the treated water at both facilities flows into a clear well were it is sterilized and fluorinated prior to conveyance to the public supply system as it passes through storage facilities and the pumping station.

Water treatment processes do not change in Phase II of the proposed Project at the Gatun Treatment Facility; however, the presumption that Miraflores Lake water will return to a fresh water quality condition prior to Phase II will allow for the decommissioning and replacement of the desalinization plant at the Miraflores Treatment Facility with a potable water production plant as at the Gatun Treatment Facility.

3.1.5 Water Transportation and Discharge

Water influent to the retention reservoir is treated either for transportation and discharge to the canal lake system or for conveyance to the public potable water supply system, or discharged through the saltwater intrusion prevention system to the ocean ship channels.

Transportation of treated water from both treatment facilities to the canal lake system can be accomplished through reinforced fiberglass pipe and/or steel concrete lined pipe appropriately sized to accommodate maximum anticipated flow volumes and installed

above- and/or below grade. Installation of above grade pipelines will require easements along the pipeline alignments, would be constructed in discrete sections anchored on durable cradles, and secured with a barrier system to prevent unauthorized access. Installation of below grade pipelines also requires easements along the pipeline alignments, would be constructed in discrete sections and laid in engineered beddings.

Conveyance of treated water from potable water production processes at the Gatun Treatment Facility to ACP and/or IDAAN potable water supply tie-ins can be accomplished as described in the above paragraph. However, conveyance of treated water from potable water production processes at the Miraflores Treatment Facility to ACP and/or IDAAN potable water supply tie-ins will require the construction and installation of a conveyance structure below the water surface in the ship channel from the ship channel shoreline on the water treatment facility side to the ship channel shoreline on the ACP canal facilities side. This construction and installation task will be accomplished along side of and concurrently with the construction of the retention reservoir discharge/return culvert as described in detail in Section 3.2 and in a manner not to interfere with canal operations. The portion of this conveyance structure approaching and exiting from the shoreline of the ship channel will be installed above grade to the appropriate tie-in location. Likewise, that portion of pipelines conveying treated water from where the treatment facility discharge pipeline enters the lake system to the discharge diffuser will also require below water surface construction from the lake shoreline an appropriate distance from the shoreline that ensures optimum diffusion of the treated water and does not interfere with transit navigation through the lake.

Conveyance of treatment facility effluent to the ship channel will be accomplished through the same underground culverts that serve as the means to create "hydraulic mounding" for the saltwater intrusion system. This structure will be constructed in the same manner as referred above and as described in detail in Section 3.2.

3.1.6 Electrical Power Generation, Transmission and Interconnection

The generation, transmission and interconnection of hydroelectric power are very important components of the proposed Project having significant beneficial impacts on revenue potential and on environmental and socio-economic conditions. Three approaches, generally described below, were considered in regard to retrofitting the canal lock system with hydroelectric turbine generators to capitalize on the availability of hydraulic power potential.

1) **Parallel Path "Pit" Turbines**. This approach would involve the construction of new parallel path culverts, as shown generally shown in Plate 3.1.6, and installation of hydroelectric "pit" turbines in the parallel path culverts to capture the hydraulic energy of the lock water discharge flowing through the lock discharge culverts. This energy is converted to electric power through the turbine driven generators and used to support the power requirements of the proposed Project, as well as make excess generated power available to the public power grid. Twenty-one (21) high-volume, low-head hydroelectric "pit" turbines and power generators would be installed; nine in the Gatun Locks; six in the Pedro Miguel Locks; and, six in the Miraflores Locks. Size and design of each "pit" turbine is a function of installation location and the hydraulic head available at that location. Generally, there would be 12 - 8.9 meter-head turbines capable of generating 6.5 MW and 9 - 17 meter-head turbines capable of generating 14.2 MW. In total, the system would generate approximately 90 MW during Phase I and 110 MW during Phase II. This approach is discussed in further detail in Section 3.2.
2) **Retrofit Drain Culverts**. This approach would involve the installation of hydroelectric turbines in the lock chamber drainage culverts to capture the energy of the discharge lake water through the lock system to support the water reclamation facilities and off site electrical power requirements. The turbines would be placed within the lock culverts on the down streamside for each lowered step in elevation change. Eighteen high-volume, low-head hydroelectric turbine

power generators would be installed; nine in the Gatun Locks; three in the Pedro Miguel Locks; and, six in the Miraflores Locks. Each turbine is capable of generating an amount of hydroelectric power consistent with the volume of water flow. During Phase I of the propose project, each turbine would generate approximately 1.5 MW; all eighteen generating approximately 27 MW. During Phase II, each turbine would generate approximately 1.7 MW; for a total of approximately 30 MW. This approach is discussed in further detail in Section 3.2.

3) **Retrofit Lock Chamber Doors**. This approach is to retrofit the each set of lock chamber doors with an array of smaller high-volume, low-head hydroelectric turbine generators. This approach would require changing existing canal operations. The lock chamber doors, where each turbine is installed, would be equipped with louvers to allow a portion of the water to flow through the turbine to generate electrical power. This would necessitate a change in the canal operations protocol by which drain culvert gate valves are opened and closed to accommodate a portion of the water flow through the turbine. As a function of equipment design and lower available water head pressure, this approach would be less mechanically efficient than the previous two approaches.

Power would be generated at 115v/13.8 kV and transmitted by cable from the point of generation to an electrical substations located at the Gatun and Miraflores treatment facilities. Power at 115V/13.8kV would be conveyed from the substation to electrical equipment in the treatment facilities; concurrently, excess power would be transmitted by the combined use of below grade cable and overhead transmission lines as follows:

1) From the Gatun Electrical Substation to tie-ins with ACP electrical substation facilities and/or EDEMET substation facilities by overhead transmission;
2) From the Pedro Miguel Locks to the Miraflores Electrical Substation by overhead transmission; and
3) From the Miraflores Electrical Substation by overhead transmission to near shoreline of the ship channel, by below water surface along the alignment of the

treatment facility overflow return culvert to the far shoreline of the ship channel, and lastly by overhead transmission to tie-ins with the ACP electrical substation facilities and/or EDEMET substation facilities.

At each of the above terminal points, the transmission lines would be interconnected with appropriately sized and specified transformer and switching gear to allow electrical power to pass to the ACP electrical grid system and/or the EDEMET distribution system.

3.1.7 Solid Waste Treatment and Disposal Alternatives

The water treatment process described in sections 3.1.3 and 3.1.4 above will produce solid wastes and sludge as a byproduct of process operations. Solid wastes are most likely to consist of mineral silts, manmade refuse, vegetation debris, animal carcass, etc. and will be collected, segregated and disposed of in accordance Panamanian rules and regulations and/or World Bank standards. Wet sludge generated by treatment processes and consisting mostly of mineral solids and biomass that was entrained in the lake water will be removed, collected, dewatered, dried and the filter cake appropriately tested for hazardous compounds. Shown at Table 3.1.7 are estimates of dry solid wastes produced by the Gatun and Miraflores Treatment Facilities during Project Phases I and II. Filtrate water from the dewatering process will be recycled to the water treatment facility for further processing. If hazardous compounds are not found in the filter cake material, then the filter cake will be conveyed to soil amendment vendors for eventual use as agricultural supplements or clean fill material for other construction projects. If hazardous compounds are found in the filter cake material, then the sludge will be treated according to the character of contaminants found. Such treatment could include land farming, chemical fixation and sterilization, thermal oxidation, landfill disposal (as laws and regulation permit).

3.1.8 Seriatim of Technical Alternatives

The variety of technical approaches identified in this section for each process of the proposed Project are organized and presented as two sets of three alternatives in Tables 3.1.8 a.1 through a.3 and Tables 3.1.8 b.1 through b.3.; one set for each treatment facility (Gatun and Miraflores). For each of the two sets of tables, Alternative 1 is shaded in blue, Alternative 2 in green, and Alternative 3 in magenta. Summarized in Table 3.1.8c is the composite of these alternatives. A discussion of the description and an analysis of each of the three alternatives are provided in sections 3.2 and 3.3, respectively.

3.2 Descriptions and Discussion of Technical Alternatives

As shown in Table 3.1.8c, a set of three technical alternatives exist for each of the Gatun and Miraflores treatment facilities that accomplish the goals and objectives of the proposed Project. Given the difference between these sets is marginal, the alternatives are consolidated into one set of three and are identified as follows:

1) Alternative 1, 100% Diversion Case;
2) Alternative 2, 60% Diversion Case; and,
3) Alternative 3, 30% Diversion Case.

Each of these alternatives are described and discussed in the subsections that follow. *Discussion of alternatives implementation, as specifically pertaining to "what, where and how" issues such as the location of facilities, construction, scheduling, logistical and canal interaction operation issues, is presented for only the* ***preferred alternative*** *in Section 3.5.*

3.2.1 Technical Alternative 1, 100% Diversion Case

Technical Alternative 1 represents the case by which 100 percent of the volume of water in the exit lock chamber is diverted during discharge from Gatun and Miraflores exit

locks to the Gatun and Miraflores treatment facilities, respectively and thus referred to as the "100 % Diversion Case." Relative to processes associated with the proposed Project and the variety of approaches discussed in Section 3.1, this alternative is generally presented in the **blue** shaded portions Table 3.1.8a.1 and Table 3.1.8b.1 for the Gatun and Miraflores treatment facilities, respectively and is generally illustrated in Plate 3.2.1. A detailed discussion of each process follows:

Lock Water Recovery

As shown in Drawings PC01-FS001, -FS002, -FS004, and –FS005, a new culvert would be constructed from the proposed retention reservoir below the existing exit locks structures and tied into the existing exit lock drainage culverts. This new structural configuration would allow:

1) The drainage of all lock water discharged from the exit lock chamber to the retention reservoir;
2) The isolation of the drainage culvert from ship channel saltwater and tidal fluctuations; and
3) As necessary, the isolation of the retention reservoir from the existing exit lock drainage culvert without interfering with canal operations.

The principle of the lock water recovery system's structural design is to use the force of gravity to move water from the exit lock chamber to the retention reservoir as if it were a manometer. Gravitational force will constantly seek to maintain equilibrium in water levels between the exit lock and the retention reservoir as water in the retention reservoir is withdrawn for conveyance through the treatment processes or drained across variable height weir gate valves into the drainage culvert to the ship channel as described in detail below.

Sizing of the lock water recovery system is driven by the three parameters listed below; for which calculations are provided in Appendix E:

1) Drain water from the exit lock chamber through the lock water recovery system to the retention reservoir in eight (8) minutes so as not to impede canal operations;
2) Convey the entire volume of water typically discharged from the exit lock chamber that is necessary to allow the maximum sized ship to pass from the exit lock chamber to the ocean ship channel; and
3) Accommodate the forecasted transit capacity for year 2050.

As provided in Appendix E, the desired size of each lock water recovery system culvert is approximately 36 feet in diameter (or a cross sectional area of approximately 1,018 ft^2). The specific geometry of the culverts (cylindrical, elliptical, rectangular or arch) would be determined following the conduct of a rigorous hydraulic analysis during the engineering phase of the proposed Project. As shown in Drawings PC01-FS001, -FS002 and -FS005, a culvert would extend laterally from beneath the bottom of the retention reservoir to directly beneath the bottom of the far-side canal sidewall structure, perpendicular to each. The depth below an msl grade datum for each culvert would be determined following a rigorous geo-technical survey of the culvert alignments during the engineering phase of the proposed Project. For the purpose of this study, the depth to the centerline of each culvert is presumed to be approximately -91 feet. Drainage pipe sections, 18-foot diameter with a total length of approximately 22 feet would be installed vertically to connect the lock water recovery culvert with each existing sidewall drainage culvert.

Similarly, as shown in Drawing PC01-FS001, a second culvert would extend diagonally, at the same approximate depth, from the lateral culvert to directly beneath the existing center-wall discharge culvert. As with the sidewall laterals, drainage pipe sections, 18-foot diameter and a total length of approximately 22 feet, would be vertically installed to connect the second diagonal lock water recovery culvert with each existing center-wall drainage culvert.

The connection of each 18-foot diameter vertical drainage pipe extending from the lock water recovery culvert to the existing drainage culvert would be located "upstream" of existing discharge culvert gate valves as shown in Drawings PC001-FS001. With the existing "downstream" discharge culvert gate valves closed, lock water drain from the exit lock chamber would be diverted to the lock water recovery system and flow to the retention reservoir. Further, an isolation valve would be installed in the lock water recovery culvert downstream of the proposed culvert tie-in locations and upstream of the retention reservoir as shown in Drawing PC01-FS002. This valve configuration would allow, as necessary, the isolation of the water treatment facility(s) from existing drainage culverts in order to operate the existing drainage culverts as is done today.

As shown in Drawing PC01-FS001 and -FS004, the lock water recovery culvert is connected to the retention reservoir by four (4) 18-foot diameter vertical inlet pipes. Further, as shown in Drawings PC01-FS001, a gate valve is installed in the lock water recovery culvert at the retention reservoir providing redundancy in isolating the lock water recovery system from existing exit lock drainage culverts should such isolation be necessary.

Lock Water Retention and Discharge to Channel

As provided in Appendix E, the desired size of each of the two 25 million-ft^3 retention reservoirs (measuring 1,200 feet long, 250 feet wide and 85 feet deep) as shown in Drawings PC01-FS001 and -FS004 receives exit lock chamber water discharge from the lock water recovery system described above. Water flow to each retention reservoir, as described above, is accomplished by force of gravity; thereby eliminating the need for pumps. As influent water wells up into the reservoir it passes through a self-wiping debris screen designed to remove large debris material. The receiving and retention of influent water in the reservoir is a function of canal capacity and operations, as discussed earlier. In consideration of this and the need to accomplish first stage water treatment, the reservoir was sized to accommodate a 2½-hour retention time and have the necessary volume to optimize settling and "downstream" treatment processes (see Appendix E).

Each retention reservoir not only functions as a structure that accommodates the recovery and treatment of water discharged from the exit lock chamber, but also as a structure that is integral to the saltwater intrusion prevention system that is discussed later. As shown in Drawings PC01-FS001, -FS003 and -FS005, water outfall from each retention reservoir flows across variable height weir gate valves through the reservoir discharge culvert to the ship channel. Level controllers would be installed to control the flow of reservoir water outfall into the reservoir discharge culvert by automatically adjusting the height of the weir gate valves at the retention reservoir outfall. The level controllers would be set to constantly maintain a positive head in the reservoir of 3 to 4 inches above the level of the sea in the ship channel. This setting would prevent any backflow of ship channel water into the reservoir. This design capability to vary the water level in each retention reservoir enables treatment facility operations to dynamically manage the volume of influent retained for treatment to support canal capacity needs versus that allowed to discharge to the saltwater prevention system in the ship channel. It is the design capability to dynamically manage the variance of the level of water in each retention reservoir that enables the physical relationship between the retention reservoir structure and the exit lock chamber to behave as a manometer.

Water outfall from each retention reservoir flowing across variable height weir gate valves discharges down four (4) 8-foot vertical drain pipes that connect to a retention reservoir discharge culvert that is approximately 36 feet in diameter (or a cross sectional area of approximately 1,018 ft^2). As before, the specific geometry of the culverts (cylindrical, elliptical, rectangular or arch) will be determined following the conduct of a rigorous hydraulic analysis during the engineering phase of the proposed Project. As shown in Drawings PC01-FS001, -FS003 and -FS005, the discharge culverts would extend laterally from beneath the bottom of the retention reservoir along an alignment that courses beneath the near-side canal sidewall, the canal center-wall to beneath the edge of the far-side canal sidewall structure and perpendicular to each. The depth below an msl grade datum for each culvert will be determined following a rigorous geo-technical survey of the culvert alignments during the engineering phase of the proposed

Project. Four (4) 18-foot diameter discharge pipe sections will be installed vertically (two in each of two ship channels) to connect the retention reservoir discharge culvert with floor of the ship channel, a total length of approximately 22 feet for each.

As stated earlier a rigorous hydraulic analysis of the entire system (lock water recovery to retention to outfall discharge in the ship channel) integrating the dynamics of the components would be accomplished during the engineering phase of the proposed Project and are likely to have an impact the specifics of the systems' geometry.

Saltwater Intrusion Prevention

All three saltwater intrusion prevention concepts discussed in Section 3.1 above are employed in Technical Alternative 1 as follows:

1) Acting as a mechanical barrier between the fresh water discharged from the canal exit lock chamber and seawater in the ship channel, the retention reservoir serves the dual function in: a) managing the volume of water that is required for treatment and discharge to the canal lake system to support canal capacity requirements; and b) allowing for reservoir outfall across the variable height weir gate valves into the reservoir discharge culvert as shown in Drawings PC01-FS001 and -FS003.
2) Retention reservoir outfall discharged through the reservoir discharge culvert to the ship channel in close proximity to the exit lock chamber creates the phenomenon known as "hydraulic mounding". As discussed in Section 3.1, the effect of fresh water "hydraulic mounding" as the water wells vertically upward is the creation of a pressure gradient in the mounding zone thereby increasing the local density of the freshwater. This increase in density offsets that of saltwater creating a pressure barrier between fresh and saltwater zones at their interface.
3) "Pneumatic curtain" systems would be created by constructing two, fine air bubbling systems as shown in Drawings PC01-FS003 and -FS006; one each in

the ship channel in the vicinity of the Gatun and Miraflores lock systems. Each system would consist of air compression facilities and fine air bubbler headers constructed of eight (8) 6-inch diameter perforated coated steel pipes that span the width of the ship channel at each canal lock exit as generally shown in Drawings PC01-FS003 and -FS006. As discussed in Section 3.1, compressed air, pumped through the bubbler system, creates a substantial curtain of air bubbles that rise to the surface. In turn, this curtain of air bubbles causes the water level to rise in displacement within the bubbling zone. This displacement in the bubbling zone increases the local water pressure. At and along the interface between the bubbling zone and saltwater the densities of fresh and saltwater equalize. The cumulative affect of "hydraulic mounding" interacting with the pneumatic curtain results in an increase in the local weight/density of the freshwater. This increase in pressure offsets that of saltwater creating a pressure barrier between fresh and saltwater zones at their interface.

At the request of Wpsi, the Engineering Laboratory of the U.S. Army Corps of Engineers at Vicksburg, Mississippi conducted a review and analysis of the saltwater intrusion prevention system as described above and concurs with our technical approach for application in the Panama Canal (see Appendix E). Further, a Cooperative Research and Development Agreement between Wpsi and the Engineering Laboratory will be executed during the engineering phase of the proposed Project whereby exhaustive hydraulic modeling would be conducted to develop the empirical data to be used in the detailed design of the system.

Water Treatment

In Alternative 1, as shown in Plate 3.2.1a, there are two levels of water treatment that occur at the treatment facilities. These two levels of treatment remain the same during Phase I and Phase II at the Gatun Treatment Facility. However, at the Miraflores Treatment Facility the two treatment levels would change between Phases I and II.

Gatun Treatment Facility

The first level of water treatment conducted at the Gatun Treatment Facility involves the use of processes necessary to condition recovered lock water to a level of quality which permits its transportation back to the canal lake system without incurring negative environmental impacts. The second level of treatment involves taking a flow stream off the end of the first level prior to transporting the treated water to the canal lake system and further treating this "off-take" water to a "potable" drinking water condition in conformance with Panamanian law and World Bank standards. These treatment levels, generally described as follows, would be constructed and operated in Phase I of the proposed Project and do not change in Phase II:

1) Water flowing from the lock water recovery system into the retention reservoir allows for initiation of the first level of treatment. The retention reservoir acts as a hydraulic accumulator or surge tank and is sized to hold approximately 25.9 million ft^3, allowing 2½-hours retention time based on a maximum potential daily throughput of approximately 1,170 million gallons (see Appendix E). As shown in Drawing PC01-FS007, the retention reservoir is designed as a multi-chambered structure that incorporates the use of: a) an air-bubbler system to achieve aeration; b) a mixing chamber where chemical reagents are introduced to effect separation and settling of solids; c) a series of baffles to provide a torturous path for the water whereby solid material is "knocked-out"; and d) a settling chamber where large solid particles settle-out, are collected and removed as wet sludge material. Following treatment, water is removed from the last chamber for transportation to the canal lake system. Concurrently, an "off-take" of treated water is conveyed to the next level of treatment.
2) As shown in Plate 3.2.1b, the second level of treatment is initiated when treated "off-take" water from the retention reservoir is pumped to an aeration basin where it is further oxygenated. The treated water then gravity flows through mixing chambers where chemical reagents are introduced to promote separation and settling of entrained materials. From the mixing chambers, the water flows

through multi-chamber sedimentation and settling basins where initial clarification occurs and wet sludge is removed. The next treatment step is filtration where the water passes through mixed media filters consisting of gravel, sand and anthracite coal, followed by disinfection (chlorination and fluorination) before flowing to the clear well. In the clear well, the water is continuously monitored for compliance with Panamanian and World Bank drinking water standards for human consumption. Clear well water conforming to such standards is transported to a public water supply tie-in as discussed later, or water not conforming to such standards is recycled for additional treatment.

Miraflores Treatment Facility

In Phase I of the proposed Project, the first level of water treatment conducted at the Miraflores Treatment Facility is the same as that described above for the Gatun Treatment Facility. The second level of treatment in Phase I would involve directing the entire "treated" water stream discharged from the retention reservoir to the desalinization plant. Desalinization is necessary in Phase I because of the "brackish" condition (high salinity levels) of the lock water discharged from the Miraflores exit locks and is required to condition recovered lock water to a level of quality permitting its transportation back to the canal lake system without incurring negative environmental impacts.

The desalinization of the "brackish" water, as shown in Plate 3.2.1c, is accomplished through the use of proven technology; reverse osmosis (RO). RO is a process in which water is separated from dissolved salts in solution by filtering through semi permeable membranes at a pressure greater than the osmotic pressure caused by the dissolved salts in the "brackish" water. The RO system for the Miraflores Treatment Facility was sized on the basis of: 1) existing water quality data for the water discharged from the Miraflores exit locks; and 2) governing beneficial use standards for discharge of treated water to a fresh water body (see Appendix D). Given these required parameters it was assumed that the upper end of influent salinity levels would be approximately 21.6 ppt; and the water quality production target of the RO process for discharge to Gatun Lake is <200 mg/L TDS. Given this basis for design, the type of RO equipment selected is a

17.25-inch diameter by 60-inch spiral wound element (see Appendix E). Use of these elements provides the greatest filtration surface area for optimum efficiency. The RO facility was sized for a production of 201 mgd. RO system layout consists of 10 mgd blocks, each using 5-elements per pressure vessel and a 36:18 array. To achieve the required flow, 20 arrays would be required. The RO system would be set-up as a 4-pass, 85% recovery. Fluxes, also known as water fouling, are unknown and were assumed to have a low potential (an average gallons fouling distribution of 14 in the first pass).

Following desalinization, a flow stream is taken-off prior to transporting the treated water to the canal lake system. This "off-take" water is further conditioned, as shown in Plate 3.2.1c, to a "potable" drinking water condition in conformance with Panamanian law and World Bank standards. Such conditioning would incorporate disinfection and clear well monitoring.

Operation of the desalinization plant in Phase I would continue until Miraflores Lake water quality conforms to beneficial use standards for fresh water bodies. In Phase II it is assumed that, as a result of: 1) transporting treated de-mineralized water to Gatun Lake, 2) the isolation of Miraflores Lake by the lock water recovery system, and 3) arresting saltwater intrusion, conformance of such standards would have been achieved and the operation of the desalinization plant would no longer necessary. At this time, the desalinization plant would be decommissioned and replaced with a similar secondary level treatment plant as shown in Plate 3.2.1b.

Water Transportation and Discharge

Upon completion of the first level of treatment, water conditioned to a quality compliant with regulatory standards can be transported for discharge to the lake system without negative environmental impacts. In Phase I and II of the proposed Project, approximately 201 mgd and 597 mgd of treated water, respectively would be transported from the treatment facilities along alignments shown in Drawings PC01-FS009 (from the Gatun Treatment facility) and -FS012 (from the Miraflores Treatment Facility). The

transportation pipeline from the Gatun Treatment Facility to Gatun Lake would consist of two (2) aboveground 14-foot diameter reinforced fiber glass pipelines (see Appendix E) and would traverse a distance of approximately 8,800 feet to discharge diffusers below the water surface in Gatun Lake as shown in Drawing PC01-FS009. The exact location of these diffusing structures would be accomplished after a rigorous hydraulic study is completed during the engineering phase of the proposed Project. Similarly, the transportation pipeline from the Miraflores Treatment Facility to Gatun Lake would consist of two (2) aboveground 14-foot diameter reinforced fiber glass pipelines (see Appendix E) and would traverse a distance of approximately 12,500 ft. to discharge diffusers below the water surface in Gatun Lake as shown in Drawing PC01-FS012. As previously mentioned, the exact location of these diffusing structures would be accomplished after a rigorous hydraulic study is completed during the engineering phase of the proposed Project.

Upon completion of the second level of water treatment, water conditioned to "potable" drinking water standards could be transported to the public water supply system. In Phase I and II of the proposed Project, approximately 87 mgd and 105 mgd of "potable" water, respectively would be transported from the Gatun Treatment Facility a distance of approximately 24,500 ft. along the alignment shown in Drawing PC01-FS009 to the Mount Hope water production facility through one (1) aboveground 5-foot diameter reinforced fiber glass pipelines (see Appendix E) where it discharges to the fresh water supply system.

Likewise, in Phase I and II of the proposed Project, approximately 88 mgd and 105 mgd of "potable" water, respectively would be transported from the Miraflores Treatment Facility a distance of approximately 4,700 feet along the alignment shown in Drawing PC01-FS011 to the ACP's Miraflores water production facility through one (1) 6-foot diameter pipeline where it discharges to the fresh water supply system. As shown in Drawing PC01-FS011, the pipeline will be constructed above ground using reinforced fiberglass pipe, except for that segment that crosses the ship channel. This segment would be constructed below the bottom of the ship channel along side and concurrently

with the installation of the retention reservoir discharge culvert and would be constructed of concrete lined steel pipe.

Hydroelectric Power Generation, Transmission and Interconnection

Lock water drainage into and from lock chamber through the existing drainage culverts represents a significant hydraulic energy potential that has not been developed. Shown on Plate 3.2.1d are elevation data for each of the three lock chambers for the Gatun lock system. Given this data, hydraulic energy potentials of 8.9-meters of head, 17-meters of head and 17-meters of head are derived for the following respective lifts: 1) upper lock chamber to the lake level; 2) middle lock chamber to upper lock chamber; and 3) lower lock chamber to the middle lock chamber (see Appendix E). Installation of parallel side-path hydroelectric power "pit" turbine generators in the lock chamber drain intervals where these hydraulic heads exist enable the conversion of the energy potential into "clean" hydroelectric power. The seven (7) general locations of these intervals where "pit" turbines would be located are shown on Plate 3.2.1e. A bank of three (3) "pit" turbine units would be installed at each located; one (1) in each sidewall and center-wall. A total of 21 "pit" turbines would be installed in the following configuration:

1) Miraflores: three 17 meter-head units; and three 8.9 meter-head units.
2) Pedro Miguel: six 8.9 meter-head units.
3) Gatun: three 17 meter-head units; and three 8.9 meter-head units.

Shown on Plate 3.1.6 and Plate 3.2.1f are representation of a typical bank of "pit" turbines to be installed in parallel side path of the existing lock drainage culverts. As shown, each of seven (7) banks consists of a set of three "pit" turbines. For each bank, two (2) 18-foot diameter parallel side paths would be tunneled and constructed along the near and far sidewall structures in such a manner to enable tie-in to the existing sidewall drainage culverts having a turbine centerline elevation slightly below the centerline of the drainage culvert to prevent cavitations. One (1) 18-foot diameter center-wall side path would be tunneled and constructed below the existing center-wall structure and in such a

manner to enable tie-in to the existing center-wall drainage culverts. Each 8.9 meter-head "pit" turbine is capable of generating 6.5 MW and each 17 meter-head "pit" turbine is capable of generating 14.2 MW. The amount of hydroelectric power produced is a direct function of canal capacity. The more lockages through the canal, the more hydroelectric power generated. As provided in Appendix E, the system would generate in the range of approximately 82 to 104 MW during Phase I (year 2006 to 2016) and in the range of approximately 106 to 119 MW during Phase II (from year 2017). As shown in Table 3.2.1, the amount of hydroelectric power generated as a result of this installation more than satisfies the electrical power requirements needed to support the water recovery, reclamation and recycling operations and allows for the exportation of electrical power through ACP facilities to the public electrical power grid.

As shown in Drawings PC01-FS015 and -FS016, two power plants would be constructed; one in the general location of the Gatun and Miraflores treatment facilities to facilitate security, electrical power transmission, operations monitoring and maintenance. As also shown in these drawings, an electrical substation would be located at each power plant and at the Pedro Miguel Locks. These substations would be connected to the 115kV transmission lines, would supply power to the distribution system and would be located outdoors in a well protected fenced area. Further, the two substations co-located with the Gatun and Miraflores treatment facilities would supply power to a 5kV rated motor control center at each treatment facility. Each motor control center would be installed indoors in a well-ventilated air-conditioned building. Both indoor and outdoor electrical facilities at each treatment facility would require a 65 ft. by 150 ft. area; the facilities at Pedro Miguel Locks would be 50 ft. by 65 ft. area.

As shown in Drawings PC01-FS015 and -FS016, each bank of three generators would be connected in parallel (with single unit capability). These banks, as numbered below from south (Miraflores) to north (Gatun) would have installed capacities as shown totaling approximately 206MW @ 13.8 kV (402A) and feed the power plant distribution system through the electrical substation.

(1) Bank 1 (Miraflores, upper lock to lower lock): 42.6MW

(2) Bank 2 (Miraflores, lake to upper lock): 19.5MW

(3) Bank 3 (Pedro Miguel, lock to lake): 19.5MW

(4) Bank 4 (Pedro Miguel, lake to lock): 19.5MW

(5) Bank 5 (Gatun, lake to upper lock): 19.5MW

(6) Bank 6 (Gatun, upper lock to middle lock): 42.6MW

(7) Bank 7 (Gatun, middle lock to lower lock): 42.6MW

The power plant distribution system would feed one 15MVA unit substation at 13.8/4.16kV that would provide a power source equivalent to 30-300hp pumps to support facility operations. A second 15MVA substation 115V/13.8kV would be fed from the power plant distribution system that would step up the generating voltage for 13.8kV to 115kV. Installation of unit substations and/or step-down transformers would satisfy lower voltage electrical power requirements. High voltage transmission lines would be routed to ACP power distribution facilities and inter-connected to existing substations managed by the regional electrical power distribution company. These high voltage (115kV) transmission lines would be suspended from transmission tower structures in accordance with the most recent technology available and good design practices. To protect this system, a protective relay system would be installed that would include surge protection, grounding schemes, lightning protection and real-time calculation of short-circuit currents. All electrical motors would be equipped with soft start electronic type starters with over current protection as required by National Electric Code (U.S.) and manufactures recommendations. Electrical motors would be suited for the environment according to their intended use.

The electric power system, as described above, could operate independently from a connection to the CND electrical power grid, as well as to any specific connection to any one of the hydroelectric power generation substations. Each hydroelectric power generation substation could provide an alternative source of power to the other. For example, as shown in Table 3.2.1, when the hydroelectric power generation system is in

full operation one facility generating surplus can make-up deficits at another through the interconnection design of the system.

Solid Waste Disposal

Lock water recovery, reclamation and recycling facility processes would produce wet sludge as a process byproduct from process operations. It is anticipated that this wet sludge would consist mostly of mineral solids and biomass that was entrained in the discharged lake water. This wet sludge would be removed from the retention reservoir, mixing chambers, sedimentation and settling basins, and filtration units. Once removed, positive displacement pumps would convey the wet sludge to the dewatering process where filtrate would be removed and recycled to the retention reservoir. Filter cake removed from the dewatering process would be tested for the presence of hazardous compounds prior to packaging for transportation. If hazardous compounds were found in the sludge, the filter cake would be treated for proper disposal according to the Panamanian rules and regulations and/or World Bank standards. Filter cake found to be free of any hazardous compounds, would be packaged and transported to facilities where it could be used for beneficial purposes, such as liner material for landfill operations, clean construction fill, soil amendments to support agriculture operations, and stabilization of soil erosion.

3.2.2 Technical Alternative 2, 60% Diversion Case

Technical Alternative 2 is designed to divert 60 percent of the volume of water in the exit lock chamber from Gatun and Miraflores exit locks to the Gatun and Miraflores treatment facilities, respectively and thus referred to as the "60 % Diversion Case." Relative to processes associated with the proposed Project and the variety of approaches discussed in Section 3.1, this alternative is generally presented in the green shaded portions at Table 3.1.8a.2 and Table 3.1.8b.2 for the Gatun and Miraflores treatment facilities, respectively and is generally illustrated in Plate 3.2.2. A detailed discussion of each process follows:

Lock Water Recovery

Alternative 2 differs from Alternative 1 in that "wet wells" would be constructed and pumping systems would be installed, as shown in Drawing PC01-FS017, to divert approximately 60 percent of the lock water discharged from the exit lock chamber to the retention reservoir. As shown in Drawing PC01-FS017, 2-sets of three wet-wells would be constructed, one each in the exit lock structures at Gatun and Miraflores lock systems; two adjacent to each discharge culvert outlet port located along the sidewalls of the canal, and one constructed in the center culvert. Each wet well would be equipped with level controls and four (4) vertical turbine pumps. As water flows into the wet well and engages the level controller, the vertical turbine pumps turn-on and move approximately 2.6 million gallons in eight minutes through a 36-foot diameter lock water recovery culvert which interconnects the three wet-wells to the retention reservoir, as shown in Drawing PC01-FS017. The lock water recovery culvert would be installed in the same manner as in Alternative 1. When the established volume has been pumped, the vertical turbine pumps cease and water from the discharge culvert would flows over the wet-well weirs into the ship channel.

Lock Water Retention

Each retention reservoir, having a capacity of approximately 15.5 million-ft^3, receives exit lock chamber water pumped from the wet well turbine pumps through influent ports constructed in the bottom of the reservoir as shown in Drawing PC01-002. The design and operation of the retention reservoir is largely the same as that discussed above in Alternative 1, the principal difference is that it was sized to accommodate the required retention time and volume to optimize the settling and treatment processes for a reduced volume throughput (see Appendix E).

Saltwater Intrusion

The pneumatic curtain proposed in Alternative 1 would be applied in Alternative 2. However, by physically diverting approximately 60 percent of the exit lock chamber discharge to the retention reservoir and allowing the remaining balance to flow through the existing discharge culverts to the ship channel the benefit gained from "hydraulic mounding" in mitigating saltwater intrusion is significantly reduced. Rather than welling up vertically, as designed in Alternative 1, horizontal discharge from the exit lock co-mingling with vertical discharge from the retention reservoir discharge culvert would not achieve the desired differential pressure necessary to offset the density of saltwater. The net affect of this condition is that the effectiveness of the mitigation of saltwater intrusion is reduced to an approximate range of 50 to 80 percent.

Water Treatment

Water treatment operations in Alternative 2 represent no change from those described in Alternative 1.

Water Transportation and Discharge

Water transportation and discharge operations in Alternative 2 represent no change from those described in Alternative 1 with one exception; conveyance of treated water to the Mount Hope and Miraflores water production facilities would be tied directly into IDAAN's fresh water supply system. A connection into the ACP fresh water system is not proposed in this alternative.

Hydroelectric Power Generation, Transmission and Interconnection

For Alternative 2, hydroelectric power turbine generators would be installed within the lock system drain culverts of the lock systems to take advantage of the tremendous potential of the available hydroelectric power. The amount of hydroelectric power

generated as a result of this installation more than satisfies the electrical power requirements needed to support the water recovery, reclamation and recycling operations and enables the exportation of electrical power through ACP facilities to the public electrical power grid.

The hydroelectric power turbine generators would be installed as follows: 1) three sets of three (nine total) at the Gatun Locks; 2) one set of three (three total) at the Pedro Miguel Locks; and, 3) two sets of three (six total) at the Miraflores Locks. Each of the 18 bevel gear "bulb" turbines selected for installation would be capable of generating a maximum of 2.94 MW of electrical power, for a combined total of approximately 53 MW. The amount of hydroelectric power produced is a direct function of canal capacity. The more lockages through the canal, the more hydroelectric power generated. In Phase 1 of facility operations (at current canal capacity) each turbine would generate 1.5 MW providing a total power output of approximately 27 MW. In Phase II of facility operations (at projected canal capacity in year 2016) each turbine would generate 1.67 MW providing a total power output of approximately 30 MW. Each turbine unit would be installed inside the lock drain culvert on the down stream side of each successive step taken downward in elevation from lock chamber to lock chamber.

Hydroelectric power generation, transmission and interconnection operations in Alternative 2 also represent the following additional changes to those described in Alternative 1:

1) The introduction of pump operations to convey water from the point of culvert discharge to the retention reservoir rather than by force of gravity will consume considerably more electrical power; and,
2) Transmission of electrical power to the Gatun and Miraflores electrical substations will be tied directly into CND's designated electrical distribution system.

A connection into the ACP system is not proposed in this alternative. At Table 3.2.2 are shown facility electrical power requirements compared to the hydroelectric power generation values. Comparing the net values with those of Table 3.2.1 it is readily evident just how much more electrical power is consumed in Alternative 2; to the extent that in Phase II the proposed Project will require more power than it is capable of generating.

Solid Waste Disposal

Solid waste disposal operations in Alternative 2 represent no change from those described in Alternative 1.

3.2.3 Technical Alternative 3, 30% Diversion Case

Technical Alternative 3 is designed to divert 30 percent of the volume of water in the exit lock chamber is diverted from Gatun and Miraflores exit locks to the Gatun and Miraflores treatment facilities, respectively and thus referred to as the "60 % Diversion Case." Relative to processes associated with the proposed Project and the variety of approaches discussed in Section 3.1, this alternative is generally presented in the shaded portions Table 3.1.8a.2 and Table 3.1.8b.2 for the Gatun and Miraflores treatment facilities, respectively and is generally illustrated in Plate 3.2.2. A detailed discussion of each process follows:

Lock Water Recovery

As shown in Drawing PC01-FS018, lock water recovery operations in Alternative 3 represent no change from those described in Alternative 2; except as follows:

1) "Wet-wells" would be constructed and pumping systems would be installed, as shown in Drawing PC01-FS018, to divert approximately 30 percent of the lock water discharged from the exit lock chamber to the retention reservoir;

2) Each "wet-well" would be equipped with two (2) vertical turbine pumps; and
3) A 16-foot diameter lock water recovery culvert interconnecting the wet-wells to the retention reservoir, as shown in Drawing PC01-FS018 would be installed to meet the 8-minute drain window parameter. The lock water recovery culvert would be installed in the same manner as in Alternative 1.

Lock Water Retention

Lock water retention described in Alternative 2 represents no change from that of Alternative 2, with one exception; the retention reservoir would have a design capacity of approximately 7.8 million ft^3.

Saltwater Intrusion

Saltwater intrusion prevention operations in Alternative 3 represent no change from those described in Alternative 2.

Water Treatment

Water treatment operations in Alternative 3 represent no change from those described in Alternative 1.

Water Transportation and Discharge

Water transportation and discharge operations in Alternative 3 represent no change from those described in Alternative 1 with one exception; treated water conveyance to the Mount Hope and Miraflores water production facilities will be tied directly into ACP's fresh water supply system. A connection into the IDAAN fresh water system is not proposed in this alternative.

Hydroelectric Power Generation, Transmission and Interconnection

Hydroelectric power generation, transmission and interconnection operations in Alternative 3 represent no change from those described in Alternative 2, with one exception; transmission of electrical power to the Gatun and Miraflores electrical substations will be tied directly into ACP's electrical system. A connection into the CND system is not proposed in this alternative. Table 3.2.3 shows facility electrical power requirement compared to the hydroelectric power generation values. Comparing the net values with those of Table 3.2.1 and Table 3.2.2 it is readily evident that not as much electrical power is consumed in this alternative as in Alternative 2; to the extent that in Phase II the proposed Project will require more power than it is capable of generating.

Solid Waste Disposal

Solid waste disposal operations in Alternative 3 represent no change from those described in Alternative 1.

3.3 Analysis of Technical Alternatives

An analysis of each technical alternative described and discussed in Section 3.2 above was conducted to determine the levels of reliability, operability, constructability and adaptability defined as follows:

> *Reliability*: Reliability is the measure of chance that a Project system and its component subsystems have in accomplishing the design tasks on the basis of historical experience and/or empirical data. Thus reliability is generally expressed as: R = *number of past successes* ÷ *number of trials*. Given that the project system consists of layered or cascading subsystems in series, the failure of any one component results in the failure of the system to perform according to design and thereby places project objectives at risk. The probability of the success of all the components is a measure of the system reliability. Assuming

that the components fail independently of each other system reliability is expressed as:

$$R_s = \prod_{i=1}^{N} R_i$$

where "*N*" represents the number of components and "*i*" denotes any of the components in the system. Thus reliability of a system with a series dependence in the operations of its components is less than or equal to the reliability of any one component. Therefore, the more reliable the system the closer its reliability value is to 1.0.

However, since this project incorporates processes that represent systems that are in series with integrated parallel components a discussion is necessary of reliability for an in parallel system/subsystem that is integrated within a system which is in series. For systems or subsystems that are in parallel, only one or more of *"N"* components are required to operate successfully to achieve success. All *"N"* components must fail to cause system failure. Such a structure arises when two or more components (pumps, generators, turbines, etc.) operate in parallel supporting a system function. All must fail before the system function fails. The probability of failure of component *"i"* is $(1 - R_i)$. The probability of system success *"R_s"* consisting of *"N"* components is:

$$R_s = 1 - \prod_{i=1}^{N} (1 - R_i)$$

Thus the reliability of a system/subsystem with parallel structure is greater than or equal to the reliability of any of its components. Shown in Table 3.3a are the failure and success values for all major system components for all technical alternatives. The probabilistic approach described above also applies to the analysis of operability below. The computations of values for reliability are provided in Appendix E.

Operability: Operability is the measure of the likelihood of realistic deviations from intent of process unit design and/or process parameters where intent is how a system is expected to operate in the absence of deviations. This measure is derived from a semi-quantitative risk analysis whereby, on an-order-of-magnitude basis, an estimate of the frequency of a deviation, the severity of the consequence and the effectiveness of protective systems can be combined to obtain an approximate value of the risk associated with system operations. Shown in Table 3.3b are deviation probabilities and operability values for all major system components for all technical alternatives. The computations of values for operability are provided in Appendix E.

Constructability: Constructability is a measure of the difficulty in constructing the proposed project. This measure is derived from a semi-quantitative assessment whereby, on an-order-of-magnitude basis, an estimate of the difficulty in constructing each major component of the project is assessed, a value assigned and combined with all the others to obtain an approximate value representing the difficulty of construction. Shown in Table 3.3c and Table 3.3d are the level of difficulty metrics and the constructability values, respectively for all major system components for all technical alternatives. As shown Table 3.3c the least difficult construction activities is assigned a value of "1" (routine) whereas the most difficult activities are assigned a value of "10". Following the assignment of values, as shown in Table 3.3d, the values for activities associated with the construction of each system are summed and an average calculated. A weighted value is then applied to each average, the sum of which represents the composite level of construction difficulty. This procedure is shown in detail at Appendix E.

Adaptability: Adaptability is a measure of the flexibility of the proposed project in accommodating future canal operations. This measure is derived from a semi-quantitative assessment whereby, on an-order-of-magnitude basis, an estimate of the adaptability of each major component of the project is assessed; a valued assigned and combined to obtain an approximate value representing the level of

adaptability. Shown in Table 3.3e are level of flexibility metrics that reflect the level of adaptation of existing facilities to future operations requirements and the degree of modifications required. As shown Table 3.3e the most flexible rating is assigned a value of "1" whereas the least flexible rating is assigned a value of "5" (inflexible). Following the assignment of values for all system elements, as shown in Appendix E, the flexibility values for activities associated with adaptation to future operational needs are summed and an average calculated. A weighted value is then applied to each average, the sum of which represents the composite level of construction difficulty. This procedure is shown in detail at Appendix E.

3.3.1 Alternative 1, 100% Diversion Case

Using the values presented Tables 3.3a through 3.3e and applying the definitions in section 3.3 above, an assessment of reliability, operability, constructability and adaptability relative to the description and discussion of Alternative 1 is provided in the following subsections.

3.3.1.1 Reliability

Shown at Table 3.3.1.1 are the reliability values for Alternative 1, and as shown the composite value is 0.987 with 1.0 being the highest possible value. The mathematical derivations of probability values shown in Table 3.3.1.1 are provided in Appendix E.

3.3.1.2 Operability

Shown at Table 3.3.1.2 are the operability values for Alternative 1, and as shown the composite value is 0.977 with 1.0 being the highest possible value. The mathematical derivations of probability values shown in Table 3.3.1.2 are provided in Appendix E.

3.3.1.3 Constructability

Shown at Table 3.3.1.3 are the constructability values for Alternative 1, and as shown the total weighted average value is 3.5 on of scale of 1.0 (routine) to 10.0 (most difficult). The mathematical derivations of level of construction difficulty shown in Table 3.3.1.3 are provided in Appendix E.

Construction issues that present the greatest challenge for this alternative are those associated with the construction of lock water recovery tunnels and culverts, retention reservoir discharge tunnels and culverts, turbine installation and access tunnels, parallel side-paths for the turbines, and the tie-in of each to existing canal structures so as not to interfere with canal capacity operations. Difficult as they are, each of these issues can be successfully resolved by the application of standard and acceptable engineering and construction practices and in a manner not to interfere with canal capacity operations (see Appendix E).

3.3.1.4 Adaptability

Shown at Table 3.3.1.4 are the operability values for Alternative 1, and as shown the total weighted average value is 2.1 on a scale of 1.0 (very flexible) to 5.0 (inflexible). The mathematical derivations of level of construction difficulty shown in Table 3.3.1.4 are provided in Appendix E.

3.3.2 Alternative 2, 60% Diversion Case

Using the values presented at Tables 3.3a through 3.3e and applying the definitions in section 3.3 above, an assessment of reliability, operability, constructability and adaptability relative to the description and discussion of Alternative 2 is provided in the following subsections.

3.3.2.1 Reliability

Shown at Table 3.3.2.1 are the reliability values for Alternative 2, and as shown the composite value is 0.967 with 1.0 being the highest possible value. The mathematical derivations of probability values shown in Table 3.3.2.1 are provided in Appendix E.

3.3.2.2 Operability

Shown at Table 3.3.2.2 are the operability values for Alternative 2, and as shown the composite value is 0.968 with 1.0 being the highest possible value. The mathematical derivations of probability values shown in Table 3.3.2.2 are provided in Appendix E.

3.3.2.3 Constructability

Shown at Table 3.3.2.3 are the constructability values for Alternative 2, and as shown the total weighted average value is 2.9 on of scale of 1.0 (routine) to 10.0 (most difficult). The mathematical derivations of level of construction difficulty shown in Table 3.3.2.3 are provided in Appendix E. Two construction issues of significant concern in regard to Alternative 2 are likely to cause interruption to canal operations. First, interruptions are likely to be incurred to construct the wet-wells. This issue can be mitigated to the extent that temporary cofferdam structures would be installed with dewatering equipment during construction of the wet-wells; however some disruption to canal operations would be incurred. Second, access to the existing lock drainage culverts to install in-place the hydroelectric turbine-generators are extremely limited, requiring the closure of each culvert to accomplish installation. It is not likely that interruption of canal operation to achieve installation could be effectively mitigated.

Construction issues that present the greatest challenge for this alternative are those associated with the construction of each wet-well, the lock water recovery tunnels and culverts, retention reservoir discharge tunnels and culverts, the tie-in of each to existing canal structures and the installation of turbines in existing lock drainage culverts so as not

to interfere with canal capacity operations. Tunneling and culvert construction issues can be remedied as discussed in section 3.3.1.3 above; however, construction of wet-wells in existing canal sidewall and center-wall structures cannot likely be accomplished without extended disruption to canal capacity operations. Further, the installation of hydroelectric turbines in existing lock drainage culverts presents access issues regarding the placement and assembly of equipment. Access to the existing lock drainage culverts to install in-place the hydroelectric turbine-generators are extremely limited, requiring the closure of each culvert to accomplish installation. It is not likely that interruption of canal operation to achieve installation could be effectively mitigated.

3.3.2.4 Adaptability

Shown at Table 3.3.2.4 are the operability values for Alternative 2, and as shown the total weighted average value is 2.8, on a scale of 1.0 (very flexible) to 5.0 (inflexible). The mathematical derivations of level of construction difficulty shown in Table 3.3.2.4 are provided in Appendix E.

3.3.3 Alternative 3, 30% Diversion Case

Using the values presented Tables 3.3a through 3.3f and applying the definitions in section 3.3 above, an assessment of reliability, operability, constructability and adaptability relative to the description and discussion of Alternative 3 is provided in the following subsections.

3.3.3.1 Reliability

Shown at Table 3.3.3.1 are the reliability values for Alternative 3, and as shown the composite value is 0.967 with 1.0 being the highest possible value. The mathematical derivations of probability values shown in Table 3.3.3.1 are provided in Appendix E.

3.3.3.2 Operability

Shown at Table 3.3.3.2 are the operability values for Alternative 3, and as shown the composite value is 0.968 with 1.0 being the highest possible value. The mathematical derivations of probability values shown in Table 3.3.3.2 are provided in Appendix E.

3.3.3.3 Constructability

Shown at Table 3.3.3.3 are the constructability values for Alternative 3, and as shown the total weighted average value is 2.9 on of scale of 1.0 (routine) to 10.0 (most difficult). The mathematical derivations of level of construction difficulty shown in Table 3.3.3.3 are provided in Appendix E.

Construction issues presented in section 3.3.2.3 above also apply to this section for Alternative 3.

3.3.3.4 Adaptability

Shown at Table 3.3.3.4 are the operability values for Alternative 3, and as shown the total weighted average value is 3.2 on a scale of 1.0 (very flexible) to 5.0 (inflexible). The mathematical derivations of level of construction difficulty shown in Table 3.3.3.4 are provided in Appendix E.

A summary of all the above values for all three alternatives is presented in Table 3.3f.

3.4 Cost Comparison of Technical Alternatives

Provided in the subsections below are initial budget cost estimates to implement Phase I and Phase II of Alternatives 1, 2 and 3. The data presented in these subsections are summarized in Table 3.4. Initial implementation financing to launch the proposed Project will address those budget requirements for Phase I only. Follow-on financing to

expand facilities consistent with the requirements of Phase II would be initiated at the appropriate time on or about year 2016.

3.4.1 Alternative 1, 100% Diversion case

Shown at Table 3.4.1a and Table 3.4.1b are estimated costs of labor, materials and equipment to construct Alternative 1 for Phase I and Phase II, respectively. As shown at Table 3.4.1c the composite estimated costs for implementation of Alternative 1 reflecting engineering, construction, and project management is approximately $419 million. Incorporated into project management are the following activities: 1) engineering management and oversight during the design and construction phase and QA/QC; 2) construction management which includes planning, construction oversight, surveying, scheduling, procurement, equipment/material handling and QA/QC; 3) operations management which includes regulatory compliance (environmental, labor, health & safety), ACP and government agency liaison, public relations, and field services (housing, subsistence, transportation, health, finance, etc.); and 4) financial management which includes project finance accounting, payroll, accounts receivable and payable, ledger cost control, internal review and auditing, contracts management, and investor liaison.

3.4.2 Alternative 2, 60% Diversion Case

Shown at Table 3.4.2a and Table 3.4.2b are estimated costs of labor, materials and equipment to construct Alternative 2 for Phase I and Phase II, respectively. As shown at Table 3.4.2c the composite estimated costs for implementation of Alternative 2 reflecting engineering, construction, and project management is approximately $338 million.

3.4.3 Alternative 3, 30% Diversion Case

Shown at Table 3.4.3a and Table 3.4.3b are estimated costs of labor, materials and equipment to construct Alternative 3 for Phase I and Phase II, respectively. As shown at

Table 3.4.3c the composite estimated costs for implementation of Alternative 3 reflecting engineering, construction, and project management is approximately $304 million.

3.5 Selection, Discussion and Economics of Preferred Technical Alternative

3.5.1 Selection of Preferred Technical Alternative

Given information and analysis presented in sections 3.2, 3.3 and 3.4 above, Alternative 1 is the preferred alternative for the following reasons:

1) Alternative 1 best achieves the goals and objectives of the proposed Project as presented in Section 1.0;
2) Implementation of Alternative 1, particular during the construction, presents the least chance of interruption of service to canal capacity operations;
3) Although some components of Alternative 1 present technical challenges; particularly during that portion of construction operations when culverts and parallel side-path tunnels are being installed, Alternative 1, as shown in Table 3.3f, offers the highest overall level of operability, the greatest degree of adaptability for future operations relative to future growth projections in canal capacity, and presents a very high level of reliability over throughout the life of the proposed Project; and
4) Although Alternative 1 requires the larger capital investment compared to Alternatives 2 and 3, in consideration of the operable flexibility the investment acquires when compared to Alternative 2 or 3, Alternative 1 is the most efficient and lower cost investment scenario for the following reason: the discounted value of Alternative 1 after ten years is more favorable when compared to those scenarios where additional investments are required for Alternative 2 or 3 to expand facility transit capacity to meet canal capacity expectations (see Appendix E).

3.5.2 Discussion of Preferred Technical Alternative

Articulated in the subsections below are discussions of issues relative to the implementation of Alternative 1.

3.5.2.1 Locations of Proposed Project Facilities

Selection of proposed Project facility sites where the proposed facilities would be constructed and operated was based on the following selection criteria:

1) That having the least impact to existing facilities operations during the construction and operation the proposed facilities;
2) That having the closest relative proximity to exit lock facilities and operations;
3) That presenting the least interference with preferred alignment of proposed additional "third-set" canal lock systems; and
4) That having close proximity to the preferred proposed location of additional ("third-set") lock systems to enable feasible flexibility to interconnect the additional locks to the proposed Project facilities in the future should it be desirous to do so.

Gatun Treatment Facility

Given the above facility location criteria, the proposed site plan for the Gatun Treatment Facility is shown in Drawing PC01-FS009 (two sheets). The proposed facility location is northeast of the lower lock chamber of the Gatun lock system and is currently unoccupied. This location would present the least interference with canal operations during construction and would be located between existing exit lock system and the preferred alignment of the proposed additional lock system. Also shown on Drawing PC01-FS009 is the proposed alignment for the pipelines that convey treated water to Gatun Lake and "potable" water to the Mount Hope treatment plant. The proposed

pipeline alignment presents the least interference with existing facilities and facility operations and should not create a significant impact when being constructed.

Miraflores Treatment Facility

Considering the facility location criteria presented above, the proposed site plan for the Miraflores Treatment Facility is shown in Drawing PC01-FS011 (Phase I) and Drawing PC01-FS013 (Phase II). Respectively, these drawing represent treatment facility scenarios that integrate a desalinization system in Phase I and a conventional water treatment system in Phase II. The proposed facility location is on the west side of the Miraflores lock system and is currently unoccupied. This location would present the least interference with canal operations during construction and would be located between existing exit lock system and the preferred alignment of the proposed additional lock system. Shown on Drawing PC01-FS012 and Drawing PC01-FS014 are the proposed alignments for the pipelines that convey treated water to Gatun Lake and "potable" water to the Miraflores Lake treatment plant, respectively. As shown in Drawing PC01-FS012, the proposed alignment for the treated water pipeline to Gatun Lake courses along the western shores of Miraflores Lake and the Galliard Cut to Gatun Lake. This alignment is technically feasible to construct, presents the least interference with existing facilities and facility operations and should not create a significant impact when being constructed. As shown in Drawing PC01-FS014, the proposed alignment for the "potable" water pipeline exits the treatment facility above ground, traverses the ship channel below ground and follows an above ground route from the far shoreline to the Miraflores Lake treatment facility that presents the least interference with existing facilities and facility operations. This alignment is technically feasible to construct and should not create a significant impact when being constructed. Construction that portion of it below the ship channel would be accomplished concurrent with the construction of the retention reservoir discharge culvert (as discussed later).

Location of the Saltwater Intrusion Prevention System

The orientation and placement of the saltwater intrusion prevention system is generally described as follows. Confirmation of exact location and sizing of each system

component will follow rigorous hydraulic modeling and analysis. As mentioned earlier, a Cooperative Research and Development Agreement between Wpsi and the U.S. Army Corps of Engineers Engineering Laboratory will be executed during the engineering phase of the proposed Project whereby exhaustive hydraulic modeling would be conducted to develop the empirical data to be used in the detailed design of the system.

Discharge ports rising vertically from the retention reservoir discharge culvert will be located as generally shown in Drawings PC01-FS003, -FS004, -FS005, -FS009 and -FS011. These discharge ports will be located linearly across and in the concrete channel floor approximately 50-feet from the exit lock doors. The fine-air bubbling system that will create the pneumatic curtain will be located across and on-top of the concrete channel floor; it will consist of two systems interconnected to each other and each having an air compressor station on opposite sides of the ship channel, as shown in Drawings PC01-FS009 and –FS011. The fine air bubbler will be located approximately 600-feet from the exit lock doors. The orientation of this system was presented before and discussed with several senior port captains of the ACP, chaired by Captain Arcelio Hartley. During the presentation and discussion that followed, the captains expressed concern regarding to the current manner by which water is released from the lower lock chambers. Principally, discharge water flowing from the existing sidewall ports creates upper and lower currents or eddies that produce a circular motion that diffuses as the flow moves toward the ocean in the ship channel. This phenomenon is illustrated in Plate 3.5.2a. These eddies frequently create navigational hazards to the pilots of the vessels. As vessels depart and enter the lower lock chambers, strong discharge eddies from the center wall discharge ports move the vessel off its course into the sidewall "knuckle," causing damage to the vessel and/or canal structure. During our discussions, the captains' opinion was that the proposed saltwater intrusion prevention system would most likely reduce or eliminate this hazard and would make approach and egress from the lower lock chambers less hazardous and easier to navigate.

3.5.2.2 Orientation of Proposed Project Facilities

Shown in Drawing PC01-FS008 is the process diagram for the Gatun Treatment Facility. Process diagrams for the Miraflores Treatment Facility are shown in Drawing PC01-FS010 and Drawing PC01-FS013 representing Phase I (desalinization system) and Phase II (conventional water treatment system) treatment scenarios, respectively. These diagrams depict the relative location of treatment processes with respect to flow and treatment sequences. As shown in these diagrams, each lock water recovery culvert and/or each treatment facility can be isolated from the existing lock discharge culvert. Should such isolation be necessary, it can be accomplished by closing the isolation valves shown as "Item 8" on each drawing and opening the existing discharge culvert isolation miter-gate valve. When isolation occurs operations as they exist today continue unabated without adversely impacting canal operations. When isolation is no longer required, the valve positions are returned to their original operating position as shown in the drawings.

3.5.2.3 Construction of Proposed Project Facilities

This principal construction issues that present the greatest challenge in implementing Alternative 1 are: 1) tunneling for and construction of lock water recovery and retention reservoir discharge culverts and the tie-in of these to the existing lock drainage culverts; 2) tunneling for and construction of hydroelectric turbine-generator parallel side-paths and the tie-in of these to the existing lock drainage culverts; and 3) construction of below grade retention reservoirs.

Construction of Tunnels, Culverts and Side-Paths

Provided at Appendix E is a feasibility study of the tunneling and construction of the culverts and parallel side paths of Alternative 1. The feasibility study identified and discussed numerous feasible technical approaches that could be implemented to construct the tunnels, culverts and side-paths. The basis in evaluating each approach incorporated the following considerations: 1) rock formations are relatively soft to medium hardness; 2) there are numerous works to be excavated including tunnels, connecting chambers and

vertical tie-ins; and 3) use of the tunnel boring machines may be excessively expensive and not justified for a project of this type. Of the approaches identified, discussed and evaluated, the following approach was found to be the most the desirable and recommended:

1) The retention reservoir for each treatment facility will be excavated first. This provides a working and staging site closer to the level of the tunnel thus not requiring as deep a shaft structure. The shaft will be excavated from the base of the retention reservoir with initial supports provided. Upon completion of the shaft opening, the excavation of the tunnel will commence. Excavation of the tunnel will advance with muck materials being staged in the base of the retention reservoir and hauled at the earliest opportunity to a pre-approved disposal site. Initial tunnel liners will be installed to support the tunnel opening. Once the tunnel opening is completed with initial supports installed, concentrated efforts will be dedicated to the excavation of the vertical shafts.
2) Using the "heading and bench" method, a "road header" machine will be used to excavate the tunnels to the specific engineered size, geometry and specification. This method involves the use of smaller excavation advances where the whole face is not excavated at one time. The road header will start at the top of the tunnel excavating a section approximately ten (10) feet wide and ten (10) feet high conforming to the final shape of the opening. This excavation will be supported and the next section would be excavated. This process will continue until a specified length of tunnel is excavated. Once the entire opening is made, the process starts again until the tunnel is completed.
3) At this time it is recommended that plates be preinstalled in the existing culverts and concrete bottom of the ship channel. This pre-installation is necessary to seal the "tie-in" area that will eventually be opened by tunnel excavation from water intrusion during construction. This pre-installation can be accomplished, as time permits, during scheduled periods of maintenance when access is available to the area(s) without interruption to canal operations (see Appendix E for detail).

4) Groundwater will probably be a problem during tunnel excavation. The tunnels will be excavated with a slight upgrade so the any nominal groundwater will flow to the portal. If excessive inflows are encountered, holes will be drilled into the rock in advance of the tunnel excavation or into the wall of the tunnel and grout injected to stop the inflows. If it is determined that groundwater is a problem at all locations, it may be necessary to pre grout the tunnel alignment to cutoff grout water inflows. Water that is channeled to the shaft will be collected in a sump and pumped as necessary to the surface, cycled through settling tanks and discharged into the lock or ocean. Oil separators will also be used to aid in cleaning the water prior to discharge.
5) Excavation for vertical culverts and tie-ins to existing drainage culverts and ship channel bottoms will be performed using a full face raised boring machine with initial supports installed as the work progresses (see Appendix E for detail).
6) Once the excavations are all complete, the shafts and tunnel can be final lined. Final tunnel and shaft linings typically consist of either a steel liner such as a pipe, a cast in place concrete liner or a cast-in-place inter-liner in a concrete segment tunnel. Typically, steel liners can either be pipe types assembled in the tunnels, pipe to pipe or in sections assembled to form rings with the rings being assembled to form the liner. Cast-in-place concrete lining is commonplace, especially for tunnels of the size described for the proposed Project. To accomplish cast-in-place, casting forms are placed inside the tunnel with concrete placed in the opening between the forms and the rock forming the final lining. This concrete final lining can either be reinforced or non-reinforced depending on the design specifications of the tunnel.
7) Once all the above and all associated work is complete the sealing plates from 3) above are removed and the project is activated.

Construction of parallel side-paths, though different in orientation and structure, will be constructed in the same general manner as described above.

Construction of Retention Reservoirs

Shown in Drawing PC01-FS007 are details of the retention reservoir to be constructed at the Gatun and Miraflores treatment facilities. As shown in Drawings PC01-FS009 and Drawing PC01-FS011, each of the retention reservoirs at the Gatun and Miraflores treatment facilities would be approximately 520-feet and 180-feet from existing canal lock structures, respectively. Our present knowledge of subsurface soils and rock in the vicinity to the proposed facility locations indicates that excavating to construct the retention reservoir structures will not present a hazard to canal structures. However, to ensure such will not occur, an extensive geo-technical study should be conducted for each site, the data for which would be rigorously evaluated to determine the level of risk to existing structures and the appropriate mitigation measures to protect them during excavation and construction of the reservoirs. Withstanding the outcome of this analytical evaluation, it is envisioned that "sheet piles" will be installed during excavation and a "slip-forming" technique used during construction, the combination of which should provide sufficient protection to existing canal structures.

3.5.2.4 Electrical Power Transmission

High voltage (115kV) lines originating from the point of production will be installed in the parallel side-path access tunnels and emerge above ground at central points on the eastern side of the canal structures. These central points will be selected so as not to interfere with canal operations during construction and operations. From this central point, above ground high voltage transmission lines will be suspended from transmission tower structures in accordance with the most recent technology available and good design practices along the most appropriate route to the treatment facility electrical substation. Transmission lines will be aluminum cable steel reinforced (ACSR) and match the requirements of CND. From the propose Project substation, high voltage electrical power transmission lines will be routed to ACP power distribution facilities and inter-connected to existing electrical power distribution substations managed by CND. High voltage lines will be continuously monitored for evidence physical damage, theft or vandalism.

Electrical power meters will be installed at the location where power is transferred from the treatment facility operation to the ACP and/or CND.

3.5.2.5 Proposed Project Schedule

Shown at Plate 3.5.2b is a preliminary planning schedule for the proposed Project incorporating the significant activity categories associated with implementation of Alternative 1, Phase I. As shown on the plate, the project can be completed from closure of project financing to commissioning and start-up in approximately 30 months. Those activities shown with "dashed" lines indicate flexible time periods during which work in the ship channel can occur without disrupting ongoing canal operations.

3.5.2.6 Proposed Project Logistical Support Requirements

Implementation of Alternative 1 will require a significant level of field services to support the construction, installation and start-up of operations phase of the proposed Project. Such service requirements will likely include housing, transportation, health services, sanitation, food service, laundry, subsistence supply, financial services and communications to support a maximum labor population in the range of approximately 500 to 700 personnel. Such field service support operations could be provided from existing vacant facilities located on properties current owned and managed by the ACP or ARI; in which case, proponents of the proposed Project would lease them and invest a reasonable amount of expense to restore and/or renovate the facilities to accommodate support services during the construction, installation and start-up phase of the proposed project.

3.5.3 Economic Analysis of the Proposed Project

The economic analysis of Technical Alternative 1 is based on a variety of parameters that include project finance factors, required capital investment and facilities operations expense; all of which were integrated into a base project economic model to determine

essential project "yardsticks" for evaluation. Such "yardsticks" include gross revenue, net cash flow, present value profit (PVP), the PVP to investment ratio, and payout (time period to "breakeven"). Once the base economic model was constructed several sensitivity scenarios were run to evaluate proposed Project economic performance on the basis of adjusting revenue streams earned by the proposed Project.

3.5.3.1 Project Economic Model Factors and Parameters

The following are the various factors and parameters used in the development of the economic model for the proposed Project:

1) Financial factors:
   a) At the time the model was being constructed the credit rating for the Government of Panama according to *Standard and Poor's* was a *BB* rating. As such the interest rate for the cost of capital to implement the proposed Project was presumed to be approximately 8.5 percent.
   b) An inflation index of 5 percent throughout the project was used.
   c) An initial value of $100 per acre-foot ($0.081 per cm^3) for treated water purveyed to the public utility system was used.
   d) An initial value of $0.11 per kilowatt-hour of net electrical power generated and conveyed to the public electrical grid was used and discounted 20 percent to account for public agency to public agency service fee reductions.
   e) A transit forecast allowing for an arithmetic increase from the current 13,400 (37 daily) to 16, 425 (45 daily) in the 10th full-year of the project (year 12 in the model) was assumed to be enabled by the proposed Project.
   f) The current annual average transit revenue on per transit basis of approximately $41, 148 was used initially then indexed annually by the rate of inflation.
   g) Values for water and power production were arithmetically increase on the basis of transit forecasts in item e) above.
2) Expense parameters:

a) A wage hour scale consistent the prevailing Panamanian labor regulations was used.

b) Not more than an average of eight (8) hours of overtime per operations and skilled technical employees (at "time and ½ ") was established for each work month.

c) Employee benefits (medical, dental, life insurance, disability, etc.) were presumed to account for not more than 34% of the cost of labor.

d) Employee expenses for training, continuing education, health and safety, etc., was presumed to account for not more than 12.5% of labor costs.

e) The annual average of miscellaneous fees for external auditing, legal administration, technical consultants, etc., was presumed not to exceed $250,000 annually.

f) The annual average facility indemnification costs were presumed to be approximately $500,000.

g) The annual average of equipment and materials costs to support facility operations and maintenance was presumed not exceed 1.5% of the capital investment.

3) Economic "Yardsticks"

a) Gross Revenue represents the sum of all revenue streams that may include sell of treated water; sell of excess electrical power and/or the value of incremental transit revenue attributed to the proposed Project.

b) Net Cash Flow (NCF) represents gross revenue less expenses and project finance debt service charges.

c) Present Value Profit (PVP) represents the time value of capital invested in the project and the profit derived from it. Recognizing that money today is more valuable than money some number of years from now, use of discounted cash flow is especially useful when comparing alternative proposals. PVP relates the sum of profit realized from a project some number of years in the future.

d) The PVP-to-investment ratio provides recognition of profit generation after payout in terms of current worth some number of years from now.

e) Payout is the measure of time (years) required for NCF to retire the project

debt obligation.

3.5.3.2 Project Economic Model and Sensitivity Scenarios

Given the factors and parameters above, a project economic model was constructed and is provided at Table 3.5.3a. This table is presented in four variations, each variation representing a sensitivity scenario. These scenarios are briefly described as:

1) Scenario A: Use of revenue streams derived from the sell of "potable" water, excess electric power and the value of incremental increase in transit volume attributable to the proposed Project;
2) Scenario B: Use of revenue streams derived from the sell of excess electric power and the value of incremental increase in transit volume attributable to the proposed Project;
3) Scenario C: Use of revenue streams derived from the sell only excess electric power generated by the proposed Project; and
4) Scenario D: Use of revenue streams derived from only the value of incremental increase in transit volume attributable to the proposed Project.

In all scenarios above, water is presumed to be treated to enable canal capacity increases and excess electrical power generated, whether or not revenue is generated from the sell of "off-take" potable water to IDAAN or excess power sold to distribution entities and conveyed to the utility grid operated by CND; thus the level of investment ($420M) does not change.

The results of each economic model for the sensitivity scenarios identified above are collated and presented in Table 3.5.3b. As shown in the table, there is a significant difference between scenarios A and B compared to C and D. Scenarios C and D required a debt obligation retirement period of 15 years compared to ten (10) years for Scenarios A and B. This difference results from the early stress on net cash flow when transit activity is less and not of a sufficient magnitude to generate revenues to overcome the

debt obligations. As transit activity increases, revenues increase beyond the offsetting obligation to reduce debt. Given this relationship, the ability to sell water and power is an important factor in cash flow management in the early phase (first ten years) of the proposed project and demonstrates that Scenario A is the superior scenario with Scenario B a distant alternate choice.

Given the presumption that Scenario A is preferred, as shown in Table 3.5.3 – Scenario A, the annual net cash flows following deductions for project financing debt service and operating expenses increase from values of $3.1 million in project year 3 (start-up) to a value of $285.2 million in year 12 (10th year of operations). The cumulative NCF for the proposed Project after ten (10) operational years is approximately $1,571 million. The NCF value for each project year is discounted to generate a present value profit (PVP). The cumulative PVP for the project after ten (10) operational project years is approximately $771 million. The subsequent PVP-to-investment ratio is 1.84.

3.6 Implementation Financing

This section addresses Wpsi's vision of how: 1) the proposed Project could be developed as a privately financed concession venture within the framework of existing ACP operations; 2) the general structure of project financing that enables the implementation of the proposed Project; and, 3) the mechanism by which investment and costs are recovered to retire Project debt and achieve profitability.

3.6.1 Overview of Concession Relationship

Wpsi, Inc. envisions establishing a joint venture that would privately finance the design, construction and operations of the proposed Project, structured as shown in Plate 3.6.1. This private joint venture, with the consent of Panamanian authorities, would establish a concession relationship with the ACP, whereby the proposed Project facilities could be privately operated and managed by the joint venture yet is accountable to and under the operational control of the ACP to ensure continuity and security of canal operations.

As shown on Plate 3.6.1, Wpsi, Inc., a California Corporation, Champi & Associates, a New Jersey corporation, Point Enterprises International, a New Jersey corporation, F. Alfaro & Associates, a Panamanian corporation, and Robert Wheeler & Associates, a New Jersey corporation form the core management team of the Project venture being responsible for engineering, construction, operations, and financial management, respectively. This joint venture has the necessary technical, construction, operations and financial management expertise that is necessary to execute the proposed project that would include, as also shown in Plate 3.6.1, equity partner participation on a magnitude necessary to secure project financing. Further, the joint venture intends to organize, in cooperation and in coordination with the Panamanian authorities, an operating entity chartered according to Panamanian law as a waterworks and power generation entity to operate and maintain the Project facilities until such appropriate time, the Project would be transferred back to the ACP or the ACP's designee.

3.6.2 Project Financing Strategy and Structure

Assuming that the ACP is amenable to entering into a quasi-concession relationship for the design, development, construction, operation and maintenance of the proposed Project, implementation of Project financing is envisioned to occur in two phases as outlined in broad terms as follows:

Phase I

1) Enjoin joint venture partnership and respective equity commitments;
2) Identify and acquire additional equity commitments from private investors and/or financial institutions, as required, to round out equity contribution requirements to make the Project bankable;
3) Solicit long-term debt financing from the Inter-American Development Bank (IDB) under it's A/B Loan program, by which the IDB would provide a portion of the required debt financing under it's A-Loan and would round-out the balance of

the required debt financing through a syndicated B-Loan or placement in the private market;

4) Approach export credit agencies such as the U.S. Export/Import Bank for the provision of export credit financing related to equipment and materials; and
5) Approach other multilateral financial institutions such as the Multilateral Investment Guarantee Agency for the provision of an equity guaranty, if required, to make the Project Bankable.

The activities outlined above will define the preliminary structure and participants in the Project. If any one of the above activities results in a "no-go", then deriving suitable alternatives will be necessary. After the preliminary structure is defined, Phase II, as generally outlined below, will ensue.

Phase II

Phase II involves the negotiation of all relevant agreements necessary to execute Project financing. The principal agreements include, but are not limited to, the following:

1) The Concession Agreement;
2) Joint Venture Equity Partner Agreement(s)
3) Principal Project Financing Agreements; and,
4) Other Project Agreements such as purchase and sale agreements or leases for the Project site and all easements, rights-of-way and other interests in and over the land required to construct, own and operate the Project; EPC; O&M; raw water supply agreement, if applicable; take-off agreements for water and energy; interconnections agreements; etc.

The Project financing process is more complex than depicted above. In addition to structuring the equity and debt and execution of the financing and Project documents, a thorough environmental and social impact analysis will be performed in accordance with ANAM's requirements. Project execution will then be enabled. The process by which

funds flow into and out of the Project is envisioned as depicted in Plate 3.6.2. As shown on this plate, Project loan and investment funds would flow from the principal financing institutions to an offshore bank to the Project Company (the Panamanian entity) for purchase of goods and services to execute the Project. In return, funds from the Project beneficiary (off-takers) would flow through the Panamanian operating unit to the offshore Project bank, the joint venture and principal financing institutions to service debt and equity.

3.6.3 Investment/Cost Recovery Strategy

As depicted on Plate 3.6.2, funds flowing from the Project beneficiary to the Panamanian operating unit represent proceeds from the sale of treated water and generated power produced by the Project. As described in Section 1.3, approximately 15 percent of the water being treated by Project facilities will be treated to "potable" safe drinking water standards and conveyed to the ACP which in-turn conveys it to IDAAN. To recover cost and expense in conveying treated water from Project facilities to the ACP, the Project would negotiate with the ACP and recover from it a treatment, handling and transportation charge for that volume of water passing through the ACP to IDAAN. The negotiated charge would ensure the ACP recovers it's own handling and transfer cost to IDAAN. If the ACP does not desire to participate in this scenario, then the Project would convey the water directly to IDAAN and sell the same at spot market value prices. Similarly, hydroelectric power generated by the Project will be transmitted to Project substations that are inter-connected with SIN and CND whereby generated power could be sold to the power grid at spot market prices. Lastly, the volume of water treated by Project facilities to beneficial use standards and conveyed by pipeline to the lake systems supporting canal operations is done so at the expense of the Project. To recover cost and expense, the Project, under the concession contract, would be entitled to negotiate with the ACP and recover from it a treatment, handling and transportation charge for that volume of water discharged to the lake systems.

In the interest of "good will", before-tax profit generated by this Project will be shared

with the Project host and beneficiary, the Panama Canal Administration (ACP). Initially, it is anticipated that ten (10) percent of earned Project before tax profit will be deposited into a third party trust, mutually agreeable to the Project joint venture, the ACP and Project creditor(s) *for the intended use by Panamanian authorities to finance the construction of wastewater treatment facilities for communities located along the perimeter of Gatun Lake so as to enable the curtailing sanitary pollutant discharges to the lake system.* Project contributions to this trust will increase to 15 percent and 20 percent during the fifth and eighth years of Project operations.

4.0 HUMAN HEALTH, EVIRONMENTAL AND ECOLOGICAL ANALYSIS

The current land use and general development plan for the Panama Canal region is shown in Plate 4.0a. Land use and development plan details for: 1) the area in the vicinity of the Gatun Locks and a portion of Gatun Lake; 2) the remainder of Gatun Lake, the Gaillard Cut and the area in the vicinity of Pedro Miguel Locks; and, 3) Miraflores Lake and the Miraflores Locks are shown on Plate 4.0b, 4.0c and 4.0d, respectively. As relevant to this analysis, these plates show the areas of forest and vegetation, agricultural and industrial land use areas, and areas of high, medium and low-density population in the Panama Canal region and surrounding watershed areas. As shown in these plates, areas of high population density are generally located in the cities of Balboa, Panama City, and Colon.

Areas shaded in green on the plates show the tropical ecosystem that is rich in its diversity of plant and animal life: it is an important habitat for tropical migratory birds, and rare and endangered animals. Two forest types exist that are rare elsewhere in Central America: 1) dry tropical forests which dominate the Pacific region; and, 2) wet tropical forests which dominate the Atlantic region[74]. The forest cover of the watershed has been reduced from approximately 70 percent in 1947 to 30 percent in 1997. Deforestation is a result of several factors: 1) population pressures and expansion of the urban areas of Panama City and Colon; 2) the spread of cattle ranching; and, 3) slash and burn farming. A consequence of deforestation is increased erosion and siltation of water bodies in the canal region such that storage capacity is reduced and the operation of the Panama Canal, which depends on water supplied by the canal lakes, jeopardized[75].

The proposed Project would divert a portion of the water discharged from the Gatun and Miraflores exit locks to reservoir structures for subsequent treatment to meet beneficial use criteria for discharge to the canal lake system and drinking water criteria for public consumption. Approximately 44 percent of the treated water would be recycled to Gatun

[74] Ibid. 60.
[75] Ibid. 62.

Lake in Phase I. The reservoir structure and treatment facilities at the Miraflores locks would be located on the west side of the canal to avoid infrastructure such as pipelines crossing roads or passing through several communities and existing ACP facilities. Through inclusion of pneumatic and hydraulic barriers, the project is designed to reduce to the greatest extent possible saltwater intrusion into the fresh water bodies of Miraflores and Gatun lakes.

The Project, as previously discussed, will be conducted in phases. In Phase I, as shown in Plate 1.3a, approximately 962 mgd will be diverted from each of the exit locks at the Gatun and Miraflores lock systems. After treatment, approximately 201 mgd from each treatment facility will be recycled to Gatun Lake; the balance of approximately 87 mgd will be purveyed to the ACP and/or IDAAN for use as drinking water. Further, in Phase I parallel side-path "pit" hydroelectric turbine generators will be installed adjacent to existing the drainage culverts between lock chambers capable of producing approximately 90 MW of clean electricity in excess of project needs that would be made available to the ACP and/or CND.

In Phase II, as shown in Plates 1.3b, approximately 1,170 mgd will be diverted from each of the exit locks at the Gatun and Miraflores lock systems in or around year 2016. It is anticipated that within 10 years of facilities operation, as a result of "flushing" Miraflores Lake with flows from the Pedro Miguel lock system concurrently with the elimination of saltwater intrusion into Miraflores Lake from the Miraflores lock system, the existing "brackish" water condition in Lake Miraflores will have improved significantly and the aquatic habitat returned to a fresh water condition. Implementation of Phase II also involves significant increases in the water purveyed to the ACP and/or IDAAN and in electricity produced and made available to the ACP and/or CND.

In analyzing the anticipated environmental (human health and ecological) impacts of the proposed Project, short and long-term impacts presented were developed and compared to baseline conditions as presented in Section 2.7.

4.1 Human Health Impacts

The principal human health impact of the proposed Project relates to the provision of drinking water. Of the total population of 2.8 million in Panama, half live in the Panama City - Colon corridor of the Panama Canal Zone[76]. About eighty per cent of these urban dwellers depend on water from Gatun Lake and Madden Lake for their drinking water supply[77]. Increasing urbanization of the Panama Canal watershed, with concomitant deforestation and pollution from human activities, has resulted in a reduction in the potable water supply.

4.1.1 Short-term Impacts and Mitigation Measures

No short-term impacts are anticipated as a result of implementation of the proposed Project.

4.1.2 Long-term Impacts and Mitigation Measures

The proposed Project is anticipated to have a positive impact on human health in expanding the availability of potable water supply to the general population through its purveyance to IDAAN. In supporting continued and increased operation of the Panama Canal and provision of electric power, it will promote economic growth in the region. With responsible application, increased economic growth can result in improved living conditions with a concomitant improvement in health.

4.2 Environmental Impacts

4.2.1 Water Quality

4.2.1.1 Short-term Impacts and Mitigation Measures

[76] Ibid. 14.
[77] Ibid. 62.

Short-term impacts are not anticipated.

4.2.1.2 Long-term Impacts and Mitigation Measures

The most immediate impact will be on the water quality of Miraflores Lake and subsequently water in the Gaillard Cut. Salinity levels in Miraflores Lake will decline to levels approaching those of Gatun Lake, i.e. near freshwater quality. The proposed Project will also significantly improve other water quality parameters including dissolved oxygen levels, reduction in bacterial levels, and total solids.

Reclamation and treatment of lock water to meet drinking water requirements will relieve the burden on existing fresh water bodies for drinking water. This is especially important for Alhajuela Lake where the water quality is compromised by pollutant loading from the increasing population density around the lake. Replenishment of fresh water to Gatun Lake will also serve to meet the increased fresh water need for the anticipated increase in ship transit.

The projected shortfall in municipal and industrial water production is shown in Table 2.3.2e. The estimated shortfall by 2010 is 119.5 million gallons per day, increasing to 280.5 million gallons per day by 2050. In increasing the supply of potable and beneficial-use water, the proposed Project will significantly contribute to efforts to reduce the water shortfall and permit sustainable development of the Canal Zone.

4.2.2 Air Quality

4.2.2.1 Short-term Impacts and Mitigation Measures

During construction of the proposed Project, particulate emissions from equipment as well as dusts from site development activities will impact air quality in the Project area.

Emissions reduction control on construction equipment will be used where available. Dust control measures will be implemented as necessary.

4.2.2.2 Long-term Impacts and Mitigation Measures

No adverse impacts are anticipated. Emissions from using fossil fuels will be reduced by hydroelectric power generated by the proposed Project. It is estimated that as much as approximately 21MW of fossil fuel fired electrical power generation could be eliminated.

4.2.3 Solid and Hazardous Waste Generation

4.2.3.1 Short-term Impacts and Mitigation Measures

Excavated soils and construction debris generated in constructing the treatment units will be containerized and disposed of as a non-hazardous waste or hazardous waste as appropriate. Stockpiles will be covered and lined to prevent sediment generation and leachate contamination respectively.

4.2.3.2 Long-term Impacts and Mitigation Measures

No adverse long-term impacts are anticipated as a result of implementing the proposed Project. Treatment, in reducing bacterial levels, will reduce sludge; removal of sediment will also remove entrapped contaminants such as oil and grease, pesticides, and other ship derived wastes. The treatment end product, filter cake, may be used, depending on analysis, as a soil amendment. The reduction in sediment will ultimately improve the ecosystem in the reduction of aquatic weeds.

4.3 Ecological Impacts

4.3.1 Sensitive Life Forms

Existing inventories of life form species indicate that at the present time there are no known sensitive life forms located in the specific habitat of the where the proposed Project facilities would be located.

4.3.1.1 Short-term Impacts and Mitigation Measures

Not applicable.

4.3.1.2 Long-term Impacts and Mitigation Measures

Not applicable.

4.3.2 Ecological Systems

4.3.2.1 Short-term Impacts and Mitigation Measures

Construction of the proposed project facilities will result in a loss of terrestrial habitat in the Project area, including wetlands in the Gatun Locks area. Design of the facilities to have as small a footprint as possible will minimize the loss. It is not anticipated that terrestrial fauna will be adversely impacted. Indeed, exposed soil may benefit the green iguana, a protected species, which uses soft soils for laying eggs. Turtles and crocodiles may also use this habitat to lay eggs.

4.3.2.2 Long-term Impacts and Mitigation Measures

The principal long-term impacts will be to aquatic flora and fauna and are anticipated to be beneficial. Reduction in bacterial and sediment levels in the water will ultimately reduce the growth of fresh waterweeds such as the water hyacinth and water cucumber. As the salinity in Miraflores Lake is reduced to levels similar to that of Gatun Lake, there will be an increase in aquatic species of fish in the lake. This in turn may result in an increase in birds such as the tern that feed on aquatic fish. Similarly, the increasing fresh

water quality of Miraflores Lake will encourage population by bethnic organisms found in Gatun Lake.

Reduction in the bacterial load in extracted lock water will ultimately reduce the bacterial load released to the Pacific and Atlantic Oceans. If combined with a system-wide treatment of sewage, this measure would ameliorate the ecosystems in these two oceans, possibly significantly for the extensive coral reef adjacent to the Atlantic entrance of the canal.

5.0 SOCIO-ECONOMIC ANALYSIS

The proposed Project was evaluated for potential socio-economic impacts. As it will be located in an uninhabited area, it was found that there would likely be insignificant impacts to the, cultural heritage, indigenous peoples, archaeology, population or health of the population. The Project will likely create impacts to the region on an economic basis only.

There are three major elements of the proposed Project that are expected to have significant economic impacts:

1) The addition of potable water supplies for consumption in the Panama-Colon region is likely to create increased development capacity. An increase of development capacity can potentially support domestic growth and increase the overall welfare in the region.
2) Similarly, the increased development capacity created by the power generated by the proposed Project will allow for economic expansion.
3) Finally, the availability of a sustainable supply of clean freshwater for use to sustain lake levels required to support current and projected canal capacity, a major economic driver within Panama, also enhances the overall water quality of the canal lake system.

5.1 Socio Economic Impacts Created by Addition of Water to Potable Water Supply

The availability of fresh water resources is critical to achieving economic development in central Panama, especially with the capacity requirements of the Canal itself. The extended dry periods of 1993 and 1997 showed that the region requires a steady and reliable source of water to fuel future development, as the system is close to equilibrium right now. The proposed Project will help to provide much of this supply of water.

At the completion of Phase I construction of the proposed Project, the Gatun and Miraflores treatment facilities are expected to treat approximately 577 million gallons of water per day, 175 million gallons per day of which will purveyed to the ACP and/or the IDAAN. As shown in Table 2.3.3e, by interpolation, the total estimated average demand for water within the IDAAN service area during the Phase I period (Year 2006 to 2016) will be approximately 356.1 million gallons per day. The completion of the first phase of the proposed Project would increase IDAAN's service capacity by generating enough water to satisfy approximately 49.1 percent of current demand levels.

The increased availability of water created by the proposed Project would generate the "exclusive" service capacity for each of the potential end users listed Table 5.1a.

By year 2016, operations at the Gatun Locks treatment facility and Miraflores Locks treatment facility will have increased their recovery rates for treated water. The facilities are projected to treat approximately 1,404 million gallons per day, and are expected to recover 210 million gallons per day, which will be purveyed to the ACP and/or IDAAN. As shown in Table 2.3.3e, by interpolation, the total estimated average demand for water within the IDAAN service area during the Phase II period (Year 2017 to 2031) will be approximately 418.8 million gallons per day. Phase II of the proposed Project would increase IDAAN's service capacity by generating enough water to satisfy approximately 50.1 percent of current demand levels.

The increased availability of water created by the proposed Project would generate the "exclusive" service capacity for each of the potential end users listed in Table 5.1b.

5.2 Socio Economic Impacts Created by Addition Of Electrical Power to National Central Dispatch

Currently, the SIN provides electricity through two of its agencies; ETESA and the CND. Current electricity production capacity for SIN is approximately 1,305 megawatts. Accounting for system losses, there is approximately 1,041 megawatts of hydroelectric

power available to meet potential demand. Near the completion of Phase I of the proposed Project in year 2010, approximately 57 megawatts will be available for use by the CND. This will increase the system's total capacity by approximately 3 percent. As current demand is estimated in the range of at 884 to 1629 megawatts, the project will increase SIN's reserve power capacity during the Phase I period by an approximate range of 36 to 112 percent.

By year 2015, Phase II of the proposed Project is also expected to generate approximately 57 megawatts of net available hydroelectric power for use by the CND. With current proposed projects for SIN, 2010 production capacity is projected at 2,689 megawatts, with 2,313 megawatts available to meet demand. Thus the proposed Project will increase SIN's capacity by approximately 2 percent. With demand in year 2015 estimated at approximately 2,289 megawatts, the proposed project will increase reserve power capacity by approximately 138 percent.

5.3 Socio Economic Impacts Created by Additional Panama Canal Capacity

The proposed Project will reclaim and treat water from the Gatun and Miraflores Locks, and more importantly, will prevent further saltwater intrusion into the canal lake system. A significant portion of that water will be returned to Gatun Lake. The combined affect of saltwater intrusion prevention and the flushing of these lakes with fresh water will contribute to the long-term and progressive diminishment of salinity levels in both lakes. Where before, each transit through the canal allowed saltwater to intrude into the canal lake system, thereby threatening its freshwater quality and creating potential long-term adverse environmental and socio-economic impacts; as a result of the proposed Project, the ACP will be able increase the canal transit capacity without threatening the quality of the canal lake system. This acquired "freedom of action" allows the ACP to address increases in canal capacity free from fear of serious adverse environmental or socio-economic impacts that would otherwise limit canal capacity and potential economic growth.

Currently, the ACP allows roughly 37 transits per day. That figure is expected to increase to 44 transits per day by year 2010. That would allow total traffic in the Canal to increase by 20 percent, to roughly 16,000 annual transits in year 2010. With toll rates increasing at an average rate of 4.0 percent per year for the last two years, the corresponding toll collection is projected to be roughly US$993 million, or approximately 72 percent more than the US$578 million collected in year 2001.

By year 2030, it is projected that the ACP will be able to increase transits to 55 per day because of improved lake water quality, a 149 percent increase from current levels. This would equate to 20,075 annual transits, with corresponding tolls of approximately US$2,720 million, a 471 percent increase from year 2001 toll levels.

5.4 Potential Impacts to Employment, Commerce and Income

The extent of potential impacts that the proposed Project will have on the local employment base is difficult to quantify. Because the Project will create a capacity for new jobs to exist, and not directly create new jobs, it is difficult to quantify the allocation of new jobs between various industries. As discussed in the section above, the Project will create an additional potable water supply that will crate the ability to serve various user types at increasing capacities. The Project will create the ability to create new jobs, with the actual job generation dependent on investment in infrastructure, utilization of natural resources, government spending, and government policies and levels of entrepreneurship within the country.

By year 2050, the proposed Project will have created the ability to add 1.2 million wet industry jobs to the economy, 2.0 million dry industry-manufacturing jobs, 6.1 million utilities employees, 34.2 million retail employees, or 2.5 million hospital employees. Each figure represents the maximum potential capacity for each of the employment types, and the creation of one job type would decrease the capacity of another type. Very likely, the additional water would be used to serve a mix of the employment types listed above, as well as residential households and agricultural uses.

Because of the nature of the uncertainty surrounding the mix of eventual employment uses, it is difficult to predict the project's exact impacts on income levels. The proposed Project will very likely have a significant positive impact on total income for Panama. Depending on the quality of jobs created within the mix of employment, per capita incomes have the potential to increase as well.

5.5 Potential Impacts to Housing

Similar to the proposed Project's potential impacts on employment, the proposed Project will create the ability to add housing to the housing stock, but will not directly add additional housing. By year 2050, the proposed Project will have created the capacity for 4.6 million additional households. This figure represents the maximum capacity that could be created by the Project, and would be diminished if water were directed to other uses, such as employment or agriculture. As noted above, the likely scenario will be that the new water will support a mix of the potential uses.

5.6 Potential Impacts on Agriculture

As noted above, the proposed Project will create the ability to irrigate additional agricultural land. The proposed Project will not directly create additional agricultural land nor change the land use at any site to that of agricultural. By year 2050, the proposed Project will have created the capacity for 3.4 million hectares of agricultural land. This figure represents the maximum capacity that could be created by the Project, and would be diminished if water were directed to other uses, such as employment or residential housing. As noted above, the likely scenario will be that the new water will support a mix of the potential uses.

6.0 FINDINGS AND CONCLUSIONS

In the course of developing this feasibility study for the proposed Project, Wpsi, Inc. relied on information, data and materials provided to it by the APC and that available in the public domain. Such information, data and materials included engineering studies, environmental reports, operation procedures, historical data and statistics, development plans, rules and regulations, and numerous other documents as listed in Section 8.0 below. Given this body of intellectual material, our understanding and assessment of it, current and projected conditions in the Panama Canal region were established by which the feasibility of the proposed project was evaluated. Our findings and conclusion that resulted from this effort are presented below.

Findings

In regard to conditions in the Panama Canal region the following findings were identified:

1) The Panama Canal system is at or near its maximum capacity. In order to satisfy customer demand for increased capacity, the ACP must implement water resource and/or engineered systems alternatives that would enable it to increase canal capacity;

2) The estimated annual requirements for fresh water needed to operate the Panama Canal and successfully satisfy forecasted ship transit activity is expected to increase by approximately 139 billion gallons (382 million gallons per day) in ten years (2010) and 697 billion gallons (1.9 billion gallons per day) in fifty years (2050);

3) The demand for M&I water in the Panama Canal Region is likely to increase from approximately 353.1 mgd in year 2010 to approximately 514.1 mgd in year 2050

resulting in potential significant shortfalls of supply that increase from 119.5 mgd in year 2010 and to 280.5 mgd in year 2050;

4) The discharge of untreated sewage throughout the Panama Canal watershed has resulted in higher than acceptable levels of faecal bacteria in the water that, if left unmitigated, will soon create a circumstance whereby only bottled water will be safe to drink in the Panama City-Colon regions;

5) The current trend line reduction in annual average rainfall for the entire Panama Canal drainage basin is approximately 1.4 billion gallons per year; equivalent to approximately 27 transits per year; and

6) In consideration of: a) the loss of a production facility for turn-around maintenance or mechanical upgrades, b) an annual average rate of domestic and economic growth outside the ranges of 0.9% and 4.4%, respectively, c) an increase in canal capacity, d) implementation of ARI's general development plan for the canal region that achieve development results that modestly exceed initial goals and objectives and, e) emerging power export opportunities outside the Republic of Panama; a reduction of the reserve margin from the range of 14% in the near term to 3.5% in the long term could easily evolve into a negative attribute that adversely affects pursuit of growth opportunities and diminish prosperous expectations.

In regard our technical analysis of alternatives to achieve the goals and objective of the proposed Project the following findings were identified:

7) The recovery, reclamation and recycling of lock water from the chamber of exit locks is technically feasible; such that
   a. Enough water would be recycled to the lake system in Phase I to allow a 22% capacity increase to 45 lockages per day by year 2012 and an increase in

capacity of approximately 50% in Phase II to 55 lockages per day on or before year 2025, and

b. The completion of Phase I and Phase II of the proposed Project would increase IDAAN's service capacity by generating enough "potable" drinking water to satisfy approximately 49.1 percent and 50.1 percent of current demand levels, respectively.

8) Saltwater intrusion through the canal systems to Miraflores Lake and Gatun Lake can be arrested by the combined use of pneumatic curtain and hydraulic mounding systems such that Miraflores Lake can be returned to fresh water condition;

9) The generation of "clean" hydroelectric power with the installation of seven banks of three each parallel side-path "pit" turbine-generators is technically feasible, practical and

a. As current demand is estimated at 884 megawatts, the proposed project will increase SIN's reserve power capacity by approximately 36 percent; and,

b. With demand in year 2010 estimated at approximately 1,629 megawatts, the proposed project will increase reserve power capacity by approximately 112 percent.

10) Alternative 1 is the preferred alternative to accomplish Finding 7 having the greatest combined degree of reliability, operability, constructability, and flexibility;

11) Implementation of Alternative 1 as a privatized project, operated as a concession of the ACP, is financially feasible, practical, operable and in conformance with the rule and regulations that govern ACP operations.

In regard our analysis of human health, environmental, ecological and socio-economic impacts associated with the implementation of the proposed Project the following findings were identified:

12) Human health, adversely affected by the reduction in the "potable" water supply that has resulted from increased urbanization in the Panama Canal watershed region, with concomitant deforestation and pollution from human activities, will be favorably impacted with increases in "potable" water supply acquired by the implementation of the proposed Project.

13) Withstanding some short-term negative impacts during construction of the proposed Project that are manageable, associated long-term impacts are
    a. The proposed Project will significantly improve lake water quality parameters including dissolved oxygen levels, reduction in bacterial levels, and total solids,
    b. The reclamation and treatment of lock water to meet drinking water requirements will relieve the burden on existing fresh water bodies for drinking water that is especially important for Alhajuela Lake where the water quality is compromised by pollutant loading from the increasing population density around the lake,
    c. Production of "clean: hydroelectric power presents the potential to reduce or eliminate up to approximately 57 MW initially during Phase I thereby creating a beneficial air quality impact, otherwise there are no long-term adverse air quality impacts,
    d. There are no long-term adverse solid and hazardous waste generation impacts,
    e. The reduction in bacterial and sediment levels in lake water resulting from recycling treated water to the lake systems will: 1) ultimately reduce the growth of fresh waterweeds such as the water hyacinth and water cucumber, 2) as the salinity in Miraflores Lake is reduced to levels similar to that of Gatun Lake, there will be an increase in aquatic species of fish in the lake, 3) this in turn may result in an increase in birds such as the tern that feed on

aquatic fish, and 4) the increasing fresh water quality of Miraflores Lake will encourage population by bethnic organisms found in Gatun Lake,

14) The increased availability of fresh water resources enhances the opportunity for Panama to achieve economic development in Panama Canal region; and

15) Given the increases of canal capacity derived by implementation of the proposed Project and toll rates increases at an average rate of 4.0% per year, the corresponding toll collection resulting from Phase I of the proposed Project is projected to be approximately US$1,025 million by year 2012, or 77 percent more than the US$578 million collected in year 2001, and approximately US$1,303 million by year 2025, a 125 percent increase from year 2001 toll levels.

Conclusions

Implementation of Alternative 1 best achieves the goals and objectives of the proposed Project and inures the following benefits:

1) Assures current canal capacity and enables sustained canal capacity growth;

2) Enables the sustained growth of transit revenues and associated economic benefit;

3) Enables termination of saltwater intrusion in the canal's lake system and a significant improvement in the water quality of those fresh water bodies;

4) Enables the augmentation of potable water supplies to sectors of the region in need of it;

5) Enables the production of significant additional hydraulically generated "clean" electrical power to support the expansion of regional commercial activity without adverse environmental impacts; and,

6) Enhances the productive management and long-term protection of the regional watershed supporting the Panama Canal.

7.0 RECOMMENDATIONS

Wpsi. Inc. recommends that the APC implement Technical Alternative 1 of this Feasibility Study to achieve the objectives identified in Section 1.0. Further, Wpsi, Inc. recommends that Inter-American Development Bank facilitate financial processes to assist implementation of Technical Alternative 1 of this Feasibility Study on behalf of the ACP. Still further, Wpsi, Inc. recommends that the proposed Project be implemented as a privately financed concession project, whereby a concession relationship would be established between joint ventured private parties, who desire to privately develop the proposed Project and the ACP, in which a consortium of private investors would finance the design, construction and operation of the proposed Project by which:

1) Water treated for public consumption passes from concession operations through ACP water treatment facilities to IDAAN's supply system; and

2) Excess hydroelectric power generated by concession operations passes through ACP electric power interconnection facilities to the public electricity grid managed by CND.

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QUALITY CONTROL REVIEWER

Joyce Clarke

Dr. Joyce Clarke, Principal Scientist

Table 2.1.1
Physical Characteristics
Panama Canal Lock System

Lock	Lock Width by Length (ft)	Lift Height (ft)	Lift Volume (ft^3)	Bed Level (ft)
Lower Miraflores	110 x 1,051	26	3.005×10^6	-52.0
Upper Miraflores	110 x 1,071	28	3.298×10^6	-20.3
Pedro Miguel	110 x 1,071	31	3.652×10^6	+11.0
Upper Gatun	110 x 1,071	28	3.298×10^6	+13.0
Middle Gatun	110 x 1,051	29	3.352×10^6	-15.3
Lower Gatun	110 x 1,051	28	3.237×10^6	-44.3

Table 2.2
Estimated Annual Fresh Water Requirement to Support
Panama Canal Operations

Year	Number of Transits per Year/Transit per day	Total Gallons Required (nearest billion)	Change in Gallons Required From Base Year Requirement (nearest billion)
Current (data point base year)	13,400 / 37	697	0
2010 @ 15% increase	15,330 / 42	797	100
@ 20% increase	16,080 / 44	836	139
2050	26,800 / 73	1,394	697

Table 2.3.1
Current M&I Water Production Capacity, Panama Canal Region

Service Region	Plant (Operator)	Water Production Plant Capacity (mgd)
Panama City Metropolitan/Arraijan	Cabra (IDAAN) Chilibre (IDAAN) Mananitas (IDAAN) Miraflores (ACP) Tocumen (IDAAN) Villalobos (IDAAN)	2.0 135.0 0.7 48.0 1.5 3.5
Colon	Escobal (IDAAN) Mount Hope (ACP) Rio Gatun (IDAAN) Sabanitas (IDAAN)	0.1 24.0 2.0 6.0
Panama Este	Chepo Pacora	0.9 0.4
Panama Oste	Chorrera	9.5
Total Water Production Capacity		**233.6**

Table 2.3.2a
Baseline Metered M&I Water Demand
Panama Canal Region

Baseline Parameter	Baseline Demand Rate	Baseline Rate Unit Population	Year 2000 Baseline Demand (mgd)
Residential	73.1 gpd/customer[1]	1,548,260	**113.2**
Agricultural	100 gpd/hectare	33,302	3.3
Wet Industry	287 gpd/employee	54,955	15.8
Other Manufacturing	172 gpd/employee	20,952	3.6
Fabrication & Construction	8997 gpd/1K Balboa	466	4.2
Port	0.07 gpd/metric tons	27,395,281	1.9
Utilities	56 gpd/employee	12,845	0.7
Retail	10 gpd/employee	512,197	5.1
Hospital	135 gpd/bed	4,911	0.7
Education	9.2 gpd/student	488,787	4.5
Hospitality	0.66 gpd/guest	1,163,691	0.8
Subtotal, Non-residential			**40.6**
Total			**153.8**

Table 2.3.2b
Baseline IDAAN System Losses,
Non-metered Residential Demand and
Excessive Use
Panama Canal Region

Baseline Parameter	Percent of Supply	Year 2000 Baseline Demand (mgd)
Unaccounted-for Water Consumption (~36%)		
IDAAN System Losses	26	61.1
Excessive Use	10	24.5
Non-metered Residential Demand Estimate		55.7
Total	**141.3**	

Table 2.3.2c
Baseline M&I Water Demand Summary
Panama Canal Region

Baseline Parameter	Year 2000 Baseline Demand (mgd)
Metered Water Demand	153.8
Unaccounted –for Water Consumption	141.3
Total	**295.1**

Table 2.3.3a
Projected Estimations of Residential Customer Population and M&I Water Demand
Panama Canal Region

Year	Projected Population		Estimated Water Demand	
	Population	Percent Increase (from base year)	Million Gallons per Day	Percent Increase (from base year)
2000	1,548,260	N/A	113.2	N/A
2010	1,867,746	21	135.5	21
2020	2,108,456	36	153.1	39
2030	2,310,036	49	168.1	56
2040	2,462,974	59	179.8	73
2050	2,571,481	66	188.2	88

Table 2.3.3b
Projected Estimations of Non-Residential Customer Population and M&I Water Demand (mgd)
Panama Canal Region

Baseline Parameter	Year									
	2010		2020		2030		2040		2050	
	Population	Demand	Population	Demand	Population	Demand	Population	Demand	Population	Demand
Agricultural	32,574	3.3	31,898	3.2	31,273	3.2	30,699	3.1	30,175	3.0
Wet Industry	67,128	19.3	78,689	22.6	88,468	25.4	97,356	27.9	100,611	28.9
Other Manufacturing	25,593	4.4	30,001	5.2	33,729	5.8	37,118	6.4	38,359	6.6
Fabrication & Construction	632	5.7	824	7.4	1,030	9.3	1,260	11.3	1,447	13.0
Port/ Warehousing	36,230,259	2.5	47,914,517	3.4	63,366,949	4.4	83,802,790	5.9	110,829,190	7.8
Utilities	15,690	0.9	18,392	1.0	20,678	1.2	22,755	1.3	23,516	1.3
Retail	625,652	6.3	733,400	7.3	824,541	8.2	907,385	9.1	937,725	9.4
Hospital	5,622	0.8	6,106	0.8	6,521	0.9	6,883	0.9	7,152	1.0
Education	569,158	5.2	621,401	5.7	665,710	6.1	703,095	6.5	730,866	6.7
Hospitality	316,891	0.2	365,269	0.2	413,209	0.3	461,899	0.3	509,516	0.3
Total (mgd)		**48.6**		**56.9**		**64.8**		**72.6**		**78.0**

Table 2.3.3c
Projected Estimations of IDAAN System Losses,
Non-metered Residential Demand
and Excessive Use (mgd)
Panama Canal Region

Parameter	Year				
	2010	**2020**	**2030**	**2040**	**2050**
IDAAN System Losses	73.7	84.8	95.6	106.1	116.0
Excessive Use	29.1	32.8	36.0	38.5	40.3
Unmetered Residential Demand Estimate	66.2	74.6	81.8	87.5	91.6
Total	**169.0**	**192.2**	**213.4**	**232.1**	**247.9**

Table 2.3.3d
Projected M&I Water Demand Summary (mgd)
Panama Canal Region

Demand	Year				
	2010	**2020**	**2030**	**2040**	**2050**
Metered Water Demand, Residential	135.5	153.1	168.1	179.8	188.2
Metered Water Demand, Non-Residential	48.6	56.9	64.8	72.6	78.0
Unaccounted-for Water Consumption	169.0	192.2	213.4	232.1	247.9
Total	**353.1**	**402.2**	**446.3**	**484.5**	**514.1**

Table 2.3.3e
Projected Shortfall in M&I Water Production Capacity (mgd)
Panama Canal Region

Parameter	Year					
	2001	**2010**	**2020**	**2030**	**2040**	**2050**
Total Estimated M&I Water Demand	295.1	353.1	402.2	446.3	484.5	514.1
Current (Baseline) M&I Water Production Capacity	233.6					
Shortfall in Requirement Satisfaction	**61.5**	**119.5**	**168.6**	**212.7**	**250.9**	**280.5**

Table 2.4a
Water Quality Data Ranges
Alhajuela Lake, Panama Canal Watershed

Water Quality Parameter	Value		
Temperature (°C)	26.9	31.5 24.0	27.7
Fecal Coliforms (count/100ml)	9	1,700 0	154
Total Coliforms (count/100ml)	ND	8,000 6	787
PH	6.7	8.8 6.0	7.4
Secchi (inches)	82	120 12	61
Turbidity (JTU units)	1.8	93 0	7.1
DO – TOP (ppm)	6.1	8.8 3.0	6.6
DO – BOT(ppm)	4.7	8.8 0.01	3.5
TOC (ppm)	7	21 3	5
BOD (ppm)	1.5	2.66 0.03	0.9
Total Solids (ppm)	ND	144 74	102
Conductivity (umhos)	115	268 80	126
Kjeldahl Nitrogen (ppm)	0.16	0.4 <0.1	0.13
Nitrates (ppm)	0.02	0.575 <0.01	0.05
Total Phosphorus (ppm)	0.03	0.15 <0.01	0.03
Alkalinity (ppm)	46	85 24	51
Chloride (ppm)	5.3	10.0 3.5	5.6
Iron (ppb)	32	2100 <20	183

Hi
Dry Wet
Lo

Table 2.4b
Water Quality Data Ranges
Gatun Lake, Panama Canal Watershed

Region	Water Quality Parameter					
	Temp **(°C)**	***Fecal Coliforms*** **(count/100ml)**	**Total Coliforms (count/100ml)**	***pH*** **(units)**	**Secchi (inches)**	***Turbidity*** **(JTU units)**
Monte Lirio	30.5 28.4 28.8 27.2	600 21 22 0	870 11 172 0	8.3 7.0 7.5 6.1	372 228 239 120	3.0 0.4 0.5 0.0
Gatun Lake, North	29.7 27.8 28.9 27.2	78 2 4 0	720 45 112 0	8.1 7.5 7.6 6.5	528 232 244 144	3.0 0.5 0.3 0.0
Escobal	30.0 27.9 29.0 27.7	340 11 46 0	180 26 44 0	8.6 7.3 7.5 6.2	420 240 293 144	3.0 0.6 0.3 0.0
Vino Tinto	30.0 28.5 29.0 27.8	73 5 6 0	90 43 30 6	7.7 7.4 6.7 4.6	384 279 243 132	3.4 0.4 1.6 0.4
Ciricito	30.4 28.0 29.7 27.8	370 22 2 <1	ND	7.7 6.9 5.9 5.5	288 188 181 144	8.1 2.0 1.7 0.5
Barro Colorado	29.8 28.2 29.1 27.0	120 3 2 0	1,600 264 ND 7	8.0 7.6 7.6 6.3	330 144 146 24	10.0 2.6 2.0 0.0
La Laguna	29.2 28.5 28.7 27.8	20 2 3 <1	ND	7.7 7.1 6.8 6.4	312 163 86 18	20 1.6 11 0.7

Notes:

	Hi	
Dry		Wet
	Lo	

Table 2.4b (continued)
Water Quality Data Ranges
Gatun Lake, Panama Canal Watershed

Region	Water Quality Parameter					
	DO-TOP **(ppm)**	***DO-BOT*** **(ppm)**	**TOC** **(ppm)**	***BOD*** **(ppm)**	***Total Solids*** **(ppm)**	***Conductivity*** **(umhos)**
Monte Lirio	8.5 6.7 5.9 3.6	8.6 6.1 4.6 0.7	12 ND 6 1	2.1 0.6 0.3 0	101 ND 77 61	202 118 99 83
Gatun Lake, North	7.6 6.3 5.9 4.3		8 6 5 4	2.1 0.2 ND 0	80 76 69 54	132 113 99 82
Escobal	8.0 5.2 6.4 4.1	7.5 4.8 5.7 3.6	8 5 5 3	1.25 0.5 0.5 0	ND	123 91 86 81
Vino Tinto	8.0 5.7 6.2 4.2	7.5 4.5 4.1 1.2	7 5 5 4	1.35 ND 0.51 0	0.6 0.5 0.05 0.4	123 91 87 83
Ciricito	9.0 5.9 6.6 3.4	8.1 2.6 4.5 1.2	ND	3.1 0.6 1.3 0.15	ND	68 64 ND 59
Barro Colorado	8.5 7.2 5.8 4.2		13 5 6 3	2.2 0.5 0.3 0	120 80 ND 66	143 105 95 92
La Laguna	8.5 5.9 5.9 4.8	7.0 6.0 1.3 0.5	ND	4.4 0.5 1.4 0.15	ND	76 60 ND 51

Hi
Dry Wet
Lo

Table 2.4b (continued)
Water Quality Data Ranges
Gatun Lake, Panama Canal Watershed

Region	Water Quality Parameter					
	Kjeldahl Nitrogen (ppm)	***Nitrates*** (ppm)	**Total Phosphorus** (ppm)	**Alkalinity** (ppm)	***Chloride*** (ppm)	***Iron*** (ppb)
Monte Lirio	0.25 <0.1 0.25 <0.05	0.11 <0.01 <0.01 <0.01	0.16 0.05 0.01 <0.01	60 ND 36 26	7.0 4.3 5.1 3.0	1,800 <20 61 <20
Gatun Lake, North	1.3 0.2 0.16 <0.1	0.18 <0.02 <0.02 <0.01	0.08 0.03 0.02 <0.01	46 34 32 26	9.4 5.2 5.9 4.5	250 56 <20 <20
Escobal	0.3 0.11 0.12 <0.1	0.04 0.014 0.014 <0.01	0.36 0.04 0.016 <0.01	41 29 29 21	8.0 5.8 5.3 4.5	1,400 26 49 <5
Vino Tinto	0.3 0.11 0.14 <0.1	0.04 0.14 0.012 <0.01	0.095 0.016 0.015 <0.005	34 30 22 16	6.5 5.1 5.6 4.5	1205 20 93 <20
Ciricito	0.74 <0.1 0.19 <0.1	0.07 0.01 <0.01 <0.01	0.1 0.013 0.013 <0.005	32 22 ND 18	5.4 5.1 ND 4.8	2,900 35 456 <20
Barro Colorado	0.26 0.09 0.13 <0.01	0.098 0.03 0.03 <0.01	0.14 0.023 0.015 <0.01	46 40 34 29	9.0 5.6 5.5 4.0	335 81 45 <20
La Laguna	0.3 0.11 0.14 <0.1	0.107 <0.01 <0.01 <0.01	1.26 0.04 0.03 <0.01	40 32 ND 29	6.4 4.7 ND 4.2	4,120 113 975 15

Notes:

Hi
Dry Wet
Lo

Table 2.4c (continued)
Water Quality Data Ranges
Chagres-Gamboa-Gaillard Cut, Panama Canal Watershed

Region	Water Quality Parameter					
	DO-TOP **(ppm)**	***DO-BOT*** **(ppm)**	**TOC (ppm)**	***BOD*** **(ppm)**	***Total Solids*** **(ppm)**	***Conductivity*** **(umhos)**
Chagres - Chilibre	8.0 4.2 2.9 <0.1		14 7 5 2	3.7 0.5 0.6 0	254 145 128 90	286 131 122 104
Chilibre-Chilibrillo Area	6.7 4.3 2.6 <0.1		11 7 8 3	9.7 1.8 1.2 0	254 176 170 113	283 206 206 103
Gamboa Beach	7.8 5.3 4.6 2.4		14 6 6 3	1.3 0.5 ND 0.1	950 116 119 70	173 117 116 80
Gamboa Outfall	7.3 4.3 4.9 2.4		12 6 6 3	6 2.4 ND 0.4	199 ND 113 1	176 124 123 113
Gamboa Area Summit I	7.1 4.1 4.5 3.8		10 5 6 3	1.38 0.41 0.61 0.1	293 105 140 42	135 122 124 100

Hi
Dry Wet
Lo

Table 2.4c (continued)
Water Quality Data Ranges
Chagres-Gamboa-Gaillard Cut, Panama Canal Watershed

Region	Water Quality Parameter					
	Kjeldahl Nitrogen (ppm)	***Nitrates*** (ppm)	**Total Phosphorus** (ppm)	**Alkalinity** (ppm)	***Chloride*** (ppm)	***Iron*** (ppb)
Chagres - Chilibre	0.72 0.12 0.18 <0.1	0.4 0.05 0.18 <0.01	0.24 0.04 0.04 <0.01	130 56 58 32	35.0 6.5 5.5 5.0	2,600 62 434 <20
Chilibre-Chilibrillo Area	0.66 0.26 0.22 <0.1	0.465 0.026 0.111 <0.01	0.232 0.057 0.12 <0.01	132 103 95 25	13.5 7.7 6.6 5.0	2,400 126 539 <20
Gamboa Beach	0.46 0.17 0.14 <0.1	1.09 0.05 0.08 <0.01	0.5 0.04 0.03 <0.01	73 44 44 30	8.0 5.9 5.6 4.0	2,000 208 507 <20
Gamboa Outfall	0.4 0.17 0.12 <0.1	0.15 0.08 0.12 <0.01	0.19 0.03 0.03 0.01	66 45 47 32	7.0 6.2 5.4 4.5	900 350 334 20
Gamboa Area Summit I	0.5 ND 0.12 <0.1	0.38 ND 0.18 0.07	0.09 0.02 0.03 0.01	54 51 49 37	9.3 5.9 5.4 4.6	1,600 220 407 80

Hi
Dry Wet
Lo

Table 2.4c
Water Quality Data Ranges
Chagres-Gamboa-Gaillard Cut, Panama Canal Watershed

Region	Water Quality Parameter					
	Temp **(°C)**	***Fecal Coliforms*** **(count/100ml)**	**Total Coliforms** **(count/100ml)**	***pH*** **(units)**	**Secchi** **(inches)**	***Turbidity*** **(JTU units)**
Chagres - Chilibre	30.5 27.3 27.3 25.7	6,000 30 240 0	13,000 1,287 1,249 15	8.6 7.1 6.1 5.0	300 146 63 8	92 2.3 9.5 1
Chilibre-Chilibrillo Area	30.5 26.7 27.9 25.0	6,000 1,454 886 <1	8,180 2,883 3,778 15	8.6 7.4 6.9 5.0	84 74 35 8	92 3.1 16.0 0.6
Gamboa Beach	30.4 28.1 29.8 26.4	1,400 102 132 0	3,200 400 688 0	7.8 7.0 7.1 5.3	204 71 56 4	55 9.8 11.3 1
Gamboa Outfall	29.0 27.6 28.2 27.0	34,000 1,059 3,896 20	89,700 ND 20,305 12	7.2 6.5 7.0 5.8	72 19 46 6	93 16 9 1
Gamboa Area Summit I	30.4 28.3 28.4 26.6	1200 92 84 4	3,600 447 367 43	8.0 7.2 6.9 6.3	96 48 30 6	39 5.5 15.9 4

Hi
Dry Wet
Lo

Table 2.4d
Water Quality Data Ranges
Miraflores Lake, Panama Canal Watershed

Water Quality Parameter	Value		
Temperature (°C)	27.7	32.0 24.0	28.4
Fecal Coliforms (count/100ml)	228	5,900 0	408
Total Coliforms (count/100ml)	ND	21,500 10	3,947
pH	7.2	8.1 5.0	6.7
Secchi (inches)	23	120 6	32
Turbidity (JTU units)	6	58 0	16
DO – TOP (ppm) *DO – BOT*(ppm)	6.4	8.5 0.1	4.7
TOC (ppm)	6	13 3	9
BOD (ppm)	0.86	1.7 0.28	1.22
Total Solids (ppm)	ND	1,233 58	529
Conductivity (umhos)	1,751	3,800 170	969
Kjeldahl Nitrogen (ppm)	0.18	0.6 0.1	0.21
Nitrates (ppm)	0.02	0.22 0.01	0.15
Total Phosphorus (ppm)	0.04	0.12 0.01	0.04
Alkalinity (ppm)	59	114 36	50
Chloride (ppm)	543	1,020 5.8	237
Iron (ppb)	51	2,500 20	528

	Hi	
Dry		Wet
	Lo	

Table 2.4e
Gatun Lake Salinity Monitoring Data
May (red) and November (blue), 1999 Sampling Episodes

Monitoring Station		Temperature (°C)	Conductivity (mS/cm)	Salinity (ppt)	Depth (ft)
Gatun Locks - East					
(1)	Upper, 73 ft	27.89	0.297	0.0	0
		27.87	0.34	0.0	20
		27.87	0.353	0.0	55
	Lower, 43 ft	27.71	0.306	0.0	0
		27.9	0.35	0.0	20
		27.9	0.4	0.0	55
		28.92	0.119	0.0	0
		28.83	0.126	0.0	20
		28.84	0.129	0.0	40
(2)	Upper, 73 ft	27.9	1.9	0.5	0
		27.91	1.82	0.4	20
		27.92	2.31	0.7	55
	Low	27.89	1.83	0.5	0
		27.9	1.84	0.5	20
		27.9	2.21	0.7	55
		28.98	0.126	0.0	0
		28.98	0.127	0.0	20
		28.97	0.133	0.0	40
(3)	Upper 73 ft	27.94	6.79	4.2	0
		27.94	8.21	4.2	20
		27.94	8.2	4.2	55
	Low	27.93	7.79	4.0	0
		27.94	8.11	4.2	20
		27.95	9.68	5.1	55
		29.96	0.115	0.0	0
		28.91	0.116	0.0	20
		28.91	0.117	0.0	40
(22)		29.04	0.111	0.0	0
		28.93	0.11	0.0	20
		28.92	0.11	0.0	40
Gatun Locks, North Approach					
(4)	Bridge	27.97	15.8	9.7	0
		28.03	45.8	29.7	20
		28.06	50.1	32.7	55
		28.88	0.118	0.0	0
		28.84	0.118	0.0	20
		28.82	0.118	0.0	40
(4a) 510		28.02	23.2	15.2	0
		28.05	49.6	32.5	20
		28.06	50.9	33.4	55
(4b)		28.03	29.3	17.9	0
		28.06	48.2	31.2	20
		28.08	51.3	33.6	55
Gatun-East					
(10)		29.13	0.111	0.0	0
		29.0	0.116	0.0	20
		28.97	0.13	0.0	40
(11)		29.31	0.11	0.0	0
		29.01	0.111	0.0	20
		28.96	0.12	0.0	40
(16)		29.39	0.11	0.0	0
		29.04	0.11	0.0	20
		28.97	0.111	0.0	40
(17)		29.56	0.11	0.0	0
		29.07	0.11	0.0	20
		28.97	0.111	0.0	40
(23)		29.46	0.109	0.0	0
		29.02	0.109	0.0	20
		28.9	0.111	0.0	40

(25)	29.78	0.109	0.0	0
	29.12	0.108	0.0	20
	29.02	0.11	0.0	40
(28)	29.02	0.11	0.0	0
	29.08	0.108	0.0	20
	29.0	0.109	0.0	40
(29)	29.99	0.109	0.0	0
	29.06	0.108	0.0	20
	28.96	0.108	0.0	40
	29.99	0.109	0.0	0
	29.06	0.108	0.0	20
	28.96	0.108	0.0	40
Gatun-West				
(5)	28.97	0.115	0.0	0
	28.95	0.115	0.0	20
	28.92	0.112	0.0	40
(6)	28.98	0.115	0.0	0
	28.97	0.115	0.0	20
	28.97	0.114	0.0	40
(7)	29.0	0.117	0.0	0
	28.96	0.116	0.0	20
	28.95	0.116	0.0	40
(8)	29.09	0.17	0.0	0
	28.96	0.116	0.0	20
	28.95	0.116	0.0	40
(13)	29.3	0.112	0.0	0
	29.01	0.111	0.0	20
	28.95	0.111	0.0	40
(14)	29.45	0.11	0.0	0
	29.07	0.11	0.0	20
	29.0	0.112	0.0	40
(19)	29.51	0.11	0.0	0
	29.07	0.11	0.0	20
	28.97	0.11	0.0	40
(20)	29.69	0.109	0.0	0
	29.07	0.109	0.0	20
	28.99	0.109	0.0	40
(26)	29.49	0.109	0.0	0
	29.17	0.109	0.0	20
	29.91	0.109	0.0	40
(30)	29.6	0.11	0.0	0
	29.21	0.107	0.0	20
	29.09	0.107	0.0	40
	29.6	0.11	0.0	0
	29.21	0.107	0.0	20
	29.09	0.107	0.0	40
Gatun-Center				
(9)	29.10	0.112	0.0	0
	29.06	0.113	0.0	20
	29.97	0.114	0.0	40
(12)	29.19	0.11	0.0	0
	29.03	0.11	0.0	20
	28.97	0.116	0.0	40
(16)	29.48	0.11	0.0	0
	29.08	0.111	0.0	20
	29.0	0.112	0.0	40
(18)	29.57	0.11	0.0	0
	29.1	0.109	0.0	20
	28.98	0.11	0.0	40
(21)	29.45	0.109	0.0	0
	29.07	0.109	0.0	20
	28.99	0.111	0.0	40
(24)	29.44	0.108	0.0	0
	29.16	0.108	0.0	20
	28.97	0.111	0.0	40
(27)	29.0	0.109	0.0	0
	29.07	0.108	0.0	20
	29.0	0.109	0.0	40

Table 2.4f
Miraflores Lake Salinity Monitoring Data
October, 1999 Sampling Episodes

Monitoring Station	Temperature (°C)	Conductivity (mS/cm)	Salinity (ppt)	Depth (ft)
Miraflores Locks - East				
Lower Chamber				
(1) 50-1,000 ft	28.06	20.0	12.0	0
	27.84	37.9	23.8	20
	27.84	39.6	25.1	40
	27.85	40.1	25.5	55
(2) 400-650 ft	28.16	20.0	12.0	0
	27.86	38.0	24.0	20
	27.85	39.7	25.2	40
	27.86	40.5	25.9	55
(3) 900-150 ft	28.27	17.4	12.4	0
	27.88	38.4	24.5	20
	27.87	40.2	25.5	40
	27.87	40.3	25.7	55
Lower Chamber During Water Level Increases from 44 to 70 ft				
1	27.87		22.6	15
2			23.0	
3			23.4	
4			23.5	
5			23.2	
6			23.1	
7			23.0	
8			22.8	
9			22.2	
10			21.9	
11			21.7	
12			21.0	
13			20.1	
14			19.5	
15			19.4	
16			21.1	
17			21.3	
18			19.8	
19			18.8	
20			19.0	
21			19.5	
22	27.87	32.7	20.9	
23			20.4	
24			19.2	
25			20.1	
26			19.4	
27	27.87	31.7	19.5	
28			19.3	
29			19.4	
30			18.6	
31			18.5	
32			18.4	
Upper Chamber	28.02	3.29	1.3	0
Low Level 44 ft	27.76	5.5	2.6	20
(1) 50-1,000 ft	27.84	23.1	14.1	55

Monitoring Station	Temperature (°C)	Conductivity (mS/cm)	Salinity (ppt)	Depth (ft)
Miraflores Locks - East				
(2) 500-400 ft	27.98	3.29	1.3	0
	27.76	4.59	2.0	20
	27.79	17.2	9.8	55
Upper Chamber Beginning Increase Water Level from 44 to 70 ft				
1			1.9	15
2			2.0	
3			4.2	
4			3.9	
5	27.76	6.99	3.7	
6			3.0	
7			2.7	
8			2.8	
9	27.77	5.53	2.7	
10			2.5	
11			2.5	
12	27.79	5.02	2.4	
13			2.2	
14			2.2	
15	27.8	4.58	2.0	
Upper Chamber High Level 70 ft				
(1) 860-120 ft	27.81	5.92	2.8	0
	27.79	6.07	3.0	20
	27.8	6.31	3.1	55
(2) 450 ft	27.81	4.27	1.8	0
	27.81	4.81	2.2	20
	27.8	6.09	2.9	55
(3) 190-790 ft	27.81	4.2	1.8	0
	27.83	4.86	2.2	20
	27.81	5.7	2.7	55

Table 2.4g
Salinity Levels, Miraflores Locks (depth 12m)
Panama Canal

Lock Location	Salinity Value (ppt)
Pacific Ocean (just outside first lower lock chamber)	28
Inside Lower Lock (prior to lift)	10.0
Inside Upper Lock (following movement of ship from lower to upper lock chamber)	1.8
Miraflores Lake	1.0

Table 2.4h
Beneficial Use Water Standards[1]
Regulation 24-99, DGNTI-COPANIT, Republic of Panama

Water Quality Parameter	Value
Temperature (°C)	± 3°C ambient
Fecal Coliforms (count/100ml)	<2.2 - <500
PH	6.0 – 9.0
Turbidity (JTU units)	2.0 - 30.0
DO (ppm)	<5.0
BOD (ppm)	5 – 60
Total Solids (ppm)	5 – 50
Conductivity (umhos)	3.0
Nitrates (ppm)	<10.0
Chloride (ppm)	<0.5 – <5.0
Iron (ppb)	300 - 5,000.0

Notes: 1) Beneficial uses include habitat restoration, aquifer recharge, agriculture, recreation, animal consumption, and urban and industrial use.

Table 2.5.2a
Average Annual and 5-Year Moving Average Rainfall Amounts
Alhajuela Lake - Upstream Drainage Area

Year	Annual Average Rainfall (mm)	5-Year Moving Average (mm)	Year	Annual Average Rainfall (mm)	5-Year Moving Average (mm)	Year	Annual Average Rainfall (mm)	5-Year Moving Average (mm)
1911	2527		1941	2904	2882	1971	2838	2966
1912	2445		1942	2593	2885	1972	2637	2852
1913	2518		1943	2908	2819	1973	2687	2872
1914	2493		1944	3033	2706	1974	2328	2817
1915	3373	2671	1945	2710	2830	1975	3194	2737
1916	2800	2726	1946	2499	2749	1976	1765	2522
1917	2793	2795	1947	2096	2649	1977	2306	2456
1918	2669	2826	1948	2187	2505	1978	2900	2499
1919	2703	2863	1949	2691	2437	1979	2582	2549
1920	2669	2727	1950	2983	2491	1980	2503	2411
1921	3333	2833	1951	2698	2531	1981	3300	2718
1922	2691	2813	1952	3194	2751	1982	2061	2669
1923	2597	2799	1953	2691	2851	1983	2906	2670
1924	2843	2827	1954	3162	2946	1984	2437	2641
1925	2742	2841	1955	2993	2948	1985	2454	2632
1926	3126	2800	1956	3296	3067	1986	2569	2485
1927	3670	2996	1957	2019	2832	1987	3663	2806
1928	2955	3067	1958	2532	2800	1988	3250	2875
1929	2479	2994	1959	2777	2723	1989	2690	2925
1930	2204	2886	1960	3297	2784	1990	2708	2976
1931	3578	2977	1961	2623	2650	1991	2648	2992
1932	3161	2875	1962	2602	2766	1992	2966	2852
1933	2900	2864	1963	2959	2852	1993	3115	2825
1934	2710	2910	1964	2672	2831	1994	2843	2856
1935	4078	3285	1965	2598	2691	1995	3124	2939
1936	2578	3085	1966	3568	2880	1996	3778	3165
1937	3238	3100	1967	3209	3001	1997	1889	2950
1938	3600	3240	1968	2586	2927	1998	3183	2963
1939	2466	3192	1969	2601	2912	1999	4061	3207
1940	2205	2817	1970	3597	3112	2000	3520	3286

Table 2.5.2b
Average Annual and 5-Year Moving Average Rainfall Amounts
Gatun Lake – Downstream Drainage Area

Year	Annual Average Rainfall (mm)	5-Year Moving Average (mm)	Year	Annual Average Rainfall (mm)	5-Year Moving Average (mm)	Year	Annual Average Rainfall (mm)	5-Year Moving Average (mm)
1911	2360		1941	2616	2666	1971	2395	2596
1912	2592		1942	2920	2628	1972	2274	2555
1913	2579		1943	3031	2597	1973	2379	2563
1914	2592		1944	2888	2697	1974	2395	2527
1915	2917	2608	1945	2687	2828	1975	2810	2451
1916	2732	2682	1946	2274	2760	1976	1865	2345
1917	3004	2765	1947	2360	2648	1977	2189	2782
1918	2303	2710	1948	2252	2492	1978	2485	2349
1919	2353	2662	1949	2806	2476	1979	2319	2334
1920	2235	2525	1950	3025	2543	1980	2295	2231
1921	2739	2527	1951	2507	2590	1981	3323	2522
1922	2400	2406	1952	2453	2609	1982	1949	2474
1923	2578	2461	1953	2505	2659	1983	2233	2424
1924	2899	2570	1954	2928	2684	1984	2453	2451
1925	2432	2610	1955	2849	2648	1985	2199	2431
1926	2971	2656	1956	2776	2702	1986	2021	2171
1927	2878	2752	1957	2200	2652	1987	2846	2350
1928	2883	2813	1958	2350	2621	1988	2407	2385
1929	2257	2684	1959	2437	2522	1989	2119	2318
1930	2049	2608	1960	3158	2584	1990	2570	2393
1931	2740	2561	1961	2495	2528	1991	2302	2449
1932	2943	2574	1962	2495	2587	1992	2456	2371
1933	2532	2504	1963	2704	2659	1993	2685	2426
1934	2754	2604	1964	2652	2701	1994	2205	244
1935	3602	2914	1965	2592	2588	1995	2795	2489
1936	2446	2855	1966	3035	2696	1996	2862	2601
1937	3110	2889	1967	2479	2692	1997	1592	2429
1938	3186	3020	1968	2338	2619	1998	2528	2396
1939	2388	2946	1969	2577	2604	1999	3171	2590
1940	2029	2632	1970	3192	2724	2000	2655	2562

Table 2.5.3
Percent Decrease in Annual Rainfall and Runoff
During Recent ENSO Events

Stations	ENSO Event Year					
	1930	**1957**	**1976**	**1977**	**1982**	**1997**
Rainfall Station						
Madden Lake-Upstream	22.3	28.8	37.8	18.7	27.4	33.4
Gatun Lake-Downstream	20.5	14.6	27.6	15.0	24.3	39.2
Gatun Total	21.1	19.3	30.9	16.3	25.4	36.7
Runoff Station						
Madden Lake-Upstream	ND	33.8	30.9	20.6	18.1	36.8
Gatun Lake-Downstream	ND	37.4	31.5	25.6	23.5	49.3
Gatun Total	ND	35.9	31.2	23.6	21.3	44.3

Table 2.6.1
Current Electrical Power Generation Capacity (MW)
SIN, Republic of Panama

Power Generation Company	Means of Power Generation	Installed Capacity (MW)
Electrical Power Generation Facilities Operated by Electrical Power Generators		
ACP		
Gatun	Hydro	24.0
Alhajuela Dam	Hydro	36.0
Miraflores	Fossil Fuel Fired	93.0
Total		**153.0**
COPESA	Fossil Fuel Fired	**44.0**
Empresa de Generacion Electrica (EGE) – Bayano		
Bayano	Hydro	150.0
Sub Estacion Panama	Fossil Fuel Fired	40.0
Total		**190.0**
EGE – Chiriqui		
La Estrella	Hydro	42.0
Los Valles	Hydro	48.0
Total		**90.0**
EGE - Fortuna	Hydro	**300.0**
EGE – Las Minas		
BLM #1, #4	Fossil Fuel Fired	140.0
Catepillar	Fossil Fuel Fired	30.0
Ciclo-Comb	Fossil Fuel Fired	160.0
Monte Esperanze	Fossil Fuel Fired	20.0
San Francisco	Fossil Fuel Fired	10.0
TG-CCBLM	Fossil Fuel Fired	34.8
Total		**394.8**
Hidro Panama – Anton	Hydro	**1.5**
Pan Am	Fossil Fuel Fired	**96.0**
Petroelectrica	Fossil Fuel Fired	**55.0**
Petroterminales	Fossil Fuel Fired	**15.0**
Sub Total		**1,339.3**
Electrical Power Generation Facilities Operated by Electrical Power Distributors		
EDE – Elektra Noreste[1]		
Chepillo	Fossil Fuel Fired	0.135
Condadora	Fossil Fuel Fired	4.157
Boca de Cupe	Fossil Fuel Fired	0.070
Garachine	Fossil Fuel Fired	0.480
Jaque	Fossil Fuel Fired	0.285
La Palma	Fossil Fuel Fired	1.550
Nargana	Fossil Fuel Fired	0.155
Otoque	Fossil Fuel Fired	0.275
Rio Azucar	Fossil Fuel Fired	0.070
San Miguel	Fossil Fuel Fired	0.250
Sante Fe	Fossil Fuel Fired	1.235
Taboga	Fossil Fuel Fired	1.275
Tucuti	Fossil Fuel Fired	0.070
Yaviza	Fossil Fuel Fired	0.570
Total		**10.577**
EDE – Metro Oeste		
Bocas del Toro[1]	Fossil Fuel Fired	2.690
Capria	Fossil Fuel Fired	9.6
Chiriqui Grande[1]	Fossil Fuel Fired	0.922
Chitre	Fossil Fuel Fired	14.5
Dolega	Hydro	3.04
La Yeguada	Hydro	7.0
Macho Monte	Hydro	0.77
Total		**38.522**
Sub Total		**49.1**
Total		**1,388.4**
Net Total Connected to SIN		**1,374.2**

Note: 1 – Not connected to SIN (14.2MW)

Table 2.6.2a
Recent Electrical Power Consumption (GWh)
SIN, Republic of Panama

Calendar Year	Electrical Power Consumption (GWh), Excluding Electrical Power System Losses				Consumption Increase From Previous Year	
	Distributed	Large Clients	Exports	Total	GWh	Percent Change
1998	3,997	0	0	3,997	-	-
1999	4,210	0	97	4,307	310	7.8
2000	4,496	0	15	4,511	204	4.7
2001e	4,602	46	126	4,774	263	5.8

Table 2.6.2b
Monthly and Annual Maximum Electrical Power Demand (MW)
SIN, Republic of Panama

Maximum Monthly Demand (MW)													Annual Maximum Demand
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1999	705.6	706.3	733.0	752.0	743.7	746.1	727.3	746.3	739.0	737.9	727.1	754.5	**754.5**
2000	726.1	735.1	754.1	768.4	766.9	754.9	765.4	777.0	763.8	762.6	768.3	764.5	**777.0**
2001e	742.0	757.4	794.3	829.6	812.5	831.3	826.3	839.3	799.8	807.4	806.6	829.0e	**839.3**

Table 2.6.2c
Monthly Electrical Power Transmission System and
Annual Electrical Power Distribution System Losses
SIN, Republic of Panama

Electrical Power System Losses (GWh)													Annual Losses
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1999	11.6	8.1	9.0	10.3	10.6	13.2	10.6	12.4	12.0	17.6	18.8	16.1	**150.2**
	Distribution System Losses												**745.2**
2000	19.0	16.2	9.2	11.8	11.7	11.7	14.7	14.3	18.4	16.0	11.5	7.9	**162.5**
	Distribution System Losses												**768.8**
2001e	7.3	8.5	11.0	11.6	12.9	8.6	11.7	11.2	11.3	11.7	11.2	11.4e	**128.5e**
	Distribution System Losses												**810.0e**

Table 2.6.2d
Recent Historical Annual Electrical Power Demand,
Peak System Load and System Load Factor
SIN, Republic of Panama

Year	Electrical Power Demand		Peak Load		Load Factor (%)
	GWh[1]	Rate of Growth (%)	MW	Rate of Growth (%)	
1990	2,746	-	464.4	-	67.5
1991	2,897	5.5	488.5	5.2	67.7
1992	3,012	4.0	518.0	6.0	66.2
1993	3,199	6.2	541.2	4.5	67.5
1994	3,400	6.3	591.5	9.3	65.6
1995	3,619	6.5	619.2	4.7	66.7
1996	3,796	4.9	639.9	3.4	67.5
1997	4,254	12.1	706.6	10.4	68.7
1998	4,296	1.0	726.4	2.8	67.5
1999	4,457	4.8	754.5	3.9	67.4
2000	4,674	4.9	777.0	3.0	70.1
2001	4,903e	4.9e	849.3e	9.3	-

Note: 1 - Demand includes electrical power system losses.

Table 2.6.2e
Electrical Power Demand Forecast
SIN, Republic of Panama

Year	Medium Demand Scenario		High Demand Scenario	
	Peak Load (MW)	Power Demand (GWh	Peak Load (MW)	Power Demand (GWh)
2001	849	5,179	884	5,391
2002	897	5,467	946	5,767
2003	947	5,771	1,013	6,170
2004	999	6,092	1,084	6,601
2005	1,055	6,431	1,160	7,063
2006	1,114	6,789	1,241	7,558
2007	1,176	7,167	1,328	8,089
2008	1,242	7,567	1,422	8,654
2009	1,312	7,990	1,522	9,261
2010	1,385	8,435	1,629	9,910
2011	1,463	8,906	1,744.0	10,605
2012	1,544	9,403	1,867.0	11,348
2013	1,631	9,928	1,998.0	12,144
2014	1,722	10,482	2,139.0	12,955
2015	1,818	11,067	2,289.0	13,906

Table 2.6.2f
Forecasted Electrical Power Production capacity v. Demand Forecast
SIN, Republic of Panama

Year	Net Production Capacity[1] (MW)	Net Available Power[2] (MW)	Power Demand[3] (MW)	Reserve Power		Power Shortage	
				MW	%	MW	%
2001	1,305	1,041	884	157	18	0	0
2002	1,385	1,111	946	165	17	0	0
2003	1,418	1,144	1,013	131	13	0	0
2004	1,466	1,189	1,084	105	10	0	0
2005	1,561	1,274	1,160	114	10	0	0
2006	1,587	1,301	1,241	71	5	0	0
2007	1,672	1,378	1,328	50	4	0	0
2008	1,815	1,505	1,422	83	6	0	0
2009	1,862	1,551	1,522	29	2	0	0
2010	2,005	1,680	1,629	51	3	0	0
2011	2,100	1,768	1,744	24	1	0	0
2012	2,261	1,915	1,867	48	3	0	0
2013	2,499	2,127	1,998	129	6	0	0
2014	2,594	2,220	2,139	81	4	0	0
2015	2,689	2,313	2,289	24	1	0	0

Note: 1 – Actual Installed or projected installed x 0.95 reliability
2 – Net Production capacity less estimated system losses
3 – High demand scenario value

Table 2.8.1a
Population Projections
Republic of Panama

Year	Population Projection
1990	2,329,329
2001	2,855,694
2015	3,451,379
2025	3,779,091
2050	4,262,033

Table 2.8.1b
Population Projections
Provinces of Panama and Colon
Republic of Panama

Year	Population Projection
2000	1,548,260
2010	1,867,746
2020	2,108,456
2030	2,310,036
2040	2,462,974
2050	2,571,481
2060	2,643,151

Table 3.1.7
Estimated Solid Waste Production (dry)
Miraflores and Gatun Treatment Facilities

Treatment Facility	Solid Waste Production (lbs/day - dry)	
	Phase I	**Phase II**
Gatun	97,020	231,433
Miraflores	242,550	385,722
Total	**339,570 (170 tons per day)**	**617,155 (309 tons per day)**

Table 3.1.8a.1
Gatun Treatment Facility
Alternative 1,

Process	Technical Approaches				
	1	2	3	4	5
Lock Water Recovery	Wet wells installed adjacent to existing discharge culverts, pump 30% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.			
Saltwater Intrusion	Pneumatic Curtain	Hydraulic Mound	Retention Reservoir	Pneumatic Curtain and Hydraulic Mound	
Lock Water Retention	Below grade, 30% lock capacity	Below grade, 60% lock capacity			Single-chamber design
Water Treatment	Sedimentation and aeration				
Water Transportation					
Water Discharge			Side stream to ACP	Side stream to IDAAN	
Hydroelectric Power Generation		Retro-fit culverts	Retro-fit lock doors		
Electrical Interconnection/ Transmission	Tie-in to ACP only	Tie-in to EDEMAT only			
Solid Waste Disposal		No treat			

Table 3.1.8a.2
Gatun Treatment Facility
Alternative 2

Process	Technical Approaches				
	1	2	3	4	5
Lock Water Recovery	Wet wells installed adjacent to existing discharge culverts, pump 30% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.	Tie-in to existing discharge culverts, gravity drain 100% of exit lock volume.		
Saltwater Intrusion	Pneumatic Curtain	Hydraulic Mound	Retention Reservoir	Pneumatic Curtain and Hydraulic Mound	All
Lock Water Retention	Below grade, 30% lock capacity	Below grade, 60% lock capacity	Below grade, 100% lock capacity	Multi-chamber design	Single-chamber design
Water Treatment	Sedimentation and aeration	Sedimentation, aeration, filtration, demineralization and detoxification			
Water Transportation	Above ground pipeline	Below ground pipeline			
Water Discharge	Gatun Lake	Ship Channel	Side stream to ACP	Side stream to IDAAN	Side stream to ACP and IDAAN
Hydroelectric Power Generation	Construct parallel paths, install "pit" turbines	Retro-fit culverts	Retro-fit lock doors		
Electrical Interconnection/ Transmission	Tie-in to ACP only	Tie-in to EDEMAT only	Tie-in to both ACP and EDEMAT		
Solid Waste Disposal	Test/Treat as necessary	No treat	Landfill	Land farm	Co-mingle with dredged material

Table 3.1.8a.3
Gatun Treatment Facility
Alternative 3

Process	Technical Approaches				
	1	2	3	4	5
Lock Water Recovery		Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.	Tie-in to existing discharge culverts, gravity drain 100% of exit lock volume.		
Saltwater Intrusion		Hydraulic Mound	Retention Reservoir	Pneumatic Curtain and Hydraulic Mound	All
Lock Water Retention		Below grade, 60% lock capacity	Below grade, 100% lock capacity	Multi-chamber design	
Water Treatment		Sedimentation, aeration, filtration, demineralization and detoxification			
Water Transportation					
Water Discharge		Ship Channel		Side stream to IDAAN	Side stream to ACP and IDAAN
Hydroelectric Power Generation	Construct parallel paths, install "pit turbines	Retro-fit culverts			
Electrical Interconnection/ Transmission		Tie-in to EDEMAT only	Tie-in to both ACP and EDEMAT		
Solid Waste Disposal		No treat			

Table 3.1.8b.1
Miraflores Treatment Facility
Alternative 1

Process	Technical Approaches					
	1	2	3	4	5	6
Lock Water Recovery	Wet wells installed adjacent to existing discharge culverts, pump 30% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.				
Saltwater Intrusion	Pneumatic Curtain	Hydraulic Mound	Retention Reservoir	Pneumatic Curtain and Hydraulic Mound		
Lock Water Retention	Below grade, 30% lock capacity	Below grade, 60% lock capacity			Single-chamber design	
Water Treatment		Sedimentation, aeration, filtration, demineralization and detoxification	Sedimentation and aeration			
Water Transportation						
Water Discharge			Side stream to ACP	Side stream to IDAAN		
Hydroelectric Power Generation		Retro-fit culverts	Retro-fit lock doors			
Electrical Interconnection/ Transmission	Tie-in to ACP only	Tie-in to EDEMAT only				
Solid Waste Disposal		No treat				

Table 3.1.8b.2
Miraflores Treatment Facility
Alternative 2

Process	Technical Approaches					
	1	2	3	4	5	6
Lock Water Recovery	Wet wells installed adjacent to existing discharge culverts, pump 30% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.	Tie-in to existing discharge culverts, gravity drain 100% of exit lock volume.			
Saltwater Intrusion	Pneumatic Curtain	Hydraulic Mound	Retention Reservoir	Pneumatic Curtain and Hydraulic Mound	All	
Lock Water Retention	Below grade, 30% lock capacity	Below grade, 60% lock capacity	Below grade, 100% lock capacity	Multi-chamber design	Single-chamber design	
Water Treatment	Sedimentation, aeration and desalinization initially, then filtration and detoxification	Sedimentation, aeration, filtration, demineralization and detoxification	Sedimentation and aeration			
Water Transportation	Above ground pipeline	Below ground pipeline				
Water Discharge	Gatun Lake	Ship Channel	Side stream to ACP	Side stream to IDAAN	Side stream to ACP and IDAAN	
Hydroelectric Power Generation	Construct parallel paths, install "pit" turbines	Retro-fit culverts	Retro-fit lock doors			
Electrical Interconnection/ Transmission	Tie-in to ACP only	Tie-in to EDEMAT only	Tie-in to both ACP and EDEMAT			
Solid Waste Disposal	Test/Treat as necessary	No treat	Landfill	Land farm	Co-mingle with dredged material	

Table 3.1.8b.3
Miraflores Treatment Facility
Alternative 3

Process	Technical Approaches					
	1	2	3	4	5	6
Lock Water Recovery		Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.	Tie-in to existing discharge culverts, gravity drain 100% of exit lock volume.			
Saltwater Intrusion		Hydraulic Mound	Retention Reservoir	Pneumatic Curtain and Hydraulic Mound	All	
Lock Water Retention		Below grade, 60% lock capacity	Below grade, 100% lock capacity	Multi-chamber design		
Water Treatment	Sedimentation, aeration and desalinization initially, then filtration and detoxification	Sedimentation, aeration, filtration, demineralization and detoxification				
Water Transportation						
Water Discharge		Ship Channel		Side stream to IDAAN	Side stream to ACP and IDAAN	
Hydroelectric Power Generation	Construct parallel paths, install "pit" turbines	Retro-fit culverts				
Electrical Interconnection/ Transmission		Tie-in to EDEMAT only	Tie-in to both ACP and EDEMAT			
Solid Waste Disposal		No treat				

Table 3.1.8c
Composite of Alternatives
Gatun and Miraflores Treatment Facilities

Process	Gatun Treatment Facility Technical Alternatives			Miraflores Treatment Facility Technical Alternatives		
		2			2	
Lock Water Recovery	Tie-in to existing discharge culverts, gravity drain 100% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 30% of exit lock volume.	Tie-in to existing discharge culverts, gravity drain 100% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 60% of exit lock volume.	Wet wells installed adjacent to existing discharge culverts, pump 30% of exit lock volume.
Saltwater Intrusion	Pneumatic Curtain, Hydraulic Mounding and Retention Reservoir	Pneumatic Curtain	Pneumatic Curtain	Pneumatic Curtain, Hydraulic Mounding and Retention Reservoir	Pneumatic Curtain	Pneumatic Curtain
Lock Water Retention	Below grade, 100% lock capacity; Multi-chamber design	Below grade, 60% lock capacity; Multi-chamber design	Below grade, 30% lock capacity; Single chamber design	Below grade, 100% lock capacity; Multi-chamber design	Below grade, 60% lock capacity; Multi-chamber Design	Below grade, 30% lock capacity; Single chamber design
Water Treatment	Sedimentation, aeration, filtration, demineralization and detoxification	Sedimentation, aeration, filtration, demineralization and detoxification	Sedimentation and aeration	Sedimentation, aeration and desalinization initially, then filtration and detoxification	Sedimentation, aeration, filtration, demineralization and detoxification	Sedimentation and aeration
Water Transportation And Discharge	Above and below grade pipeline; Discharge to Gatun Lake and ship channel; Side stream to ACP and IDAAN	Above and below grad pipeline; Discharge to Gatun Lake; Side Stream to IDAAN	Above and below grade pipeline; Discharge to Gatun Lake; Side stream to ACP	Above and below grade pipeline; Discharge to Gatun Lake and ship channel; Side stream to ACP and IDAAN	Above and below grade pipeline; Discharge to Gatun Lake; Side Stream to IDAAN	Above and below grade pipeline; Discharge to Gatun Lake; Side stream to ACP
Hydroelectric Power Generation, Electrical Transmission & Interconnection	Construct parallel paths, install "pit" turbines, overhead transmission, tie-in to both ACP and EDEMAT	Retro-fit culverts, overhead transmission, tie-in to EDEMAT only	Retro-fit lock doors, overhead transmission, tie-in to ACP only	Construct parallel paths, install "pit" turbines, overhead and below surface transmission, tie-in to both ACP and EDEMAT	Retro-fit culverts, overhead and below surface transmission, tie-in to EDEMAT only	Retro-fit lock doors, overhead and below surface transmission, tie-in to ACP only
Solid Waste Disposal	Test, treat as necessary; Landfill, land farm or other lawful disposal	Test, treat as necessary; Landfill, land farm or other lawful disposal	Test, treat as necessary; Landfill, land farm or other lawful disposal	Test, treat as necessary; Landfill, land farm or other lawful disposal	Test, treat as necessary; Landfill, land farm or other lawful disposal	Test, treat as necessary; Landfill, land farm or other lawful disposal

Table 3.2.1
Net Hydroelectric Power Generation
Alternative 1, 100% Diversion Case

Project Year	Generated Power (MW)	Facility Power Requirement (MW)	Net Power Generated (MW)
3[1]	81.9	24.6	57.3
4	83.7	26.2	57.5
5	85.4	27.9	57.5
6	87.1	29.7	57.4
7	88.8	31.5	57.3
8	90.6	33.3	57.3
9	92.3	35.2	57.1
10	94.0	37.2	56.8
11	95.8	39.2	56.6
12	97.5	41.2	56.3
13	99.3	43.3	55.0
14	100.7	45.3	55.4
15	102.5	45.7	56.8
16	104.2	49.8	54.4
17	105.8	51.9	53.9
18	107.5	54.2	53.3
19	109.2	56.6	52.6
20	110.9	59.0	51.9
21	112.5	61.3	51.2
22	114.2	63.9	50.3
23	115.9	66.4	49.5
24	117.5	68.9	48.6
25	119.2	71.5	47.7

Note: 1 – First year of facility operations

Table 3.2.2
Net Hydroelectric Power Generation
Alternative 2, 60% Diversion Case

Phase	Treatment Facility	Generated Power (MW)	Facility Power Requirement (MW)	Net Power Generated (MW)
I	Gatun	13.5	6.4	7.1
	Miraflores	13.5	5.6	7.9
	Total			15.0
II	Gatun	15.0	13.7	1.3
	Miraflores	15.0	17.2	(2.2)
	Total			(0.9)

Table 3.2.3
Net Hydroelectric Power Generation
Alternative 3, 30% Diversion Case

Phase	Treatment Facility	Generated Power (MW)	Facility Power Requirement (MW)	Net Power Generated (MW)
I	Gatun	13.5	5.0	8.5
	Miraflores	13.5	4.2	9.3
	Total			17.8
II	Gatun	15.0	12.0	3.0
	Miraflores	15.0	15.5	(0.5)
	Total			2.5

Table 3.3a
Failure and Reliability Values
System Process Components for All Alternatives

Process Component	Fraction of Failures[1]	Reliability Values
Aerator	0.03	0.97
Air compressors	0.03	0.97
Box culverts	0.001	0.999
Bubbler conveyance and header	0.01	0.99
Centrifugal pumps	0.02	0.98
De-aerator	0.03	0.97
Dewatering structure	0.001	0.999
Disinfection	0.02	0.98
Electrical generators	0.03	0.97
Electrical switches	0.02	0.98
Filtrate recycle	0.02	0.98
Filtration	0.03	0.97
Gate Valves	0.01	0.99
Hydroelectric turbines	0.01	0.99
Interconnection gear	0.01	0.99
Level controllers	0.02	0.98
Mixing-feed sump structure	0.001	0.999
Mixing structure	0.001	0.999
Retention reservoir	0.001	0.999
Reverse Osmosis	0.001	0.999
Sedimentation structure	0.001	0.999
Sludge pumps	0.04	0.96
Steel pipeline	0.01	0.99
Transmission lines	0.01	0.99
Turbine pumps	0.02	0.98
Variable weirs	0.02	0.98
Wet well structure	0.001	0.999

Note: 1) Values extracted from following references: a) "Standard Handbook of Engineering Calculations", pgs 5-22 to 5-24, McGraw-Hill, Inc., 1972; b) "Perry's Chemical Engineers Handbook", Sixth Edition, pg 24-15, McGraw-Hill, Inc., 1984; c) "Mark's Standard Handbook for Mechanical Engineers", Eighth Edition, Section 14, McGraw-Hill Inc; d) "Wastewater Engineering", Third Edition, Metcalf & Eddy; e) "Machinery's Handbook", 23d Edition, Industrial press, Inc.; f) "Goulds Pump Manual", Fourth Edition, Goulds Pumps Inc.; g) "Design of Reinforced Concrete", Jack C. McCormac, Harper & Row, 1978; and h) "Foundation Analysis and Design", Third Edition, McGraw-Hill, Inc..

Table 3.3b
Operability Values
System Process Components for All Alternatives

Process Component	Probability of Deviation[1]	Operability Values
Aerator	0.02	0.98
Air compressors	0.02	0.98
Bubbler conveyance and header	0.001	0.999
Centrifugal pumps	0.03	0.97
Culverts	0.001	0.999
De-aerator	0.02	0.98
Dewatering structure	0.001	0.999
Disinfection	0.02	0.98
Electrical generators	0.02	0.98
Electrical switches	0.01	0.99
Filtrate recycle	0.02	0.98
Filtration	0.02	0.98
Gate valves	0.02	0.98
Hydroelectric turbines	0.02	0.98
Interconnection gear	0.01	0.99
Level controllers	0.02	0.98
Mixing-feed sump structure	0.001	0.999
Mixing structure	0.001	0.999
Retention reservoir	0.001	0.999
Sedimentation structure	0.001	0.999
Sludge pumps	0.03	0.97
Steel pipeline	0.01	0.99
Transmission lines	0.03	0.97
Turbine pumps	0.03	0.97
Variable weirs	0.02	0.98
Wet well structure	0.001	0.999

Note: 1: Values derived from following references: a) "Guidelines for Hazard Evaluation Procedures", Second Edition, Center for Chemical Process Safety (AIChE); b) "Strategy of Process Engineering", John Wiley & Sons; c) "Operability Studies and Hazard Analysis", H. G. Lawley, Loss Prevention, Vol 8, 1974; d) "Loss Prevention in the Process Industries", F. P. Lee, London: Butterworths, 1980; e) "Human Error and Plant Operation", T. A. Kletz and G. D. Whittaker, Imperial Chemical Industries, England, 1973; and f) "Failure Modes, Effects, and Criticality Analysis", Proceedings Reliability and Maintainability Symposium, American Society of mechanical Engineers, 1972.

Table 3.3c
Level of Difficulty Metric
Constructability Analysis

Level of Difficulty	Metric
Routine	1
Somewhat difficult, using standard approach	2
Somewhat difficult, using standard approach and specialized skills	3
Difficult, may require specialized skills	5
Difficult, may require innovative approach and specialized skills	7
Very difficult, requires specialized skills	9
Very difficult, requires innovative approach and specialized skills	10

Table 3.3d
Constructability Values
System Process Components for All Alternatives

Process Component	Constructability Values[1]
Aeration system construction and installation	1
Air compressor station construction and installation	1
Appurtenances (pipe, valves, pumps, fittings, etc.)	1
Bubbler conveyance and header construction	5
Culvert tunneling, construction and tie-ins	9
Dewatering facility construction	1
Disinfection system installation	1
Electric generator installation	3
Electrical substation construction and installation	2
Filtrate recycle system installation	1
Filtration system installation	1
Hydroelectric turbine installation	10
Interconnection electrical facilities tie-in	2
Mixing basin construction	1
Pipelines construction	3
Process control and communication systems installation	2
Pump station construction and installation	1
Retention reservoir excavation and construction	3
RO(desalinization) plant	1
Sedimentation basin construction	1
Sludge conveyance system installation	1
Sludge removal system construction and installation	1
Transmission system construction	2
Turbine Parallel Side-Path Tunneling	9
Variable weir construction and installation	3
Wet well construction	10

Notes: 1: Values derived from consultation with a) VA Tech Hoest MCE Corp; b) General Electric, Power Systems Division; c) Jenny Engineering Corporation; d) Point Enterprises, Inc.; e) Dillon Construction, Inc.; and F. Alfaro & Associates.

Table 3.3e
Level of Flexibility Metric
Adaptability Analysis

Level of Flexibility	Metric
Very flexible, requires no modifications	1
Flexible, requires some minor modifications	2
Somewhat flexible, requires moderate modifications	3
Somewhat flexible, requires major modifications	4
Inflexible	5

Table 3.3f
Summary of
Operability, Constructability, Reliability and Adaptability Values
All Alternatives

Alternative	Operability	Constructability	Reliability	Adaptability
1	0.977	3.3	0.987	2.1
2	0.968	3.1	0.967	2.8
3	0.968	3.1	0.967	3.2

= Highest Value

Table 3.3.1.1
Reliability Values
Alternative 1, 100% Diversion Case

Process Component	Reliability Values
Lock Water Recovery System	0.989
Lock Water Retention/Treatment System	0.999
Saltwater Intrusion Barrier System	0.999
Potable Water Treatment System	0.919
Treated Water Transportation and Discharge System	0.999
Hydroelectric Power Generation, Transmission and Interconnection System	0.999
Solid Waste Disposal System	0.999
Composite Value	**0.987**

Table 3.3.1.2
Operability Values
Alternative 1, 100% Diversion Case

Process Component	Operability Values
Lock Water Recovery System	0.979
Lock Water Retention/Treatment System	0.999
Saltwater Intrusion Barrier System	0.999
Potable Water Treatment System	0.938
Water Transportation and Discharge System	0.999
Hydroelectric Power Generation, Transmission and Interconnection System	0.951
Solid Waste Disposal System	0.999
Composite Value	**0.977**

Table 3.3.1.3
Constructability Values
Alternative 1, 100% Diversion Case

Process Component	Average Constructability Values	Weighted Average Constructability Values
Lock Water Recovery System	5.0	1.0
Lock Water Retention/Treatment System	1.6	0.2
Saltwater Intrusion Barrier System	4.0	0.8
Potable Water Treatment System	1.3	0.1
Water Transportation and Discharge System	1.8	0.1
Hydroelectric Power Generation, Transmission and Interconnection System	3.6	1.1
Solid Waste Disposal System	1.0	0.05
Average Value	**2.6**	
Total Weighted Average Value		**3.3**

Table 3.3.1.4
Adaptability Values
Alternative 1, 100% Diversion Case

Process Component	Average Adaptability Values	Weighted Average Adaptability Values
Lock Water Recovery System	1.0	0.2
Lock Water Retention/Treatment System	2.2	0.2
Saltwater Intrusion Barrier System	3.0	0.6
Potable Water Treatment System	2.5	0.3
Water Transportation and Discharge System	3.3	0.2
Hydroelectric Power Generation, Transmission and Interconnection System	1.8	0.5
Solid Waste Disposal System	2.3	0.1
Average Value	**2.3**	
Total Weight Average Value		**2.1**

Table 3.3.2.1
Reliability Values
Alternative 2, 60% Diversion Case

Process Component	Reliability Values
Lock Water Recovery System	0.989
Lock Water Retention/Treatment System	0.979
Saltwater Intrusion Barrier System	0.999
Potable Water Treatment System	0.919
Water Transportation and Discharge System	0.999
Hydroelectric Power Generation, Transmission and Interconnection System	0.999
Solid Waste Disposal System	0.999
Composite Value	**0.967**

Table 3.3.2.2
Operability Values
Alternative 2, 60% Diversion Case

Process Component	Operability Values
Lock Water Recovery System	0.99
Lock Water Retention/Treatment System	0.979
Saltwater Intrusion Barrier System	0.999
Potable Water Treatment System	0.938
Water Transportation and Discharge System	0.999
Hydroelectric Power Generation, Transmission and Interconnection System	0.999
Solid Waste Disposal System	0.999
Composite Value	**0.968**

Table 3.3.2.3
Constructability Values
Alternative 2, 60% Diversion Case

Process Component	Average Constructability Values	Weighted Average Constructability Values
Lock Water Recovery System	5.0	1.25
Lock Water Retention/Treatment System	1.4	0.1
Saltwater Intrusion Barrier System	2.3	0.5
Potable Water Treatment System	1.3	0.1
Water Transportation and Discharge System	1.8	0.1
Hydroelectric Power Generation, Transmission and Interconnection System	3.8	0.95
Solid Waste Disposal System	1.0	0.05
Average Value	**2.4**	
Total Weighted Average Value		**3.1**

Table 3.3.2.4
Adaptability Values
Alternative 2, 60% Diversion Case

Process Component	Average Adaptability Values	Weighted Average Adaptability Values
Lock Water Recovery System	3.6	0.7
Lock Water Retention/Treatment System	2.8	0.3
Saltwater Intrusion Barrier System	3.7	0.7
Potable Water Treatment System	2.5	0.2
Water Transportation and Discharge System	3.3	0.2
Hydroelectric Power Generation, Transmission and Interconnection System	1.8	0.5
Solid Waste Disposal System	3.0	0.2
Average Value	**3.0**	
Total Weighted Average Value		**2.8**

Table 3.3.3.1
Reliability Values
Alternative 3, 30% Diversion Case

Process Component	Reliability Values
Lock Water Recovery System	0.989
Lock Water Retention/Treatment System	0.979
Saltwater Intrusion Barrier System	0.999
Potable Water Treatment System	0.919
Water Transportation and Discharge System	0.999
Hydroelectric Power Generation, Transmission and Interconnection System	0.999
Solid Waste Disposal System	0.999
Composite Value	**0.967**

Table 3.3.3.2
Operability Values
Alternative 3, 30% Diversion Case

Process Component	Operability Values
Lock Water Recovery System	0.99
Lock Water Retention System	0.979
Saltwater Intrusion Barrier System	0.999
Water Treatment System	0.938
Water Transportation and Discharge System	0.999
Hydroelectric Power Generation, Transmission and Interconnection System	0.999
Solid Waste Disposal System	0.999
Composite Value	**0.968**

Table 3.3.3.3
Constructability Values
Alternative 3, 30% Diversion Case

Process Component	Average Constructability Values	Weighted Average Constructability Values
Lock Water Recovery System	5.0	1.0
Lock Water Retention/Treatment System	1.4	0.1
Saltwater Intrusion Barrier System	2.3	0.5
Potable Water Treatment System	1.3	0.1
Water Transportation and Discharge System	1.8	0.1
Hydroelectric Power Generation, Transmission and Interconnection System	3.8	0.95
Solid Waste Disposal System	1.0	0.05
Average Value	**2.4**	
Total Weighted Average Value		**3.1**

Table 3.3.3.4
Adaptability Values
Alternative 3, 30% Diversion Case

Process Component	Average Adaptability Values	Weighted Average Adaptability Values
Lock Water Recovery System	3.8	0.8
Lock Water Retention System	3.6	0.4
Saltwater Intrusion Barrier System	4.3	0.8
Water Treatment System	3.3	0.3
Water Transportation and Discharge System	3.8	0.2
Hydroelectric Power Generation, Transmission and Interconnection System	1.8	0.5
Solid Waste Disposal System	4.0	0.2
Average Value	**3.5**	
Total Weighted Average Value		**3.2**

Table 3.4
Summary of Project Budget Estimates ($M)
Alternative 1, 2 and 3

Project Phase	Alternatives		
	1 100% Diversion Case	2 60% Diversion Case	3 30% Diversion Case
I	419.15	338.20	303.55
II	45.17	45.17	27.80
Total	464.32	383.37	331.35

Table 3.4.1a
Project Construction Cost Estimate ($K)
Alternative 1, 100% Diversion Case, Phase I

PHASE I															
Treatment Facility	**Cost Category**	**Lock Water Recovery System**		**Lock Water Retention System**								**Saltwater Intrusion System**			
		Recovery Culvert	Tie-ins	Reservoir	Debris Screen	Aeration	Level Controls	Gate Valves	Mixing	Sedimentation	Sludge Removal	Discharge Culvert	Bubbler	Compressor Station	
Gatun	Labor	456	187	4,191	60	71	31	152	77	N/A	195	665	156	145	
	Materials	418	171	3,849	66	66	35	168	70	N/A	215	610	144	160	
	Equipment	2,929	1,200	3,247	84	55	45	213	60	N/A	272	4,269	120	202	
	Subtotal	3,803	1,558	11,287	210	192	111	533	207	N/A	682	5,544	420	507	
Miraflores	Labor	456	187	11,245	60	71	31	152	77	N/A	195	665	156	145	
	Materials	418	171	10,325	66	66	35	168	70	N/A	215	610	144	160	
	Equipment	2,929	1,200	8,713	84	55	45	213	60	N/A	272	4,269	120	202	
	Subtotal	3,803	1,558	30,283	210	192	111	533	207	N/A	682	5,544	420	507	
Total		7,606	3,116	41,570	420	384	222	1,066	414	N/A	1,364	11,088	840	1,014	

PHASE I															
Treatment Facility	**Cost Category**	**Water Treatment, Conventional System**						**Water Transportation & Discharge**		**Hydroelectric Power Generation, Transmission & Interconnection**					**Solid Waste Removal**
		Aeration	Mixing	Sedimentation	Filtration	Disinfection	Sludge Removal	Pipelines	Pump Stations	Parallel Side-path Tunnels	Turbine-Generators	Substations	Transmission	Interconnection	
Gatun	Labor	2,198	627	5,520	748	2,075	558	535	680	1,259	5,352	2,850	679	N/A	1,357
	Materials	2,018	692	5,069	825	2,288	616	891	638	1,245	11,756	3,143	749	N/A	1,496
	Equipment	1,702	877	4,277	1,045	2,898	780	4,456	809	8,817	30,230	3,982	950	N/A	1,895
	Subtotal	5,918	2,196	14,866	2,618	7,261	1,954	5,882	2,127	11,321	47,338	9,975	2,378	N/A	4,748
		Water Treatment, Desalinization System													
Miraflores		De-Aerator	Feed Sump	Filter Assembly	RO Blocks	Disinfection	Clear Well								
	Labor	68	174	299	8,269	1,927	148	1,837	680	1,801	5,418	3,800	1,019	N/A	1,357
	Materials	75	160	330	9,120	2,152	136	5,053	638	1,651	11,898	4,191	1,124	N/A	1,496
	Equipment	95	135	418	11,552	2,783	115	15,312	809	11,556	30,595	5,309	1,425	N/A	1,895
	Subtotal	238	469	1,047	28,941	6,862	399	22,202	2,127	15,008	47,911	13,300	3,568	N/A	4,748
Total		6,156	2,665	15,913	31,559	14,123	2,353	28,084	4,254	26,329	95,249	23,275	5,946	N/A	9,496

GRAND TOTAL FOR PHASE I	
Labor	**71,061**
Materials	**87,870**
Equipment	**175,575**
TOTAL	**334,506**

Table 3.4.1b
Project Cost Estimate ($K)
Alternative 1, 100% Diversion Case, Phase II

PHASE II														
Treatment Facility	**Cost Category**	**Lock Water Recovery System**		**Lock Water Retention System**								**Saltwater Intrusion System**		
		Box Culvert	Tie-ins	Reservoir	Debris Screen	Aeration	Level Controls	Gate Valves	Mixing	Sedimentation	Sludge Removal	Box Culvert	Bubbler	Compressor Station
Gatun	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Miraflores	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total		N/A	N/N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

PHASE II															
Treatment Facility	**Cost Category**	**Water Treatment System**						**Water Transportation & Discharge**		**Hydroelectric Power Generation, Transmission & Interconnection**					**Solid Waste Removal**
		Aeration	Mixing	Sedimentation	Filtration	Disinfection	Sludge Removal	Pipelines	Pump Stations	Turbines	Generators	Substations	Transmission	Interconnection	
Gatun	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,655	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,552	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,969	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5,176	N/A	N/A	N/A	N/A	N/A	N/A
Miraflores	Labor	2,198	627	5,520	748	2,075	558	N/A	1,655	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	2,018	692	5,069	825	2,288	616	N/A	1,552	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	1,702	877	4,277	1,045	2,898	780	N/A	1,969	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	5,918	2,196	14,866	2,618	7,261	1,954	N/A	5,176	N/A	N/A	N/A	N/A	N/A	N/A
Total		5,918	2,196	14,866	2,618	7,261	1,954	N/A	10,352	N/A	N/A	N/A	N/A	N/A	N/A

GRAND TOTAL FOR PHASE II	
Labor	**15,036**
Materials	**14,612**
Equipment	**15,517**
TOTAL	**45,165**

Table 3.4.1c
Composite Implementation Cost Estimate ($M)
Alternative 1, 100% Diversion Case, Phase I Only

Cost Category	Cost Estimate
Engineering	51.19
Construction	334.51
Project Management	33.45
Total	**419.15**

Table 3.4.2a
Project Cost Estimate (SK)
Alternative 2, 60% Diversion Case, Phase I

PHASE I														
Treatment Facility	**Cost Category**	**Lock Water Recovery System**		**Lock Water Retention System**								**Saltwater Intrusion System**		
		Recovery Culvert	Wet Wells	Reservoir	Debris Screen	Aeration	Level Controls	Gate Valves	Mixing	Sedimentation	Sludge Removal	Box Culvert	Bubbler	Compressor Station
Gatun	Labor	456	2,088	4,191	60	71	N/A	N/A	77	N/A	195	N/A	156	145
	Materials	418	1,638	3,849	66	66	N/A	N/A	70	N/A	215	N/A	144	160
	Equipment	2,929	1,365	3,247	84	55	N/A	N/A	60	N/A	272	N/A	120	202
	Subtotal	3,803	5,091	11,287	210	192	N/A	N/A	207	N/A	682	N/A	420	507
Miraflores	Labor	456	2,088	11,245	60	71	N/A	N/A	77	N/A	195	N/A	156	145
	Materials	418	1,638	10,325	66	66	N/A	N/A	70	N/A	215	N/A	144	160
	Equipment	2,929	1,365	8,713	84	55	N/A	N/A	60	N/A	272	N/A	120	202
	Subtotal	3,803	5,091	30,283	210	192	N/A	N/A	207	N/A	682	N/A	420	507
Total		7,606	10,182	41,570	420	384	N/A	N/A	414	N/A	1,364	N/A	840	1,014

PHASE I														
Treatment Facility	**Cost Category**	**Water Treatment System**						**Water Transportation & Discharge**		**Hydroelectric Power Generation, Transmission & Interconnection**				**Solid Waste Removal**
		Aeration	Mixing	Sedimentation	Filtration	Disinfection	Sludge Removal	Pipelines	Pump Stations	Turbine-Generators	Substations	Transmission	Interconnection	
Gatun	Labor	2,198	627	5,520	748	2,075	558	535	680	12,910	2,850	679	N/A	1,357
	Materials	2,018	692	5,069	825	2,288	616	891	638	5,062	3,143	749	N/A	1,496
	Equipment	1,702	877	4,277	1,045	2,898	780	4,456	809	13,500	3,982	950	N/A	1,895
	Subtotal	5,918	2,196	14,866	2,618	7,261	1,954	5,882	2,127	31,472	9,975	2,378	N/A	4,748
		Water Treatment, Desalinization System												
		De-aerator	Feed Sump	Filter Assembly	RO Blocks	Disinfection	Clear Well							
Miraflores	Labor	68	174	299	8,269	1,927	148	1,837	680	12,910	3,800	1,019	N/A	1,357
	Materials	75	160	330	9,120	2,152	136	5,053	638	5,062	4,191	1,124	N/A	1,496
	Equipment	95	135	418	11,552	2,783	115	15,312	809	13,500	5,309	1,425	N/A	1,895
	Subtotal	238	469	1,047	28,941	6,862	399	22,202	2,127	31,472	13,300	3,568	N/A	4,748
Total		6,156	2,665	15,913	31,559	14,123	2,353	28,084	4,254	62,944	23,275	5,946	N/A	9,496

GRAND TOTAL FOR PHASE I	
Labor	**85,157**
Materials	**72,752**
Equipment	**112,653**
TOTAL	**270,562**

Table 3.4.2b
Project Cost Estimate ($K)
Alternative 2, 60%N/A Diversion Case, Phase II

PHASE II														
Treatment Facility	**Cost Category**	**Lock Water Recovery System**		**Lock Water Retention System**								**Saltwater Intrusion System**		
		Pipeline	Wet Wells	Reservoir	Debris Screen	Aeration	Level Controls	Gate Valves	Mixing	Sedimentation	Sludge Removal	Box Culvert	Bubbler	Compressor Station
Gatun	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Miraflores	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

PHASE II															
Treatment Facility	**Cost Category**	**Water Treatment System**						**Water Transportation & Discharge**		**Hydroelectric Power Generation, Transmission & Interconnection**					**Solid Waste Removal**
		Aeration	Mixing	Sedimentation	Filtration	Disinfection	Sludge Removal	Pipelines	Pump Stations	Turbines	Generators	Substations	Transmission	Interconnection	
Gatun	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,655	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,552	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,969	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5,176	N/A	N/A	N/A	N/A	N/A	N/A
Miraflores	Labor	2,198	627	5,520	748	2,075	558	N/A	1,655	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	2,018	692	5,069	825	2,288	616	N/A	1,552	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	1,702	877	4,277	1,045	2,898	780	N/A	1,969	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	5,918	2,196	14,866	2,618	7,261	1,954	N/A	5,176	N/A	N/A	N/A	N/A	N/A	N/A
Total		5,918	2,196	14,866	2,618	7,261	1,954	N/A	10,352	N/A	N/A	N/A	N/A	N/A	N/A

GRAND TOTAL FOR PHASE II	
Labor	**15,036**
Materials	**14,612**
Equipment	**15,517**
TOTAL	**45,165**

Table 3.4.2c
Composite Implementation Cost Estimate ($M)
Alternative 2, 60% Diversion Case, Phase I Only

Cost Category	Cost Estimate
Engineering	40.58
Construction	270.56
Project Management	27.06
Total	**338.20**

Table 3.4.3a
Project Cost Estimate (SK)
Alternative 3, 30% Diversion Case, Phase I

PHASE I														
Treatment Facility	**Cost Category**	**Lock Water Recovery System**		**Lock Water Retention System**								**Saltwater Intrusion System**		
		Recovery Culvert	Wet Wells	Reservoir	Debris Screen	Aeration	Level Controls	Gate Valves	Mixing	Sedimentation	Sludge Removal	Box Culvert	Bubbler	Compressor Station
Gatun	Labor	456	1,698	3,764	49	58	N/A	N/A	63	N/A	159	N/A	156	145
	Materials	418	1,332	2,952	54	54	N/A	N/A	57	N/A	175	N/A	144	160
	Equipment	2,929	1,110	2,460	68	45	N/A	N/A	49	N/A	221	N/A	120	202
	Subtotal	3,803	4,140	9,176	171	157	N/A	N/A	169	N/A	555	N/A	420	507
Miraflores	Labor	456	2,088	10,098	49	58	N/A	N/A	63	N/A	159	N/A	156	145
	Materials	418	1,820	7,920	54	54	N/A	N/A	57	N/A	175	N/A	144	160
	Equipment	2,929	1,365	6,600	68	45	N/A	N/A	49	N/A	221	N/A	120	202
	Subtotal	3,803	5,273	24,618	171	157	N/A	N/A	169	N/A	555	N/A	420	507
Total		7,606	9,413	33,794	342	314	N/A	N/A	338	N/A	1,665	N/A	840	1,014

PHASE I															
Treatment Facility	**Cost Category**	**Water Treatment System**						**Water Transportation & Discharge**		**Hydroelectric Power Generation, Transmission & Interconnection**				**Solid Waste Removal**
		Aeration	Mixing	Sedimentation	Filtration	Disinfection	Sludge Removal	Pipelines	Pump Stations	Turbines-Generators	Substations	Transmission	Interconnection	
Gatun	Labor	1,973	510	4,488	608	1,663	333	535	449	12,910	2,850	679	N/A	906
	Materials	1,540	562	4,121	671	1,834	368	891	421	5,062	3,143	749	N/A	999
	Equipment	1,299	713	3,477	849	2,322	466	4,456	533	13,500	3,982	950	N/A	1,266
	Subtotal	4,812	1,785	12,086	2,128	5,819	1,167	5,882	1,403	31,472	9,975	2,378	N/A	3,171
		Water Treatment, Desalinization System												
		De-aeration	Feed Pump	Filter Assembly	RO Blocks	Disinfection	Clear Well							
Miraflores	Labor	55	141	243	6,723	1,567	120	1,837	449	12,910	3,800	1,019	N/A	906
	Materials	61	130	268	7,415	1,750	111	5,053	421	5,062	4,191	1,124	N/A	999
	Equipment	77	110	340	9,392	2,263	94	15,312	533	13,500	5,309	1,425	N/A	1,266
	Subtotal	193	381	851	23,530	5,580	325	22,202	1,403	31,472	13,300	3,568	N/A	3,171
Total		5,005	2,166	12,937	25,658	11,399	1,492	28,084	2,806	62,944	23,275	5,946	N/A	6,342

GRAND TOTAL FOR PHASE I	
Labor	**77,494**
Materials	**63,094**
Equipment	**102,252**
TOTAL	**242,840**

Table 3.4.3b
Project Cost Estimate ($K)
Alternative 3, 30% Diversion Case, Phase II

PHASE II														
Treatment Facility	**Cost Category**	**Lock Water Recovery System**		**Lock Water Retention System**								**Saltwater Intrusion System**		
		Pipeline	Wet Wells	Reservoir	Debris Screen	Aeration	Level Controls	Gate Valves	Mixing	Sedimentation	Sludge Removal	Box Culvert	Bubbler	Compressor Station
Gatun	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Miraflores	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

PHASE II															
Treatment Facility	**Cost Category**	**Water Treatment System**						**Water Transportation & Discharge**		**Hydroelectric Power Generation, Transmission & Interconnection**					**Solid Waste Removal**
		Aeration	Mixing	Sedimentation	Filtration	Disinfection	Sludge Removal	Pipelines	Pump Stations	Turbines	Generators	Substations	Transmission	Interconnection	
Gatun	Labor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Miraflores	Labor	1,973	510	4,488	608	1,663	333	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Materials	1,540	562	4,121	671	1,834	368	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Equipment	1,299	713	3,477	849	2,322	466	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotal	4,812	1,785	12,086	2,128	5,819	1,167	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total		4,812	1,785	12,086	2,128	5,819	1,167	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GRAND TOTAL FOR PHASE II															
								Labor							**9,575**
								Materials							**9,096**
								Equipment							**9,126**
								TOTAL							**27,797**

Table 3.4.3c
Composite Implementation Cost Estimate ($M)
Alternative 3, 30% Diversion Case, Phase I Only

Cost Category	Cost Estimate
Engineering	36.43
Construction	242.84
Project Management	24.28
Total	**303.55**

Table 3.5.3 - A (Water, Power and Transit Revenue Streams) Project Economics, Lock Water Reclamation Project, Panama Canal, Panama

Table 3.5.3.1, Project Economic Parameters

Year	Interest Rate	Discount Factor	Rate of Inflation	$/m³ (water)[1]	$/Kwh (power)[2]	Transits (ships/yr)	Transit Revenue (e$M/yr)[3]	Water Dschgd (Bgal/yr)[4]	Production Water (Bgal/yr)[5]	Production Power (Kwh)
0	0.085	1.0000	1.0000	0.0000	0.0000	13,505	0.0	0.0	0.0	0.0
3		0.7829	1.0500	0.0913	0.1092	13,797	604.8	717.4	215.2	81,914
4		0.7216	1.0511	0.0958	0.1147	14,089	642.3	732.6	229.8	83,648
5		0.6650	1.0521	0.1007	0.1205	14,381	681.8	747.8	244.8	85,381
6		0.6129	1.0532	0.1060	0.1268	14,673	723.5	763.0	260.1	87,115
7		0.5649	1.0542	0.1116	0.1335	14,965	767.4	778.2	275.9	88,849
8		0.5207	1.0553	0.1176	0.1408	15,257	813.7	793.4	292.1	90,582
9		0.4799	1.0563	0.1241	0.1486	15,549	862.4	808.5	308.7	92,316
10		0.4423	1.0574	0.1311	0.1569	15,841	913.7	823.7	325.8	94,050
11		0.4076	1.0584	0.1387	0.1659	16,133	967.8	838.9	343.2	95,783
12		0.3757	1.0595	0.1468	0.1756	16,425	1,024.7	854.1	361.1	97,517

Table 3.5.3.2, Expense Parameters

Labor

	No. Empl	No. Shifts	Wage/Hr ($)	No. Reg Hours	OT Hrs/ Mo/Empl	Total	($)
Recep/Ad	2	1	5.50	2,080			22,880
Opns	36	3	4.00	2,080	8		1,645,056
Chemist	3	1	12.50	2,080			78,000
Lab Tech	6	3	8.00	2,080			299,614
Sys Techs	6	3	8.00	2,080			299,520
Machinist	3	3	8.00	2,080	8		160,128
Stck Wrhse	3	3	8.00	2,080			149,760
Acctng/Ad	3	1	10.50	2,080			65,520
Supv	3	3	10.50	2,080			196,560
Mngr	1	1	15.00	2,080			31,200
Sub-total/plant	180						2,948,238
Total	**360**						**5,896,475**

Operating Expenses

	Factor	Total
Plant Management Fee		0
Misc. Fees		250,000
Employee Benefits	0.34	2,004,802
Employee Expenses	0.125	737,059
Insurance		500,000
Commercial License Tax		0
Equip/Materials	0.015	12,600,000
Total		**16,091,861**
Grand Total, Epenses		**21,988,336**

Table 3.5.3.3, Pro Forma Cash Flow and Profit Analysis

Year	Invstmnt ($M)	Transit Rev($M)[6]	Water Rev($M)[7]	Power Rev($M)[8]	Gross Rev ($M)	Expense ($M)	Debt Svc ($M)	NCF ($M)[9]	PVP ($M)
0	$ (420)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		13.44	29.74	27.43	70.61	21.99	45.57	3.05	2.39
4		27.98	61.33	57.68	146.99	23.09	45.57	78.33	56.52
5		43.70	63.15	60.64	167.49	23.11	45.57	98.81	65.71
6		60.65	64.97	63.79	189.42	23.13	45.57	120.71	73.99
7		78.93	66.74	67.09	212.76	23.16	45.57	144.03	81.37
8		98.60	68.48	70.59	237.67	23.18	45.57	168.92	87.95
9		119.75	70.15	74.28	264.19	23.20	45.57	195.41	93.77
10		142.48	71.70	78.16	292.33	23.23	45.57	223.54	98.87
11		166.86	73.16	82.29	322.31	23.25	45.57	253.49	103.33
12		193.01	74.43	86.61	354.06	23.27	45.57	285.22	107.16
Total		**$945**	**$644**	**$ 669**	**$ 2,258**	**$ 231**	**$456**	**$ 1,571**	**$771**
PVP/I (%)									**1.84**
Pay Out (yrs)									**5.1**

Footnotes:

1. Basis is $100 per acre-foot of water increased annually by inflation index
2. Basis is 80% of base price of $0.11/Kwh increased annualy by inflation index
3. Annual average transit fee of ~$42,148 per transit increased annually at a rate of 4%
4. Basis is transit volume
5. Initial rate is 30% of water discharged then prorated annually to 60% in project year 25
6. Incremental revebue generated from increased canal transit volume
7. Basis is 80% of unit price times volume treated for potable consumption
8. Net power produced times unit price
9. Gorss revenue less expense and debt service

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Table 3.5.3 - Scenario B (Power and Transit Revenue Stream), Project Economics, Lock Water Reclamation Project, Panama Canal, Panama

Table 3.5.3.1, Project Economic Parameters

Year	Interest Rate	Discount Factor	Rate of Inflation	$/m^3 (wtr)	$/Kwh (pwr)[1]	Transits (ships/yr)	Transit Revenue (e$M/yr)[2]	Water Dschgd (Bgal/yr)[3]	Production Water (Bgal/yr)[4]	Production Power (Kwh)
0	0.085	1.0000	1.0000	0.0000	0.0000	13,505	0.0	0.0	0.0	0.0
3		0.7829	1.0500	0.0000	0.1092	13,797	604.8	717.4	215.2	81,914
4		0.7216	1.0511	0.0000	0.1147	14,089	642.3	732.6	229.8	83,648
5		0.6650	1.0521	0.0000	0.1205	14,381	681.8	747.8	244.8	85,381
6		0.6129	1.0532	0.0000	0.1268	14,673	723.5	763.0	260.1	87,115
7		0.5649	1.0542	0.0000	0.1335	14,965	767.4	778.2	275.9	88,849
8		0.5207	1.0553	0.0000	0.1408	15,257	813.7	793.4	292.1	90,582
9		0.4799	1.0563	0.0000	0.1486	15,549	862.4	808.5	308.7	92,316
10		0.4423	1.0574	0.0000	0.1569	15,841	913.7	823.7	325.8	94,050
11		0.4076	1.0584	0.0000	0.1659	16,133	967.8	838.9	343.2	95,783
12		0.3757	1.0595	0.0000	0.1756	16,425	1,024.7	854.1	361.1	97,517

Table 3.5.3.2, Expense Parameters

Labor

	No. Empl	No. Shifts	Wage/Hr ($)	No. Reg Hours	OT Hrs/ Mo/Empl	Total	($)
Recep/Ad	2	1	5.50	2,080			22,880
Opns	36	3	4.00	2,080	8		1,645,056
Chemist	3	1	12.50	2,080			78,000
Lab Tech	6	3	8.00	2,080			299,520
Sys Techs	6	3	8.00	2,080			299,520
Machinist	3	3	8.00	2,080	8		160,128
Stck Wrhse	3	3	8.00	2,080			149,760
Acctng/Ad	3	1	10.00	2,080			62,400
Supv	3	3	10.50	2,080			196,560
Mngr	1	1	15.00	2,080			31,200
Sub-total/plant	180						2,945,024
Total	**360**						**5,890,048**

Operating Expenses

	Factor	Total
Plant Management Fee		0
Misc. Fees		250,000
Employee Benefits	0.34	2,002,616
Employee Expenses	0.125	736,256
Insurance		500,000
Commercial License Tax		0
Equip/Materials	0.015	12,600,000
Total		**16,088,872**

Grand Total, Epenses **21,978,920**

Table 3.5.3.3, Pro Forma Cash Flow and Profit Analysis

Year	Invstmnt ($M)	Transit Rev($M)[5]	Water Rev($M)	Power Rev($M)[6]	Gross Rev ($M)	Expense ($M)	Debt Svc ($M)	NCF ($M)[7]	PVP ($M)
0	$ (420)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		13.44	0.00	27.43	40.87	21.98	45.57	-26.68	-20.89
4		27.98	0.00	57.68	85.66	23.08	45.57	17.01	12.27
5		43.70	0.00	60.64	104.34	23.10	45.57	35.67	23.72
6		60.65	0.00	63.79	124.44	23.12	45.57	55.75	34.17
7		78.93	0.00	67.09	146.02	23.15	45.57	77.30	43.67
8		98.60	0.00	70.59	169.19	23.17	45.57	100.45	52.30
9		119.75	0.00	74.28	194.04	23.19	45.57	125.27	60.12
10		142.48	0.00	78.16	220.63	23.22	45.57	151.85	67.16
11		166.86	0.00	82.29	249.15	23.24	45.57	180.34	73.51
12		193.01	0.00	86.61	279.63	23.26	45.57	210.80	79.20
Total		**$945**	**$0**	**$ 669**	**$ 1,614**	**$ 231**	**$456**	**$928**	**$425**
PVP/I (%)									**1.01**
Pay Out (yrs)									**6.5**

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Footnotes:

1 Basis is 80% of base price of $0.11/Kwh increased annualy by inflation index

2 Annual average transit fee of ~$42,148 per transit increased annually at a rate of 4%

3 Basis is transit volume

4 Initial rate is 30% of water discharged then prorated annually to 60% in project year 25

5 Incremental revebue generated from increased canal transit volume

6 Net power produced times unit price

7 Gorss revenue less expense and debt service

Table 3.5.3 - Scenario C (Power Revenue Stream Only) Project Economics, Lock Water Reclamation Project, Panama Canal, Panama

Table 3.5.3.1, Project Economic Parameters

Year	Interest Rate	Discount Factor	Rate of Inflation	$/m³ (water)	$/Kwh (power)[1]	Transits (ships/yr)	Transit Revenue (e$M/yr)	Water Dschgd (Bgal/yr)[2]	Production Water (Bgal/yr)[3]	Production Power (Kwh)
0	0.085	1.0000	1.0000	0.0000	0.0000	13,505	0.0000	0.0	0.0	0.0
3		0.7829	1.0500	0.0000	0.1092	13,797	0.0000	717.4	215.2	81,914
4		0.7216	1.0511	0.0000	0.1147	14,089	0.0000	732.6	229.8	83,648
5		0.6650	1.0521	0.0000	0.1205	14,381	0.0000	747.8	244.8	85,381
6		0.6129	1.0532	0.0000	0.1268	14,673	0.0000	763.0	260.1	87,115
7		0.5649	1.0542	0.0000	0.1335	14,965	0.0000	778.2	275.9	88,849
8		0.5207	1.0553	0.0000	0.1408	15,257	0.0000	793.4	292.1	90,582
9		0.4799	1.0563	0.0000	0.1486	15,549	0.0000	808.5	308.7	92,316
10		0.4423	1.0574	0.0000	0.1569	15,841	0.0000	823.7	325.8	94,050
11		0.4076	1.0584	0.0000	0.1659	16,133	0.0000	838.9	343.2	95,783
12		0.3757	1.0595	0.0000	0.1756	16,425	0.0000	854.1	361.1	97,517
13		0.3463	1.0605	0.0000	0.1861	16,717	0.0000	869.3	379.4	99,251
14		0.3191	1.0616	0.0000	0.1973	16,973	0.0000	882.6	397.2	100,767
15		0.2941	1.0627	0.0000	0.2095	17,265	0.0000	897.8	416.3	102,501
16		0.2711	1.0637	0.0000	0.2226	17,557	0.0000	913.0	435.8	104,235
17		0.2499	1.0648	0.0000	0.2368	17,812	0.0000	926.2	454.8	105,752
18		0.2303	1.0659	0.0000	0.2522	18,104	0.0000	941.4	475.0	107,485

Table 3.5.3.3, Pro Forma Cash Flow and Profit Analysis

Year	Invstmnt ($M)	Transit Rev($M)	Water Rev($M)	Power Rev($M)[4]	Gross Rev($M)	Expense ($M)	Debt Svc ($M)	NCF ($M)[5]	PVP ($M)
0	$ (420)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		0.00	0.00	27.43	27.43	21.99	30.38	-24.94	-19.53
4		0.00	0.00	57.68	57.68	23.09	30.38	4.21	3.04
5		0.00	0.00	60.64	60.64	23.11	30.38	7.15	4.76
6		0.00	0.00	63.79	63.79	23.13	30.38	10.28	6.30
7		0.00	0.00	67.09	67.09	23.16	30.38	13.56	7.66
8		0.00	0.00	70.59	70.59	23.18	30.38	17.03	8.87
9		0.00	0.00	74.28	74.28	23.20	30.38	20.70	9.93
10		0.00	0.00	78.16	78.16	23.23	30.38	24.55	10.86
11		0.00	0.00	82.29	82.29	23.25	30.38	28.66	11.68
12		0.00	0.00	86.61	86.61	23.27	30.38	32.96	12.38
13		0.00	0.00	91.18	91.18	23.30	30.38	37.51	12.99
14		0.00	0.00	95.81	95.81	23.32	30.38	42.11	13.44
15		0.00	0.00	104.16	104.16	23.34	30.38	50.44	14.84
16		0.00	0.00	106.26	106.26	23.37	30.38	52.51	14.24
17		0.00	0.00	111.67	111.67	23.39	30.38	57.90	14.47
18		0.00	0.00	117.65	117.65	23.41	0.00	94.24	21.70
Total		**$0**	**$0**	**$1,295**	**$1,295**	**$371**	**$456**	**$469**	**$148**
PVP/I (%)									**0.35**
Pay Out (yrs)									**14.9**

Table 3.5.3.2, Expense Parameters

Labor

	No. Empl	No. Shifts	Wage/Hr ($)	No. Reg Hours	OT Hrs/ Mo/Empl	Total ($)
Recep/Ad	2	1	5.50	2,080		22,880
Opns	36	3	4.00	2,080	8	1,645,056
Chemist	3	1	12.50	2,080		78,000
Lab Tech	6	3	8.00	2,080		299,520
Sys Techs	6	3	8.00	2,080		299,520
Machinist	3	3	8.00	2,080	8	160,128
Stck Wrhse	3	3	8.00	2,080		149,760
Acctng/Ad	3	1	10.50	2,080		65,520
Supv	3	3	10.50	2,080		196,560
Mngr	1	1	15.00	2,080		31,200
Sub-total/plant	180					2,948,144
Total	**360**					**5,896,288**

Operating Expenses

	Factor	Total
Plant Management Fee		0
Misc. Fees		250,000
Employee Benefits	0.34	2,004,738
Employee Expenses	0.125	737,036
Insurance		500,000
Commercial License Tax		0
Equip/Materials	0.015	12,600,000
Total		**16,091,774**
Grand Total, Epenses		**21,988,062**

June-02

Footnotes:

1 Basis is 80% of base price of $0.11/Kwh increased annualy by inflation index

2 Basis is transit volume

3 Initial rate is 30% of water discharged then prorated annually to 60% in project year 25

4 Net power times power rate

5 Gross revenue less expenses and debt service

Table 3.5.3 - Scenario D (Transit Revenue Stream Only) Project Economics, Lock Water Reclamation Project, Panama Canal, Panama

Table 3.5.3.1, Project Economic Parameters

Year	Interest Rate	Discount Factor	Rate of Inflation	$/m³ (water)	$/Kwh (power)	Transits (ships/yr)	Transit Revenue (e$M/yr)[1]	Water Dschgd (Bgal/yr)[2]	Production Water (Bgal/yr)[3]	Production Power (Kwh)
0	0.085	1.0000	1.0000	0.0000	0.0000	13,505	0.0	0.0	0.0	0.0
3		0.7829	1.0500	0.0000	0.0000	13,797	604.8	717.4	215.2	81,914
4		0.7216	1.0511	0.0000	0.0000	14,089	642.3	732.6	229.8	83,648
5		0.6650	1.0521	0.0000	0.0000	14,381	681.8	747.8	244.8	85,381
6		0.6129	1.0532	0.0000	0.0000	14,673	723.5	763.0	260.1	87,115
7		0.5649	1.0542	0.0000	0.0000	14,965	767.4	778.2	275.9	88,849
8		0.5207	1.0553	0.0000	0.0000	15,257	813.7	793.4	292.1	90,582
9		0.4799	1.0563	0.0000	0.0000	15,549	862.4	808.5	308.7	92,316
10		0.4423	1.0574	0.0000	0.0000	15,841	913.7	823.7	325.8	94,050
11		0.4076	1.0584	0.0000	0.0000	16,133	967.8	838.9	343.2	95,783
12		0.3757	1.0595	0.0000	0.0000	16,425	1,024.7	854.1	361.1	97,517
13		0.3463	1.0605	0.0000	0.0000	16,717	1,084.7	869.3	379.4	99,251
14		0.3191	1.0616	0.0000	0.0000	16,973	1,145.3	882.6	397.2	100,767
15		0.2941	1.0627	0.0000	0.0000	17,265	1,212.0	897.8	416.3	102,501
16		0.2711	1.0637	0.0000	0.0000	17,557	1,281.4	913.0	435.8	104,235
17		0.2499	1.0648	0.0000	0.0000	17,812	1,352.0	926.2	454.8	105,752
18		0.2303	1.0659	0.0000	0.0000	18,104	1,429.2	941.4	475.0	107,485

Table 3.5.3.3, Pro Forma Cash Flow and Profit Analysis

Year	Invstmnt ($M)	Transit Rev($M)[4]	Water Rev($M)	Power Rev($M)	Gross Rev ($M)	Expense ($M)	Debt Svc ($M)	NCF ($M)[5]	PVP ($M)
0	$ (420)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3		13.44	0.00	0.00	13.44	21.99	30.38	-38.93	-30.48
4		27.98	0.00	0.00	27.98	23.09	30.38	-25.49	-18.39
5		43.70	0.00	0.00	43.70	23.11	30.38	-9.80	-6.51
6		60.65	0.00	0.00	60.65	23.13	30.38	7.14	4.38
7		78.93	0.00	0.00	78.93	23.16	30.38	25.39	14.34
8		98.60	0.00	0.00	98.60	23.18	30.38	45.04	23.45
9		119.75	0.00	0.00	119.75	23.20	30.38	66.17	31.75
10		142.48	0.00	0.00	142.48	23.23	30.38	88.87	39.31
11		166.86	0.00	0.00	166.86	23.25	30.38	113.23	46.16
12		193.01	0.00	0.00	193.01	23.27	30.38	139.36	52.36
13		200.94	0.00	0.00	200.94	23.30	30.38	147.26	50.99
14		206.60	0.00	0.00	206.60	23.32	30.38	152.90	48.80
15		215.14	0.00	0.00	215.14	23.34	30.38	161.42	47.48
16		223.91	0.00	0.00	223.91	23.37	30.38	170.16	46.13
17		230.11	0.00	0.00	230.11	23.39	30.38	176.34	44.06
18		239.55	0.00	0.00	239.55	23.41	0.00	216.14	49.77
Total		**$2,262**	**$0**	**$0**	**$2,262**	**$371**	**$456**	**$1,435**	**$444**
PVP/I (%)									**1.1**
Pay Out (yrs)									**10.3**

Table 3.5.3.2, Expense Parameters

Labor

	No. Empl	No. Shifts	Wage/Hr ($)	No. Reg Hours	OT Hrs/ Mo/Empl	Total ($)
Recep/Ad	2	1	5.50	2,080		22,880
Opns	36	3	4.00	2,080	8	1,645,056
Chemist	3	1	12.50	2,080		78,000
Lab Tech	6	3	8.00	2,080		299,520
Sys Techs	6	3	8.00	2,080		299,520
Machinist	3	3	8.00	2,080	8	160,128
Stck Wrhse	3	3	8.00	2,080		149,760
Acctng/Ad	3	1	10.50	2,080		65,520
Supv	3	3	10.50	2,080		196,560
Mngr	1	1	15.00	2,080		31,200
Sub-total/plant	180					2,948,144
Total	**360**					**5,896,288**

Operating Expenses

	Factor	Total
Plant Management Fee		0
Misc. Fees		250,000
Employee Benefits	0.34	2,004,738
Employee Expenses	0.125	737,036
Insurance		500,000
Commercial License Tax		0
Equip/Materials	0.015	12,600,000
Total		**16,091,774**

Grand Total, Epenses **21,988,062**

June-02

Footnotes:

1 Annual average fee of ~$42,148 increased annualy at a rate of 1.04%

2 Basis is transit volume

3 Initial rate is 30% of water discharged then prorated annually to 60% in project year 25

4 Incremental revenue generated from increased canal transit volume

5 Gross revenue less expenses and debt service

Table 3.5.3b

Summary of Project Economic Modeling Results
(Scenarios A, B, C and D)

Scenario	NCF ($M)	PVP ($M)	PVP/I	Payout (years)	Term of Model (years)
A	1,571	771	1.84	5.1	10
B	928	425	1.01	6.5	10
C	469	148	0.35	14.9	15
D	1,435	444	1.1	10.3	15

Table 5.1a
"Exclusive" Service Capacity Increases
From Additional Supply of "Potable" Water, Phase I

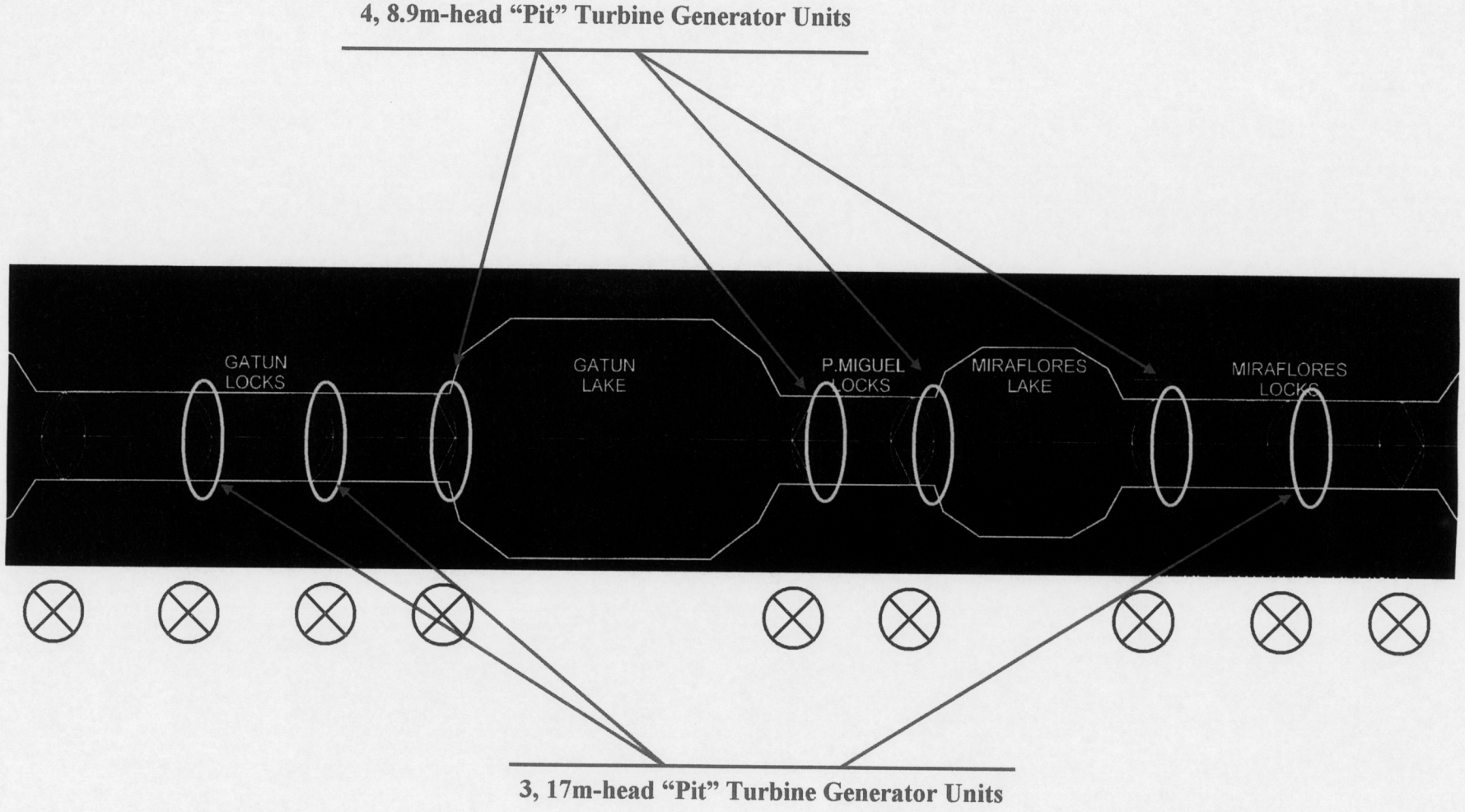
Demand Sector	Baseline Demand Rate (gals. per day)	"Exclusive" Potential Capacity Increase by Addition of 175 mgd (Project Phase I)
Residential Customers	73.10	2,393,981
Hectacres of Agriculture	100.00	1,750,000
Wet Industry Employees	287.00	609,756
Other Manufacturing Employees	172.00	1,017,442
Fabrication & Construction Employees	9.00	19,444,444
Metric Tons of Cargo	0.07	1.775×10^{10}
Utilities Employees	56.00	3,125,000
Retail Employees	10.00	17,500,000
Hospital Employees	135.00	1,296,296
Students	9.20	19,021,739
Hospitality Employees And Guests	0.66	265,151,515

** Note: Very likely, the additional water would be used to service a mix of the above potential user types. The table represents the potential capacity if all additional water were to be used by a single user.

Table 5.1b
"Exclusive" Service Capacity Increases
From Additional Supply of "Potable" Water, Phase II

Demand Sector	Baseline Demand Rate (gals. per day)	"Exclusive" Potential Capacity Increase by Addition of 210 mgd (Project Phase I)
Residential Customers	73.10	2,872,777
Hectacres of Agriculture	100.00	2,100,000
Wet Industry Employees	287.00	731,707
Other Manufacturing Employees	172.00	1,220,930
Fabrication & Construction Employees	9.00	23,333,333
Metric Tons of Cargo	0.07	3,000,000,000
Utilities Employees	56.00	3,750,000
Retail Employees	10.00	21,000,000
Hospital Employees	135.00	1,555,555
Students	9.20	22,826,097
Hospitality Employees And Guests	0.66	318,181,818

** Note: Very likely, the additional water would be used to service a mix of the above potential user types. The table represents the potential capacity if all additional water were to be used by a single user.



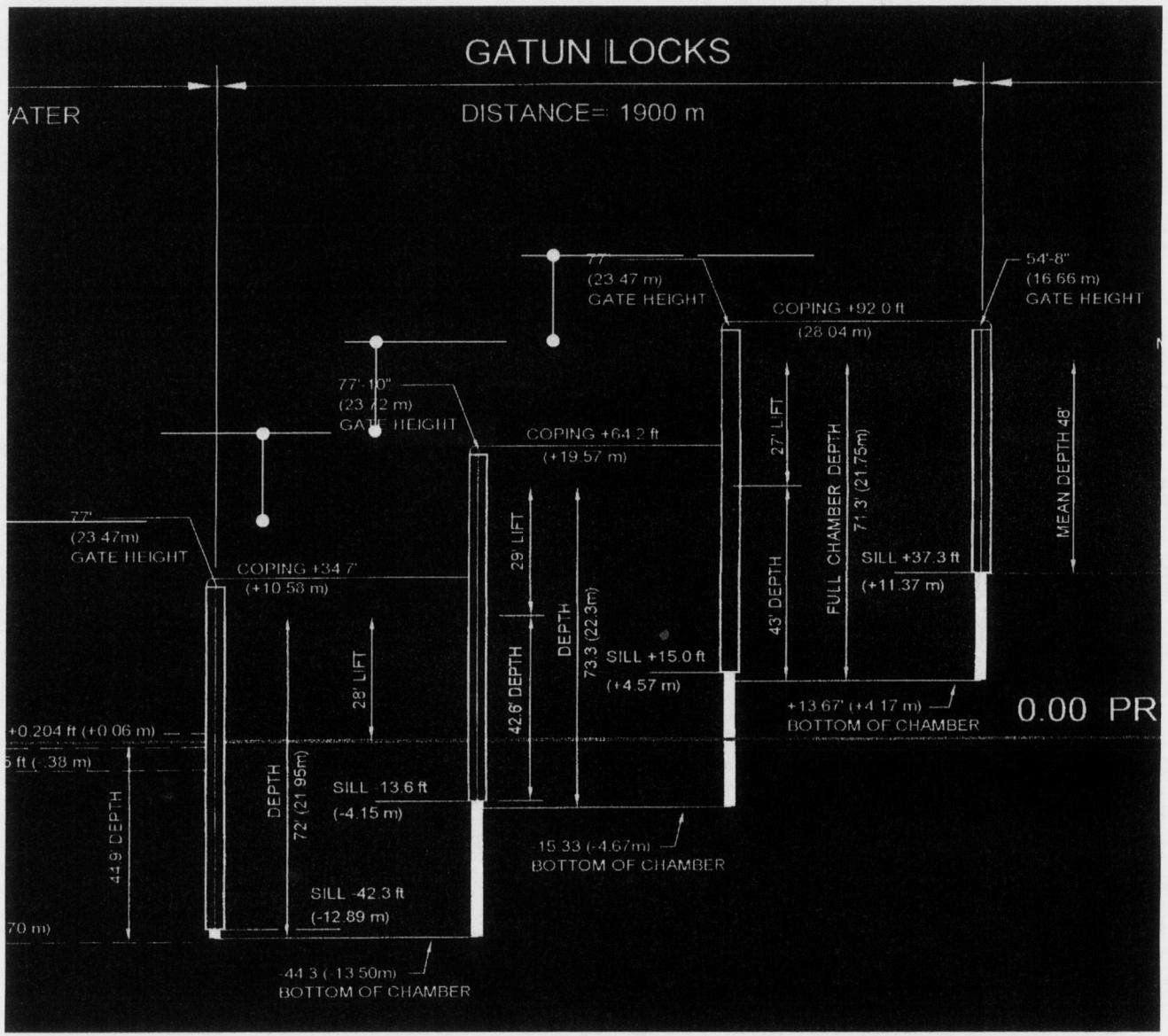
⊗ **Location of Lock Doors**

Proposed Location
"Pit" Turbine Generators
Panama Canal

Wpsi, Inc.
Santa Ana, CA 92705

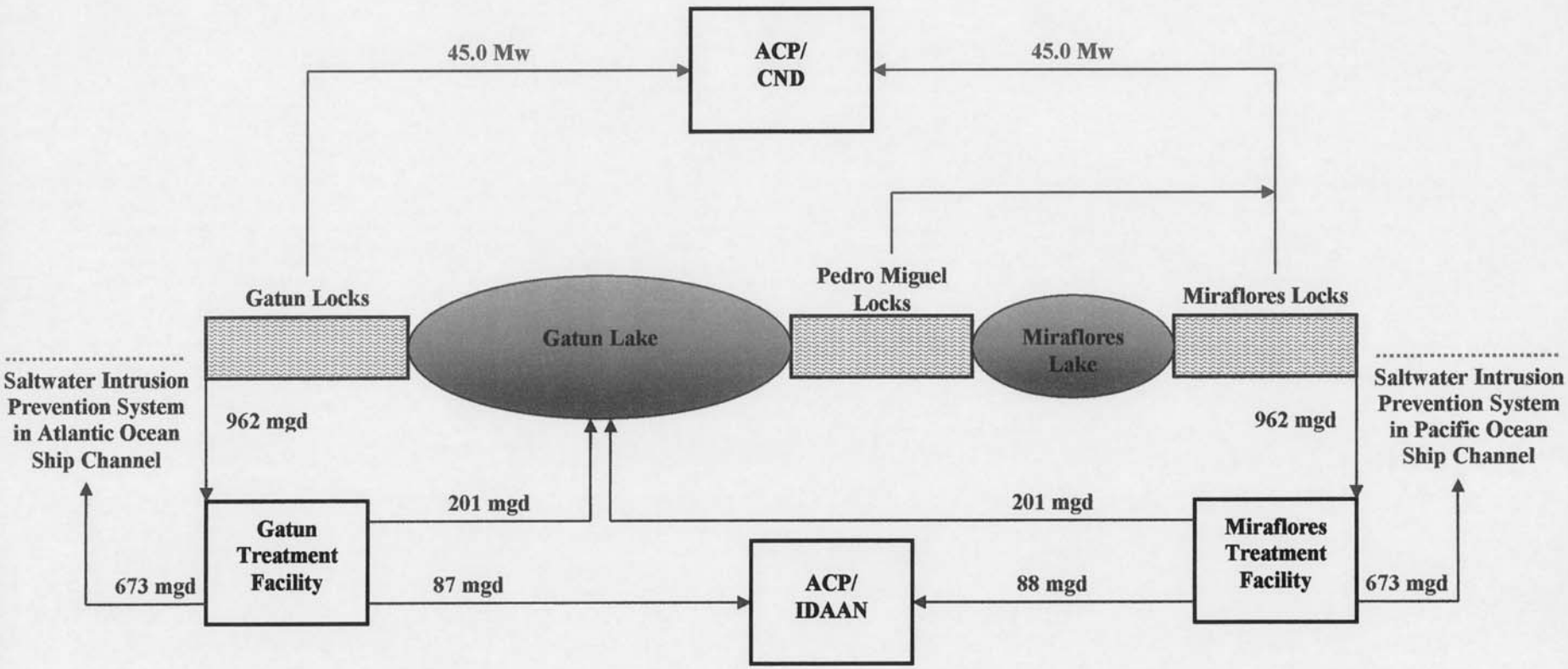
04-02

PLATE
3.2.1e



From APC drawings

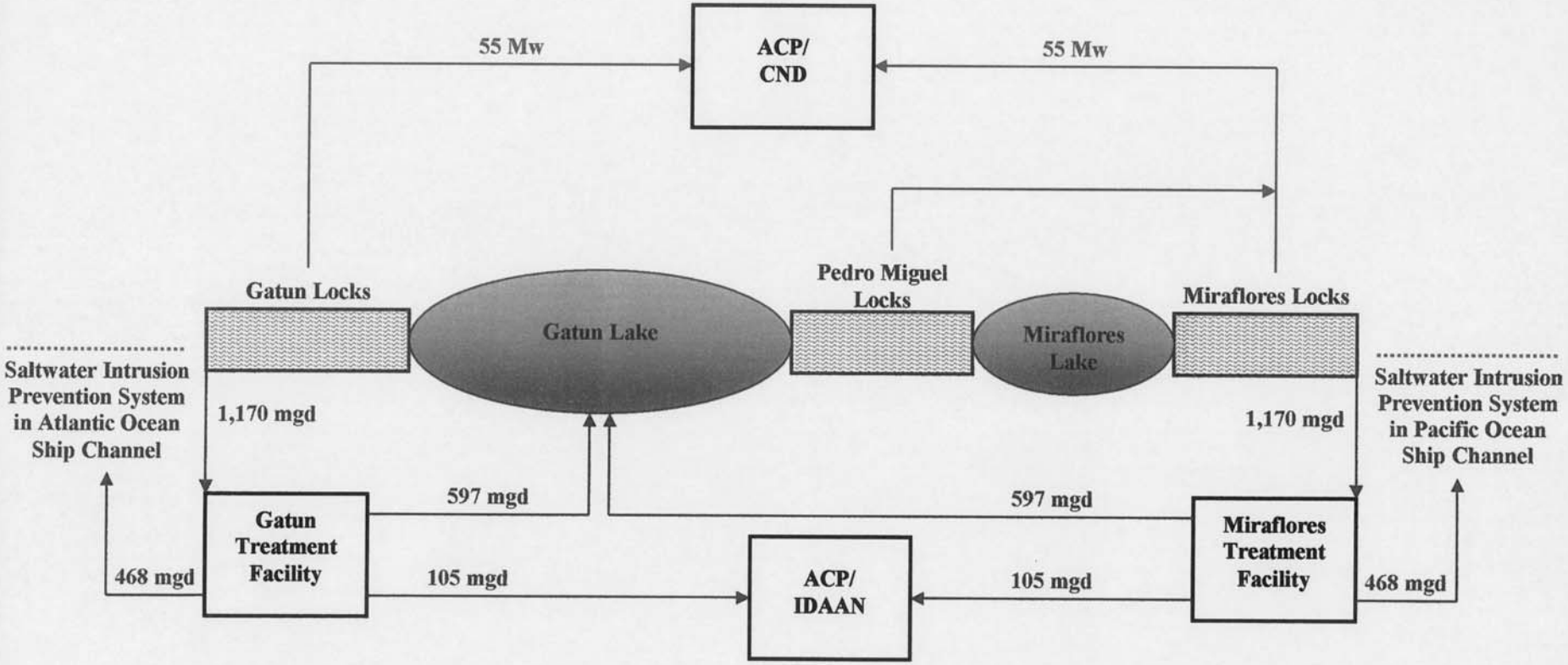
Hydraulic Energy Potential, Panama Canal		
Wpsi, Inc. Santa Ana, CA 92705	04-15	PLATE 3.2.1d



Notes:
ACP – Panama Canal Authority
CND – National Central Dispatch (electricity grid operator)
IDAAN – National Water Authority
LPY – Lockages per year

Phase I
Proposed Project Development Concept

Wpsi, Inc. Santa Ana, CA 92705	12-01 (rev 04-02)	PLATE **1.3a**



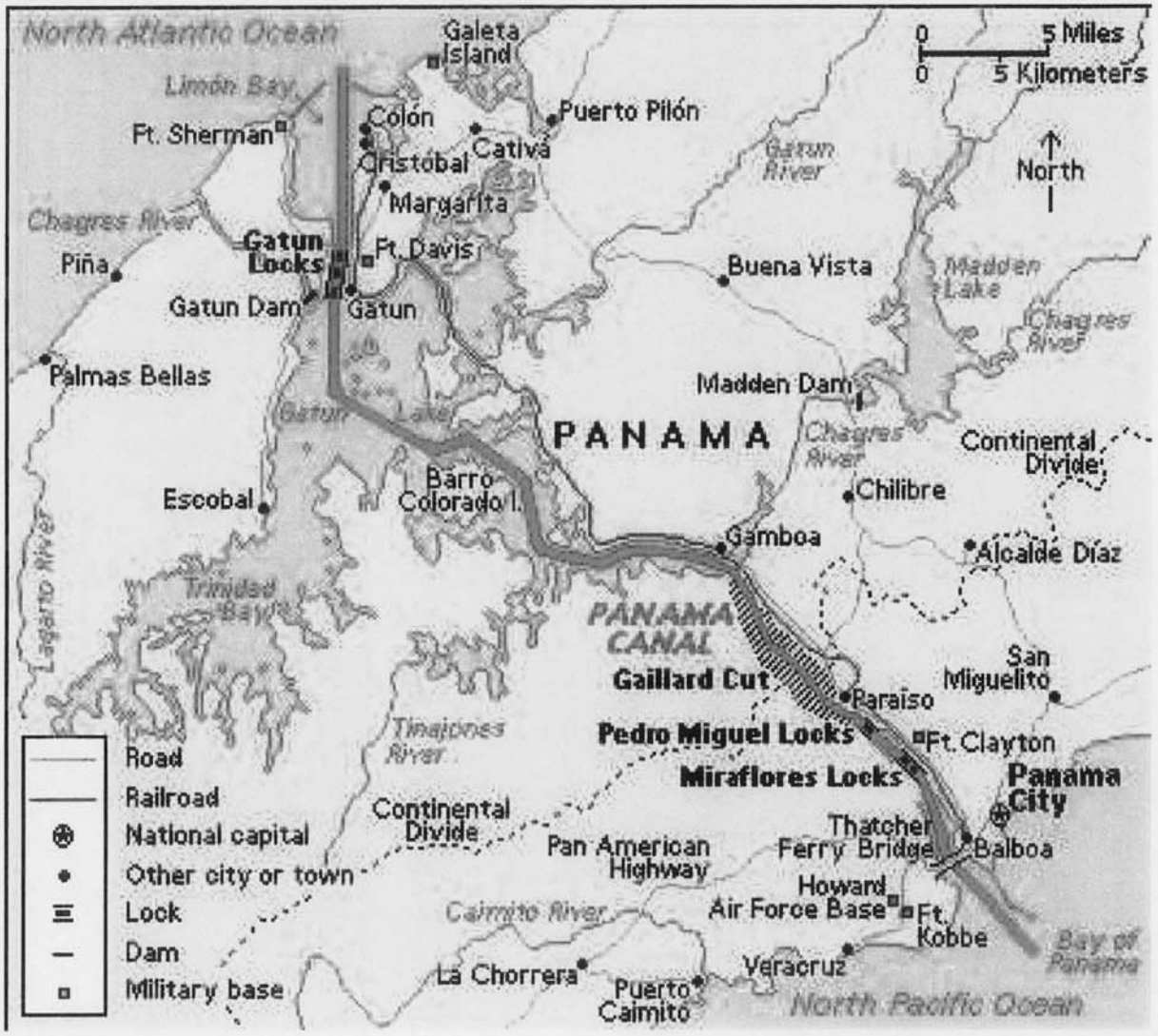
Notes:
ACP – Panama Canal Authority
CND – National Central Dispatch (electricity grid operator)
IDAAN – National Water Authority
LPY – Lockages per year

Phase II
Proposed Project Development Concept

Wpsi, Inc.
Santa Ana, CA 92705

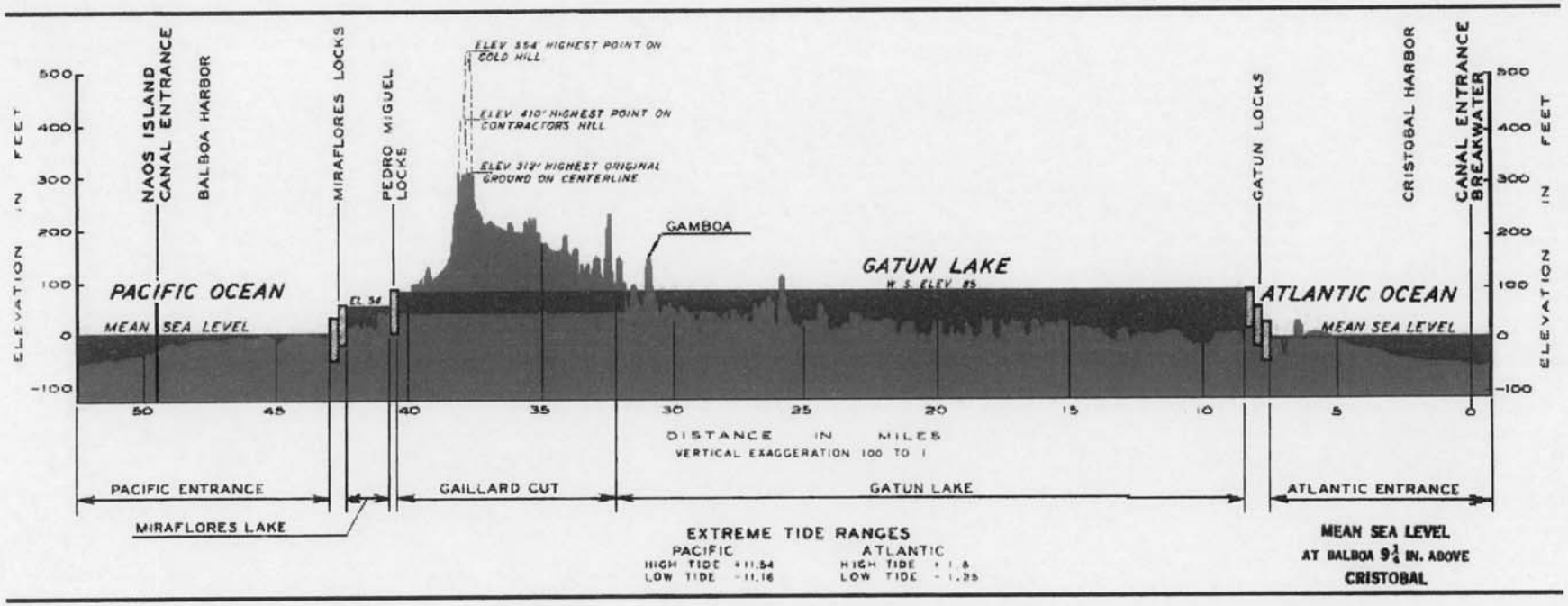
12-01
rev 04-02

PLATE
1.3b



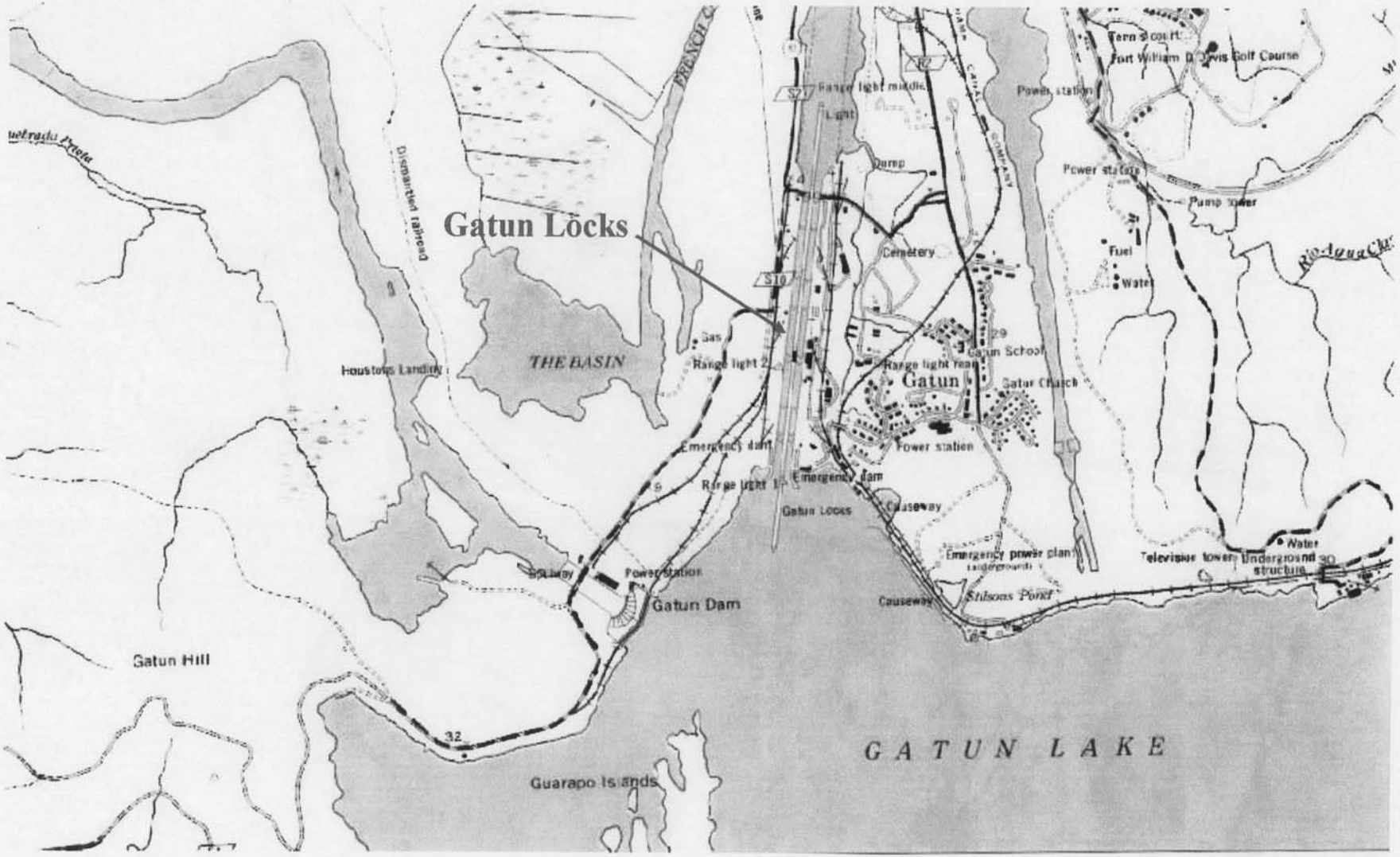
Panama Canal and Canal Lock System

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **2.1a**



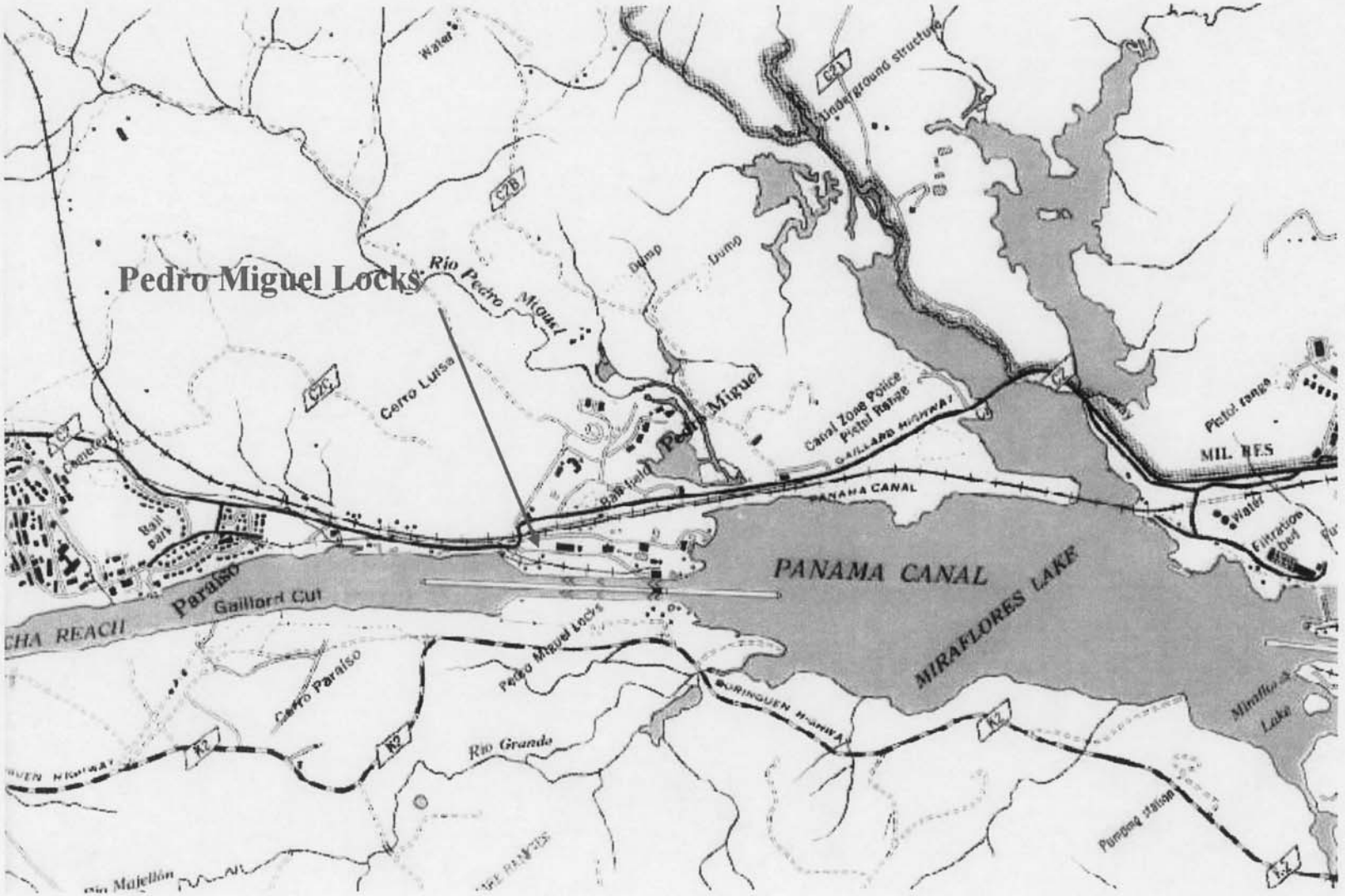
PROFILE OF THE PANAMA CANAL

Panama Canal Cross Section and Elevation		
Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **2.1b**



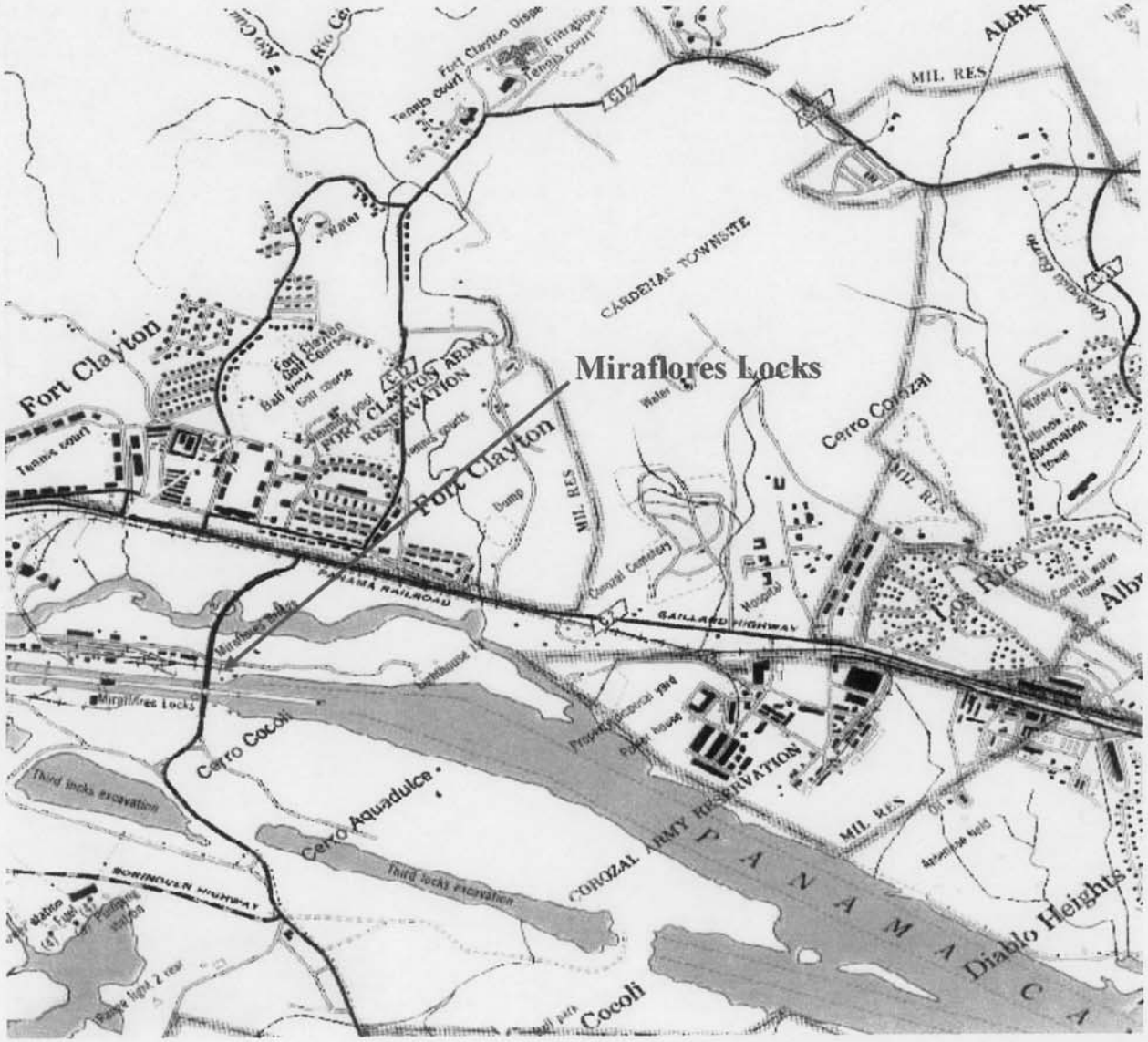
Gatun Locks, Panama Canal

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **2.1c**



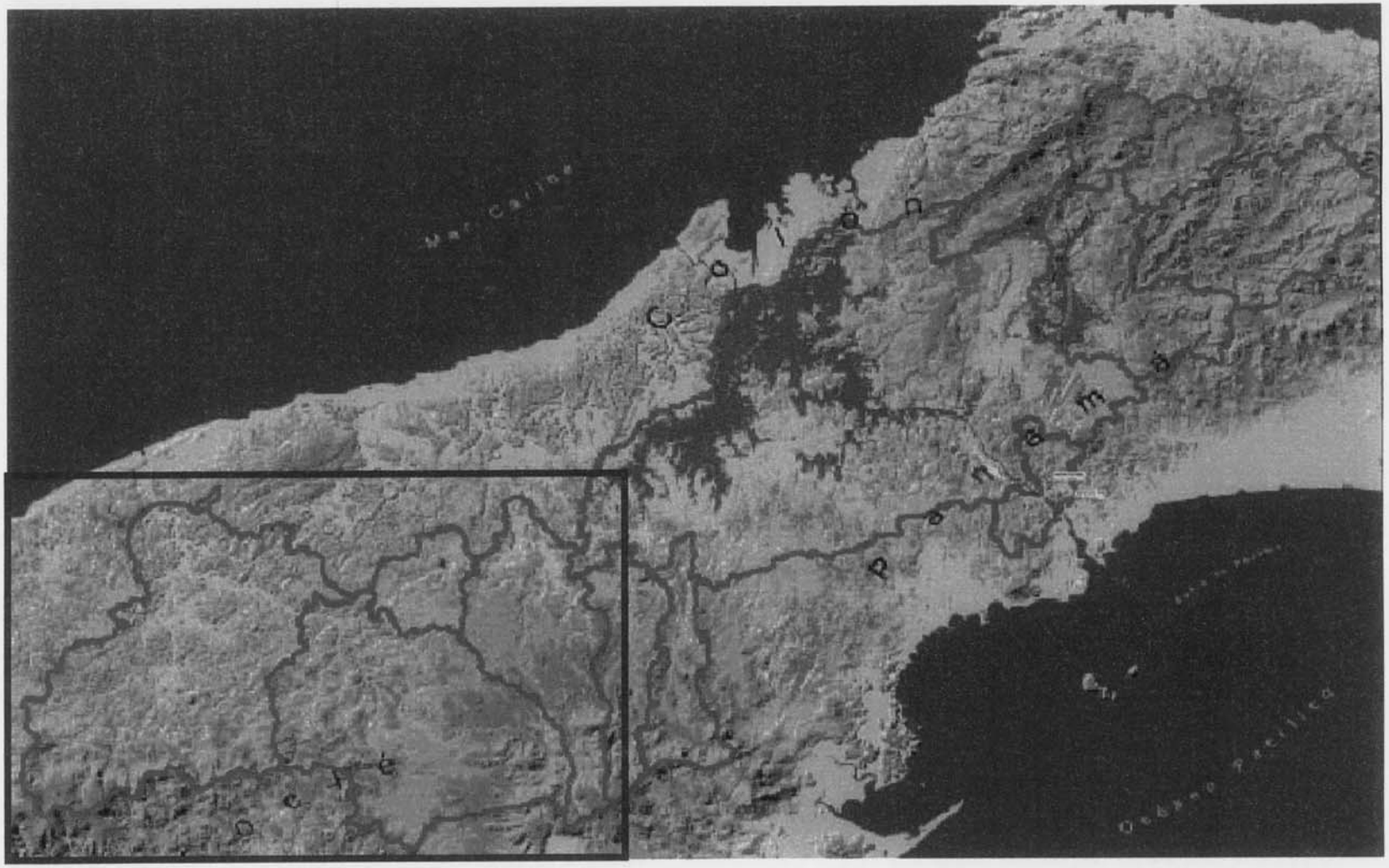
Pedro Miguel Locks, Panama Canal

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **2.1d**



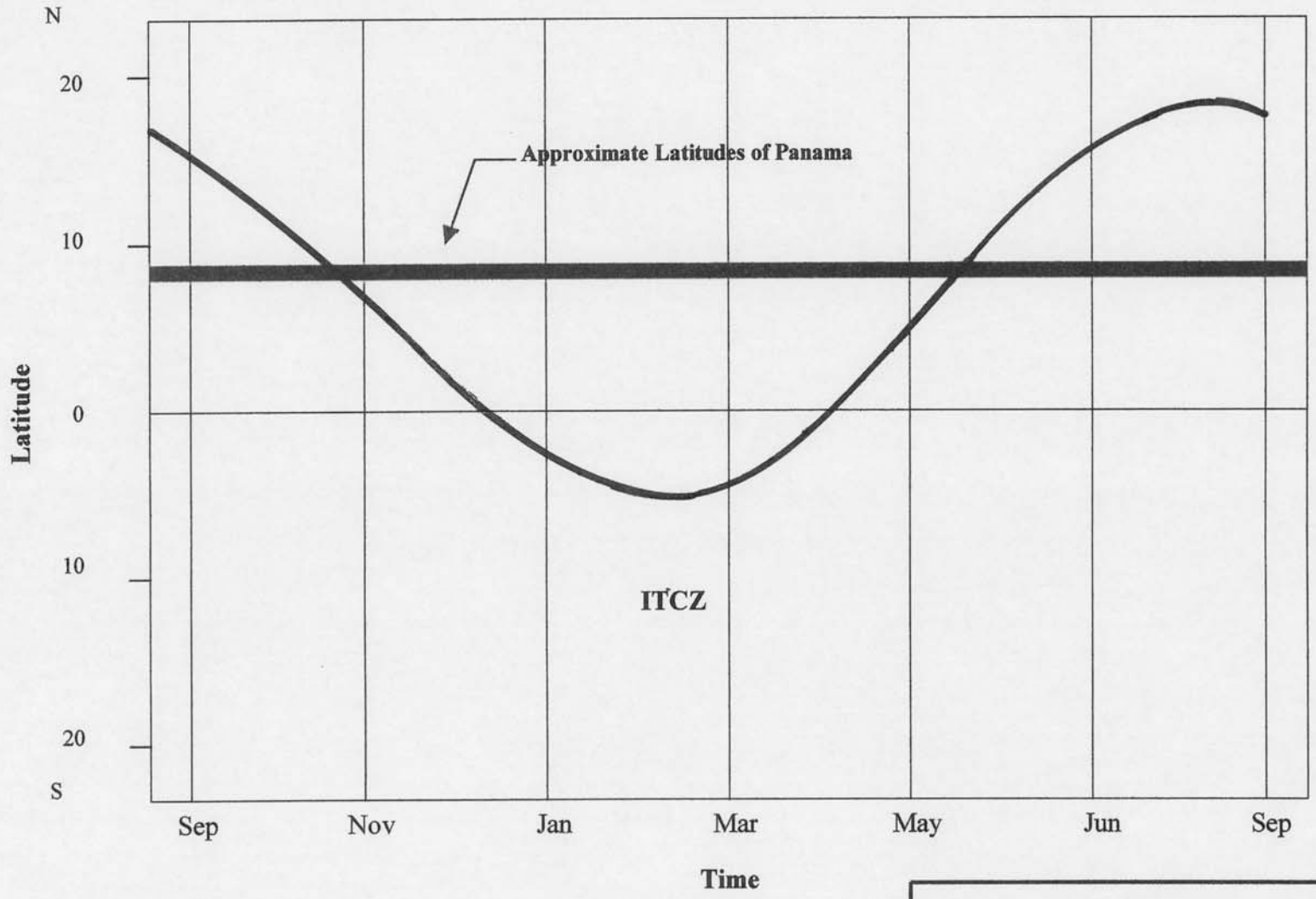
Miraflores Locks, Panama Canal

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **2.1e**



Occidental Watershed Region

Occidental Watershed, Panama Canal		
Wpsi, Inc. Santa Ana, CA 92705	04-02	PLATE **2.1f**

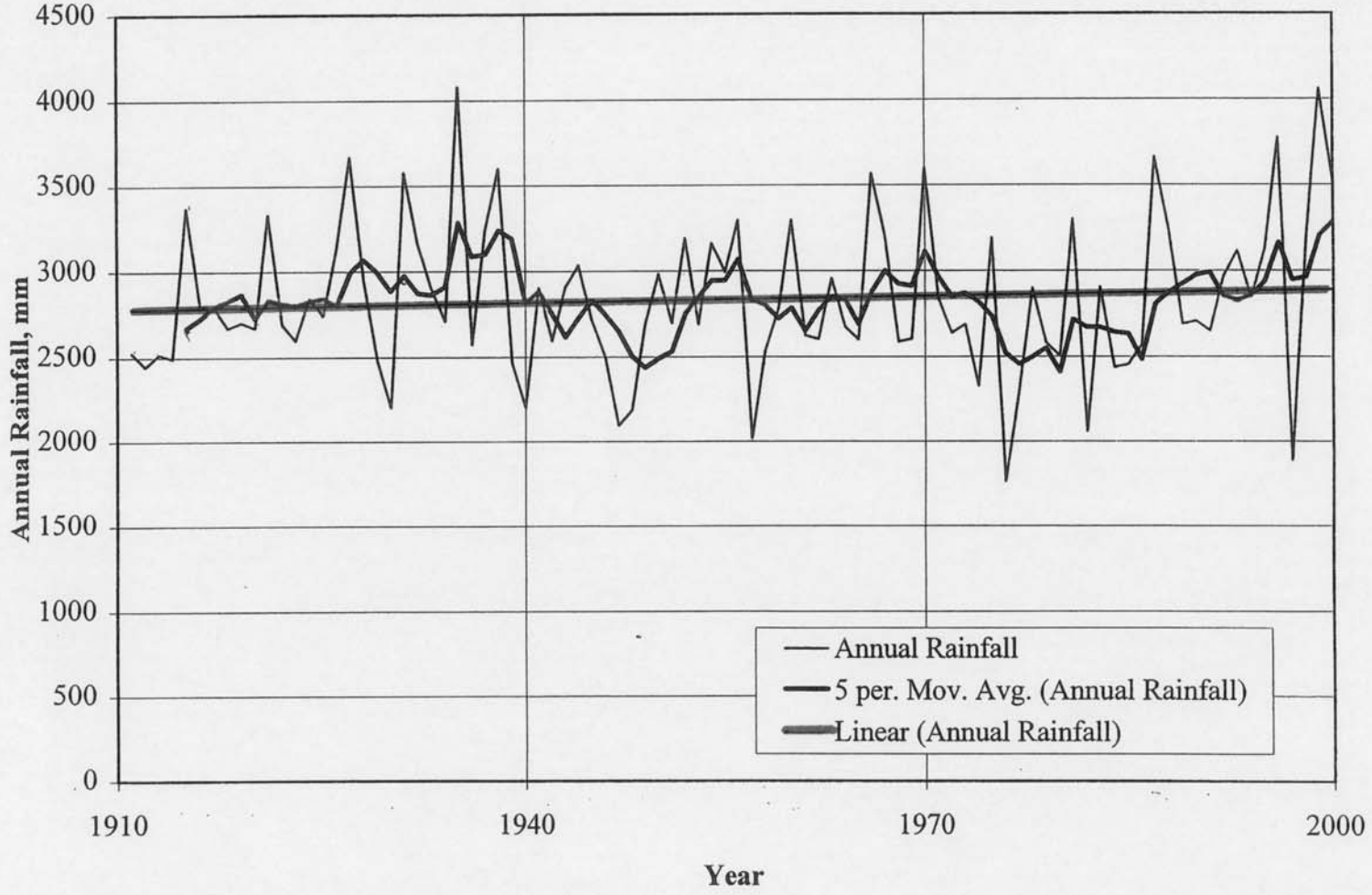


Annual Position of ITCZ

Wpsi, Inc.
Santa Ana, CA 92705

12-01

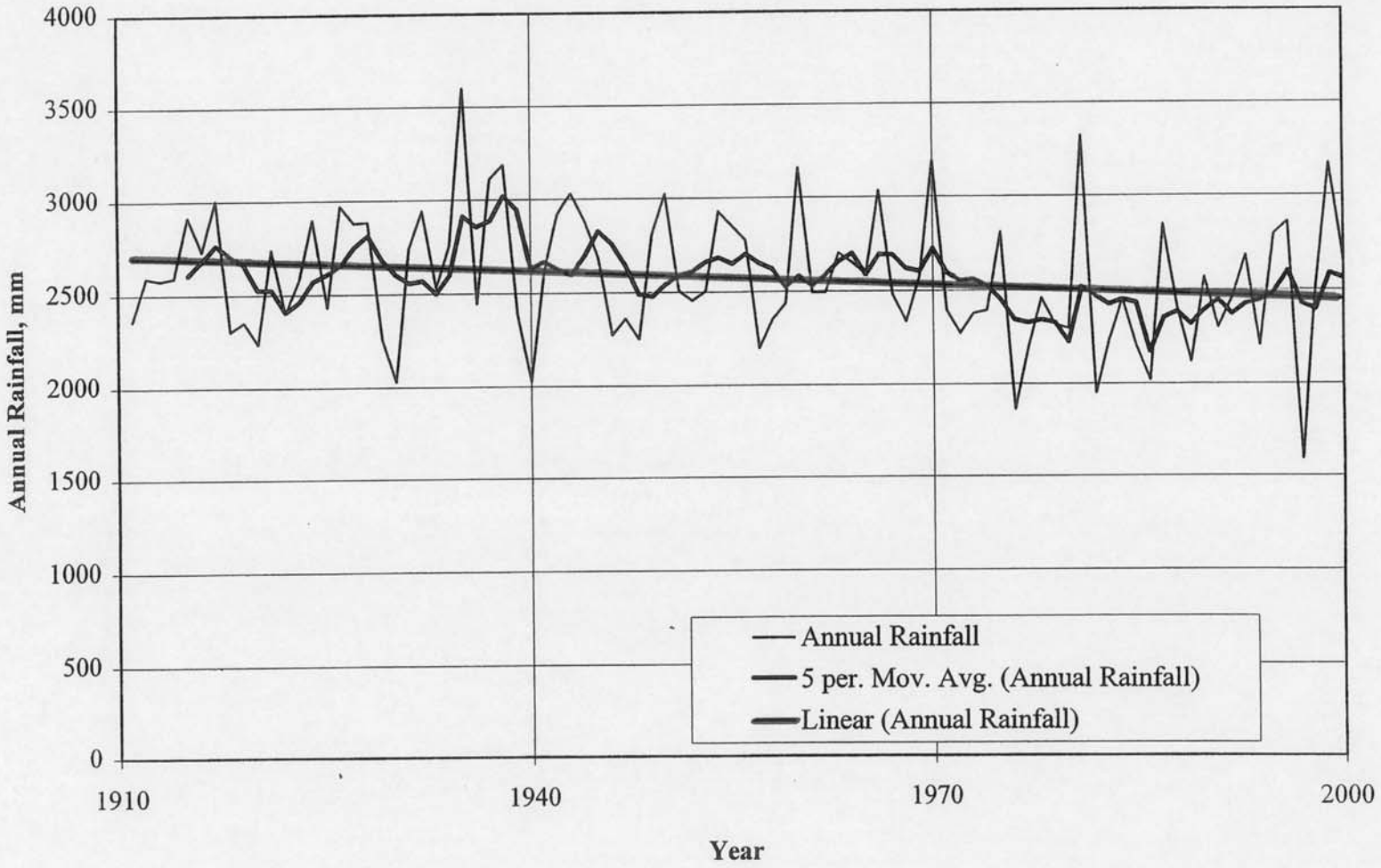
PLATE 2.5



Data and chart prepared by Montgomery Watson Harza

Madden Lake – Upstream
Annual Basin Average Rainfall

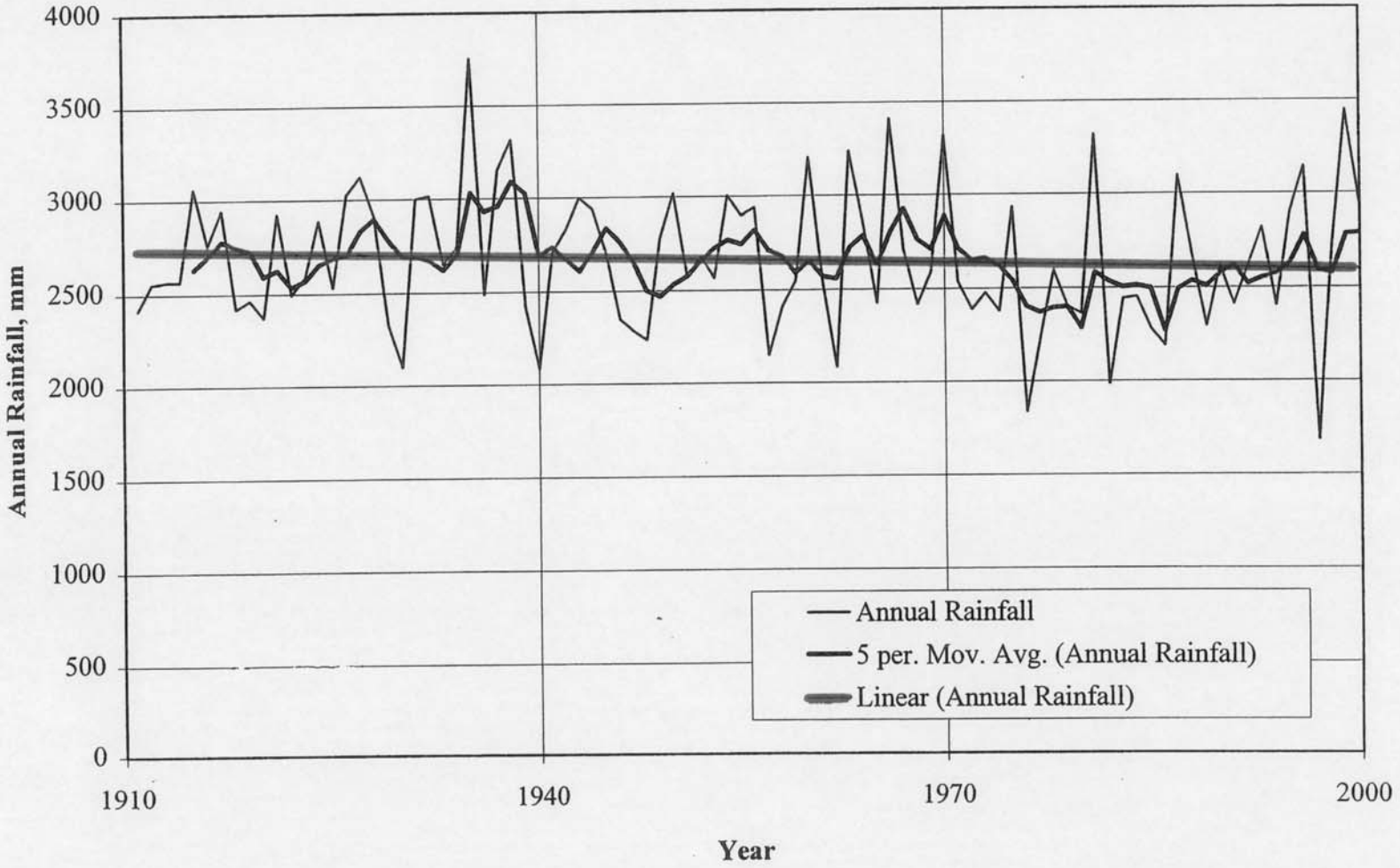
Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE 2.5.2a



Data and chart prepared by Montgomery Watson Harza

Gatun Lake - Downstream
Annual Basin Average Rainfall

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **2.5.2b**



Data and chart prepared by Montgomery Watson Harza

Gatun Total
Annual Basin Average Rainfall

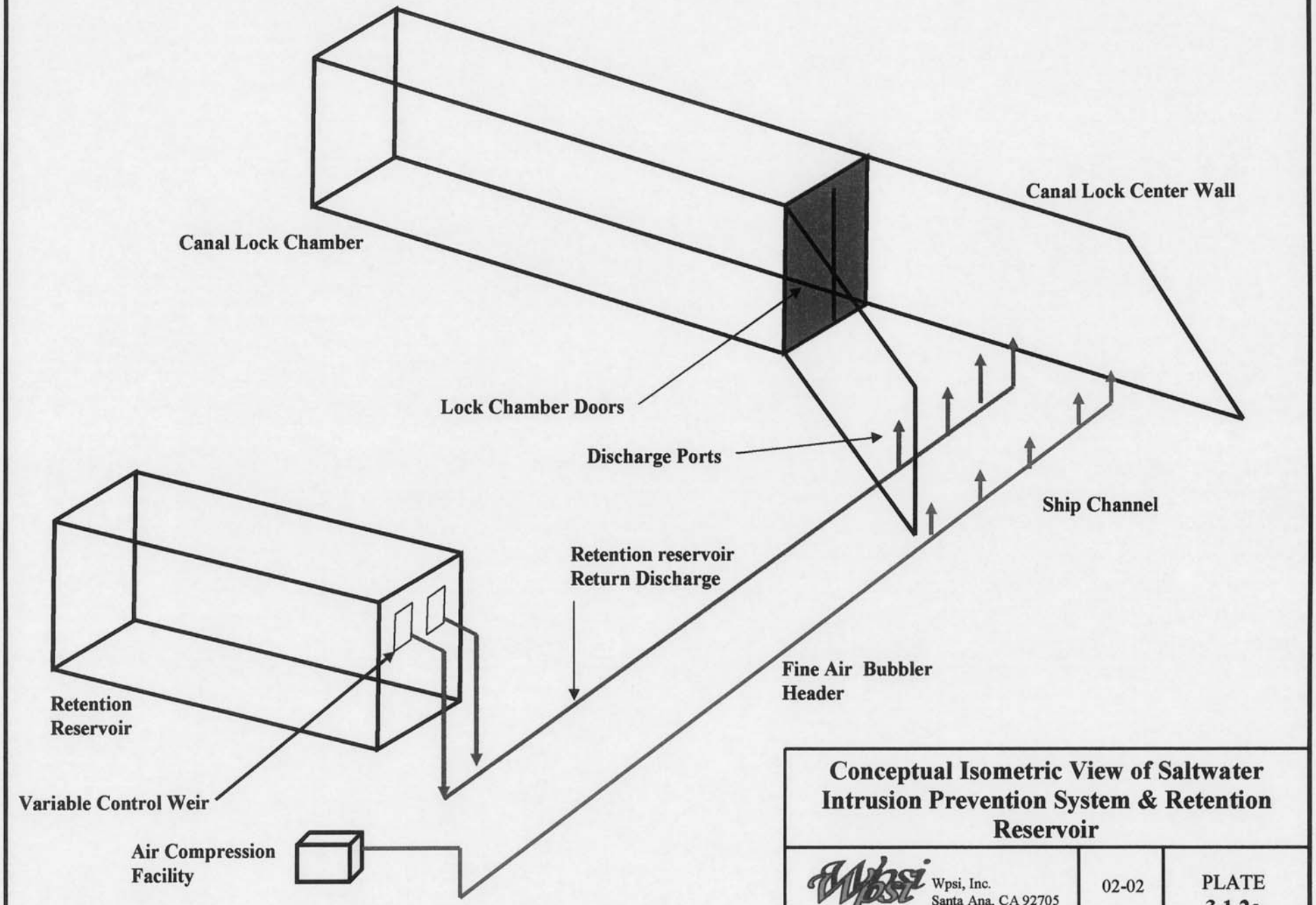
Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE 2.5.2c

Electric Power System
Republic of Panama

Wpsi, Inc.
Santa Ana, CA 92705

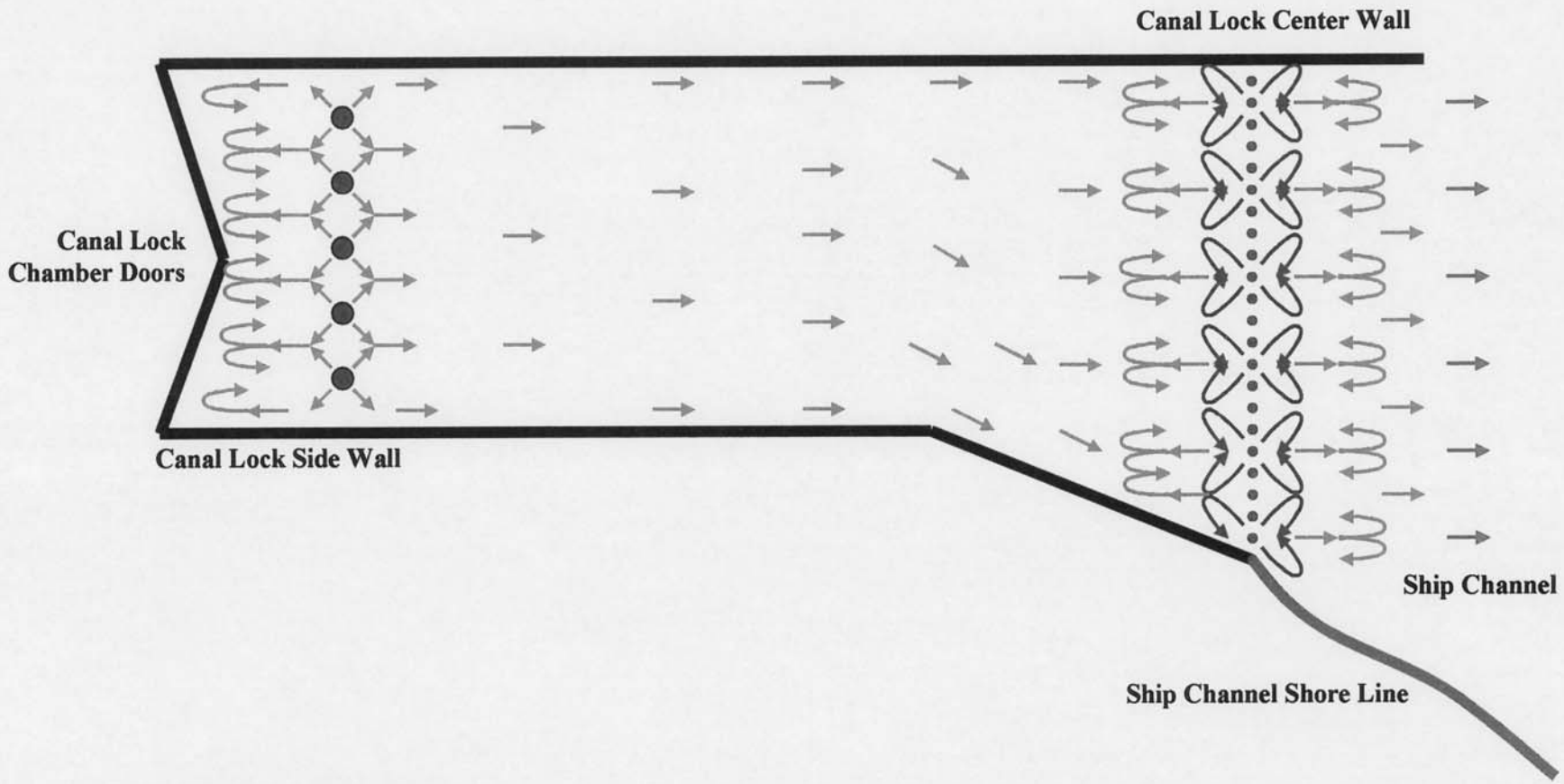
12-01

PLATE
2.6.1



Conceptual Isometric View of Saltwater Intrusion Prevention System & Retention Reservoir

Wpsi, Inc. Santa Ana, CA 92705	02-02	PLATE **3.1.2a**



Lock Water Return Discharge Ports

Fine Air Bubbler (pneumatic wall)

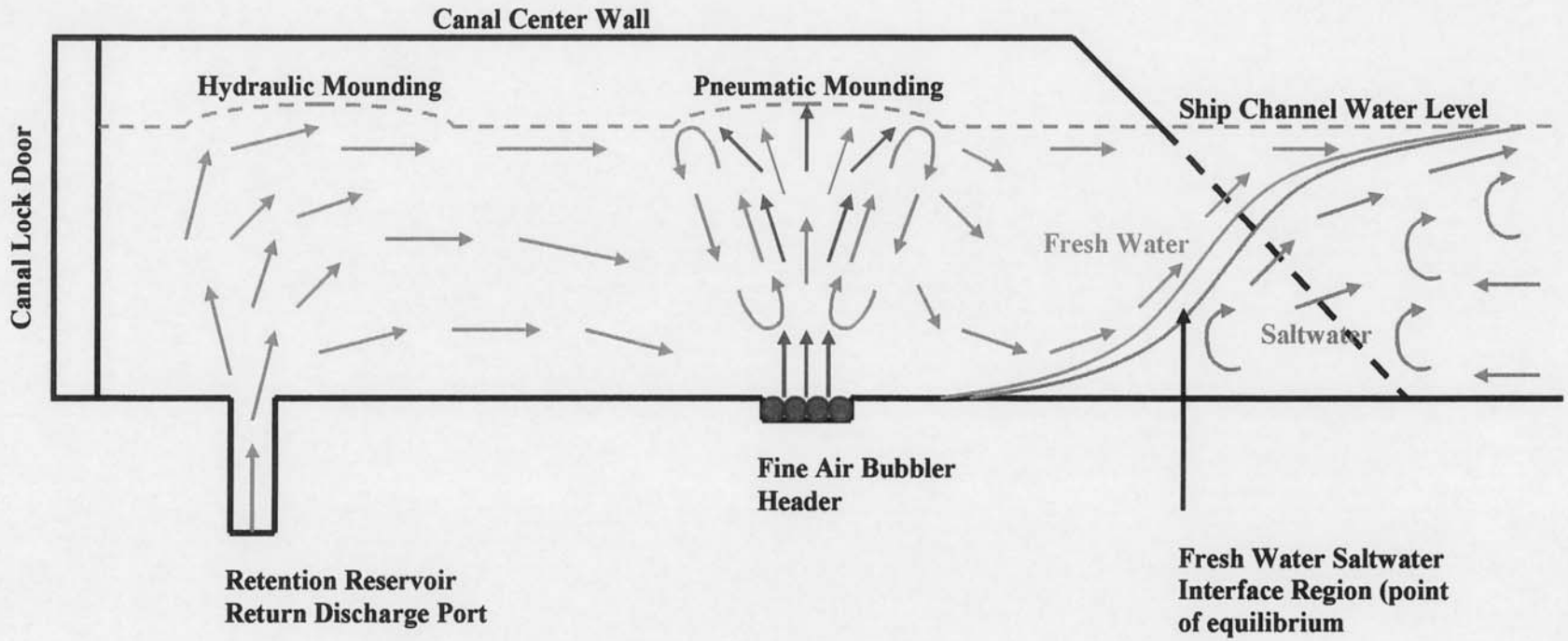
Conceptual Flow of Water

Conceptual Flow of Air

Conceptual Flow of Saltwater

Conceptual Plan View
Saltwater Intrusion Prevention System

Wpsi, Inc. Santa Ana, CA 92705	02-02	PLATE **3.1.2b**



Conceptual Water Flow

Conceptual Air Flow

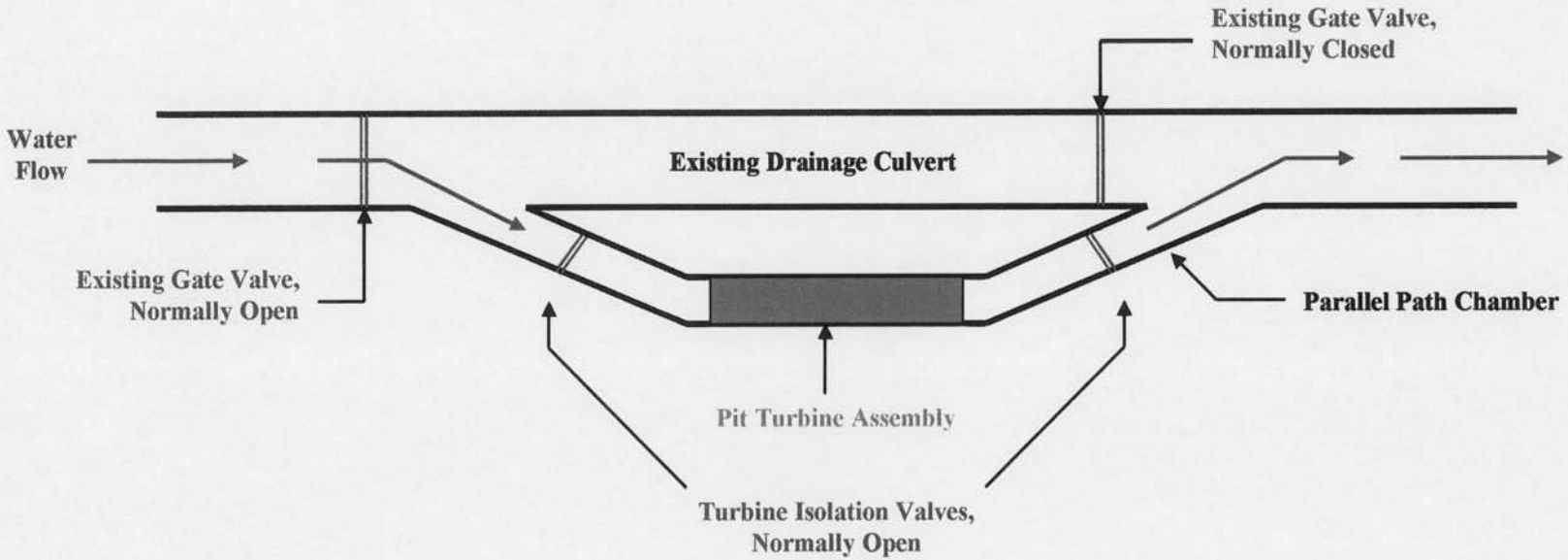
Conceptual Cross Section View
Saltwater Intrusion Prevention System

Wpsi, Inc. Santa Ana, CA 92705	02-02	PLATE 3.1.2c

Plan View, Side Wall Culverts

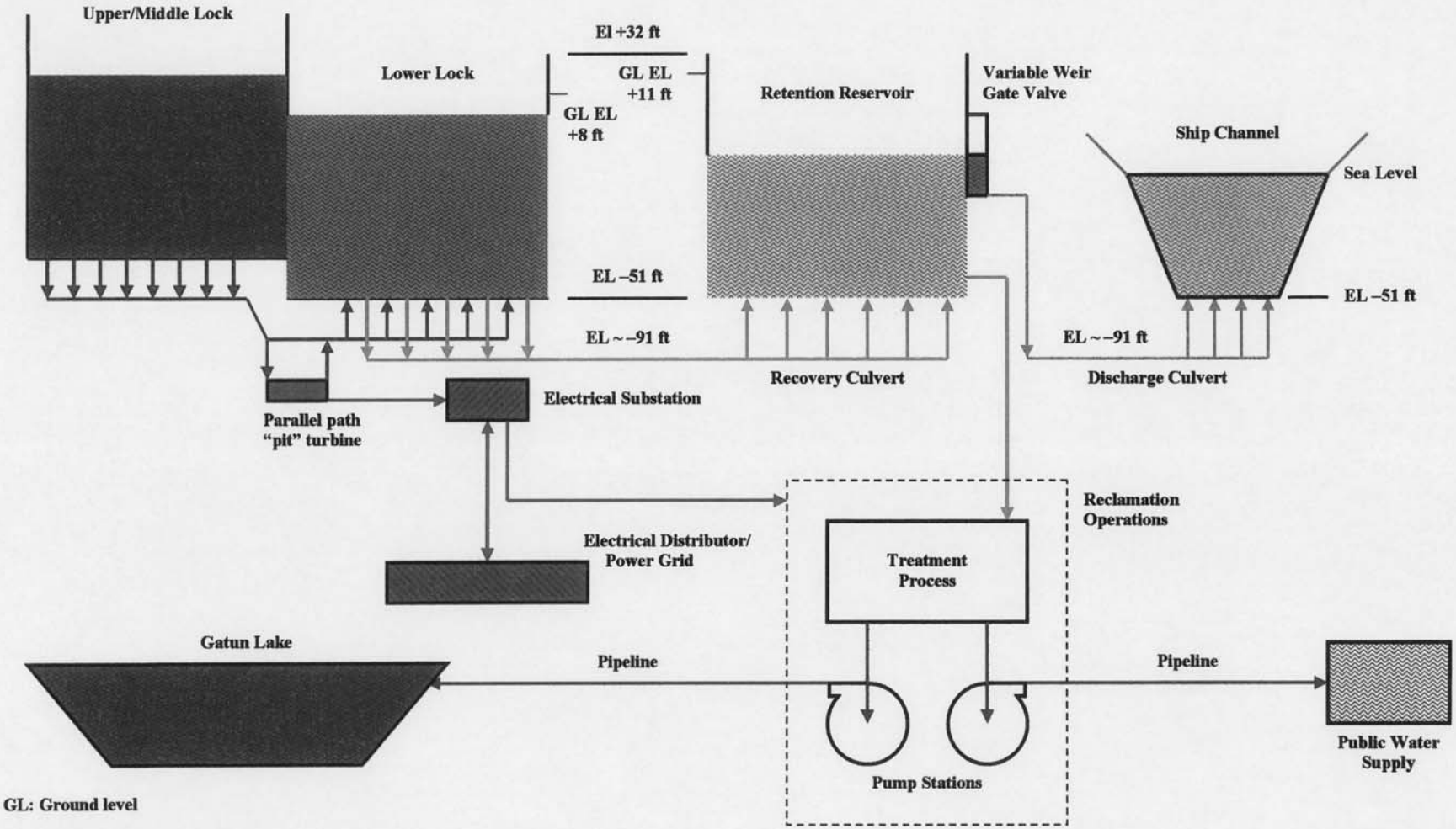
And

Elevation View, Center Wall Culvert



Parallel Path Hydroelectric "Pit" Turbine Installation Diagram, Panama Canal

Wpsi, Inc. Santa Ana, CA 92705	04-02	PLATE **3.1.6**



GL: Ground level

EL: Elevation (datum is sea level)

→ Drainage from upper to lower lock through existing 18 ft. dia. culvert

→ Drainage from lower lock to retention reservoir through new reservoir inlet culvert

→ Discharge from retention reservoir to ship channel through new discharge culvert

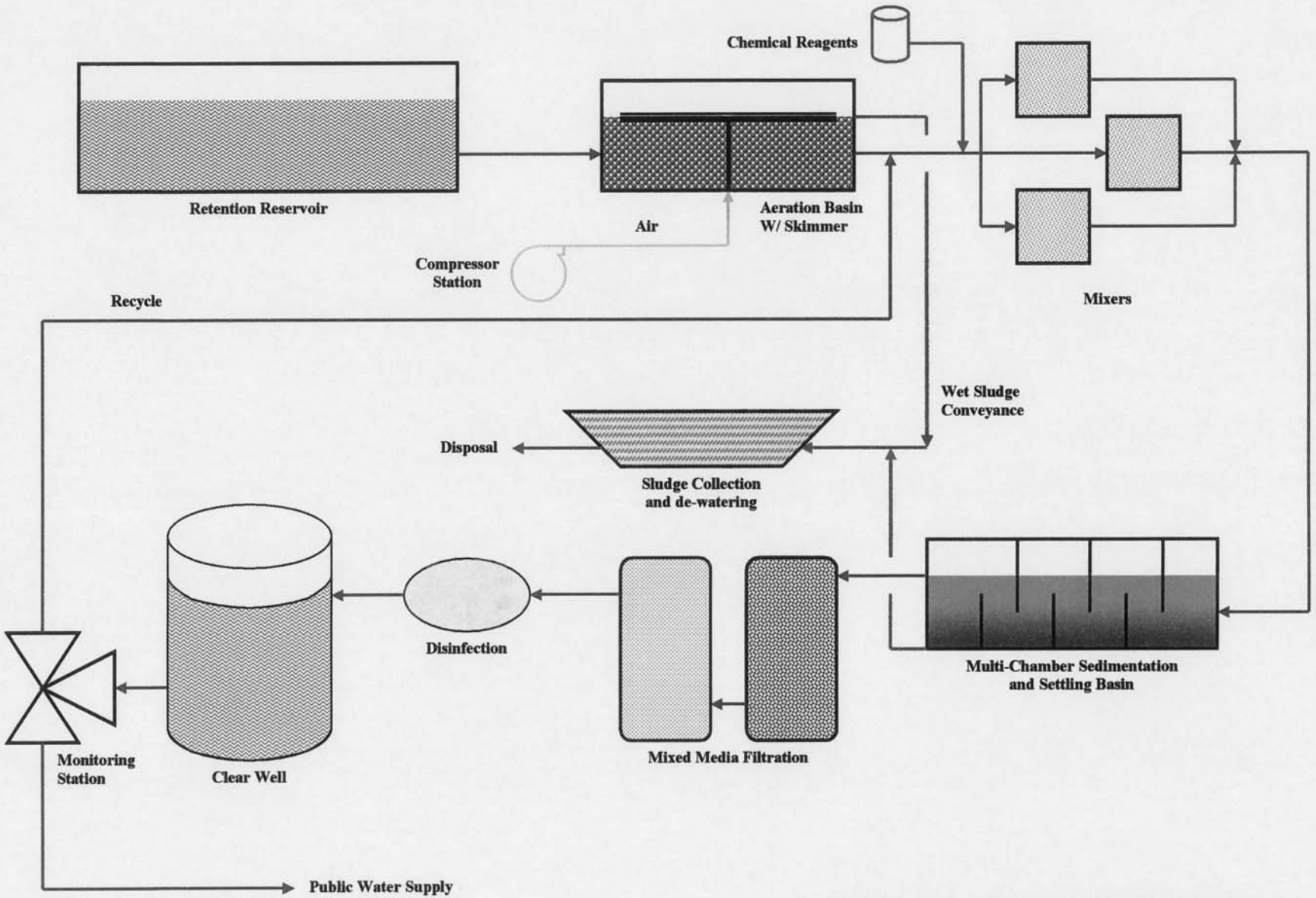
→ Flow of electrical power

Process Diagram, Alternative 1
Panama Canal Lock Water Reclamation Project

Wpsi, Inc.
Santa Ana, CA 92705

04-15

PLATE
3.2.1a

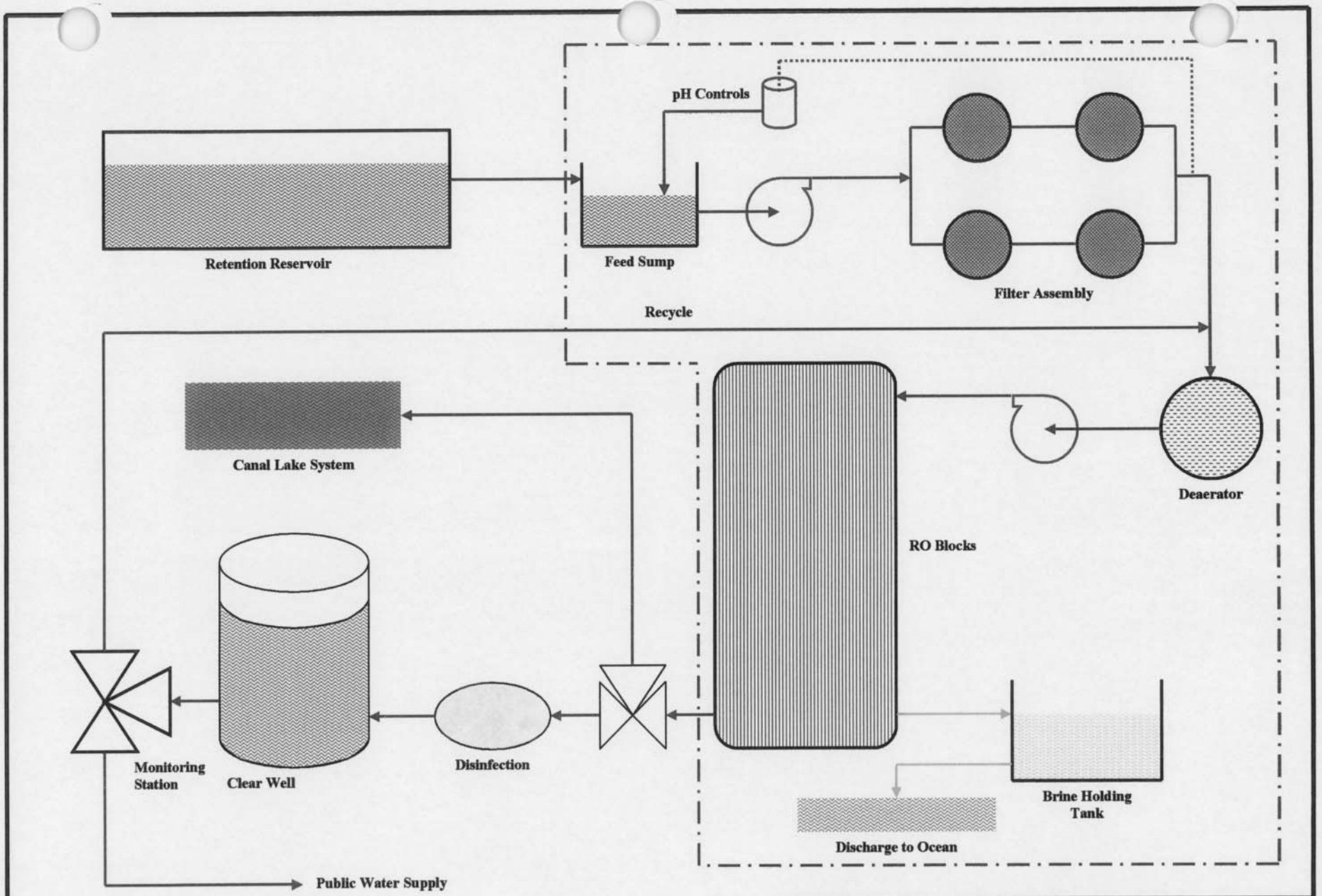


Process Diagram
Second Level of Water Treatment

Wpsi, Inc.
Santa Ana, CA 92705

04-15

PLATE
3.2.1b

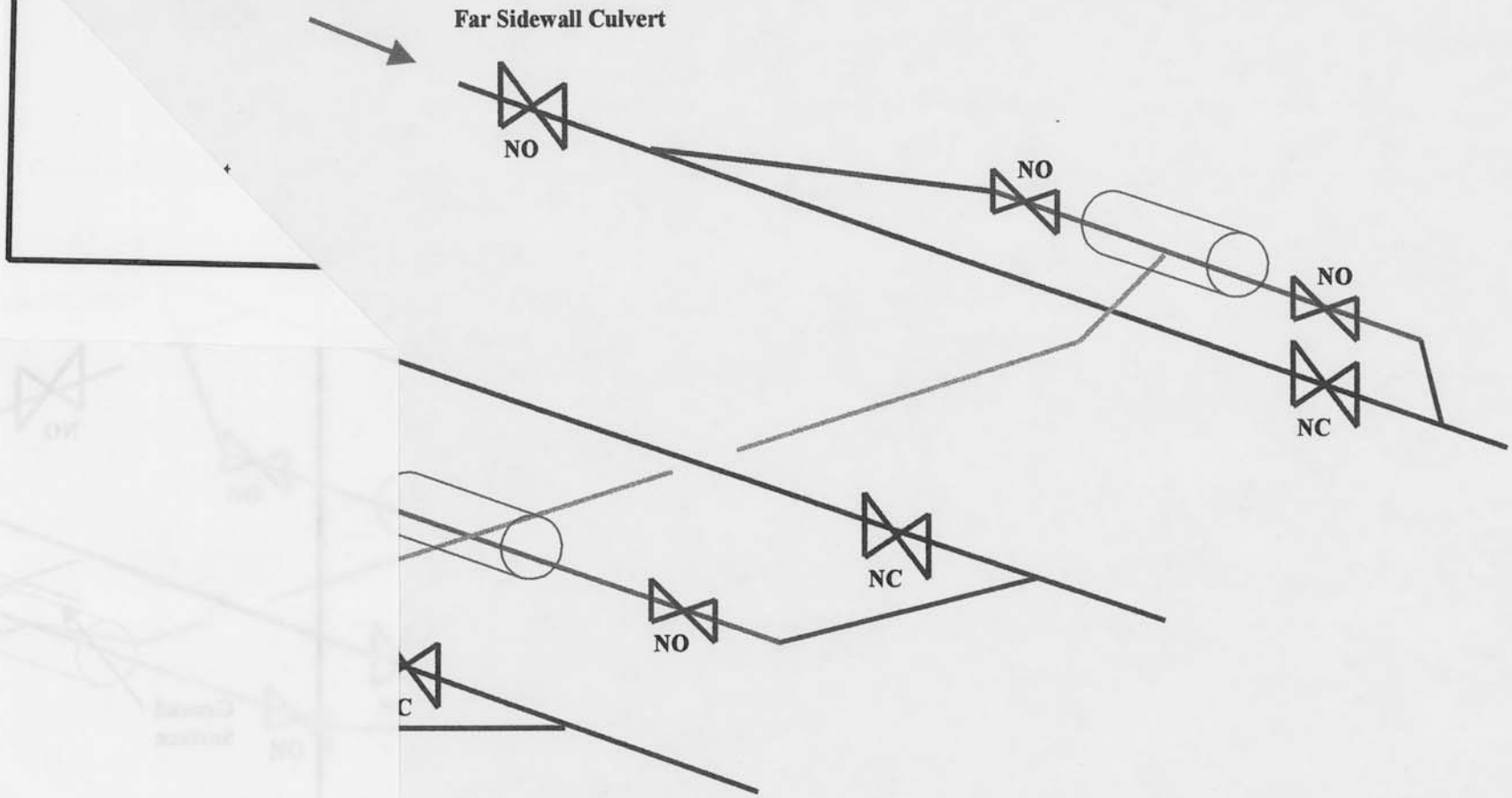


Process Diagram
Desalinization Plant

Wpsi, Inc.
Santa Ana, CA 92705

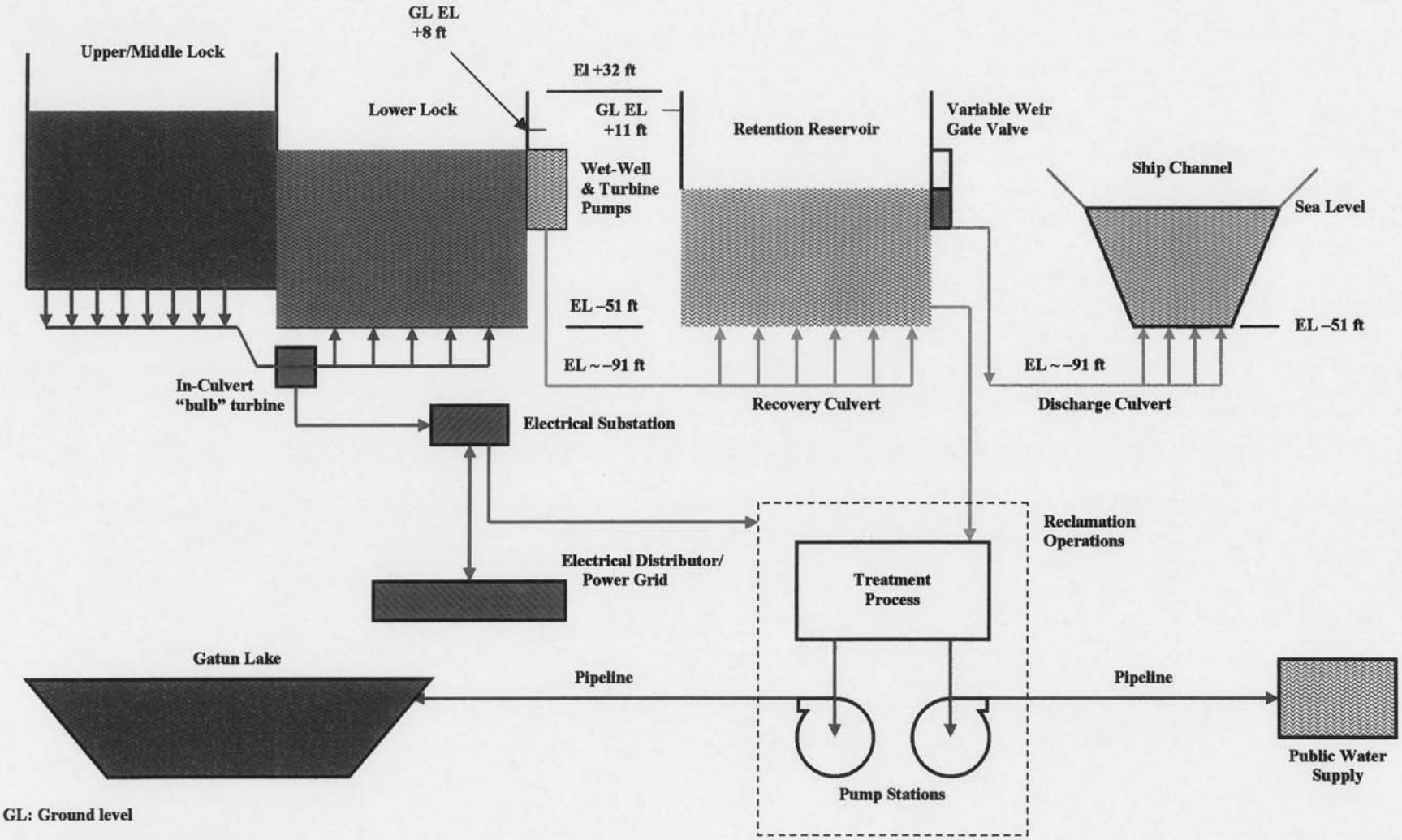
04-15

PLATE
3.2.1c



Configuration Diagram
Parallel Path Hydroelectric "Pit" Turbines
Panama Canal

Wpsi, Inc. Santa Ana, CA 92705	04-02	PLATE **3.2.1f**



GL: Ground level

EL: Elevation (datum is sea level)

→ Drainage from upper to lower lock through existing 18 ft. dia. culvert

→ Drainage from lower lock to retention reservoir through new reservoir inlet culvert

→ Discharge from retention reservoir to ship channel through new discharge culvert

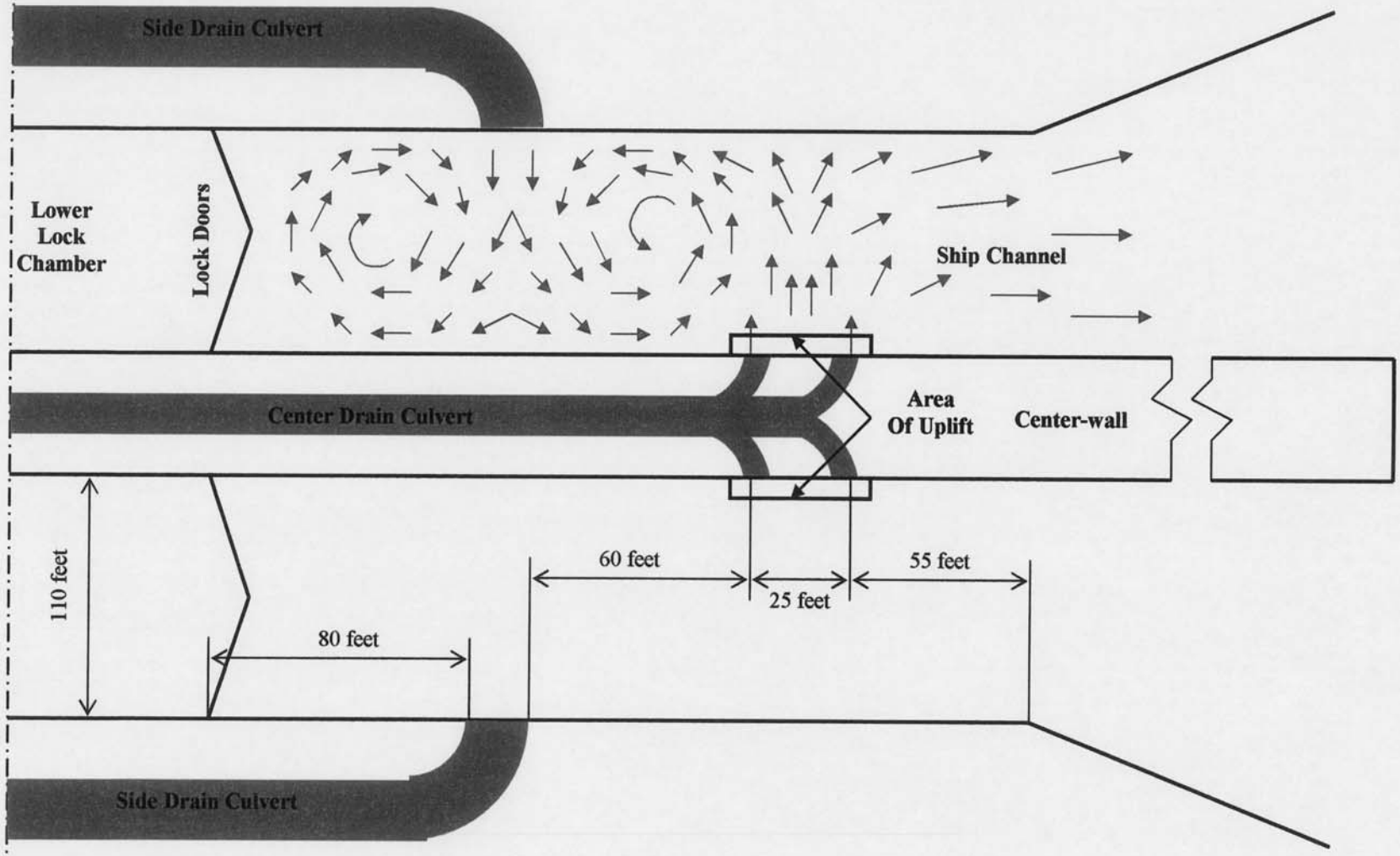
→ Flow of electrical power

Process Diagram, Alternatives 2 & 3
Panama Canal Lock Water Reclamation Project

Wpsi, Inc.
Santa Ana, CA 92705

04-15

PLATE
3.2.2



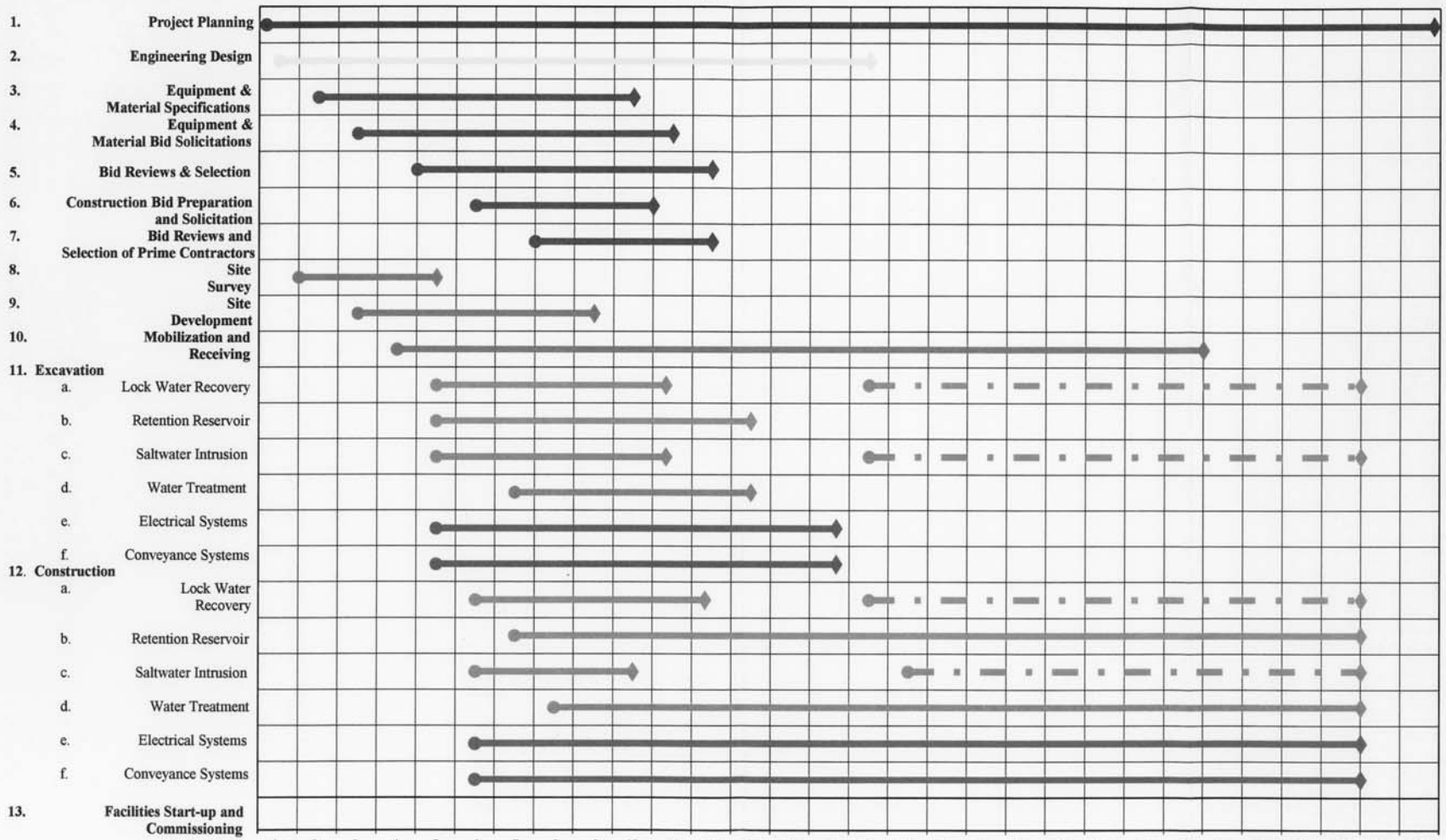
Current Exit Lock Chamber Discharge Flow Patterns From Side and Center-wall Discharge Ports

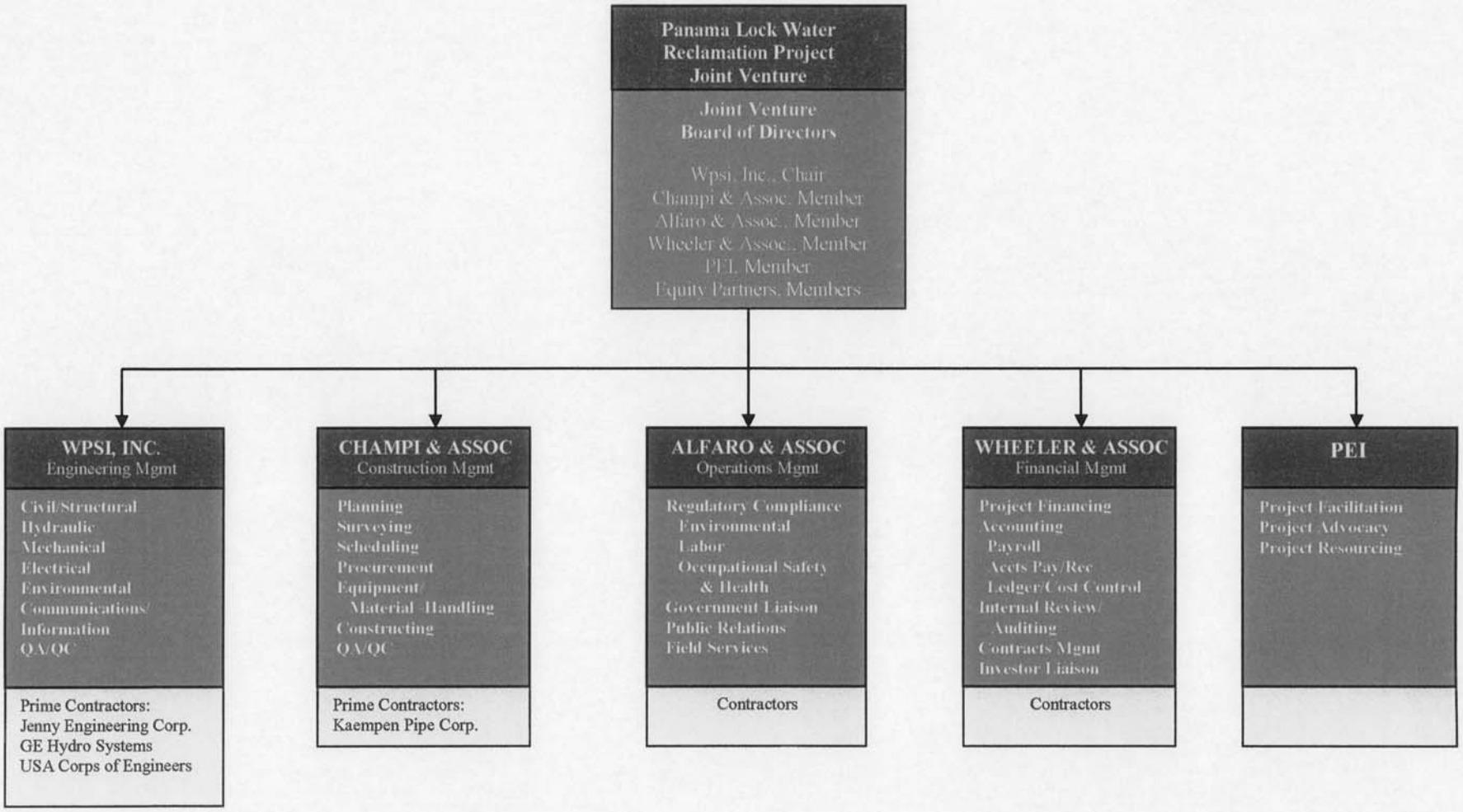
Wpsi, Inc.
Santa Ana, CA 92705

04-02

PLATE
3.5.2a

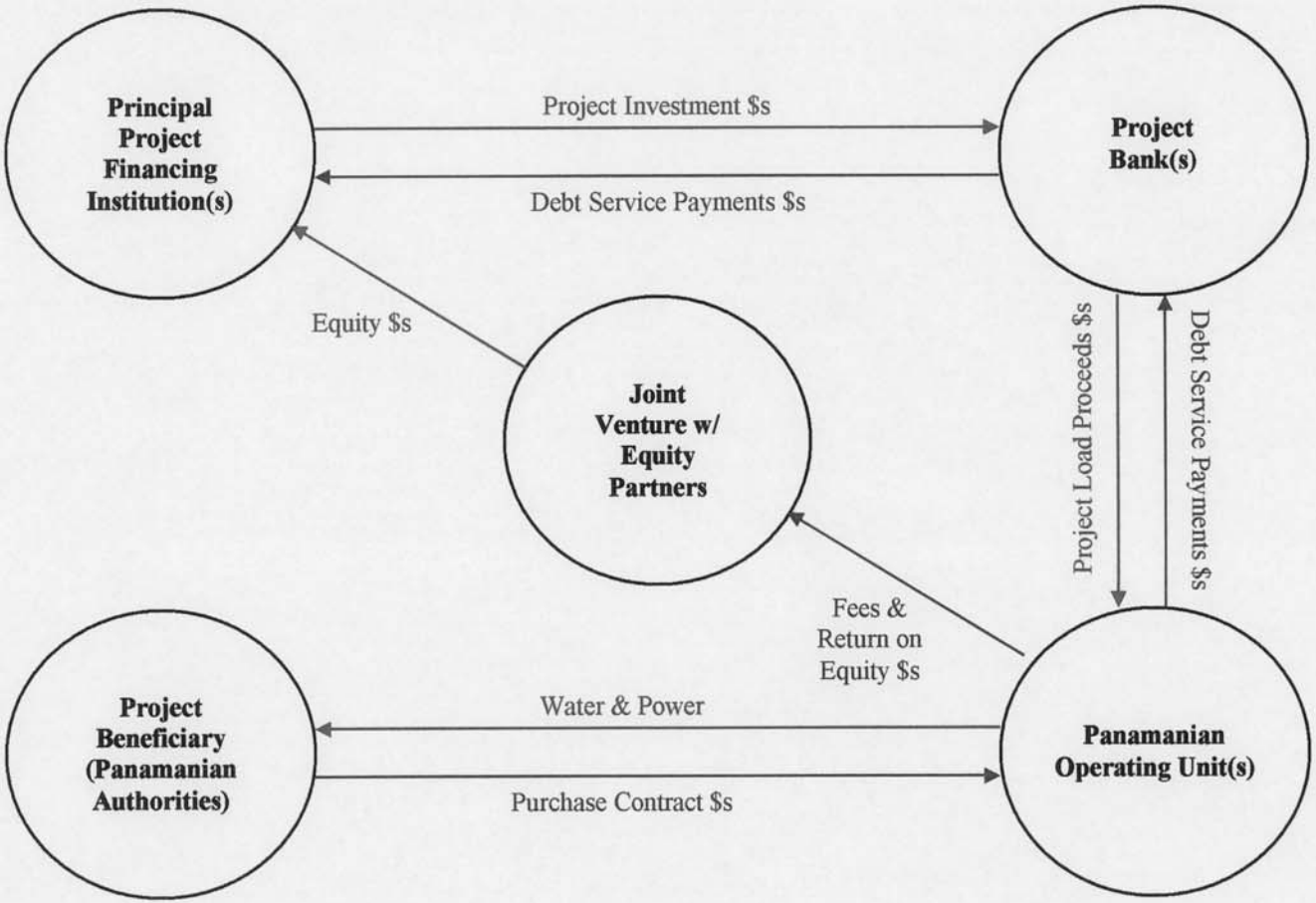
Plate 3.5.2b, Project Schedule





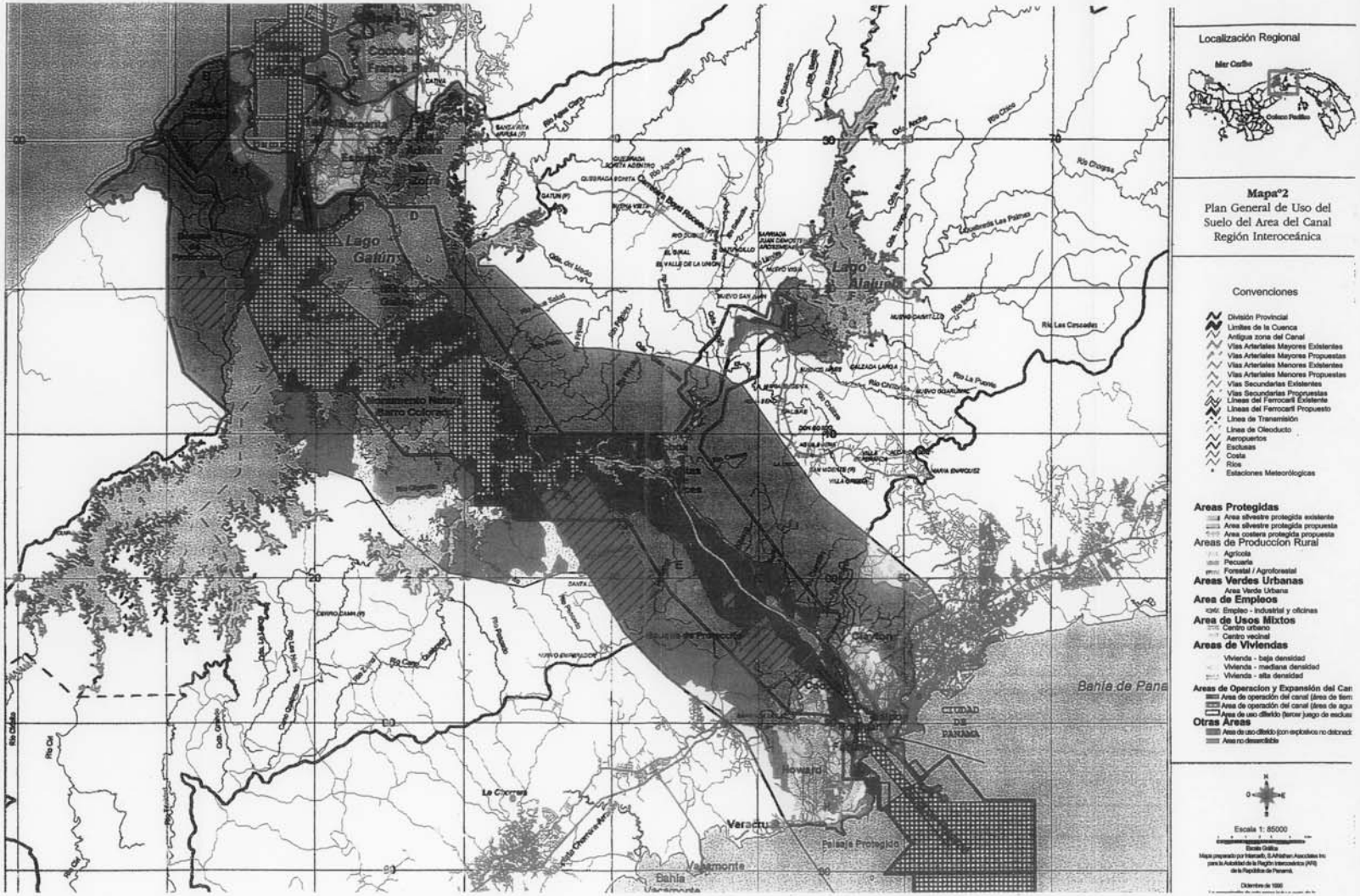
Proposed Project Organization Chart
Panama Lock Water Reclamation Project

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE 3.6.1



Proposed Project Funding Process
Panama Lock Water Reclamation Project

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE 3.6.2

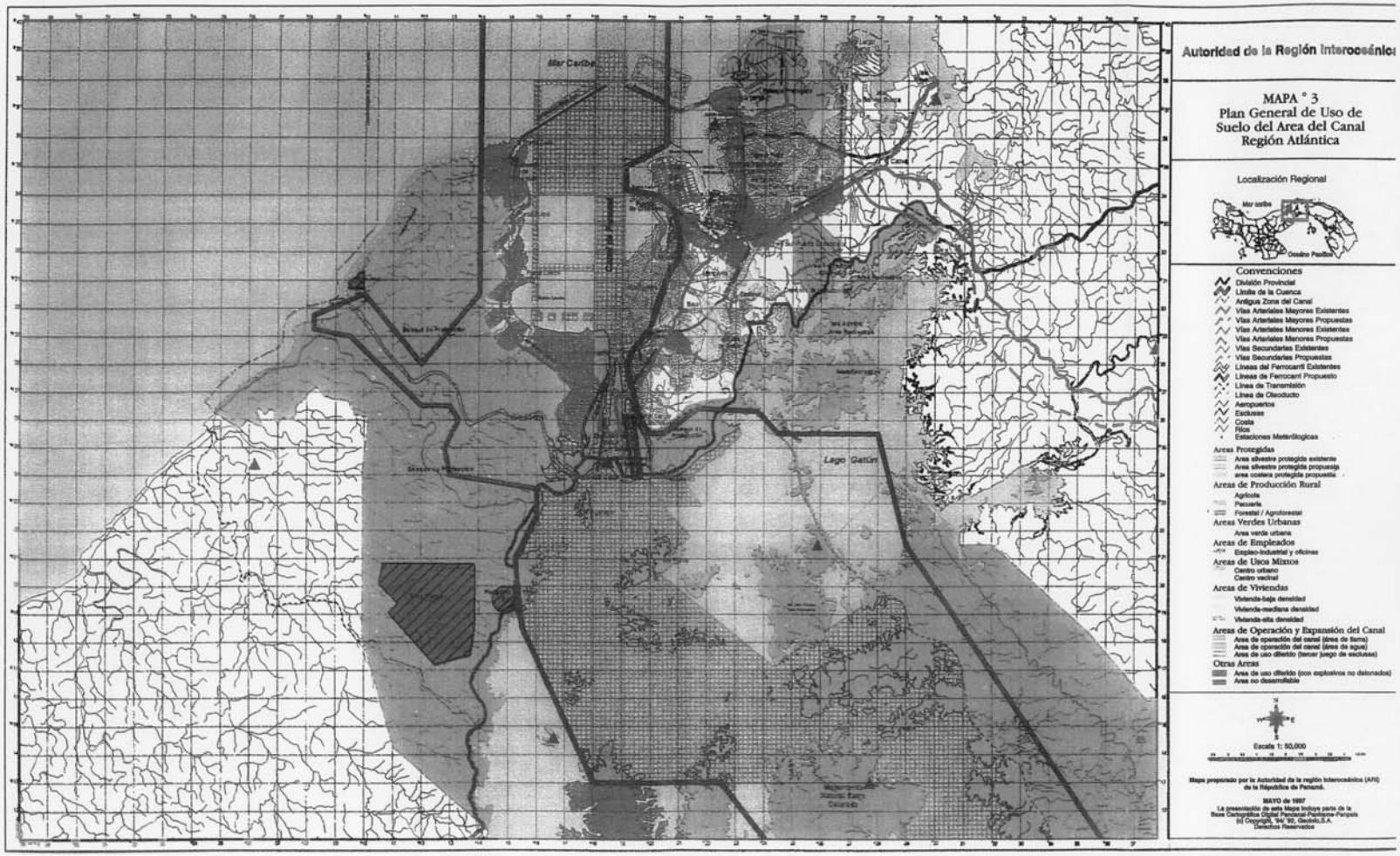


Development Plan Land Uses
Panama Canal Region

Wpsi, Inc.
Santa Ana, CA 92705

12-01

PLATE
4.0a

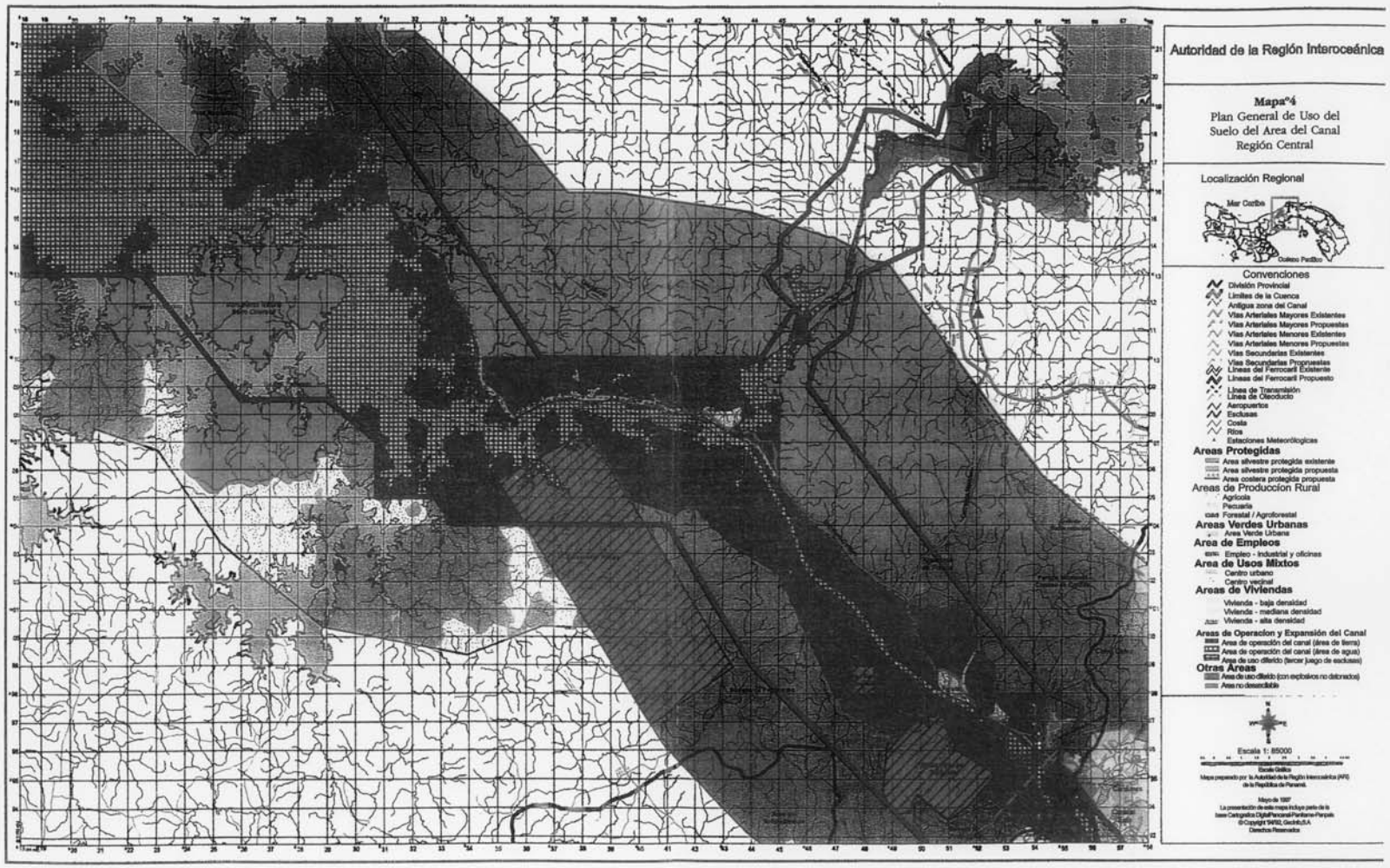


Development Plan Land Uses
Gatun Locks and Gatun Lake
Panama Canal Region

Wpsi, Inc.
Santa Ana, CA 92705

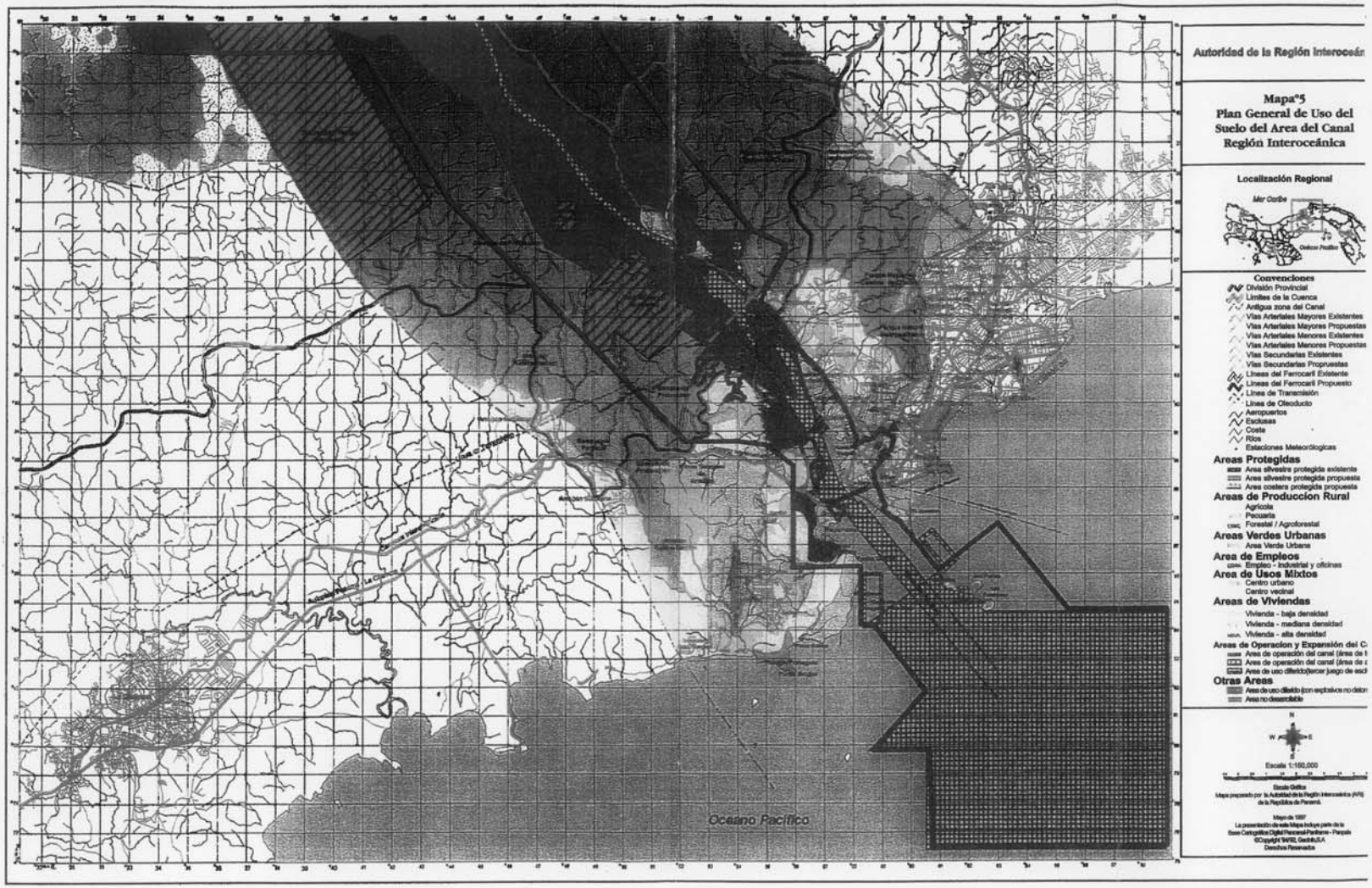
12-01

PLATE
4.0b



Development Plan Land Uses
Gatun Lake and Pedro Miguel Locks
Panama Canal Region

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **4.0c**



Development Plan Land Uses
Miraflores Lake and Miraflores Locks
Panama Canal Region

Wpsi, Inc. Santa Ana, CA 92705	12-01	PLATE **4.0d**

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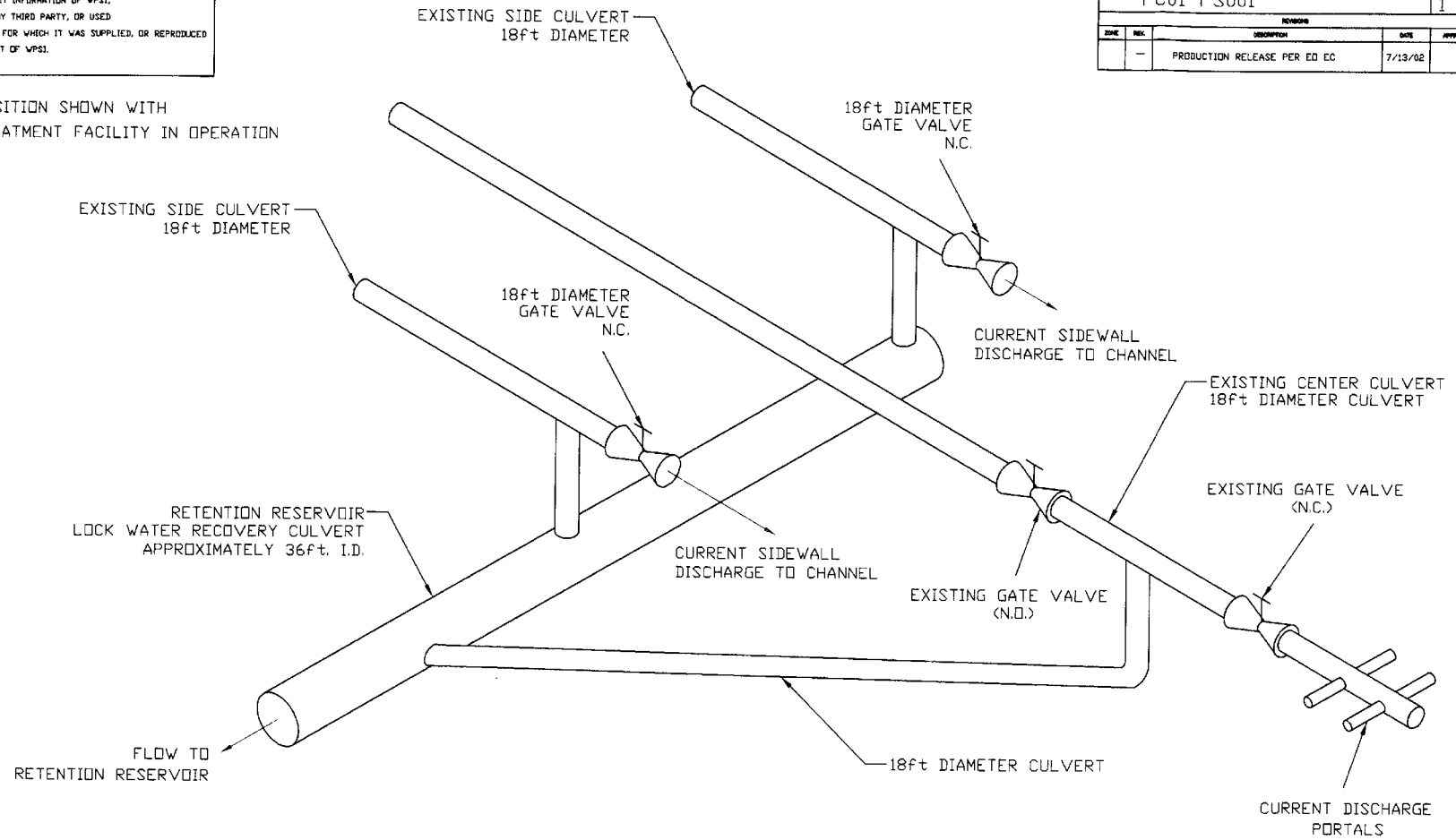
PC01-FS001	1	—

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	—	PRODUCTION RELEASE PER ED EC	7/13/02	

NOTE: VALVE POSITION SHOWN WITH
WATER TREATMENT FACILITY IN OPERATION



N.C. = NORMALLY CLOSED
N.O. = NORMALLY OPEN

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WPSI

DWG. TITLE: GATUN/MIRAFLORES
LOCK WATER RECOVERY SYSTEM
AND TIE-INS

DRAWN	SIZE	FSCM NO.	DWG. NO.	REV.
D. SPANI	D	—	PC01-FS001	—
ISSUED	SCALE 1 / 1		SHEET 1 OF 1	

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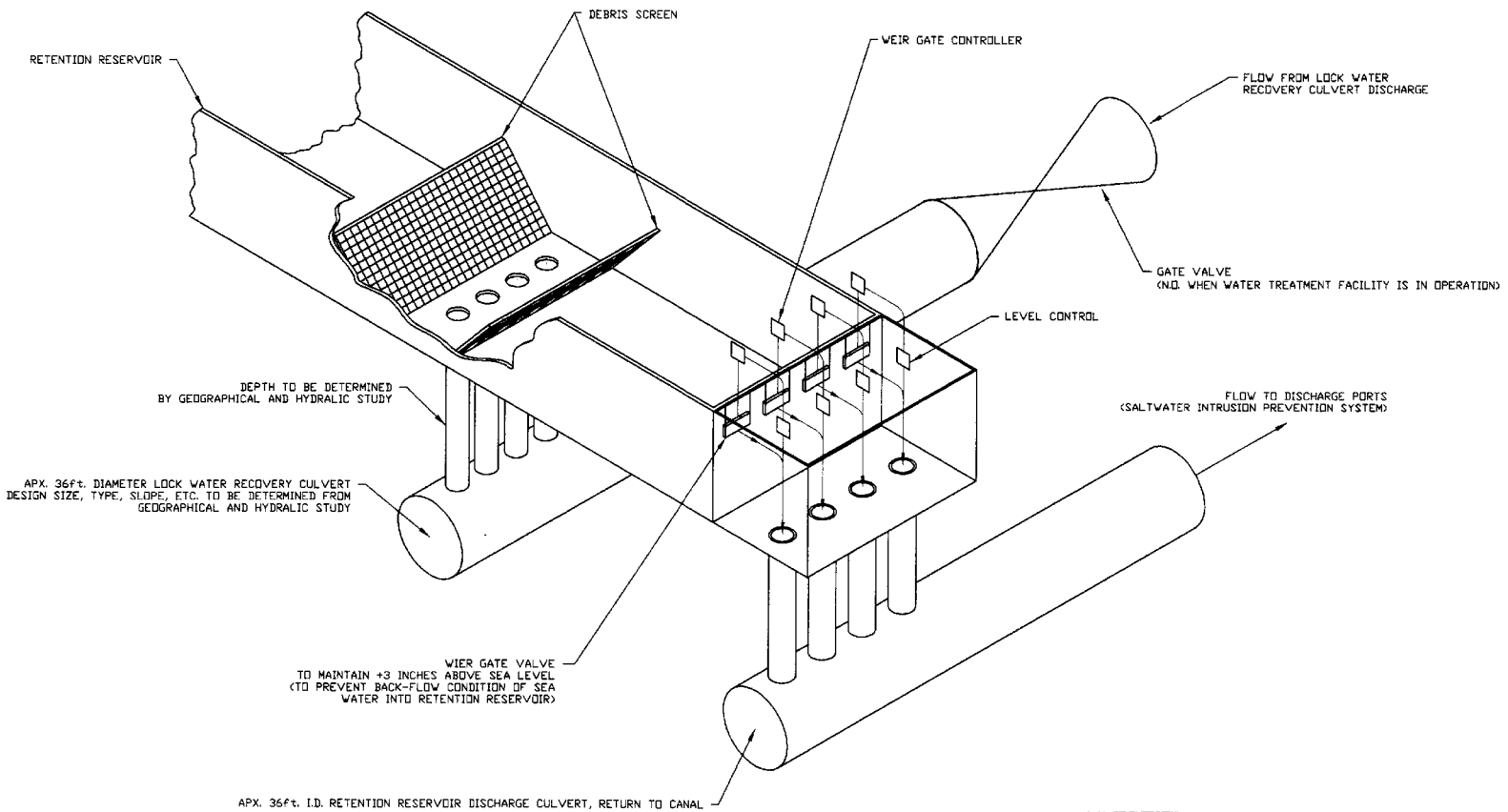

N.O. = NORMALLY OPEN

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WPSI

DWG. TITLE: LOCK WATER RECOVERY AND RETENTION RESERVOIR DISCHARGE CULVERTS

DRAWN: D. SPANI | SIZE: D | PROJ. NO. —— | DWG. NO. PC01-FS002 | REV. –

SCALE 1 / 1 | SHEET 1 OF 1

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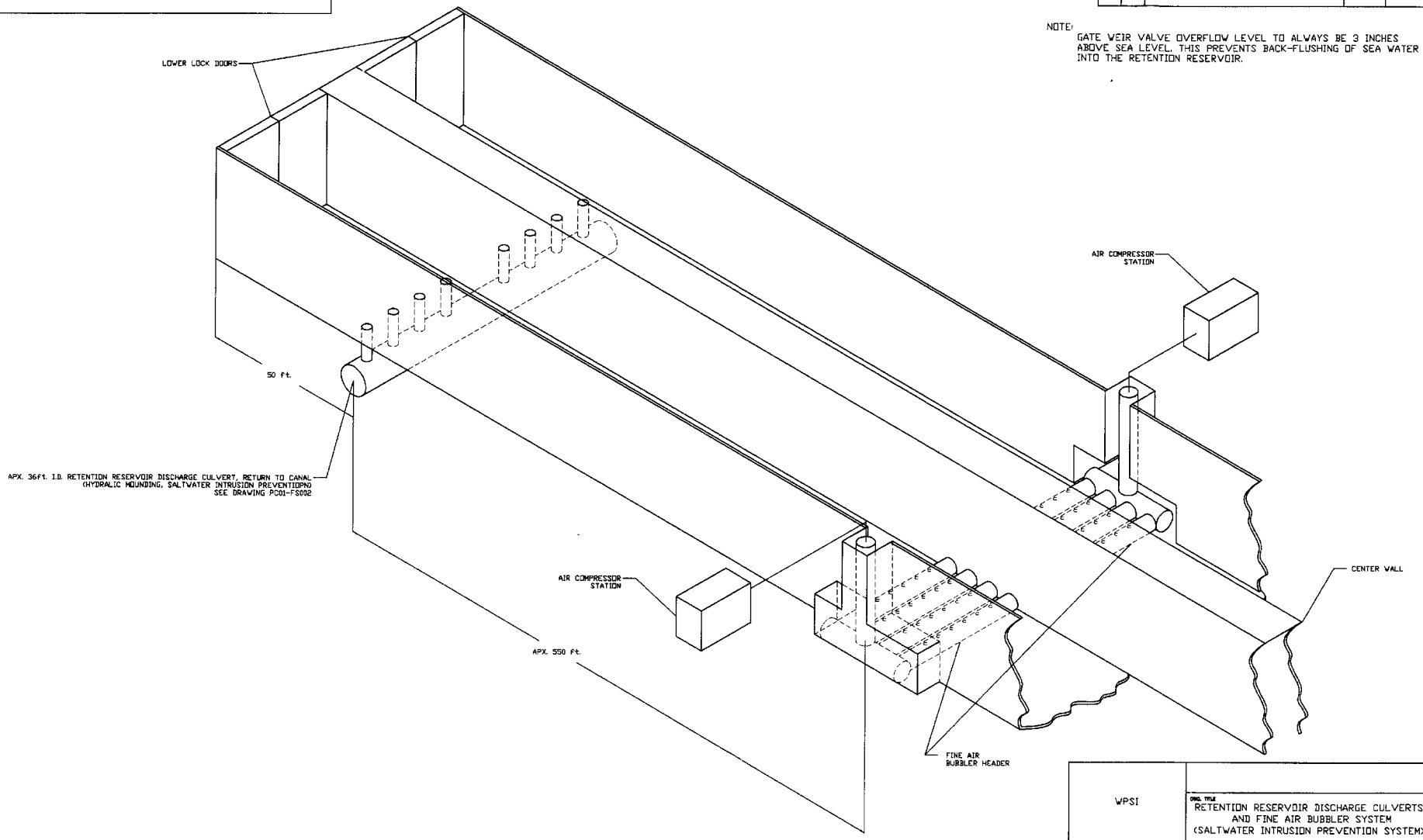
DWG. NO. PC01-FS003 SHEET 1 REV. –

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	–	PRODUCTION RELEASE PER EO EC	7/13/02	

NOTE:
GATE WEIR VALVE OVERFLOW LEVEL TO ALWAYS BE 3 INCHES ABOVE SEA LEVEL. THIS PREVENTS BACK-FLUSHING OF SEA WATER INTO THE RETENTION RESERVOIR.



WPSI

DWG. TITLE
RETENTION RESERVOIR DISCHARGE CULVERTS AND FINE AIR BUBBLER SYSTEM (SALTWATER INTRUSION PREVENTION SYSTEM)

DRAWN D. SPANI

SIZE D FSCM NO. DWG. NO. PC01-FS003 REV. –

SCALE 1 / 1 SHEET 1 OF 1

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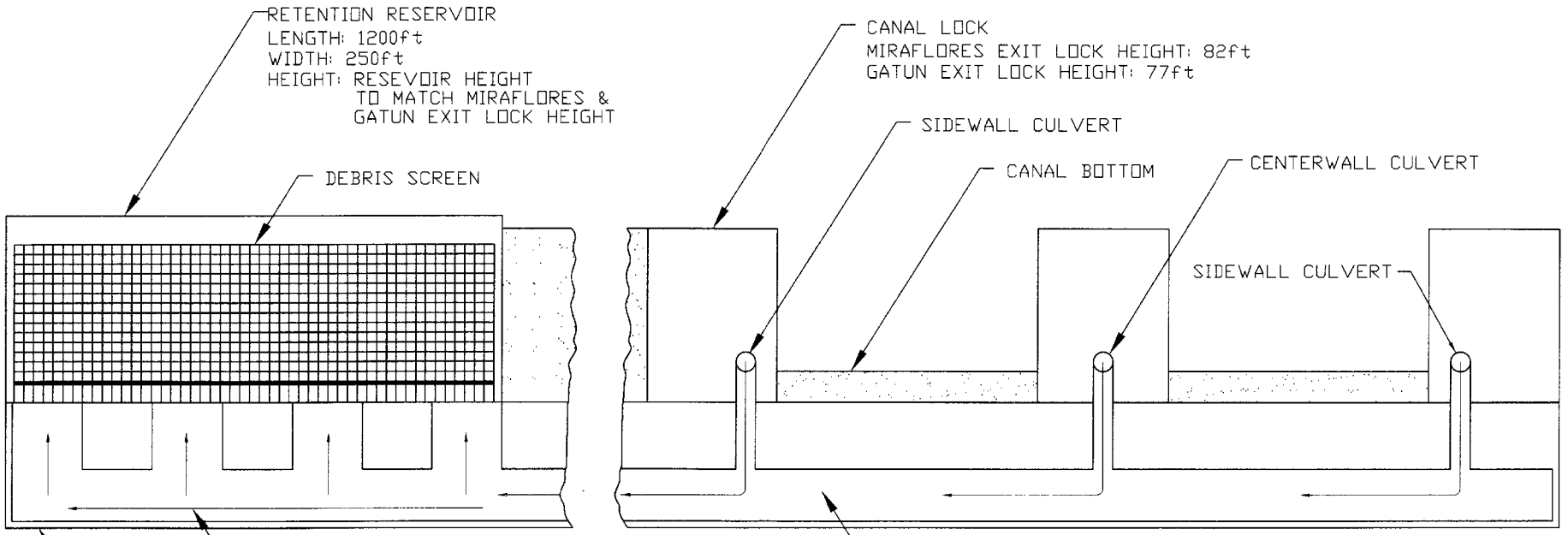
DWG. NO. PC01-FS004 SHEET 1 REV. –

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	–	PRODUCTION RELEASE PER ED EC	7/13/02	



WPSI

DWG. TITLE: CROSS SECTION OF RETENTION RESERVOIR, LOCK WATER RECOVERY CULVERT AND LOCK DISCHARGE CULVERT

DRAWN: D. SPANI

CHECKED:

SIZE: D FSCM NO. —

DWG. NO. PC01-FS004 REV. –

SCALE 1 / 1

SHEET 1 OF 1

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DWG. NO. PC01-FS005 SHEET 1 REV. –

ZONE	REV.	DESCRIPTION	DATE	APPROVED
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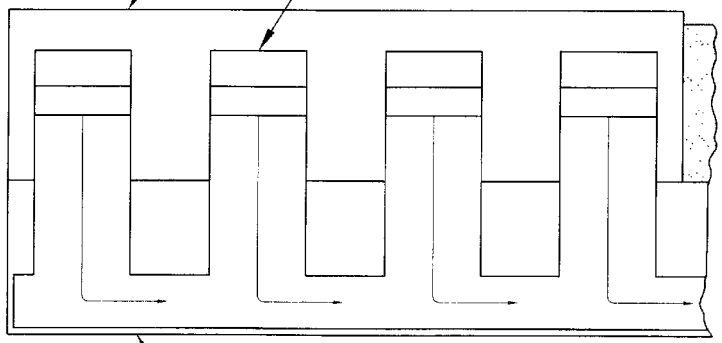
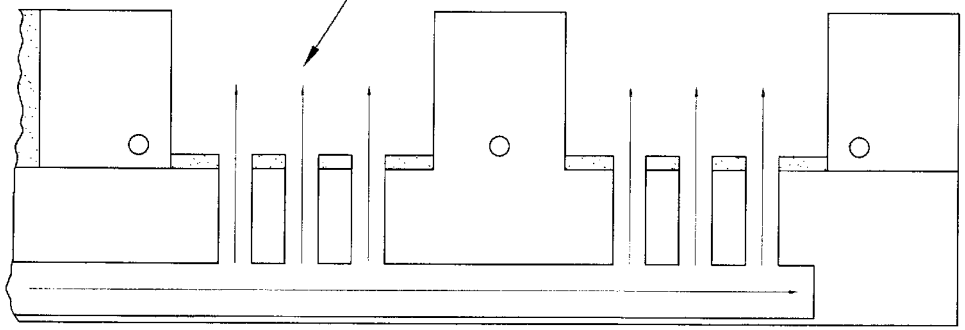
RETENTION RESERVOIR
LENGTH: 1200ft
WIDTH: 250ft
HEIGHT: RESEVOIR HEIGHT
TO MATCH MIRAFLORES &
GATUN EXIT LOCK HEIGHT

WEIR GATE VALVE



36ft. I.D.
RETENTION RESERVOIR DISCHARGE CULVERT
TO CANAL

HYDRALIC MOUNDING
(CAUSED BY RETURN FLOW
FROM RETENSION RESEVOIR)



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WPSI

DRAWN D. SPANI

DWG. TITLE: CROSS SECTIONS OF LOCK WATER RECOVERY SYSTEM AND RESERVOIR DISCHARGE CULVERTS

SIZE D | FSCM NO. | DWG. NO. PC01-FS005 | REV. –

SCALE 1 / 1 | SHEET 1 OF 1

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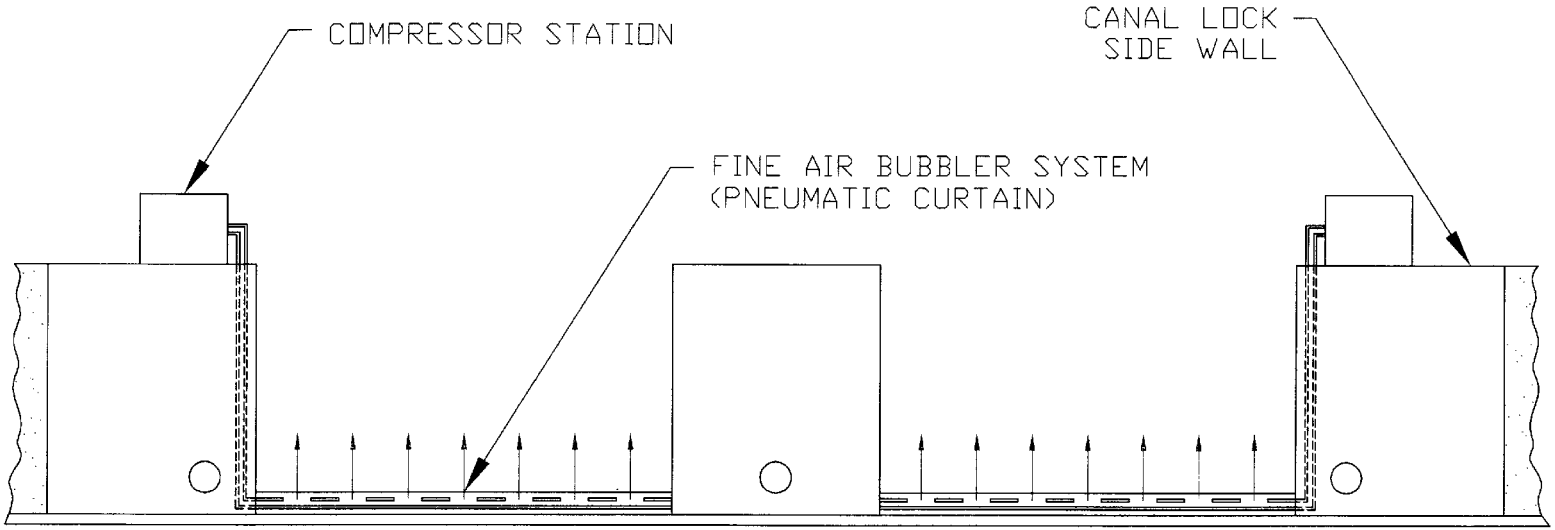
DWG. NO. PC01-FS006 SHEET 1 REV. –

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	–	PRODUCTION RELEASE PER ED EC	7/13/02	



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AUTOCAD RELEASE 2002

WPSI

DWG. TITLE: CROSS SECTION OF FINE AIR BUBBLER SYSTEM

DRAWN: D. SPANI

SIZE D | FSCM NO. | DWG. NO. PC01-FS006 | REV. –

SCALE 1 / 1 | SHEET 1 OF 1

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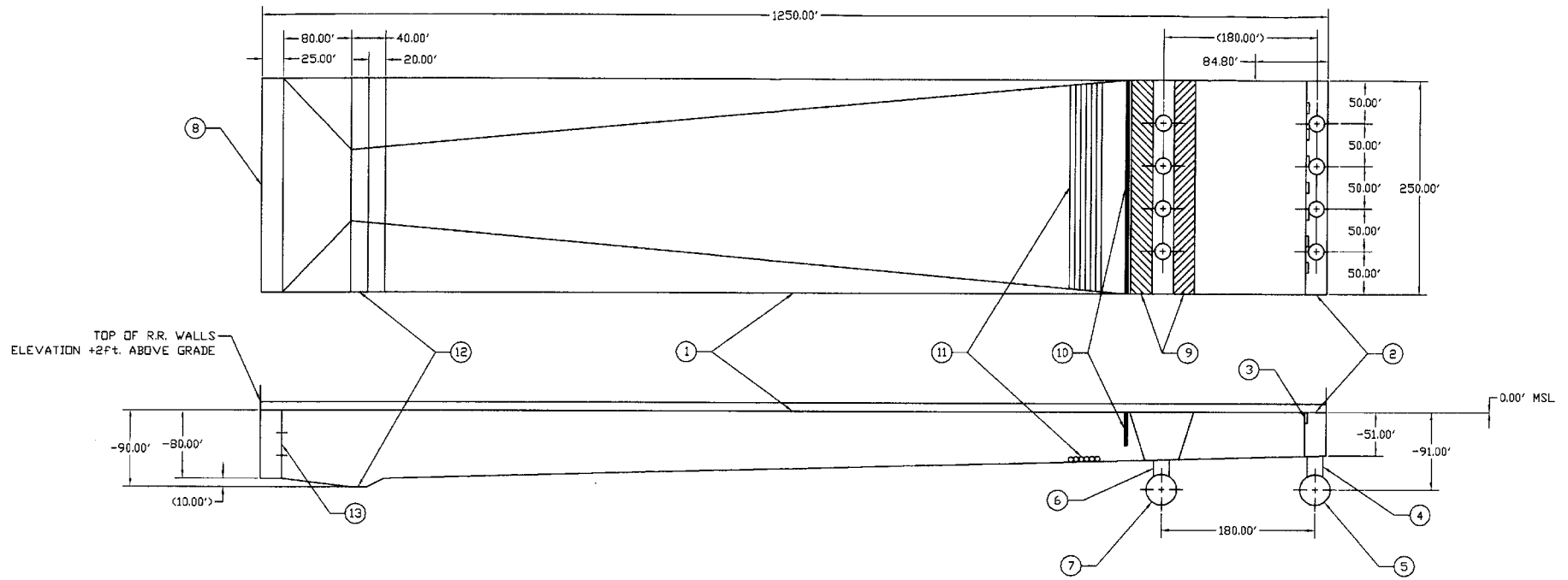
DWG. NO. PC01-FS007 | SHEET 1 | REV. —

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	—	PRODUCTION RELEASE PER EO EC	7/13/02	



ITEM NUMBER	ITEM DESCRIPTION
1	RETENTION RESERVIOR CONCRETE (VOLUME 20,625,000 CUBIC ft.)
2	OVER-FLOW CATCH BASIN
3	WEIR CONTROL VALVES (7 EACH)
4	18ft DIAMETER VERTICAL DISCHARGE PIPE
5	36ft. DIAMETER RETENTION RESERVOIR DISCHARGE CULVERT
6	18ft DIAMETER VERTICAL INLET RISER
7	36ft. DIAMETER LOCK WATER RECOVERY CULVERT
8	VERTICAL TURBINE PUMPS WET WELL
9	SELF CLEANING DEBRIS SCREEN
10	UNDER-FLOW BAFFLE
11	AERATION AND CHEMICAL REAGENT MIXING
12	SEDIMENTATION CATCH BASIN
13	MID-LEVEL FLOW BARRIER WALL

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WPSI

DRAWN D. SPANI | ISSUED

DWG. TITLE: RETENTION RESERVIOR DETAIL

SIZE D | TECH. NO. — | DWG. NO. PC01-FS007 | REV. —

SCALE 1 / 1 | SHEET 1 OF 1

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DWG. NO. PC01-FS008 | SHEET 1 | REV. –

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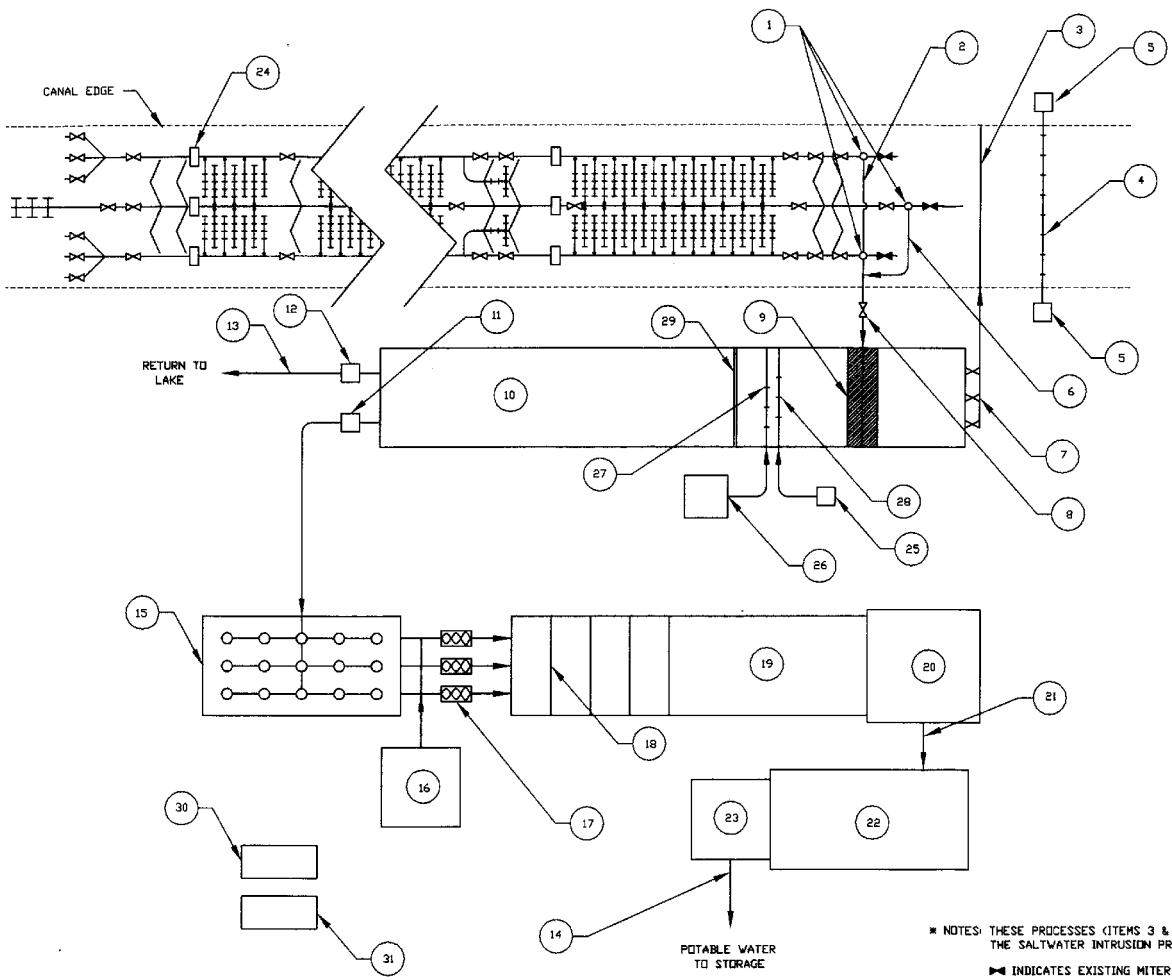

ITEM NUMBER		ITEM DESCRIPTION
1		TIE-IN
2		UNDERGROUND CULVERT APX. 36ft. DIA. (FLOW TO RETENTION RESERVIOR)
3	*	UNDERGROUND CULVERT APX. 36ft. DIA. (DISCHARGE FLOW TO CANAL "HYDRALIC MOUNDING")
4	*	FINE AIR BUBBLER SYSTEM (PUEUMATIC BARRIER)
5		AIR COMPRESSOR STATION (2)
6		18ft DIAMETER CULVERT
7		WIER GATE VALVES
8		GATE VALVE
9		SELF WIPPING DEBRIS SCREEN
10		RETENTION RESEVOIR (20,625,000 CUBIC ft.)
		1250ft X 250ft X 90ft DEEP
11		PUMP HOUSE
12		PUMP HOUSE
13		12ft DIAMETER PIPELINES (2 EACH) LAKE GATUN REPATREATION RECYCLED WATER
14		6ft DIAMETER PIPELINE POTABLE WATER TO IDAAN
15		AERATION BASIN (360ft X 250ft X 33ft DEEP)
16		CHEMICAL REAGENT FACILLITY
17		MIXERS
18		SEDIMENTATION CHAMBERS (115ft X 250ft X 50ft DEEP)
19		SETTLING SEDIMENTATION BASIN (495ft X 250ft X 50ft DEEP)
20		MEDIA FILTRATION, ANTHRACITE/COAL, SAND, GRAVEL
21		6ft DIAMETER PIPELINES (2 EACH)
22		CLEAR WELL (495ft X 250ft X 50ft DEEP)
23		PUMP HOUSE
24		HYDROELECTRIC PIT TURBINE INSTALLED IN PARALLEL PATH CULVERTS
		TOTAL: 9 EACH (6.5MW AND 14.2MW UNITS)
25		AIR COMPRESSOR STATION
26		CHEMICAL REAGENT PUMP HOUSE
27		CHEMICAL REAGENT INJECTOR
28		COARSE AIR BUBBLER SYSTEM, AERATION AND CHEMICAL MIXING
29		FLOW BAFFLE
30		OUTDOOR FENCED AREA (ELECTRICAL SUB STATION)
31		INDOOR FACILITIES (ELECTRICAL SWITCHGEAR)

* NOTES: THESE PROCESSES (ITEMS 3 & 4) ARE USED TO CREATE THE SALTWATER INTRUSION PREVETION SYSTEM.

⋈ INDICATES EXISTING MITER GATE VALVES WOULD BE IN A CLOSED POSITION WHILE WPSI FACILITY IS IN OPERATION

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DWG. TITLE: PROCESS DIAGRAM, GATUN TREATMENT FACILITY

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SCALE 1 / 1 | SHEET 1 OF 1

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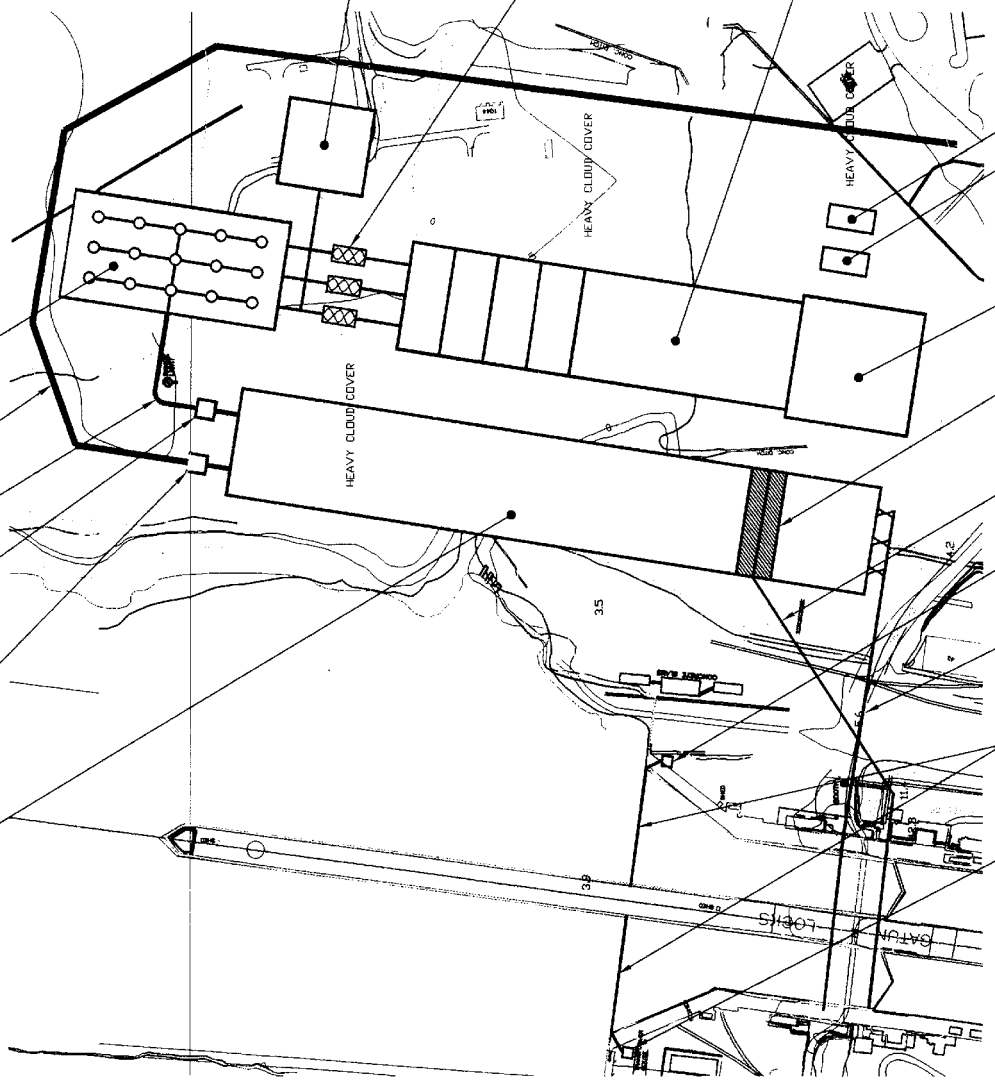

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WPSI

DWG. TITLE: SITE PLOT PLAN,
GATUN TREATMENT FACILITY
AND ALIGNMENT OF TREATED WATER PIPELINE

DRAWN: D. SPANI
ISSUED:
SIZE: D | FSCM NO. | DWG. NO. PC01-FS009 | REV. -
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ZONE	REV.	DESCRIPTION	DATE	APPROVED
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SEE PC01-FS009
SHEET 1

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WPSI

DWG. TITLE: SITE PLOT PLAN,
GATUN TREATMENT FACILITY
AND ALIGNMENT OF TREATED WATER PIPELINE

DRAWN	SIZE	FSCM NO.	DWG. NO.	REV.
D. SPANI	D	—	PC01-FS009	-
ISSUED	SCALE 1/1		SHEET 2 OF 2	

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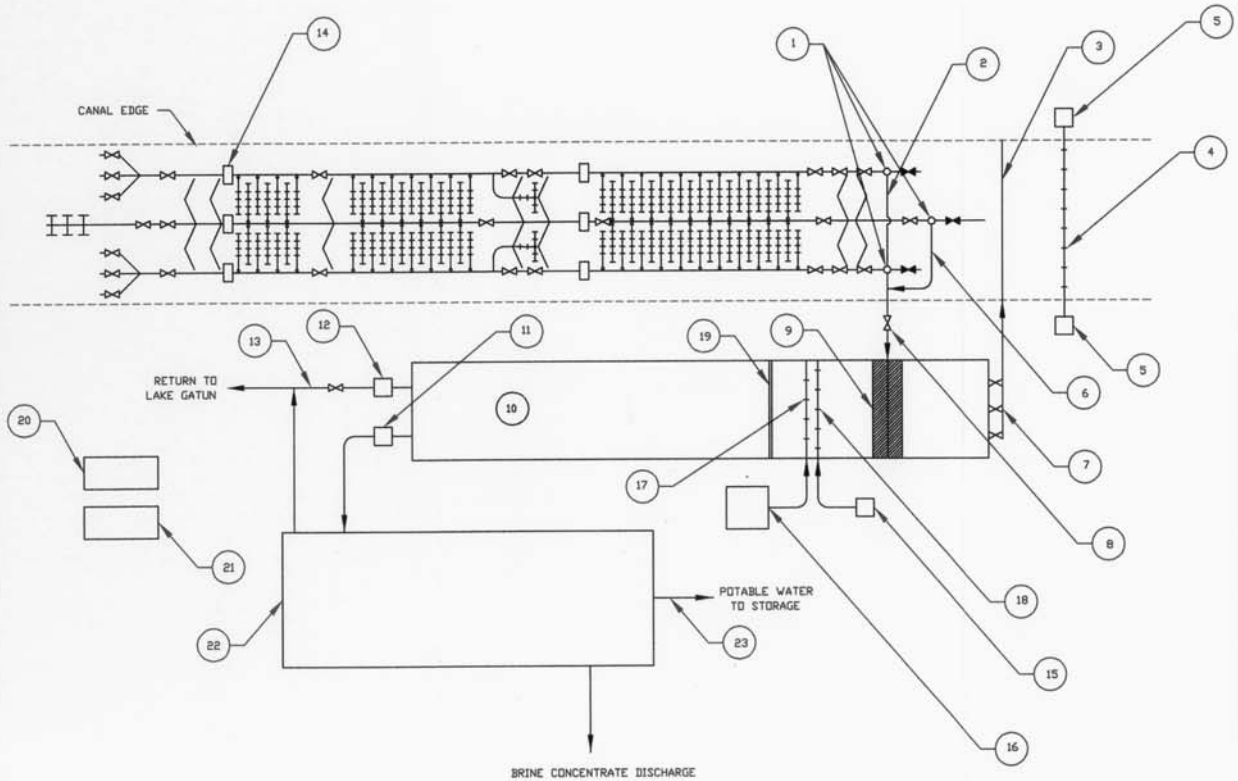

ITEM NUMBER		ITEM DESCRIPTION
1		TIE-IN
2	*	UNNDERGROUND CULVERT APX. 36ft. DIA. (FLOW TO RETENTIOPN RESERVIOR)
3	*	UNNDERGROUND CULVERT APX. 36ft. DIA. (FLOW TO CANAL, HYDRALIC MOUNDING)
4		FINE AIR BUBBLER SYSTEM (PNEUMATIC BARRIER)
5		AIR COMPRESSOR STATION (2)
6		18ft DIAMETER UNDERGROUND CULVERT
7		WIER GATE VALVES
8		GATE VALVE
9		SELF WIPPING DEBRIS SCREEN
10		RETENTION RESEVOIR (20,625,000 CUBIC Ft.)
		1250 ft X 250ft X 90ft DEEP
11		PUMP HOUSE
12		PUMP HOUSE
13		12ft DIAMETER PIPELINES (2 EACH) LAKE GATUN REPATREATION RECYCLED WATER
14		HYDROELECTRIC PIT TURBINES INSATALLED IN PARALLEL PATH CULVERTS
		TOTAL: 6 EACH, 6.5MW AND 14.2MW UNITS
15		AIR COMPRESSOR STATION
16		CHEMICAL REAGENT PUMP HOUSE
17		CHEMICAL REAGENT INJECTOR
18		COARSE AIR BUBBLER SYSTEM
19		FLOW BAFFLE
20		OUTDOOR FENCED AREA (ELECTRICAL SUB STATION)
21		INDOOR FACILITIES (ELECTRICAL SWITCHGEAR)
22		DESALINIZATION FACILITY
23		6ft. DIA. PIPELINE, POTABLE WATER TO IDAAN

* NOTES: THESE PROCESSES (ITEMS 3 & 4) ARE USED TO CREATE THE SALTWATER INTRUSION PREVETION SYSTEM.

⋈ INDICATES EXISTING MITER GATE VALVES WOULD BE IN A CLOSED POSITION WHILE WPSI FACILITY IS IN OPERATION

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WPSI

DWG. TITLE: PROCESS DIAGRAM, MIRAFLORES TREATMENT FACILITY (PHASE I)

DRAWN: D. SPANI | ISSUED | SIZE: D | FSCM NO. | DWG. NO. PC01-FS010 | REV. –

SCALE 1 / 1 | SHEET 1 OF 1

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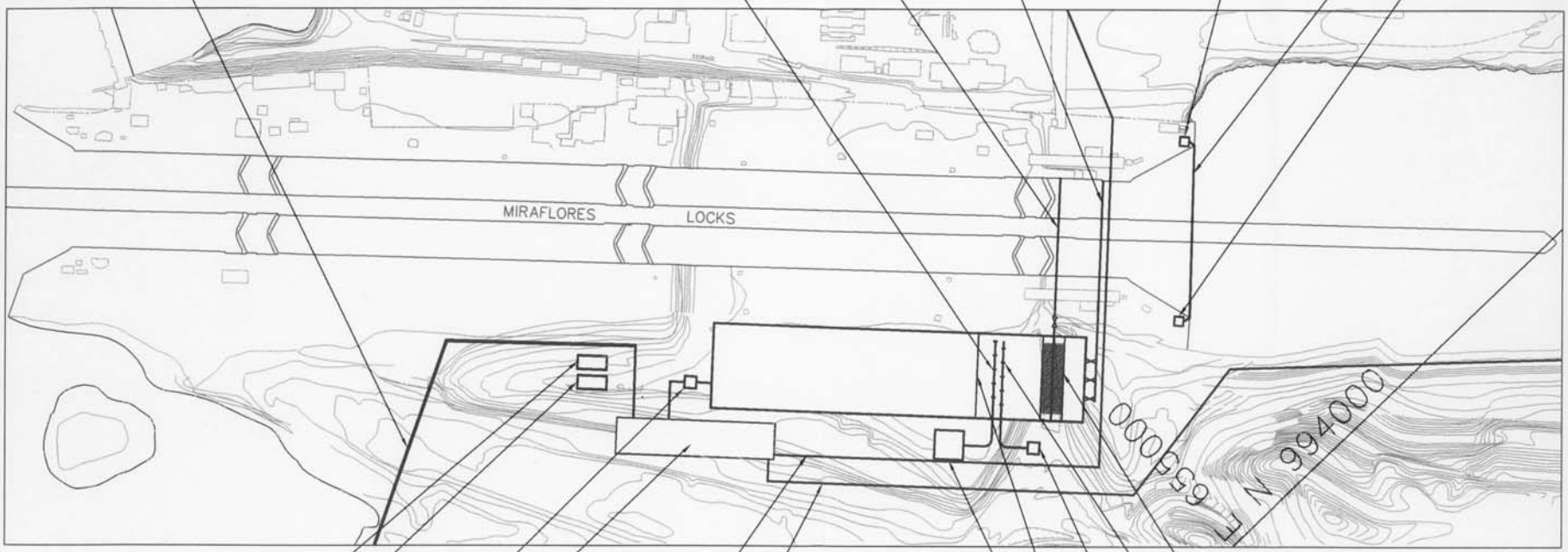

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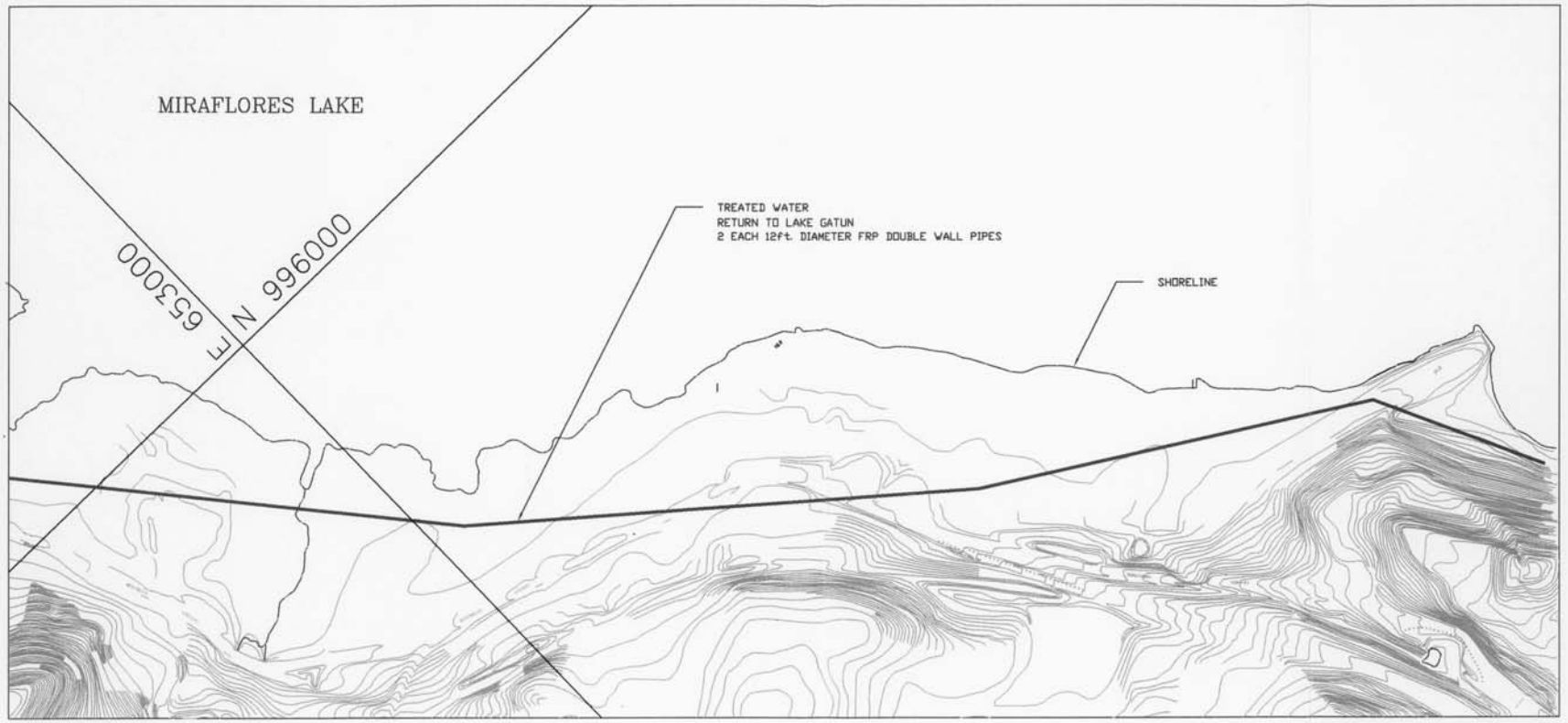

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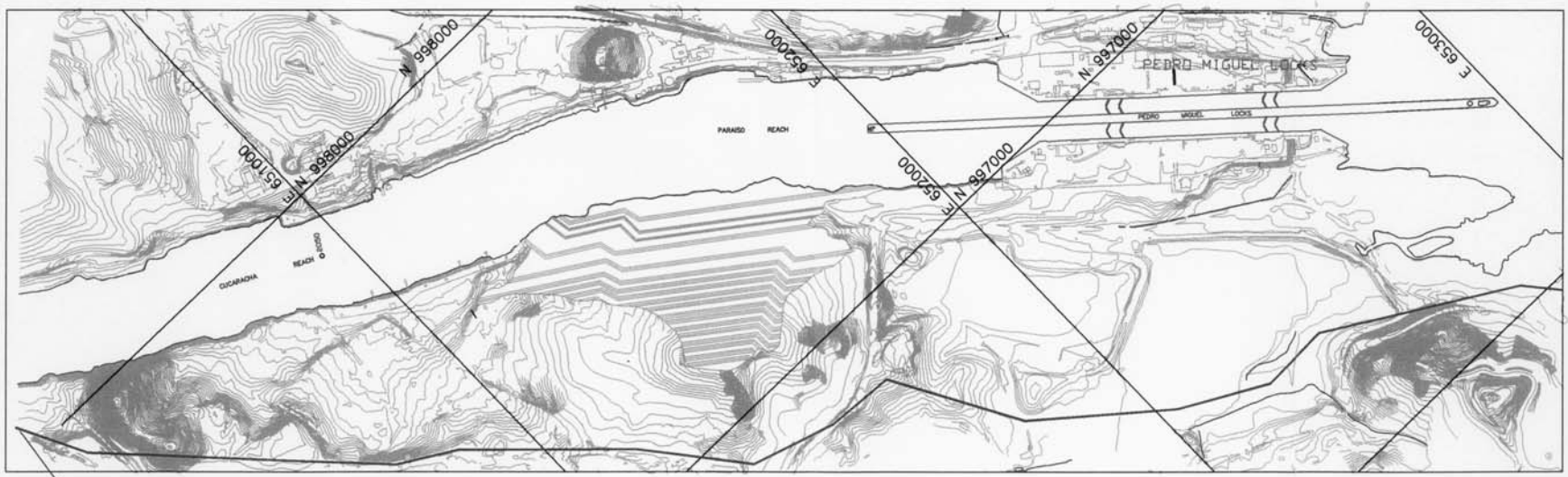

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DWG. TITLE
ALIGNMENT OF TREATED WATER
PIPELINE FROM
MIRAFLORES TREATMENT FACILITY (PHASE II)

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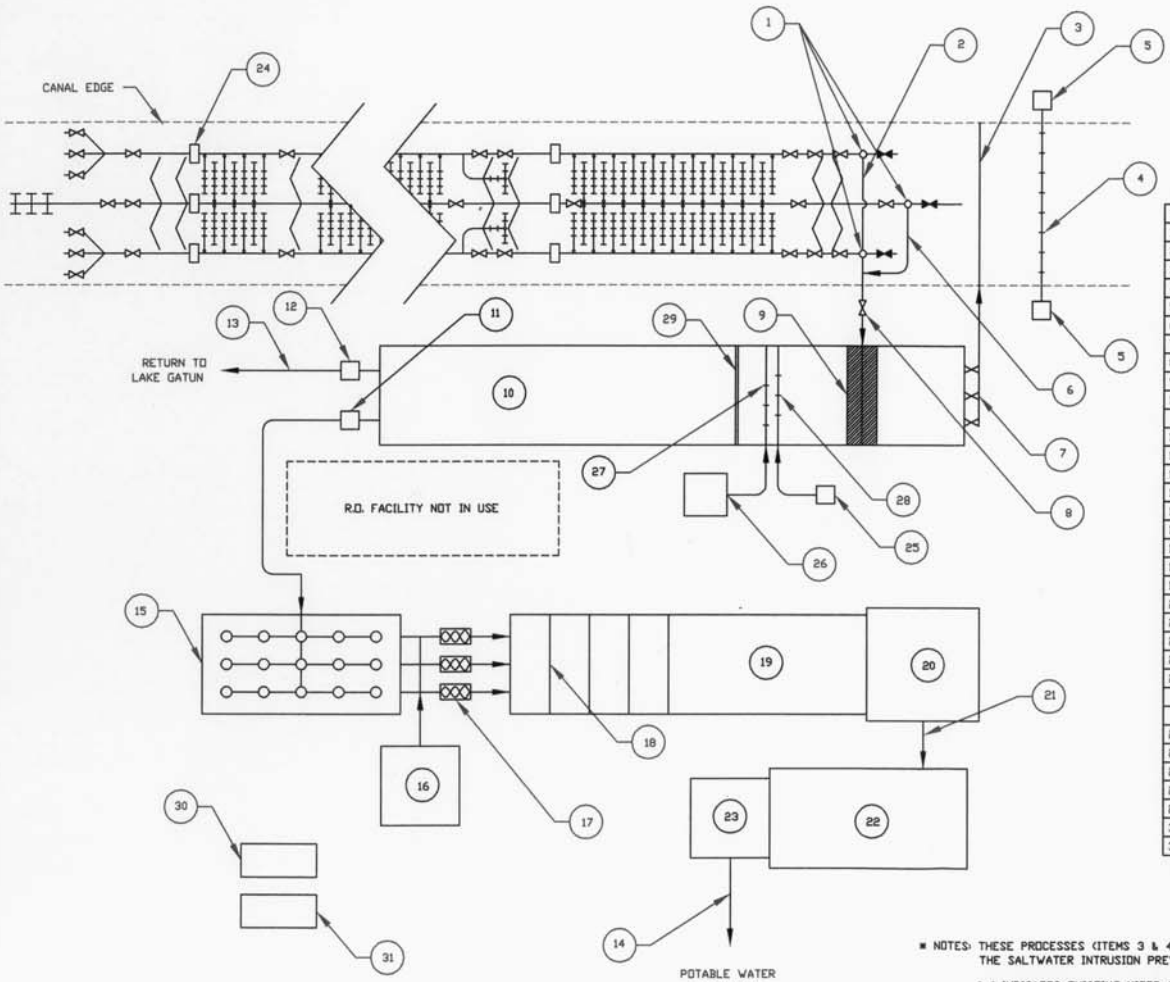

ITEM NUMBER		ITEM DESCRIPTION
1		TIE-IN
2		UNDERGROUND CULVERT, APX. 36ft. DIA. (FLOW TO RETENTION RESERVIOR)
3	*	UNDERGROUND CULVERT, APX. 36ft. DIA. (FLOW TO CANAL, SUPPORT HYDRALIC MOUNDING)
4	*	FINE AIR BUBBLER SYSTEM (PNEUMATIC BARRIER)
5		AIR COMPRESSOR STATION (2)
6		18ft DIAMETER UNDRGROUND CULVERT
7		WIER GATE VALVES
8		GATE VALVE
9		SELF WIPPING DEBRIS SCREEN
10		RETENTION RESEVOIR (20,625,000 CUBIC ft.)
		1250ft X 250ft X 90ft DEEP
11		PUMP HOUSE
12		PUMP HOUSE
13		12ft DIAMETER PIPELINES (2 EACH) LAKE GATUN REPATREATION, RECYCLED WATER
14		6ft DIAMETER PIPELINE, POTABLE WATER TO IDAAN
15		AERATION BASIN (360ft X 250ft X 33ft DEEP)
16		CHEMICAL REAGENT FACILLITY
17		MIXERS
18		SEDIMENTATION CHAMBERS (115ft X 250ft X 50ft DEEP)
19		SETTLING SEDIMENTATION BASIN (495ft X 250ft X 50ft DEEP)
20		MEDIA FILTRATION, ANTHRACITE/COAL, SAND, GRAVEL
21		6ft DIAMETER PIPELINES (2 EACH)
22		CLEAR WELL (495 ft X 250ft X 50ft DEEP)
23		PUMP HOUSE
24		HYDROELECTRIC PIT TURBINES INSTALLED IN PARALLEL PATH CULVERTS
		MIRAFLORES 6 UNITS AND PEDRO MIGUEL (NOT SHOWN) 6 UNITS
		6.5MW AND 14.2MW UNITS
25		AIR COMPRESSOR STATION
26		CHEMICAL REAGENT PUMP HOUSE
27		CHEMICAL REAGENT INJECTOR
28		COARSE AIR BUBBLER SYSTEM
29		FLOW BAFFLE
30		OUTDOOR FENCED AREA (ELECTRICAL SUB STATION)
31		INDOOR FACILITIES (ELECTRICAL SWITCHGEAR)

* NOTES: THESE PROCESSES (ITEMS 3 & 4) ARE USED TO CREATE THE SALTWATER INTRUSION PREVETION SYSTEM.

⋈ INDICATES EXISTING MITER GATE VALVES WOULD BE IN A CLOSED POSITION WHILE WPSI FACILITY IS IN OPERATION

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NOTES:
1. SEE DRAWING #: PC01-FS006 FOR REFERENCE.

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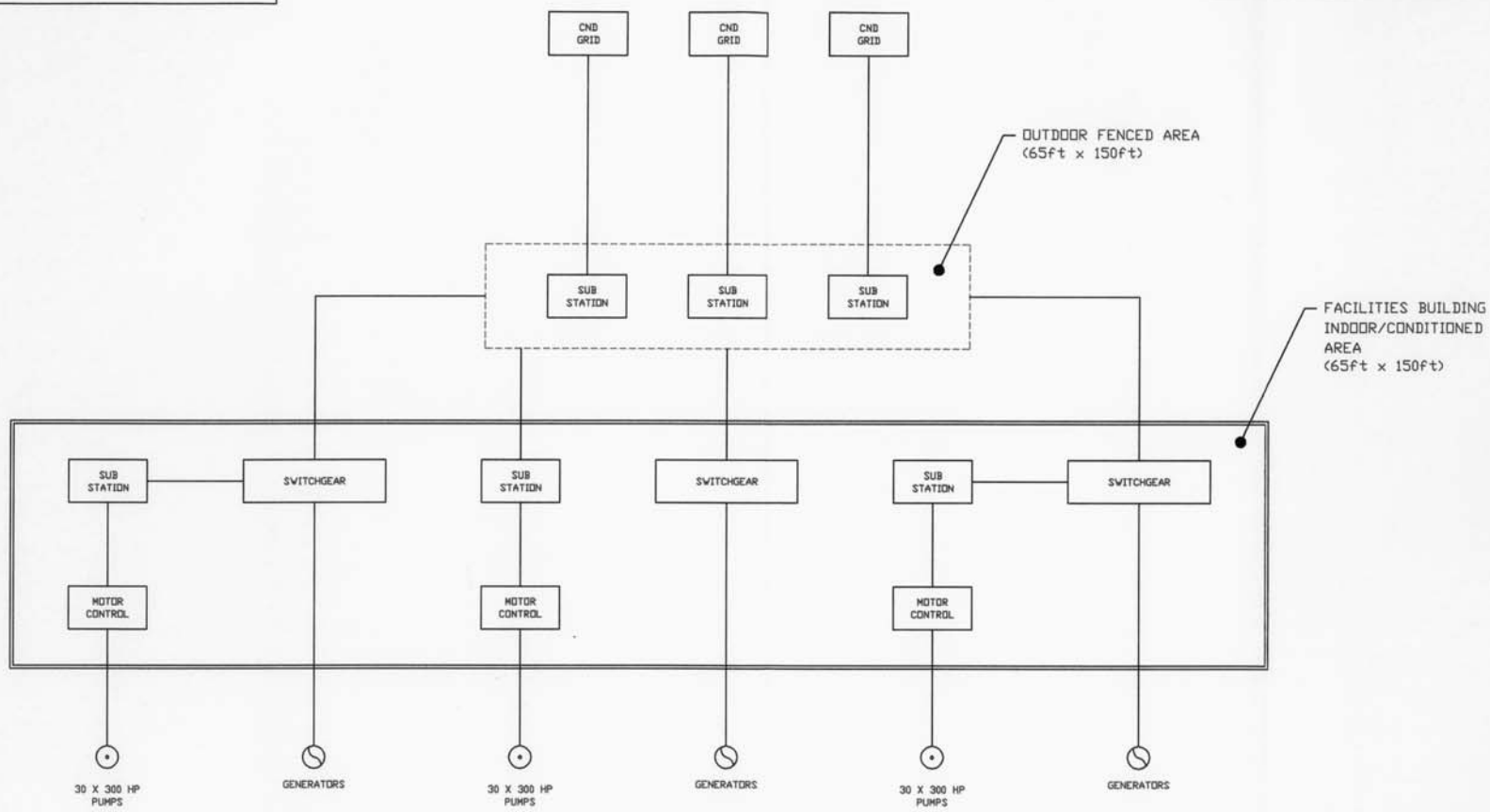

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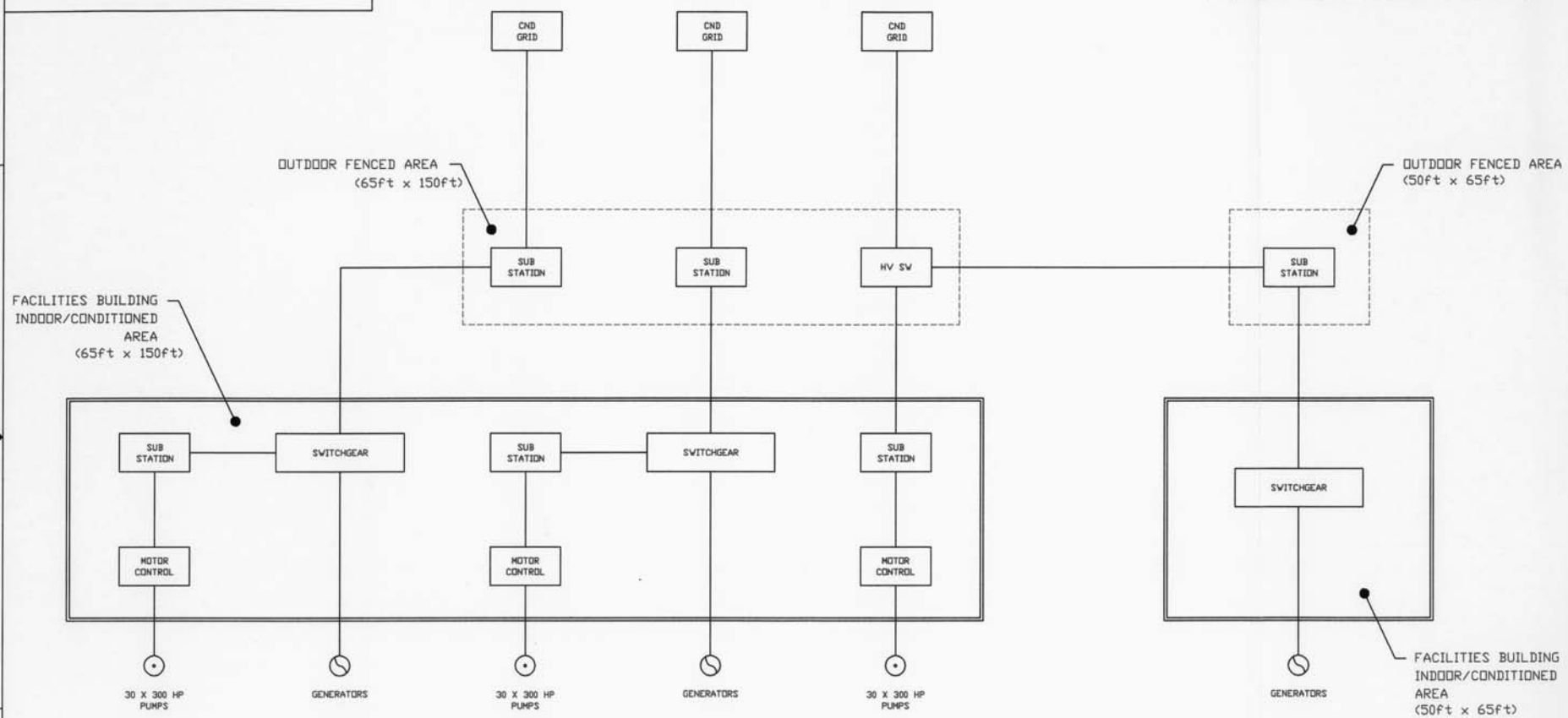

TYPICAL FOR MIRAFLORES LOCKS

TYPICAL FOR PEDRO MIGUEL LOCKS

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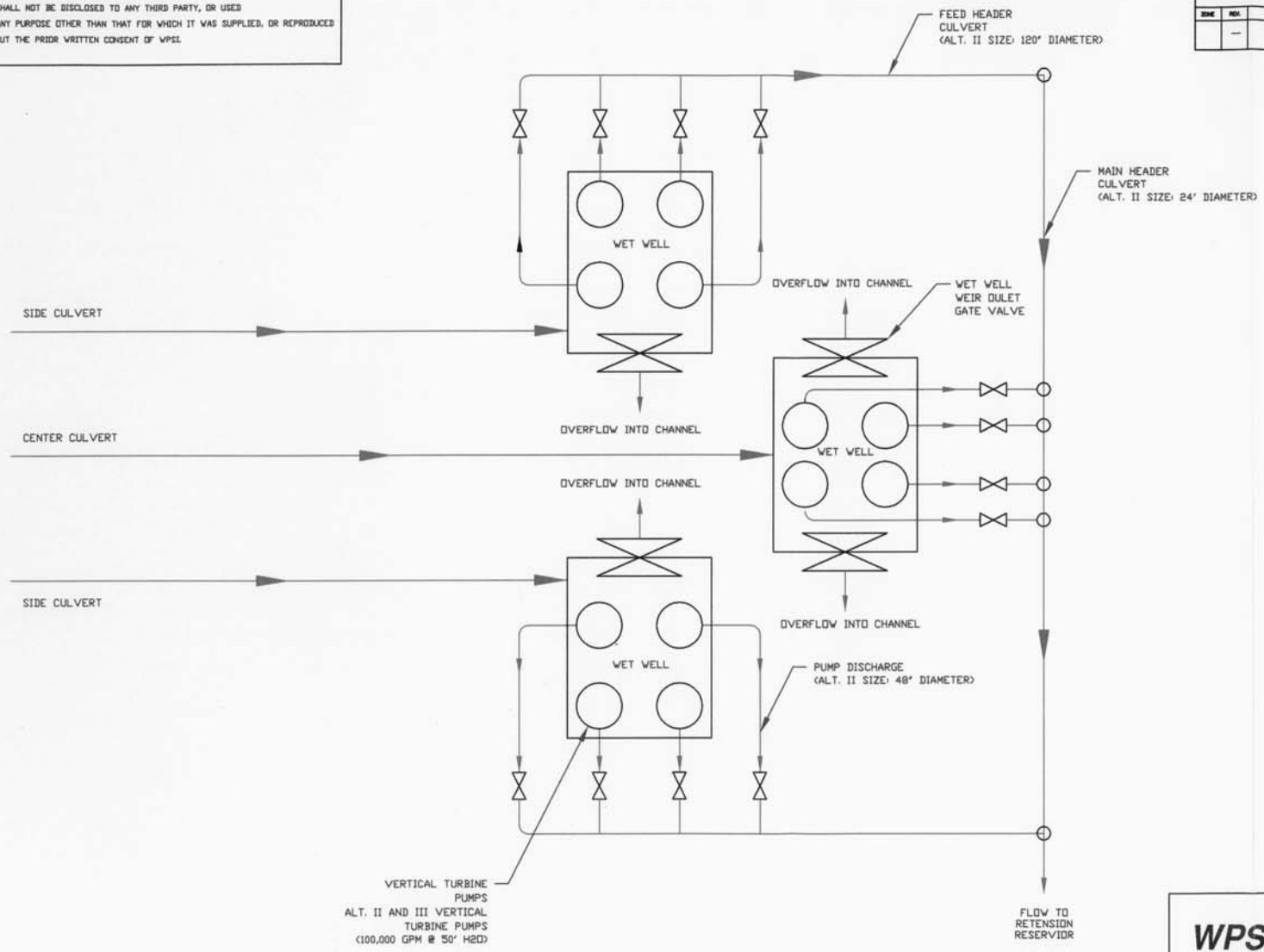

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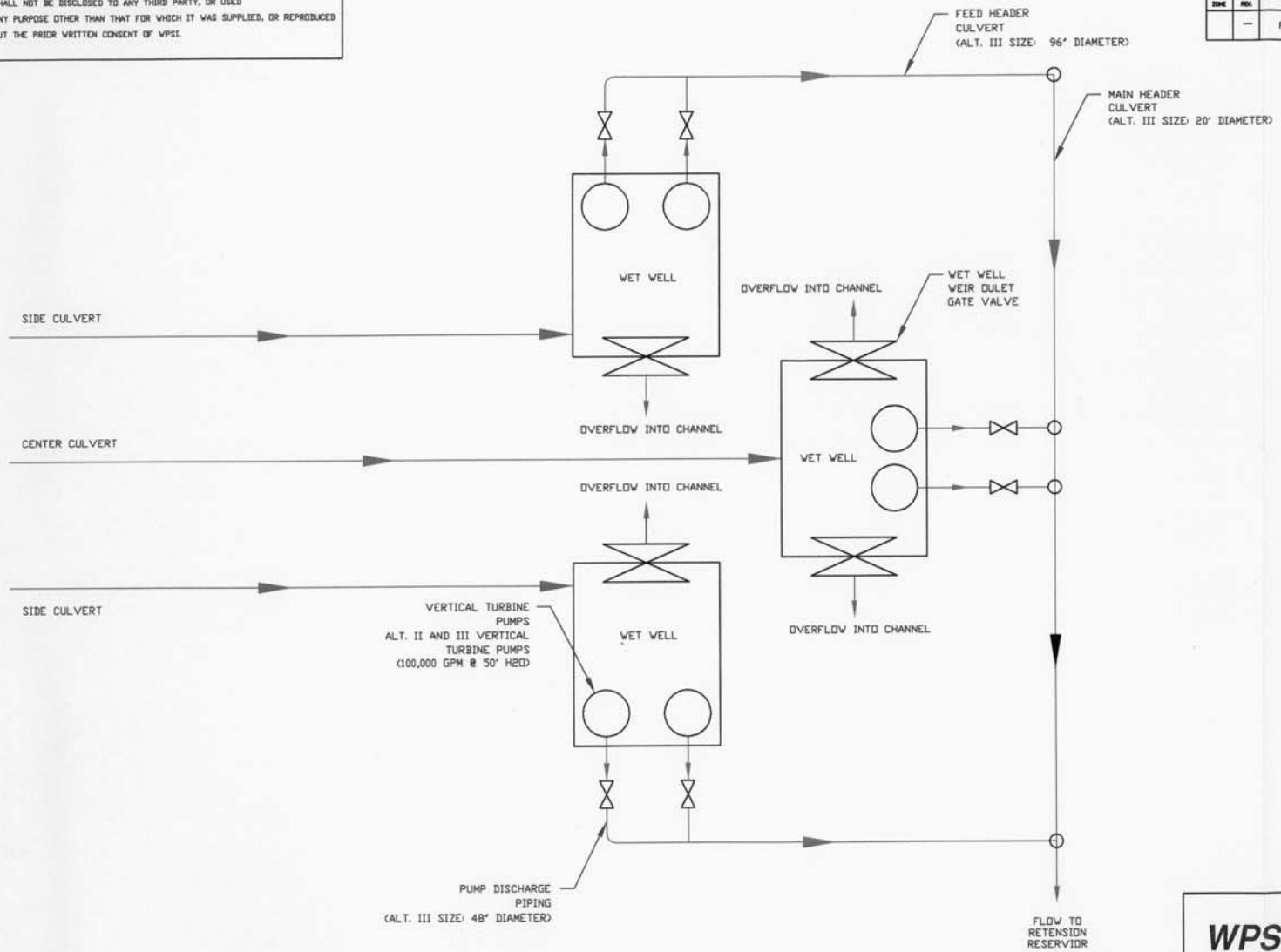

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US Army Corps
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Salinity Intrusion in the Panama Canal

T. M. Parchure, Steven C. Wilhelms, Soraya Sarruff,
William H. McAnally

February 2000

Laboratory

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Preface

The work described here was conducted at the Coastal and Hydraulics Laboratory (CHL) of the U. S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, during 1999. Funding was provided by the Canal Capacity Projects Office, Panama Canal Commission (PCC) through the U.S. Army Engineer District, Mobile under Memorandum of Agreement ISSA 97-003, Work Order 23. Mr. Billy Brown of the Mobile District served as U.S. Army Corps of Engineers program manager. Messrs. John Gribar and Rigoberto Delgado served as the PCC primary points of contact.

Dr. Trimbak M. Parchure, CHL, was the principal investigator for the described work. Dr. Parchure conducted the work under general supervision of Dr. Robert T. McAdory, Chief, Tidal Hydraulics Branch, Dr. William H. McAnally, Chief, Estuaries and Hydrosciences Division, and Dr. James R. Houston, Director, Coastal and Hydraulics Laboratory. Other contributors to the work were Dr. Steven C. Wilhelms, Ms. Soraya Saruff, and Dr. McAnally of CHL, Mr. Delgado, PCC, Mr. Cesar Kiamco, PCC, and Mr. A. David Schuldt, USAE District, Seattle (retired) who wrote Appendix C.

The report is published by the Coastal and Hydraulics Laboratory. The CHL was formed in October 1996 with the merger of the Waterways Experiment Station (WES) Coastal Engineering Research Center and Hydraulics Laboratory. WES has now become part of ERDC. Dr. James R. Houston is the Director of CHL.

During the preparation and publication of this report, Dr. Lewis E. Link was Acting Director of ERDC and Col. Robin Cababa, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic feet per sec (cfs)	0.028317	cu meters per sec
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	5/9	degrees Celsius or kelvins[1]
fathoms	1.8288	meters
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2.59	kilometers
square yards	0.8361274	square meters
tons (2240 pounds mass)	1.01605	metric tons
tons (2240 pounds mass)	1016.05	kilograms
yards	0.9144	meters

1 Introduction

Objective

This report documents the results of salinity intrusion analyses for the Panama Canal, Panama. The objective of these analyses is to provide an early estimate of changes in salinity intrusion and freshwater usage that may result from an expansion of canal locks capacity, and to identify measures that may reduce salinity intrusion and freshwater consumption if unacceptable increases are forecast.

Background

The Panama Canal is an 80-kilometer (50-mile) long, man-made waterway connecting the Atlantic Ocean (Caribbean Sea) and Pacific Ocean (Bay of Panama) for purposes of navigation (Figure 1-1). It became operational on August 15, 1914. Ship traffic through the canal has steadily increased in terms of size and frequency and currently about thirty-eight ships transit the canal each day. The canal between the two oceans passes through two natural fresh water lakes—Gatun Lake and Miraflores Lake (see Figure 1-2).

Fresh water from Gatun and Miraflores lakes is used for filling the navigation locks while transiting ships in and out of the lakes. Salt water from the ocean gets added to the lakes by density currents and fresh water from the lakes is lost to the sea during transit of ships. The net loss of fresh water is estimated by the Panama Canal Commission to be about fifty-two million gallons per lockage operation. Fresh water is also supplied to the local population in two cities for drinking purposes at the rate of about forty-seven million gallons per day. During years of low rainfall, a shortage of fresh water is experienced for canal operations.

The Panama Canal Commission is considering expanding the existing ship transit capacity of the canal, which may further increase freshwater consumption and increase salt intrusion from the ocean. The Commission needs an estimate of the potential adverse effects of capapacity expansion and an early indication if remedial measures can be expected to provide protection from those impacts.

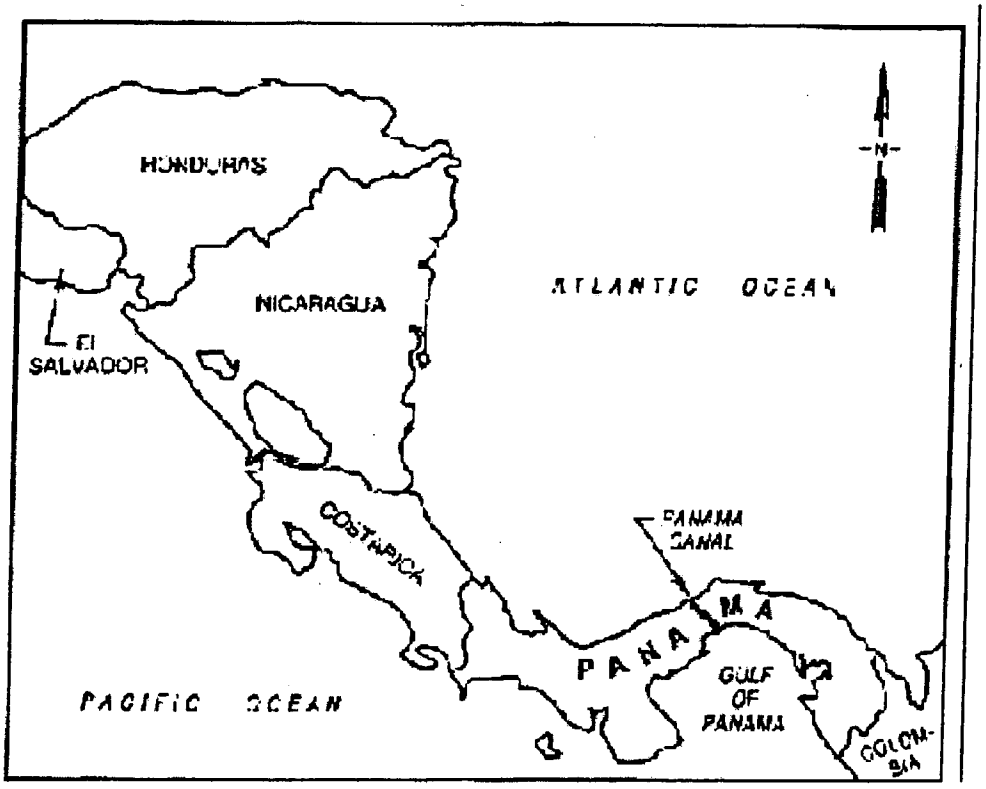


Figure 1-1. Location map

Approach

The objectives were achieved by combining desktop reviews and analytic tools with simple, unverified numerical models that provided rapid estimates of salinity intrusion through the locks and freshwater usage. The following tasks were performed: data on ship transits and observed salinities assembled by Panama Canal Commission staff were compiled and analyzed; a literature review identified potential salinity mitigation methods; spreadsheet calculations characterized salt loading and water usage; a two-dimensional width-averaged (2DV) numerical model was run to define density-driven flow out of the upper locks; and a two-dimensional depth-averaged (2DH) numerical model was run to depict the dispersion path of salt water if it were released into Gatun Lake. The numerical models were applied without verifying them to field observations, an approach which is satisfactory for demonstrating feasibility of plans. If a canal capacity expansion plan is selected for design, these models should be verified to field data before testing the design plan.

Three conditions - existing conditions, use of holding ponds to recirculate lock lift water and conserve fresh water, and use of a Syncrolift lock (see Part 2) to increase transit capacity - were examined, and a number of salinity intrusion mitigation measures were examined for feasibility. Model results for two mitigation methods are presented here - a salt water sump and a gated transition chamber.

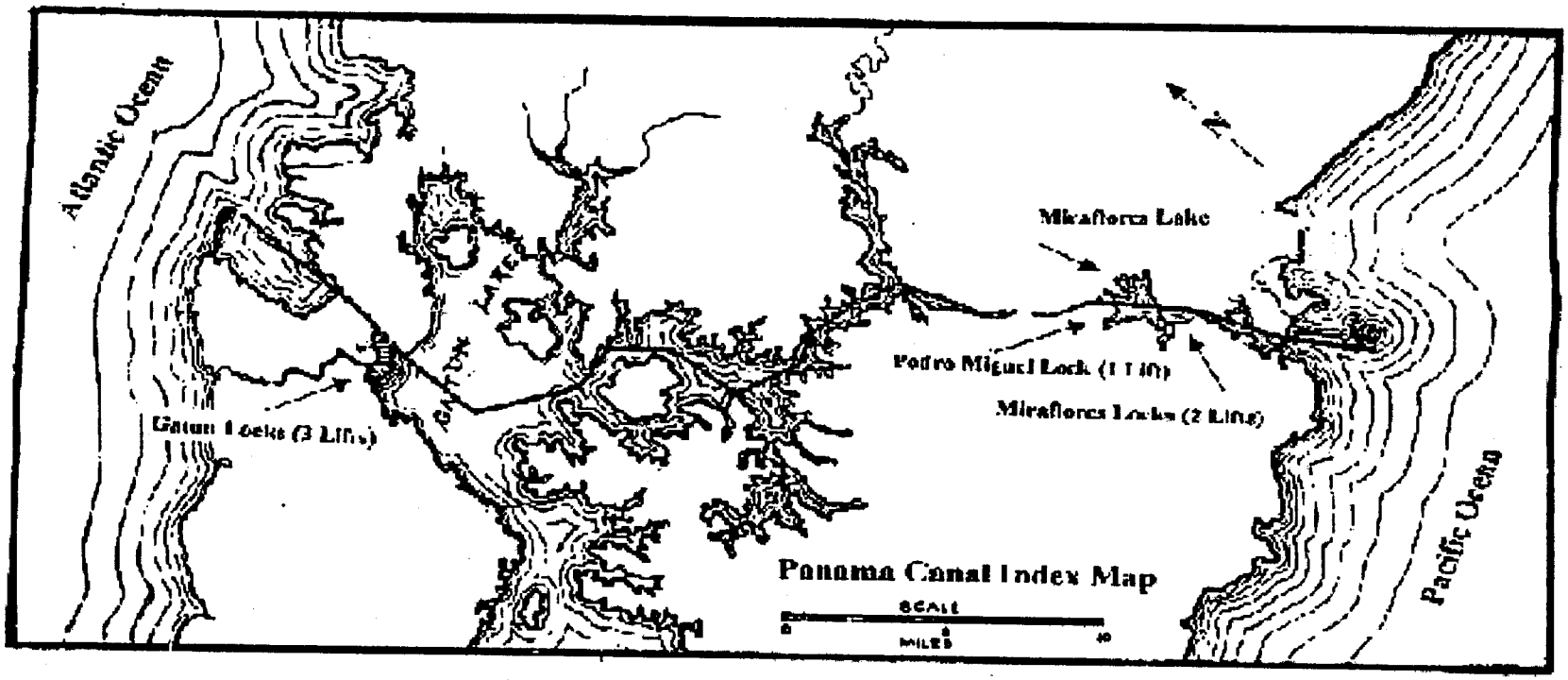


Figure 1-2. Panama Canal index map (provided by PCC)

2 The Panama Canal

Design

The 80 km (50 mile) long man-made Panama Canal connects the Atlantic Ocean on the North side and the Pacific Ocean on the South side (Figure 1-2). On its way it passes through Gatun Lake and Miraflores Lake, in which controlled water levels are maintained at 26 m (85 feet) and 16.5 m (54 feet) above mean sea level, respectively. During high rainfall season Gatun Lake is maintained at a level of 26.7 m (87.5 feet).

Both the Gatun Lake and Miraflores Lake are fresh water lakes. Gatun Lake has an estimated storage of 5.2 billion cubic m (183 billion cubic feet) at a lake level of 26 m (85 feet) and 5.56 billion cu ft (196 billion cubic feet) at an elevation of 26.7 m (87.5 feet). It has a surface area of 435 sq km (168 square miles) at an elevation of 26.7 m (87.5 feet). Gatun Lake was created by placing an earthen dam across the Chagres River. The Gatun Dam is nearly 2.4 km (1.5 mile) long and 0.8 km (half mile) wide at the base, sloping to a width of 30.48 m (100 feet) at the crest, which is 32 m (105 feet) above the sea level, or 6 m (20 feet) above the normal level of Gatun Lake. Another series of dams was constructed under the Madden Dam Project, which stores rain water from the catchment area of about 3367 sq km (1300 sq miles). The main features include the main concrete dam, a hydro power station and several earth and gravel-fill dams. Water level in the Gatun Lake is regulated by releasing excess water to the sea over the spillway of Gatun Dam and by letting in water from the Madden Dam. Water level in Miraflores Lake is regulated through the Miraflores Dam, which is a gravity concrete dam. The dam has a spillway with a design capacity of 2832 cu m/s (100,000 cfs) at the highest allowable level. Miraflores Lake is much smaller compared to the Gatun Lake. It has a surface area of 3.94 sq km (1.52 sq miles) at an elevation of 16.5 m (54 feet). Available active storage of Miraflores Lake between elevations 16 m and 17 m (53 and 55 feet) is approximately 2.5 million cu m (88 million cu feet) and the total storage is on the order of 19 million cu m (670 million cubic feet).

Fresh water from these two lakes is used for filling the navigation locks while transiting ships through the canal. Salt water from the ocean gets added to the lakes during transit of ships from the ocean to the lakes, and fresh water from the lakes is lost to the sea while transiting ships from the lakes to the sea. The net loss of fresh water is estimated to be about 0.20 million cu m (52 million

gallons) per lockage operation. Fresh water from Gatun Lake is also supplied to the local population in two cities for drinking purposes at the rate of about 0.18 million cu m (47 million gallons) per day. During years of low rainfall, a shortage of fresh water is experienced for canal operations.

The Panama Canal has six twin locks, grouped in three sets, namely Miraflores Locks (2 lifts) and Pedro Miguel Lock (1 lift) on the Pacific side and Gatun Locks (3 lifts) on the Atlantic side (Figure 2-1). The three navigation locks on each end lift ships from the ocean to the Gatun Lake through a height of 26 m (85 feet) above sea level and then lower them through three locks, bringing them back to the ocean level. The channel that connects Gatun Lake to the Miraflores Lake is called Gaillard Cut. Ships travel for about 37 km (23 miles) from Gatun Locks to the north end of Gaillard Cut. The twin locks serve two purposes; one as a stand-by in case of closure of one system of locks and the second to serve as an alternate system of locks for transiting multiple small ships in a single transit.

Physical characteristics of the six locks are given in Table 2-1 below.

Table 2-1
Lock Characteristics

Lock	Width & Length (ft)/(m)	Lift Height (ft)/(m)	Lift Volume (cft)/(cu m)	Bed Level (ft)/(m)
Lower Miraflores Lock	110 x 1051 ft 33.5 x 320.3 m	26 ft 7.9m	3.005×10^6 0.851×10^5	-52 ft -16 m
Upper Miraflores Lock	110 x 1071 ft 33.5 x 326.4 m	28 ft 8.5 m	3.298×10^6 0.934×10^5	- 20.3 ft - 6.2 m
Pedro Miguel Lock	110 x 1071 ft 33.5 x 326.4 m	31 ft 9.5 m	3.652×10^6 1.034×10^5	+ 11.0 ft + 3.4 m
Upper Gatun Lock	110 x 1071 ft 33.5 x 326.4 m	28 ft 8.5 m	3.298×10^6 0.934×10^5	+ 13.0 ft + 3.9 m
Middle Gatun Lock	110 x 1051 ft 33.5 x 320.3 m	29 ft 8.8 m	3.352×10^6 0.949×10^5	-15.3 ft - 4.7 m
Lower Gatun Lock	110 x 1051 ft 33.5 x 320.3 m	28 ft 8.5 m	3.237×10^6 0.917×10^5	- 44.3 ft -13.5 m

Balboa Port is located on the Pacific Ocean side and the Port of Cristobal is located on the Atlantic side. Two breakwaters are constructed on the Atlantic side to form Limon Bay, which provides shelter for ships against waves.

Operation

The canal operation consists of two distinct parts, namely raising a ship and lowering a ship. Water from Gatun Lake is released into the higher Gatun Lock and in the Pedro Miiguel Lock for lifting ships in these locks. Water from Miraflores Lake is released into upper Miraflores lock and from there to the lower Miraflores lock for lifting ship from a lower elevation. Large culverts are provided for filling and emptying the locks. A safe rate of change in water elevation in a lock is dependent on the distribution of water. For the Panama

Canal locks a maximum rate of 2.3 m (7.5 ft) per minute with a good water distribution is considered optimum. It takes about 10 minutes to fill or empty a lock.

A ship has to transit through six locks and also sail through an 80.5 km (50-mile) long navigation channel. It requires about nine hours for an average ship to transit the canal. Larger ships are transited during daylight hours whereas smaller vessels are transited at any convenient time. Hydraulics of the Panama Canal Locks is described in detail in a paper by Whitehead (1915).

Traffic

Although 85 years old, the strategically located canal is still one of the most highly traveled waterways of the world. It operates 24 hours a day, 365 days a year transiting vessels of all nations. Since the opening of the waterway to world commerce, the canal has provided transit service to more than 700,000 vessels. Toll collection, which has reached about 500 million dollars a year, is a major source of income for the Republic of Panama. The physical dimensions of locks place a restriction on the maximum size of ship that can transit through the canal. This size, popularly known as the Panamax ship, is shown in Figure 2-2. The maximum length, width and draft for the Panamax ship are 294 m (965 ft), 33.5 m (110 ft) and 12 m (39.5 ft) respectively.

The number of ships that transited through the canal during 1995 through 1998 is shown in Figures 2-3 through 2-6.

Salinity

Very meager data are available on the salinity of water in the two lakes and inside and outside locks. Historical data on salinity are not available probably because in the past years an increase in salinity of lake water was neither noticed nor threatened under normal canal operation. Only during the recent years concern over possible increase in lake salinity was perceived due to increase in ship transits per day and low fresh water inflows. It is learned from verbal communication from PCC officials that the salinity of Miraflores Lake increased quickly immediately after commissioning of the canal, which lead to changing the location of intake for supply of fresh water to the city. Salt accumulation was noticed on the pipes of the power station. A steady-state salinity was however reached shortly (maybe within the first year or so) and the salinity of Miraflores Lake has been less than one part per thousand ever since. Salinity of Gatun Lake is known to be close to or equal to zero. It is reasonable to assume that the salt intake per ship transit is balanced by salt output from both the lakes resulting from the freshwater released per transit from the Gatun Lake.

Field data on salinity collected by PCC are summarized in Table 2-2 below.

Table 2-2 Observed Salinities	
Location and Time	Observed Salinity (ppt)
Pacific Ocean just outside L1 All times.	10.0
Inside L1 Before lift.	8.0
Inside L2 After moving ship from L1 to L2	1.5
Miraflores Lake All times	1.0

Proposed Expansion

The present system has reached its maximum capacity and there is no scope for increasing the number of ships transiting the canal per day. In order to increase transits, the Panama Canal Commission is considering various alternatives. Construction of an additional system of locks is a very expensive option. Providing a Syncrolift type of locks at both ends of the canal is being considered. See description below.

Syncrolift

Raymond Pearlson of Miami, Florida, USA, invented the Syncrolift shiplift system in 1954. In 1979, the original company, named Pearlson Engineering, became Syncrolift Inc, which is a subsidiary of Rolls Royce, UK. The system essentially consists of a large platform, which can be lowered into water, a ship positioned over it and then the platform raised vertically above water along with the ship. It has three principal components: (1) a structural steel platform, (2) electrically powered wire rope hoists for raising and lowering the platform, and (3) an electric motor system to operate the system. Ships are dry docked on the platform using conventional procedure for setting the keel blocks and placing the bilge blocks. Ships raised above water are transported horizontally over rails to the desired location on land. The first Syncrolift was built in Miami, Florida in 1957, and it is still operational. By 1998, 220 Syncrolifts had been installed in 66 countries with lifting capacities from 101,600 kg (100 tons) to 60.9 million kg (60,000 tons).

The advantages of Syncrolift over a conventional lock system are:

- Lower initial cost
- Shorter construction time
- Less susceptible to biological fouling
- No under water work

- No use of fresh water for raising ship. However, freshwater may be lost through density current exchange when the lock doors are opened.

An artist's impression of the Syncrolift lock is shown in Figure 2-7. A schematic diagram of Syncrolift combined with flushing of salt water is shown in Figure 2-8. Dimensions of Syncrolift under consideration for Panama Canal site are shown in Figure 2-9. This information and additional details are available in an article published in the Dock and Harbor Authority, January/February 1999.

Evaluation of Mitigation Options

The following points need to be considered while evaluating alternatives for controlling salinity intrusion. Combination of alternatives may have to be considered to achieve the intended objectives.

- Construction feasibility
- Low initial cost
- Low operational cost
- Long life
- Ease of operation
- Low vessel throughput time
- Low increase in lake water salinity
- Low fresh water consumption

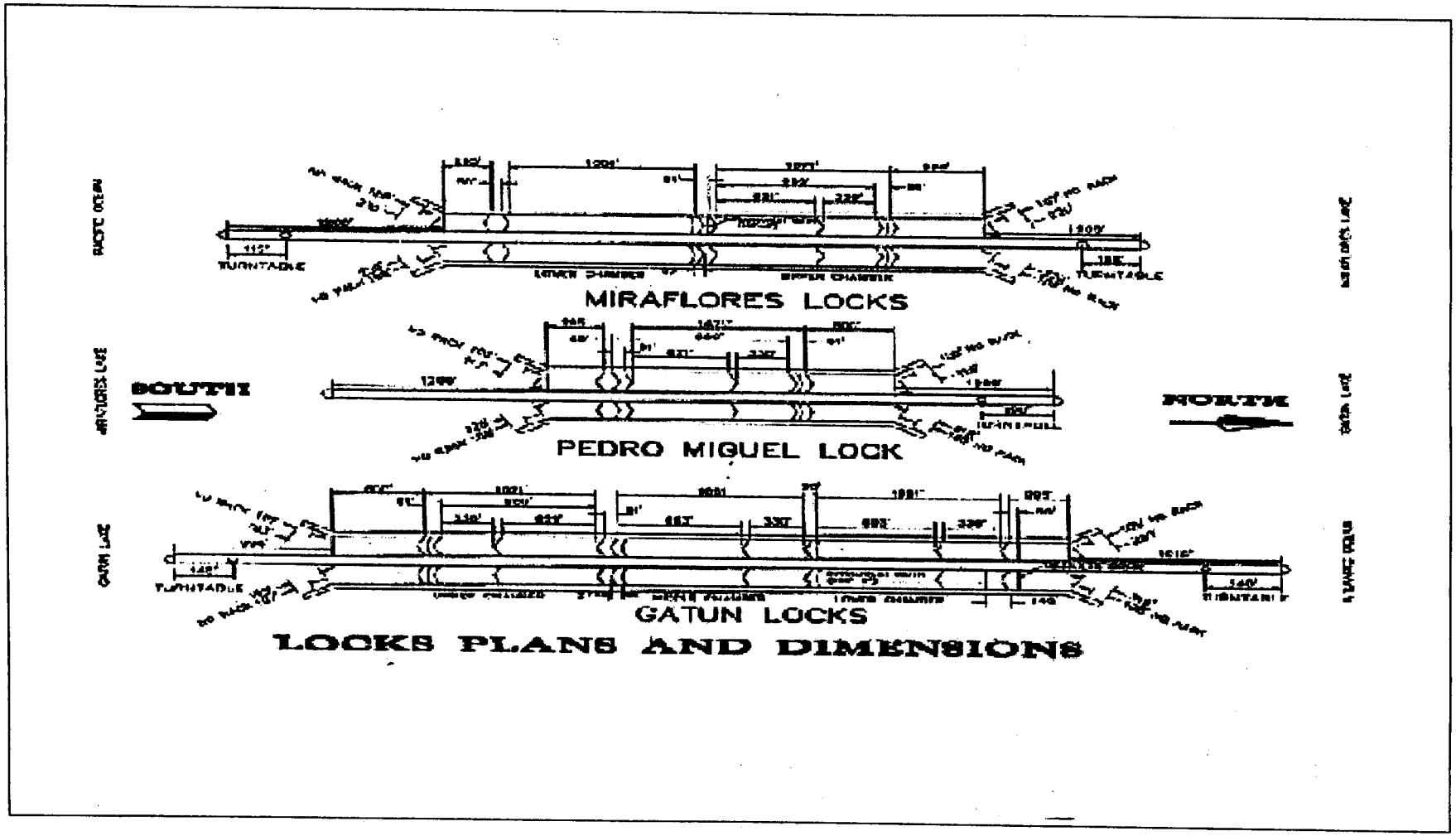


Figure 2-1. Existing locks layout and dimesions.

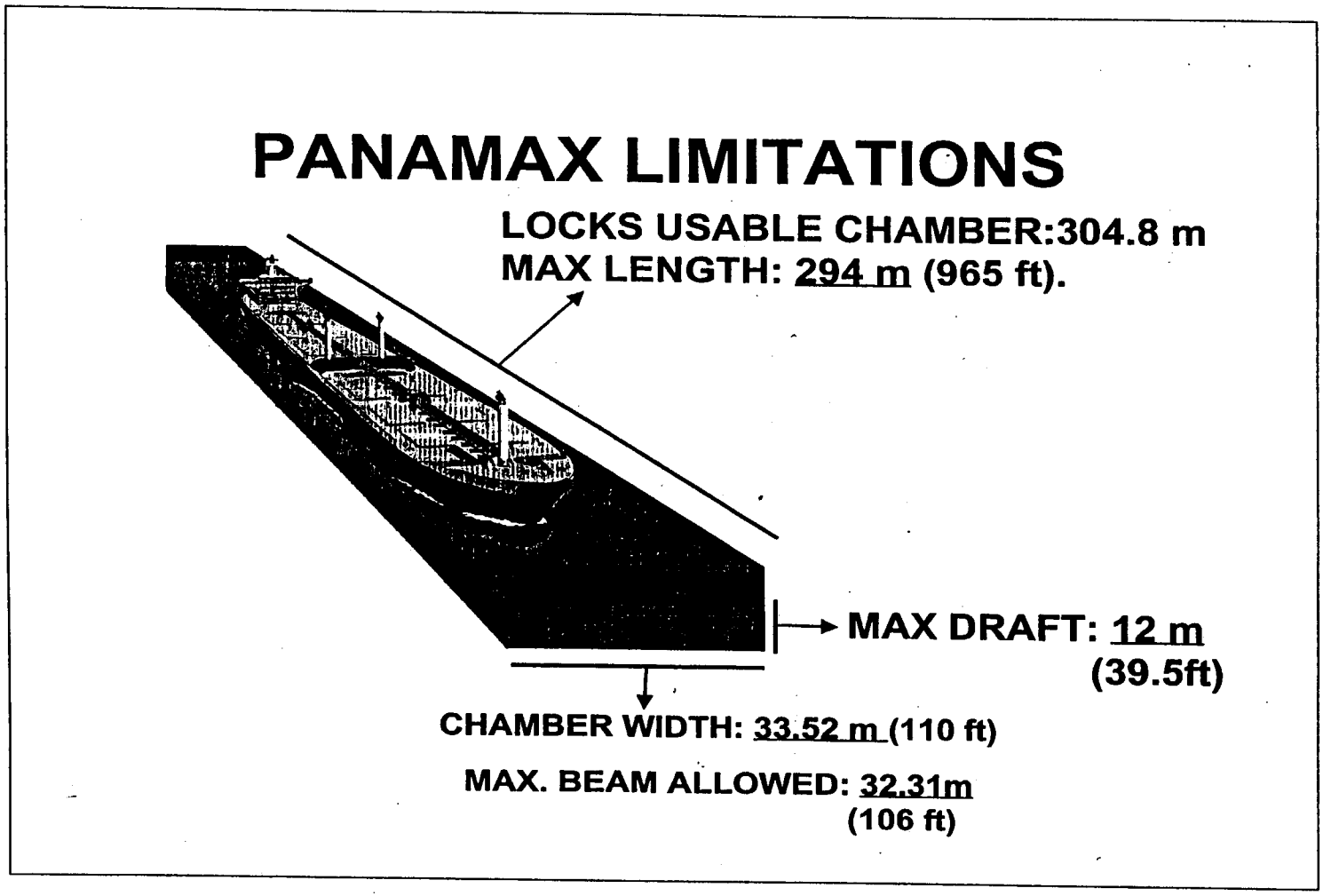


Figure 2-2. Panamax-size vessel and required lock dimensions

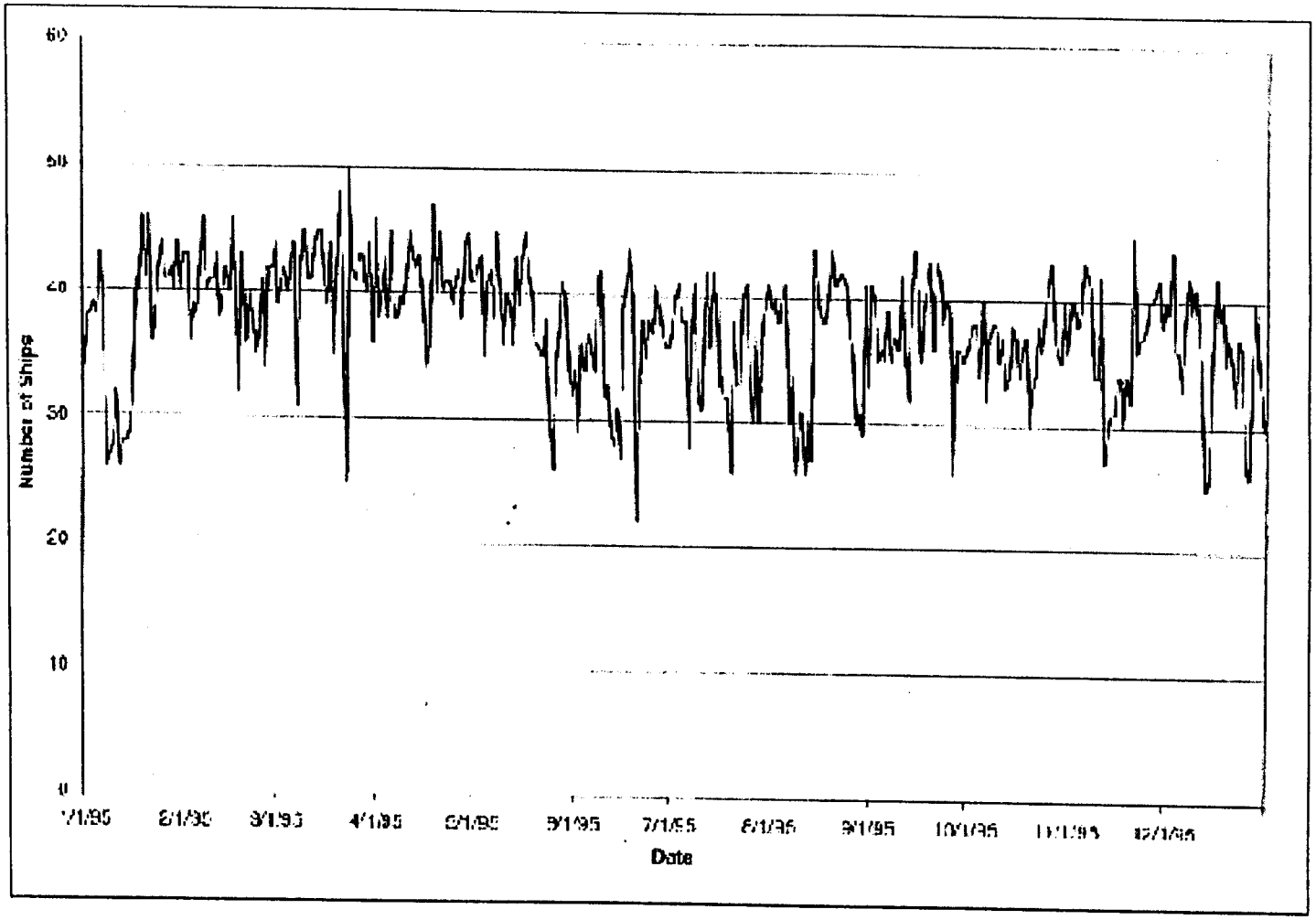


Figure 2-3. Ship transits 1995

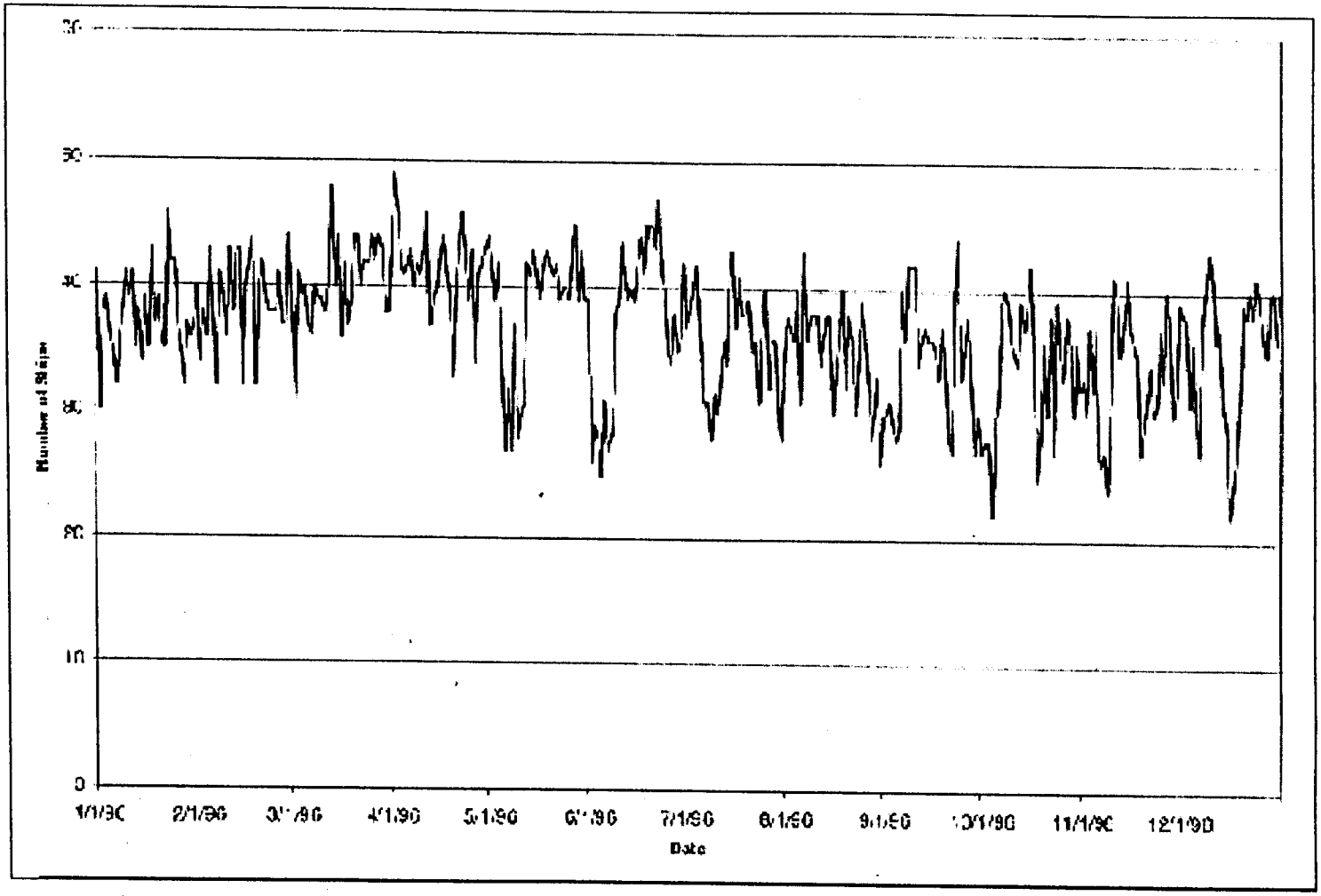


Figure 2-4. Ship transits 1996

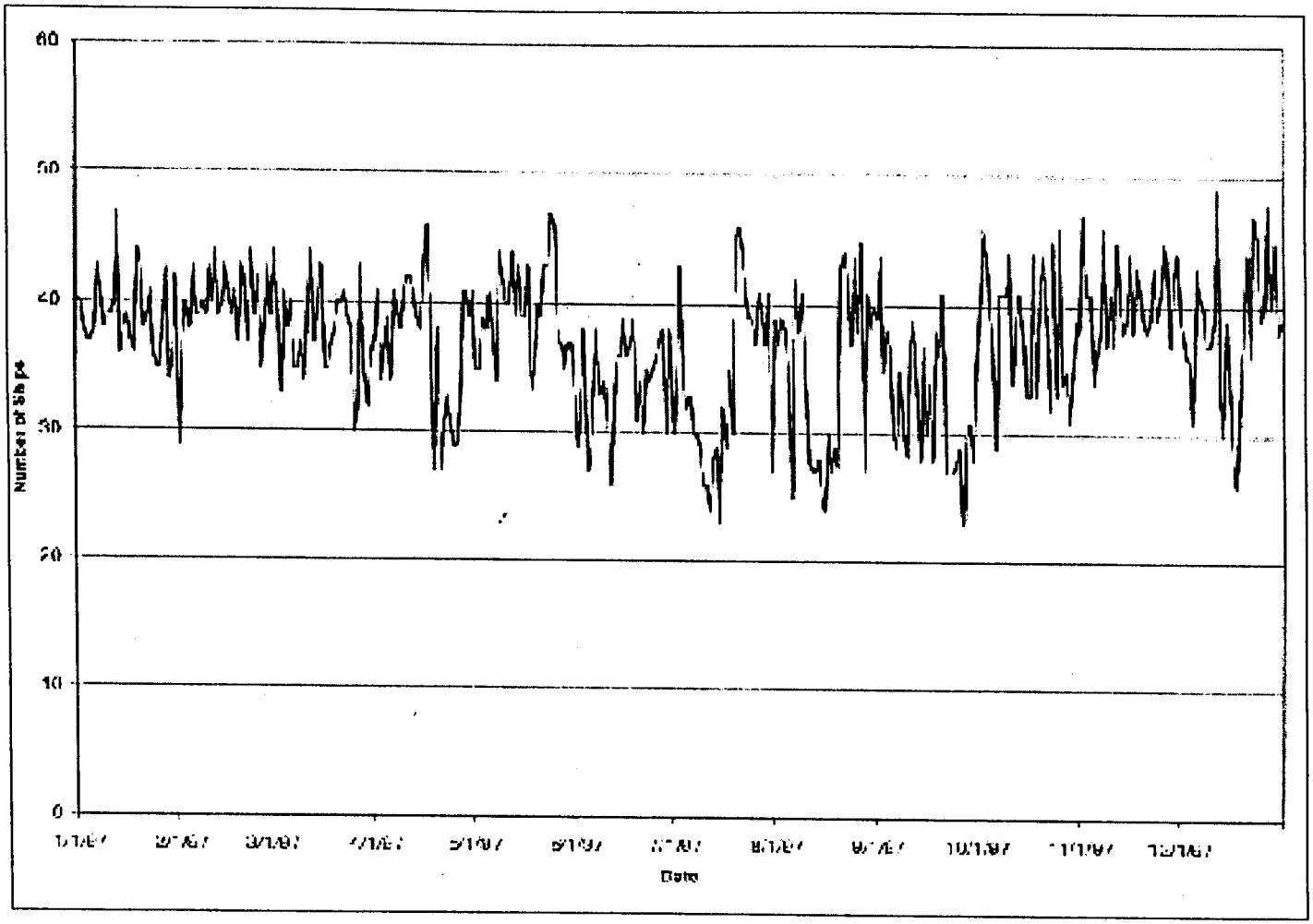


Figure 2-5. Ship transits 1997

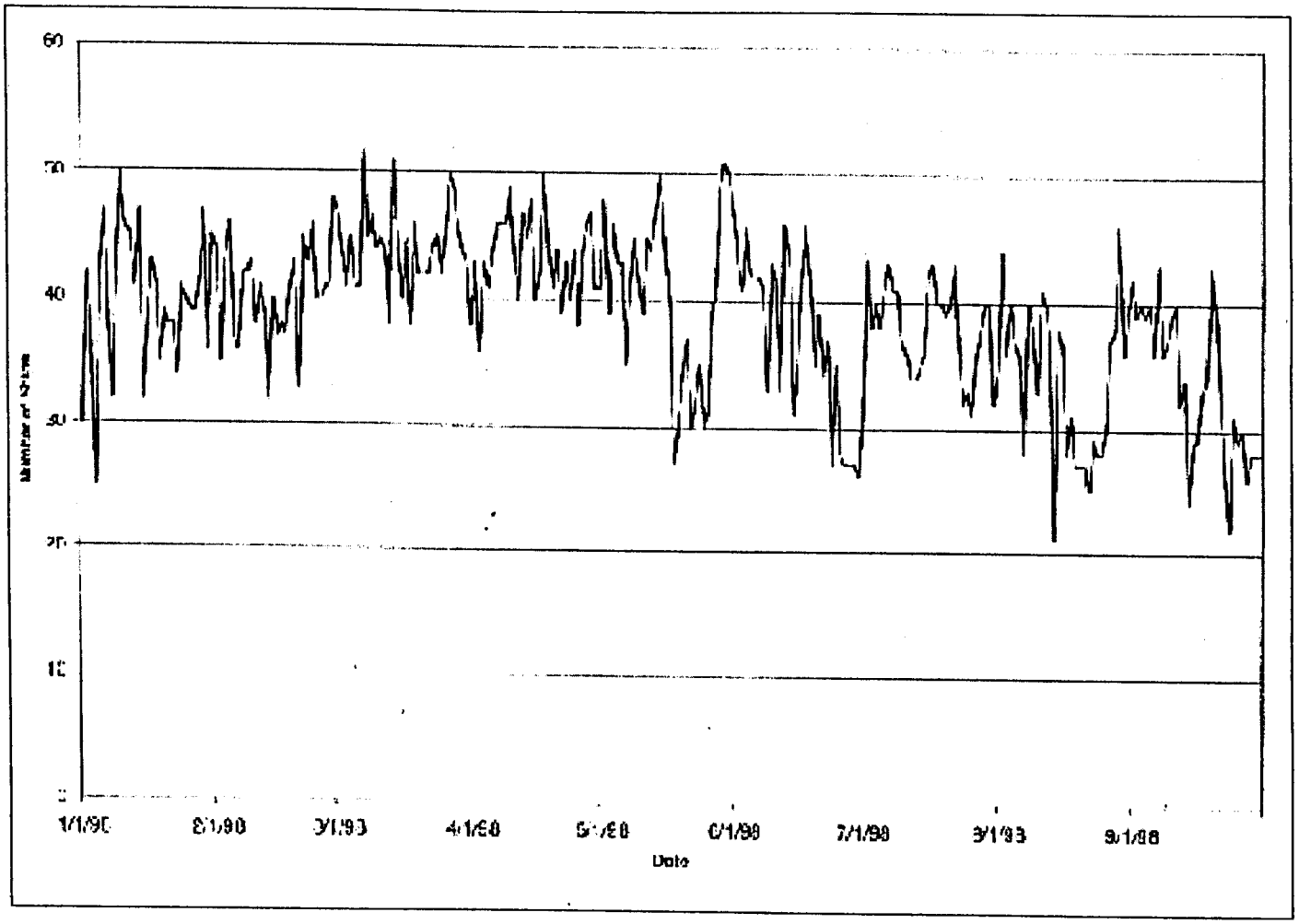


Figure 2-6. Ship transits 1998

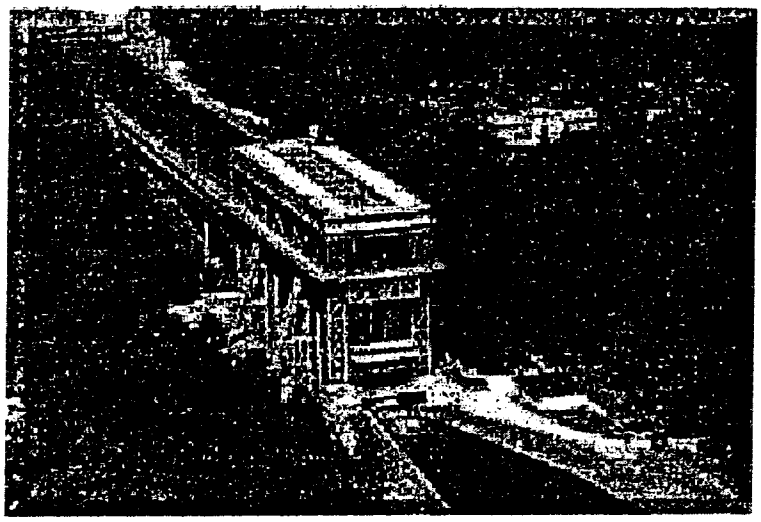


Figure 2-7. Artist's impression of a syncrolift lock. (Source: Syncrolift, Inc. Reprinted with permission.)

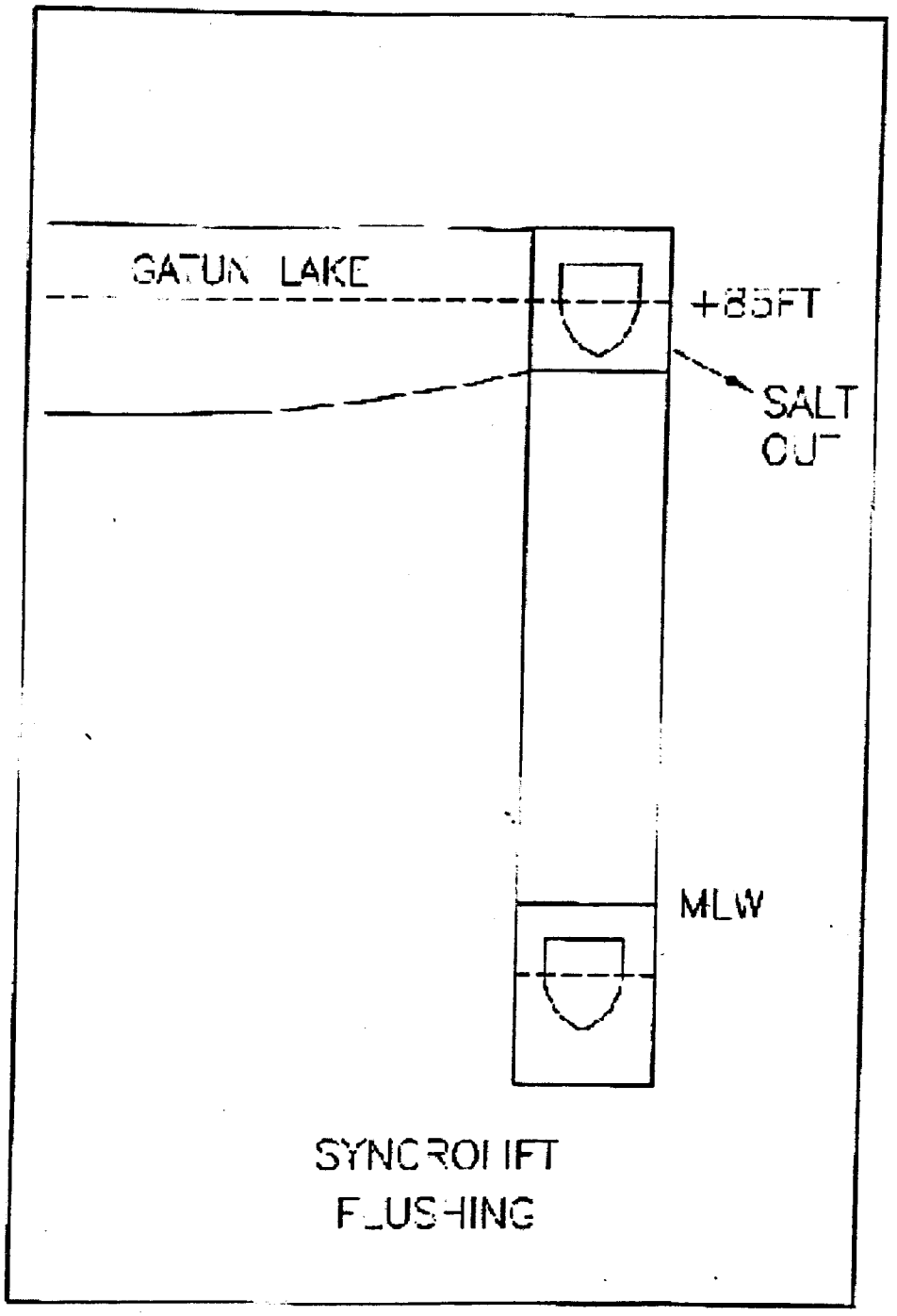


Figure 2-8. Schematic of Syncrolift Lock with flushing

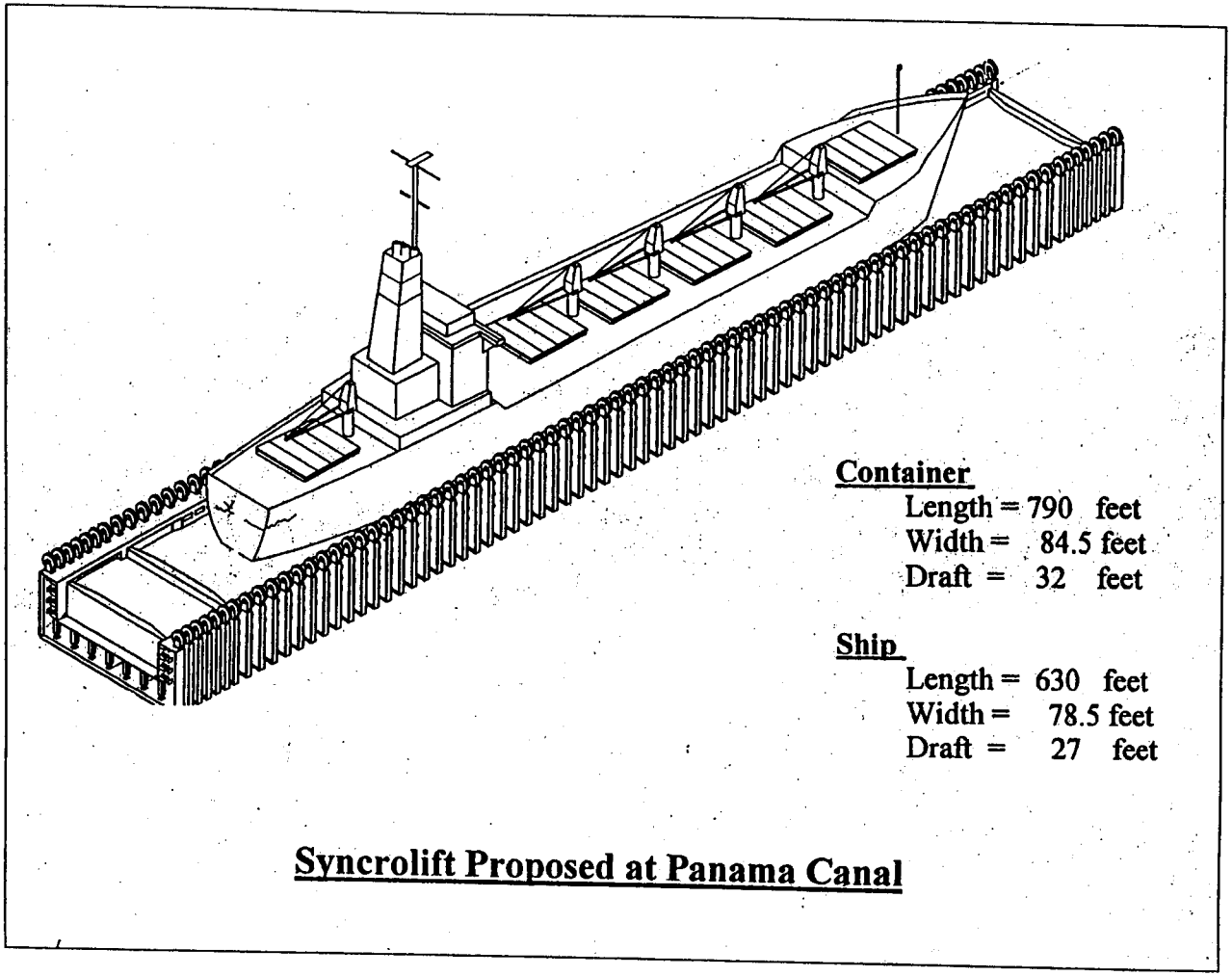


Figure 2-9. Syncrolift Lock dimensions. (Source: Syncrolift, Inc. Reprinted with permission

3 Salt Loading and Freshwater Usage

This section describes the process of salinity intrusion and some straightforward analytical methods for calculating the amount of salt transported into the canal through the locks and the amount of fresh water lost to the sea through the lockage process. The analytical methods are used to back-calculate the maximum salinity that can occur in the Syncrolift lock without increasing salinity intrusion into Gatún Lake and also to evaluate one option for conserving fresh water within the canal – recirculating lift water by collecting it in holding ponds and pumping it back for reuse.

Salinity Intrusion

Seawater contains about 35 grams of dissolved salts per kg, with the primary salt constituents being chloride and sodium ions. This concentration is commonly referred to as "salinity," and was traditionally defined in terms of the mass concentration of halides (principally chlorine forms) in the water and expressed in parts per thousand (ppt). The standard was "Standard Seawater" or "Normal Water" taken from the North Sea and prepared for scientific use and instrument calibration by the Hydrographic Laboratories in Copenhagen, Denmark, and later by the Institute for Oceanographic Services, Wormly, England. The definition of salinity has changed slightly several times in response to practical demands and improved instrumentation.

In 1978 an international panel sponsored by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) recommended that the old salinity definitions be replaced with a "Practical Salinity Scale" based on conductivity and employing no units, replacing the ppt units with the sign $*10^{-3}$. The new scale was defined to yield values close to the old scales, so that 35 ppt was about $35*10^{-3}$. That notation never caught on, but recently the units of "practical salinity units" (psu) have come into more common use. Nevertheless, in this report the traditional units of ppt are used to describe salinities defined under the new, conductivity-ratio-based definition.

The presence of dissolved salts increases the density of water, such that at 35 ppt, water is about 2 percent more dense than at 0 ppt. This seemingly small

difference produces density currents. Given still salt water on one side of a barrier and fresh water on the other side, hydrostatic pressure is equal at the water surface, but the pressure on the salt water side increases more rapidly with depth. This pressure difference produces a net force toward the fresh water side, which will elevate the fresh water side if the barrier is removed. The combination of a raised fresh water level and increased salt water pressure with depth creates a flow of salt water under the fresh and of fresh water over the salt (see Part 5). The speed of the density underflow will be proportional to the square root of the density difference (Keulegan, 1969).

As noted previously, density flows will occur from lock chambers containing water that is either saltier or fresher than the water into which the gates are opened. When chamber containing fresh water is opened to a salt water basin, the salt water will flow into the chamber over the lower portion of the water column and fresh water will flow out over the upper portion of column. If turbulence is present, the two layers will mix, at least partly.

Calculating Salinity and Exchanges in the Locks

The amount of salt intruding into Gatun Lake from lockages can be calculated by analytical or numerical means. In this section a set of simple mass balance equations are used to estimate salt loading and freshwater usage by the locks. For convenient reference, the six locks in the system are given the following notation:

L1: Lowest lock on the Pacific side
L2: Lock between Miraflores Lake and L1.
L3: Lock between Miraflores Lake and Gatun Lake. (Pedro Miguel)
L4: Highest lock directly connected to Gatun Lake.
L5: Middle lock on Atlantic side.
L6: Lowest lock connected to Atlantic Ocean.

A schematic longitudinal section of all the locks is given in Figure A-1 of Appendix A and in Table 2-1, which provide dimensions, lifts, and relevant levels of all the locks.

In these calculations, the following assumptions are made:

a. Tidal variation in sea level can be neglected. All computations are made for mean sea level (msl).

b. Mean sea level can be assumed to be roughly equivalent to the Canal's Precise Level Datum (PLD) without biasing the calculations.

c. Number of lockages is assumed to be the same as the number of ship transits.

d. An average blockage ratio of 0.8 is assumed for calculating submerged volume of ship from the length, beam and draft dimensions.

e. Ocean salinity is assumed to be 35 parts per thousand. Observations (see Part 2) indicate that the local salinity near the lowest gate is much less than ocean salinity because fresh water from the lake is added to the sea for each ship transit and a transition zone exists between the lowest locks and the open sea. Based on the limited observations it is assumed that salinity just outside the lowest lock is 10 ppt on the Pacific side and 8 ppt on the Atlantic side.

f. Volume of water in Miraflores Lake is about 19 million cu m (670 million cft).

g. Net transfer of fresh water from the lake to the sea is about 0.2 million cu m (52 million gallons) per lockage, about 0.1 million cu m (26 million gallons) directly to fill the locks and about 0.1 million cu m (26 million gallons) pushed into the highest lock by density flow.

The following generic lock exchange equations can be used to characterize lock water and salt exchanges. Given the schematic lock shown in Figure 3-1, the left-hand-side (LHS) can be another lock or the sea and the right-hand-side (RHS) can be another lock or Miraflores Lake, Gaillard Cut, or Gatun Lake. The initial conditions (time = 0) for lock volume and salinity are given by:

$$S(0) = S_0 \qquad (1)$$
$$V(0) = V_T - V_L$$

where V_T = total lock volume when filled to full lift height and V_L = volume required to fill lock from minimum fill condition (min in Figure 3-1) to full lift height (max). From this initial condition, a one-way upbound ship transit from left to right occurs in four steps as given below. It is assumed that dissolved salt in the lock chamber is completely mixed[1] at the end of each step.

Step 1: Open LHS gates, move ship into lock, close gates.

The displacement of the entering ship forces an equivalent net volume of water out of the lock to the LHS and density currents force opposite but equal exchanges of saltier water from the LHS for fresher water in the lock. The volume of water exchanged by density flows, V_{LHS}, can be expressed as a fraction of the water volume in the lock:

$$V_{LHS} = E_{LHS}(V_T - V_S) \qquad (2)$$

where E_{LHS} = an exchange coefficient between 0 and 1, V_S = displacement volume of the ship, and the net volume (V_T - V_S) is the lesser of the two

[1] The complete mixing assumption is reasonable overall, since: a) lower salinity (thus usually lower density) filling water enters the chamber from the bottom and rises through higher salinity water with considerable turbulence; and b) during movement from one chamber to the next, ship propwash generates substantial mixing.

connected chamber volumes. At the end of Step 1, the volume and salinity of the water inside the lock chamber are given by:

$$V(1) = V(0) - V_S$$
$$= V_t = V_L$$

$$S(1) = \frac{S(0)V(0) - S(0)V_{LHS} + S_{LHS}V_{LHS} - S(0)V_s}{V(1)} \tag{3}$$

$$= \frac{S(0)(V(0) - V_{LHS} - V_L) + S_{LHS}V_{LHS}}{V(1)}$$

where S_{LHS} = salinity of the water outside the lock on the left-hand-side.

Step 2: Fill lock chamber

Applying conservation of mass for water and salt once more yields equations for volume and salinity within the chamber at the end of Step 2:

$$V(2) = V_T - V_S$$
$$S(2) = \frac{S(1)V(1) + S_L V_L}{V(2)} \tag{4}$$

where S_L = salinity of the lift water, which can be the salinity of the water outside the right-hand-side of the lock (either the next higher lock or lake) or, if a holding pond is employed, the salinity of water in the holding pond.

Step 3: Open right-hand-side (RHS) gates, move the ship out of the lock, and close the gates

During the step there is densimetric exchange with the RHS and water from the RHS flows into the lock to replace the ship displacement. The densimetric exchange volume is given by:

$$V_{RHS} = E_{RHS}(V_T - V_S) \tag{5}$$

At the end of the step the volume and salinity within the chamber are:

$$V(3) = V_T$$
$$S(3) = \frac{S(2)(V(2) - V_{RHS}) + S_{RHS}(V_{RHS} + V_S)}{V(3)} \tag{6}$$

where S_{RHS} = salinity of the water outside the RHS gates.

Step 4: Drain lift volume from the lock

At the end of step 4 the volume and salinity are given by:

$$V(4) = V_T - V_L$$
$$S(4) = S(3) \tag{7}$$

and the lock is in the same fill configuration as the initial condition so that another cycle can begin.

By substitution of known values and algebraic manipulation, these equations can be used to derive an expression for the salinity in the lock chamber at the end of N one-way, upbound lockages:

$$\begin{aligned} S_N &= S(0) + N(S(4) - S(0)) \\ &= S_0 + N\left\{ S_0 \left[\frac{(V_T - V_L - V_S - V_{RHS})(V_T - V_S - V_L - V_{LHS})}{V_T (V_T - V_S)} - 1 \right] \right. \\ &\quad + S_L \left[\frac{V_L (V_T - V_S - V_{RHS})(V_T - V_S - V_L - V_{LHS})}{V_T (V_T - V_S)(V_T - V_L)} \right] \\ &\quad \left. + S_{RHS} \left[\frac{V_{RHS} + V_S}{V_T} \right] + S_{LHS} \left[\frac{V_{LHS} (V_T - V_S - V_L - V_{LHS})}{V_T (V_t - V_S)} \right] \right\} \end{aligned} \tag{8}$$

A similar process can be used to develop expressions for the salinity with one-way downbound lockages and two-way lockages.

Equation 8 has been coded in spreadsheet format to facilitate evaluation of some salt mitigation alternatives for specific locks, and results for existing conditions are shown in Tables 3-1 and 3-2 for the Miraflores and Gatun Locks, respectively. The assumed initial condition was zero salinity in the locks and Miraflores Lake, and 10 ppt just outside the lowest lock on the Pacific side and 8 ppt on the Atlantic side (see Part 2). The exchange coefficients, E_{LHS} and E_{RHS}, can be determined empirically by fitting Equation 8 to observed salinities in the Panama Canal Locks. Given the limited observations of Part 2, they were estimated to be about 0.5 (Keulegan, 1957), and Tables 3-1 and 3-2 show them to yield results that are reasonably consistent with the the observed salinities (Part 2). After about 20 lockages the lock chamber salinities have reached equilibrium values ranging from 0.1 ppt in L4 to 3 ppt in L1. Tuning of these coefficients will generate lock salinities in even closer agreement with the observations, but the limited number of observations and the simplicity of the method do not justify it. Appendix A employs the basic equations with the exchange coefficients transformed into transfer coefficients in order to precisely match observed lock salinities and then compute salt loadings and water flows through each set of locks. Those calculations show the salt loading to be extremely sensitive to the calculated in-lock salinities. For example, varying the ambient salinity of Miraflores Lake from 1.1 ppt to 1.4 ppt causes the net salt input to the lake to vary from +17,000 lbs per transit to -44,000 lbs per transit. A near-equilibrium salinity occurs if the lake has a salinity of 1.18 ppt.

Table 3-1
Pacific Locks Salinity

PARAMETER		LHS	LOCK 1		LOCK 2		LAKE MIRAFLORES		LOCK 3		LAKE GATUN	
TOTAL FILLED VOL (VT) cf			9.02E+06		8.76E+06		8.70E+08		8.71E+06			
LIFT VOL (VL) cf			3.01E+06		3.30E+06		3.65E+06		3.65E+06			
SHIP VOL (VS) cf			1.14E+06		1.14E+06		1.14E+06		1.14E+06			
EXCHANGABLE VOL, cf			6.01E+06	5.46E+06	5.46E+06	5.46E+06	8.66E+08	5.06E+06	5.06E+06	5.06E+06		
VT-VL			6.01E+06		5.46E+06		8.66E+08		5.06E+06			
VT-VS			7.88E+06		7.62E+06		8.69E+08		7.57E+06			
VT-VL-VS			4.87E+06		4.32E+06		8.65E+08		3.92E+06			
EXCHANGE COEFS (ELHS & ERHS)		0.50	0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
EXCHANGE VOL (VLHS & VRHS)			3.01E+06	2.73E+06	2.73E+06	2.73E+06	4.33E+08	2.53E+06	2.53E+06	2.53E+06		
TERM 1	S0*		5.63E-02		3.79E-02		4.93E-01		2.92E-02			
TERM 2	SL*		9.07E-02		7.86E-02		4.17E-03		7.69E-02			
TERM 3	SLHS*		2.18E-01		2.00E-01		4.96E-01		1.93E-01			
TERM 4	SRHS*		4.29E-01		4.42E-01		4.22E-03		4.21E-01			

LOCKAGES	LHS SALINITY ppt		LOCK 1 SALINITY ppt		LOCK 2 SALINITY ppt		MIRAFLORES SALINITY ppt		LOCK 3 SALINITY ppt		GATUN SALINITY ppt	
0		10.00		3.05		0.00		0.00		0.00		0
1		10.00		2.35		0.47		0.23		0.02		0
2		10.00		2.56		0.65		0.44		0.03		0
3		10.00		2.66		0.78		0.61		0.04		0
4		10.00		2.74		0.89		0.74		0.05		0
5		10.00		2.80		0.98		0.85		0.06		0
6		10.00		2.85		1.05		0.94		0.06		0
7		10.00		2.88		1.11		1.01		0.07		0
8		10.00		2.92		1.15		1.07		0.07		0
9		10.00		2.94		1.19		1.12		0.07		0
10		10.00		2.96		1.22		1.16		0.08		0
11		10.00		2.98		1.25		1.19		0.08		0
12		10.00		2.99		1.27		1.22		0.08		0
13		10.00		3.00		1.28		1.24		0.08		0
14		10.00		3.01		1.29		1.25		0.08		0
15		10.00		3.02		1.31		1.27		0.08		0
16		10.00		3.03		1.31		1.28		0.08		0
17		10.00		3.03		1.32		1.29		0.09		0
18		10.00		3.04		1.33		1.29		0.09		0
19		10.00		3.04		1.33		1.30		0.09		0
20		10.00		3.04		1.33		1.30		0.09		0
21		10.00		3.04		1.34		1.31		0.09		0
22		10.00		3.05		1.34		1.31		0.09		0
23		10.00		3.05		1.34		1.31		0.09		0
24		10.00		3.05		1.34		1.32		0.09		0
25		10.00		3.05		1.35		1.32		0.09		0
26		10.00		3.05		1.35		1.32		0.09		0
27		10.00		3.05		1.35		1.32		0.09		0
28		10.00		3.05		1.35		1.32		0.09		0
29		10.00		3.05		1.35		1.32		0.09		0
30		10.00		3.05		1.35		1.32		0.09		0
31		10.00		3.05		1.35		1.32		0.09		0
32		10.00		3.05		1.35		1.32		0.09		0
33		10.00		3.05		1.35		1.32		0.09		0
34		10.00		3.05		1.35		1.32		0.09		0
35		10.00		3.05		1.35		1.32		0.09		0
36		10.00		3.05		1.35		1.32		0.09		0
37		10.00		3.05		1.35		1.32		0.09		0
38		10.00		3.05		1.35		1.32		0.09		0
39		10.00		3.05		1.35		1.32		0.09		0
40		10.00		3.05		1.35		1.32		0.09		0

Table 3-2
Atlantic Locks Salinity

PARAMETER		LHS	LOCK 6		LOCK 5		LOCK 4		LAKE GATUN	
TOTAL FILLED VOL (VT) cf			9.36E+06		8.36E+06		8.48E+06			
LIFT VOLUME (VL) cf			3.24E+06		3.35E+06		3.65E+06			
SHIP VOLUME (VS) cf			1.14E+06		1.14E+06		1.14E+06			
EXCHANGABLE VOL, cf			6.12E+06	5.01E+06	5.01E+06	5.01E+06	4.83E+06	4.83e+06		
VT-VL			6.12E+06		5.01E+06		4.83E+06			
VT-VS			8.22E+06		7.22E+06		7.34E+06			
VT-VL-VS			4.98E+06		3.87E+06		3.69E+06			
EXCHANGE COEFS (ELHS&ERHS)		0.5	0.5	0.50	0.50	0.50	0.50	0.50	0.50	
EXCHANGE VOL (VLHS&VRHS)			3.06E+06	2.50E+06	2.50E+06	2.50E+06	2.42E+06	2.42E+06		
TERM 1	S0*		6.18E-02		3.08E-02		2.61E-02			
TERM 2	SL*		1.04E-01		7.58E-02		7.48E-02			
TERM 3	SLHS*		2.27E-01		1.96E-01		1.91E-01			
TERM 4	SRHS*		3.89E-01		4.36E-01		4.19E-01			

LOCKAGES	LHS SALINITY		LOCK 6 SALINITY ppt		LOCK 5 SALINITY ppt		LOCK 4 SALINITY ppt		LAKE GATUN SALINITY ppt	
0		8.00		0.00		0.00		0.0		0
1		8.00		1.82		0.36		0.07		0
2		8.00		2.11		0.46		0.09		0
3		8.00		2.18		0.49		0.10		0
4		8.00		2.19		0.49		0.10		0
5		8.00		2.20		0.49		0.10		0
6		8.00		2.20		0.50		0.10		0
7		8.00		2.20		0.50		0.10		0
8		8.00		2.20		0.50		0.10		0
9		8.00		2.20		0.50		0.10		0
10		8.00		2.20		0.50		0.10		0
11		8.00		2.20		0.50		0.10		0
12		8.00		2.20		0.50		0.10		0
13		8.00		2.20		0.50		0.10		0
14		8.00		2.20		0.50		0.10		0
15		8.00		2.20		0.50		0.10		0
16		8.00		2.20		0.50		0.10		0
17		8.00		2.20		0.50		0.10		0
18		8.00		2.20		0.50		0.10		0
19		8.00		2.20		0.50		0.10		0
20		8.00		2.20		0.50		0.10		0
21		8.00		2.20		0.50		0.10		0
22		8.00		2.20		0.50		0.10		0
23		8.00		2.20		0.50		0.10		0
24		8.00		2.20		0.50		0.10		0
25		8.00		2.20		0.50		0.10		0
26		8.00		2.20		0.50		0.10		0
27		8.00		2.20		0.50		0.10		0
28		8.00		2.20		0.50		0.10		0
29		8.00		2.20		0.50		0.10		0
30		8.00		2.20		0.50		0.10		0
31		8.00		2.20		0.50		0.10		0
32		8.00		2.20		0.50		0.10		0
33		8.00		2.20		0.50		0.10		0
34		8.00		2.20		0.50		0.10		0
35		8.00		2.20		0.50		0.10		0
36		8.00		2.20		0.50		0.10		0
37		8.00		2.20		0.50		0.10		0

Tables 3-3 and 3-4 list the results of the salt loading calculations.

Table 3-3
Estimates of Salinities Resulting from Ships Transiting from Pacific Entrance

Location and stage	Salinity (ppt)	Transfer Coefficient (%)
Pacific Ocean	35.0	100.0
Pacific Ocean just outside L1	10.0	28.6
Inside Lock L1 after ship enters	8.0	22.9
Inside Lock L1 after full lift	5.5	15.8
Inside Lock L2 after ship enters	1.5	4.3
Inside Lock L2 after full lift	1.3	3.7
Inside Lock L2 after ship leaves	1.0	2.9
Miraflores Lake	1.0	2.9
Inside Lock L3 after ship enters	0.3	0.7
Inside Lock L3 after full lift	0.1	0.4

Table 3-4
Estimate of salt transfer coefficients from Atlantic Entrance

Location and stage	Salinity (ppt)	Transfer coefficient %)
Atlantic Ocean	35.0	100.0
Atlantic Ocean just outside L6	10.0	28.6
Inside Lock L6 after ship enters	8.0	22.8
Inside Lock L6 after full lift	5.4	15.6
Inside Lock L5 after ship enters	1.5	4.3
Inside Lock L5 after full lift	0.8	2.3
Inside Lock L4 after ship enters	0.2	0.4
Inside Lock L4 after full lift	0.1	0.2

Zero-Dimensional Model of Gatun Lake Salinity

Using the basic approach given in the above exchange equations, a zero-order numerical model[1] was developed to describe the salinity accumulation in Gatun Lake. The model computes the salinity of Gatun Lake based upon the inflow of fresh water from Madden Lake, local tributaries, exchange with the Pedro Miguel and Gatun locks, and the influx of salt from the proposed Syncrolift Locks on both ends of the canal. Equation 9 shows the mass balance equation used for the model.

$$S_{GL}^{t+1} = \frac{\left(\begin{array}{l} V_{GL} * S_{GL} + (V_{Madden} + V_{trib}) * S_{Madden} \\ + (V'_{L3} - V_S) * S_{L3} * EX_{L3} * N + (V'_{L4} - V_S) * S_{L4} * EX_{L4} * N_L \\ +2 * ((V_{sync} - V_{sync}^{ship}) * S_{sync} * EX_{sync} * N_{sync}) \end{array} \right)}{\left(\begin{array}{l} V_{GL} + V_{Madden} + V_{trib} \\ + ((V'_{L3} - V_S) * EX_{L3} + (V'_{L4} - V_S) * EX_{L4}) * N_L \\ +2 * ((V_{sync} - V_{sync}^{ship}) * EX_{sync} * N_{sync}) \end{array} \right)} \quad (9)$$

where S_{GL}^{t+1} is salinity in Gatun Lake at the end of the time step, S_{GL} is the salinity in Gatun Lake at the beginning of the time step and V_{GL} is the volume of Gatun Lake; V_{Madden} and V_{trib} are volumetric inflows into Gatun Lake from Lake Madden and local tributaries, S_{Madden} is the salinity of the inflows from Madden Lake and the local tributaries; V_S is ship volume, V_{L3}, S_{L3}, and EX_{L3} are the lock volume, salinity, and average exchange ratio for lock 3 (Pedro Miguel Locks); V_{L4}, S_{L4}, and EX_{L4} are the lock volume, salinity, and exchange ratio for L4 (Uppermost lock at Gatun Locks); N_L is the number of lockages per time interval at the Gatun or Pedro Miguel Locks; and V_{sync}, V_{sync}^{ship}, S_{sync}, EX_{sync}, and N_{sync} are the lock volume, ship volume, salinity, exchange ratio, and number of lockages per time interval for the Syncrolift facilities.

The observed salinity in and around the L1 (Miraflores Locks) provides a means of estimating the in-lock salinity of the Pedro Miguel Locks. The salinity of the brackish water seaward of L1 was measured at 8-10 ppt, a reduction by a factor of nearly 4 compared to seawater. It seems likely that the Miraflores Lake's salinities would demonstrate similar tendencies in the vicinity of Pedro Miguel Locks. Thus, the salinity at the entrance to L3 would be less than 0.7 ppt by a factor of 3-4, estimated at 0.200 ppt. The dilution that occurs during filling of L3 with fresh water will further reduce the salinity exposed to Gatun Lake to approximately 0.100 ppt.

Using this loading rate and the zero-order model, a steady-state salinity can be estimated for Gatun Lake at about 0.030 ppt (Figure 3-2), which is well below the maximum salinity for drinking water of 0.250 ppt and at an appropriate level,

[1] EXCEL spreadsheet model entitled Lake Gatun Zero-Order Salinity Intrusion Model v1.1 Sep 1999.

since there are no reported salinity problems within Gatun Lake. The zero-order model also shows the time scale of salinity equilibrium into Gatun Lake to be on the order of 6-10 years. Table 3-5 gives the conditions used in this calculation and for other examples presented in subsequent figures.

Table 3-5
Data Used in Zero-Order Model Analysis

Location/Process	Variable	Case 1	Case 2	Case 3	Case 4
Gatun Lake	Time interval	1 yr			
	Initial salinity, ppt	0			
	Volume, cf	1.82E+11			
Madden Lake and Tributary Inflow Average	Annual spill volume, cf	5.73E+09			
	Annual power volume, cf	6.66E+10			
	Annual Tributary Volumes, cf	4.53E+10			
	Salinity, ppt	0			
Exchange during lift operations Pedro Miguel Locks	Annual lock volume, cf	5.12E+10			
	Exchange coefficient	0.5			
	Lock salinity, ppt	0.1			
	Number of lockages/day	38			
Exchange during lift operations Gatun Locks	Annual lock volume, cf	5.45E+10			
	Exchange coefficient	0.5			
	Lock salinity, ppt	0.1			
	Number of lockages/day	38			
Exchange during lift operations Miraflores syncrolift	Annual lock volume, cf	0	8.74E+09		
	Exchange coefficient	0	0.5		
	Lock salinity, ppt	0	35	4.5	0.3
	Number of lockages/day	20			
Exchange during lift operations Gatun Syncrolift	Annual lock volume, cf	0	8.74E+09		
	Exchange coefficient	0.5			
	Lock salinity	0	35	4.5	0.3
	Number of lockages	20			

The Syncrolift facilities were added to the loading equation with an exchange coefficient of 50 percent, similar to the conventional locks. Its volume was based on dimensions of 243.8 m (800 ft) long by 26.9 m (88.5 ft) wide by 9.8 m (32 ft) deep, which will contain a ship with a displacement of 30,242 cu m (1.068 million cubic feet). With an in-lock salinity of 35.0 ppt (seawater), the steady state condition within Gatun Lake would be about 1.7 ppt (Figure 3-3) for 20 lockages per day. Even for a much lower salinity loading of 10 ppt (brackish water outside of Miraflores Locks), the steady state concentration is estimated at 0.500 ppt, which is double the drinking water maximum of 0.250 ppt. These results clearly indicate that, without mitigating technology, salinity in Gatun Lake could become unacceptably high once additional locks are put into operation.

Varying the salinity of the Syncrolift lock provides insight into the potential impacts on Gatun Lake salinity. Without exceeding the drinking water maximum in Gatun Lake, the allowable salinity in the Syncrolift Lock is approximately 4.5 ppt (Figure 3-4). However, if an allowable increase in Gatun Lake salinity of 0.010 ppt is adopted (from 0.030 to 0.040 ppt), then the salinity within the Syncrolift Lock could not exceed 0.300 ppt (Figure 3-5).

Recirculation of Lift Water in Holding Ponds

In this scenario, depicted schematically in Figure 3-6, the lockage process consists of the steps listed above for a one-way transit upbound, and when the uppermost lock (L3 or L4) is filled, part of the lift volume is drawn from an upper holding pond and part from Gatun Lake. When the lowest lock (L1 or L6) is drained to accept the next ship at sea level, the lift volume is drained into the lower holding pond. Water from the lower holding pond is pumped to the upper pond for reuse.

In a recirculation operation, the salinity of the water used to fill the uppermost lock will be the salinity of the upper holding pond, which at the end of one lockage is given by:

$$S_L = S_{UHP}(1) = \frac{S_{UHP}(0)V_{UHP}(0) - S_{UHP}(0)V_L + V_P S_{LHP}(0)}{V_{UHP}(1)} \quad (10)$$

where the numbers in parentheses indicate the lockage number, S_{UHP} is salinity of the upper pond, S_{LHP} is salinity of the lower pond, V_P is the water volume pumped from the lower pond to the upper pond during one lockage, and V_{UHP} is volume of the upper pond, given by:

$$V_{UHP}(1) = V_{UHP}(0) - V_L + V_P \quad (11)$$

The salinity of the lower holding pond after one lockage will be:

$$S_{LHP}(1) = \frac{S_{LHP}(0)V_{LHP}(0) + S_{LL}(0)V_L - S_{LHP}(0)V_P}{V_{LHP}(1)} \quad (12)$$

where S_{LL} is the salinity of the lowest lock chamber at the end of a lockage and V_{LHP} is volume of the lower holding pond, given by:

$$V_{LHP}(1) = V_{LHP}(0) + V_L - V_P \quad (13)$$

During each one-way lockage, the volume of fresh water consumed by the existing procedure over N lockages can be approximated by:

$$V_F(N) = \sum_{n-1}^{N} [V_L(1-F) + V_{RHS,HL} + V_S] \quad (14)$$

where $V_{RHS,HL}$ is the right-hand-side exchange volume for the highest lock. With the holding pond recirculation procedure, the freshwater consumption will be:

$$V_{F,P}(N) = V_{UHP} + \sum_{n=1}^{N} [V_L(1-F) + V_{RHS,HL} + V_S] \quad (15)$$

where F is the fraction of the lift volume drawn from the upper holding pond.

More fresh water will be consumed by two-way lockages than by one-way, since an extra lift volume is used to fill one lock chamber that cannot be filled from the next higher lock, but the ratio of the two volumes (Equation 15 divided by 14) for one-way lockage can be used to approximate the overall savings in fresh water consumption.

Equation 8 and Equations 10-15, coded in a spreadsheet[1] and combined with the following assumptions, provide a tool for examining the salinity and fresh water usage effects of this operation. The additional assumptions are:

a. Each pond is well-mixed at the end of each lockage.

b. The salinity just seaward of the lowest locks is proportional to the salinity of the water in the lowest lock chamber, but cannot rise above sea salinity of 35 ppt.

c. The small differences in individual lock lift volumes is neglected.

Assumption *b* above is based on the observation that salinities just seaward of the lowest locks were just 8 to 10 ppt instead of 35 ppt, apparently because of dilution with freshwater from lock and spillway operations. If recirculating lift water reduces freshwater consumption, those seaward salinities will rise. A verified numerical model of the waterways seaward of the locks can predict the rise in salinity, but this screening-level evaluation is limited to the reasonable approximation that the ratio of salinity just outside the lock to salinity just inside the lock is constant.

In the spreadsheet several parameters are highlighted in yellow to indicate that they can be changed to evaluate different procedures and assumptions for the holding pond recirculation operation. In the following, six cases are explicitly considered, as listed in Table 3-6 with the equilibrium salinity results for Pedro Miguel Lock (L3) and highest Gatun Lock (L4).

Figures 3-7 and 3-8 show the results for Case P1 for the Gatun Locks and Miraflores Locks, respectively. The Gatun Locks reach an equilibrium condition

[1] EXCEL spreadsheet titled "HOLDINGPOND.XLS."

Table 3-6
Cases for Holding Pond Alternative

Case	Parameter				Results[1]		
	Initial Holding Pond Salinity ppt	Fraction of Lift Water from Pond, %	Ratio of Volume of Upper Holding Pond, V_{UHP} / V_L	Limiting Salinity in Highest Lock, ppt	L3 Equilibrium Salinity ppt	L4 Equilibrium Salinity ppt	Fresh Water Usage % of normal
Base	–	0	–	–	0.09	0.1	100
P1	0	100	2	0	0.28	1.3	40
P2	0	50	2	0	0.16	0.8	70
P3	0	100	4	0	0.22	1.3	40
P4	0	100	2	0.3	0.16	0.3	60
P5	8	100	2	0.3	0.22	0.3	40
P6	4	50	2	0.3	0.16	0.3	70

[1] Note that results are approximate and should not be considered precise to two significant digits. Extra digits are shown only to highlight differences in results.

after about 80 lockages, with the holding ponds reaching a salinity of about 10 ppt and L4 reaching 1.3 ppt. Despite an initial increase in freshwater consumption due to filling the ponds, Case P1 reduces long term consumption substantially, to about 40 percent of that used by the normal method. This amounts to one lift volume of 0.1 million cu m (3.6 million cft) per lockage once the initial two lift volumes used to fill the pond are saved. L3 salinity does not rise as high as L4 in the Gatun Locks, since the volume of Miraflores Lake buffers the salinity increase in L3 (at the cost of increasing salinity in Miraflores Lake), and it is not at equilibrium after 100 lockages. Extension of the calculations to 600 lockages (the number shown to be needed for equilibrium by the zero-order model) shows L3 to reach a maximum of about 0.28 ppt for case P1.

Cases P4-P6 add a maximum salinity criterion to the holding pond procedure to reduce salinity intrusion to Gatun Lake, in that once the salinity in the uppermost lock exceeds a preset limit, both holding ponds are flushed and refilled with fresh water. The criterion is expressed as a limiting salinity as shown in column 5 of Table 3-6. Figure 3-9 illustrates the salinity responses of L4 for a limiting salinity of 0.3 ppt. Once the salinity limit is reached at about 12 lockages it cycles more often as the seaward limit salinity rises, requiring refilling the ponds after 7 cycles the second time and with increasing frequency until they must be flushed and refilled every 3 lockages at 100 lockages. Despite this increased frequency, the method is seen to still conserve fresh water, reducing consumption by about 40 percent.

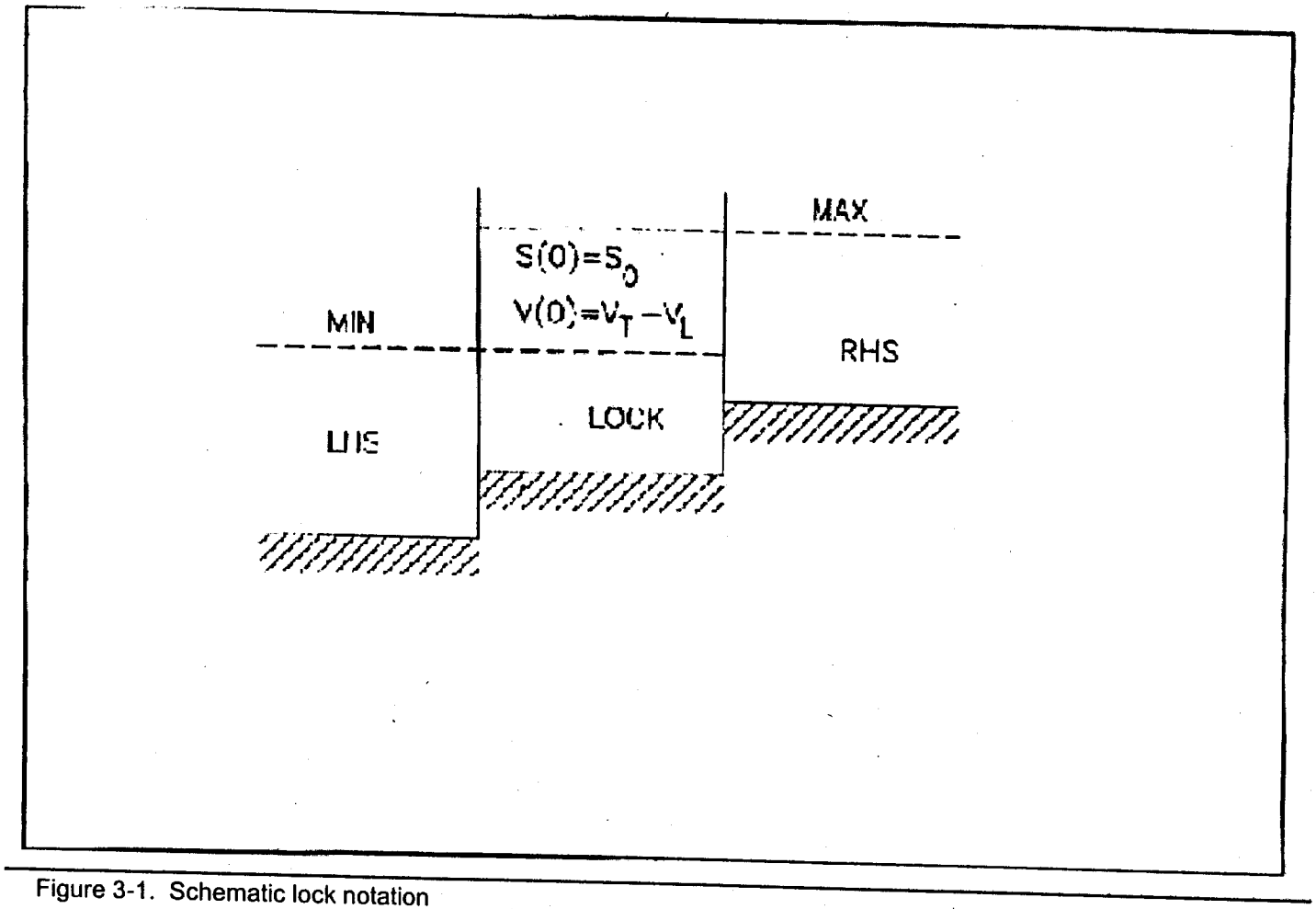


Figure 3-1. Schematic lock notation

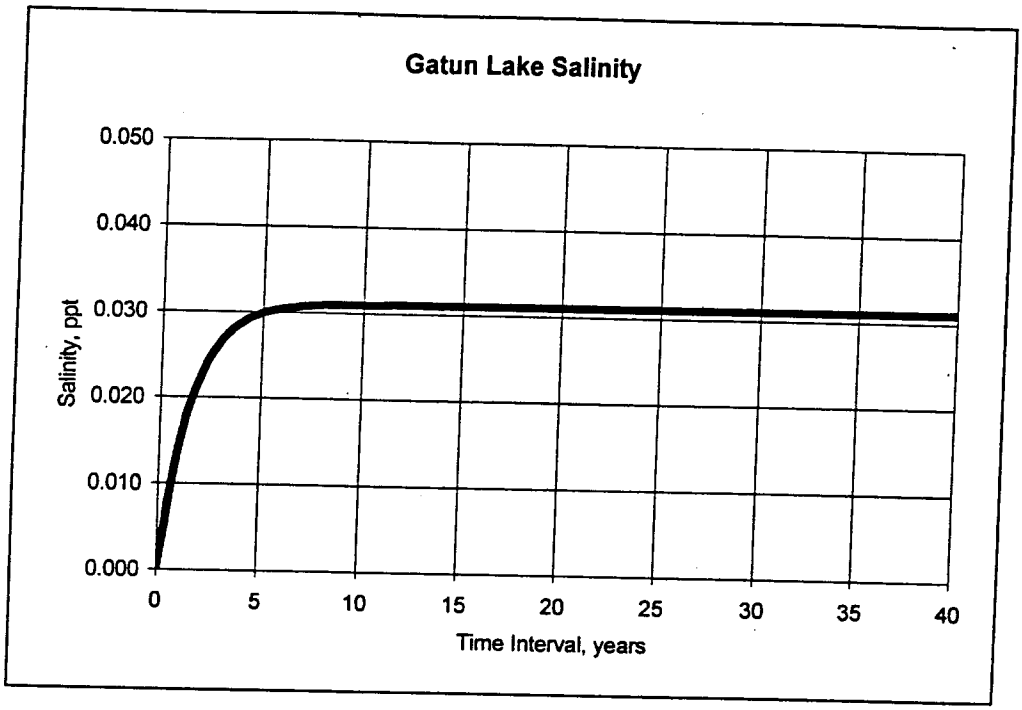


Figure 3-2. Case 1: Gatun Lake Salinity, 38 locks/day on conventional locks, no lockages/day on Syncrolift Locks, lock exchange ratio of 50 percent, salinity of 0.100 ppt in conventional locks and 0.0 ppt in Syncrolift Lock

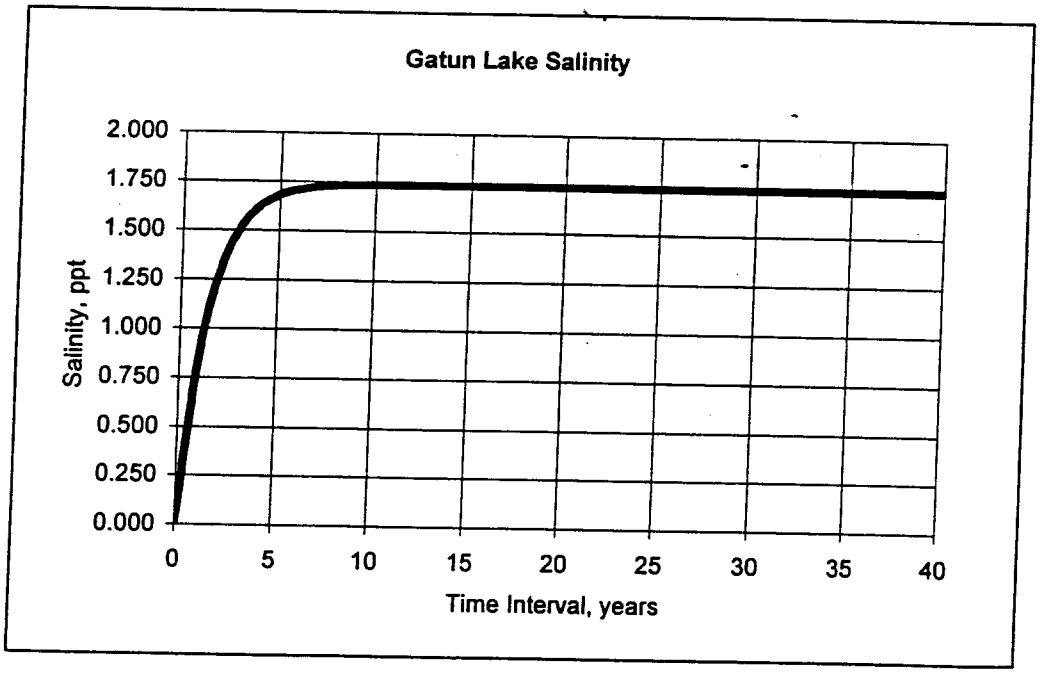


Figure 3-3. Case 2: Gatun Lake Salinity, 38 locks/day on conventional locks, 20 lockages/day on Syncrolift Locks, lock exchange ratio of 50 percent, salinity of 0.100 ppt in conventional locks and 35.0 ppt in Syncrolift Lock

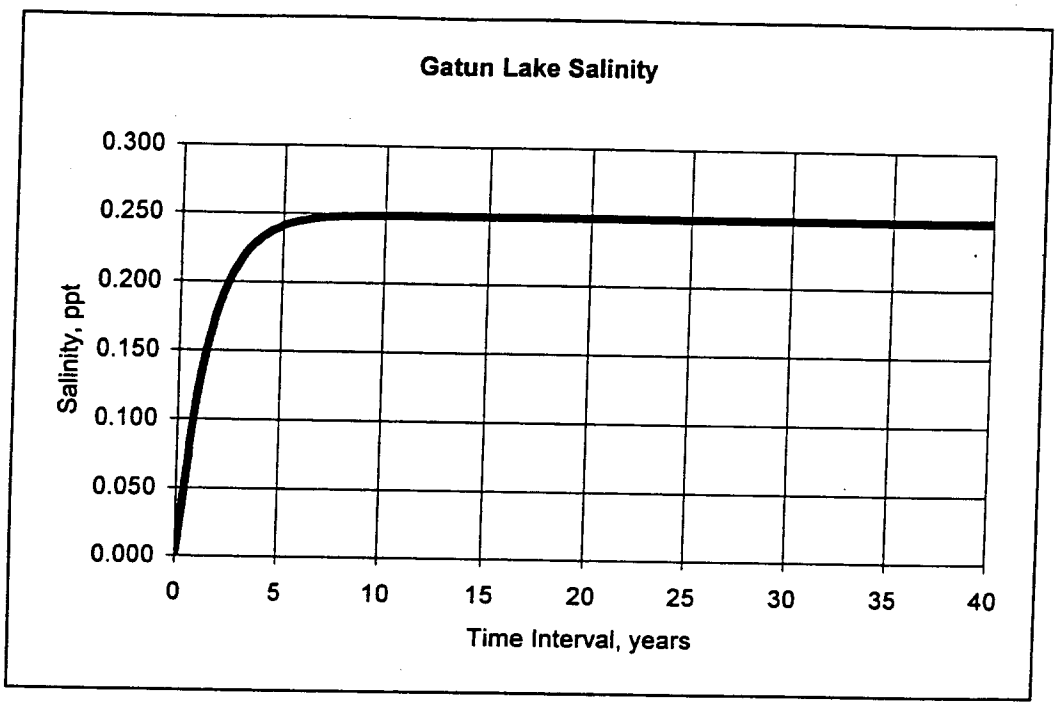


Figure 3-4. Case 3: Gatun Lake Salinity, 38 locks/day on conventional locks, 20 lockages/day on Syncrolift Locks, lock exchange ratio of 50 percent, salinity of 0.100 ppt in conventional locks and 4.5 ppt in Syncrolift Lock

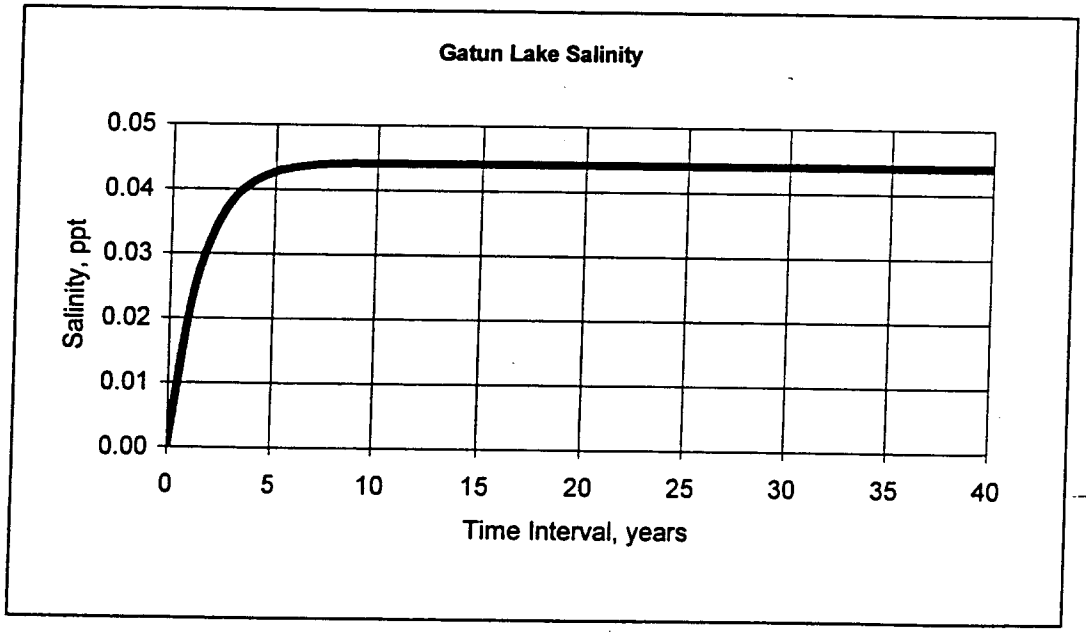


Figure 3-5. Case 4: Gatun Lake Salinity, 38 locks/day on conventional locks, 20 lockages/day on Syncrolift Locks, lock exchange ratio of 50 percent, salinity of 0.100 ppt in conventional locks and 0.300 ppt in Syncrolift Lock

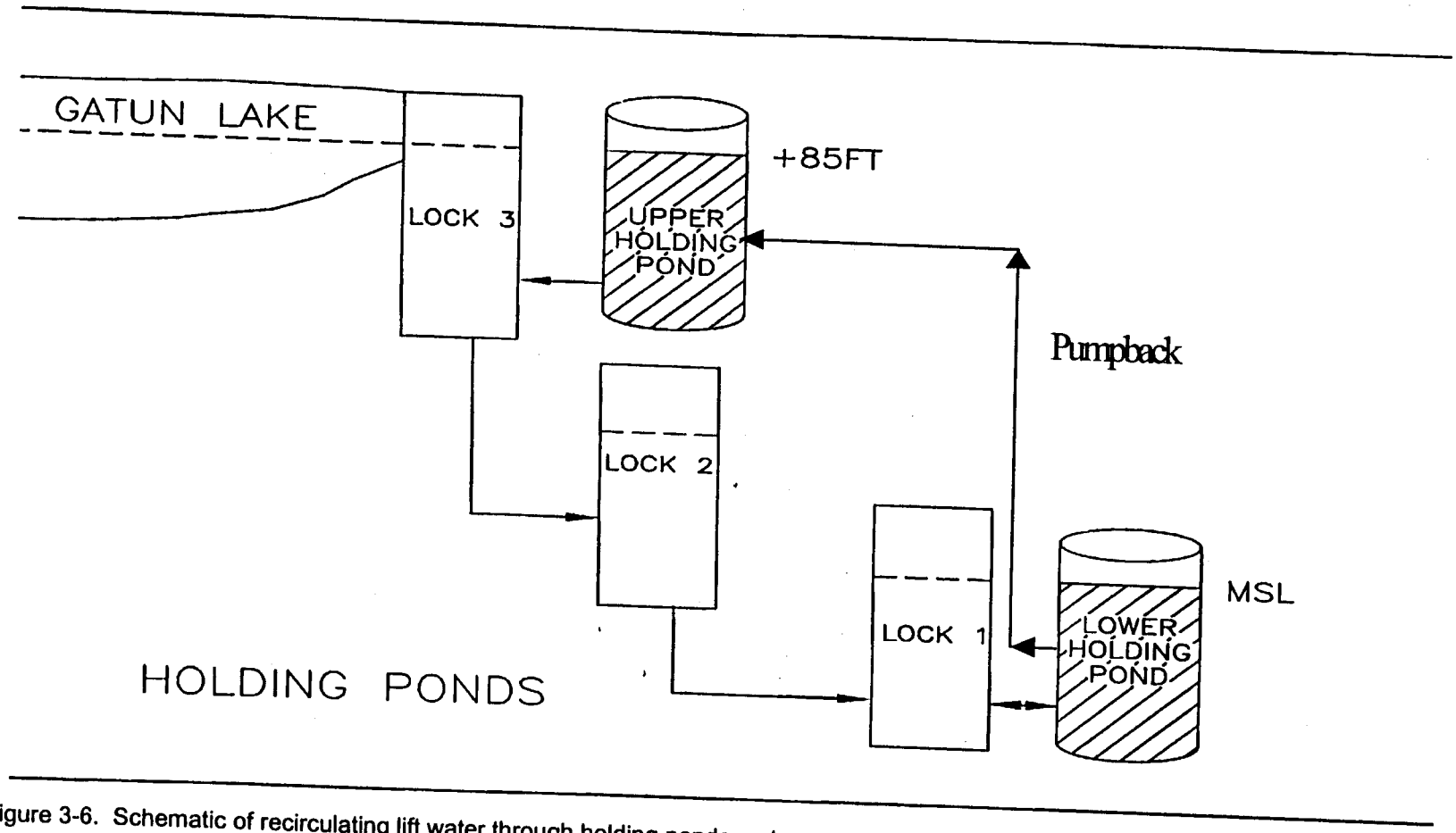
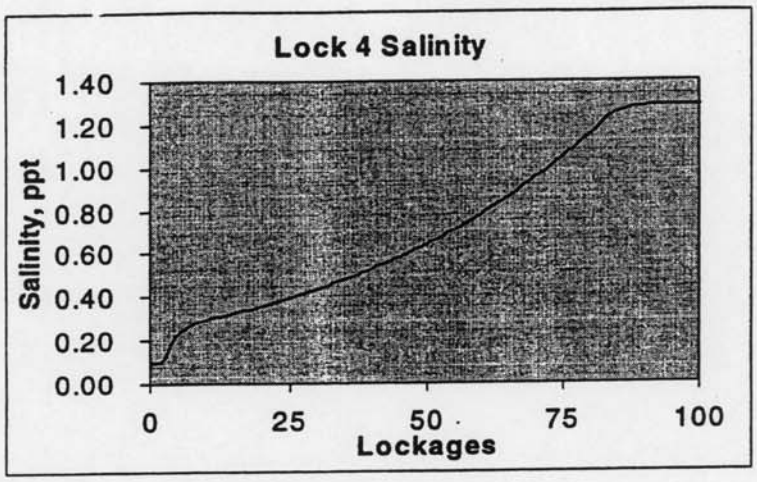
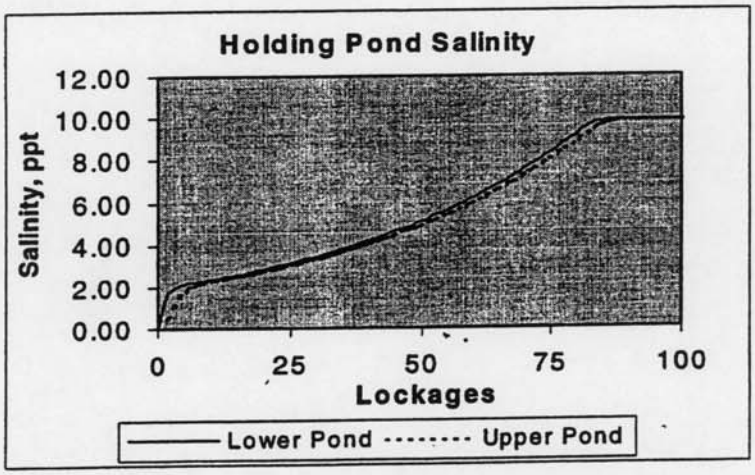


Figure 3-6. Schematic of recirculating lift water through holding ponds and pumping





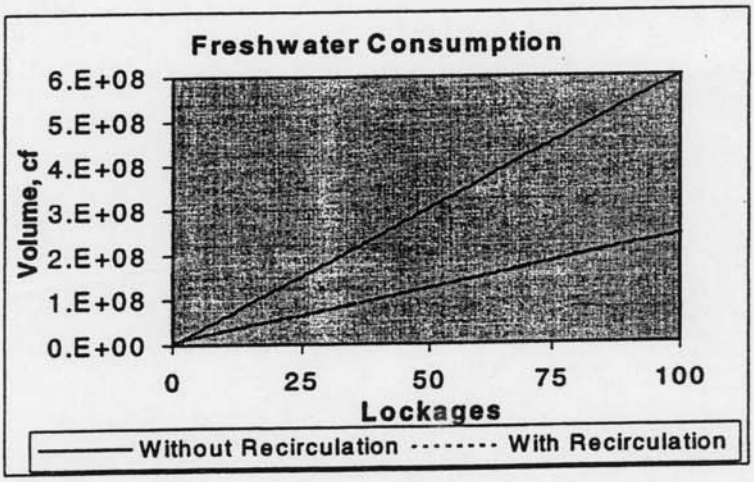
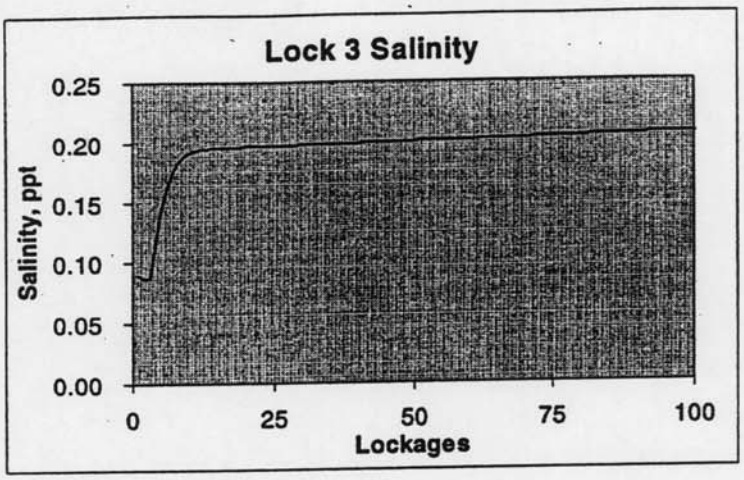
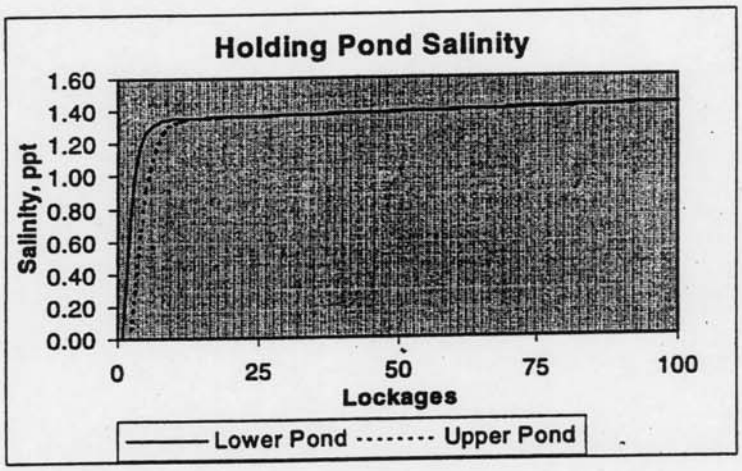


Figure 3-7. Gatun Locks salinities and freshwater consumption with holding pond recirculation for Case 1: ponds holding two lift volumes with initial salinity of 0 ppt; 100 percent of lift volume from holding pond





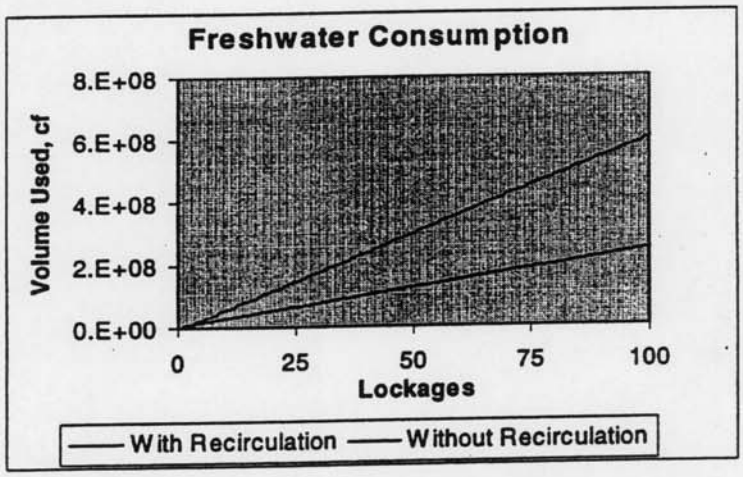
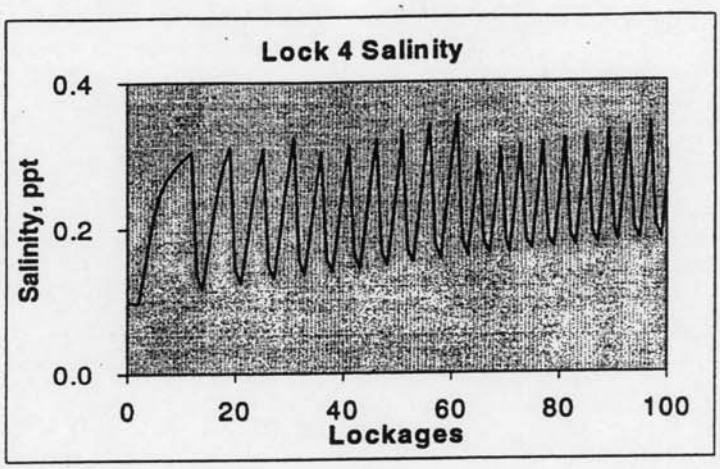
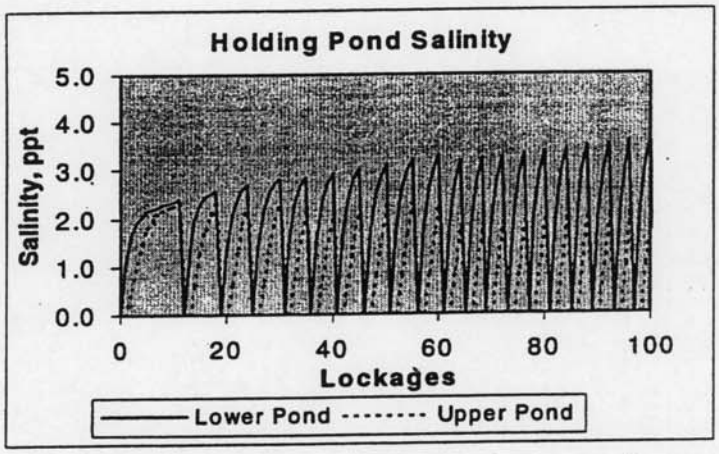


Figure 3-8. Miraflores Locks salinities and freshwater consumption with holding pond recirculation for Case 1: ponds holding two lift volumes with initial salinity of 0 ppt; 100 percent of lift volume from holding pond





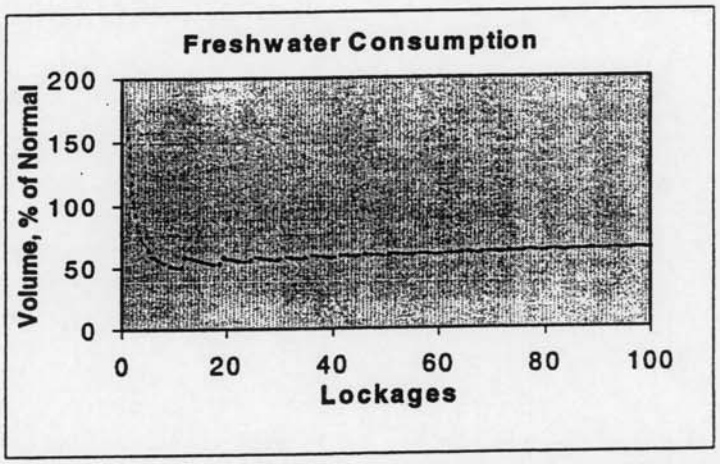


Figure 3-9. Gatun Locks salinities and freshwater consumption with holding pond recirculation for Case P4: ponds holding two lift volumes with initial salinity of 0 ppt; 100 percent of lift volume from holding pond, and limiting salinity of 0.3 ppt

4 Methods of Reducing Saltwater Intrusion in Navigation Locks

A review of the literature was performed to identify methods which have been shown to successfully reduce salt water intrusion through navigation locks. Methods and designs from the United States, the Netherlands, France, and China are briefly described here. This section draws on the published literature, Appendices B and C, and an unpublished review by the Panama Canal Commission (Kiamco 1999).

Survey of Methods

Flushing canal with fresh water

A repressive method of combating salinity intrusion through locks is to flush the "collector" canal with fresh water in the direction of the sea. However, this method is not very effective when used alone. The difference in density allows a comparatively large volume of salt water to enter the canal through the lock and a comparatively large volume of fresh water would be required to mix with it and carry it away. Tests have shown that the dimensions of canals very greatly affect the degree of salt intrusion. A small increase in depth causes a comparatively large rise in the salinity of the water in a canal.

Pneumatic barriers

Pneumatic barriers are curtains of air bubbles rising from perforated pipes placed on the bottom of a channel or lock chamber perpendicular to the axis of the channel (See Figure 4-1). The rising bubbles create a vertical current of water, which reduces the magnitude of any exchange currents passing over it, provided the volume of air is adequate. The mechanics of flow and mixing near a pneumatic barrier are described by McAnally (1973).

Pneumatic barriers reduce salt intrusion that is caused by density exchange currents. This is important, as salt intrusion is largely due to density exchange

currents. The efficiency of pneumatic barriers in reducing exchange currents during locking operations has been studied extensively in the laboratory and the field. Field studies were conducted in the Ijmuiden locks, the Netherlands. Salinity intrusion can be reduced by 50 to 80 percent depending upon the amount of air used. The efficiency decreases with increasing water depth in the locks. Experience shows that the pneumatic barriers can be expensive to operate and need careful operation and maintenance. Further, since they induce intense mixing, their use precludes capture techniques such as selective withdrawal once mixing has begun.

Water barriers

Theoretically, a vertical current like that produced by a pneumatic barrier can also be induced by pumping water, thus creating a water barrier, which would also reduce the magnitude of the exchange currents. Initial experiments with this method have been carried out on models.

Selective withdrawal of salt water during intrusion

The salt water tending to enter the canal when the inner gates of a lock are opened can be withdrawn and discharged back into the sea during the exchange process through a slot in the bottom of the lock located at the point where the lock meets the adjoining fresh water basin. The volume of fresh water wasted corresponds to the quantity of water withdrawn through the slot. If withdrawal cannot be entirely selective, the amount of fresh water wasted during each complete locking cycle will exceed the volume of the lock chamber. This system has been applied at the Terneuzen-locks, the Netherlands. Salt-water intrusion is prevented at the cost of a relatively large amount of fresh water due to limitations in the selective withdrawal of salt water.

Selective withdrawal of salt water after intrusion

The intrusive salt water is collected in a sump of adequate volume made by deepening part of the canal, selectively withdrawn from it and discharged in a steady stream (see Figure 4-2). The volume of fresh water wasted corresponds to the quantity of water withdrawn from the sump. Since the salt water is diluted as it enters and while it remains in the sump, more fresh water will be wasted than when using the method described in item 4 above. A drawback of this method is that not all the intrusive salt water is trapped in the sump; some of it passes on into the canal and has to be removed by flushing. Large volumes of fresh water are required to expel even small quantities of salt water. The basin has to be large enough to avoid overtopping by salt water and to allow selective withdrawal of the salt water. This method is employed at the Chittenden Locks in Seattle Washington as described in a subsequent section.

Equalization by pumping instead of gravity

If there is a considerable difference between average canal level and high water on the seaward side of the lock, salt intrusion can be greatly reduced by pumping the water in the lock chamber back into the sea instead of allowing it to reach the canal. Large-capacity pumps would be required to remove the large quantities of water in lock chambers in a short time. The pumping capacity required could be reduced by storing the water in a basin between the lock and the sea and artificially keeping the level in the basin lower than that in the lock chamber. This advantage of the method is that there is more time for pumping water out of the basin.

Exchanging while gates are closed

The salt water can be withdrawn from the lock chamber through orifices near the bottom and replaced by letting fresh water into the chamber through orifices near the surface of the water. Fresh water can be replaced by salt water in like manner, the salt water being admitted near the bottom and the fresh water being withdrawn near the surface. If this exchange process is completed before the gates are opened, waters of different density are prevented substantially from mixing thus obviating exchange currents. There would be a certain amount of mixing while the exchange is being effected; the vessels in the lock chamber would also cause some fresh water to be wasted due to mixing. The fresh water can be withdrawn and admitted through the wall of the chamber or through the gates at the fresh-water end.

Movable sill

One of the measures used to reduce the exchange flows is to have a movable sill, which is adjusted to the draft of the ships to be locked (see Figure 4-3). This option involves risk of mechanical damage, which may make the option ineffective or may block navigation. It is employed at the Chittenden Locks in Seattle Washington as described in a subsequent section.

Simultaneous exchange of salt and fresh water

Locks of this type have perforated false floors to evacuate or to introduce salt water and have openings in the side walls for the exchange of fresh water while the lock gates are close. The system has been applied in the Mardyck sluice at Dunkirk with dimensions of 145 x 12 x 4 m (Ribes and Blanchet, 1965, Monadier, 1981) and the Kreekrak sluices, the Netherlands, with dimensions of 330 x 24 x 6 m (Kolkman and Slagter, 1976). The saltwater intrusion can be reduced to about 5 percent of the lock chamber volume with a freshwater loss of about 60 percent of the lock volume.

Canal gate

Another option for the lakeside canal is to have two or more deeper basins and a gate at the freshwater end, so that the length of the canal is available for temporarily trapping salt water. By itself, such a design will offer few significant advantages, but in combination with other measures it can be used to retain brackish water until such time as flushing can be accomplished. For example, if a movable sill and selective withdrawal were used, but sometimes failed to capture all the salt water, a long canal with sills at intervals would trap the excess salt water for an extended period, then it could be flushed (item 1) when an ample supple of freshwater became available

New developments

Various new lock types have been designed and tested to reduce freshwater losses (Van der Kuur, 1985, Kolkman, 1986, and NN, 1986). An example is the lift lock, which has an inner lock chamber which moves vertically. The outer lock chamber is twice as deep as normal. The inner lock chamber is always filled with salt water. Other lock types have been studied, such as locks with artificial reed screens to decrease exchange flows and locks with horizontal flexible membranes to prevent mixing between salt and fresh water (van der Kuur, 1985). Freshwater losses with this type of lock are reduced to about 5 percent of the lock chamber volume, whereas saltwater intrusion is only about 5 percent of the lock volume.

Selecting The Method

For existing locks

A method that might be considered for canals linked with existing locks is to flush them daily with copious quantities of fresh water. The quantity of water required to flush wide, deep canals is considerable; it would not always be possible to satisfy the maximum permissible salinity requirements in certain places. If flushing does not produce the desired result, a stretch of canal close to the lock could be deepened and used as a sump in which the salt water would collect. A pumping station operating with a deep suction nozzle would withdraw the salt water and pump it into the sea. If necessary, a wall could be built between the pumping station and the sump with orifices near the bottom of the latter. Alternatively, the salt water could be removed by gravity if the water level in the canal were either temporarily or permanently higher than that of the sea.

The quantity of salt water intruding into an existing canal owing to exchange flow caused by differences in density can be reduced by means of an air-bubble curtain placed near the lock gates. This option could be combined with the sump method described above or with an adjustable barrier. Whether a single method or a combination of methods is adopted depends on their local feasibility.

For projected locks

Installing water curtain equipment in existing locks is difficult because of the size of the pipes required. It is even questionable whether this method would be so much better than the other options as to warrant its adoption for new locks. The qualitative control of fresh water constantly has to be stepped up and it is essential to be economical with fresh water for many reasons.

There are four methods is addition to the three already described for existing locks that may be considered for new locks, viz.

a. Construction of a sump next to the lock on the landward side from which the intrusive salt water can be selectively withdrawn

b. Replace salt water in the lock chamber by fresh water while the lock gates are closed

c. Pump the water required for equalization into the sea.

d. Adjustable barrier

Navigation Locks in the Netherlands

The most important 15 navigation locks in the Netherlands and the methods employed in them for salinity intrusion control are described below. The main features of options are:

a. The flushing method is used for all locks; water from the canal is flushed through openings placed as low as possible in the lock or sluice structures.

b. The velocity of the current passing through the openings may exceed a certain magnitude to ensure that the water discharged will contain the maximum amount of salt.

c. Since the salt water pumped from the polders in various places as well as that coming in through the locks reaches the canals, the fresh water flowing towards the locks also helps to overcome the salinization of the country's water and soil.

d. It should be noted that it would always be necessary to flush the systems with a certain quantity of fresh water, no matter how effective any steps taken to reduce the waste of fresh water through locks may be.

e. Air curtain equipment has already been installed in a number of locks and others are to be equipped with the system in the near future.

f. Supplementary systems are being considered for certain locks.

g. One or more locks at seven sites in the Netherlands are equipped with pneumatic barriers, viz. at Harlingen, Den Helder, Ijmuiden, Hartel canal/Brielse Meer, Haringvliet, Volkerak and Terneuzen.

Abraham et al. (1973) have provided a brief description of salinity intrusion control measures at several docks in the Netherlands. A section of that report is reproduced verbatim below.

1 Delfzijl

Salinization of the canals running from the locks is countered by replacing the water in the canals at regular intervals by rainwater and by water drawn from Lake IJssel. The locks are provided with apertures located well below the water line so as to make the replacement process as effective as possible.

2 Lauwerszee

Damming off the Lauwerszee has very greatly reduced the salinity of the adjoining parts of the provinces of Friesland and Groningen. Sluices are incorporated in the dam through which excess water may be discharged. Provision has been made for the comparatively small lock to be fitted with air-curtain equipment, if required.

3 Harlingen

Salt intrusion through the locks is countered by replacing the water in the canals at regular intervals by rainwater and by water drawn from Lake IJssel. Air-curtain equipment is also used to further reduce salinization.

4 Zuyder Zee Barrier Dam

There are locks in the dam beside the two sets of sluices with which the water in Lake IJssel is controlled. Arrangements are being made to equip all the locks with pneumatic barriers.

5 Den Helder

Salt intrusion through the three locks and the sea dock lock is countered by replacing the water in the canals at regular intervals by rain water and by water drawn from Lake IJssel. Arrangements are being made to replace gravity discharge by pumping. A sump is to be built near the pumping station in which to store the salt water from the locks prior to its being pumped into the sea. The most important lock is equipped with a pneumatic barrier.

6 Ijmuiden

Salt intrusion through the North Sea Canal is countered by replacing the water at regular intervals by water from the adjoining regions and from Lake IJssel. The four locks are equipped with a pneumatic barrier. Arrangements are being made to install a pumping station to supplement gravity discharge through a sluice. The construction of a deep sump to collect the salt water is also being

contemplated together with a salt baffle to maximize the salinity of the water discharge into the sea.

7 New Waterway– New Maas

There are a number of locks along the New Waterways and the New Maas, both of which are open to the sea. Salt intrusion in the canals running from the locks is countered by replacing the water by rain water and water drawn from the River Rhine. The quantity of river water required could be somewhat reduced by installing pneumatic barriers in the locks but there are as yet no plans to make any such provisions.

8 Hartel Canal and Brielse Meer

The Hartel canal is the landward shipping link between Europoort and the Old Maas. There are pneumatic barriers in the two locks that give access to the Old Maas to reduce salinization of the latter. The canal is also flushed with river water, which runs out through the locks, which are also equipped with pneumatic barriers.

The Brielse Meer is a fresh-water lake south of the Hartel canal; a lock links it with the Old Maas. The lake must be protected as well as possible against salinization if the salt intrudes beyond the lock when Rhine is low. Consequently, a great deal has been done to counter salt intrusion at this point. There are two pumps in two culverts by means of which water can be pumped out of the lock chamber. There is air-curtain equipment and a deep sump in the canal next to the lock to which the pumps can be connected to remove any salt water that may get through the lock.

9 Haringvliet

The Haringvliet lock is fitted with pneumatic barriers. There are deep culverts in the sluice next to the lock connected with a sump from which any salt water can be withdrawn.

10 Volkerak

There are two locks linking the rivers with Zeeuwse Meer. The water south of the dam will be strongly saline until the Eastern Schldt dam is finally closed in 1978; meanwhile, salt intrusion through the locks is being reduced by means of pneumatic barriers.

11 Canal Across Walcheren

Salt intrusion through the locks at flushing was investigated by conducting model experiments to discover whether a canal flushing system would be effective or whether the locks will have to be equipped with pneumatic barriers at both ends.

12 Canal Across South Beveland

A modern system of countering salt intrusion is being considered; the salt water in the lock chambers would be replaced by fresh before opening the gates giving access to the fresh-water lake. The fresh water used would serve to clean the adjoining canal.

13 Scheldt-Rhine Canal

Two locks are being incorporated in the canal linking Antwerp with the Rhine. Salt intrusion will be countered by replacing the salt water in the lock chambers by fresh water flowing in through apertures in the walls while the gates are closed. As in the new system described in 13, the fresh water used would serve to clean the adjoining stretch of the fresh-water lake.

14 Terneuzen

There is one old and two new locks in the canal between Terneuzen and Gent. Pneumatic barriers reduce salt intrusion through the new inland-waterways lock. A sump has been constructed next to the new sea lock with deep culverts the orifices of which are built into the lock to carry the salt water trapped in the basin towards the sea. The level of the water in the canal is almost always above that of the high tides, so discharge is by gravity. Moreover, salt intrusion is further reduced by means of pneumatic barriers.

15 Kreekrak

The Kreekark lock in the Netherlands has dimensions of 320 x 24 x 5 m. The lock is used in achieving a water level change of 1.3 to 2.3 m. It is navigable for 4-barge push-tows of 11,000 metric tons (10,000 tons), with the design annual traffic capacity of 66 million metric tons (60 million tons). Fresh water reservoirs are provided on both sides of the chamber. A salt-water reservoir with a size of 40 hectares is also provided. The area of the salt-water reservoir is 26 times that of the chamber. The lock is operational since 1986 and is functioning well. The Kreekrak lock is an improved version of Mardyck lock in France. It also uses a complete exchange system; however, the fresh water loss is reduced to about 15 to 30 percent. The reasons for improved performance are: a) open fresh water channel used instead of long culverts, b) lift gate is provided at the immediate outlet of culverts, which can be adjusted according to tidal level changes, thus preventing salt water intrusion, and c) the bottom slab is channel shaped and water being discharged through outlets on the sides of channel eliminate vertical currents, which produce salt and fresh water mixing.

16 Philip

The Philip lock has dimensions of 280 x 24 x 5 m and is navigable for 4-barge pushtow of 11,000 metric tons (10,000 tons). The lock is subjected to two-way water head and water level difference of 1.7 m. Philip lock made the following improvements over the Kreekrak lock: 1) Since outlets in channeled bottom are located at the middle of the channel sides, water below outlets cannot drain well, so bottom slabs of T and inverted T shapes are used. 2) Weir gates at

the freshwater outlets are not closed to the top; thus the freshwater between the operating valves and the weir gate will get salted with a loss of 5%. 3) When salt water surface travels towards the bottom during exchange, there will be vertical currents in culverts at the bottom of salt-water body causing greater flushing. 4) When the chamber is full of fresh water and a ship enters, the water levels in the front and back of the ship are different. This provides opportunity for salt water to enter the chamber and fresh water to enter culverts.

Hiram Chittenden Locks, Seattle WA, USA

Salt water intrusion problems in USA are predominantly related to estuaries and inland navigation. A summary note on these problems is given in Appendix B. Other problems have been related to salt water intrusion at dams. The primary U. S. location where salt intrusion through locks has been addressed is the Hiram Chittenden Locks on the Lake Washington Ship Canal, Seattle, WA.

Construction of these locks was accomplished during 1911-1917 to provide access to and from the salt water regime of Puget Sound and the fresh water lakes of Lake Union and Lake Washington in the state of Washington, USA. The intrusion of salt water into the fresh water regime is controlled through a number of operational and structural methods. Foremost are the salt water scavenging drain, maintaining salt water barrier in the upright position, and use of a small lock to prevent salt water intrusion into Lake Washington. During critical years, the potential for intrusion becomes an intensified coordination process of water / lock usage with municipal water supply authorities, environmental agencies and the general public on operational uses of fresh water at the lock structures. Appendix C describes the design and operations employed at the Chittenden Locks.

Navigation Locks in China

The Haihe lock in China has made the following improvements.

a. In view of limited land area available, the design rejected the fresh water reservoir option. Instead, a fresh water culvert plan is adopted.

b. The lock design adopts grade crossing of four-way culverts with a control valve on each of the culverts at the cross.

c. The available land allows to build a reservoir only 5 times that of the lock chamber area. Hence a pump station with a capacity of 20 cubic meters per second has been provided.

d. The lock has less flow dividing piers.

e. Froude number of about 1.0 is achieved at the point of water exchange at the outlets.

Navigation Locks in France

The Mardyck lock at Dunkirk Harbor in France uses a complete exchange system. The lock dimensions are 148.6 x 12.0 x 4.0 m and water level difference is about 2.0 m. It is navigable for push tows of 3,000-ton barges and its complete water exchange requires 12 minutes. Since the lock's salt prevention measure is a combination of water exchange and salt-water trough, fresh water losses may be as high as 55 percent. The lock has been running well over its 30 years of operation.

Salinity Intrusion Problems in Norway

The problems in Norway are related to strong currents and ice formation at surface. Use of air bubbles is found to be effective in breaking down density stratification.

The Norwegian coast is basically relatively steep, with high mountains surrounding long and deep fjords, with a brackish layer on the top. Therefore, the saltwater intrusion problem as experienced in other countries like the Netherlands, or England, is not so common in Norway. In the southeastern part of the country, mainly in the Glomma estuary area, we find saltwater intrusion problems which are somewhat similar to what is typically found abroad. In the rest of the country, saltwater intrusion problems are of a different kind. Two types of problems have been experienced in Norway which can be related to navigation problems as well. Both problems are connected to the presence of saltwater intrusion in estuary or fjord areas.

The first problem is related to the outflow of fresh or brackish water through a narrow entrance. The presence of the saltier water masses below creates a strong density stratification which, in turn, creates a strong concentration of surface currents in the upper water masses. Since the area under consideration is used as a fishing harbour as well, these strong surface currents have created some navigation problems for the fishing vessels moving in and out of the harbour area. In particular, the maneuvering conditions can be difficult when incoming waves from the open sea are entering the harbour area and then meet the opposing brackish layer flow, causing the waves to steepen considerably.

The other case is of a somewhat different kind. In the winter time and under calm weather conditions, the fresh water from the river mouth will spread out in the surface layers in the fjord area. Due to the stable density stratification caused by the saline water below, the surface layer will be exposed to cooling and subsequent ice formation. The saline water stratifications will in this case act as a preventor for transport of excess heat from below. This ice might, in turn, cause difficulties for navigation to and from harbours in the area.

In the latter case, the problem was solved by means of an air-bubble plant installed in the river mouth area. In order to break down the stable density stratification, the intrusive salt water in the river mouth area was forced by the air bubble plant to mix with the fresh water.

Syncrolift Lock

The Syncrolift Lock described in Part 2 as being considered for installation in the Panama Canal presents a somewhat different challenge for preventing salt water intrusion. Since the lock is filled to the same level at all times, water within it is not diluted by the addition of fresh lift water.

During discussions of the Syncrolift lock numerical experiments presented in Part 5 of this report, the PCC-COE design team formulated a conceptual design for preventing salinity intrusion. Depicted in Figure 4-4, it consists of a small gated antechamber at the upper lock position in the dam, separated from the lake by a movable gate. After the lock is lifted into position at the top and seated against the dam, the lock gates are opened so that saline water in the lock and fresh water in the antechamber begin to mix. Salty water is then withdrawn from the bottom of the antechamber as freshwater is released at the surface at the same flow rate. These flows are continued until the lock water is freshened to the required degree, and then the antechamber gates are opened to permit the ship to move into the lake. This concept is modeled in Part 5 of this report.

Summary and Conclusions

a. All over the world salt intrusion through navigation locks connected to ocean is being increasingly regarded as a serious threat to the quality of water in the canals that link ocean with the locks.

b. There are several ways of preventing salt-water intrusion in the navigation locks. The selection of method is based on factors such as site conditions, cost, volume and frequency of ship traffic etc.

c. The most effective and at the same time most expensive method is exchanging fresh water for salt water within the lock while gates are closed; however, it can also lead to adverse motion of vessels within the lock.

d. The option of equalizing levels by pumping instead of gravity, which only concerns the salt water required for equalization, is not very effective.

e. The selective withdrawal of salt water usually calls for substantial alterations or additions to locks and may require fairly large quantities of fresh water.

f. The water barrier method has not been tested thoroughly but should perform about the same as the pneumatic barrier.

g. Pneumatic barriers constitute a simple method of countering salt intrusion. This method will not keep all the salt out but may reduce intrusion quite considerably. Pneumatic barriers have been successfully

installed at several locks and can be combined with other systems. The pneumatic barrier method of preventing salt intrusion is found to be suitable for practically all the locks adjoining the sea in the Netherlands. Pneumatic barriers are already operating in 13 locks.

h. Establishing a canal on the upstream side of the lock and flushing the canal with fresh water is less effective than the other methods and involve wasting large quantities of fresh water. It is nevertheless the oldest way of getting rid of intrusive salt. It can be retained as a useful supplement to one or more of the other methods.

i. For the proposed new locks, the interests served by any measures taken to combat salt intrusion are considered for each case individually. Methods other than the pneumatic barrier system might be chosen based on certain considerations and the locks will be designed accordingly.

NOTE: See Appendix E for non-cited references used in Part 4.

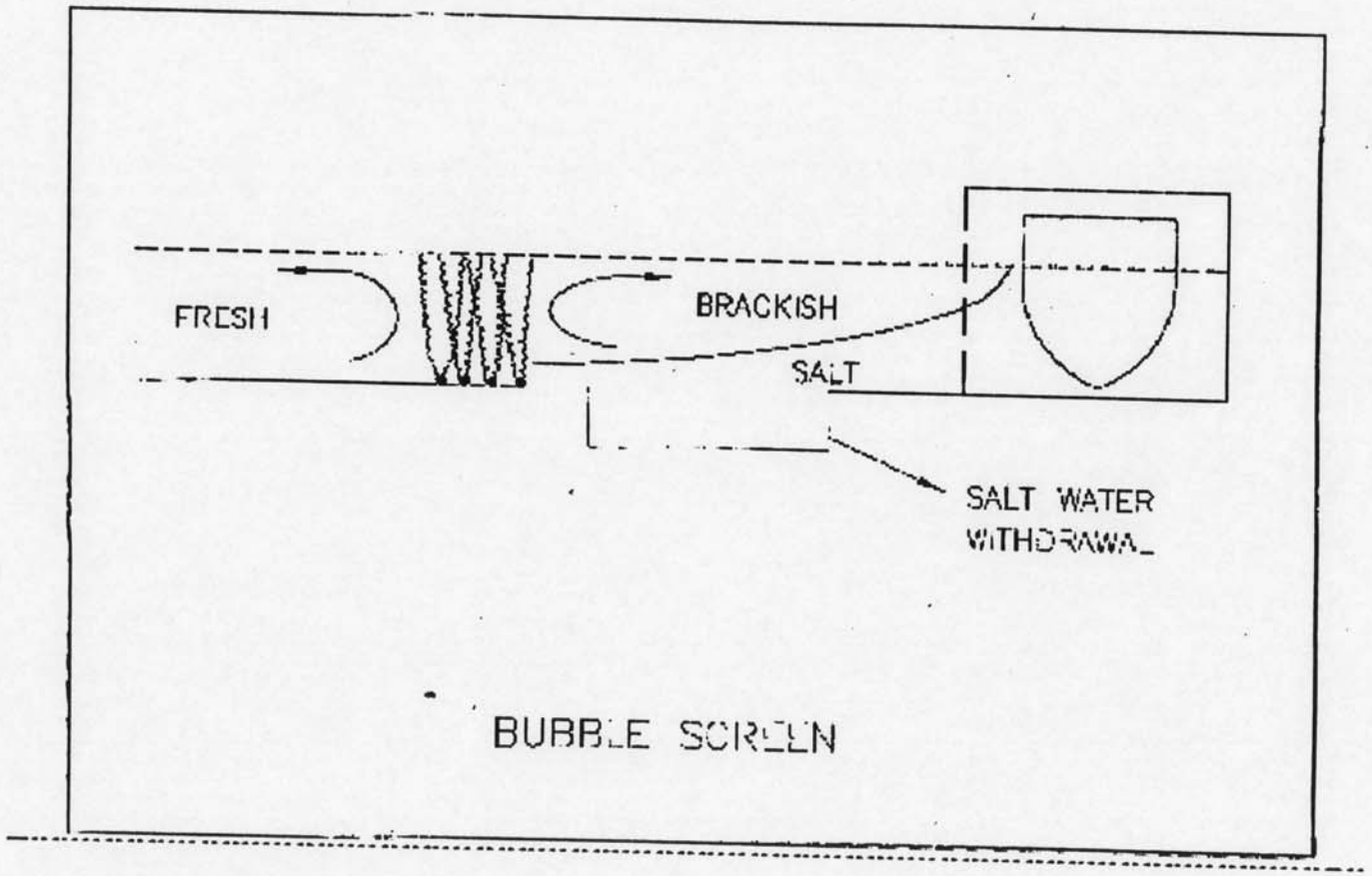


Figure 4-1. Bubble Screen

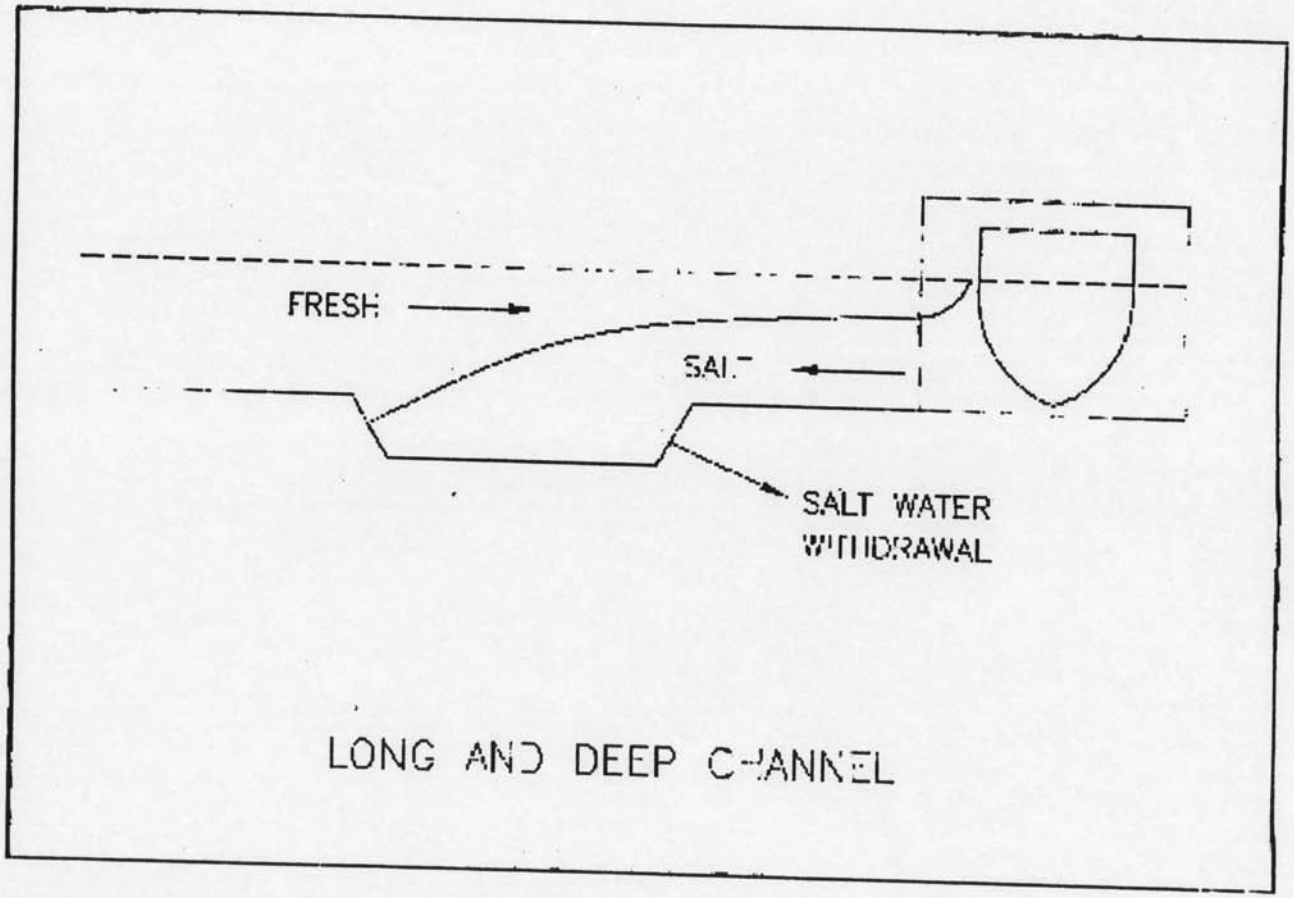


Figure 4-2. Long and deep channel

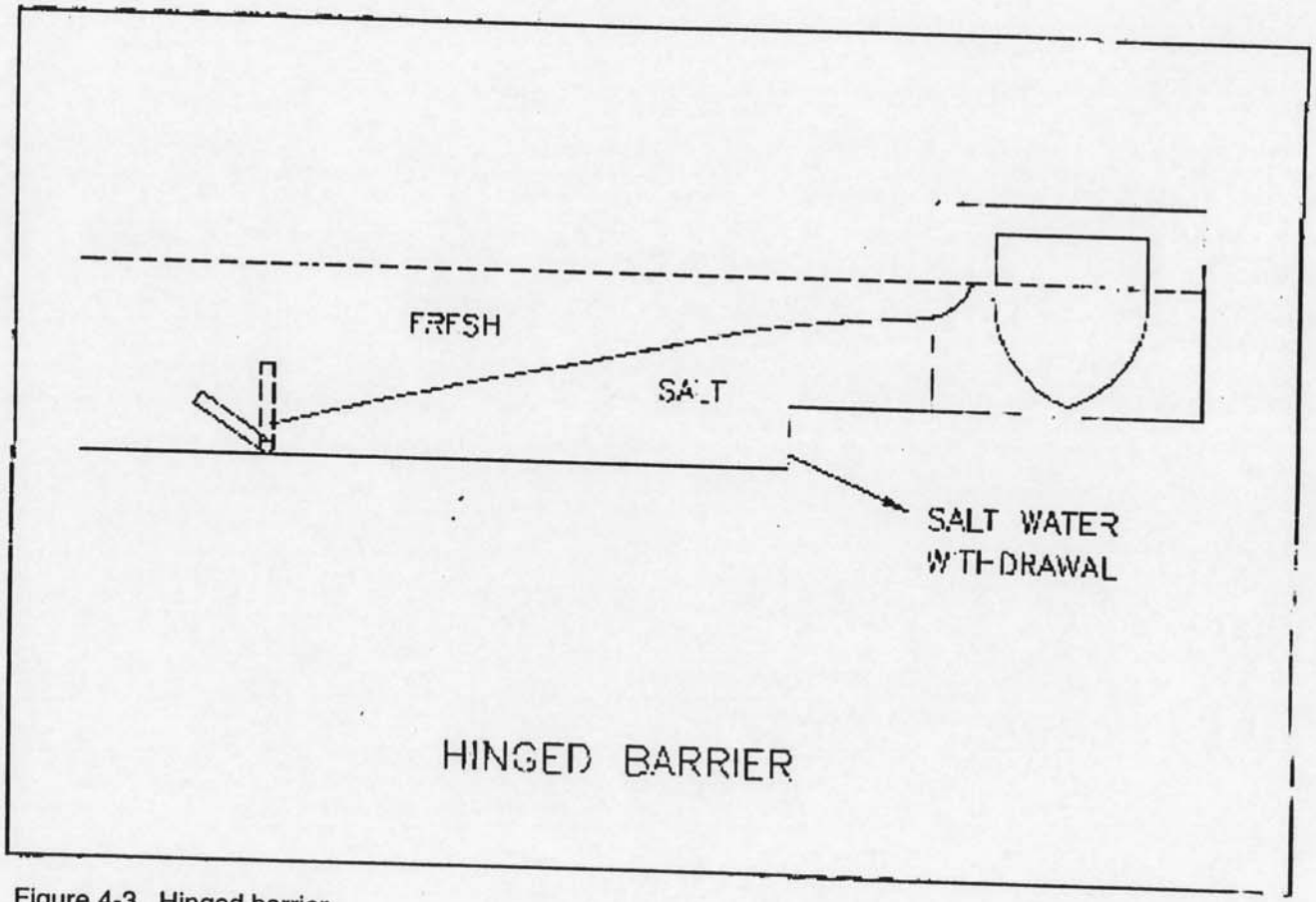


Figure 4-3. Hinged barrier

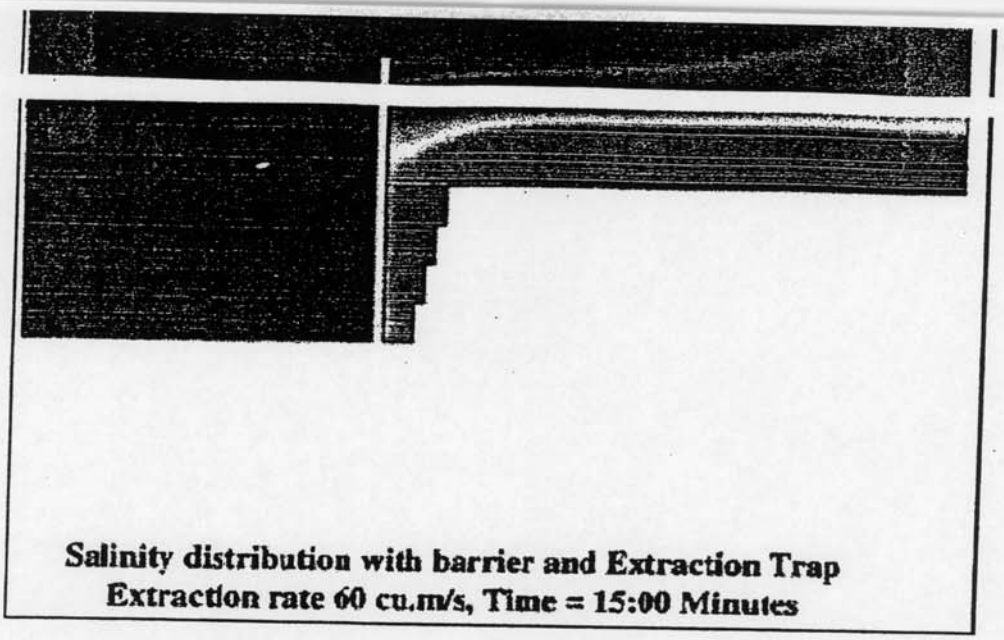


Figure 4-4. Schematical syncrolift lock with gated salt water extraction chamber

5 Modeling Density Flows

The two-dimensional width-averaged numerical model, CE-QUAL-W2, was used to investigate density flow from the uppermost Gatun Lake lock into a navigation channel. A channel sump for collecting and retaining salt water from the locks and a salinity barrier with bottom extraction were simulated. The results of these simulations are summarized here.

Model and Assumptions

CE-QUAL-W2 is a time-varying, mechanistic, two-dimensional (vertical-longitudinal) hydrodynamic and water quality reservoir model. The model is capable of simulating an extensive list of chemical and biological and hydrodynamic processes that affect water quality of a reservoir. This includes the impacts of density stratification due to temperature or salinity. The model assumes lateral homogeneity and is best suited for water-bodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, and estuaries and simulates the effects on reservoir water. Details of the model are provided by Environmental and Hydraulics Laboratory (1986) and Cole and Buchak (1995).

Two computational grids were developed for modeling Gatun Lake salinity intrusion. The segment distribution (longitudinal cell lengths) used for both computational grids is shown in Figures 5-1 and 5-2. The ship lift was 250 m long by 28 m wide by 10 m deep, the sump was 500 m long by 100 m wide by 10 m deep. The upper entrance canal was 750 m long by 100 m wide by 10 m deep. The numerical model does not allow moving boundaries, thus a ship was not simulated in the grid. The first grid simulated a Syncrolift lock chamber opening into a 100-m-wide canal with a 10-m-deep by 500-m-long salinity collection sump (Figure 5-3). During lock operation, the sump was to collect salt water and then drain the salt water back to the sea. The second grid simulated a barrier gate (Figure 5-4) to retain escaping salt water with simultaneous extraction through a bottom withdrawal. The barrier gate was located 35 m upstream of the entrance to the ship lift with a crest set at 3 m deep. The extraction sump was 10-m deep between the barrier gate and the ship lift. For the extraction simula-tions, a large reservoir width (1000 m at the upstream end) was simulated outside of the immediate vicinity of the ship lift to provide a large

reservoir surface area. This allowed the withdrawal of water without significantly lowering the pool.

Experimental Conditions

Several data files were assembled to describe the initial salinity conditions across the computational grid. In the simulated part of Gatun Lake, the salinity was set at 0, while salinity within the ship lift was homogeneous and initially set at 5 ppt and 10 ppt for different simulations. Water temperature was set at a constant 30°C for the entire grid and did not vary during model operation.

The initial conditions were defined to simulate the instantaneous opening of the ship lift gates. The model runs simulated up to 2 hours of time.

Plans Tested

Tested plans included several variations of a sump to capture salt water carried out of the lock by density flows, following the design of the Lake Washington Ship Canal saltwater sump. Two plans are presented here, a long sump in a lock approach channel with a salt water drain in the end nearest the lock, as depicted in Figure 4-2, and a gated chamber (near-field barrier) built into the lock structure to capture salt water and replace it with fresh water before the gate is opened for ship movement. The latter design concept was developed by the COE-PCC study team during the testing procedure. For both cases the bottom salt water extraction rate was set at 60 m^3/s.

Either of these plans can be used with the existing locks or the Syncrolift lock.

Results

Salt Water Sump. The dense water within the ship lift slumped out toward the upstream channel, cascading down into the salinity sump in the approach channel (Video 1). The salinity filled the sump with concentrations greater than 0.5 ppt. Even though the numerical model was more diffusive than the actual conditions would be, these results showed that more fresh water would likely be used to drain the salinity sump than would be used for a conventional lock operation. Thus, this alternative was modified to simulate the near-field barrier with bottom extraction.

Near-Field Barrier. The results of this simulation are presented in Video 2 and Video 3. The salt water slumps into the trap when the lock gate is opened and is withdrawn through the bottom. Fresh water from the approach channel skims in over the barrier gate to replace the salt water that has been withdrawn. The velocity of the freshwater over the barrier gate prevents salt water from escaping into the approach channel. Video 4 shows the particle tracks from this simulation. This alternative captures the salt water and removes it before it can

escape into the lake, but introduces currents over the barrier that may cause ship motion within the lock.

Recommendations

This numerical model offers the capability to quickly simulate and assess stratified flow during lock operation. Once it has been verified, it can be used in a design-level effort.

Of the two alternatives simulated in the model, the near-field salinity barrier with bottom extraction appears most feasible. The canal sump for trapping salt water would likely result in excessive use of freshwater to flush the large volume of saltwater/freshwater mixture from the sump. The near-field barrier with bottom extraction showed better promise of salinity exclusion provided by the velocity pattern over the barrier. Further research should be conducted into the extraction alternative to determine the maximum time allowable for the saltwater exchange and the degree to which this alternative can meet this requirement. Effects on vessels within the lock and variations in barrier depth and extraction rates and, in concert with other alternatives, such as in-lock flushing, should be included in more detailed studies for design purposes.

Table 5.1
Lake Gatun Zero-Order Salinity Intrusion Model v1.1 Sep 1999

Panama Canal																						
Flows and time interval are based on the number of lockages					13870									Number of Syncro Lift Lockages per time interval			7300					Computation of Trib Inflow to Lake Gatun
			Average Madden Lake and Tributary Inflow for time interval				Exchange during lift operations Pedro Miguel Lock			Exchange during lift operations Gatun Lock			Mass of salt, lbs	Exchange during lift operations Miraflores Syncrolift			Exchange during lift operations Gatun Syncrolift			Mass of salt, lbs		
Time Interval	Salinity - LG ppt	Volume - LG, cf	Spill - ML, cf	Qpower - ML, cf	Trib - LG, cf	Salinity - ML, cf	Qlock, cf	Phi portion of lock	Salinity - lock, ppt	Qlock, cf	Phi portion of lock	Salinity - lock, ppt		Qlock, cf	Phi portion of lock	Salinity - lock, ppt	Qlock, cf	Phi portion of lock	Salinity - lock, ppt	Total Inflow, cf	Less Madden Releases, cf
0	0.000	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100	3.30E+08	8.74E+09	0.500	0.300	8.74E+09	0.500	0.300	1.64E+08	1.18E+11	4.53E+10
1	0.022	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
2	0.033	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
3	0.038	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
4	0.041	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
5	0.043	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
6	0.043	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
7	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
8	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
9	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
10	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
11	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
12	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
13	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
14	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
15	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
16	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
17	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
18	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
19	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
20	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
21	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
22	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
23	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
24	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
25	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
26	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
27	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
28	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
29	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
30	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
31	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
32	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
33	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
34	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
35	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
36	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
37	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
38	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
39	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
40	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
41	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
42	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
43	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
44	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
45	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
46	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
47	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
48	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
49	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
50	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
51	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			

(Continued)

Table 5.1 (Concluded)

Panama Canal																						
Flows and time interval are based on the number of lockages					13870									Number of Syncro Lift Lockages per time interval			7300					Computation of Trib Inflow to Lake Gatun
			Average Madden Lake and Tributary Inflow for time interval				Exchange during lift operations Pedro Miguel Lock			Exchange during lift operations Gatun Lock			Mass of salt, lbs	Exchange during lift operations Miraflores Syncrolift			Exchange during lift operations Gatun Syncrolift			Mass of salt, lbs		
Time Interval	Salinity - LG ppt	Volume - LG, cf	Spill - ML, cf	Qpower - ML, cf	Trib - LG, cf	Salinity - ML, cf	Qlock, cf	Phi portion of lock	Salinity - lock, ppt	Qlock, cf	Phi portion of lock	Salinity - lock, ppt		Qlock, cf	Phi portion of lock	Salinity - lock, ppt	Qlock, cf	Phi portion of lock	Salinity - lock, ppt		Total Inflow, cf	Less Madden Releases, cf
52	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
53	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
54	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
55	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
56	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
57	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
58	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
59	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
60	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
61	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
62	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
63	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
64	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
65	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
66	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
67	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
68	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
69	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
70	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
71	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
72	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
73	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
74	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
75	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
76	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
77	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
78	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
79	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
80	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
81	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
82	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
83	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
84	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
85	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
86	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
87	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
88	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
89	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
90	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
91	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
92	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
93	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
94	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
95	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
96	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
97	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
98	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
99	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			
100	0.044	1.82E+11	5.73E+09	6.66E+10	4.53E+10	0.00	5.12E+10	0.500	0.100	5.45E+10	0.500	0.100		8.74E+09	0.500	0.300	8.74E+09	0.500	0.300			

Table 5.2
Zero-Order Miraflores Lake Salinity Modelv1.0 Aug 1999

Panama Canal											
	Flows are based on the number of lockages				38						
			Inflow from Pedro Miguel Lock Operation		Exchange during lift Operations			Exchange during lift operations			
Time days	Salinity - ML, ppt	Volume cf	Qlock, cf	Salinity, ppt	Qlock, cf	Phi, portion of lock	Salinity - lock, ppt	Qlock, cf	Phi, portion of lock	Salinity - lock, ppt	Mass of salt, lbs
0	0.00	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0	1.49E+08	0.500	1.500	6.98E+06
1	0.11	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
2	0.20	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
3	0.27	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
4	0.32	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
5	0.36	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
6	0.39	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
7	0.41	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
8	0.43	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
9	0.45	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
10	0.46	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
11	0.47	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
12	0.47	8.23E+08	9.55E+0	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
13	0.48	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
14	0.48	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
15	0.48	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
16	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
17	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
18	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
19	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
20	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
21	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
22	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
23	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
24	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
25	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
26	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
27	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
28	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
29	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
30	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
31	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
32	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	

(Sheet 1 of 3)

Table 5.2 (Continued)

Panama Canal											
	Flows are based on the number of lockages				38						
			Inflow from Pedro Miguel Lock Operation		Exchange during lift operations			Exchange during lift operations			
Time days	Salinity - ML, ppt	Volume cf	Qlock, cf	Salnity ppt	Qlock, cf	Phi, portion of lock	Salinity - lock, ppt	Qlock, fc	Phi, portion of lock	Salinity - lock, ppt	Mass of salt, lbs
33	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
34	0.49	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
35	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
36	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
37	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
38	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
39	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
40	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
41	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
42	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
43	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
44	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
45	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
46	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
47	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
48	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
49	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
50	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
51	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
52	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
53	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
54	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
55	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
56	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
57	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
58	0.50	8.23E+08	9.55E+07	0.000	1.40E+08	0.500	0.10	1.49E+08	0.500	1.500	
59	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
60	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
61	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
62	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
63	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
64	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	

(Sheet 2 of 3)

Table 5.2 (Concluded)

Panama Canal											
	Flows are based on the number of lockages				38						
			Inflow from Pedro Miguel Lock Operation		Exchange during lift operations			Exchange during lift operations			
Time days	Salinity - ML, ppt	Volume cf	Qlock, cf	Salnity ppt	Qlock, cf	Phi, portion of lock	Salinity - lock, ppt	Qlock, fc	Phi, portion of lock	Salinity - lock, ppt	Mass of salt, lbs
65	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
66	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
67	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
68	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
69	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
70	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
71	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
72	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
73	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
74	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
75	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
76	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
77	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
78	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
79	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
80	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
81	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
82	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
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84	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
85	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
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87	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
88	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
89	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
90	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
91	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
92	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
93	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
94	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
95	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
96	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
97	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
98	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
99	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	
100	0.50	8.23E+08	9.55E+0	0.000	1.40E+	0.500	0.10	1.49E+08	0.500	1.500	

(Sheet 3 of 3)

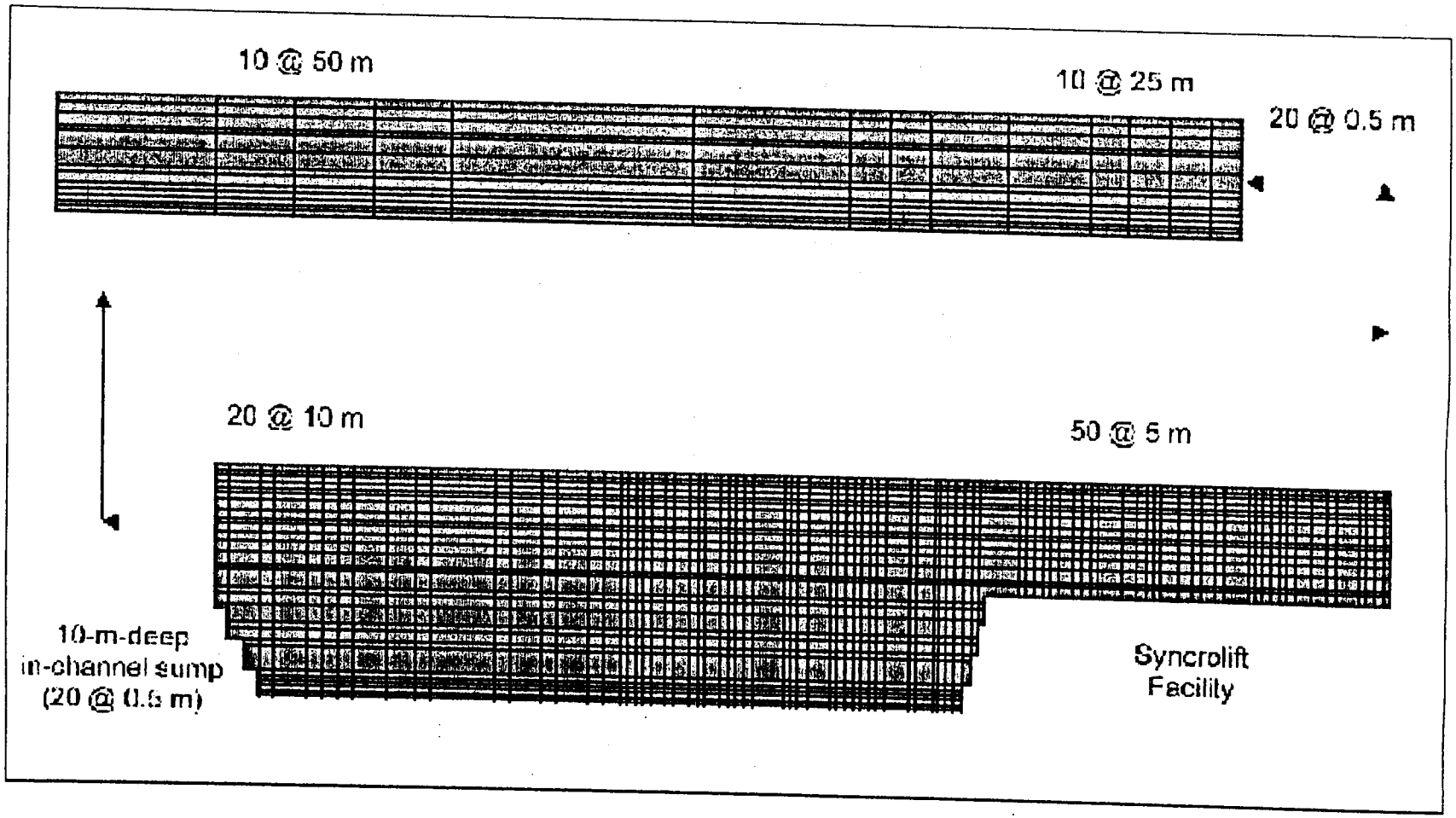

Figure 5-1. Details: Segment distribution for Lake Gatun computational grids

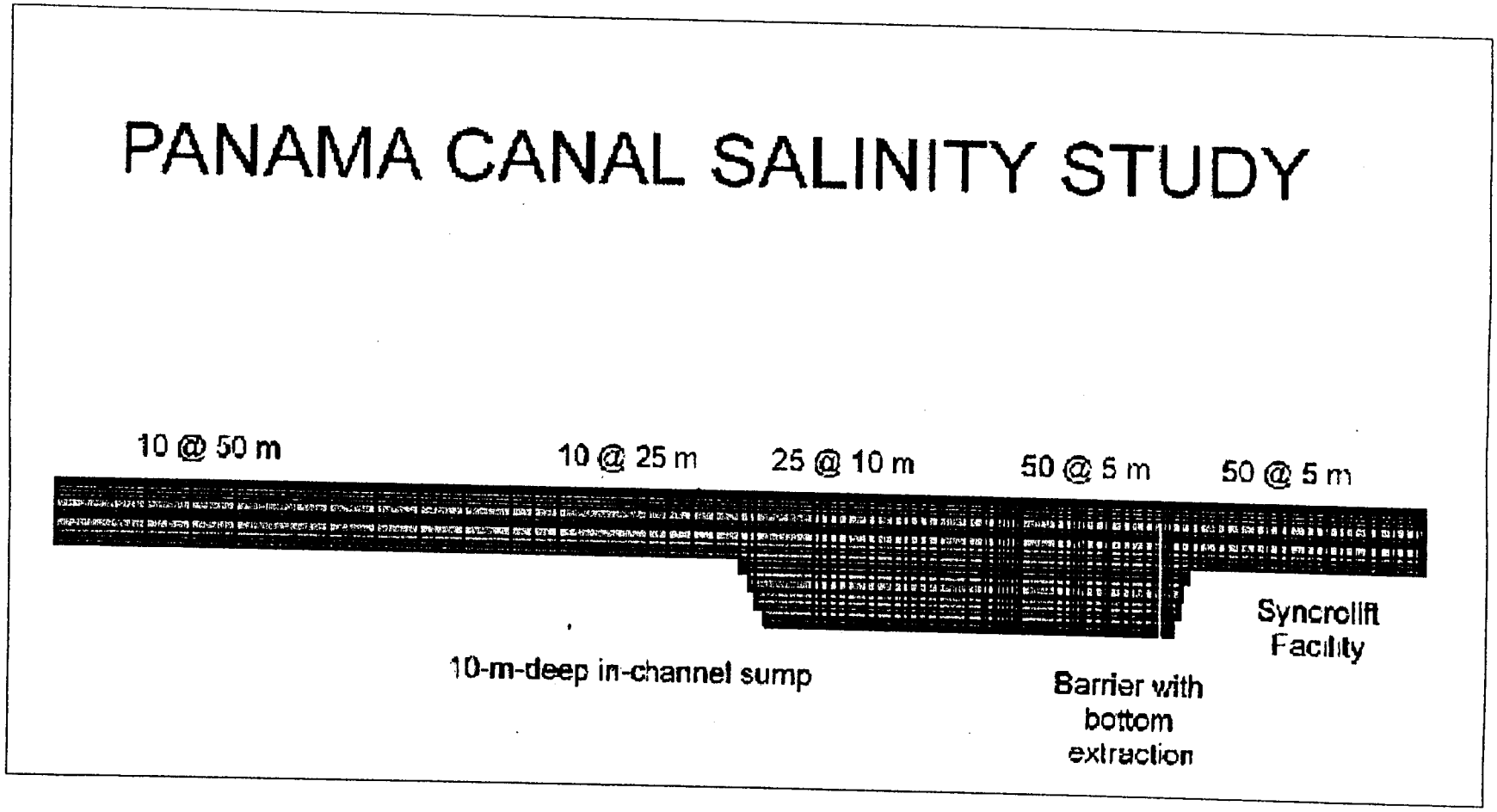

Figure 5-2. Segment distribution for Lake Gatun computational grids

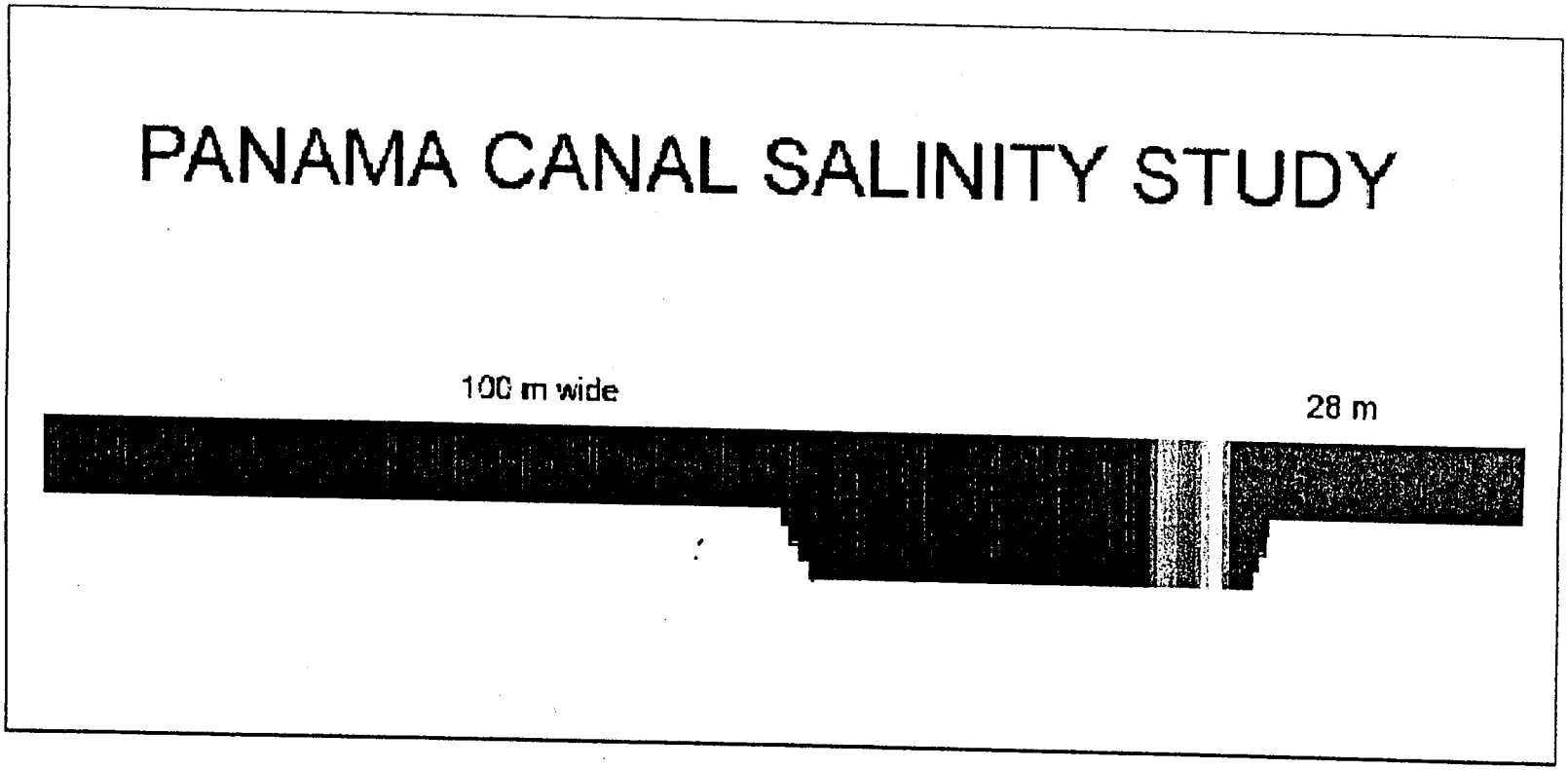

Figure 5-3. Width contours 10-m-deep channel sump

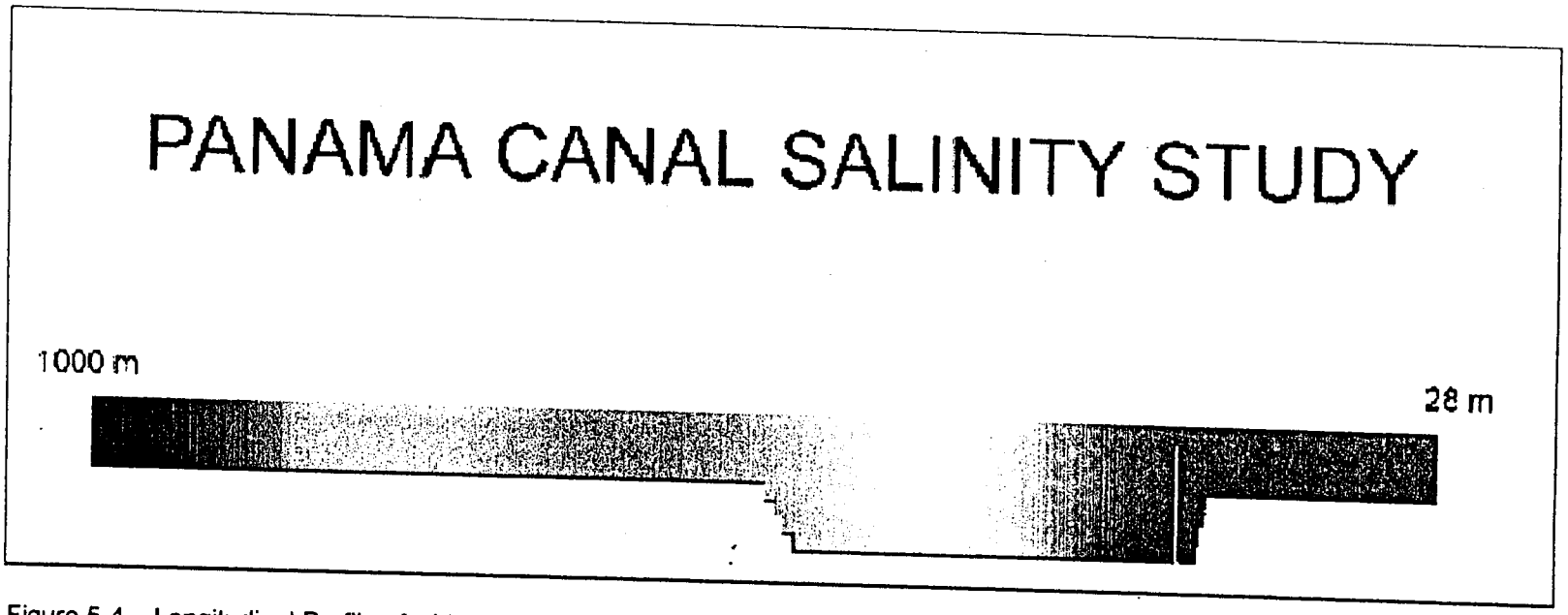

Figure 5-4. Longitudinal Profile of width used in salinity trap and extraction calculations

6 Modeling Salt Movement Across Gatun Lake

Objective

The objective of this portion of the work is to examine how salinity moves into Gatun Lake from the locks if the salt water is not captured immediately in front of the lock. The results will help Canal managers compare capacity expansion and fresh water conservation plans and to assess the need for remedial measures to maintain the desired salinity level across the lake.

Models and Assumptions

The hydrodynamics of Gatun Lake were modeled in two dimensions by using the TABS-MD numerical modeling system of the U.S. Army Corps of Engineers. TABS-MD consists of a number of computer-based numerical models for open-channel flow and transport. For the effort described here, the depth-averaged two-dimensional hydrodynamic model RMA-2 and companion transport model RMA-4 were used. RMA-2 provides a finite element solution of the Reynolds form of the two-dimensional, constant density Navier-Stokes equations for turbulent open channel flows. RMA-4 solves the two-dimensional advection-diffusion equation for multiple dissolved constituents. (See Appendix D for discussion of the governing equations and assumptions.)

Salinity flow out of the locks will have a significant three-dimensional density-driven structure that will be fully captured only by a three-dimensional model that has been verified to field observations. However, the objectives of this effort can be met by application of two-dimensional models as described in this section and the preceding section of this report. The two-dimensional width-averaged numerical model of Part 5 accurately depicts the density-driven vertical flow structure near the lock, and the depth-averaged results presented in this section will be more accurate farther from the locks, where diffusive transport dominates, and where the waterway is much wider. The models used here have not been verified to field observations, but the calculations are physics-based and have been applied to many sites by the Corps of Engineers and others (Heath et al., 1999) so the results are considered qualitatively reliable and quantitatively

useful when one set of model far-field results is compared with another, e.g., existing conditions versus the Syncrolift plan and wet versus dry season..

For the purposes of this study, a mesh representing Gatun Lake and the Panama Canal with its Atlantic and Pacific entrances was developed (See Figure 6-1). This mesh, constructed using maps provided by the Panama Canal Commission, was employed by RMA-2 and RMA-4 to solve the governing equations across the area of interest. Elevations of the lake bottom are shown by shading in Figure 6-1.

Experimental Conditions

The hydrodynamic calculations assumed that 38 lockage operations occur per day at both Atlantic and Pacific entrances; thus, boundary rating curves were applied at both entrances to provide outflows equal to the lift volume required to execute that many lockages. These curves remove water from the lake by taking into account the volume of the lock and the water surface elevation in the vicinity of the lock at the time. Outflows over the spillways were specified as zero during the dry season and were calculated from water surface elevations during the wet season. Fresh water inflows to the system were applied at four locations: Madden Lake, Gatun River at Ciento, Ciri Grande River at Los Cañones, and Trinidad River at El Chorro. Evaporation was considered, as well as possible outflows from the lake for municipal uses and power generation. Model runs were performed for a two month period, which was sufficient to reach a quasi-steady-state condition.

The existing conditions were evaluated for two seasons, wet and dry. During dry season, which lasts approximately 5 to 6 months out of the year, the inflows at the locations mentioned above are significantly lower than those present during wet season. As a result, the Gatun Dam spillway does not operate during this time. On the other hand, the wet season inflows are up to 4 times larger than the dry season, thereby increasing the water surface elevation of the lake and opening the spillway for operation. For the modeling process, Gatun Lake was kept at a water surface elevation of 26 m (85 feet) during dry season and at 27 m (87.5 feet) for wet season.

Based on field observations and the calculations shown in Part 3 and Appendix A, a salinity of 0.083 ppt was applied as a boundary condition at the Gatun Dam locks. Likewise, a salinity value of 0.13 was applied as the boundary condition at the Pedro Miguel Locks. For the Syncrolift lock plan, a unit concentration was specified at the lock location. Since the depth-integrated model does not calculate water density and density currents, this unit concentration can be approximately any specified salinity in the lock by simply multiplying the model results by the specified lock concentration. The existing lock results may be similarly extended to other in-lock concentrations by a ratio of the specified concentration to the values listed above. Extending these results to other lock salinities and comparing the syncrolift tracer results to existing lock results is only approximate, since diffusion rate in the model is proportional to

the concentration gradient. Thus, more rapid initial diffusion will be computed for the 1.0 ppt lock condition than for the 0.08 ppt lock condition.

Plans Tested

Two lock configurations – the existing locks and an additional lock (Syncrolift) adjacent to each set of locks – and two hydrologic conditions – wet and dry seasons – were examined. In summary, four model runs were made:

a. Existing conditions during dry season

b. Existing conditions during wet season.

c. Syncrolift lock (only) at both entrances during dry season.

d. Syncrolift lock (only) at both entrances during wet season.

Results

Figure 6-2 shows a snap-shot comparison of wet and dry seasons for existing conditions in the vicinity of the Pedro Miguel Locks after two months. The dry season permits salinity to intrude much further than the wet season, and salinity contours are seen to intrude nearly to Madden Lake. However, during the wet season the salt is swept back to the locks and out via the spillway.

Figure 6-3 shows a comparison between wet and dry seasons at the Atlantic side of Gatun Lake. As seen in the figure, salinity concentrations remain higher on this side more readily during wet season, since the salt is not confined in a narrow channel as on the Pacific side. Nevertheless, salinity values do not exceed 0.027 ppt inside the lake even in the worst case, which corresponds to the lack of observed salinity buildup in Gatun Lake. The Gatun spillway is seen to play a key role during wet season in removing higher salinity water from the lake, for the low concentration plume is drawn to the spillway.

Similar scenarios play out when adding the Syncrolift locks to the system. Figure 6-4 portrays how tracer in the Syncrolift locks diffuses from the Pedro Miguel Locks for wet and dry seasons. The contours on Figures 6-4 and 6-5 show the fraction of the initial lock concentration present in different areas of the mesh after the model has run for two months.

Figure 6-5 shows a closer look at the Gatun Locks area, where we again see that the Gatun spillway is important in alleviating salinity concentrations during the wet season. We should note, though, that the increased tracer concentrations observed in the vicinity of the Gatun Locks during dry season are mostly a product of tracer diffusing up through the lake from the Pedro Miguel Locks. Film loops accompanying this report show this situation clearly.

Recommendations for Design Phase

This modeling approach depicts what happens to salt that is not captured close to the locks. If the final design for expanding canal capacity ensures that no more salt water will be released from the locks than under existing conditions, Gatun Lake need not be modeled during the design phase. However, this modeling approach, either in two-dimensions or three-dimensions, can be used to predict salinities in the waterways at the sea ends of both locks to improve the boundary conditions assumed in Part 3 of this report.

If Gatun Lake transport is modeled in the design phase, the three-dimensional version of these models (TABS-10) should be used to ensure that densimetric transport is reproduced. The model should be verified to field measurements of current speed and direction and salinity, with low-threshold instruments employed to successfully measure the small flow speeds and salinities of the lake.

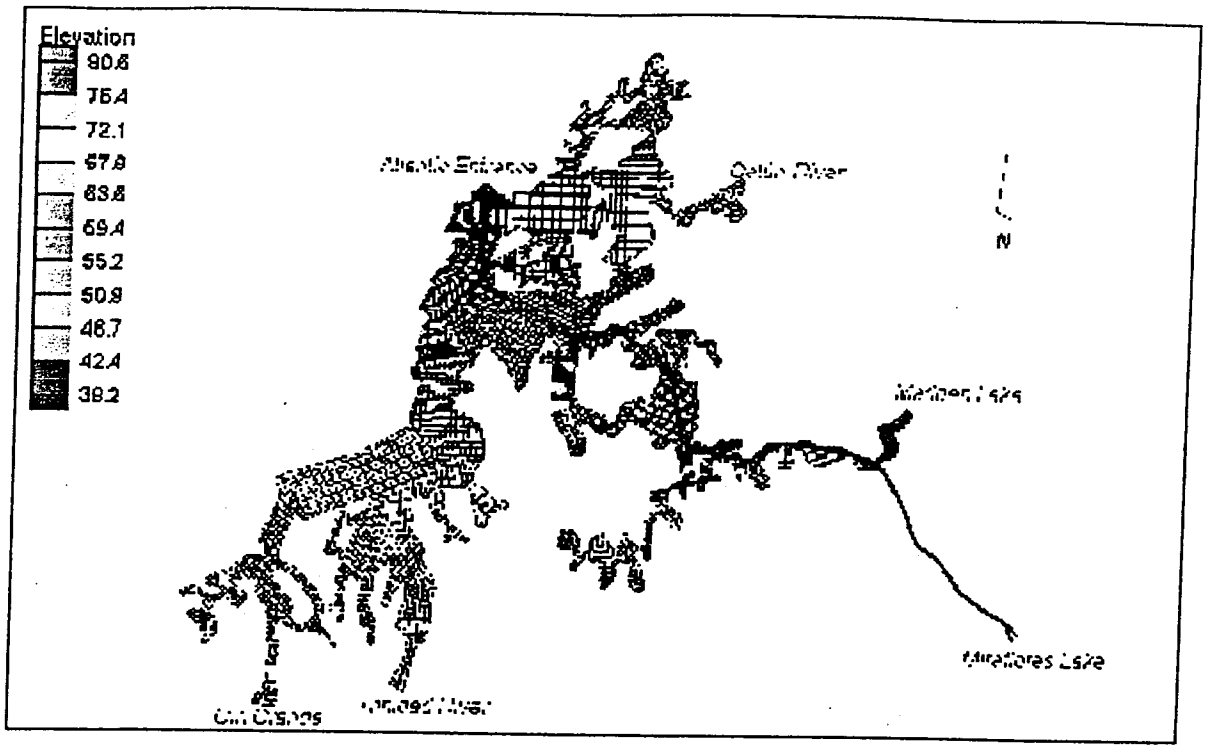

Figure 6-1. Depth-integrated model computational mesh of Gatun Lake and Panama Canal. Shaded areas indicate bottom elevation of lake in feet

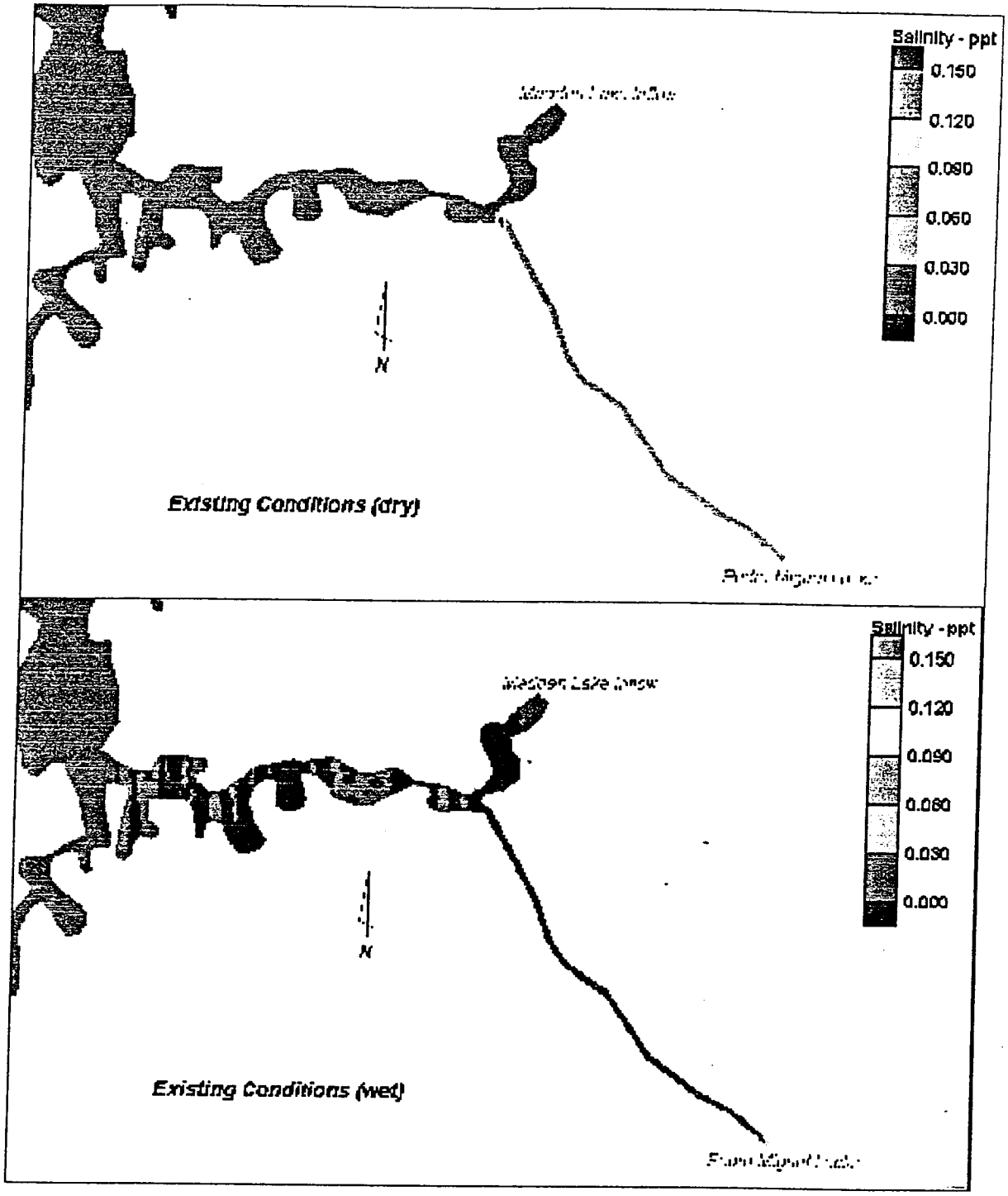

Figure 6-2. Salinity Profiles at Pedro Miguel Locks and Surrounding Areas for dry and wet seasons

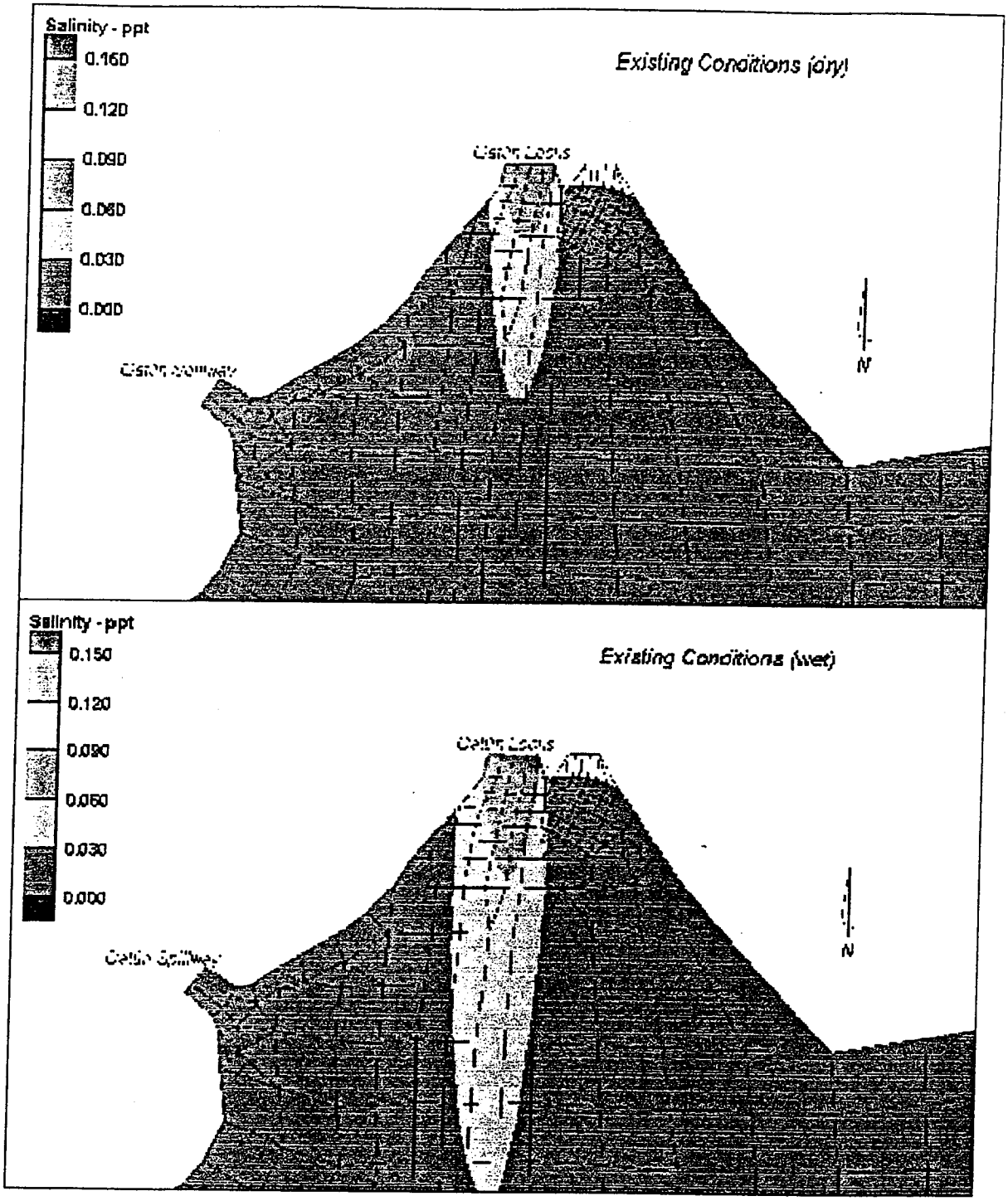

Figure 6-3. Salinity patterns near Gatun Locks for dry and wet seasons

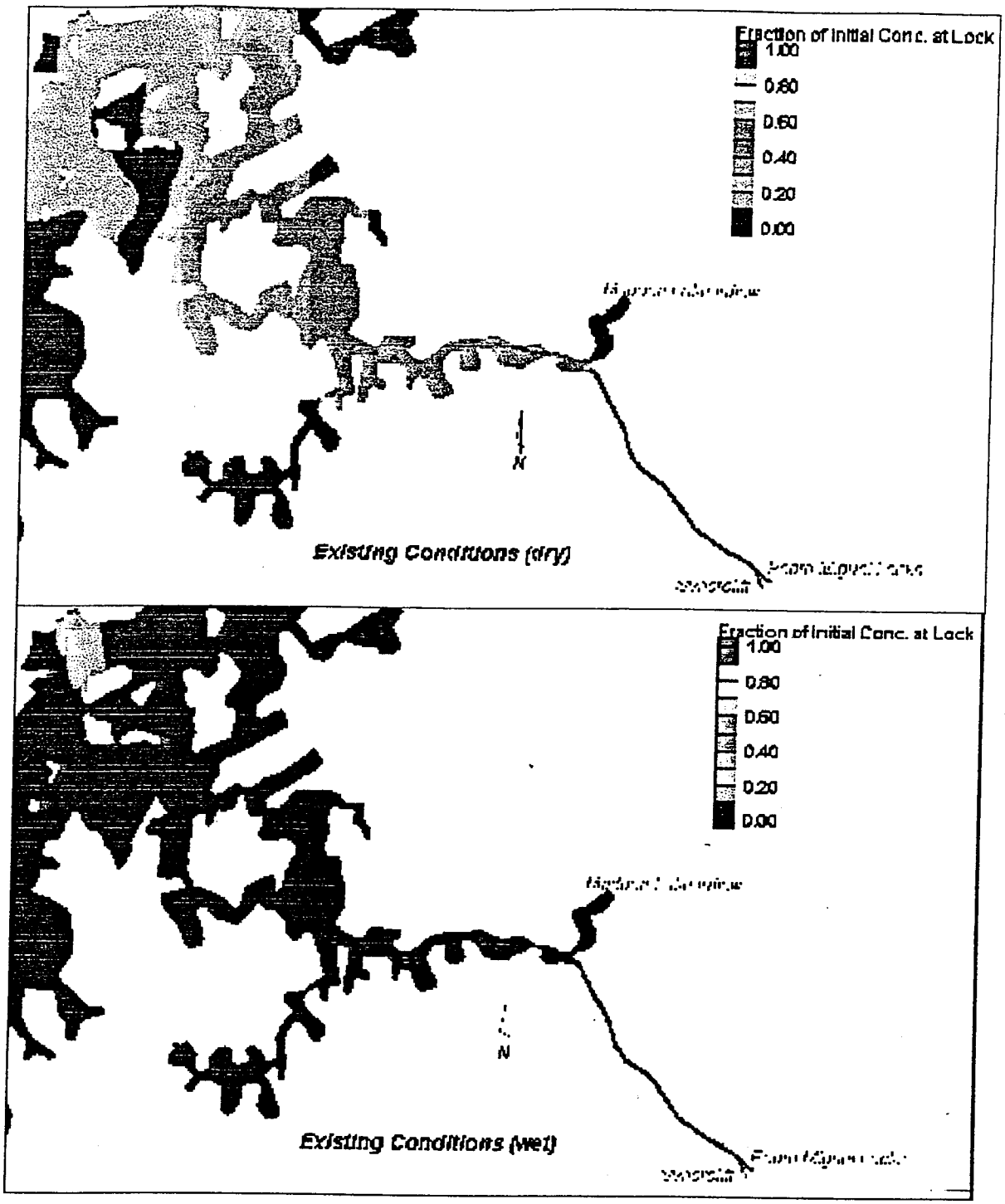

Figure 6-4. Concentration patterns for the Syncrolift lock plan in dry and wet seasons

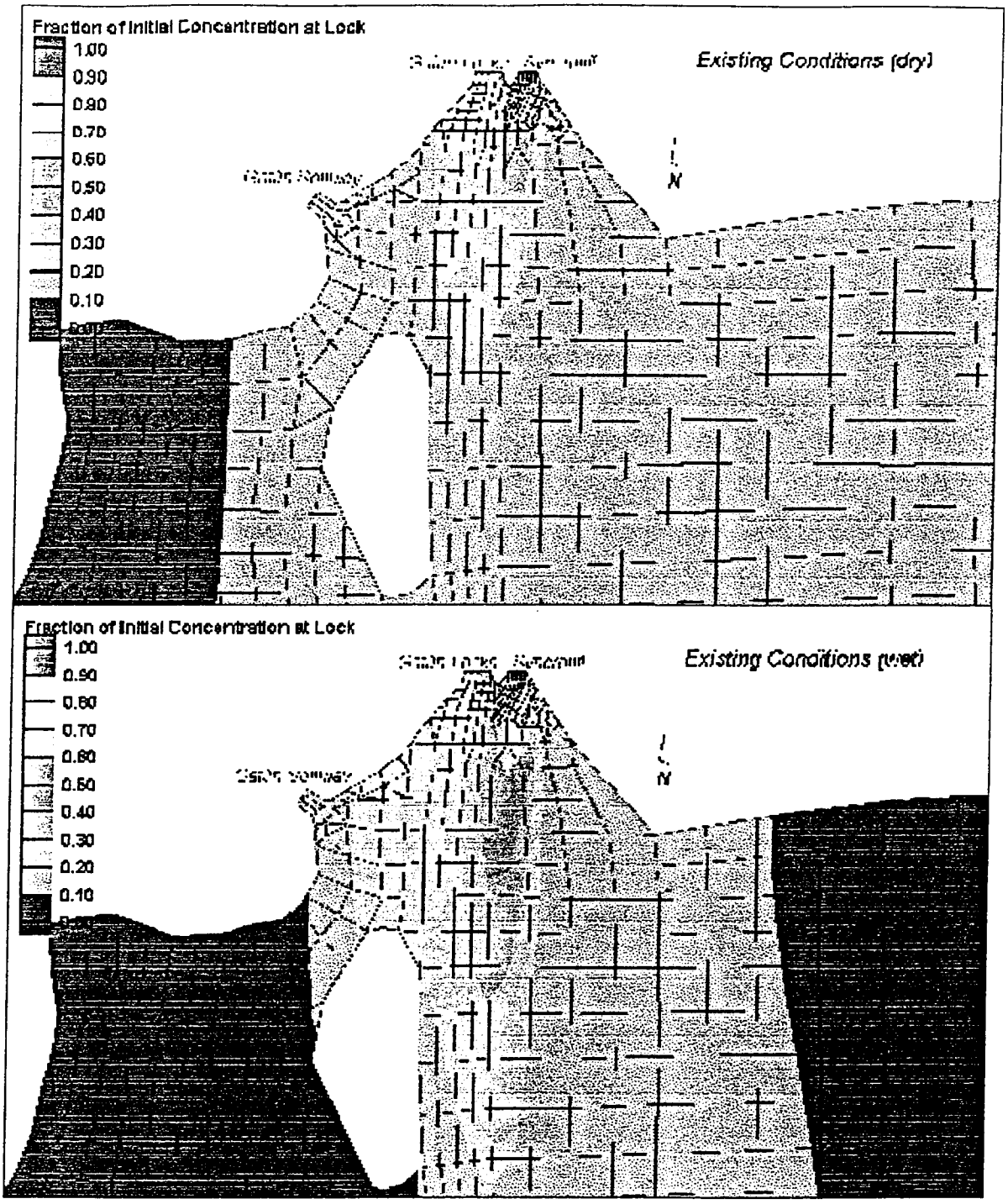

Figure 6-5. Concentration patterns at Gatun Locks for dry and wet seasons with both existing locks and Syncrolift in operation

7 Summary and Conclusions

A review of salinity control measures at locks worldwide shows a variety of methods being employed, including salt water barriers, sumps to collect and drain salty water, and mixing devices to limit intrusion. A detailed evaluation of the Hiram Chittenden Locks in Seattle, Washington, USA, shows that a salt water sump with a hinged barrier is an effective approach to salt water intrusion control.

Salt water is slightly more dense than freshwater, causing it to flow under fresh water in a density current unless mixed by strong currents, ship propwash, or artificial mixing devices such as bubble screens. Density currents may lead to greater saltwater intrusion than would occur in well-mixed waters, but offers an opportunity to capture some of the salt water before it intrudes into the freshwater zone upstream of the locks.

A set of tools has been developed that supports evaluation of salinity intrusion and freshwater consumption through the Panama Canal locks for Gatun Lake. They include:

a. A simple mixing analysis coded in spreadsheet form that provides zero-dimensional models for the salinity of individual locks and for Miraflores Lake and Gatun Lake plus a freshwater consumption model for Gatun Lake.

b. A depth-integrated two-dimensional numerical model for dispersive transport of salt water into Gatun Lake.

c. A width-integrated two-dimensional numerical model for densimetric advection and dispersion of salty water from the locks into a channel.

The numerical models employ the graphical user environment of the U. S. Army Corps of Engineers Surface Water Management System (SMS) to manage the models and display their results. The zero-dimensional models have been adjusted to yield results roughly comparable to limited field observations of salinity in the Panama Canal. The two-dimensional models are physics-based and have been successfully employed in many applications; however, they have not been verified to field observations in Gatun Lake.

These tools have been applied in a feasibility-level evaluation of the following alternatives for expansion of Panama Canal capacity.

a. Use of holding ponds to conserve fresh water by recirculating lift water.

b. Installation of a Syncrolift lock chamber adjacent to the Miraflores and Gatun Locks.

c. A sump in the channel upstream of the locks to capture more dense salty water and drain it before it reaches the lake.

d. A gated chamber upstream of the locks to hold salty water while it is drained to the sea and replaced with freshwater.

Analyses using the tools listed above show that:

a. Freshwater consumption can be reduced by up to about 60% by recirculating lift water through holding ponds, albeit at the cost of increasing salinity in the ocean approach channels and ultimately in the uppermost locks. If this option is employed, the potential for increased salinity intrusion and necessary remedial measures should be addressed.

b. A sump in the channel upstream of the locks can capture salt water through selective withdrawal, and is most effective for higher salinity (and thus more dense) water in the locks; however, higher salinity in the locks (now about 0.1 ppt in the uppermost Miraflores and Gatun Locks) risks greater salinity contamination of the lake if any lock water escapes the sump. A sump requires some sort of confined channel upstream of the lock to train the densimetric flow out of the lock.

c. A salinity of greater than 0.3 ppt in the uppermost locks, including a Syncrolift lock, risks unsatisfactory buildup of salt water in Gatun Lake unless some means of capturing most of the salt water is incorporated in the facility.

d. A gated chamber on the lake side of the uppermost lock offers the option of draining salty water from the lock and replacing it with fresh water before opening for ship passage. This technique provides positive salinity control at the locks, either standard or Syncrolift, at the cost of a delay in the vessels' exit of the lock.

Recommendations

We recommend:

a. Further consideration of recirculating lift water through holding ponds as a means of freshwater conservation.

b. Further consideration of a gated chamber at the uppermost lock entrance on each side to reduce salinity intrusion into Gatun Lake if either the

Syncrolift lock or the holding pond/recirculation alternatives are considered for design.

c. Use of the tools developed here in the design phase of any canal improvement plans. They should be verified to a comprehensive field data set of water levels, velocities, salinities, and temperatures before use in a design effort.

d. Addition of a model of the sea approaches to calculate the salinity there under any alternative that might alter the salinity, such as the recirculation/holding pond option.

e. Field data collection in support of further modeling should be synoptic to the maximum degree possible, should include acoustic Doppler current profiling, and should include salinity meters capable of measurements to hundredths of a ppt. If field instruments are not available to meet this requirement, water samples may be collected and analyzed in a laboratory to the required accuracy.

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OF
GAILLARD CUT

FAMILY	SCIENTIFIC NAME	COMMON NAMES	W-1	W-2	W-3	W-4	E-1	E-2
ANACARDIACEAE	Anacardium excelsium	Espavé	C	C	C		C	C
	Astronium graveolens	Zorro						O
	Mangifera indica	Mango	O	C	O		C	C
	Spondias mombin	Jobo, Hog plum	C	C	C		C	C
ANNONACEAE	Annona reticulata	Anón	C	C			C	C
	A. spraguey	Toreta	C	C			C	
	Xylopia frutescens	Malagueto	C	C	C		C	C
	X. sp.	Malagueto	C	C			C	C
ARACEAE	Dieffenbachia longispatha	Otó de lagarto				*		
	Philodendron sp.	Philodendron	*					
ARALIACEAE	Didymopanax morototoni	Mangabe, Guarumo de pava	C	C	C	O	C	C
	Sciadodendron excelsum	Jobo, Corroncho de largarto						C
BIGNONIACEAE	Jacaranda copaia	Jacaranda, Cigarrillo	C	C			C	C
	Bignonia sp.?	Liana, Bejuco	*	*				
	Probably Arrabidaea sp.	Bejuco	*	*				
	Tabebuia guayacan	Guayacán	C	C			C	C
	T. rosea	Roble de sabana	O					
BOMBACACEAE	Ceiba pentandra	Ceiba, Bongo	*					*
	Ochroma pyramidale	Balsa, Balso	C	C	C	C	C	C
	Pseudobombax septenatum	Barrigón, Ceibo barrigón	C	C			C	C
BORAGINACEAE	Cordia alliodora	Laurel	C	C		C	C	C
BURSERACEAE	Bursera simaruba	Carate, Indio desnudo, Almácigo	C	C	C	C	C	C
CAESALPINIOIDEAE	Cassia multijuga?	Cañafístulo de Montaña, Bronze shower					C	C
	C. sp.	Cassia						
	C. reticulata	Laureño						*
COCHLOSPERMACEAE	Cochlospermum vitifolium	Poro-poro, Brazilian rose	C	C	C	C	C	C
COMBRETACEAE	Terminalia amazonia	Amarillo real	C	C	C			C
CYATHEACEAE	Cyathea sp.	Helecho arbóreo, Tree fern	O	*				
CYCLANTHACEAE	Carludovica palmata	Portorrico, Jipi-japa	C	C	C			C
	Cyclanthes bipartitus	Lengua de buey	O	*	*			*
CYPERACEAE	Cyperus sp.	Junco	O	*	*			
	Scleria secans?	Cortadera	C	C			C	C
DILLENIACEAE	Curatella americana	Chumico				*		*
	Davilla nitida	Chumiquillo						
ELAEOCARPACEAE	Muntingia calabura?	Periquito, Capulín						

FAMILY	SCIENTIFIC NAME	COMMON NAMES	W-1	W-2	W-3	W-4	E-1	E-2	E-
EUPHORBIACEAE	Croton billbergianus	Sangr[illegible]llo					C	C	O
	Chamaesyce hirta	Hier[illegible] pollo						*	
	Hevea brasiliensis	Caucho, [illegible]ubber tree						*	
	Sapium caudatum	Olivo, Wild fig		C				C	
FLACOURTIACEAE	Hasseltia floribunda	Parimontón, Raspa lengua							*
GESNERIACEAE	Kohleria tubiflora	Undetermined						*	
GRAMINEAE	Chusquea sp.	Carricillo	C	C			C	C	C
	Gynerium sagittatum	Caña blanca, Wild cane			C				C
	Hyparrhenia rufa	Faragua		C	C			C	C
	Panicum grande	Guinea	*						
	P. maximum	Guinea grass		C			C	C	C
	P. purpurascens	Pará grass				*			
	Paspalum sp.	Undetermined		*					
	P. virgatum	Cabezona						*	
	Pennisetum purpureum	Elefante, Napier grass						*	
	Saccharum spontaneum	Caña silvestre, Caña salvaje	O	C	A	A	C	C	VF
	Setaria sp.	Rabo de mono		*				*	*
GUTTIFERAE	Vismia baccifera	Achiotillo, Pintamozo	C	C			C	C	C
LAURACEAE	Ocotea sp.?	Sigua	C	C				C	
	Persea americana	Aguacate						*	
LECYTHIDACEAE	Gustavia sp.	Membrillo	C	C		C	C	C	C
MALPIGNIACEAE	Byrsonima crassifolia	Nance		C	C	C	C	C	C
MARANTHACEAE	Calathea sp.	Calatea	*	*					
MELASTOMATACEAE	Clidemia sp.	Undetermined							
	Miconia argentea	Papelillo	C	C			VF	C	C
	M. sp.?	Dos caras	C	C			C	C	C
MELIACEAE	Cedrela odorata	Cedro, Spanish cedar			*		*	*	
	Trichilia sp.	Alfajía					C	C	
MIMOSOIDEAE	Acacia melanoceras	Cachito							*
	Enterolobium cyclocarpum	Corotú	C	C		C	C	C	C
	Mimosa sp.	Dormidera, Sensitive plant	*	*	*	*	*	*	*
	Inga sp.	Guavo	C	C		C	C	C	C
	Pithecellobium sp.	Pichinde							C
MORACEAE	Brosium alicastrum	Verbá, Berbá						O	O
	Castilla elastica	Hule, Caucho	C	C					
	Cecropia sp.	Guarumo, Trumpet tree	C	C	C	C	C	C	C
	Ficus sp.	Higuerón	C	C	C		C	C	C
	F. sp.	Undetermined	O						
MUSACEAE	Heliconia sp.	Bijao, Chichica	*	*	*	*	*	*	*
	Musa sp.?	Platanillo	*	*			*		
MYRTACEAE	Syzygium jambos	Pomarosa, Rose apple	*	*			*		
	Psidium guajava	Guayaba						*	

	SCIENTIFIC NAME	COMMON NAMES	W-1	W-2	W-3	W-4		E-2	E-
PALMAE	Acanthorrhiza warscewiczii	Palma de escoba							*
	Astrocaryum standleyanum	Chonta, Black palm					C	C	C
	Bactris sp.	Caña brava	C						C
	Desmoncus sp.	Matamba							C
	Elaeis oleifera	Corozo, Corocito	C	C			C	C	VF
	Oenocarpus panamanus	Maquenque, Trufa	C	C					
	Roystonea regia	Palmera real		O			C	C	
	Scheelea zonensis	Palma real, Corozo	C	C			C	C	VF
PAPILIONDIDEAE	Andira inermis	Almendro de río, Cabbage bark					C	C	
	Crotalaria retusa?	Crotalaria	*	*		*			*
	C. vitellina?	Crotalaria		*					
	Diphysa robinioides	Macano							*
	Erythrina fusca	Gallito, Palo santo	C			C	C	C	C
	Glyricidia sepium	Mata ratón, Balo						*	
	Mucuna pruriens?	Pica-pica		*		*			*
	Ormosia sp.	Peronil	*						
PIPERACEAE	Piper sp.	Cordoncillo	*	*			*	*	*
	P. sp.	Hinojo oloroso							*
POLYGONACEAE	Coccoloba sp.	Uvero						*	
	Triplaris cumingiana	Vara santa	C	C		C	C	C	C
RUBIACEAE	Cephaelis sp.	Undetermined	*	*					
	Genipa americana	Jagua	C				C	C	C
	Isertia sp.?	Undetermined							*
RUTACEAE	Zanthoxylum sp.	Arcabú, Prickly yellow	C					C	C
SAPINDACEAE	Paulinia sp.?	Bejuco	*	*					
SAPOTACEAE	Chrysophyllum cainito	Caimito	C	C					C
SELLAGINELLACEAE	Selaginella sp.	Selaginela						*	*
SIMAROUBACEAE	Simarouba amara	Aceituno						*	
SOLANACEAE	Solanum asperum	Friega platos							*
	S. sp.?	Undetermined							
STERCULIACEAE	Guazuma ulmifolia	Guácimo, Bastard cedar	C	C	C	C	C	C	C
	Helicoteres guazumaefolia	Majaguillo, Guácimo torcido		*					
	Sterculia apetala	Panamá, Panama tree		C		C	C	C	
TILIACEAE	Apeiba tibourbou	Cortezo, Monkey comb	C	C	C	C	C	C	C
	Luehea speciosa	Guácimo colorado	C	C	C		C	C	C
	L. sp.	Guácimo pacheco	C	C					C
ULMACEAE	Trema micrantha	Capulín, Jordancillo	C	C				C	C
VERBENACEAE	Lantana camara	Lantana							C
	Vitex gigantea	Cuajado blanco						O	O
VOCHYSIACEAE	Vochysia herruginea	Mayo, Yemerí mayo, Pegle					C	C	
ZINGIBERACEAE	Costus villosissimos	Caña agria	*	*					*

KEY: O=Occasional; C=Common; VF=Very Frequent; A=Abundant; *=Observed, but numbers not recorded

Appendix F

List of Wildlife Recorded from Panama Canal Watershed

Class	Order	Scientific Name	Spanish Common Name
Mammalia	Lagomorpha	Sylvilagus brasiliensis	Conejo muleto
	Rodentia	Sciurus granatensis	Ardilla colorada
		S. variegatoides	Ardilla negra
		Coendou rothschildi	Puerco espin
		Hydrochaeris hydrochaeris*	Poncho, Capibara
		Agouti paca*	Conejo pintado
		Dasyprocta punctata*	Neque, Machango
		Proechymis semispinosos	Mocangue
	Carnivora	Urocyon cinereoargenteus	Micho de cerro
		Procyon cancrivorus*	Gato manglatero
		P. lotor*	Gato manglatero
		Nasua nasua	Gato solo
		Lutra annectens (longicaudis?)	Nutria
		Potos flavus	Cosumbi
		Bassaricyon gabbii	Olingo
		Mustela frenata	Comadreja
		Eira barbara	Gato negro
		Galictis vittata	Lobo pollero
		Felis onca*	Tigre, Jaguar
		F. pardalis*	Manigordo
		F. wiedii*	Tigrillo congo
		F. jagouaroundi*	Tigrillo congo
		F. concolor*	Puma
	Sirenia	Trichechus manatus*	Manati
	Perissodactyla	Tapirus bairdii*	Tapir, Macho de monte
	Artiodactyla	Tayassu pecari*	Puerco de monte
		T. tajacu*	Zaino
		Odocoileus virginianus*	Venado de cola blanca
		Mazama americana	Venado colorado
	Primates	Alouata palliata*	Mono aullador
		Ateles geoffroyi*	Mono arana colorado

Class	Order	Scientific Name	Spanish Common Name
...mmalia	Primates (cont.)	Saguinus geoffroyi*	Mono titi
		Aotus trivirgatus*	Mono nocturno, Jujuna
		Cebus capucinus*	Mono cariblanco
	Marsupialia	Didelphis marsupialis	Zorra
		Caluromys derbianus	Zorra roja
	Chiroptera	Desmodus rotundus	Vampiro comun
		Noctilio leporinus	Murcielago pescador
		Diclidurus virgo	Murcielago blanco
		Vampyrum spectrum	Falso vampiro
		Diacmus youngii	Vampiro overo
	Edentata	Myrcecophaga tridactyla#	Oso caballo
		Tamandua tetradactyla	Oso hormiguero
		Cyclopes didactyles*	Tapacacara, Gato balsa
		Bradypus infuscatus	Perezoso de 2 dedos
		Cabassous centralis*	Armadillo rabo de puerco
		Dasypys novemcictus*	Armardillo
Amphibia	Anura	Bufo marinus	Sapo comun
		B. typhonius	Sapo
		Hyla phlebodes	Rana
		H. crepitans	Rana
		Agalychnis callidryas	Rana
		Dendrobates auratus	Rana
		Colestethus nubicola	Rana
		Leptodactylus pentadactylus	Rana
		L. bolivianus	Rana
		Rana warschewitschi	Rana
		Atelopus varius zeteki*	Rana dorada
Reptilia	Apoda	Oscaecilia ochrocephala	Cecilia
	Crocodilia	Crocodylus acutus*	Lagarto aguja
		Caiman crocodylus fuscus*	Babilla
	Squamata	Iguana iguana*	Iguana verde
		Anolis auratus	Lagartija
		A. biporcatus	Lagartija
		Corithophanes cristatus	Camaleon

Class	Order	Scientific Name	Spanish Common Name
Reptilia	Squamata (cont.)	Basiliscus basiliscus	Meracho
		Thecadactylus rapicaudus	Salamenguesa
		Lepidoblepharis sanctaemartea	Salamenguesa
		Mabuya mabouya	Mata caballo
		Gonotodes albogularis	Limpiacasa
		Ameiva ameiva	Borriguero
		A. festiva	Borriguero
		Lachesis muta	Berrugosa
		Bothrops atrox	Berrugosa
		B. schlegelii	Taboba de pestana
		Micrurus mipartitus	Coral
		Boa constrictor	Boa
		Corallus annulatus	Boa
		Rhadinaea decorata	Culebra
		Rhinobothryum bovalli	Falsa coral
		Xenodon vabdocephalus	Culebra
		Clelia clelia	Culebra
Aves	Tinamiformes	Tinamus mayor*	Perdiz de arca
		Crypturellus soui	Perdiz de rastrojo
	Podicipediformes	Podiceps dominicus	Buzo
		Podilymbus podiceps	Buzo
	Pelecaniformes	Annhinga anhinga	Cuervo de aguja
		Pelecanus occidentalis	Pelicano
		Phalacrocorax olivaceus	Pati cuervo
		Fregata magnificens	Tijereta de mar
	Cicorniformes	Butorides virescens	Martinete
		Casmerodios albus	Garza real
		Tigrisoma lineatun	Garza tigre rayada
		Cochlearius cochlearius	Garzota cuchara
		Agami agami	Garza pechicastana
		Ixobrychus exilis	Garza enana
	Anaseriformes	Dendrocygna viduata	Jacamillo
		D. bicolor	Yaguoso colorado
		D. autumnalis*	Guichichi
		Cairina moschata*	Pato real

Class	Order	Scie	c Name	Spanish Common Name
Aves	Anaseriformes (cont.)	Anas americana		Pato calvo
		A. platyrhynchos*		Ana de real
		A. cyanoptera		Cerceta colorado
		A. discors		Cerceta ala azul
		A. clypeata		Pato cuchara
		Aythya collaris*		Pato de collar
		A. affinis*		Pato pechiblanco
		Oxyura dominica*		Pato tigre
	Falconiformes	Sarcoramphus papa		Rey de gallinazo
		Cathartes aura		Noneca
		C. burrovianus		Guala
		Coragyps atratus		Gallote
		Elanus leucurus#		Milano
		Elanoides forficatus#		Gavilan tijereta
		Leptodon cayanensis#		Gavilen cabecigris
		Chondrohieraly uncinatus#		Gavilan piquiganchudo
		Harpagus bidentatus#		Gavilan bidente
		Ictinia plumbea#		Gavilan plomizo
		Accipiter superciliosus#		Gavilancito enano
		Buteo magnirostris#		Cuiscui
		B. jamaicensis#		Guaranguao
		B. albonatatus#		Gavilan negro
		Buteogallus antharacinus#		Gavilan cangrejo
		Harpya harpyja#		Harpia
		Spizaetus tyrannus#		Aguila crestuda negra
		Herpetotheres cacinnas#		Vaquero
		Micrastur ruficollis#		Halcon de monte rayado
		M. semitorquatus#		Halcon del monte collarejo
		M. mirandollei#		Halcon gateador
		Daptrius americanus#		Caracara
		Miluago chimachima#		Chimango
		Falco peregrinus*		Halcon peregrino
	Galliformes	Crax rubra		Pavon, Pava rubia
		Penelope purpurascens		Pava cimba
		Ortalis cineiceps		Paisana
		Odontophorus gujanensis		Gallito de monte
		Rhynchortyx cinctus		Gallito de monte menor
		Colinus cristatus		Codorniz
		Odontophorys erythrops		

Class	Order	Scientific Name	Spanish Common Name
Aves	Gruiformes	Aramus guarauna	Carrao
		Armides cajanea	Cocaleca gris
		Gallinula chloropus	Gallineta de agua
		Porphyrula martinica	Polla sultana
		Fulica americana	Gallineta cenicienta
		Heliornis fulica	Patico de agua
	Charadriiformes	Pluvialis dominica	Chorlito dorado
		Charadrius collaris	Turillo
		Caladris canutus	Playero gordo
		Jacana jacana	Gallito de agua barbudo
		Tringa solitaria	Playero solitario
		Actitis macularia	Playerito coleador
		Gallinago gallinago	Agachadiza
		Laros argentatus	Gaviota argentea
		L. pipixcan	Gaviota de franklin
		Chlidonias niger	Gaviotin negro
		Sterna hirundo	Gaviotin comun
	Columbiformes	Columba cayennensis*	Torcaza comun
		C. speciosa*	Paloma escamosa
		C. nigrirostris*	Tres pesos son
		C. talpacoti	Tortolita colorada
		Leptotila verreauxi	Paloma rabiblanca
		Geotrygon veraguensis	Paloma verdusca
	Psittaciformes	Brotogeris jugularis#	Perico piquiblanco
		Pionus menstruus#	Cazanga
		Amazona autumnalis#	Loro mona roja
		A. farinosa#	Loro verde o real
		Ara macao#	Guacamaya bandera
		A. chloroptera#	Guacamaya roja
		A. severa#	Guaquita
		Amazona ochrocephala#	Loro mona amarilla
	Cuculiformes	Piaya minuta	Pajaro ardilla enano
		Crotophaga major	Cocinera
		C. ani	Garrapatero comun
		Dromococcyx phasianellus	Pajaro gallo
		Neomorphus geoffroyi	Hormiguero montanes
		Coccyzus americanus	Cuclillo piqui-amarillo

Class	Order	Scientific Name	Spanish Common Name
ves	Strigiformes	Otus guatamalae#	Buhito jaspeado
		Lophostrix cristata#	Buho penachudo
		Pulsatrix perspicillata#	Buho de anteojos
		Ciccaba virgata#	Buho montanes
		C. nigrolineata#	Buho blanquinegro
		Tito alba#	Lechuza
	Caprimulgiformes	Lurocalis semitorquatus	Tapacamino selvatico
		Chordeiles acutipennis	Tapacamino menor
		Nyctidromus albicollis	Capacho
		Caprimulgus rufus	Dormilon moreno
	Apodiformes	Chaetura spinicauda	Vencejo de rabadilla blanquecina
		Glaucis hirsuta	Ermitano barbudo
		Threnetes ruckeri	Pico de hoz
		Colibri delphinae	Colibri de coronilla
		Amazilia amabilis	Colibri hermoso
		A. tzacatl	Colibri colicastana
		Chalybura urochrysia	Colibri colibronceado
		Damaphila julie	Colibri pechiviolaceo
		Thalurania colombica	Colibri de coronilla
		Klais guimeti	Colibri cabeciviolaceo
		Lophornis delattri	Coqueta corona leonada
	Trogoniformes	Trogon massena	Aurora
		T. melanurus	Aurora colilarga
		T. viridis	Tragon de cola blanca
		T. rufus	Tragon gracioso
		T. violaceus	Tragon violaceo
	Coraciformes	Ceryle torquata	Martin pescador grande
		C. alcyon	Martin pescador pasajero
		Chloroceryle americana	Martin pescador verde
		Electron platyrhynchum	Pajaro raqueta piquiancha
		Momotus momota	Pajaro raqueta de coronilla azulada
	Piciformes	Capito maculicoronatus	Capitan corona manchada
		Aulacorynchus prasinus	Currutaco
		Selenidera spectabilis	Pichilingo prieto
		Celeus loricatus	Carpintero prieto
		Campehilus haematogaster	Carpintero acanelado

lass	Order	Scier	Name	Spanish Common Name
Aves	Piciformes (cont.)	Pteroglossus torquata		Pichilingo
		Ramphastos sulfuratus		Paleton
		Piculus callopteros		Carpintero de mejilla rayada
		Dryocopus lineatus		Carpintero real barbirayado
	Passeriformes	Dendrocincla fuliginosa		Trepador pardo
		Decohychura longicaudata		Trepador cola de una
		Dendrocolaptes certhia		Trepador barreteado
		Xiphorphynchus lachrymosus		Trepador listado
		Lepidocolaptes souleyetii		Trepador cabecirayado
		Sclerurus guatemalensis		Raspa hoja
		Thamnophilus punctatus		Pavita hormiguera ceniza
		Thamnistes anabatinus		Hormiguero bermejon
		Dysithamnus punticeps		Hormiguero coronipunteado
		Myrmotherula fulviventris		Hormiguero leonado
		Pittasoma michleri		Merendero
		Chiroxiphia lanceolata		Toledo
		Shiffornis turdinos		Saltarin paralauta
		Sapayoa aenigma		Verdon de montana
		Cotinga nattererii		Cotinga azul mayor
		Sirystes sibilator		Papamosca copeton
		Platyrinchus mystaceus		Piquichato gargantiblanco
		Tolmomyias assimilis		Moscareta amarilleja
		Elaenia chiriquensis		Mononcita
		Ramphocelus dimidiatus		Sangretoro
		Myopagis gaimardii		Monona montaraz
		Leptopogon amaurocephalus		Moscareta cabeciparda
		Ornithion brunneicapillu		
		Trachycineta bicolor		Golondrina
		Neochelidon tibialis		Golondrina
		Thryothorus rufalbus		Ruisenor
		Henicornina leucosticta		Ruisenor
		Mycrobates cinereiventris		Ruisenor
		Vireo altiloquus		Ruisenor
		V. flavoviridis		Ruisenor
		Hylophilus aurantiifrons		Ruisenor
		Cyanerper lucidus		Ruisenor
		Dendroica pensylvanica		Canario
		Wilsonia canadensis		Canario
		Gymnostinops montezuma		Canario
		Cacicus cela		

Class	Order	Scientific Name	Spanish Common Name
Aves	Passeriformes (cont.)	Icterus mesomelas	
		I. galbual	Calandria
		Euphonia anneae	Calandria
		E. minuta	Calandria
		Tangara florida	Calandria
		T. gyrola	Calandria
		Piranga flava	Calandria
		Habia rubica	Calandria
		Tachyphonus delatrii	Calandria
		Heterospingus rubrifrons	Calandria
		Chrysothlypis chrysomelas	
		Saltator maximus	
		S. atriceps	
		Tiaris olivacea	
		Atlapetes brunneinucha	
		Emberizoides herbicola	
		Zonotrichia capensis	

* Endangered
\# Threatened

Appendix G

Fish Species Recorded from Gatun Lake, Canal Locks, and Adjacent Drainages

Canal Locks, and Adjacent Drainages*

Family	Scientific Name
Primary Consumers	
Astroblepidae	Astroblepus longifilis
Callichthyidae	Hoplosternum thoracatum
Characinidae	Astyanax fasciatus
	A. ruberrimus
	Brycon argenteus
	B. chagrensis
	B. petrosus
	B. striatulus
	Bryconamericus cascajalensis
	B. emperador
	Characidium sp.
	Cheirodon affinis
	Compsura gorgonae
	Ctenolucius hujeta
	Curimata magdalenae
	Gasteropelecus maculatus
	Gephyrocharax atricaudata
	Hoplias microlepis
	Hyphessobrycon panamensis
	Piabucina panamensis
	Roeboides guatamalensis
	R. occidentalis
	Saccoderma sp.
Doradidae	Trachycorystes amblops
Hypopomidae	Hypopomus occidentalis
Loricariidae	Ancistrus chagresi
	Chaetostoma fischeri
	Leptoancistrus canensis
Loricariidae Cont.	Loricaria uracantha
	Plecostomus plecostomus
Pimelodidae	Imparales sp.
	Pimelodella chagresi
	Rhamdia wagneri
Sternopygidae	Eigenmannia virescens
Trichomycteridae	Trichomycterus striatus
Secondary Consumers	
Anguillidae	Anguilla rostrata
Cichlidae	Aequidens coeruleopunctatus
	Cichla ocellaris**
	Cichlasoma maculicauda
	Geophagus crassilabris
	Neotroplus panamensis
Cyprinodontidae	Rivulus brunneus
	R. chucunaque
	R. montium
Poeciliidae	Brachyrhaphis cascajalensis
	B. episcopi
	B. sp.
	Gambusia nicaraguensis
	Neoheterandria tridentiger
	Phallichthys amates
	Poecilia mexicana
	Poeciliopsis elongata
	Priapichthys darienensis

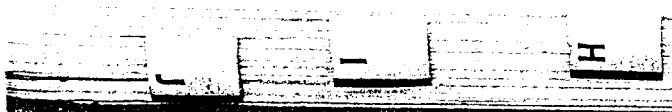
F	V	Species
Synbranchidae		Synbranchus marmoratus
		Peripheral Consumers
Ariidae		Arius multiradiatus
		Felichthys pinnimaculatus
		Galeichthys jordani
		G. seemani
		Netuma oscula
		N. planiceps
		Selenapsis dowi
Atherinidae		Melaniris chagresi
Belonidae		Strongylura marina
Bothidae		Citharichthys gilberti
Carangidae		Caranx hippos
		Oligoplites saurus
Centroponidae		Centropomus armatus
		C. ensiferus
		C. nigrescens
		C. parallelus
		C. pectinatus
		C. robalito
		C. undecimalis
		C. unionensis
Clupeidae		Ilisha fuerthii
		Sardinella stolifera
Elopidae		Elops saurus
		Megalops atlanticus

Family	Species
Eleotridae	Dormitator latifrons
	D. maculatus
	Eleotris amblyopsis
	E. picta
	E. pisonis
	Euleptoeleotris clarki
	E. shropshirei
	Gobiomorus dormitor
	G. maculatus
	Guavina guavina
	Hemieleotris latifasciatus
	Leptophilypnus fluviatilis
	L. panamensis
Engraulidae	Anchoa panamensis
	A. spinifer
	Anchoviella curta
	A. elongata
	A. lucida
Gerridae	Diapterus peruvianus
	Eucinostomus argenteus
	Gerres cinereus
Gobiesocidae	Gobiesox nudus
Gobiidae	Awaous tajasica
	A. transandeanus
	Bathygobius soporator
	Garmannia hildebrandi
	G. homochroma
	Gobionellus microdon
	Microgobius miraflorensis
	Sicydium antillarum
	S. salvini
Lutjanidae	Lutjanus argentiventris
	L. aya
	L. colorado
	L. novemfasciatus

	Species
Mugilidae	Agonostomus macracanthus
	A. monticola
	Chaenomugil proboscideus
	Joturus pichardi
	Mugil curema
Pomadasyidae	Pomadasys bayanus
	P. crocro
Pristidae	Pristis microdon
Sciaenidae	Bairdiella ronchus
	Cynoscion albus
	Micropogonias altipinnis
Soleidae	Achirus fluviatilis
	A. mazatlanus
	Trinectes maculatus
Syngnathidae	Oosthethus lineatus
	Pseudophallus mindii
	Syngnathus elcapitanense
Tetraodontidae	Sphoeroides annulatus
	S. testudineus

*Tabulated in connection with the 1974 Gatun Lake sea water pumping feasibility study; list does not include the Chinese carp (Ctenopharyngodon idella) introduced in 1977 as a weed control agent, and two species of cichlids (Tilapia nilotica and T. rendalli) that apparently accidentally reached Gatun Lake in 1983 from pond aquaculture facilities.

**Accidentally introduced in 1967.



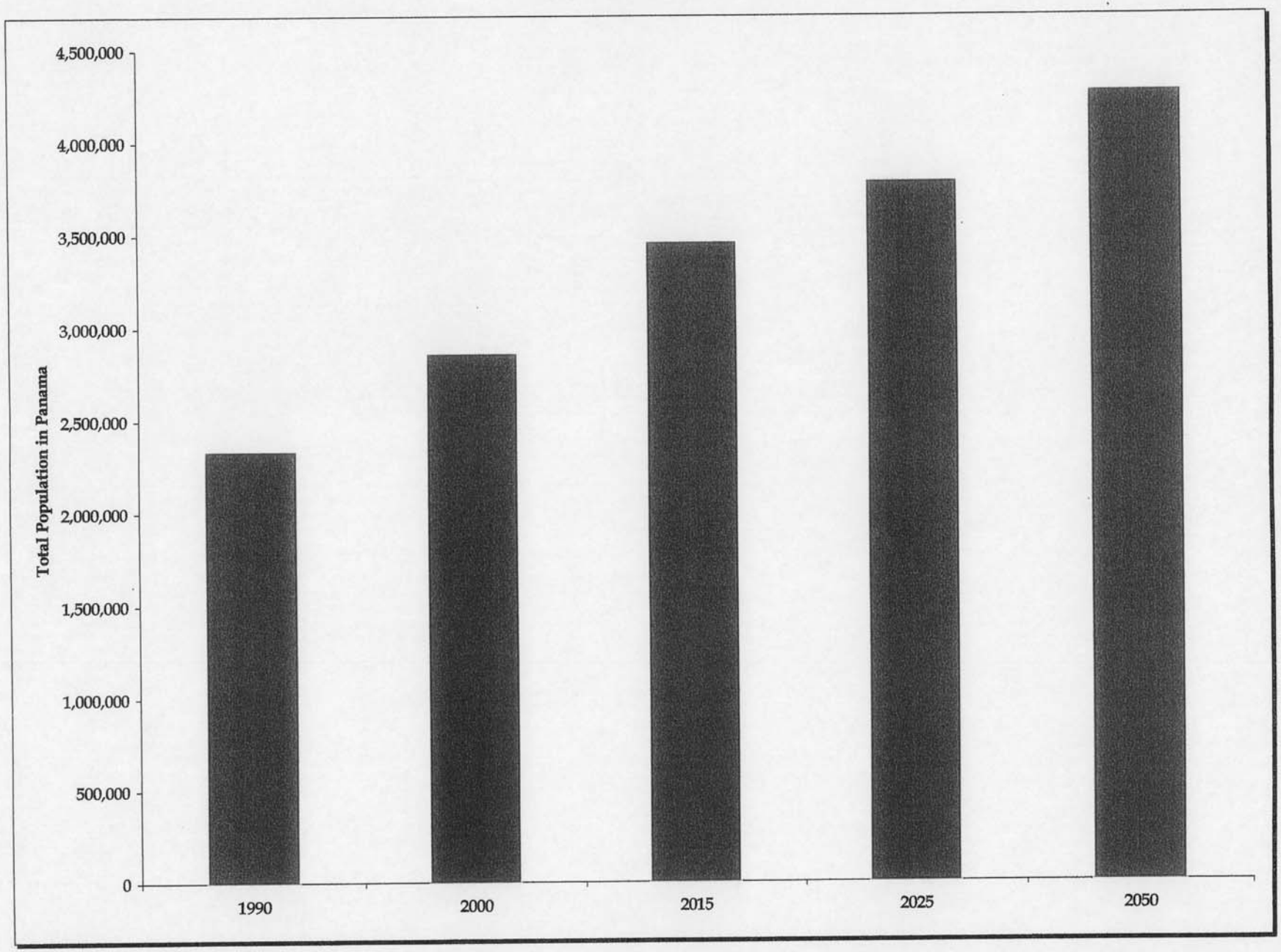
APPENDIX C-1

POPULATION GROWTH TRENDS
PANAMA
1990 THROUGH 2050

Source: United Nations, Population Division

APPENDIX C-1

POPULATION GROWTH TRENDS
PANAMA, 1990 THROUGH 2050



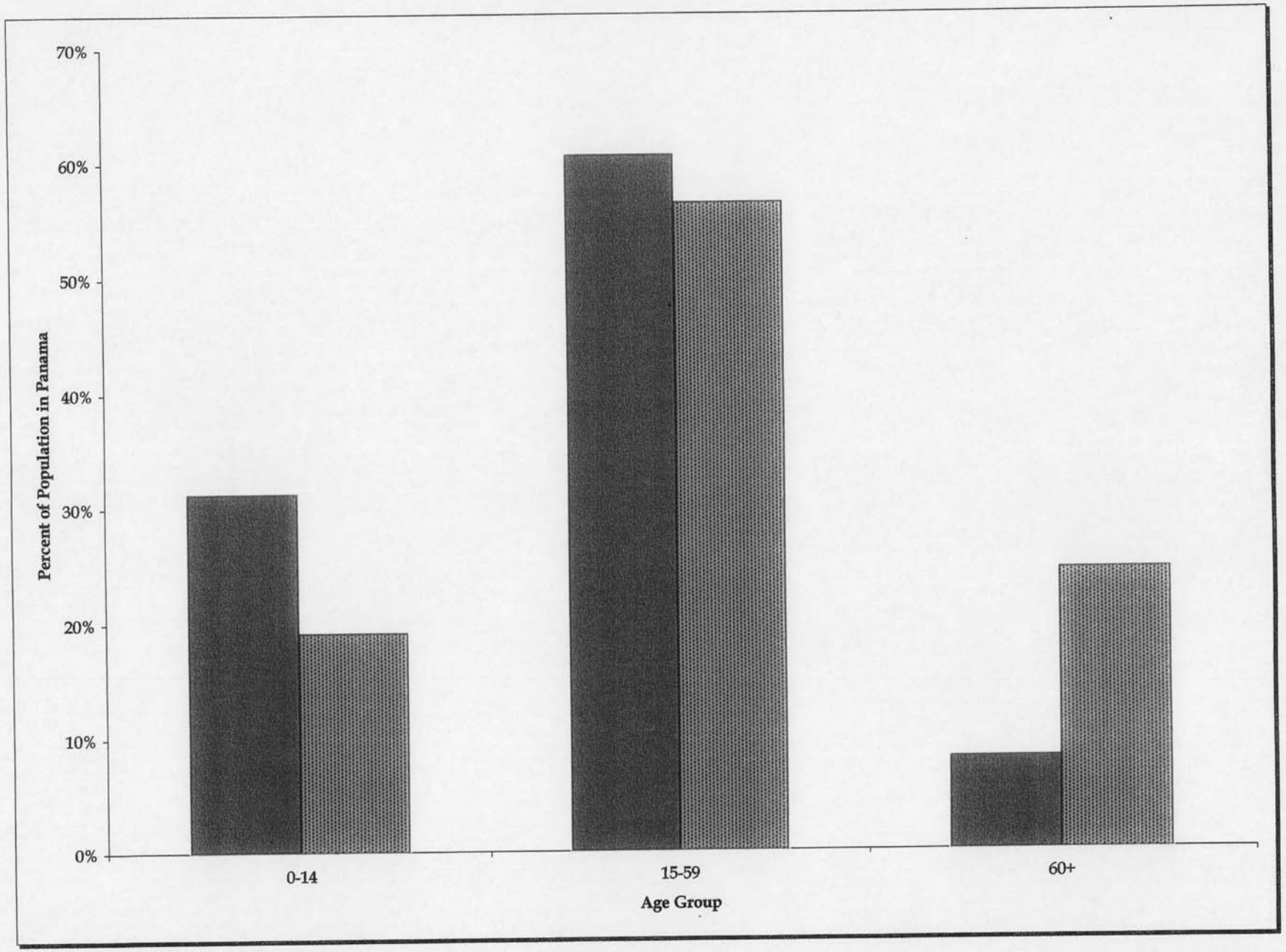
Source: United Nations Population Division

APPENDIX C-2

POPULATION DISTRIBUTION TRENDS
PANAMA
1990 THROUGH 2050

Source: United Nations, Population Division

APPENDIX C-2
POPULATION DISTRIBUTION TRENDS
PANAMA, 2000 THROUGH 2050



Source: United Nations Population Division

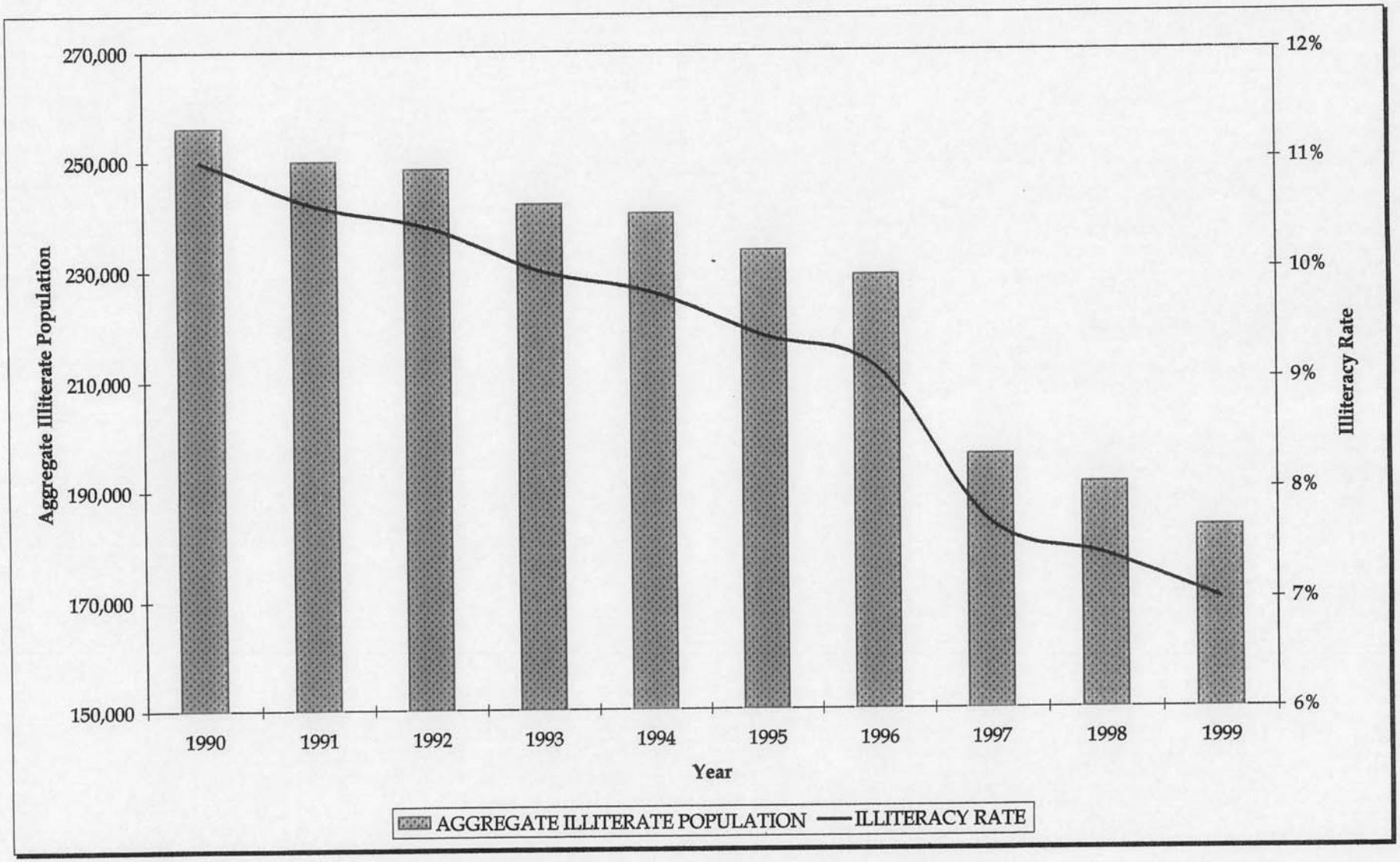
APPENDIX C-3

AGGREGATE ILLITERATE POPULATION AND PERCENTAGE OF ILLITERATE POPULATION PANAMA 1990 THROUGH 1999

Source: American Chamber of Commerce & Industry, Panama

APPENDIX C-3

AGGREGATE ILLITERATE POPULATION AND PERCENTAGE OF ILLITERATE POPULATION
PANAMA, 1990 THROUGH 1999



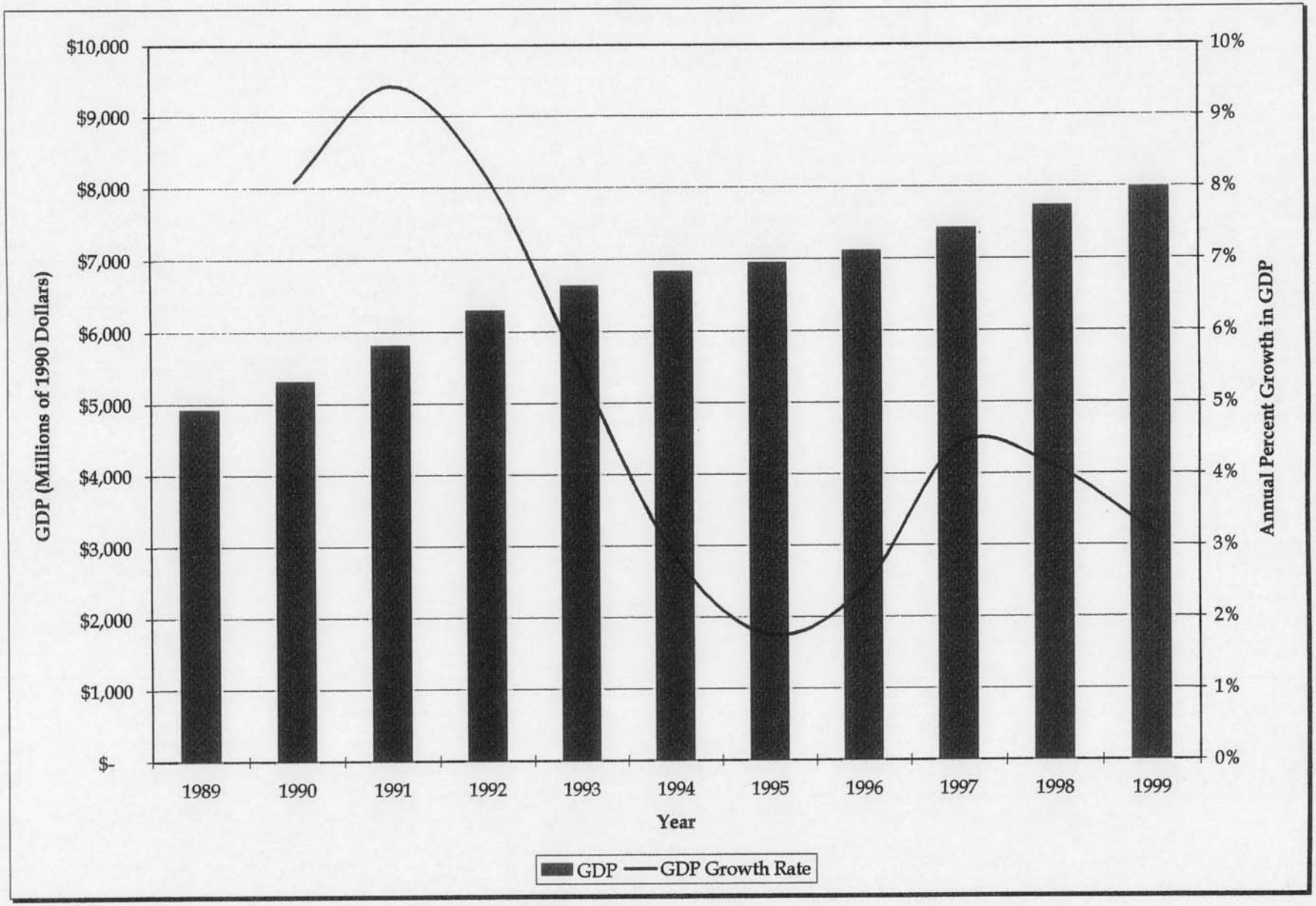
Source: American Chamber of Commerce & Industry of Panama

APPENDIX C-4

GROSS DOMESTIC PRODUCT
PANAMA
1990 THROUGH 1999

Source: American Chamber of Commerce & Industry, Panama

GROSS DOMESTIC PRODUCT
PANAMA, 1989 THROUGH 1999



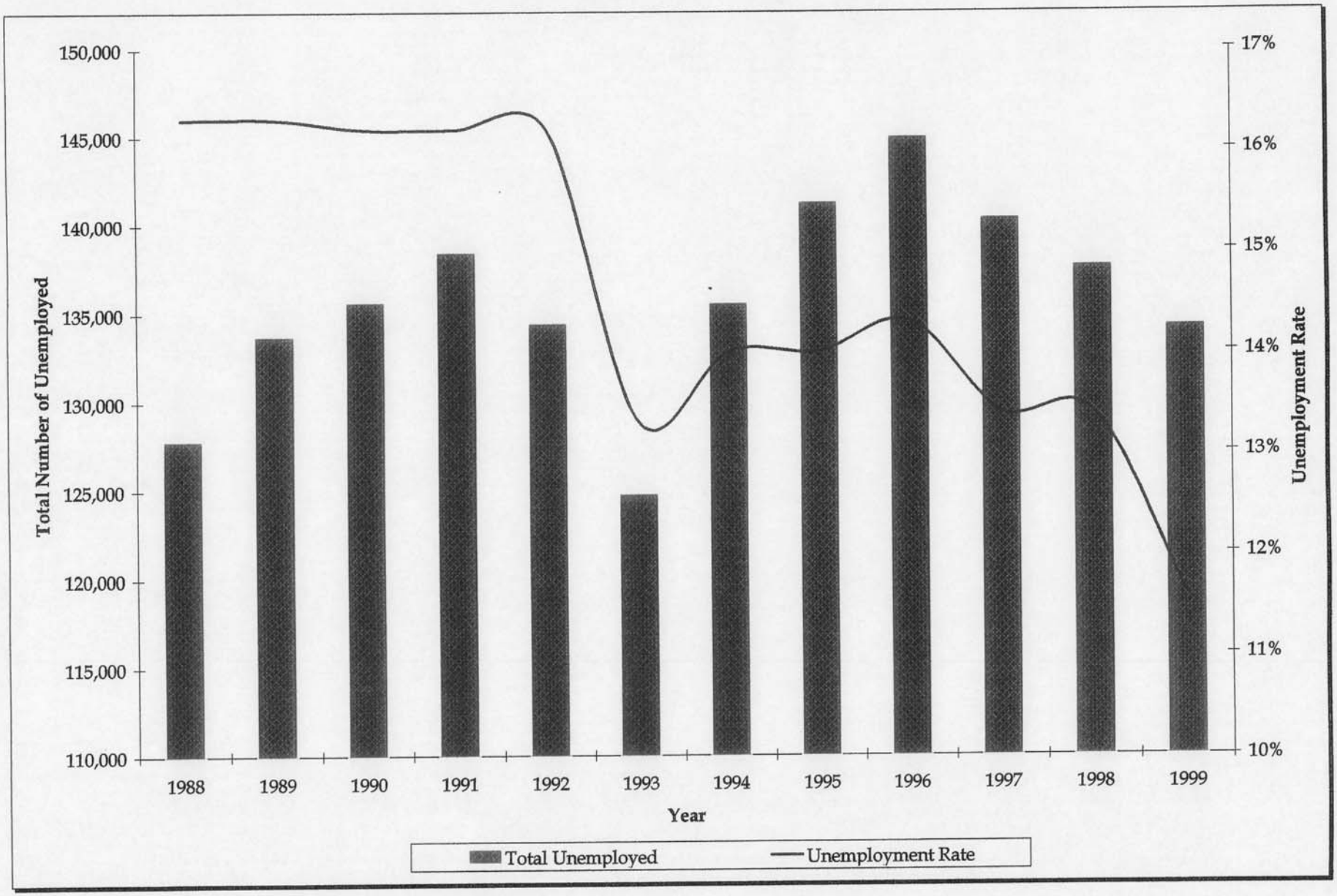
Source: American Chamber of Commerce & Industry of Panama

APPENDIX C-5

UNEMPLOYMENT RATES
PANAMA
1990 THROUGH 1999

Source: American Chamber of Commerce & Industry, Panama

UNEMPLOYMENT RATES
PANAMA, 1988 THROUGH 1999



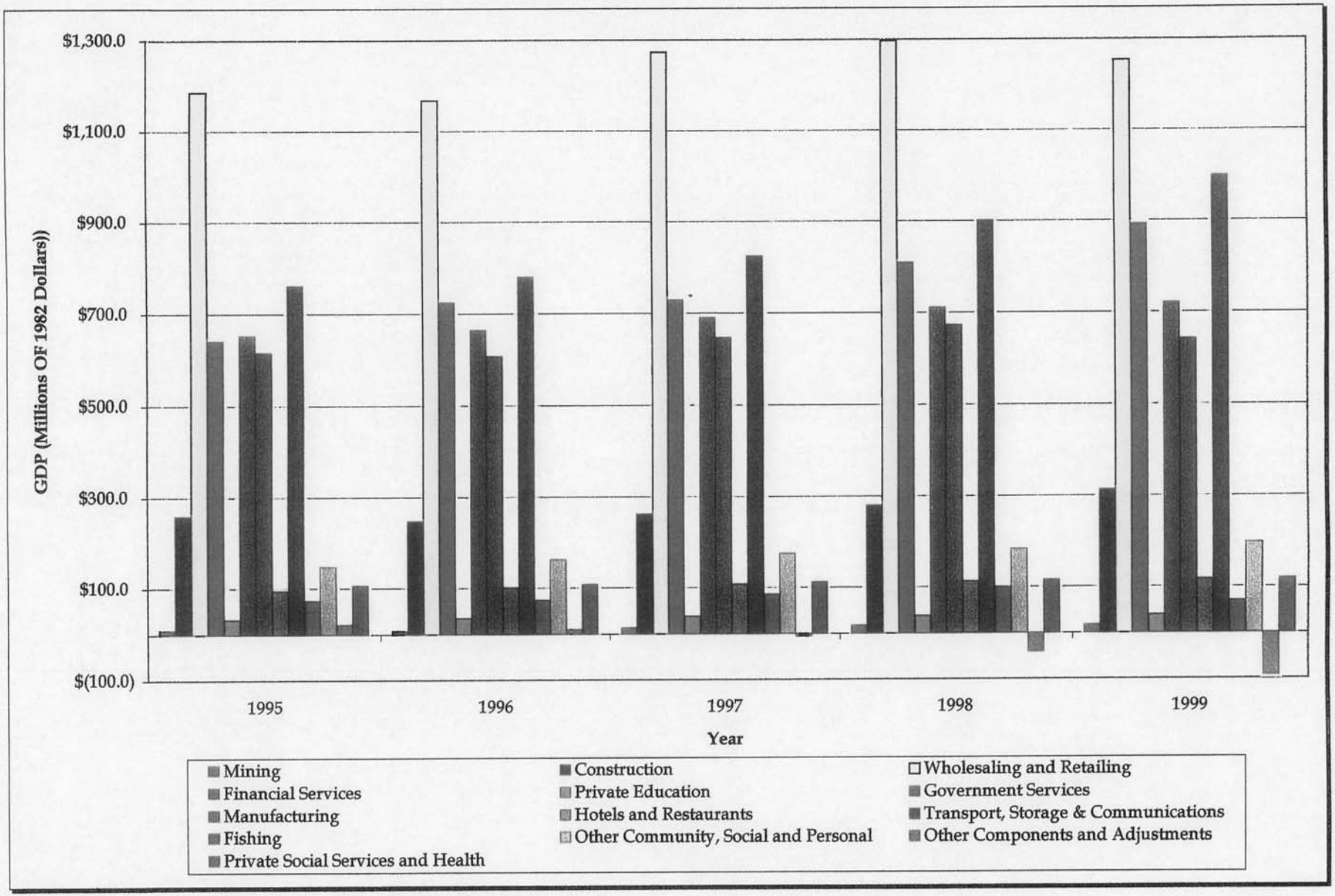
Source: American Chamber of Commerce & Industry of Panama

APPENDIX C-6

GROSS DOMESTIC PRODUCT
BY INDUSTRY SECTOR
PANAMA
1995 THROUGH 1999

Source: American Chamber of Commerce & Industry, Panama

GROSS DOMESTIC PRODUCT BY INDUSTRIAL SECTOR
PANAMA, 1995 THROUGH 1999



Source: American Chamber of Commerce & Industry of Panama

APPENDIX C-7

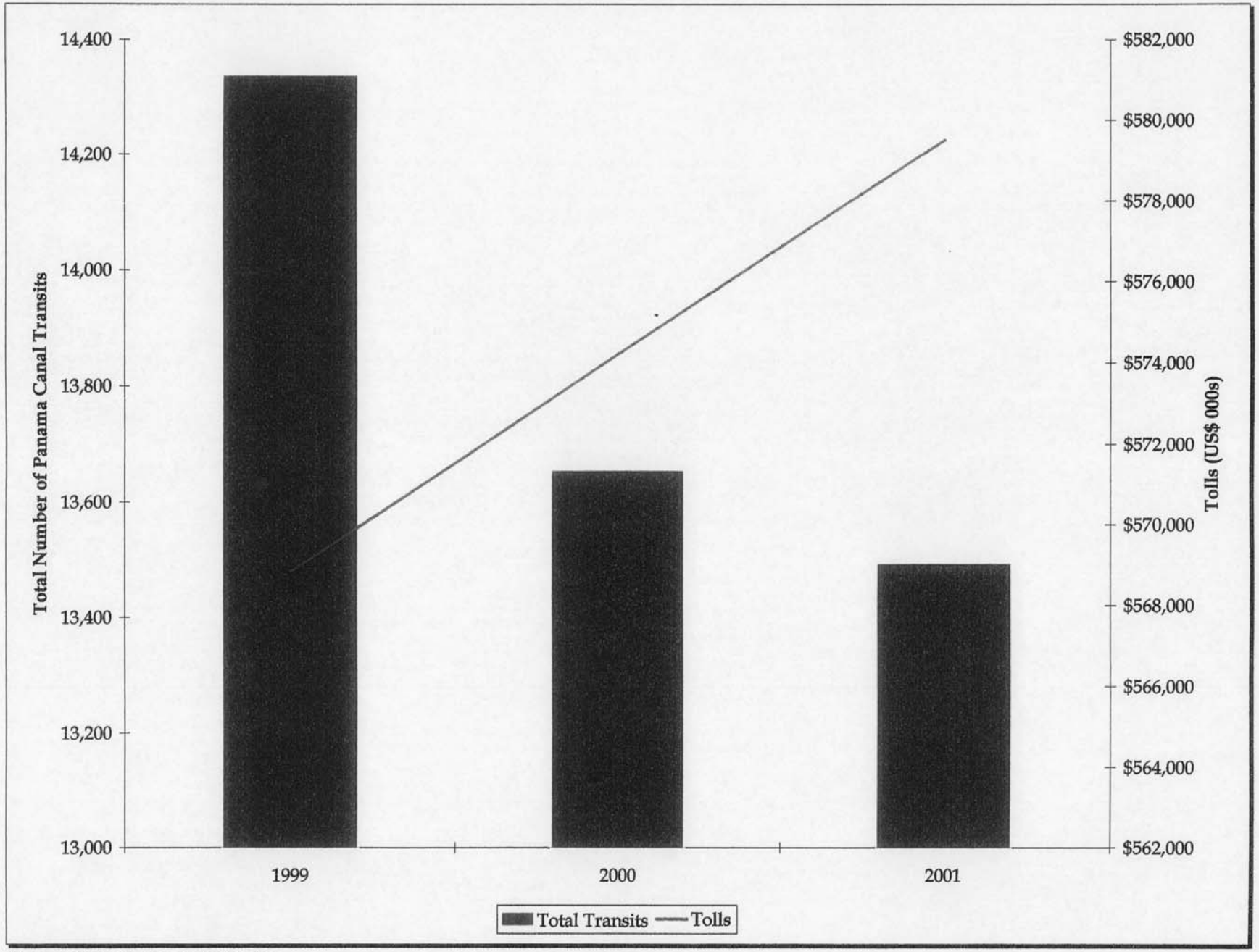
PANAMA CANAL TRAFFIC
PANAMA
1999 THROUGH 2001

Source: Panama Canal Authority.

AP X C-7

PANAMA CANAL TRAFFIC

PANAMA, 1999 THROUGH 2001



Source: Panama Canal Authority

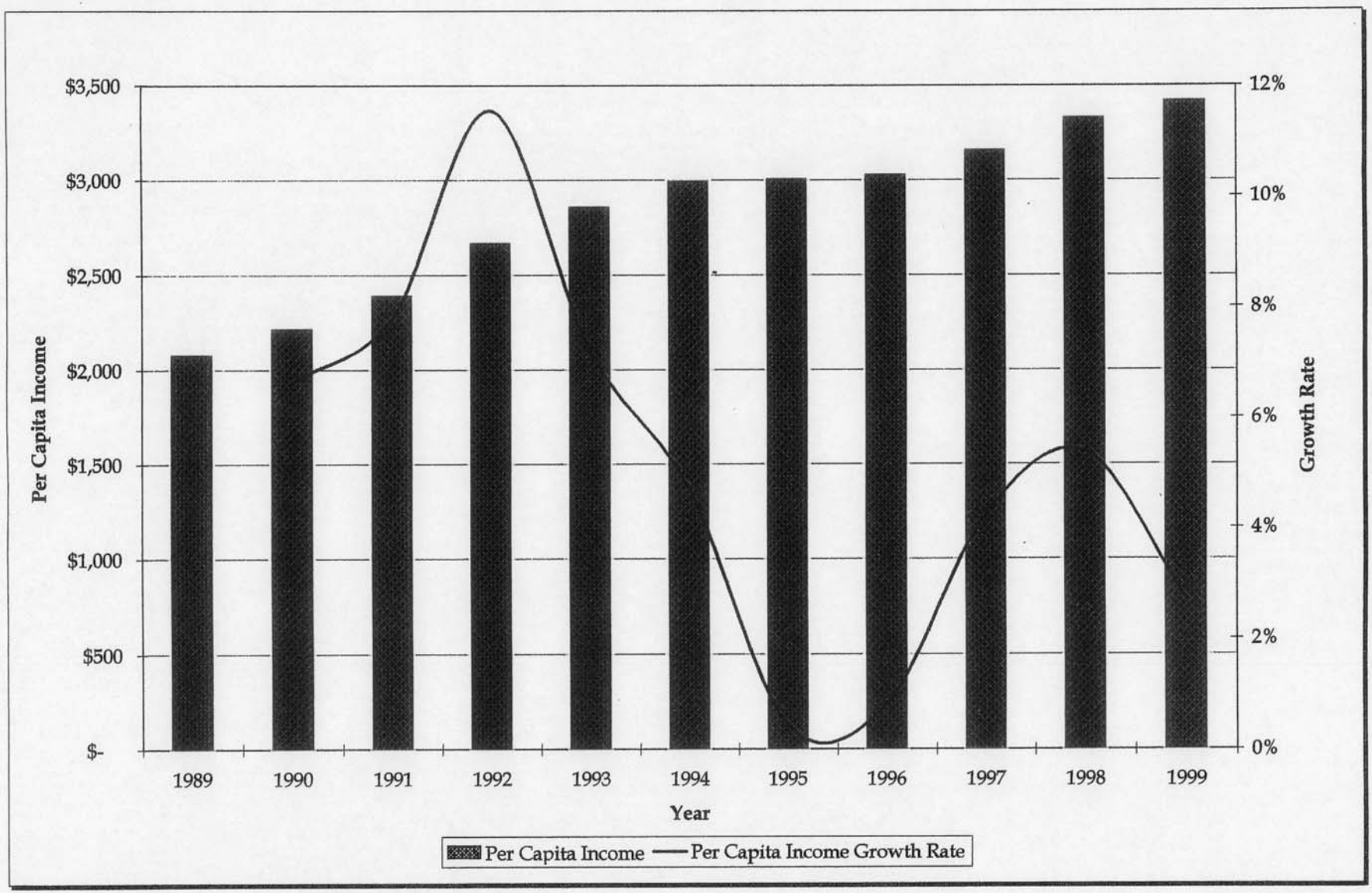
APPENDIX C-8

PER CAPITA INCOME
PANAMA
1989 THROUGH 1999

Source: Panama Council for Investment and Development

APPENDIX C-8

PER CAPITA INCOME
PANAMA, 1989 THROUGH 1999



Source: Panama Council for Investment and Development

DRINKING WATER STANDARDS

REPUBLIC OF PANAMA

REPUBLICA DE PANAMA
MINISTERIO DE COMERCIO E INDUSTRIAS

DESPACHO SUPERIOR

DIRECCION GENERAL DE NORMAS Y TECNOLOGIA INDUSTRIAL

Resolución N° 597 **Panamá** 12 **de** noviembre **de 1999.**

El Ministro de Comercio e Industrias
En Uso de sus Facultades Legales

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CONSIDERANDO :

1. Que de acuerdo a lo establecido en el numeral 4 del Artículo 92, de la Ley 23 de 15 de julio de 1997, los Comités Sectoriales de Normalización tienen por función la preparación de la Norma de un Sector, dentro de los lineamientos internacionales establecidos para esta actividad con la posibilidad de ser adoptadas y publicadas como Normas Técnicas Panameñas.

2. Que mediante Nota 5066-DMS-DGS-SDGSA-DA del 14 de noviembre de 1998 la Dra. AIDA L. MORENO DE RIVERA, Ministra de Salud, solicitó la revisión del Reglamento Técnico. AGUA. AGUA POTABLE. DEFINICIONES Y REQUISITOS GENERALES.

3. Que de conformidad a lo anterior, se estableció el Comité AGUA, a fin de elaborar el Reglamento Técnico Agua. Agua Potable. Definiciones y Requisitos Generales.

4. Que el Reglamento Técnico N° 23-395-99 fue sometido a un período de encuesta pública, el día 14 de enero de 1999.

5. Que de acuerdo al artículo 95 Título II de la precipitada Ley la Dirección General de Normas y Tecnología Industrial del Ministerio de Comercio e Industrias velará por que los Reglamentos Técnicos sean establecidos en base a objetivos legítimos, tales como la seguridad nacional, la prevención que puedan inducir a error, la protección de la salud o seguridad humana, de la vida o salud vegetal, o del medio ambiente.

6. Que la presente resolución se fundamenta en los siguientes argumentos:

   - Que estos Reglamentos serán aplicados a los Sistemas de tratamiento de Agua Completo.

   - Que es función del Estado velar por la Salud de la población y del ambiente;

   - Que conforme al Código Sanitario vigente, en su artículo 3, del Libro I en su Título

2.1.3 **Grupo Coliforme Total**: Comprende todas las bacterias en forma de bacilos aerobios y anaerobios facultativos, Gram Negativos no esporulados, que pueden desarrollarse en presencia de sales biliares y otros agentes tensoactivos con similares propiedades de inhibición del crecimiento y fermentan la lactosa con la producción de ácido y gas a una temperatura de 35 °C a 37 °C en un período de 24 a 48 horas.

2.1.4 **Grupo Coliforme Fecal**: Comprende todas las bacterias en forma de bacilos aerobios y anaerobios facultativos Gram negativos no esporulados, que pueden desarrollarse en presencia de sales biliares u otros agentes tensoactivos con similares propiedades de inhibición del crecimiento y fermentan la lactosa con la producción de ácido y gas a una temperatura de 44,5 °C ± 0,2 °C en menos de 24 ± 2 horas.

2.1.5. **Recuento Total de Bacterias:** Es el cómputo del número total de colonias desarrolladas (en la suposición de que una bacteria de origen a una colonia) en agar nutritivo incubado a una temperatura de 35 °C en un período de 24 ± 2 horas.

2.1.6. **Característica**: Es aquella propiedad química, física, biológica o radiológica, que incluye los parámetros de calidad de agua.

2.1.7. **Parámetros:** Son aquellas características químicas, físicas, biológicas o radiológicas, de calidad de agua, que puede ser sometido a medición.

2.1.8. **Cloro Libre Residual**: Es aquella porción del cloro que sirve como medida de su capacidad para oxidar la materia orgánica.

2.1.9. **Sistema de Abastecimiento de Agua Potable:**
Es el que comprende las obras, equipos, sustancias química y materiales empleados para la captación, conducción, tratamiento, almacenamiento y distribución del agua potable a los usuarios.

2.1.10. **Agua Tratada:** Agua reacondicionada por cualquier tipo de tratamiento físico o químico para el consumo humano.

2.1.11. **Agua No Tratada:** Agua no reacondicionada por previo tratamiento físico o químico y que procede de cualquier fuente o recurso de agua.

2.1.12. **APHA:** **American Public Health Association.**

2.1.13. **AWWA:** **American Water Works Association.**

2.1.14. **WPCF:** **Water Pollution Control Federation.**

2.1.15. **UNT:** **Unidad Nefelométrica de Turbiedad.**

2.1.16. **Bq/l :** **Becquerel por litro**

3. REQUISITOS

3.1 **Características Biológicas:** Los valores **máximos** permitidos que se establecen para agua potable, incluyen todos los valores conforme a la clasificación de aguas que aparecen en la Tabla No. 1.

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TABLA No. 1

CARACTERÍSTICAS BIOLÓGICAS PARA EL AGUA POTABLE			
CARACTERÍSTICAS	UNIDAD	VMP[1]	OBSERVACIONES
1. Biológicas			
A. Agua distribuida por tubería			
A.1 Agua tratada que entra al sistema de distribución			
Bacterias coliformes fecales	N° de colonias /100ml	0	
Bacterias coliformes totales	N° de colonias /100ml	0	
A.2. Agua no sometida a tratamiento que entra en el sistema de distribución.			
Bacterias coliformes fecales	N° de colonias /100ml	0	
Bacterias coliformes totales	N° de colonias/100ml	3	
A.3. Agua en el sistema de distribución			
Bacterias coliformes fecales	N° de colonias /100ml	0	
Bacterias coliformes totales	N° de colonias /100ml	3	
B. Agua no distribuida por tuberías			
Bacterias coliformes fecales	N° de colonias /100ml	0	
Bacterias coliformes totales	N° de colonias /100ml	10	
CARACTERÍSTICAS	**UNIDAD**	**VMP**	**OBSERVACIONES**
C. Agua Embotellada			
Bacterias coliformes fecales	N° de colonias /100ml	0	La fuente de abastecimiento de agua debe estar exenta de contaminación fecal al igual que el agua final del proceso.
Bacterias coliformes totales	N° de colonias/100ml	0	
D. Parámetros de cumplimiento para todas las condiciones (A, B y C)			
Protozoarios (patógenos) Helmintos (patógenos) Organismos de vida libre (algas y otros) Enterovirus Otros Organismos			Los conocimientos actuales no han permitido establecer valores guías para las características biológicas. No obstante, la presencia de cualquiera de estos organismos en el agua potable es indicativo de contaminación y causa de enfermedad. Por lo tanto, no deben estar presentes en el agua de consumo humano.

(1) Valor máximo permitido

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3.2 **Características Organolépticas:** Las características Organolépticas influyen, más que nada en las propiedades que son detectadas por los consumidores en forma sensorial. Las características organolépticas del agua potable deben cumplir con los valores indicados en la Tabla No. 2.

3.3 **Características Químicas Inorgánicas:** Las propiedades del agua permiten la existencia de muchas clases de elementos disueltos en ella, aspecto éste que conduce a reacciones que pueden incidir desfavorablemente sobre la salud. Los valores máximos permitidos de las características químicas inorgánicas para el agua potable, se indican en la Tabla No. 3.

TABLA No. 2

VALORES DE LAS CARACTERÍSTICAS ORGANOLÉPTICAS Y FÍSICAS PARA EL AGUA POTABLE			
CARACTERÍSTICAS	**VALORES MÁXIMOS PERMISIBLES**	**UNIDADES**	**OBSERVACIONES**
OLOR Y SABOR	Aceptable para la mayoría de los consumidores	-----	-----
COLOR	15	Unidades de color	Unidades de color en la escala Platino-Cobalto
TURBIEDAD	1,0	UNT	Preferiblemente menor de 1.0 UNT
POTENCIAL DE HIDROGENO	6,5 – 8,5	Unidades de Ph	-----
ACEITE Y GRASA	-----	-----	Debe estar exenta

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TABLA No. 3

VALOR MÁXIMO PERMITIDO DE LAS CARACTERÍSTICAS QUÍMICAS INORGÁNICAS PARA EL AGUA POTABLE		
CARACTERISTICAS	VALOR MÁXIMO PERMITIDO (mg/L)	OBSERVACIONES
Alcalinidad	120,00	Como carbonato de calcio
Aluminio	0,20	
Antimonio	0,005	
Arsénico	0,01	
Bario	0,7	
Cadmio	0,003	
Cianuro	0,001	
Cloro Residual (1)	1,5	Valor mínimo 0.8 mg/L
Cloruro	250,00	
Cobre	1,00	
Cromo	0,05	
Dureza Total	100,00	Como carbonato de calcio
Fluoruro	1,00	
Hierro	0,30	
Manganeso	0,1	
Mercurio	0,001	
Molibdeno	0,07	
Níquel	0,02	
Nitrato	10,00	
Nitrito	1,00	
Plata	0,05	
Plomo	0,01	
Selenio	0,01	
Sodio	200,00	
Sólidos Disueltos Totales	500,00	
Sulfato	250,00	
Zinc	5,00	

(1) Observaciones para el cloro residual: La cloración de los abastecimientos públicos de agua representa el proceso más importante usado en la obtención de agua de calidad sanitaria adecuada, "potable". La desinfección por cloro y sus derivados significa una disminución de bacterias y virus hasta una concentración inocua. La adición de cloro estará sujeta a una concentración máxima de trihalometanos de 0.1 mg/L.

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3.4 Características químicas orgánicas.

Los valores máximos permitidos para los parámetros químicos orgánicos que no aparecen en la tabla a continuación (tabla No.4) no deben exceder los valores guías de la OMS/OPS que se establecen en la resolución 248.

TABLA No. 4

VALORES MÁXIMOS PERMITIDOS PARA LAS CARACTERÍSTICAS QUÍMICAS ORGÁNICAS EN EL AGUA POTABLE		
CARACTERÌSTICAS	VALOR MÁXIMO PERMITIDO EN MILIGRAMOS/LITROS (mg/L)	OBSERVACIONES
DETERGENTES	0, 2	------
TRIHALOMETANOS	0, 1	------
COMPUESTO FENOLICOS	0, 001	------
PLAGUICIDAS	------	------
HIDROCARBUROS	------	------
PCB (Bifenilos Policlorados)	------	------

3.5 Características radioactivas.

Los valores máximos permitidos para las características radioactivas se indican en la Tabla No. 5.

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TABLA No. 5

VALORES MÁXIMOS PERMITIDOS PARA LAS CARACTERÍSTICAS RADIOACTIVAS EN EL AGUA POTABLE			
CARACTERÍSTICAS	VALOR MÁXIMO PERMITIDO	UNIDADES	OBSERVACIONES
Radioactividad Alfa Global (1)	0,1	Bq/L	
Radioactividad Beta Global (1)	1	Bq/L	

(1) Para facilitar la tareas del monitoreo de la calidad de agua es recomendable rastrear por la presencia de radiaciones originadas por emisores de rayos (Alfa) o emisores de rayos (Beta). En caso de ser detectadas estas radiaciones a niveles iguales a la norma, se aplicarán las medidas de control correspondientes.

4. TOMA DE MUESTRA

Las muestras para los análisis biológicos, físicos, químicos y radiológicos se tomarán de acuerdo a los Reglamentos Técnicos DGNTI-COPANIT 21-393-99 y 22-394-99.

5. ENSAYOS

5.1 Los siguientes son los ensayos físicos que deberán desarrollarse según la norma de frecuencia de muestreo y la última versión del Standard Method.

5.1.1 Determinación de Turbiedad.
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 2130

5.1.2 Determinación de Color
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 2120

5.1.3 Determinación de pH
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500 H

5.1.4 Determinación de Olor
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 2150

5.1.5 Determinación de sabor
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 2160

5.1.6 Determinación de Aceites y Grasas en el Agua
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 5520

5.2 Ensayos químicos inorgánicos que se utilizan en un sistema de abastecimiento de Agua Potable.

5.2.1 Determinación de Dureza
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 2340

5.2.2 Determinación de Arsénico
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-As

5.2.3 Determinación de Bario
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Ba

5.2.4 Determinación de Cadmio
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Cd

5.2.5 Determinación de Plomo
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Pb

5.2.6 Determinación de Mercurio
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Hg

5.2.7 Determinación de Nitratos
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-NO_3^-

5.2.8 Determinación de Nitritos
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-NO_2^-

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5.2.9 Determinación de Selenio
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Se

5.2.10 Determinación de Plata
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Ag

5.2.11 Determinación de Cromo
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Cr

5.2.12 Determinación de Cianuro
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-CN^-

5.2.13 Determinación de Fluoruro
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-F^{---}

5.2.14 Determinación de Cobre
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Cu

5.2.15 Determinación de Cloruro
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-Cl^-

5.2.16 Determinación de Hierro
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Fe

5.2.17 Determinación de Zinc
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Zn

5.2.18 Determinación de Manganeso
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Mn

5.2.19 Determinación de Aluminio
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Al

5.2.20 Determinación de Sulfatos
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-SO_4^{2-}

5.2.21 Determinación de Níquel
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Ni

5.2.22 Determinación de Sodio
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500-Na

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5.2.23 Determinación de Cloro Residual
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 4500-Cl

5.2.24 Determinación de Antimonio
Se efectúa de acuerdo al método estándar APHA - AWWA- WPCF 3500- Sb

5.2.25 Determinación de Molibdeno
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 3500 -Mo

5.2.26 Determinación de Alcalinidad
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 2320

5.3 Ensayos químicos orgánicos que se utilizan en un sistema de abastecimiento de Agua Potable.

5.3.1 Determinación de Detergentes
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 5540

5.3.2 Determinación de Trihalometanos
Se efectúa de acuerdo a los métodos estándares APHA - AWWA - WPCF 5710/6232

5.3.3 Determinación de Compuestos Fenólicos
Se efectúa de acuerdo a los métodos estándares APHA - AWWA - WPCF 5530/6420

5.3.4 Determinación de Plaguicidas
Se efectúa de acuerdo a los métodos estándares APHA - AWWA – WPCF 6610/6630/6640/6651

5.3.5 Determinación de Hidrocarburos
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 6440

5.3.6 Determinación de Cloruro de Vinilo
Se efectúa de acuerdo a los métodos estándares APHA - AWWA - WPCF 6210 B,C,D/6230 B,C,D

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5.3.7 Determinación de Bifenilos Policlorados
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 6431

5.4. Ensayos para determinación de características radioactivas que se utilizan en un sistema de abastecimiento de Agua Potable.

5.4.1 Determinación de Radioactividad Alfa global y Beta global
Se efectúa de acuerdo al método estándar APHA - AWWA - WPCF 7110/7030

5.5 Ensayos para determinación de características biológicas que se utilizan en un sistema de abastecimiento de agua potable.

5.5.1 Determinación de Coliformes Totales.
Se efectúa de acuerdo a los métodos estándares APHA-AWWA-WPCF 9221 B, D 9222 B, C y 9223 B

5.5.2 Determinación de Coliformes Fecales.
Se efectúa de acuerdo a los métodos estándares APHA-AWWA-WPCF 9221 E,F 9222 E, D, G y 9223

5.5.3 Determinación de la Calidad Biológicas.
Se efectúa de acuerdo a los métodos estándares APHA-AWWA-WPCF 10200, 10300, 10400, 10500, 10550, 10600, 10900 y 9510. Para protozoarios (Cryptosporidium y Giardia) método 9711.

5.5.4 Determinación de Bacterias Heterótrofas.
Se efectúa de acuerdo al método estándar APHA-AWWA-WPCF 9215

6. APENDICE

6.1 DOCUMENTOS QUE DEBEN CONSULTARSE

REGLAMENTO TECNICO DGNTI-COPANIT 21-393-99.	Calidad de Agua. Toma de muestra.
REGLAMENTO TECNICO DGNTI-COPANIT 22-394-99.	Calidad de Agua. Toma de muestra para análisis biológicos.

MINISTERIO DE COMERCIO E INDUSTRIAS
Es Copia Auténticada

APHA - AWWA -WPCF. "Standard Methods for Examination of Water and Wastewater", 19th edition 1995.

6.2 ANTECEDENTES

Para la elaboración del presente Reglamento Técnico se consultaron los siguientes documentos:

1. Environmental Protection Agency, 1995. "National Interim Primary Drinking Water Regulation".

2. EPA. "Summary of Public Comments EPA Responses to the National Interim Primary Drinking Water Regulations of Control of Trihalometanes in Drinking Water".

3. Organización Mundial de La Salud. 1995. "Guías para la Calidad del Agua Potable". Washington D.C.

4. Water Quality and Treatment. Publicación de la AWWA 1975.

SEGUNDO: El presente resuelto entrará en vigencia a partir de su publicación en la Gaceta Oficial.

COMUNIQUESE Y PUBLIQUESE

JOAQUIN E. JACOME DIEZ
MINISTRO DE COMERCIO E INDUSTRIAS

MINISTERIO DE COMERCIO E INDU...
E

- preferencia a toda otra disposición legal en materia de Salud Pública y obligan a las personas naturales y jurídicas y entidades u otras que en un futuro existan, transitoria o permanentemente, en el territorio de la República de Panamá.

- Que de acuerdo al numeral 4 del artículo 85, Capítulo II del Título IV, del citado Código establece como atribución de la Dirección General de Salud Pública, el reglamentar las instalaciones y el funcionamiento de farmacias, droguerías, laboratorios químico-farmaceúticos, terapéuticos, biológicos, drogas, cosméticos y otros similares, sean de elaboración privada u oficial.

- Que de conformidad con el numeral 12 del artículo 85, anteriormente citado, se establece como atribución y deber dentro del ámbito nacional que corresponde a la Dirección General de Salud Pública, el resolver toda situación no prevista en el Código, cuando tenga relación directa con la Salud Pública.

MINISTERIO DE COMERCIO E INDUSTRIAS
Auténtica de su Original
Panamá, 1 de Dic de 1999
DIRECCION ADMINISTRATIVA

RESUELVE:

PRIMERO: Aprobar el Reglamento Técnico DGNTI-COPANIT 23-395-99. **Agua Potable. Definiciones y Requisitos Generales**, de acuerdo al tenor siguiente:

AGUA. AGUA POTABLE. DEFINICIONES Y REQUISITOS GENERALES

REGLAMENTO TECNICO DGNTI-COPANIT 23-395-99

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1. OBJETO Y CAMPO DE APLICACION

1.1 Este Reglamento Técnico tiene por objeto establecer requisitos físicos, químicos, biológicos y radiológicos que debe cumplir el agua potable.

1.2 Este Reglamento se aplica a cualquier sistema de abastecimiento de agua potable.

2. DEFINICIONES

2.1 Para efecto de este Reglamento se asumen las siguientes definiciones:

2.1.1 **Agua Potable:** Es aquella que se ajusta a los requisitos de calidad enmarcados en este Reglamento, apta para el consumo humano.

BENEFICIAL REUSE STANDARDS

REPUBLIC OF PANAMA

MINISTERIO DE COMERCIO E INDUSTRIAS
DIRECCION GENERAL DE NORMAS Y TECNOLOGIA INDUSTRIAL
RESOLUCION Nº 49
(De 2 de febrero de 2000)

El Ministro de Comercio e Industrias
En Uso de sus Facultades Legales

CONSIDERANDO :

1. Que de acuerdo a lo establecido en el numeral 4 del Artículo 92, de la Ley 23 de 15 de julio de 1997, los Comités Sectoriales de Normalización tienen por función la preparación de la Norma de un Sector, dentro de los lineamientos internacionales establecidos para esta actividad con la posibilidad de ser adoptadas y publicadas como Normas Técnicas Panameñas.

2. Que mediante Nota 4684-DMS-DGS-SDGSA-DA del 7 de octubre de 1998 la Dra. AIDA L. MORENO DE RIVERA, Ministra de Salud, solicitó la revisión del Reglamento Técnico. AGUA. CALIDAD DE AGUA. REUTILIZACION DE LAS AGUAS RESIDUALES TRATATDAS.

3. Que de conformidad a lo anterior, se estableció el Comité AGUA, a fin de elaborar el Reglamento Técnico Agua. Calidad de Agua. Reutilización de las Aguas Residuales Tratadas.

4. Que el Reglamento Técnico N° 24-99 fue sometido a un período de encuesta pública por sesenta (60) días , a partir del día 14 de enero de 1999.

5. Que de acuerdo al artículo 95 Título II de la precipitada Ley la Dirección General de Normas y Tecnología Industrial del Ministerio de Comercio e Industrias velará por que los Reglamentos Técnicos sean establecidos en base a objetivos legítimos, tales como la seguridad nacional, la prevención que puedan inducir a error, la protección de la salud o seguridad humana, de la vida o salud vegetal, o del medio ambiente.

6. Que la presente resolución se fundamenta en los siguientes argumentos:

   - Que es función del Estado velar por la Salud de la población y del ambiente;

   - Que conforme al Código Sanitario vigente, en su artículo 3, del Libro I en su Título preliminar establece que las disposiciones de este Código se aplicarán de preferencia a toda otra disposición legal en materia de Salud Pública y obligan a las personas naturales y jurídicas y entidades u otras que en un futuro existan, transitoria o permanentemente, en el territorio de la República de Panamá.

MINISTERIO DE COMERCIO E INDUSTRI

Que de acuerdo al numeral 4 del artículo 85, Capítulo II del Título IV del citado

- Que de conformidad con el numeral 12 del artículo 85, anteriormente citado, se establece como atribución y deber dentro del ámbito nacional que corresponde a la Dirección General de Salud Pública, el resolver toda situación no prevista en el Código, cuando tenga relación directa con la Salud Pública.

RESUELVE:

PRIMERO: Aprobar el Reglamento Técnico **DGNTI-COPANIT 24-99. AGUA. CALIDAD DE AGUA. Reutilización de las Aguas Residuales Tratadas**, de acuerdo al tenor siguiente:

AGUA. CALIDAD DE AGUA. REUTILIZACION DE LAS AGUAS RESIDUALES TRATADAS	**REGLAMENTO TECNICO DGNTI-COPANIT 24-99**

---

1. OBJETO Y CAMPO DE APLICACION

Los objetivos del presente Reglamento Técnico están orientados a salvaguardar la salud de los habitantes, reguardar el medio ambiente, propender a un uso racional de los recursos y establecer regulaciones para los distintos usos que pueda darse a las aguas residuales tratadas en las distintas plantas de tratamiento de aguas residuales de Panamá.

El campo de aplicación del presente Reglamento son todas las aguas residuales tratadas, provenientes de plantas de tratamiento pública, privadas o mixtas sin importar su origen y el tratamiento a que hallan sido sometidas.

Este Reglamento se debe aplicar a aguas residuales tratadas que vayan a utilizarse en:

a) Agua para el consumo de animales
b) Riego
c) Recreación y estética
d) Vida acuática y acuicultura
e) Uso urbano
f) Recarga de acuíferos
g) Restauración de hábitat
h) Uso industrial y minero

No se consideran usos en consumo humano directo y recreación con contacto directo por motivos psicológicos, que limitan esos tipos de usos para las aguas recicladas.

2. DEFINICIONES

2.1 **Autoridad competente**: autoridad designada por los reglamentos, resoluciones o leyes vigentes en la República de Panamá.

2.2. **Coliformes fecales: Comprende todos los bacilos Gram negativos, aeróbicos o anaerobios facultativos no esporulados que:**

a) En la técnica de filtración por membrana, produzcan colonias de color azul dentro de 24 + 2 horas cuando se incuban en un medio de cultivo específico para coliformes fecales a 44,5 + 0,2 °C; y/o

b) En la técnica de tubos múltiples, fermenten la lactosa con formación de gas a 44,5 + 0,2 °C dentro de 24 + 2 horas.

2.3. **Coliformes totales: Comprende todos los bacilos Gram negativos, aeróbicos o anaerobios facultativos no esporulados que:**

a) En la técnica de filtración por membrana, produzcan colonias de color verde dorado metálico de 24 + 2 horas cuando se incuban en un medio m-Endo (medio especifico para coliformes fecales) a 35 + 0,5 °C; y/o

b) En la técnica de tubos múltiples, fermenten la lactosa con formación de gas a 35 + 0,5 °C dentro de 48 horas.

2.4. **Contaminación hídrica:** Es la acción y el efecto de introducir materias o formas de energía, o inducir condiciones en el agua que, de modo directo o indirecto, impliquen una alteración perjudicial de su calidad en relación con los usos asignados al recurso. El concepto incluye alteraciones perjudiciales del entorno vinculado a dicho recurso.

2.5. **Conductividad eléctrica:** Valor recíproco de la resistencia al paso de la corriente eléctrica entre 2 placas de platino de un centímetro de área colocadas a un centímetro de distancia, colocadas en una solución acuosa a 25°C.

2.6. **Demanda bioquímica de oxígeno DBO_5:** Cantidad de oxígeno requerida para la oxidación aeró+bica biológica de los sólidos orgánicos del agua.

2.7. **Demanda Química de oxígeno DQO:** Cantidad de oxígeno requerida para oxidar a la materia orgánica sea o no biodegradable, con la excepción de compuestos aromáticos como piridina, benceno o tolueno.

2.8. **Laboratorio de pruebas y ensayos acreditado:** Laboratorio nacional, extranjero o internacional, que posee la competencia e idoneidad necesarias para llevar a cabo, en forma general, la determinación de las características, aptitud o funcionamiento de materiales o productos, y que ha sido acreditado o reconocido por el organismo de acreditación.

2.9. **Número más probable (NMP):** Valor que indica microorganismos coliformes en 100 ml de agua. Su determinación se basa en el cálculo de probabilidades, con tablas preparadas y presentadas por APHA en Standard Methods.

2.10 Razón de adsorción [illegible]

$$RAS = \frac{N_a^+}{\sqrt{\frac{C_a^{++} + M_g^{++}}{2}}}$$

2.11 Sodio porcentual: Razón entre las concentraciones de sodio y la suma de las concentraciones de calcio, magnesio, potasio y sodio, todo expresado en miliequivalentes por litro, de acuerdo a la siguiente expresión:

$$Na\ (\%) = \frac{Na}{Na + K + Mg + Ca} \times 100$$

2.12 Sólidos disueltos totales: Material remanente después de evaporar y secar a masa constante a 104 + 1°C, una muestra de agua previamente filtrada con un filtro de una porosidad no mayor de 5 micrones.

2.13 Tratamiento primario: Separación por medios físicos de los sólidos en suspensión no retenidos en el tratamiento previo, que puede incluir la separación de sólidos qu
e decantan en menos de dos horas y un tratamiento de neutralización si el caso lo requiere.

2.14 Tratamiento secundario: Proceso que elimina de las aguas la materia orgánica biodegradable y que no ha sido retirada por el tratamiento primario. Consiste en provocar el desarrollo de microorganismos capaces de asimilar la materia orgánica.

2.15 Tratamiento terciario: Proceso de tratamiento adicional necesario para la eliminación de los sólidos suspendidos y las sustancias disueltas que permanecen en el agua residual después del tratamiento secundario convencional. Estas pueden ser compuestos orgánicos y compuestos sintéticos muy complejos.

3. REQUISITOS:

Usos de las aguas residuales tratadas.

3.1 REQUISITOS DEL AGUA PARA CONSUMO DE ANIMALES.

En todos aquellos casos en que los animales estén en contacto con el ser humano o estén destinados al consumo humano se deben cumplir con los requisitos indicados en la Norma DGNTI-COPANIT 395.

3.2 REQUISITOS PARA EL AGUA DE RIEGO.

Para la utilización de las aguas servidas tratadas en riego se deben cumplir los requisitos que se indican a continuación.

3.3 REQUISITOS QUIMICOS.

Las aguas de riego, independientemente de su origen, deben cumplir al menos con los siguientes requisitos de tipo químico, los que siempre deben ser revisados:

TABLA 3-1: Concentraciones máximas de elementos químicos en agua para riego

Elemento	Expresión	Unidad	Limite máximo
Aluminio	Al	mg/L	5.000
Arsénico	As	mg/L	0.100
Bario	Ba	mg/L	4.000
Berilio	Be	mg/L	0.100
Boro	B	mg/L	0.750
Cadmio	Cd	mg/L	0.010
Cianuro	CN	mg/L	0.200
Cloruro	Cl	mg/L	200.000
Cobalto	Co	mg/L	0.050
Cobre	Cu	mg/L	0.020
Conductividad. Eléctrica	CE	ds/m	3.000
Cromo	Cr	mg/L	0.100
Fluoruro	F	mg/L	1.000
Hierro	Fe	mg/L	5.000
Litio	Li	mg/L	2.500
Litio (cítricos)	Li	mg/L	0.075
Manganeso	Mn	mg/L	0.200
Mercurio	Hg	mg/L	0.001
Molibdeno	Mo	mg/L	0.010
Níquel	Ni	mg/L	0.200
Plata	Ag	mg/L	0.200
Plomo	Pb	mg/L	5.000
Selenio	Se	mg/L	0.020

Elemento	Expresión	Unidad	Limite máximo
Sodio porcentual	% Na	%	35.000
Sulfato	SO_4^{2-}	mg/L	350.000
Vanadio	V	mg/L	0.100
Zinc	Zn	mg/L	2.000

Relación de Adsorción de sodio

Los valores recomendados varían según la concentración de sales expresada en términos de conductividad eléctrica; se recomienda que no se sobrepase el límite de bajo o sin riesgo de sodificación, el que depende del contenido de sales del agua. Al final del texto, se incluye el diagrama de Clasificación de Aguas del Unites States Departament of Agriculture, publicado en el texto Diagnostico y Rehabilitación de Suelos Salinos y Sódicos.

3.4 REQUISITOS MICROBIOLOGICOS.

Los requisitos microbiológicos y los procesos de tratamiento recomendados para las aguas recicladas son los siguientes:

Tabla 3-2: Procesos recomendados para tratamiento de aguas r ecicladas y parámetros para calidad de aguas recuperadas usadas para Riego (a).

Tipo de riego	Proceso de Tratamiento	Parámetros Recomendados para la Calidad de Agua
Riego superficial (b) o de aspersión para cultivos de comestibles (c), no procesados comercialmente, cuando los productos no tienen contacto directo con las aguas recuperadas.	Tratamiento secundario (d) Filtración (e) Desinfección	pH = 6.0 - 9.0 DBO = 20 mg/L (g) Turbiedad = 3.0 NTU (h) Coliformes Fecales = <200/100 mL(i) Cloro residual = >1 mg/L (j) SST = 5.0 mg/L (m)
Riego superficial (b) de cultivos de comestibles, no procesado, cuando la parte comestible crece sin contacto con la tierra o con las aguas recuperadas.	Tratamiento secundario Desinfección es recomendada pero no requerida, como el caso de viñas, huertos, cultivos de semillas (no consumidos por seres humanos), árboles sin partes comestibles, forraje y cultivos de fibra (f).	PH = 6.0 - 9.0 DBO = 40 mg/L(max) (g) SST = 40 mg/L (max) Coliformes fecales = <500/100 mL(i) Cloro residual: entre 1 y 2 mg/L (j) Turbiedad = <3.0 NTU (h)
Riego superficial (b) o aspersión en cultivos de comestibles, procesados comercialmente (k), riego de huertos, irrigación superficial o de aspersión en cultivos no comestibles.	Tratamiento secundario (d). Desinfección (f)	pH = 6.0 - 9.0 DBO = 40 mg/L (max) (g) SST = 40 mg/L (max) Coliformes fecales = <500/100 mL (i) Cloro residual: entre 1 y 2 mg/L (j)
Riego superficial de forrajeras, y cultivos no	Tratamiento primario y avanzado con la adición de	pH = 6.0 - 9.0 DBO = 60 mg/L (g)

Tipo de riego	Proceso de Tratamiento	Parámetros Recomendados para la Calidad de Agua
comestibles (l).	químicas. Desinfección.	SST = 50 mg/L Coliformes fecales = <1000/100 mL (i) Cloro residual: entre 1 y 2 mg/L (j)

Notas:

a) Los límites de calidad que son recomendados se aplican a aguas recuperadas en el lugar de descarga de la instalación de tratamiento.

b) Incluye riego por surcos, goteo e inundación.

c) Incluye cultivos de plantas tales como papas, zanahorias, rábanos, ajo, cebolla y remolacha.

d) Los procesos de tratamiento secundarios, incluyen lodos activados, reactores consecutivos, filtros de flujo lento, unidades rotatorias de contacto biológico y varios sistemas de estabilización en lagunas.

e) Filtración, definido como el proceso de procesar aguas por suelos naturales o filtros naturales como arena y antracita.

f) Desinfección, definido como la destrucción, desactivación, remoción de organismos patógenos mediante procesos químicos, biológicos o físicos. La desinfección puede ser realizada con cloro, ozono, radiación UV, procesos con membranas u otros procesos conocidos.

g) Determinado por una prueba de DBO durante 5 días.

h) Deben cumplir con el límite de turbiedad antes de la desinfección. La turbiedad no debe exceder 5 NTU (Unidades Nefelométricas de Turbiedad) en cualquier momento.

i) El valor medio determinado de los resultados bacteriológicos de los últimos 7 días para los que se han realizado análisis.

j) Cloro residual después de un período mínimo de 30 minutos de contacto del cloro con las aguas tratadas. Se considera un límite máximo de 2 mg/l, para evitar la formación de compuestos órgano clorados, tales como los trihalometanos.

k) Cultivos de comestibles, procesados comercialmente, son aquellos que antes de ser comercializados han recibido un tratamiento químico o físico suficiente para matar organismos patógenos.

l) Cultivos no comestibles, que incluyen praderas para animales que dan leche, forraje y cultivos de semillas.

m) Sólidos Suspendidos Totales

3.5 REQUISITOS PARA EL AGUA DESTINADA A RECREACIÓN Y ESTETICA.

Estética.

Las aguas servidas tratadas destinadas a estética u ornamentación deben estar exentas de las siguientes substancias.

- Materias que sedimenten formando depósitos indeseables.
- Desechos flotantes, aceites, espumas y sólidos de cualquier tipo.

Recreación sin contacto directo.

El agua destinada a la recreación sin contacto directo debe ser sometida al menos a un tratamiento secundario, con filtración y desinfección. Debe cumplir con los siguientes requisitos.

TABLA 3-3: Requisitos para agua destinada a recreación sin contacto directo

Característica	Requisitos
Ph	6,0 - 9,0
Temperatura	± 3°C de la temperatura normal
Sólidos flotantes visibles y espumas no naturales	Ausentes
Claridad	Visualización de disco Secchi a 1,5 m.
Aceites flotantes y grasas	máximo 5 mg/l
Aceites y grasas emulsionadas	Máximo 10 mg/l
Color, escala platino cobalto	Máximo 50 unidades.
Turbiedad	30 unidades máximo
Coliformes fecales	ausentes.
DBO	< 5,0 mg/l
Cloro residual	< 5,0 mg/l
Substancias que produzcan olores desagradables	Ausentes.

3.6 REQUISITOS DE CALIDAD DEL AGUA PARA VIDA ACUATICA Y ACUICULTURA.

Las aguas recicladas, destinadas a ser usadas para vida acuática deben cumplir con los requisitos de tratamientos y calidad que se indican en la Tabla 3-4:

TABLA 3-4: REUTILIZACIÓN PARA ACUICULTURA

Procesos de tratamiento y parámetros de calidad, recomendados para aguas recuperadas y reutilizadas en la industria de Acuicultura.

Tipo de Reutilización	Proceso Recomendado para Tratamiento	Parámetros Recomendados para calidad de aguas
Para la cultivo de comida y peces ornamentales, camarones y mariscos	• Tratamiento secundario (a) • Filtración (b) • Desinfección (c)	•. pH = 6.0-9.0 •. DBO = 20 mg/L (d) •. Turbiedad = 3.0 NTU (e) •. Coliformes fecales =< 200/100 mL (f) •. Cloro residual = 0.5 –1.0 mg/L (max) (g) •. DO = > 5 mg/L
Para el cultivo de plantas acuáticas, como lechuga marina, jacinto, etc.	•. Tratamiento secundario (a) •. Desinfección (c)	•. pH = 6.0 - 9.0 •. DBO = 30 mg/L (d) •. SST = 30 mg/L •. Coliformes fecales < 500/100 Ml (e) •. Cloro residual = 0.5–1.0 mg/L (max) (g)

Notas:

a) Los procesos de tratamiento secundarios, incluyen lodos activados, reactores consecutivos, filtros de flujo lento, unidades rotatorias de contacto biológico y varios sistemas de estabilización en lagunas.

b) Filtración, definido como el proceso de procesar aguas por suelos naturales o filtros naturales como arena y antracita.

c) Desinfección, definido como la destrucción, desactivación, remoción de organismos patógenos mediante procesos químicos, biológicos o físicos. La desinfección puede ser realizada con cloro, ozono, radiación UV, procesos con membranas u otros procesos conocidos.

d) Determinado por una prueba de DBO durante 5 días.

e) Deben cumplir con el límite de turbiedad antes de la desinfección. La turbiedad no debe exceder 5 NTU en ningún momento.

f) El valor medio determinado de los resultados bacteriológicos de los últimos 7 días para los que se han realizado análisis.

g) Cloro residual después de un período mínimo de 30 minutos de contacto del cloro con las aguas tratadas.

Si se presentaran substancias biotóxicas estas deben ser determinadas por el bioensayo correspondiente. El valor obtenido se expresa en LTm96, debiendo utilizarse los factores de seguridad que se indican a continuación

TABLA 3-5: Factores de seguridad para diferentes tóxicos

Tóxico	Factor de seguridad
Pesticidas	1/100 de la LTm96
Metales pesados	1/100 de la LTm96
Cianuros	1/10 de la LTm96
Tóxico no acumulativo	1/10 de la LTm96
Tóxico acumulativo y persistente	1/100 de la LTm96
Detergentes	1/10 de la LTm96

Para organismos filtradores debe cumplirse con la parte microbiológica que establecen las disposiciones sobre alimentos en lo que se refiere a la crianza y recolección de estos.

Este tipo de uso del agua reciclada deberá respetar los límites máximos para la presencia de metales pesados, con el propósito de preservar la fauna íctica y la vida acuática, de acuerdo a lo indicado en la Tabla 3-6:

Tabla 3.6. Limites máximos para metales pesados en aguas destinadas a acuicultura y vida acuática

Parámetro	Expresión	Unidad	Limite máximo
Aluminio	Al	mg/L	0.100
Arsénico	As	mg/L	0.050

Cobre	Cu	mg/L	0.002
Cianuro	CN	mg/L	0.005
Hierro	Fe	mg/L	0.300
Plomo	Pb	mg/L	0.002
Mercurio	Hg	mg/L	0.001
Níquel	Ni	mg/L	0.065
Nitrógeno amoniacal	NH_4	mg/L	1.370
Nitrito	$N0_2$	mg/L	0.060
Selenio	Se	mg/L	0.001
Plata	Ag	mg/L	0.001
Zinc	Zn	mg/L	0.030

3.7 REQUISITOS DE CALIDAD DEL AGUA PARA USO URBANO

Las aguas recicladas, destinadas al uso urbano deben cumplir con los requisitos de tratamientos y calidad que se indican en la Tabla 3-7:

TABLA 3-7: REUTILIZACION URBANA

Procesos recomendados para el tratamiento de aguas recuperadas y parámetros para la calidad de aguas recuperadas y reutilizadas para usos urbanos.

Tipo de Reutilización	Proceso de Tratamiento	Parámetros para la Calidad de Aguas
Incluyen riego de cementerios, áreas verdes en caminos públicos, viveros, fabricación de concreto, limpieza de vías públicas y banquetas y áreas de trabajo al aire libre, tales como lavado de autos y otros.	Tratamiento secundario Desinfección	pH = 6.0 – 9.0 DBO = <40 mg/L SST = <40 mg/L Coliformes fecales < 200/100 m/L Cloro residual < 2 mg/L

Notas:

- Los procesos de tratamiento secundarios, incluyen lodos activados, reactores consecutivos, filtros de flujo lento, unidades rotatorias de contacto biológico y varios sistemas de estabilización en lagunas.
- Cloro residual después de un período mínimo de 30 minutos de contacto del cloro con las aguas tratadas.
- Desinfección, definido como la destrucción, desactivación, remoción de organismos patógenos mediante procesos químicos, biológicos o físicos. La desinfección puede ser realizada con cloro, ozono, radiación UV, procesos con membranas o otros procesos conocidos.

3.8 REQUISITOS DE CALIDAD DEL AGUA PARA SER USADAS EN RECUPERACION DE HABITAT

Las aguas recicladas, destinadas a ser usadas en recuperación de hábitat deben cumplir con los

requisitos de tratamientos y calidad que se establecen para riego o para acuicultura en la presente Norma. La autoridad competente deberá decidir cual requisitos deben cumplirse, en función de las características de la vida silvestre del hábitat que se desee recuperar.

3.9 REQUISITOS DE CALIDAD DEL AGUA PARA SER USADAS EN RECARGA DE ACUIFEROS

Las aguas recicladas, destinadas a ser usadas en recarga de acuíferos deben cumplir con los requisitos de tratamientos y calidad que se establecen en la Tabla 3-8:

TABLA 3-8: RECARGA DE ACUIFEROS SUBTERRANEOS

Procesos de tratamiento y parámetros para la calidad de aguas recuperadas y usadas para recargar acuíferos.

Tipo de Reutilización	Proceso de Tratamiento	Parámetros para la Calidad de aguas
Inyección directa que recarga agua subterránea que es usada o podrá ser usada para uso doméstico (agua potable).	•. Tratamiento secundario •. Coagulación/floculación •. Filtración •. Extracción de compuestos orgánicos •. Desinfección	•. PH = 6.0-9.0 •. DBO = < 5 mg/l •. Turbiedad = < 2 NTU •. Coliformes fecales =< 2.2/100 ml •. Cloro residual = < 1 mg/l
Recarga mediante aplicación a la superficie de la tierra (sistema de percolación o infiltración en forma natural)	•. Tratamiento secundario •. Desinfección	•. PH = 6.0 - 9.0 •. DBO < 30 mg/L •. SST <30 mg/L •. Coliformes fecales =<500/100 mL •. Cloro residual = < 1 mg/L

Además de lo anterior deben cumplirse los límites máximos para metales pesados, recomendados en esta Norma para aguas de riego.

3.10 REQUISITOS DE CALIDAD DEL AGUA PARA USO INDUSTRIAL Y COMERCIAL

En el caso de reuso industrial y comercial de las aguas recicladas, se pueden dar una gran variedad de requerimientos, que van desde usos mineros hasta usos industriales tales como refrigeración, los que tienen particulares estándares de calidad físico – química para las aguas. Por lo anterior sólo se ha normado la calidad microbiológica, de acuerdo a lo

TABLA 3-9: REUTILIZACIÓN EN USOS INDUSTRIALES Y COMERCIALES

Procesos de tratamiento y parámetros para la calidad de aguas recuperadas y reutilizadas para usos industriales y comerciales en la República de Panamá.

Tipo de Reutilización	Proceso de Tratamiento	Parámetros para la calidad de agua
Procesos industriales, refrigeración, calderas, etc.	•) Tratamiento secundario •) Filtración (b) •) Desinfección (c)	•) pH = 6.0 - 9.0 •) DBO = 20 mg/L max (d) •) Turbiedad = < 3.0 NTU (e) •) Coliformes fecales =< 200/100 •) Cloro residual =< 1.0 mg/L (g)
Usos comerciales, control de incendios, compactación de suelos, concretos, procesos mineros, etc.	•) Tratamiento secundario •) Desinfección (c)	•) pH = 6.0 - 9.0 •) DBO = 40 mg/L max (d) •) SST = < 40 mg/L max •) Cloro Residual = < 1 mg/L (g) •) Turbiedad <15 NTU (e)

Notas:

a) Los procesos de tratamiento secundarios incluyen, lodos activados, reactores consecutivos (sequencing batch reactors), filtros de flujo lento, unidades rotatorias de contacto biológico y varios sistemas de estabilización en lagunas.
b) Filtración, definido como el proceso de procesar aguas por suelos naturales o filtros de arena o antracita.
c) Desinfección, definido como la destrucción, desactivación, remoción de organismos patógenos por maneras químicas, biológicas o físicas. La desinfección puede ser realizada mediante cloración, ozonación, desinfectantes químicos, radiación UV, procesos con membranas o otros procesos conocidos.
d) Determinado por una prueba de DBO de 5 días.
e) Deben cumplir con el límite de turbiedad antes de la desinfección. La turbiedad debe ser basada en un periodo de 24 horas. La turbiedad no debe de exceder 5 NTU en ningún momento.
f) El valor medio determinado de los resultados bacteriológicos de los últimos 7 días para los que se han realizado análisis
g) Cloro residual total medido después de un período mínimo de 30 minutos de contacto.

4. TOMA DE MUESTRAS

Generalidades.

Las plantas de tratamiento deberán llevar su propio control de los parámetros señalados en la presente norma, de acuerdo con el tipo de uso que se quiera dar a las aguas tratadas, sin perjuicio de los controles que realice la autoridad competente.

La toma de muestras debe ser efectuada por personal idóneo de un laboratorio acreditado. Debe ser realizada en cada uno de los puntos de evacuación o descarga de las plantas de tratamiento de aguas residuales, siendo responsabilidad de los operadores de la planta. Los controles de la autoridad competente serán efectuados sin previo aviso, efectuando los muestreos y determinando las características de los efluentes de la planta de tratamiento.

Obtención de la Muestra.

Muestra puntual.

Cada muestra puntual deberá estar constituida por la mezcla homogénea de dos submuestras de igual volumen, extraídas de la superficie y del interior de fluido, debiéndose observar las condiciones de colecta, tipo de envase, preservación y tiempo máximo entre la toma de muestra de acuerdo a lo señalado en la Tabla 4-1 y realizando el análisis correspondiente al método oficial.

Muestra compuesta.

La muestra compuesta esta constituida por una mezcla homogénea de 3 muestras puntuales obtenidas cada 3 horas. Además se deben cumplir las condiciones de extracción de muestras que se señalan en la presente norma.

Las muestras serán puntuales para los parámetros: Color, Temperatura, pH, Sólidos sedimentables, Sulfuros, Cianuros, y Nitrógeno en sus diferentes formas. Las determinaciones de los Sólidos sedimentables, la Temperatura y Oxígeno disuelto deberán ser realizadas en terreno. El pH deberá determinarse en un tiempo inferior a dos horas después de haberse extraído la muestra.

Las muestras serán compuestas para los parámetros: Sólidos suspendidos, DBO, Arsénico Cadmio, Cobre, Cromo, Mercurio, Níquel, Plomo, Sulfato, Fósforo y Zinc.

Lugar de muestreo

El lugar de muestreo será una cámara o dispositivo especialmente habilitado para ta efecto, en donde concurran previamente mezclados, todos los líquidos provenientes de proceso de tratamiento de las aguas.

La cámara o dispositivo de control deberá ser habilitado por la planta de tratamiento de t forma que permita realizar sin dificultades el aforo o medición de los caudales descargad con un sistema universalmente aceptado para estos efectos.

La autoridad competente se reserva la facultad de tomar muestras de control en lugar diferentes si así lo estima conveniente.

4.1 CONDICIONES PARA LA EXTRACCIÓN DE LAS MUESTRAS.

Las muestras deben cumplir las condiciones que se señalan en la Tabla siguiente, en cuanto a tipo de envase, lugar de análisis, envase, preservación, y tiempo.

TABLA 4-1. Lugar de análisis, tipo de envase, preservación y tiempo límite para realizar el análisis en muestras de aguas recicladas

Parámetro	Lugar de análisis	Envase	Preservación	Tiempo
PH	Terreno	P o V	-----	---
Temperatura	Terreno	P o V	-----	---
Sólidos suspendidos	Laboratorio	P o V	-----	24 horas
Sólidos sedimentables	Pref. Terreno	P o V	-----	24 horas
DBO_5	Laboratorio	P o V	Llenar envase, enfriar 2-5 °C. Oscuridad.	24 horas
Arsénico	Laboratorio	P o V	Acidificar a pH < 2 con HCl	1 mes
Cadmio	Laboratorio	P o VB	Acidificar a pH < 2 con HCl	1 mes
Cianuro	Laboratorio	P o V	Agregar NaOH a pH >12. Enfriar a 2-5 °C. Oscuridad	24 horas
Cobre	Laboratorio	P o VB	Acidificar pH <2 con $HN0_3$	1 mes
Cromo total	Laboratorio	P o VB	Acidificar pH <2 con $HN0_3$	1 mes
Cromo hexavalente	Laboratorio	P o VB	Enfriar a 2-5 °C	24 horas
Fósforo	Laboratorio	V o VB	Acidificar pH <2 con HSO_4	1 mes
Mercurio	Laboratorio	VB	Acidificar pH <2 con HSO_4 para mercurio enfriar a 2-5 °C	1 mes
Níquel	Laboratorio	P o VB	Acidificar pH <2 con $HN0_3$	1 mes
Nitrógeno amoniacal	Laboratorio	P o V	Acidificar pH <2 con HSO_4 enfriar a 2-5 °C Oscuridad	24 horas
Plomo	Laboratorio	P o V.B.	Acidificar pH <2 con $HN0_3$	1 mes
Sulfatos	Laboratorio	P o V	Enfriar a 2-5 °C	1 semana
Zinc	Laboratorio	P o VB	Acidificar pH <2 con $HN0_3$	1 mes
DQO	Laboratorio	V	Acidificar pH <2 con HSO_4	1 mes

P : Envase plástico V : Envase vidrio VB : Envase vidrio borosilicato

Volúmenes de Muestra.

En el Tabla N° 4-2 se indican los volúmenes mínimos de muestra a utilizar de acuerdo a los parámetros a determinar

TABLA 4-2. Volúmenes de muestra según parámetro a analizar

Volumen mínimo de muestra	Parámetros
2 litros: Muestra natural	Sólidos sedimentables, DBO_5, sólidos suspendidos, sulfatos poder espumógeno y cromo hexavalente.
1 litro: Muestra con ácido nítrico pH 2	Cadmio, cobre, cromo total, níquel plomo y zinc
1 litro: Muestra, ácido clorhídrico pH 2	Aceites, grasas e hidrocarburos
1 litro: Muestra ácido sulfúrico pH 2	Arsénico, fósforo, nitrógeno amoniacal y DQO
300 ml: Muestra con ácido nítrico pH 2	Mercurio
1 litro: Muestra con hidróxido de sodio pH	Cianuro
500 ml: Muestra hidróxido de sodio pH 9 y acetato de zinc	Sulfuro

4.2 FRECUENCIA DE LOS MUESTREOS PARA CADA TIPO DE PARAMETRO SE INDICA A CONTINUACION

La frecuencia mínima de muestreos para cada tipo de parámetro que se debe controlar en las plantas de tratamiento de aguas servidas se indica en la tabla 4-3:

TABLA 4-3. Frecuencia mínima de control de muestreo para los distintos parámetros

Parámetro	Frecuencia
Reacción (pH)	Diario
Cloro residual	Diario
Coliformes fecales	Semanal
Conductividad eléctrica	Diario
Sólidos sedimentables	Semanal
Sólidos suspendidos totales	Semanal
Demanda bioquímica de oxígeno	Semanal
Nitrógeno y Fósforo	Mensual
Metales pesados	2 veces al año

5. ENSAYOS

Métodos de análisis oficiales

Serán oficiales los métodos de análisis establecidos en la última edición del " Standard Methods for the Examination of Water and Wastewater", publicada por la A.P.H.A., A.W.W.A., y W.P.C.F.. En casos excepcionales debido a condiciones especiales la autoridad competente podrá aceptar modificaciones a los métodos oficiales.

El método de análisis utilizado para cada parámetro, deberá ser el que corresponda para las características específicas de la muestra, debiéndose observar en cada caso, las interferencias y límites de detección de dicho método.

6. APENDICE

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SEGUNDO: **La presente resolución entrará en vigencia a partir de su publicación en Gaceta Oficial.**

COMUNIQUESE Y PUBLIQUESE

BACK-UP TO

SECTION 3.0

FLOW, EQUIPMENT SIZING AND ENERGY GENERATION CALCULATIONS

DETERMINE SIZING OF RETENTION RESERVOIR

Determine capacity of the reservoir
Use: Max.55 ship transits per day
26,000,000.gallions per ship
Max.60% retention of Max. flow
Reservoir holding time of 2.5 hours

Determine Max flow into the reservoir in gallons per hour GPH

$$\frac{55 \times 26{,}000{,}000.}{24} = 59{,}583{,}333.\text{GPH}$$

Determine max. required capacity of reservoir in cubic feet, ft^3

$$59{,}583{,}333 \times 2.5 \times 0.13368 \times 0.60 = 11{,}947{,}650\ ft^3$$

Determine max. required capacity of the reservoir if 100% of flow was recycled back to lake Gatune.

$$59{,}583{,}333. \times 2.5 \times 0.13368 = 19{,}912{,}745.\ ft^3$$

Conclusions: the retention reservoir is sized with a capacity of 20,625,000. ft^3, referance dwg. PC01-FS007. and has been sized to accommodate 100% of the flow.

SIZING OF RETENTION RESIVOR OVERFLOW WEIRS

Determine Max. Flow through the retention reservoir weirs in gallons per min. GPM
Use: 55 ship passages per day
26,000,000.gallons per ship

$$\frac{55 \times 26{,}000{,}000.}{1440} = 993{,}055.0 \text{ GPM}$$

Determine flow in cubic feet per sec. (ft^3/s)

$$993{,}055. \times 0.002228 = 2{,}212.5 \text{ ft.}^3/s$$

Using the Thompson formula, determine the weir dimensions
Assume there will be 7 each weirs

Use: $Q = 3.33 (L - 0.2 \times H) H^{1.5}$

Where: Q = flow in $ft^3/s = (2{,}212.5 / 7 = 316 \text{ ft}^3)$
L = length of weir in ft. = 20
H = head on weir in ft. = 3

Determine max. flow through each weir

$$3.33 (20 - 0.2 \times 3) 3^{1.5} = 335.7 \text{ ft}^3/s$$

Conclusion: the max. required flow through each weir is $316 ft^3/s$, or (2,212.5 ft^3/s / 7 weirs).The calculated max. flow through each weir is 335.7 ft^3/s, therefore the weirs as sized above are capable of the max. flow requirements.

1. DETERMINE MAXIMUM FLOW AND VELOCITY IN THE CULVERT SYSTEMS

A) Determine maximum volume of discharge lock water per lockage.
USE: 52,000,000. Gallons of water per single ship transit loss.
52,000,000. / 2 = 26,000,000 gallons

B) Determine flow rate in gallons per minute (GPM)
USE: an eight minute (8 min.) lock fill/drain cycle time.
26,000,000 / 8 min. = 3,250,000 GPM

C) Determine flow velocity in both 18 ft. & 36 ft. pipe.
1. USE: $V = 0.0028368 \times GPM / D^2$
Where V = flow velocity in ft./sec
D = pipe dia. in ft.
GPM = flow rate in gallons per min.

For 18 ft. dia. Pipe: $V = \frac{0.0028368 \times 3,250,000.}{18^2} = 28.45$ ft/sec.

For 36 ft. dia. Pipe $V = \frac{0.0028368 \times 3,250,000}{36^2} = 7.1$ ft./sec.

D) Determine flow rate and velocity in the lock 18 ft. dia. drain culvert
Use: flow = 3,250,000 GPM
Two culverts in use
$\frac{3,250,000}{2} = 1,625,000$ GPM per culvert

$V = \frac{0.0028368 \times 1,625,000.}{18^2} = 14.23$ ft./sec.

E) Determine flow rate and velocity in the 4 each 18 ft. dia. Retention reservoir inlet culverts.
Use: flow = 3,250,000 GPM
Four culverts in use
$\frac{3,250,000}{4} = 812,500$ GPM per culvert

$V = \frac{0.0028368 \times 812,500}{18^2} = 7.1$ ft./sec.

F) Determine flow rate and velocity in the 4 each 18 ft. dia. retention reservoir outlet culverts.
Use: 30% flow reduction in total flow for lake Gatun water repatriation

$$\text{Flow} = \frac{3{,}250{,}000 \times .70}{4} = 568{,}750 \text{ GPM per culvert}$$

$$V = \frac{0.0028368 \times 568{,}750}{18^2} = 4.9 \text{ ft./sec. for each culvert}$$

G) Determine the flow rate and velocity in the 4 each 18 ft. dia. canal inlet culverts
Note: flow and velocity are the same as F).
Flow = 568,750 GPM per culvert
V = 4.9 ft./sec. per culvert

H) Determine flow rate and velocity in the 36 ft./dia.culvert that flows from the lock discharge to the retention reservoir.
Flow = 3,250,000. GPM

$$V = \frac{0.0028368 \times 3{,}250{,}000}{36^2} = 7.1 \text{ ft./sec.}$$

I) Determine flow rate and velocity in the 36 ft. dia. culvert that flows from the retention reservoir to the canal.
Use: 30% reduction in total flow for lake Gatun water repatriation.

$$\text{Flow} = 3{,}250{,}000\text{GPM} \times 0.70 = 2{,}275{,}000 \text{ GPM}$$

$$V = \frac{0.0028368 \times 2{,}275{,}000}{36^2} = 4.97 \text{ ft./sec.}$$

2. DETERMINE HEAD LOSS IN FEET OF WATER IN THE CULVERT SYSTEMS

Use the equation: $H_f = f \times \frac{L}{D} \times \frac{V^2}{2g}$

Where: H_f = the head loss in ft. of water
f = friction factor, concrete pipe Use: 0.02
L = length of pipe in feet
D = inside diameter of the pipe in feet
V = the velocity of flow in the pipe in ft./sec.
g = the gravitational constant, 32.174 ft./sec.

A) Determine the head loss for: 1. D), 18 ft. dia. culvert, flow to the retention reservoir
Use: L = 150ft. of pipe
V = 14.23 ft./sec.
D = 18.0 ft.

$H_f = 0.03683$ ft.of water

B) Determine the head loss for: 1. E), 18 ft. dia. retention reservoir inlet culverts.
Use: 4 each culverts,
L = 22 ft. each
V = 7.1 ft./sec.
D = 18.0 ft.
$H_f = 0.002684$ ft.of water per culvert
Total $h_f = 4 \times 0.002684 = 0.010736$ ft. head

C) Determine the head loss for: 1. F), 18 ft. dia. retention reservoir outlet culverts.
Use: 4 each culverts
L = 22 ft. each
V = 4.9 ft./sec.
D = 18.0 ft.
$H_f = 0.001854$ ft. of water per culvert
Total $H_f = 4 \times 0.001854 = 0.00746$ ft. of water

D) Determine the head loss for: 1. G), 18 ft. dia. canal inlet culverts
Note: head losses are the same as C) above
Total $H_f = 0.00746$ ft. of water

E) Determine the head loss for:1. H), 36 ft. dia. culvert that flows from the lock discharge to the retention reservoir.
Use: L = 500 ft.
V = 7.1 ft./sec.
D = 36 ft.
$h_f = 0.030$ ft. of water

F) Determine the head loss for: 1. I), 36 ft. dia. culvert that flows from the retention reservoir to the canal.
Use: L = 500 ft.
V = 4.97 ft. /sec.
D = 36 ft.
Hf = 0.021 ft. of water

The required head to flow discharge lock water through the proposed new culverts to the new retention reservoir = 2. A+B+E =0.077566 ft. x 2 sf = total $H_f = 0.155$

The required head to flow retention reservoir overflow to the canal through the new proposed culverts = 2. C+D+F = 0.03592 ft. x 2sf = total Hf = 0.07184.

Conclusion: there is sufficient head in the discharge locks, 26-30 ft. of head to flow the lock discharge to the retention reservoir within the 8 min. cycle time.As can be seen from above the required head is 0.155 ft. of water. Likewise there is also sufficant head in the

overflow of the retention resivor which is set to maintain a minimum of 0.333 feet above sealeavel. The required head is 0.07184 ft. of water

HYDRAULIC ENERGY POTENTIAL

Determine the hydraulic energy from the operations of the canal lock systems

Use: $P = \frac{Q \times (KPa)}{60{,}000 \times (eff.)}$

Where: P = electrical power in kilowatts kW
Q = flow in liters per minute L/min.
KPa = pressure / head in kilopascals
Eff = turbine efficiency

KPa = total available head 85 feet, x 0.4328 x 6.8948 = 253.65 KPa
$Q = \frac{26{,}000{,}000}{8}$ = 3,250,000 GPM x 3.7854 = 12,302,550.L/min.

26,000,000 = loss/flow of water per ship in gallons
8 = lock fill/drain time in minutes
eff = .95

$kW = \frac{12{,}302{,}550 \times 253.65}{60{,}000 \times .95}$

kW = 54,746.35

Determine the time, flow of water will be moving across the turbines in hours per day, hr/day

Use: 8 minutes per fill/drain cycle
3 each lock steps per ship
45 ships per day current max.capacity

8 x 3 = 24 minutes, this represents the minimum time required to fill/drain three locks that a ship can transition from lake Gatun +85 feet above sea level to sea level. For these calculations 30 minutes will be used.

$\frac{30 \times 45}{60}$ = 22.5 hr/day

Determine kWhr/yr per set of locks

22.5 x 54,746.35 x 365 = 449,604,399 kWhr/yr

FEASIBILITY ANALYSIS

&

CONCEPTUAL COST ESTIMATE

CULVERT TUNNELING & CONSTRUCTION

By

JENNY ENGINEERING CORPORATION

PANAMA CANAL PROJECT

FEASIBILITY STUDY
&
CONCEPTUAL COST ESTIMATES

JENNY ENGINEERING CORPORATION
CONSULTING ENGINEERS

DATE: 7/29/02

Panama Canal Locks Water Reclamation Project
Tunnel Interconnections
Engineering Feasibility Study

1. Introduction

The purpose of this study is to evaluate and determine a recommended technical approach for the design and construction of the Lock Water Recovery Tunnel and the Retention Reservoir Discharge Culvert for both the Lower Gatun Lock and the Lower Miraflores Lock. The Lock Water Recovery Tunnel connects the existing side culverts and the center culvert of the canal locks to the retention reservoir for the purpose of cycling 26 million gallons of water, each time the lock is lowered, from the locks to the retention reservoir and eventually back to Lake Gatun. Another tunnel, the Retention Reservoir Discharge Culvert, connects the overflow of the retention basin with the channels downstream from the locks connecting through two ports in the bottom of each channel. All this work is proposed for both the Lower Gatun Lock, near Colon, on the Atlantic side of the Isthmus and the Lower Miraflores Lock near Panama City on the Pacific side.

Another construction task involves the development of the tunnels for connecting the pit turbine sets distributed along the six locks including the lock at Pedro Miguel. There are seven sets of pit turbines with each set consisting of 3 turbines each, one for each lock culvert.

2. Geologic Information

The currently available geologic information is limited. On the Atlantic side near the Gatun Lock a boring indicates that the tunnels will probably be excavated in the Gatun Formation. This formation ranges from a medium hard to very hard overburden material 1.5 meters thick and consists of a mixture of sand, silt and clay as well as weathered rock. This material has moderate water content. Below this layer is a sandstone formation with rock ranging from very soft to very hard.

On the Pacific side, the tunnel system is expected to be in the La Boca Formation. This material is dominated by siltstone and sandstone layers with minor amounts of conglomerate, shale, and limestone.

Both locations appear to be sites of generally soft to moderately hard rock materials with some water intrusion. The rock and water intrusion are both concerns in the design and construction of the tunnels. The impact of these conditions is that although the rock materials will be somewhat easier to excavate overall, care will be taken in design and construction to provide for initial support of the tunnel openings within a short time frame to protect the rock from decomposing and slaking. Water, being the other concern, will be controlled by mining the tunnel up hill at a shallow grade allowing the groundwater to flow to a sump at the shaft in the reservoir for removal from the excavation. A pregrouting program will generally control excessive inflows.

3. System Description

A brief system description is important in evaluating the various methods to use in the design and construction of these interconnecting culverts. Both lock systems have a similar configuration and will be designed and constructed in a similar fashion.

- **Lock Water Recovery Tunnels**

The connections to the side culverts of the parallel locks will be through a 36 foot diameter tunnel running perpendicular to the lock. The tunnel will have a vertical, 18 foot connection to each of the side culverts. One restriction is that the actual connection to the culvert has to be made in a ten-day or less period when the canal is shut down for maintenance.

The connection to the center culvert is an 18-foot diameter tunnel, with possibly a bend in the alignment and connected to the 36-foot tunnel. This also has a vertical connection to the center culvert, but it is anticipated that the available connection time frame to the center culvert may be less since it is used for both locks.

The discharge tunnel will be connected to the reservoir through a vertical shaft entering the reservoir from the bottom.

- **Retention Reservoir Discharge Culvert**

The tunnel is a 36-foot diameter tunnel that runs from the low side of the weir at the retention basin to a site, in the channel, downstream of the locks. At this location the tunnel extends under the channel perpendicular to the direction of the channel. The connections to the channel are in the channel bottom and consist of two 18-foot diameter openings, spaced equidistant, in each channel.

- **Vertical Connections to the Existing Canal Drains and Channels**

The vertical connections include those to the two side culverts and the center culvert as well as those four connections to the downstream channel for the return tunnel. There are a number of different methods that could be selected to allow for the construction of the connections and still allow for continuous operation of the locks.

These options include but are not limited to making the connections during a periodic ten-day shut down period or placing a thin, temporary interliner into each culvert, which seals off the work site thus allowing the connections to be completed and the locks to still operate.

- **Reservoir Shafts**

The shafts at the reservoir will serve as the main access for construction of the tunnels and the vertical risers. All excavation work and final lining work will be performed from this area. The shafts will be the same diameter as the tunnels to which they connect. Once construction is complete in the risers and the tunnels, the shafts will be lined and also completed.

- **Pit Turbines**

There will be a total of 21 pit turbines installed to generate electricity. They will be installed in groups of three. In order to install a group of three turbines shafts will be constructed to access chambers where the turbines will be housed. The turbines will be connected by 18-foot diameter tunnels connected to each culvert which allow the water to flow out of the culvert, through the turbine and back into the culvert. The turbines on the outside culverts will be installed at the same level as the lock culverts. The turbine for the center culvert will be installed below the culvert through a tunnel below the lock. This configuration applies to each set of turbines.

4. Methods of Tunnel Excavation

Based on current available information there are three methods that are possible for tunnel excavation. These are drill and blast, tunnel boring machine, and roadheader machine.

- **Drill and Blast**

Although a viable method for the excavation of most rock tunnels, drill and blast will not be considered here. The reason is obvious in that blasting will not be allowed close to the locks for fear of inflicting damage to them or the mechanisms that operate them due to vibrations created by blasting..

- **Tunnel Boring Machine**

Tunnel boring machines are a viable method for the construction of tunnels. They can excavate tunnels both 25 foot and 18-foot diameter. The work can be performed with a minimum of vibration and disturbance. Since the tunnels will be excavated from the storage reservoir through a shaft at the reservoir, access for a TBM is not a problem. The one draw back to the use of the TBM is that with the tunnels being so short, approximately 350 lf each, the cost to bring the TBM on site and use it will be high. Another consideration is that in order to excavate both an 18-foot and a 36-foot tunnel diameter it will be necessary to bring in two machines, both which are expensive. Therefore, the cost of the TBMs alone will raise the overall cost of the tunnel portion of the project.

Using a TBM means that the full face, of the 36-foot diameter opening or the 18-foot diameter tunnels, will each be excavated at one time. As the TBM advances a support system or liner is placed behind the machine to maintain and support the opening. Upon the completion of the excavation the machine is dismantled in the tunnel and brought out in pieces, to be reassembled for the next tunnel. This means that the tunnel supports will have to be designed to allow for removal of the TBM.

- **Roadheader**

Available geotechnical information indicates that the rock formation through which the excavation occurs is, for the most part, a relatively soft-medium rock material. It can therefore be excavated using a roadheader. A roadheader can excavate almost any configuration and size of tunnel cross section and can be

used on the site at a lesser cost than bringing a TBM to the site. One machine can excavate both sizes of tunnel.

Chambers can be excavated with a roadheader. A TBM will only excavate an opening the size of the diameter of its head. Equipment associated with a roadheader can be kept to a minimum thus reducing the overall cost. This method may be more labor intensive, but that should not be a problem due to an abundance of labor force in Panama.

The use of a roadheader has certain advantages. Besides being less expensive overall than a TBM, one machine can generally be used for all the excavations, no matter the size. This is accomplished through a method referred to as the heading and bench method. This method involves the use of smaller excavation advances where the whole face is not excavated at one time. The roadheader will start at the top of the tunnel excavating a section say 10 feet wide and ten feet high conforming to the final shape of the opening. This excavation is supported and the next section is excavated. This process continues until a certain length of tunnel is excavated. Once the entire opening is made the process starts again until the tunnel is completed.

The roadheader can also excavate openings that vary from the circular shape excavated by the TBM. This reduces the need to employ methods other than mechanical to excavate those openings.

5. **Methods of Vertical Culvert and Channel Connection Construction**

These structures can be excavated using a number of different methods. Drill and blast has already been mentioned and discarded due to the vibrations associated with this type of construction. A second method is to use drills and splitters. With this method holes are drilled into the rock, the rock is split and rock pieces are made and removed from the tunnel.

A third method is to use the roadheader previously mentioned to excavate the chambers and to excavate the vertical connections. A fourth method uses a form of raised drilling machine to drill the entire diameter of the shaft at one time.

- **Preservation of Canal Operations During Construction**

This is the single most critical aspect of the numerous construction operations of this project. There are a number of different ways this connection work can be preformed such that impact to the canal operations can be minimized. The proposed processes include those listed below. Evaluation of each process will be performed in more detail during the study and design phases to select the method that fits the needs of the ACP and the design and construction techniques selected.

- **Culvert Liner**

The interculvert liner can consist of a plate or a ring of liner plates, placed in an existing culvert to close off the site of the connection and make a temporary, watertight seal that remains in place during the construction of the connection.

In the case of the plate, a plate approximately 20 feet in diameter and conformed to the bottom shape of the culvert whether flat or curved is brought into the

culvert during a canal maintenance or shut down period and bolted in place. This is done through the use of countersunk, threaded inserts, drilled into existing concrete. Once the inserts are in place the plate is brought in, either in sections or as one plate. A gasket is placed first with the plate over it. The plate is bolted in place and remains in place until the connection is constructed from the bottom. The plate is then unbolted during the next maintenance period, removed and the boltholes filled with a fast setting grout and smoothed to a finished surface.

Another interliner method uses a set of complete steel liner plate or flat plate rings t o develop a lining inside the opening of the culvert. These rings are bolted together to create a thin interliner. They are gasketed and sealed against water infiltration into the area of construction. It is estimated that about a 30 foot length of rings will be required to develop watertight integrity.

This work can either be performed in the dry by laborers or by divers if the culverts remain flooded. In the case of a flooded culvert, this may be the better method to use because the work can be performed by divers.

Plugs

The remaining methods require the work including the connection excavation be performed within the available canal maintenance time frame. This means that during that period the shaft has to be opened through to the culvert and one of the temporary sealing methods put into place so that the work on the shaft can continue. All these measures listed below would be placed at the top of the vertical shaft just below the invert of the culvert.

- Balloon

A balloon consists of a heavy gauge rubber type material which when put into place is inflated to seal the opening from water inflow. The balloon allows for the easy removal of it from the shaft by deflation and dragging the balloon out of the tunnel.

- Folding Plate with Rubber Ring

This is a folding plate, which when in place opens up to form a complete flat ring, and is sealed around the edges.

- Plate with Rubber Ring

Similar to the folding plate, this is a solid plate installed as one piece or pieces bolted together with an edge sealer.

- Concrete Plug

This is another method, which has been used to plug openings during construction. Although a possible option for this project it is not practical due to the setting time necessary for the concrete in the plug to harden.

Channel Connections

There are four channel connections for each lock, which allow the overflow from the reservoir to be released into the channel. These vertical shafts must be constructed without interference to canal operations. In order to perform this

work it will be necessary to seal each site at the bottom of the channel such that the work of shaft construction can be performed from below. This work can be performed by placing a plate over the channel bottom or individual plates over each opening site. These plates would be placed during a shutdown period, will use gaskets and be bolted in place. They would be of sufficient size to cover each hole and allow for a tight seal to keep water out of the construction. Placing the plates can be performed during a lock shutdown, in the water, using a crane and divers.

- **Method of Construction**

The method of construction for the lock connections and the channel connections is one of the more critical features of this project. The limited and non-guaranteed time frame for shutdown of each lock places the work plan and schedule for this work on the critical path. One possible method that could be used for this work would follow the sequence as outlined below.

A. Excavate tunnel access from the reservoir and stabilize the openings.
B. Install sealing plates in the culvert or the channel during lock shutdown.
C. Excavate upward from the tunnel through the rock and concrete materials exposing the sealing plates.
D. Support and stabilize the excavation.
E. Install the finished liner from below.
F. At next lock shutdown remove sealing plates and place the system in operation.

6. **Initial Supports**

Initial tunnel and shaft linings come in different types, but all have the same purpose, which is to hold a tunnel excavation open. Initial supports are used during the excavation process to support those rock or soil materials that have a limited stand up time or are unable to support themselves at all. These support systems usually consist of types such as rock bolts, ribs or ribs and lagging, liner plates, shotcrete lining or precast concrete segments.

Rock bolts are used where the rock holds together fairly well but fails in large masses. The bolts generally hold the masses of rock together. These bolts can be supplemented with welded wire fabric and shotcrete as necessary.

Ribs are used in areas where a full support is required to hold the excavation open. Ribs are usually spaced at a say 2-4 foot distance and are used in rock that is not falling apart but blocky.

Ribs and lagging, liner plates, and precast concrete segments are used in areas of the tunnel where the rock is falling apart and requires full support. Ribs and wood lagging consist of circumferential steel ribs with wood lagging wedged between to make a complete interior liner. Liner plates are 2-foot long plates bolted together to form a ring that also makes a complete liner. Each ring is then bolted together to make a continuous tube liner. If necessary

liner plates can be supplemented with ribs where additional strength is necessary.

Precast segments are similar to liner plates where sections are assembled to form rings and the rings are bolted together to make a tube.

7. **Final Linings**

Final tunnel and shaft linings usually consist of either a steel liner such as a pipe, a cast in place concrete liner or a cast in place inter liner in a concrete segment tunnel.

Steel liners can either be pipe types assembled in the tunnels, pipe to pipe or in sections assembled to form rings with the rings being assembled to form the liner.

Cast in place concrete lining is generally typical especially for tunnels of this size. Casting forms are placed inside the tunnel with concrete placed in the opening between the forms and the rock forming the final lining. This concrete final lining can either be reinforced or nonreinforced depending on the design needs of the tunnel.

8. **Dewatering**

Groundwater will probably be a problem during tunnel excavation. The tunnels will be excavated with a slight upgrade so the any nominal groundwater will flow to the portal. If excessive inflows are encountered, holes will be drilled into the rock in advance of the tunnel excavation or into the wall of the tunnel and grout injected to stop the inflows. If it is determined that groundwater is a problem at all locations, it may be necessary to pre grout the tunnel alignment to cutoff grout water inflows.

Water that is channeled to the shaft will be collected in a sump and pumped as necessary to the surface, cycled through settling tanks and discharged into the lock or ocean. Oil separators will also be used to aid in cleaning the water prior to discharge.

9. **Recommended Approach**

The recommended approach to this work is based on the following criteria:

- Rock formations are relatively soft to medium hardness.
- There are numerous works to be excavated including tunnels, connecting chambers and vertical tie-ins.
- Use of the TBM may be excessively expensive and not justified for a project of this type.

The reservoir for each lock will be excavated first. This provides a working and staging site closer to the level of the tunnel thus not requiring as deep a shaft structure. The shaft is excavated with initial supports provided. Upon completion of the shaft opening the tunnel excavation is started. Excavation of the tunnel advances with the muck materials being hauled to a preapproved disposal site. Initial liners are installed to support the opening. Once the tunnel opening is completed with initial

supports installed, concentrated efforts can be dedicated to the excavation of the vertical shafts.

At this time it is recommended that plates be preinstalled in the existing culverts to seal the opening area from water intrusion during construction. Excavation is performed using a full face raised boring machine with initial supports installed as the work progresses. Once the excavations are all complete the shafts and tunnel can be final lined. After this and all associated work is complete the sealing plates are removed and the project is activated.

10. Cost Estimate

A cost estimate has been developed to reflect an average cost of construction for both the discharge, return tunnels and connections. The estimate for this study is considered broad brush. This is due to the limited information available at this time. Additional information still required includes geotechnical information from the sites, hydraulic studies to evaluate flow features and the impacts of other related operational features. This estimate includes estimates for the following items

- Shafts constructed at the reservoir
- Discharge tunnels
- Return tunnels
- Vertical connections
- Initial supports and final linings
- Pit Turbine connections

Based on information from interviews conducted with Contractors in Panama the basis of estimate will feature labor rates similar to those used in non union work in Texas. These rates are considered comparable to those used in Panama.

It will be assumed that construction equipment such as cranes, dump trucks and hand tools are available in country. Specialty equipment such as TBM's or roadheaders are not available in country and will need to be brought in from another source.

PANAMA CANAL PROJECT

CONCEPTUAL COST ESTIMATES

Conceptual Cost Estimates for Panama Canal Project

Summary of Direct Cost

Gatun Lock Discharge Tunnel - Inside Diameter = 36 ft. - Length = 350 ft.	$2,705,043
Miraflores Lock Discharge Tunnel - Inside Diameter = 36 ft. - Length = 350 ft.	$2,705,043
Gatun Overflow Return Tunnel - Inside Diameter = 36 ft. - Length = 350 ft.	$2,705,043
Miraflores Overflow Return Tunnel - Inside Diameter = 36 ft. - Length = 350 ft.	$2,705,043
Gatun - Shaft from Discharge tunnel to Reservoir - Inside Diameter = 36 ft. - Depth=73 ft.	$1,097,843
Miraflores-Shaft from Discharge tunnel to Reservoir-Inside Diameter=36 ft. - Depth=73 ft.	$1,097,843
Gatun - Shaft from Reservoir to Overflow Return tunnel - Inside Diameter = 36 ft. Depth=159 ($1,097,843/73)(159) = $2,391,192	$2,391,192
Miraflores - Shaft from Reservoir to Overflow Return tunnel - Inside Diameter = 36 ft. Depth=159 ft. ($1,097,843/73)(159) = $2,391,192	$2,391,192
Gatun Discharge Tunnel from Center Culvert to Reservoir-Inside Diameter = 18 ft. - Length = 180 ft. - (($1,397,677)/350')*180 = $718,805	$718,805
Miraflores Discharge Tunnel from Center Culvert to Reservoir-Inside Diameter = 18 ft. - Length = 180 ft. - (($1,397,677)/350')*180 = $718,805	$718,805
Gatun Lock Discharge Shaft (Raise) - Inside Diameter = 18 ft. - Depth = 45 ft. Quantity = 3 (3)($279,704) = $839,112	$839,112
Miraflores Lock Discharge Shaft (Raise)-Inside Diameter=18 ft. - Depth = 45 ft. - Quantity = 3 (3)($279,704) = $839,112	$839,112
Gatun Overflow Return Shaft (Raise) - Inside Diameter = 18 ft. - Depth = 18 ft. Quantity =2 X 2 = 4 ($279,704/45')(18)(4) =$447,526	$447,526
Miraflores Overflow Return Shaft (Raise)-Inside Diameter = 18 ft. - Depth = 18 ft. Quantity = 2 X 2 = 4 ($279,704/45')(18)(4) =$447,526	$447,526
Side Pit Turbine Tunnel - I.D. = 18 ft. - Assumed Length of each Tunnel = 120 ft. 7-Locations - No. of tunnels at each Location = 3 - Total No. of Tunnels = 7 X 3 = 21 Total Length =21 * 120 = 2520 ft.-Total Cost = ($1,397,677/350)(2520 ft.) = $10,063,274	$10,063,274
Connection of Pit Turbine Tunnel to Existing Culvert = 21 X 2 connections each = 42 Connections - Total Cost for Connections = 42 X $30,000 = $1,260,000	$1,260,000
Shaft from Ground surface to Side Pit Turbine Tunnels - Quantity = 7 Shafts) Shafts - I.D. = 18 ft. - Depth = EL +39.67 - EL -(51.83+36) = 128 ft. Total Cost = (7 Shafts)(128 ft. Deep)($668,633/127') = $4,717,285	$4,717,285

Shaft from Ground surface to Side Pit Turbine Tunnels - Quantity = 7 Shafts) Shafts - I.D. = 18 ft. - Depth = EL +39.67 - EL -46.83 = 87 ft. Total Cost = (7 Shafts)(87 ft. Deep)($668,633/127') = $3,206,280	$3,206,280
Tunnel From Side Pit Turbine Shaft to Middle Culvert - I.D. = 18 ft. - Length = 150 ft. Quantity = 7 - Total Cost = (7)($1,397,677/350)(150 ft.) = $4,193,031	$4,193,031
Shaft (Raise) from 18 ft. Dia. Tunnel to Middle Culvert at Pit Turbine Locations I.D. = 18 ft. - Depth = 54 ft. - Quantity = 7 - Total Cost = 7 * ($279,704/45)(54) = $2,349,514	$2,349,514
Connection of shafts to channel / locks bottom slab - 16 connections - allow $15000 for each Connection = 16 * $15,000 = $240,000	$240,000
Special Connection of shafts to channel / locks bottom slab - 6 connections - allow $50,000 for each	$300,000
Total Direct Cost *	**$48,138,513**
Indirect Cost - Add 20%	$9,627,703
Sub-total	$57,766,215
Overhead and Mark-up - Add 10%	$5,776,622
Sub-total	$63,542,837
Contingencies - Add 15%	$9,531,426
Sub-total	$73,074,262
Mobilization and Demobilization - Add 5%	$3,653,713
	76,727,975
TOTAL	**$77,000,000**

* Direct Cost includes labor base rate, equipment, materials and supplies.

Note 1:

Rates for Panamanian labor are currently unavailable for the work described. It is understood that Texas labor rates reflect those representative for Panama in costs per hour. Panamanian rates are lower, but additional personnel are used. Number of shifts shown for various work tasks are representative if the work is performed in Texas. Number of shifts needed to perform the work is expected to be greater when done in Panama.

Note2 : Not any Special Provisions were considered for Pit Turbine in cost estimates.

Gatun / Miraflores Lock Discharge Tunnel (Inside Diameter = 36 ft.)

Direct Costs:

Total Cost of Tunnel Excavation and Initial Support	$747,335
Total Cost of Tunnel Lining	$1,125,568
Total Cost of Contact Grouting	$107,640
Total Cost of Cement Grouting	$724,500
Total Direct Cost	**$2,705,043**

1. Tunnel Crew (Tunnel Inside Diameter = 36 ft.):

Tunnel excavation and initial support installation :

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Miner at Tunnel Heading	3	$11.77	$94.16	$282.48
Utilities	2	$11.77	$94.16	$188.32
Roadheader Operator	1	$14.12	$112.96	$112.96
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Labor at Bottom of the Shaft	2	$9.24	$73.92	$147.84
Labor at Top of the Shaft	1	$9.24	$73.92	$73.92
Loader Operator	1	$12.17	$97.36	$97.36
Locomotive Operator	1	$12.17	$97.36	$97.36
Foreman	1	$20.00	$160.00	$160.00
45 Ton Crane Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
Compressor Operator	1	$9.24	$73.92	$73.92
TOTALS	17			$1,577

Progress:

Excavation and initial support installation - 12 ft. of top heading per shift.

Excavation and initial support installation - 13 ft. of middle heading per shift.

Excavation and initial support installation - 14 ft. of bottom heading per shift.

Total No. of shifts required for excavation and initial support installation of 350 ft. long tunnel = 350/12 + 350/13 + 350/14 = 30+27+25= **82**

Total Labor Cost = $129,317

2. Equipment :

	No.	Rate	Total per 8-Hours Shift
Muck car	6	$8.00	$384.00
Locomotive	1	$25.00	$200.00
Roadheader	1	$400.00	$3,200.00
Compressor	1	$7.00	$56.00
Total Cost per Shift			$3,840

Total Cost of Equipment = $314,880

3. Materials

A. Lattice Girders:

Length per ring in ft. = 135

0.5((36'+1.33+1.33+1+1)(3.14))+4(2)(3.14)(40.66)(25/360) = 135

No. of rings = 350'/3' = 117

Total Length per Tunnel in ft. = 15,795

Cost per lineal foot = $10.00

Total Lattice Girder Cost = $157,950

B. Shotcrete:

Volume of Shotcrete per ft. of tunnel (12" thick.) in C.Y. = 6

1.05((3.14)((20.33)**2 -(19.33)**2)/27)(1.25)= 6

Total length of tunnel in ft. = 350

Total Volume in C.Y. = 2,100

Cost per C.Y. = $50.00

Total Shotcrete Cost = $105,000

C. Welded Wire Fabric (WWF):

No. of Layers = 2

Area of WWF per lineal ft. of tunnel= 297

(135)(2 Layers)(1.10) = 297

Total length of tunnel in ft. = 350

Cost per SF = $0.20

Total WWF Cost = $20,790

TOTAL COST OF MATERIALS = $283,740

4. Supplies: 15% of Labor Cost **$19,398**

Total Cost of Tunnel Excavation and Initial Support Installation = **$747,335**

Tunnel Final Lining (Tunnel Inside Diameter = 36 ft.):

1. Concrete Crew:

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Foreman	1	$20.00	$160.00	$160.00
Vibrator Operator	3	$9.24	$73.92	$221.76
Pipeman and Pump	3	$9.24	$73.92	$221.76
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Compressor Operator	1	$9.24	$73.92	$73.92
Concrete Pump Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
TOTALS	12			$968.32

Progress:
Placing the tunnel invert - 20 ft. per day - One shift per day
Placing the tunnel side walls and arch - 20 ft. per day - One shift per day

Total No. of shifts required for tunnel Concreting 2*((350'/20' per day) + 5 days allow for delays) = 46 **46**

Total Cost of Tunnel Concreting Labor = **$44,543**

Allow for Labor Cost of Tunnel Concrete Form Set-Up **$44,543**

2. Materials

A. Concrete - Side walls and Arch (16" Thick) :

Total length of tunnel in ft. =	350
Volume of Concrete in C.Y./ft. =	3.5
(3.14)(((19.33)**2-(18)**2)/27) =3.5	
Cost per C.Y. * =	$60
Total Cost of Side walls and Arch Concrete =	$73,500

B. Concrete - Invert :

Total length of tunnel in ft. =	350
Volume of Concrete in C.Y./ft. =	4.3

Total Volume in C.Y.=(1.05(3.14)(19.33)**2-(3.14)(18)**2)/27 =7.9
Invert Concrete Volume CY Per Lineal ft. of Tunnel = 7.9 - 3.6 = 4.3

Cost per C.Y. * =	$60
Total Cost of Side walls and Arch	$90,300

* Including equipment and waste

A + B =Total Cost of Concrete =	163,800

C. Reinforcing Steel:

Steel per C.Y. of Concrete in Lb =	118
Total Volume of Concrete in C.Y. =	2,730
Cost per Lb =	$0.50
Total Cost of Steel =	$161,070

D. Concrete Forms:

Tunnel Length in ft. =	350
Perimeter of Tunnel Cross-section =	133
Total Area of Forms =	46,550
Cost of forms per SF =	$15.00
Total Cost of Forms per Tunnel =	$698,250

Total Cost of Materials =	**1,023,120**
3. Supplies: 15% of Labor Cost	**13,363**
Total Cost of Tunnel Lining =	**$1,125,568**

Contact Grouting:

Grout per lineal foot of Tunnel in CF =	12
Total length of tunnel in ft. =	350
Total volume of grout per tunnel in C.Y. =	156
Allow 15% for Waste = 1.15 * 156 = 179.4	179.4
Cost per C. Y. =	$600
Total Cost of Contact Grouting	**$107,640**

Cement Grouting (To Seal off Water):

Grout per lineal foot of Tunnel in C.Y. =	6
(0.5)(3.14)(40.66)(2.5' Around Tunnel Cross-Section Above Spring Line)/27= 6 CY	
Total length of tunnel in ft. =	350
Total volume of grout per tunnel in C.Y. =	2,100
Allow 15% for Waste = 1.15 * 2100 =	2,415
Cost per C. Y. =	$300
Total Cost of Cement Grouting =	**$724,500**

Tunnel (Inside Diameter = 18 ft.)

Direct Costs:

Total Cost of Tunnel Excavation and Initial Support	$449,325
Total Cost of Tunnel Lining	$579,393
Total Cost of Contact Grouting	$67,083
Total Cost of Cement Grouting	$301,875
Total Direct Cost	**$1,397,677**

1. Tunnel Crew (Tunnel Inside Diameter = 18 ft.):

Tunnel excavation and initial support installation :

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Miner at Tunnel Heading	3	$11.77	$94.16	$282.48
Utilities	2	$11.77	$94.16	$188.32
Roadheader Operator	1	$14.12	$112.96	$112.96
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Labor at Bottom of the Shaft	2	$9.24	$73.92	$147.84
Labor at Top of the Shaft	1	$9.24	$73.92	$73.92
Loader Operator	1	$12.17	$97.36	$97.36
Locomotive Operator	1	$12.17	$97.36	$97.36
Foreman	1	$20.00	$160.00	$160.00
45 Ton Crane Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
Compressor Operator	1	$9.24	$73.92	$73.92
TOTALS	17			$1,577

Progress:

Excavation and initial support installation - 12 Lineal ft. of top heading per shift.
Excavation and initial support installation - 13 Lineal ft. of bottom heading per shift.

Total No. of shifts required for excavation and initial support installation of 350 ft. long tunnel = 350/12 + 350/13 = 30+27= **57**

Total Labor Cost = $89,891

2. Equipment :

	No.	Rate	Total per 8-Hours Shift
Muck car	6	$8.00	$384.00
Locomotive	1	$25.00	$200.00
Roadheader	1	$400.00	$3,200.00
Compressor	1	$7.00	$56.00
Total Cost per Shift			$3,840

Total Cost of Equipment = $218,880

3. Materials

A. Lattice Girders:

Length per ring in ft. =	69
No. of rings = 350'/3' =	117
Total Length per Tunnel in ft. =	8,073
Cost per lineal foot =	$10.00
Total Lattice Girder Cost =	$80,730

B. Shotcrete:

Volume of Shotcrete per ft. of tunnel (6" thick.) in C.Y. =	1.7
Total length of tunnel in ft. =	350
Total Volume in C.Y. =	595
Cost per C.Y. =	$60.00
Total Shotcrete Cost =	$35,700

C. Welded Wire Fabric (WWF):

No. of Layers =	2
Area 2-Layers of WWF per lineal ft. of 69 * 2 * 1.1 Overlap = 152 SF	152
Total length of tunnel in ft. =	350
Cost per SF =	$0.20
Total WWF Cost =	$10,640

TOTAL COST OF MATERIALS = $127,070

4. Supplies: 15% of Labor Cost **$13,484**

Total Cost of Tunnel Excavation and Initial Support Installation = **$449,325**

Tunnel Final Lining (Tunnel Inside Diameter = 18 ft.):

1. Concrete Crew:

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Foreman	1	$20.00	$160.00	$160.00
Vibrator Operator	3	$9.24	$73.92	$221.76
Pipeman and Pump	3	$9.24	$73.92	$221.76
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Compressor Operator	1	$9.24	$73.92	$73.92
Concrete Pump Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
TOTALS	12			$1,020

Progress:
Placing the tunnel invert - 20 ft. per day - One shift per day
Placing the tunnel side walls and arch - 20 ft. per day - One shift per day

Total No. of shifts required for tunnel Concreting - 2*((350'/20') per day) + 5 days allow for delays) = **46**

Total Cost of Tunnel Concreting Labor = **$46,935**

Allow for Labor Cost of Tunnel Concrete Form **$46,935**

2. Materials

A. Concrete - Arch (12" Thick) :
Total length of tunnel in ft. = 350
Volume of Concrete in C.Y./ft. = 1.4
Cost per C.Y. * = $60
Total Cost of Arch Concrete = $29,400

B. Concrete - Invert :
Total length of tunnel in ft. = 350
Volume of Concrete in C.Y./ft. = 1.7
Cost per C.Y. * = $60
Total Cost of Side walls and Arch $35,700

* Including equipment

Total Cost of Concrete =	65,100	
C. Reinforcing Steel:		
steel per C.Y. of Concrete in Lb =	118	
Total Volume of Concrete =	986	
Cost per Lb =	$0.50	
Total Cost of Steel =	$58,174	
D. Concrete Forms:		
Tunnel Length in ft. =	350	
Perimeter of Tunnel Cross-section =	69	
Total Area of Forms =	24,150	
Cost of forms per SF =	$15.00	
Total Cost of Forms per Tunnel =	$362,250	
Total Cost of Materials =	**485,524**	
Total Cost of Tunnel Lining =		**$579,393**
Contact Grouting:		
Grout per lineal foot of Tunnel in CF =	8	
Total length of tunnel in ft. =	350	
Total volume of grout per tunnel in C.Y. =	97.2	
Allow 15% for Waste = 1.15 * 97	111.8	
Cost per C. Y. =	$600	
Total Cost of Contact Grouting		**$67,083**
Cement Grouting (To Seal off Water):		
Grout per lineal foot of Tunnel in C.Y. = (69')(.5)(2')/27 = 2.5	2.5	
Total length of tunnel in ft. =	350	
Total volume of grout per tunnel in C.Y. =	875	
Allow 15% for Waste = 1.15 * 875 =	1,006	
Cost per C. Y. =	$300	
Total Cost of Cement Grouting =		**$301,875**

Main Shaft at reservoir - From Discharge Tunnel To Reservoir - Inside Diameter = 36 ft.

Direct Costs:

Total Cost of Shaft Excavation and Initial Support	$639,054
Total Cost of Shaft Lining	$206,939
Total Cost of Cement Grouting	$251,850
Total Direct Cost	**$1,097,843**

3. Main Shaft at Reservoir - 36 ft. Inside Diameter - Depth=73 ft.

Shaft Crew (Shaft Inside Diameter = 36 ft.):

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Miners	8	$11.77	$94.16	$753.28
Foreman	1	$20.00	$160.00	$160.00
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Labor at Top of the Shaft	2	$9.24	$73.92	$147.84
Locomotive Operator	1	$12.17	$97.36	$97.36
Loader Operator	1	$12.17	$97.36	$97.36
45 Ton Crane Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
Compressor Operator	2	$9.24	$73.92	$147.84
TOTALS	19			$1,746.56

Progress:
Excavation and initial support installation - 1 vertical foot of shaft per shift.

Total No. of shifts required for excavation and initial support installation of one 73 ft. deep shafts= (73')/1 vertical foot = **73**

Total Labor Cost = $127,499

2. Equipment :

	No.	Rate	Total per 8-Hours Shift
Muck car	6	$8.00	$384.00
Locomotive	1	$25.00	$200.00
Jackhamer	6	$4.00	$192.00
Compressor	2	$7.00	$112.00
Total Cost per Shift			$888

Total Cost of Equipment = $64,824

3. Materials

A. Rock Bolts - #9 Steel rebar, 15' Long:

Rock bolt Pattern = 5 X 5 in SF =	25
Shaft Depth in ft. =	73
Excavation Diameter in ft. =	41
No. of Rock Bolts =	373
Cost per rock bolt =	$40
Total Cost of rock bolt =	$14,927

B. Shotcrete:

Volume of Shotcrete per ft. of Shaft (12" thick.) in C.Y. =(3.14)((20.33**2)-(19.33**2))(1.3) =6	6.0
Total depth of shaft in ft. =	73
Total Volume in C.Y. =	438
Cost per C.Y. =	$50.00
Total Shotcrete Cost =	$21,900

C. Welded Wire Fabric (WWF):

No. of Layers =	2
Area of WWF per lineal ft. of shaft = (40.7)(3.14)(1.1)(2 Layers) = 281	281
Total depth of shaft in ft. =	73
Cost per SF =	$0.35
Total WWF Cost =	$7,180

D. Drill steel Bits and Misc. supplies for 3516 C. Y. Excavated Rock @ $100 per C.Y. = $351,600

E. Lattice Girder:

Length per ring in ft. =	128
No. of rings = 73'/3' =	25
Total Length per Shaft in ft. =	3,200
Cost per lineal ft. =	$10
Total Lattice Girder Cost =	32,000

TOTAL COST OF MATERIALS = $427,606

4. Supplies: 15% of Labor Cost **$19,125**

Total Cost of Shaft Excavation and Initial Support Installation = **$639,054**

Shaft Final Lining (Shaft Inside Diameter = 36 ft.):

1. Concrete Crew:

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Foreman	1	$20.00	$160.00	$160.00
Vibrator Operator	4	$9.24	$73.92	$295.68
Pipeman and Pump	3	$9.24	$73.92	$221.76
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Compressor Operator	1	$9.24	$73.92	$73.92
Concrete Pump Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
TOTALS	13			$1,042.24

Progress:
Placing the shaft lining in 10 ft. lift.

Total No. of shifts required for shaft Concreting=8 shifts+allow 4 shifts delay= **12**

Total Cost of shaft Concreting Labor = **$12,507**

Allow for Labor Cost of shaft Concrete Form **$12,507**

2. Materials

A. Concrete

Shaft depth in ft. =	73
Shaft lining thickness in ft.=	1
Total concrete Volume in C.Y.=	422
(3.14)((19.33**2)-(18**2))/27 = 422	
Cost of Concrete per C.Y.	$70
Total Cost of Concrete =	$29,540

B. Reinforcing Steel:

Steel per C.Y. of Concrete in Lb =	118
Total Volume of Concrete =	422
Cost per Lb =	$0.50
Total Cost of Steel =	$24,898

C. Concrete Forms:

Shaft depth in ft. =	73
Perimeter of Shaft Cross-section =	113
Total Area of Forms =	8,249
Cost of forms per SF =	$15
Total Cost of Forms per Shaft =	$123,735

Total Cost of Materials = **$178,173**

3. Supplies **$3,752**

Total Cost of Shaft Lining = **$206,939**

Cement Grouting (To Seal off Water):

Grout per lineal foot of shaft in C.Y. =	10
Total shaft depth in ft. =	73
Total volume of grout per shaft in C.Y. =	730
Allow 15% for Waste = 1.15 * 730 =	840
Cost per C. Y. =	$300

Total Cost of Cement Grouting = **$251,850**

Main Shaft - From Reservoir To Overflow Return - Inside Diameter = 18 ft.)

Direct Costs:

Total Cost of Shaft Excavation and Initial Support	$338,327
Total Cost of Shaft Lining	$179,885
Total Cost of Cement Grouting	$150,420
Total Direct Cost	**$668,633**

Shaft Crew (Shaft Inside Diameter = 18 ft.):
Shaft Depth = EL. +39.67 (Ground Elevation) - EL. -87 = 127

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Miners	7	$11.77	$94.16	$659.12
Foreman	1	$20.00	$160.00	$160.00
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Labor at Top of the Shaft	2	$9.24	$73.92	$147.84
Locomotive Operator	1	$12.17	$97.36	$97.36
Loader Operator	1	$12.17	$97.36	$97.36
45 Ton Crane Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
Compressor Operator	2	$9.24	$73.92	$147.84
TOTALS	18			$1,652.40

Progress:
Excavation and initial support installation - 3 vertical foot of shaft per shift.

Total No. of shifts required for excavation and initial support installation of three 45 ft. deep shafts= (127')/3 vertical foot = **43**

Total Labor Cost = $71,053

2. Equipment :

	No.	Rate	Total per 8-Hours Shift
Muck car	6	$8.00	$384.00
Locomotive	1	$25.00	$200.00
Stoper Drills	4	$4.00	$128.00
Compressor	2	$7.00	$112.00
Total Cost per Shift			$824

Total Cost of Equipment = $35,432

3. Materials

A. Rock Bolts - #9 Steel rebar, 10' Long:

Rock bolt Pattern = 5 X 5 in SF =	25
Shaft Depth in ft. =	127
Excavation Diameter in ft. =	21
No. of Rock Bolts =	335
(3.14)(21' dia.)(127) / (5*5 Rockbolt Pattern) = 335	
Cost per rock bolt =	$40
Total Cost of rock bolt =	$13,399

B. Shotcrete:

Volume of Shotcrete per ft. of Shaft (6" thick.) in C.Y. =(3.14)((10.5**2)-(10)**2)(1.30) = 1.6 CY	1.6
Total depth of shaft in ft. =	127
Total Volume in C.Y. =	203
Cost per C.Y. =	$50.00
Total Shotcrete Cost =	$10,160

C. Welded Wire Fabric (WWF):

No. of Layers =	2
Area of WWF per lineal ft. of shaft = (21')(3.14)(1.1)(2-Layers) = 145	145
Total depth of shaft in ft. =	127
Cost per SF =	$0.35
Total WWF Cost =	$6,445

D. Drill steel Bits and Misc. supplies for 1628 C. Y. Excavated Rock @ $100 per C.Y. = $162,800

E. Lattice Girder:

Length per ring in ft. =	66
No. of rings = 127'/3' =	43
Total Length per Shaft in ft. =	2,838
Cost per lineal ft. =	$10
Total Lattice Girder Cost =	28,380

TOTAL COST OF MATERIALS = $221,184

4. Supplies: 15% of Labor Cost **$10,658**

Total Cost of Shaft Excavation and Initial Support Installation = $338,327

Shaft Final Lining (Shaft Inside Diameter = 18 ft.):

1. Concrete Crew:

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Foreman	1	$20.00	$160.00	$160.00
Vibrator Operator	3	$9.24	$73.92	$221.76
Pipeman and Pump	3	$9.24	$73.92	$221.76
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Compressor Operator	1	$9.24	$73.92	$73.92
Concrete Pump Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
TOTALS	12			$968.32

Progress:

Placing the shaft lining in 10 ft. lift.

Total No. of shifts required for shaft Concreting= 13 shifts+allow 4 shifts delay= **17**

Total Cost of shaft Concreting Labor = $16,461

Allow for Labor Cost of shaft Concrete Form $16,461

2. Materials

A. Concrete

Shaft depth in ft. =	127
Shaft lining thickness in ft.=	1
Total concrete Volume in C.Y.=	281
((3.14)((10)**2-(9**2))/27) * 127 = 281	
Cost of Concrete per C.Y.	$60
Total Cost of Concrete =	$16,860

B. Reinforcing Steel:

Steel per C.Y. of Concrete in Lb =	118
Total Volume of Concrete =	281
Cost per Lb =	$0.50
Total Cost of Steel =	$16,579

C. Concrete Forms:

Shaft depth in ft. =	127
Perimeter of Shaft Cross-section =	57
Total Area of Forms =	7,239
Cost of forms per SF =	$15
Total Cost of Forms per Shaft =	$108,585

Total Cost of Materials =	**$142,024**	
3. Supplies: 15% of Labor Cost	**$4,938**	
Total Cost of Shaft Lining =		**$179,885**

Cement Grouting (To Seal off Water):

Grout per lineal foot of shaft in C.Y. =	4
Total shaft depth in ft. =	109
Total volume of grout per shaft in C.Y. =	436
Allow 15% for Waste = 1.15 * 436 =	501.4
Cost per C. Y. =	$300

Total Cost of Cement Grouting =	**$150,420**

Lock Discharge Shaft (Raise) - Inside Diameter = 18 ft.)

Direct Costs:

Total Cost of Shaft Excavation and Initial Support	$140,414
Total Cost of Shaft Lining	$77,189
Total Cost of Cement Grouting	$62,100
Total Direct Cost Per Shaft	**$279,704**

Shaft (Raise) Crew (Shaft Inside Diameter = 18 ft.):

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Miners	7	$11.77	$94.16	$659.12
Foreman	1	$20.00	$160.00	$160.00
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Labor at Top of the Shaft	2	$9.24	$73.92	$147.84
Locomotive Operator	1	$12.17	$97.36	$97.36
Loader Operator	1	$12.17	$97.36	$97.36
45 Ton Crane Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
Compressor Operator	2	$9.24	$73.92	$147.84
TOTALS	18			$1,652.40

Progress:
Excavation and initial support installation - 2 vertical foot of shaft per shift.

Total No. of shifts required for excavation and initial support installation - for each of three 45 ft. deep shafts= (45')/2 vertical foot = **23**

Total Labor Cost = $38,005

2. Equipment :

	No.	Rate	Total per 8-Hours Shift
Muck car	6	$8.00	$384.00
Locomotive	1	$25.00	$200.00
Stoper Drills	4	$4.00	$128.00
Compressor	2	$7.00	$112.00
Total Cost per Shift			$824

Total Cost of Equipment = $18,952

3. Materials

A. Rock Bolts - #9 Steel rebar, 10' Long:

Rock bolt Pattern = 5 X 5 in SF =	25
Shaft Depth in ft. =	45
Excavation Diameter in ft. =	21
No. of Rock Bolts =	119
Cost per rock bolt =	$40
Total Cost of rock bolt =	$4,748

B. Shotcrete:

Volume of Shotcrete per ft. of Shaft (6" thick.) in C.Y. = ((3.14)((10.5**2)-(10**2))/27) * 1.4 = 1.7	1.7
Total depth of shaft in ft. =	45
Total Volume in C.Y. =	77
Cost per C.Y. =	$50.00
Total Shotcrete Cost =	$3,825

C. Welded Wire Fabric (WWF):

No. of Layers =	2
Area of WWF per lineal ft. of shaft = (3.14)(21' dia.)(2-Layers)(1.1 Waste) = 145 SF	145
Total depth of shaft in ft. =	45
Cost per SF =	$0.35
Total WWF Cost =	$2,284

D. Drill steel Bits and Misc. supplies for 570 C. Y. Excavated Rock @ $100 per C.Y. = $57,000

E. Lattice Girder:

Length per ring in ft. =	66
No. of rings = 45'/3' =	15
Total Length per Shaft in ft. =	990
Cost per lineal ft. =	$10
Total Lattice Girder Cost =	9,900

TOTAL COST OF MATERIALS = $77,756

4. Supplies: 15% of Labor **$5,701**

Total Cost of Shaft (Raise) Excavation and Initial Support Installation = $140,414

Shaft Final Lining (Shaft Inside Diameter = 18 ft.):

1. Concrete Crew:

Crew	Number Crew per	Base Rate	Wages 8 Hours	Total Labor Cost
Foreman	1	$20.00	$160.00	$160.00
Vibrator Operator	3	$9.24	$73.92	$221.76
Pipeman and Pump	3	$9.24	$73.92	$221.76
Mechanic	1	$11.77	$94.16	$94.16
Electrician	1	$11.77	$94.16	$94.16
Compressor Operator	1	$9.24	$73.92	$73.92
Concrete Pump Operator	1	$12.82	$102.56	$102.56
Warehouseman	1	$6.50	$52.00	$52.00
TOTALS	12			$1,020.32

Progress:
Placing the shaft lining in 7 ft. lift.
Placing the concrete from inside tunnel
use 0.5 C.Y. concrete bucket and winch to pull the concrete
from the tunnel invert to shaft concrete form.

Total No. of shifts required for shaft Concreting=7shifts+allow 4 shifts delay= **11**

Total Cost of shaft Concreting Labor = $11,224

Allow for Labor Cost of shaft Concrete Form $11,224

2. Materials

A. Concrete

Shaft depth in ft. =	45
Shaft lining thickness in ft.=	1
Total concrete Volume in C.Y.=	100
((3.14)((10**2)-(9**2))/27)(45) = 100 CY	
Cost of Concrete per C.Y.	$70

Total Cost of Concrete =	$7,000	
B. Reinforcing Steel:		
steel per C.Y. of Concrete in Lb =	118	
Total Volume of Concrete =	100	
Cost per Lb =	$0.50	
Total Cost of Steel =	$5,900	
C. Concrete Forms:		
Shaft depth in ft. =	45	
Perimeter of Shaft Cross-section =	57	
Total Area of Forms =	2,565	
Cost of forms per SF =	$15	
Total Cost of Forms per Shaft =	$38,475	
Total Cost of Materials =	**$51,375**	
3. Supplies	**$3,367**	
Total Cost of Shaft Lining =		**$77,189**

Cement Grouting (To Seal off Water):

Grout per lineal foot of shaft in C.Y. =	4
Total shaft depth in ft. =	45
Total volume of grout per shaft in C.Y. =	180
Allow 15% for Waste = 1.15 * 180 CY	207
Cost per C. Y. =	$300
Total Cost of Cement Grouting =	**$62,100**

CORRESPONDENCE

U.S. ARMY CORPS OF ENGINEERS

ENGINEERING LABORATORY

VICKSBURG, MS

DEPARTMENT OF THE ARMY
ENGINEER RESEARCH AND DEVELOPMENT CENTER, CORPS OF ENGINEERS
COASTAL AND HYDRAULICS LABORATORY
WATERWAYS EXPERIMENT STATION, 3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

June 17, 2002

REPLY TO
ATTENTION OF:

Inland Hydraulic Structures Branch

SUBJECT: Salinity Intrusion at the Panama Canal Locks

Mr. Wayne Spani, Vice President
Water Resources Development Corporation
2030 E. 4th Street, Suite 213
Santa Ana, California 92705

Dear Mr. Spani:

Personnel of the U.S. Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL) have reviewed, at your request, the proposal by your organization to reduce salinity intrusion at the Panama Canal locks. This proposal is based, in part, on information in the April 2000 report "Salinity Intrusion in the Panama Canal" (ERDC/CHL TR-00-4). The coupling of fresh water injection with pneumatic bubble plumes appears to be a reasonable approach to reduce the salinity immediately downstream of the locks. By reducing the local salinity, less salt will migrate into the locks and into the upstream waters.

The CHL personnel included in this review were Drs. Charlie Berger, Bob Bernard, John Hite, Nana Parchure, and Steve Wilhelms, and Messrs. Joe Letter and Chuck Tate. The opinion of this group is that significant study will be required to produce an efficient design. We recommend laboratory modeling of the processes to determine some basic mixing and transport relations. These relations will then be used with numerical simulations to evaluate potential designs. Once a design has been developed that meets the project goals, that design will be evaluated in a general physical model of the proposed installation site. Additional iterations of this process may be required. As you have requested, a scope of work and an estimate of the time and costs will be provided for CHL to conduct the study. This effort will require some additional study but will be prepared soon. Ms. Susan Borland of ERDC has discussed this proposed work with you and Mr. Tate. Ms. Borland recommends that, if this study goes forward, a Cooperative Research and Development Agreement (CRADA) would be the appropriate instrument for defining the working arrangement.

The CHL is very interested in working with you on the project in that there are possible uses for the results of this work at locks in the United States. Please contact Mr. Chuck Tate at 601-634-2120 or Charles.H.Tate@erdc.usace.army.mil for any questions or concerns regarding this study.

Sincerely,

For William D. Martin

Thomas W. Richardson
Director

DEPARTMENT OF THE ARMY
ENGINEER RESEARCH AND DEVELOPMENT CENTER, CORPS OF ENGINEERS
COASTAL AND HYDRAULICS LABORATORY
WATERWAYS EXPERIMENT STATION, 3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

REPLY TO
ATTENTION OF:

Coastal and Hydraulics Laboratory

SUBJECT: Proposed Time and Cost Estimate for the Panama Canal Salinity Intrusion

Mr. Wayne Spani
2030 East 4th Street, Suite 213
Santa Ana, California 92705

Dear Mr. Spani:

1. The Water Processing Systems Division (WPSI) of the Water Resource Development Corporation has proposed reducing the salinity intrusion to the Panama Canal locks. The WPSI has proposed hydraulic and pneumatic injection in the lock approaches. This Time and Cost estimate is for the first segment listed in the enclosed Scope of Work.

2. This study will utilize results from ongoing research in the Coastal and Hydraulics Laboratory (CHL) relating to numerical modeling of pneumatic plumes. The code involved has been used for evaluating pneumatic plumes and the associated velocity field as well as general flow modeling. Combinations of fresh-water inflow, air-injection flow rate, and injection locations will be evaluated to determine the sensitivity of the system to the variables and to develop possible design criteria. Due to the research nature of this effort, three months and $60,000 will be required. A Letter Report will be provided that documents this segment of the study and recommends a direction for the next segment of the study.

3. Time and Cost estimates for additional segments of the study will be provided once those segments are defined. This study will be conducted through a Co-operative Research and Development Agreement (CRADA), and the additional estimates will be negotiated and documented with a Letter of Agreement as defined in the CRADA.

4. Questions concerning this estimate should be directed to Mr. Chuck Tate at (601) 634-2120 or e-mail at tatec@usace.army.mil.

Encl

for THOMAS W. RICHARDSON
Director

July 29, 2002

Coastal and Hydraulics Laboratory

SUBJECT: Proposed Scope of Work for Panama Canal Salinity Intrusion

1. The purpose and object of this cooperative research and development agreement is to provide for the joint conduct of research and development investigations of techniques to reduce salinity intrusion to the Panama Canal locks through modeling.

2. The Water Processing Systems Division (WPSI) of the Water Resource Development Corporation has proposed reducing the salinity intrusion to the Panama Canal locks. The WPSI has proposed hydraulic and pneumatic injection in the lock approaches. This approach has the potential to reduce the salt concentration in the lock approach by using circulation cells established by pneumatic injection on the bottom of the approach channel. Injection of fresh water near the lock gates will provide a continuous supply of fresh water to the circulation cells that arrest the movement of the salt water to the lock gates. This proposed method has several unknowns that this Scope of Work (SOW) will address. Several segments of study will be required, with each segment based on the results of the previous work.

3. The Coastal and Hydraulics Laboratory (CHL) will use one of its numerical models to evaluate the mixing characteristics of the proposed plan. The code involved has been used for evaluating pneumatic plumes and the associated velocity field as well as general flow modeling. This evaluation will look at the combinations of fresh-water inflow, air-injection flow rate, and injection locations to determine the sensitivity of the system to the variables and to develop possible design criteria. Required information from WPSI will include approach-channel bathymetry, the time required for a ship to exit or enter the lock chamber, and the number of ships traveling each way per day.

4. Results of the first segment of the study will provide insight into physical modeling requirements needed to better define the mixing characteristics of the pneumatic plumes and the transport across the plumes. These results will be reviewed with WPSI to develop the next segment of work. It is anticipated that two-dimensional physical experiments will be necessary to accurately define the salt transport across the pneumatic plumes. The CHL has new facilities that will accommodate experiments with stratified flow, and the facilities are available for this study.

5. The final segment of the study will be to combine the experimental and numerical results to produce a design for construction. The results of this evaluation should produce the operational constraints for the design.

6. This study will be conducted with WPSI through a Co-operative Research and Development Agreement (CRADA). An estimate for time and cost will be provided for the first segment within the CRADA. The time and cost for the remaining segments will be negotiated with WPSI and documented with a Letter of Agreement.

7. The respective obligations of the parties in performing the cooperative research and development program are as follows:

CHL:

a. Shall use one of its numerical models to evaluate the mixing characteristics of WPSI's proposed hydraulic and pneumatic injection technique.
b. Shall provide technical expertise to numerically and physically model the mixing and velocity induced by the hydraulic and pneumatic injection.
c. Shall identify additional modeling efforts required to better define the mixing characteristics of the pneumatic plumes and the transport across the plumes.
d. Upon mutual agreement on cost of additional modeling efforts, shall perform such efforts as documented in a letter of agreement,

WPSI:

a. Shall provide any relevant data, internal and external studies, and information developed to date on injection techniques relating to the Panama Canal.
b. Shall supply funds to the CHL in support of the work described in this agreement
c. Shall collaborate on the application of the results of the research to the lock approaches for the Panama Canal.

8. Questions concerning this estimate should be directed to Mr. Chuck Tate at (601) 634-2120 or e-mail at tatec@usace.army.mil.

CUT SHEETS

REVERSE OSMOSIS MEMBRANE UNIT

FLUID SYSTEMS – KOCH MEMBRANE SYSTEMS

KOCH MEMBRANE SYSTEMS

FLUID SYSTEMS TFC® - SS 17.25" MegaMagnum™

High Rejection, Seawater, RO Element

PRODUCT DESCRIPTION

Membrane Chemistry:	Proprietary TFC® polyamide
Membrane Type:	TFC®-SS
Construction:	Spiral-wound with fiberglass outerwrap.
Applications:	Seawater desalination utilizing a high rejection RO membrane

SPECIFICATIONS

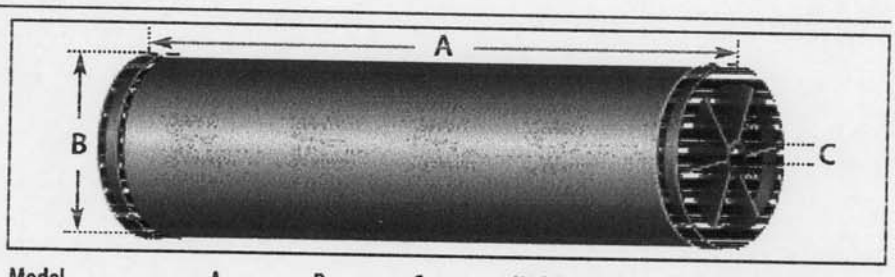
Model	Permeate Flow gpd	Permeate Flow (m³/d)	Chloride Rejection percent	Membrane Area ft²	Membrane Area (m²)
TFC® 17060 SS	40,500	(153.0)	99.6	2450	(228)

Test Conditions: 32,800 mg/l NaCl solution (isosmotic to ASTM standard seawater) at 800 psi (5,520 kPa) applied pressure, 11% recovery, 77°F (25°C) and pH 7.5.

OPERATING & DESIGN INFORMATION

Typical operating pressure:	750 - 950 psi (5,175 - 6,555 kPa)
Maximum operating pressure:	1,200 psi (8,275 kPa)
Maximum operating temperature:	113°F (45°C)
Maximum cleaning temperature:	113°F (45°C)
Maximum continuous free chlorine:	<0.1 mg/l
Allowable pH - continuous operation:	4 - 11
Allowable pH - short term cleaning:	2.5 - 11
Maximum differential pressure per element:	15 psi (104 kPa)
Maximum differential pressure per vessel:	60 psi (414 kPa)
Maximum feed turbidity:	1 NTU
Maximum feed SDI (15 minute):	5
Feed spacer thickness:	28 mil (0.7 mm)

PRODUCT DIMENSIONS AND WEIGHT



Model	A inches (mm)	B inches (mm)	C inches (mm)	Weight lbs (kg)	Part Numbers Interconnector	O-ring	Brine Seal
TFC® 17060 SS	60 (1,524)	17.25 (438.2)	4.0 (101.6)	350 (159.1)	0035269	0035479	0035718

The information contained in this publication is believed to be accurate and reliable, but is not to be construed as implying any warranty or guarantee of performance. We assume no responsibility, obligation or liability for results obtained or damages incurred through the application of the information contained herein. Refer to Standard Terms and Conditions of Sale and Performance Warranty documentation for additional information.

Performance:

Performance specifications shown on the front side of this document are nominal values. Individual element permeate flows may vary +/-15% from the values shown. Minimum chloride ion rejection is 99.3% at the conditions shown.

System performance should be predicted using KMS' ROPRO® design software. Element performance within ROPRO® is based on the nominal values shown.

System operating data should be normalized and key performance parameters tracked using KMS' NORMPRO® software.

Operating Limits:

- **Operating Pressure:** Maximum operating pressure is 1,200 psi (8,275 kPa). Typical operating pressure for TFC®-SS systems is in the range of 750 psi (5,175 kPa) to 950 psi (6,555 kPa). Actual operating pressure is dependent upon system flux rate (appropriate for feed source) as well as feed salinity, recovery and temperature conditions.
- **Permeate Pressure:** Permeate pressure should not exceed feed-concentrate pressure by more than 5 psi (34 kPa) at any time (on-line, off-line and during transition).
- **Differential Pressure:** Maximum differential pressure limits are 10 psi (69 kPa) for a 40" (1,016 mm) long element and 15 psi (104 kPa) for 60" (1,524 mm) long element. Maximum differential pressure for any length pressure vessel is 60 psi (414 kPa).
- **Temperature:** Maximum operating temperature is 113°F (45°C). Maximum cleaning temperature is 113°F (45°C).
- **pH:** Allowable range for continuous operation is pH 4 - 11. Allowable range for short term cleaning is pH 2.5 - 11.
- **Turbidity and SDI:** Maximum feed turbidity is 1 NTU. Maximum feed Silt Density Index (SDI) is 5.0 (15 minute test). Experience has shown that feedwater with turbidity greater than 0.2 NTU generally results in frequent cleanings.
- **Recovery:** Maximum recovery is site and application specific. In general, single element recovery is approximately 11% for each element. Recovery limits should be determined using KMS' ROPRO® program.

Chemical Tolerance:

- **Chlorine:** Intentional exposure of TFC®-SS membrane to free chlorine or other oxidizing agents such as permanganate, ozone, bromine and iodine is not recommended. TFC®-SS membrane has a free chlorine tolerance of approximately 1,000 ppm-hours based on testing at 77°F (25°C), pH 8. This tolerance may be significantly reduced if catalyzing metals such as iron are present or if the pH and/or temperature are different. Sodium metabisulfite (without catalysts such as cobalt) is the preferred reducing agent. TFC®-SS membrane has a chloramine tolerance of approximately 60,000 ppm-hours in the absence of free chlorine based on testing at 77°F (25°C), pH 8.
- **Cationic (Positively Charged) Polymers and Surfactants:** TFC®-SS membrane may be irreversibly fouled if exposed to cationic (positively charged) polymers or surfactants. Exposure to these chemicals during operation or cleaning is not recommended.

Lubricants:

For element loading, use only the recommended silicone lubricant (or approved equivalent), water or glycerin to lubricate O-rings and brine seals. The use of petroleum based lubricants or vegetable based oils may damage the element and void the warranty.

Service and Ongoing Technical Support:

KMS has an experienced staff of professionals available to assist endusers and OEM's for optimization of existing systems and support with the development of new applications. Along with the availability of supplemental technical bulletins, KMS also offers a complete line of KochTREAT™ and KochKLEEN® RO pretreatment and maintenance chemicals.

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WD TS 17060SS 07/02

Koch Membrane Systems, Inc., www.kochmembrane.com
850 Main Street, Wilmington, MA 01887-3388, USA, Telephone: 800-343-0499, Telephone: 978-657-4250, Fax: 978-657-5208
10054 Old Grove Road, San Diego, CA 92131, USA, Telephone: 800-525-4369, Telephone: 858-695-3840, Fax 858-695-2176
The Granary, Telegraph Street, Stafford, ST17 4AT, UK, Telephone: +44-1785-272500, Fax: +44-178-5-223149
Suite 6, Level 1, 186-190 Church Street, Parramatta, NSW 2150, Australia, Telephone: +61-2-8833-4600, Fax: +61-2-9689-3615

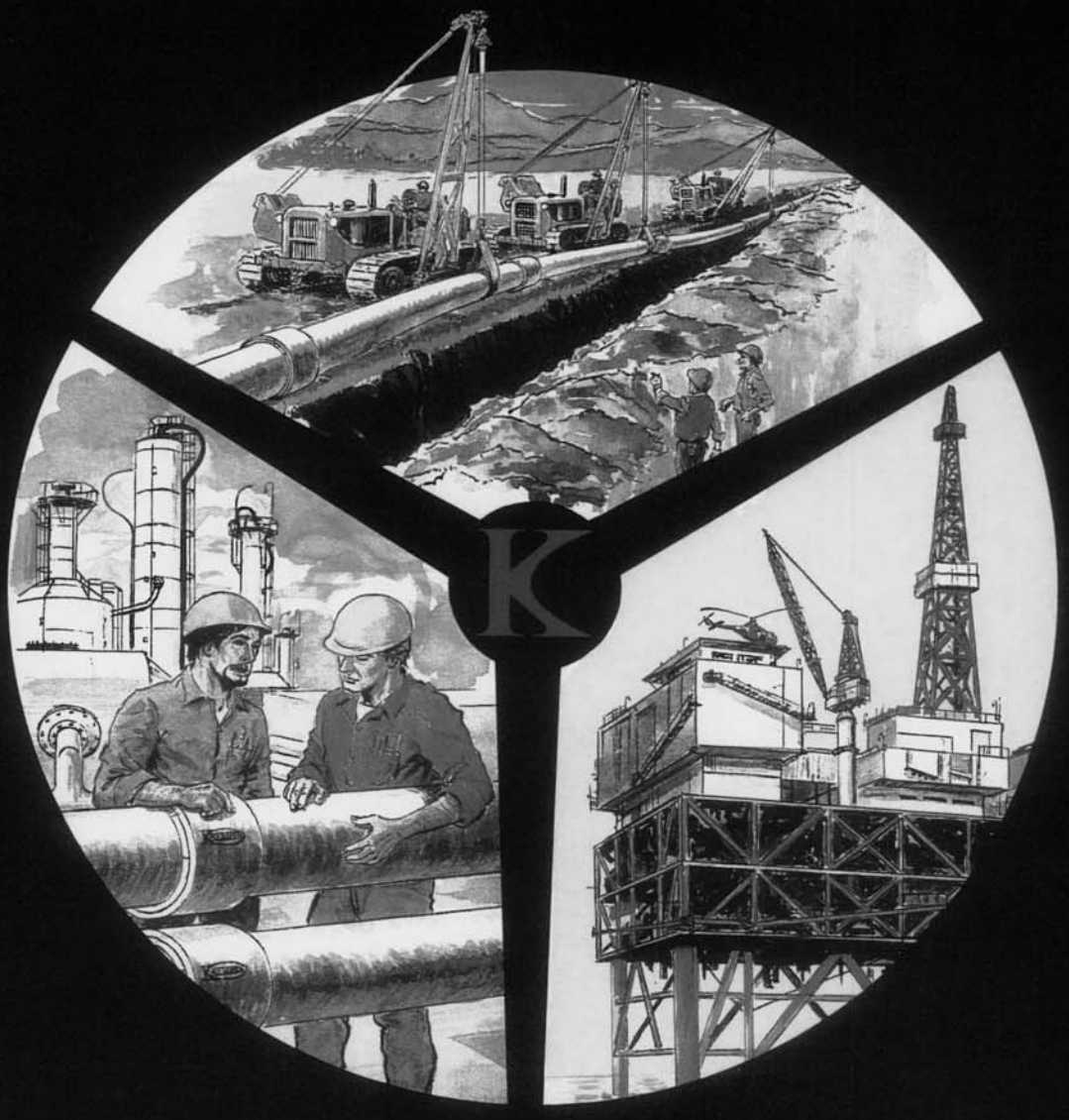
TECHNICAL INFORMATION

"FRP" CONVEYANCE STRUCTURES

By

KAEMPEN PIPE CORPOARTION

KAEMPEN



ADVANCED COMPOSITE PIPING SYSTEM

KAEMPEN U.S.A., INC.

PIPE PRESSURE CATEGORIES

PRESSURE CLASS	PRESSURE CATEGORY	"T" PIPE WALL THICKNESS (INCH)	"U" PRESSURE FACTOR (PSI-INCH)	"B" PRESSURE FACTOR (PSI-INCH)	"K" WEIGHT FACTOR (LB/INCH)
H	HIGH	0.40	10,500	30,000	1.16
STD	STANDARD	0.30	8,710	26,000	0.87
M	MEDIUM	0.20	6,700	20,000	0.58
L	LOW	0.15	3,350	10,000	0.44

With Factors from above Table, use the following formulas to calculate pressure and weight values for any pipe Pressure Class for pipe having an inside diameter "D".

PIPE USE PRESSURE (PSI) = U/D PIPE BURST PRESSURE (PSI) = B/D

PIPE WEIGHT PER FOOT (LB) = K x D

PHYSICAL PROPERTIES

PHYSICAL PROPERTIES

Tensile Strength ..... 125,000 psi
Tensile Modulus ..... 3.51×10^6 psi
Compressive Strength ..... 50,000 psi
Transverse Shear Strength ..... 43,000 psi
Density pounds per cu. in. 0.064
Maximum Operating Temp.
(standard Pipe) ..... 200 deg. F
Thermal Conductivity
10^{-4} cal-cm/sec-cm^2 Deg. C 10
Coefficient of Thermal Expansion
10^{-6} In/In °F 11

CODE COMPLIANCE

KAEMPEN COMPOSITE PIPE meets or exceeds the following Standards CONCERNING PIPE FOR USE IN THE TRANSPORT OF WATER, CHEMICALS, AND LIQUID PETROLEUM PRODUCTS:

ASME B 31.3 Refinery and Chemical Pipe
ASME B 31.4 Petroleum Transport Pipe
API SPEC 5 LR-Line Pipe
API SPEC 5 AR-Casing & Tubing
AWWA C 950-Water Pressure Pipe
NFPA 30-Liquid Petroleum Pipe
ASTM D 2996-83 Filament Wound RTR Pipe

Standard Pipe Sizes 2" to 12" (4 pressure classes)
Engineered Sizes 14" to 56" (4 pressure classes)

(Each length includes a standard TWIN LOCK COUPLING)

KAEMPEN U.S.A. INC.

PRESSURE PIPING SYSTEMS "RELIABILITY IN ANY ENVIRONMENT"

2900 E. LA CRESTA AVENUE
ANAHEIM, CALIFORNIA
USA 92806
(714) 632-1005; FAX (714) 632-1115

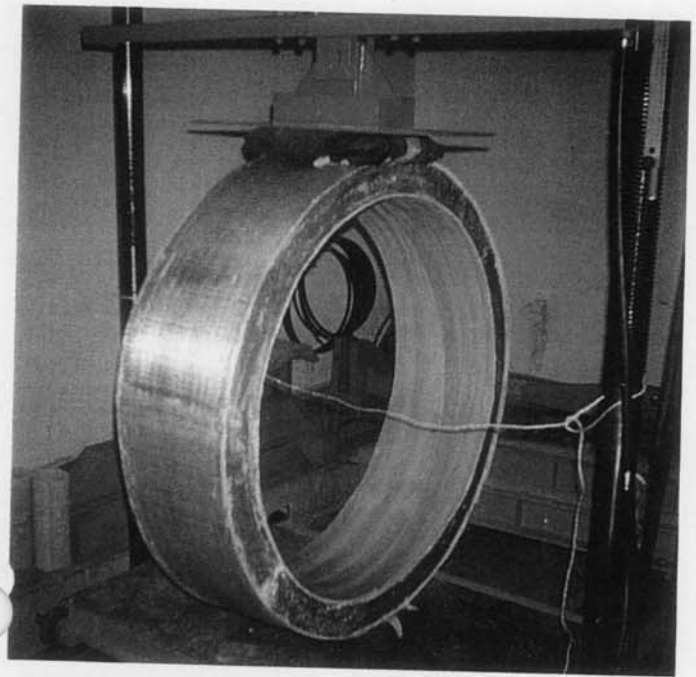
primarily corrosion, abrasion, or temperature environments according to the pipe's intended application.

The outer **COVER** ply can be tailored to resist the external environments of greatest concern, such as fire, weathering, sun exposure, humidity, burial, submersion or temperature extremes.

The unique multiple wall construction characterizing **KAEMPEN COMPOSITE PIPE** enables the pipe design engineer to be liberated from the restrictions imposed by conventional single wall thickness pipe materials and standard ASTM test procedures used to qualify non-metallic pipe.

THE DOUBLE WALL OPTION

Kaempen Composite Pipe can be supplied with an outer wall structure that provides additional ruggedness and pipe stiffness. The Kaempen Double Wall Composite Pipe provides a **SECONDARY CONTAINMENT** pipeline system that double guards against environmental pollution. Kaempen Double Wall Composite Pipe has been tested and proven in underground installations since 1977, and provides a pipe with required thermal insulation, fire protection and pipe buoyancy control.



Kaempen Double-Wall Pipe Deflects Only 2% Under Load of 6000 Lbs. per linear Foot

COMPARISONS WITH OTHER PIPE

KAEMPEN COMPOSITE PIPE IS NOT PLASTIC PIPE

Kaempen Composite Pipe WILL NOT

- melt or drastically lose strength when heated
- creep, buckle, or collapse when subjected to submersion, backfill or road traffic compression load for decades
- embrittle or become prone to impact fracture when exposed to Arctic temperatures as low as -100 degrees F
- **burn** or **leak when exposed to fire.**

KAEMPEN COMPOSITE PIPE OUTPERFORMS STEEL PIPE

Kaempen Composite Pipe material has no design yield strength and for this reason can be used at a greater fraction of its ultimate strength than steel.

Kaempen Composite Pipe is made from a composite material that is **ONE-FOURTH** the density and **THREE TIMES** the use strength of **steel. A pound** of Kaempen Composite Pipe performs as well as **twelve pounds** of the equivalent size steel pipe.

Kaempen Composite Pipe material has an insulative value **100 TIMES** better than steel. A steel pipe requires a wall thickness of 10 inches to equal the insulation effectiveness of a Kaempen Composite Pipe having a wall thickness of only a tenth of an inch.

Kaempen Composite Pipe has a pipe surface roughness substantially less than that of steel pipe and thus requires less pressure and pumping energy to transport fluids than is required by steel pipe of the same diameter and length.

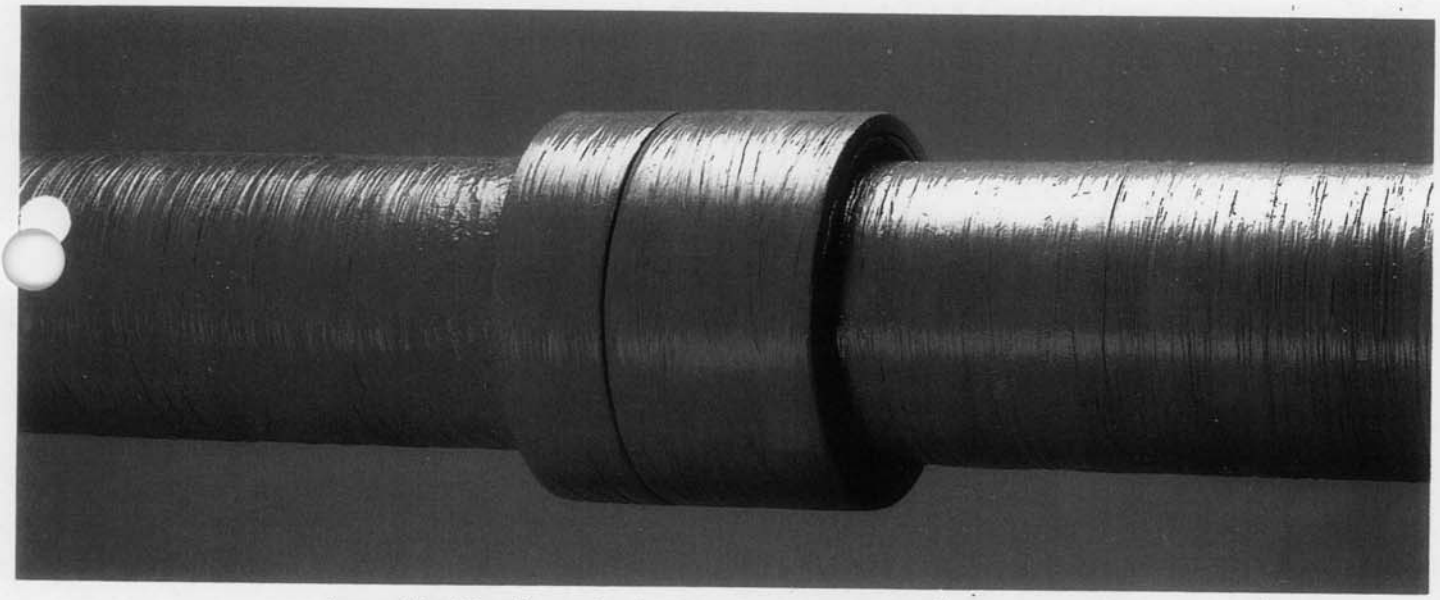
Kaempen Composite Pipe **WILL NOT CORRODE.** It is lighter and easier to ship, handle and install than steel pipe having an equivalent diameter and pressure rating.

DESCRIPTION OF KAEMPEN COMPOSITE PIPE

Kaempen Composite Pipe is a mechanically coupled composite pipe made from a tensioned filament reinforced plastic (TFRP) material developed by Dr. Charles E. Kaempen, an internationally recognized space scientist and inventor.

The Kaempen Composite Pipe material is a reinforced thermosetting resin pipe (RTRP) material which belongs to the class of Unidirectional Composites containing Sinusoidal Reinforcements. A Sinusoidal Unidirectional Composite comprises parallel twines of sinusoidally oriented strands of continuous filament reinforcement, which are impregnated with a hardenable liquid resin matrix.

The patented secret behind the enormous joint strength and pressure capability of the Kaempen Composite Pipe and the **TWIN LOCK**™ Coupler System, is the process employed in constructing the Pipe and Coupler. This process involves the manufacturing of a unique composite tubular pipe and coupling structure which utilizes both the tensile strength and the transverse shear strength of pretensioned twines of resin impregnated filament strands.



Assembled Configuration of Kaempen Twin-Lock Coupler System

THE TWIN LOCK PIPE COUPLER SYSTEM

The Twin Lock Pipe Coupler System enables Kaempen Composite Pipe to be sealed and connected to provide a pipeline with the strength and sealing integrity equivalent to that of a welded steel pipeline having the same wall thickness and diameter. Use of the **TWIN LOCK**™ Pipe Coupler System enables Kaempen Composite Pipe to be joined and sealed 20 times faster than steel pipe of equivalent size and use pressure.

The **TWIN LOCK**™ Pipe Coupler System overcomes the traditional sealing problems involved in the use of mechanical pipe couplings. The **TWIN LOCK**™ Coupler System uses a compression type FACE SEAL which increases sealing compression forces when subjected to increases in pipe pressure.

Independent studies by end users have determined that Kaempen Composite Pipe which is sealed and connected by the **TWIN LOCK**™ Coupler System is less expensive to purchase and install than equivalent size steel pipe and meets or exceeds all applicable pipe codes.

The **TWIN LOCK**™ Pipe Coupler System is the culmination of many years of field and laboratory tests. The **TWIN LOCK**™ Pipe Coupler enables composite pipe to be connected and disconnected faster and with greater sealing realiability than other pipe coupling methods.

The pressure seal of the **TWIN LOCK™ COUPLER SYSTEM** is made on polished pipe joint surfaces that prevent damage to the **FACE SEAL** during installation. This unique joint seal will facilitate removal and replacement of individual pipe fittings or pipe lengths without disturbing adjacent pipe sections.

CONSTRUCTION OF KAEMPEN COMPOSITE PIPE

Kaempen Composite Pipe is a tubular, multiple wall composite structure having two separate wall thicknesses or "plies" of unidirected twined strands which are sandwiched between two separate impermeable wall structures. The constituents of this four ply multi-wall composite pipe structure are described below:

1. The **LINER** ply is the inner impermeable wall structure that resists corrosion and wear.
2. The **CIRC** ply interior wall structure consists of circumferentially oriented twined strands of continuous filament reinforcement that primarily resists the pipe hoop stresses produced by compression and pressure loads.
3. The **LONGO** ply interior wall structure consists of longitudinally oriented twined strands of continuous filament reinforcement aligned parallel to the pipe axis to resist pipe bending and tensile end loads transferred through the flanged joints connected by the **TWIN LOCK™ Coupler System**.
4. The **COVER** ply is the outer structure that serves to provide additional protection from weathering, submersion and other external environmental influences.

KAEMPEN COMPOSITE PIPE DESIGN VERSATILITY

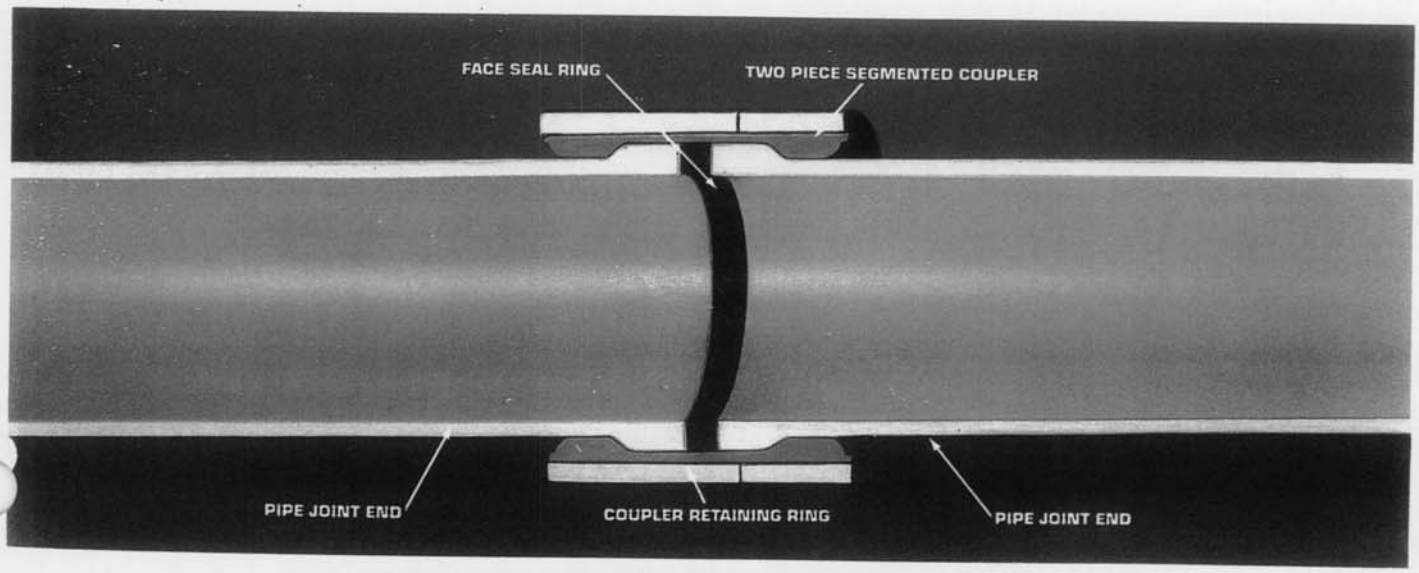
Pressure Pipe experiences two principal types of load:

1. An end load which tends to stretch the pipe
2. A radial load which tends to enlarge pipe diameter

Kaempen Composite Pipe allows the pipe design Engineer a new dimension of design versatility since the pipe's **CIRC** and **LONGO** ply wall thickness can be tailored to resist principal stresses of engineering concern.

Greater end loads can be resisted by increasing **LONGO** ply thickness; greater pressure loads can be resisted by increasing **CIRC** ply thickness.

The inner **LINER** ply can be tailored to resist



Section View of Kaempen Twin-Lock Coupler System

THE STRONGEST COMPOSITE PIPE EVER MADE

CAPABILITIES OF KAEMPEN COMPOSITE PIPE

Kaempen Pipe is the strongest composite pipe ever made. A quarter inch wall thickness pipe can resist tensile end loads as great as 12,000 lbs. per circumferential inch, while simultaneously resisting circumferential hoop loads as great as **12,000 lbs. per lineal inch.**

Each section of Kaempen Composite Pipe qualifies as an elongated pressure vessel which can meet the rigorous performance requirements established for fiberglass pressure vessels under **SECTION X** of the **ASME BOILER AND PRESSURE VESSEL CODE.** This explains why Kaempen Composite Pipe is immune to structural failures caused by fatigue, bending, cyclic flexing or pulsating pressure stresses.

Cyclic tests performed over a period of more than a year demonstrated that the Hydrostatic Design Basis Strength (HDBS) of Kaempen Composites Pipe material exceeds 60,000 psi. This value is four times greater than the highest pipe strength category for RTRP fiberglass pipe shown in Table 1 of Procedure A in ASTM D-2992.

Kaempen Composite Pipe easily resists handling damage and field abuse such as produced by wheel loads of heavy equipment or tool impact. The incredible strength of Kaempen Composite Pipe can be explained by the fact that the interior plies of the pipe wall structure consist of unidirected twined strands of parallel glass filaments.

These glass filaments behave as thousands of individual microscopic "wave guides" that soak up and dissipate the stress waves of impact energy around, as well as along the pipe body rather than through the pipe wall, where impact shock waves might fracture the resilient impermeable inner pipe liner. No other pipe possesses this unique feature which makes the pipe wall structure virtually **indestructible**.

The continuously smooth and polished interior surface of mechanically coupled Kaempen Composite pipe greatly reduces pipe wall friction, and thereby not only provides savings in energy pumping costs, but also eliminates the need to add expensive Drag Reduction Agents to pipeline liquids.

Kaempen Composite Pipe Resists Field Abuse During Installation

A 300 Foot Length of 8" Pipe Can Be Lifted to a 10 Foot Height by a Single Strap Support

FEASIBILITY ANALYSIS

HYDROELECTRIC POWER GENERATION

By

GE HYDRO-SYSTEMS

Power Systems
GE Hydro Power, Inc.
6130 Stoneridge Mall Road, Suite 275
Pleasanton, CA 94588
925 750-6100, Fax: 925 924-1338

July 23, 2002

Water Processing Systems Division
2030 E. 4th Street, Suite 213
Santa Ana, CA 92705

Attn: Mr. Wayne Spani
Vice President

Subj.: Panama Canal Locks
Water Reclamation Project
Electrical Generation

Dear Mr. Spani:

As you know, GE Hydro has been working together with Water Processing Systems Division, WPSI, to make a preliminary selection of hydroelectric generating equipment that would provide power to support the Water Reclamation Project WPSI is considering to propose to the Panama Canal Authority (ACP). This overall project is intended to recover approximately 26 million gallons of fresh water that is being discharged into the sea each time a ship passes through the canal.

The electrical equipment we have selected on a preliminary basis uses the heads and flows of the water as it is fed via gravity from the different locks within the canal through existing culverts. We found that it is possible to construct these new turbine generators in parallel culverts in an effort to minimize any downtime required of the canal locks for installation as well as for maintenance purposes.

The equipment that was selected was based on the following parameters and information that was provided by WPSI:

- Heads: Based on ACP drawings showing side elevations of the lock system;
- Flows: 104,000 cubic meters of water flow each time the lock is operated
- Lock Ops.: 22.5 times per day per gate
- Lock Timing: Approximately 8 minutes per lock
- Culvert Size: Approximately 4 Meters diameter

The culverts consist three tunnel like designs each 4 meter in diameters and are parallel to the locks.

As a result of our preliminary analysis, we determined that turbine generators using a Pit design could be located at 7 locations in or near existing culverts that would be capable of generating approximately 110 Gigawatts of electricity per year. Four of these locations would use Pit turbine generators, one for each culvert, designed for 8.9 meters of head. These 12 units would have a capacity of 6.5 Mwe each. The other three locations would also use Pit turbine generators but these would be designed to

accommodate 17.0 meter heads and would also use the existing three culverts. These 9 units would have a capacity of 14.2 MW each. The total installed capacity, therefore, would be approximately 205.8 MWe.

GE Hydro Power Inc. would be pleased to provide you with the equipment noted above for the consideration of:

Ninety-Six Million US Dollars
or
$96,000,000 USD.

The equipment that would be provided for this sum consists of the turbine generators as described above including turbine, generator, governor, gearboxes, and excitation systems. We would typically expect to ship equipment of this nature less than 18 months after contract award depending on the schedule and scope of supply.

This budgetary pricing is present day and is being provided for feasibility purposes. It is based on FOB shop but would be packaged for transoceanic shipment. Taxes, duties and other such charges are not included in this estimate. It is also based on standard GE Hydro terms and conditions a copy of which will be provided upon your request. The price could be firmed once a more definitive scope of supply and schedule has been agreed upon. Mutually agreed upon terms and conditions and project structure are also required before a firm price can be provided.

Please note the equipment selection is very preliminary at this point in the project. It is based on capturing the existing heads and flows in their present conditions, i.e. large initial heads upon gate or lock openings. We would expect to continue to work with WPSI on an exclusive basis to optimize the plant configurations with a goal to reduce the overall price. This may involve a re-design of the units or their respective layouts in an effort to better control the water flows to make them more consistent and still utilize the existing heads and configurations of the existing canal system. This would also have to be incorporated into the overall plant design including the water treatment plant.

Please review this information and other information sent to you on Wednesday, July 17, 2002, which is being incorporated into this budgetary quotation. Should you have questions or comments to this offering, please contact me at (925) 750-6103 or my cell phone at (415) 819-2336. Thank you for allowing GE Hydro Power Inc. the opportunity to provide you with information about our abilities of meeting your hydro generation needs.

Sincerely,

GE HYDRO POWER INC.

Mary Cordeff for John Ketterl

John Ketterl
Manager – Business Development

Panama Canal Authority
Panama Canal Lock Water Reclamation Project
Panama Canal, Panama

Electrical Generation

By

GE Hydro Power Inc.

Introduction:

The configuration of the Panama Canal is designed to move shipping from on ocean to another using sets of locks that passes water from one lock to another lock in a relatively short period of time. The passage of the ships requires water to be transported from one lock to the next using gravity as a means to transport the water through the locks as the ship moves through the canal system. This movement of water creates an unusual hydraulic energy potential that can be captured for the generation of electricity if the correct equipment is installed at the proper locations.

The generation of electricity can be an integral part of the overall plan to treat and reclaim the spent water used to pass each vessel through the canal system. When placed in specific locations throughout the canal system, GE Hydro can take advantage of the different water elevations, or heads, and flows to design and supply equipment and components to generate the largest amounts of electricity for use in the treatment of the spent water at other locations of the canal. Any excess power could be used elsewhere or sold for other uses.

Early in the GE Hydro investigation, it was determine that 2 methods would be explored as to where to locate the new Bulb or Pit turbines, i.e. locate the units in existing culverts or design and install the units in parallel culverts. These parallel culverts could be erected without interrupting the operation of the canal and can be integrated into the existing culvert system with minimal down time. Using existing culverts to locate the units did not show this feature as meeting the shortest possible culvert down time requirement. As such, only the parallel culvert applications were investigated to any great extent.

Preliminary Analysis:

Our review has shown that there are specific locations where the water levels or heads are capable of producing the greatest amounts of energy when the water is passed from one lock to another. The current configuration of the canal lock system consists primarily of 3 water ducts or culverts, 2 of which are located on each side of the locks and one culvert located in the center of the lock system but between the locks. Water is allowed to pass through these culverts by gravity

when each ship passes through the individual lock. It was determined that each lock requires approximately 8 minutes to fill or drain, respectively. During this transferring of water from one lock to the next, a hydraulic turbine generator combination that is designed to operate in locations such as underground culverts could be utilized for electrical generation purposes.

7 locations at various points along the canal locks were identified as potential locations to install hydroelectric turbine generators to recover this energy. These locations showed the most promise in maximizing the production of hydroelectric energy. The culverts at these locations were selected for the installation of a turbine generator set. The diameter of the culverts are approximately 4 meters in diameter. At each location, a turbine generator set will be installed in each of the three culverts for a total of 21 units, i.e. 7 locations using all three culverts at each location.

Since the culverts are underground, the selection of Bulb or Pit turbine generators was made. These units have been used by GE Hydro since the 1950's in applications where both the turbine and generator are submerged in the water flow to generate electricity. These units have an in-line enclosed generator that will allow the water to pass around the generator through the turbine with minimal hydraulic losses.

The preliminary analysis showed that the canal lock system contains 2 different but varying head distributions during the time the specific lock is filling or draining. These heads will vary as the filling and draining process goes forward depending on the lock location. It was found that an average of 8.9 meters of head is found at 4 locations within the canal system. These locations consists of 2 lock locations on either side of the Gatun Lake, and 2 locks at either side of Miraflores Lake.

The locks on the Pacific Ocean side, the Gatun Locks, can accommodate 2 units designed to accommodate a 17 meter head and another location at the Miraflores Locks also experiences a similar head. Each location would accommodate a Bulb turbine generator with gear box. Since there are 3 culverts that handle the same head and flow conditions at each location, there will be a total of 21 units installed in the canal system.

Equipment Selection:

The GE Hydro hydroelectric generating equipment and components selected consists of Bulb or Pit turbines. These designs have the capability of being installed into a culvert or tunnel system. The concept of using tunnels or culverts to transport larges amounts of water for the purposes of generating electricity has been used for more than a century in various locations throughout the World. Scandinavia, for example, has used extensive tunneling in their hydroelectric generation system for just this purpose because of the remote locations of the various bodies of water in the mountainous regions. Typically, these installations

use Francis, Kaplan, propeller and bulb or Pit turbines to accommodate the specific site conditions. Bulb and Pit turbines are reliable generating designs and have also been used in other hydroelectric applications such as in rivers where the machines are submerged in the river bed with tunnels or penstocks to guide the water through the machine.

The GE Hydro machines selected for this Panama Canal Locks Generation system have a proven track record. The GE Hydro design uses 104,000 cubic meters of water per ship passage. This translates to approximately 22.5 ships per day per lock or a total of 45 ships per day since the lock system can accommodate 2 ships either in the same or opposite directions. It is estimated the total recoverable energy per year is about 110 Gigawatt hours using this type of configuration.

The units selected for the 8.9 meter applications would be sized for 6.5 Megawatts capacity of which there would be 12 units required of this size located at 4 locations within the canal system noted earlier. The remaining 9 units located at the 17 meter head locations would consist of Bulb or Pit units with a capacity of 14.2 MW each. The size of the smaller units would be about 26 meters in length while the larger units would require approximately 30 meters in length. Further study is required to determine if the system design would be better suited using fixed speed or variable speed controls. This may prove to be a better solution to the utilization of the water flow.

Each unit would consist of a gearbox that would be used to increase the speed of the generator as well as an excitation system. The smaller units' gear box would most likely be a parallel shaft design while the larger units would use a planetary gear box arrangement.

The use of a variable speed drive also needs to be further investigated as well as a load commutated inverter. These devices may improve the efficiencies of the units as well as the start up rates of the units. Their applicability and related costs needs to be evaluated as part of the next phase of the project.

Installation and Canal Operations:

These 21 Bulb or Pit units can be installed in culverts parallel to the existing culverts. Isolation valves could also be installed, if preferred, in the event the units are to be isolated for maintenance purposes. Although the tie-in period required to integrate the new culverts into the existing culvert system is expected to be short, a specific procedure and process needs to be developed to better estimate the time required for this integration process and the requirements of any isolations valves. It is believed, however, that this down time can be worked into an existing maintenance schedule after the project is approved by the ACP.

The expected benefits of this parallel scheme include operations that are compatible with the current locks operations and schedules, minimal

maintenance within normal lock downtime and the shut down of one of the turbine generators would not require the culvert to become non-operations as long as isolation gates were installed. Using the existing culverts may not be as compatible since a longer downtime of specific locks is expected for initial installation of the equipment.

Other advantages to using a parallel scheme includes the flexibility of installation timing of the equipment, possible reduction of water losses resulting in greater energy production, and the setting of the unit could be better suited to reduce cavitation of the turbine.

Summary:

GE Hydro feels the generation of power can be accomplished using the water flows and heads of the existing canal configuration with minor additions to the culvert system. This generation can be used to help off-set the power requirements of the water reclamation plant. Any excess power can also be used in other areas of the canal system as required. Although the technical details need to be worked out and finalized, the concept has merit for this application.

The costs of the tunneling of the parallel culverts also needs to be estimated to determine if they are compatible with the financial objectives of the design configuration.

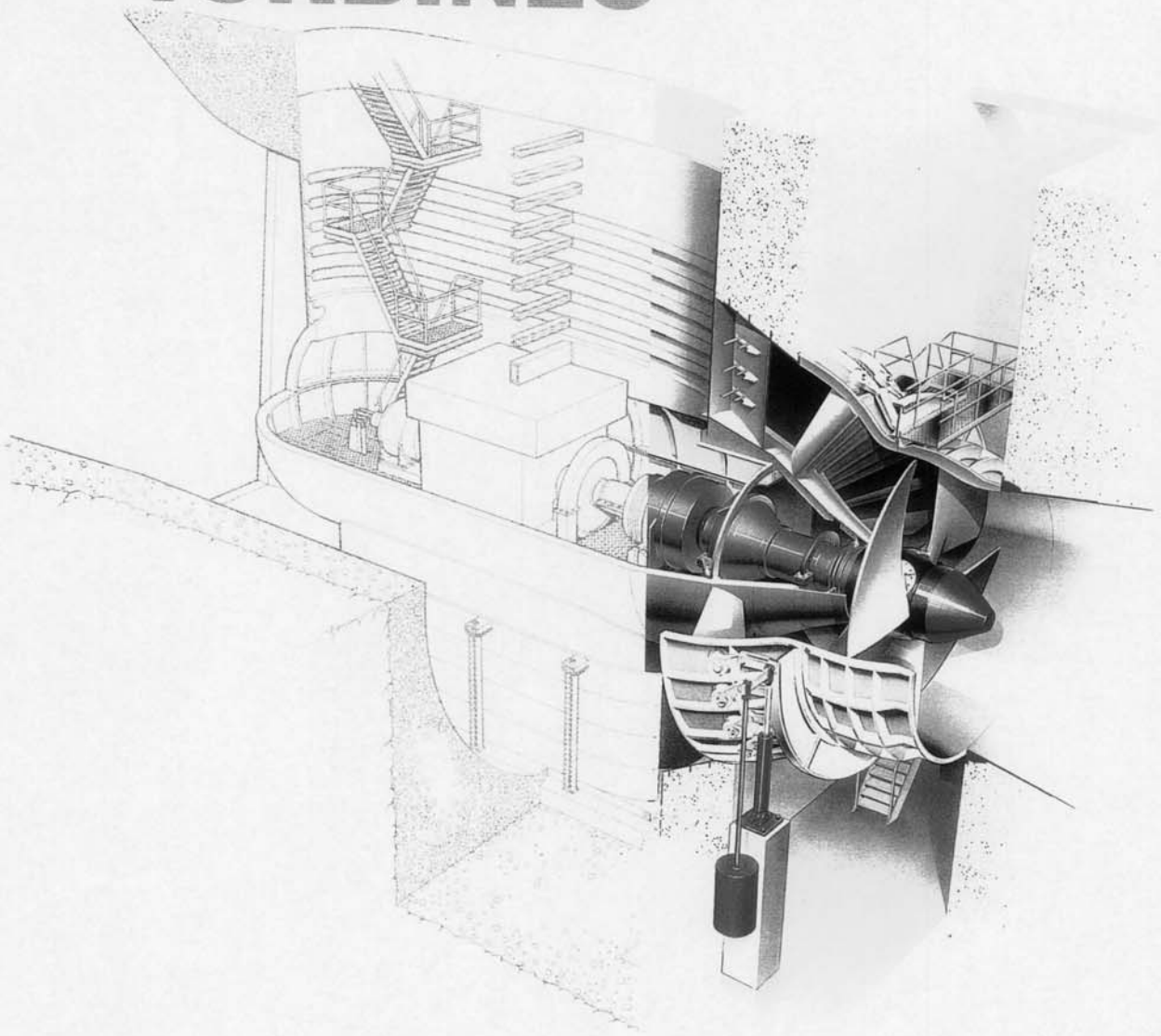
CUT SHEETS

HYDROELECTRIC POWER GENERATION

EQUIPMENT & SERVICES

GE HYDRO-SYSTEMS

BULB TURBINES



REFERENCE LIST

KVÆRNER™

Kværner Energy a.s

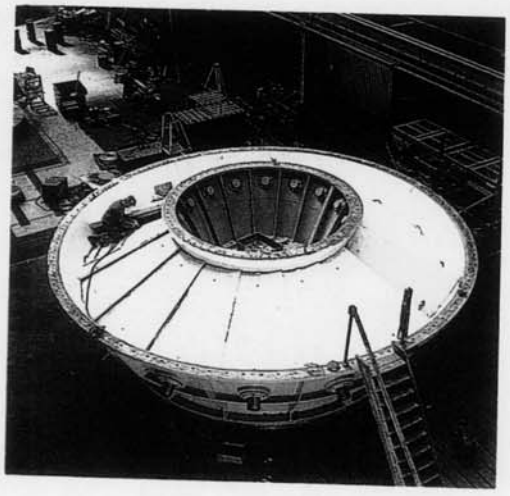
Business Area, Hydro Power

Kværner Energy a.s, Business Area Hydro Power, in addition to the Norwegian parent organisation comprises an operating company in Norway, Kvaerner Turbin AB in Sweden, Kvaerner Boving Limited in the United Kingdom, Kvaerner Boving (ANZ) Pty. Ltd. in Australia and New Zealand and Kvaerner Hydro Power Inc., in USA.

With a head office in Oslo and a representative office in London, the organisation co-ordinates the activities of all the operating companies.

This co-ordination ensures that the optimum use is made of the individual operating companies resources and that the extensive experience and know-how concentrated in these various companies are available to all of them.

Kværner Energy a.s is a member of the Kværner Group. Originating 150 years ago, the Kværner Group is the largest mechanical engineering organisation in Norway with over 17,000 employees spread over more than 50 member companies worldwide. These companies cover a wide variety of activities, ranging from oil and gas to fish-processing and environmental protection as well as shipping and shipbuilding. All the companies forming the Kværner Group are headed by the publicly owned holding company Kværner a.s which is quoted on the Oslo, Stockholm and London Stock Exchanges.



Hydro turbines	Pelton, Francis, Reversible Pump, Kaplan, Propeller and Bulb.
Valves	Spherical, Butterfly and Flow Control.
Governors	All electro-hydraulic types.
Penstocks	Surface mounted or covered, tunnel and pressure shaft linings, bifurcations and trifurcations.
Gates	All Hydro Power and Water Control types.
Trash Rack Cleaning Equipment	Various types and sizes.

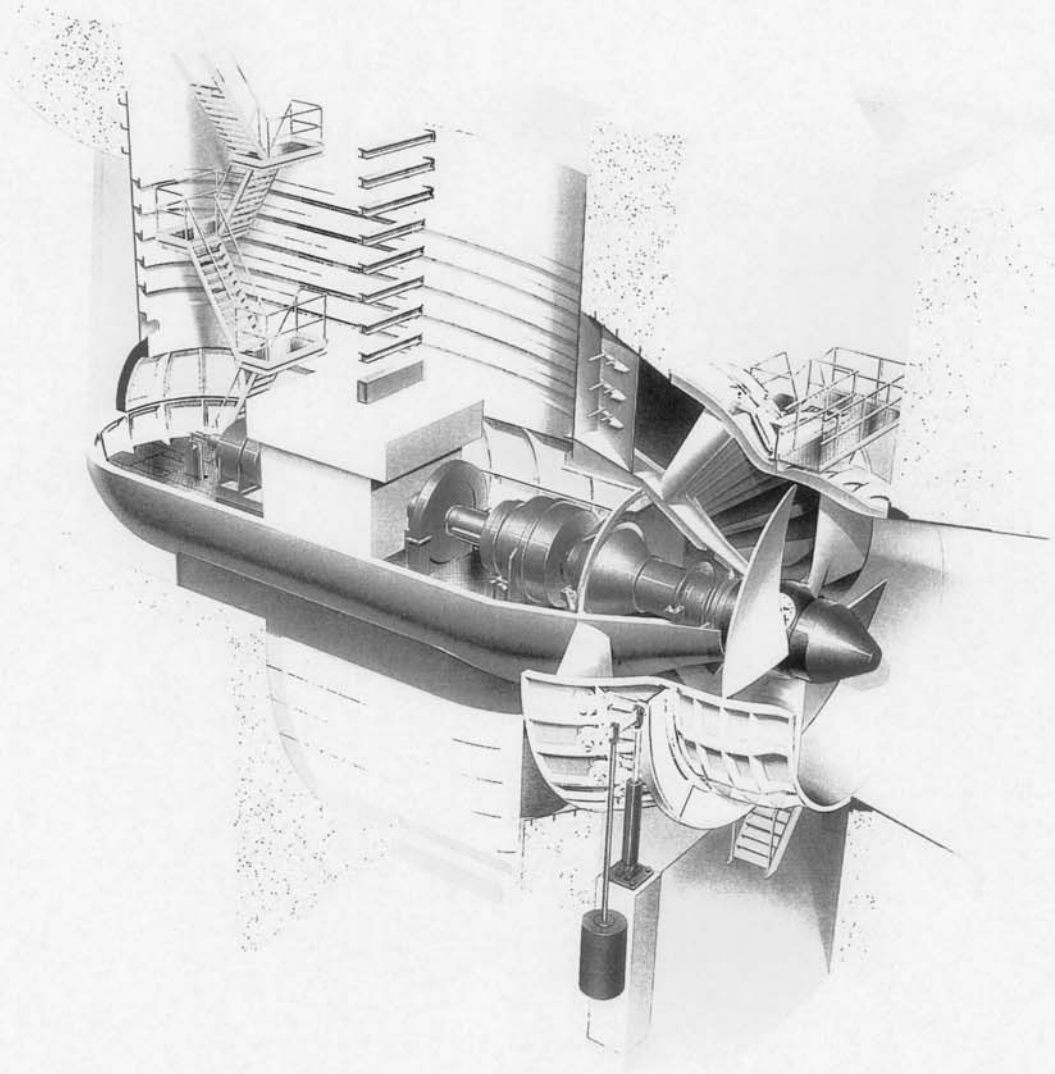
Services, Repair, Refurbishment and Upgrading

Training
All services associated with hydro installations.

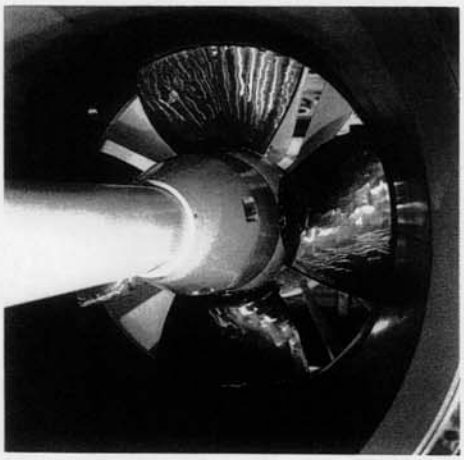
Since 1848, when our first turbine was delivered, Kværner Energy companies have delivered thousands of hydro turbines, totalling over 80,000 MW in output. Continuous improvement and development enables us to offer hydro turbines of all types and associated mechanical equipment of the most modern design for the smallest as well as the largest projects.

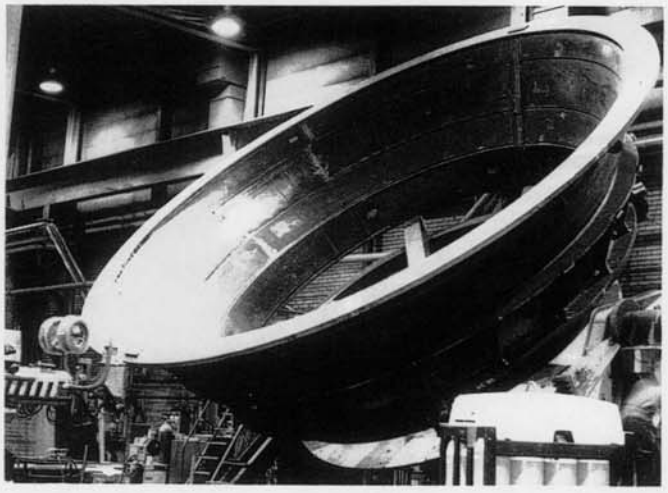
Hydraulic and mechanical research, development and design is carried out in our modern laboratories and by experienced engineers using the latest computer techniques.

Brochures giving descriptions of our laboratory facilities and all of our products are available on request.



BULB TURBINES





Work on the hydraulic and mechanical design of bulb turbines began in 1953 for Société des Forges et Ateliers de Creusot (SFAC) who were our French licensees. The result of this collaboration was the manufacture of several bulb turbines in France to our design. The largest of these installations is Pierre Benite in the river Rhone, comprising two units, each rated at 20MW, with a head range of 3.25 to 12.4m and a runner diameter of 6.1m.

The first of our deliveries was a small unit for Skogsforsen P.S. in Sweden. This was commissioned in 1959. Thereafter there was a period with little interest shown from customers in bulb turbines until the late sixties when the market changed to show a remarkable increase in demand.

The brochure on our Hydraulic Turbine Laboratory illustrates our excellent facilities for model testing bulb turbines.

The mechanical design, including construction details specific for this type of machine, has proceeded in parallel to the hydraulic development and we are able to supply all sizes of this type of turbine.

This reference list gives the main design data of all bulb turbines ordered, which have been designed and/or manufactured completely or partly by ourselves.

Column headings in the table refer to:

Year:	The year in which the order was received.
Head:	Rated net head.
Output:	Maximum power developed during continuous operation.
Runner diameter:	The maximum diameter of the runner blades.

Year	Customer	Power station/country	Number of units	Head m	Output per unit MW	Speed r.p.m.	Runner dia. m.	Notes
1958	Billeruds AB	Hällefors, Sweden	1	7.5	2.2	190.0	2.45	
1959	Koillis-Pohjan Sähkö	Siikakoski, Finland	2	3.4	1.02	105.0	3.82	
1964	Yngeredsfors Kraft AB	Skogsforsen, Sweden	1	14.0	4.5	250.0	2.18	
1965	Sperlingsholm Electriska Distributions AB	Sperlingsholm	1	3.7	0.8	125.0	2.45	
1967	Swedish State Power Board	Parki, Sweden	1	11.0	21.2	115.4	4.90	
1968	Buskerud Kraftverker	Gamlebrofoss, Norway	1	14.1	15.3	150.0	4.20	
1969	Nord-Tröndelag E. Verk	Åsmulfoss, Norway	2	10.0	12.1	125.0	4.30	
1971	Swedish State Power Board	Vittjärv, Sweden	3	5.6	12.3	75.0	5.80	
1972	Buskerud Kraftverker	Dövikfoss, Norway	1	5.85	14.7	75.0	6.40	
1972	Akerhus E. Verk	Funnefoss, Norway	2	10.3	20.0	100.0	5.2	
1972	Svanö AB	Bodum, Sweden	1	6.5	14.5	75.0	5.80	
1972	Bålforsens Kraft AB	Fjällsjö, Sweden	1	6.35	14.9	79.0	5.80	
1972	Bålforsens Kraft AB	Sil, Sweden	1	6.15	15.6	79.0	5.80	
1973	Österreichische Donaukraftwerke AG	Ottensheim, Austria	3	13.0	25.0	100.0	5.60	
1973	Graningeverkens AB	Lövön, Sweden	2	13.0	18.6	136.4	4.50	
1973	Bålforsens Kraft AB	Gäddede, Sweden	1	15.0	24.3	136.4	4.50	
1973	Hedmark Kraftverk	Kongsvinger, Norway	1	9.16	19.1	93.8	5.50	
1974	Bergvik & Ala AB	Landafors, Sweden	1	5.3	16.2	68.2	6.40	
1974	Bergvik & Ala AB	Ljusnefors, Sweden	1	6.7	19.8	75.0	6.40	
1974	Swedish State Power Board	Åsele, Sweden	1	9.2	28.7	93.8	6.10	
1974	Holmens Bruk AB	Bågede, Sweden	1	8.6	13.3	125.0	4.50	
1974	Nord-Tröndelag E. verk	Övre Fiskumfoss, Norway	1	6.7	8.4	107.1	4.3	

Year	Customer	Power station/country	Number of units	Head m	Output per unit MW	Speed r.p.m.	Runner dia. m.	Notes
1975	Akershus E.verk	Bingfoss, Norway	3	5.0	10.8	71.4	6.05	
1976	Söderfors Kraft AB	Söderfors, Sweden	2	4.5	9.4	62.5	6.10	
1976	Bålforsens Kraft AB	Täsjö, Sweden	1	12.0	13.5	150.0	4.10	
1976	Bålforsens Kraft AB	Hoting, Sweden	1	10.4	15.3	125.0	4.60	
1976	Österreichische Donaukraftwerke AG	Altenwörth, Austria	3	13.84	45.0	103.4	6.00	
1976	Swedish State Power Board	Näs, Sweden	1	5.2	14.7	75.0	5.80	
1976	AB Kallströmmen	Juveln, Sweden	1	11.0	15.7	136.4	4.20	
1976	AB Kallströmmen	Torron, Sweden	1	19.0	31.6	150.0	4.50	
1976	Hedmark Kraftverk	Braskereidfoss, Norway	1	9.2	22.1	88.2	5.80	
1977	Swedish State Power Board	Lilla Edet, Sweden	1	6.5	18.2	75.0	6.10	
1978	Swedish State Power Board	Näs, Sweden	1	5.2	14.7	75.0	5.80	
1978	AB Kattstrupeforsen	Granboforsen, Sweden	2	6.0	15.2	75.0	5.80	
1979	Bålforsens Kraft AB	Viforsen, Sweden	1	7.3	9.7	107.0	4.60	
1979	Avesta Jernverks AB	Avesta-Lillfors, Sweden	2	5.3	14.3	68.2	6.10	Generator speed 750 rpm
1980	Anjalankosen Voima Oy	Ankkapurha, Finland	1	9.8	19.8	100.0	5.40	
1980	Buskerud Kraftverker	Pikerfoss, Norway	1	11.3	15.3	125.0	4.30	
1980	Bålforsens Kraft AB	Matfors, Sweden	1	9.45	24.9	93.8	5.60	
1981	Graningeverkens AB	Volgsjöfors, Sweden	2	8.3	10.6	100.0	4.50	
1981	Graningeverkens AB	Malgomaj, Sweden	1	8.85	11.4	100.0	4.50	
1981	Kemijoki Oy	Vajukoski, Finland	1	15.0	22.0	136.0	4.60	
1981	Oy Kläsarö AB	Kläsarö, Finland	2	3.1	2.2	88.0	4.00	
1983	Fort Miller Associates	Fort Miller New York, U.S.A.	2	3.66	2.5	70.0	4.50	Pier type unit Generator speed 900 rpm

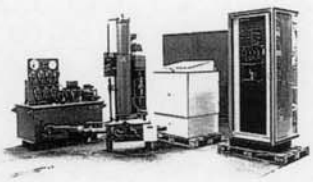
Year	Customer	Power station/country	Number of units	Head m	Output per unit MW	Speed r.p.m.	Runner dia. m.	Notes
1984	Nord Tröndelag, E. Verk	Tunnsjöfoss, Norway	1	38.0	8.5	125.0	3.65	
1984	Kemijoki Oy	Kurittukoski,Finland	1	11.0	15.9	125.0	4.60	
1984	Statkraft	Hogga, Norway	1	11.4	17.7	120.0	4.50	
1985	Swedish State Power Board	Skärblacka, Sweden	2	8.5	6.1	143.0	3.50	Pier type unit Generator speed 750 rpm
1986	Imatran Voima Oy	Tainionkoski,Finland	1	7.6	17.6	83.3	6.00	
1986	Swedish State	Vargön 3 Sweden Power Board	1	5.2	14.2	65.9	6.10	Generator speed 750 rpm
1986	Catalyst Energy Corporation through EBASCO	Sidney A Murray, Louisiana U.S.A.	8	6.1	25.0	52.2	8.20	Generator speed 600 rpm
1986	Fourth Branch Associates	Mohawk, New York U.S.A.	1	4.42	3.2	70.0	4.50	Pier Type Unit Generator speed 900 rpm
1987	Bastusels Kraft AB	Bergnäs	1	5.6	8.8	83.3	4.90	Pier Type Unit Generator speed 750 rpm
1987	Bastusels Kraft AB	Slagnäs	1	4.7	6.8	83.3	4.90	Pier Type Unit Generator speed 750 rpm
1987	Kemijoki Oy	Kokkosniva, Finland	1	10.3	24.3	94.0	5.80	
1990	Pohjolan Voima Oy	Isohaara, Finland	2	12.2	28.5	93.8	5.80	
1990	Kemijoki Oy	Kurkiaska, Finland	1	11.4	30.3	100.0	5.80	
1992	Consolidated Hydro Inc.	Eagle Phenix, USA	2	6.7	12.6	95.0	4.95	Pier Type Unit Generator speed 600 rpm
1993	Kemijoki Oy	Matarakoski/Finland	1	6.0	9.7	87.0	5.00	Pit Type Unit Generator speed 750 rpm
1994	UPM-Kymmene Oy	Äetsä/Finland	2	6.2	7.33	98.0	4.40	Pit Type Unit Generator speed 750 rpm
1995	Pato Osakeyhtio	Myllkoski, Finland	2	8.3	12.2	93.8	5.00	Pit Type Unit Generator speed 600 rpm
1996	Guigang Department	Guigang/China	4	8.5	30.9	79.0	6.90	

Kværner Energy a.s

Business Area, Hydro Power

The full range of turbines

Apart from Bulb Turbines we also produce a full range of turbines in sizes from 0.3MW to the very largest sizes.



Control Equipment

We produce a range of electro-hydraulic control units together with complementing oil pressure units suitable for all types of turbines.

Gates & Penstocks

Since the design, delivery and installation of our first gate in 1880, we have supplied most types of gates ranging in size from 200mm to 38.6m span to over 50 countries. We have produced penstocks of a wide variety of diameter with wall thicknesses up to 90m in high tensile steels for static heads up to 1186m.

Valves

In addition to lattice blade butterfly and spherical valves for turbine isolation and penstock protection, we produce a variety of different types of valves for a wide range of water control duties.

Rack Cleaning Equipment

We produce a variety of rack cleaning equipment covering the range of 2.0m to 4.0m width and with rake clearances up to 1200mm.

This page shows only part of our range of products. Our scope of supply also includes: Refurbishment and Upgrading, Repair, Training Schemes and Special Products for Hydro Services, please apply for the appropriate brochures.

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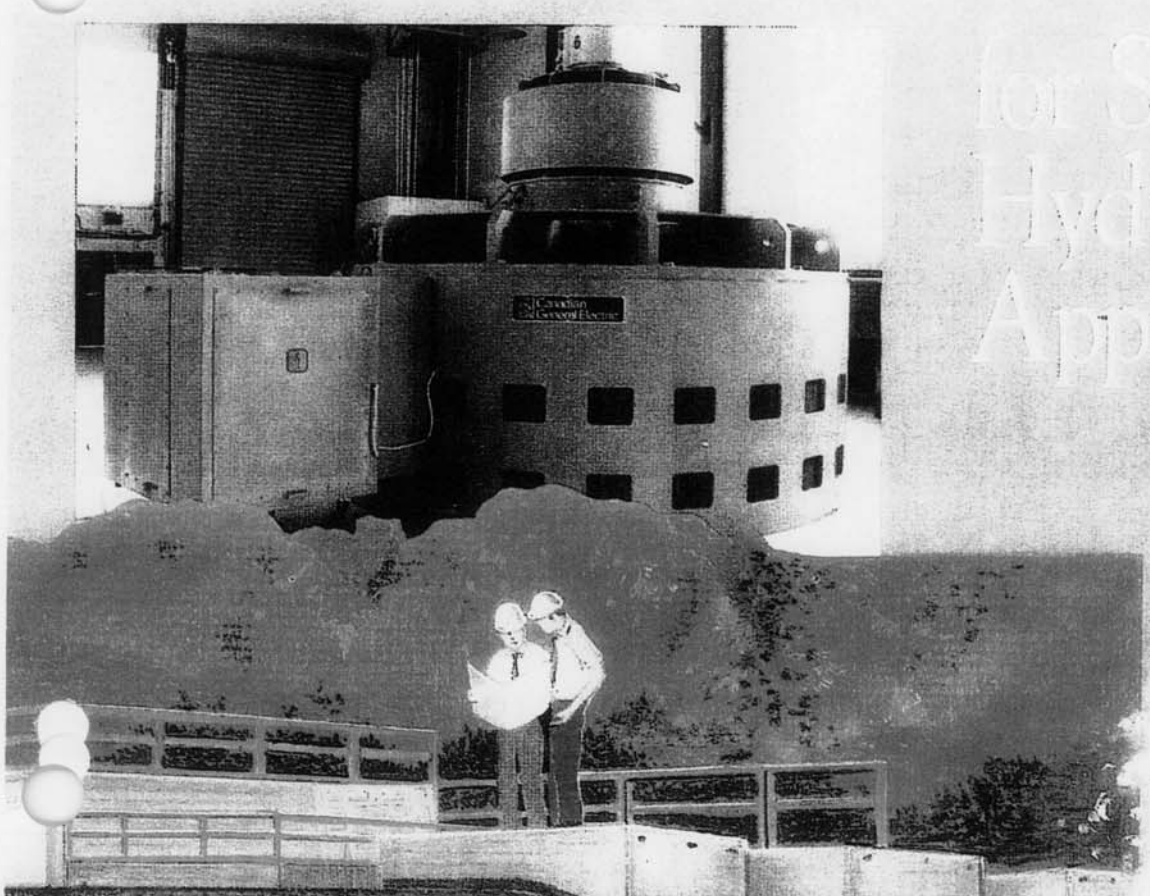
Produced by Warwicks UK Ltd., Coventry, England

Synchronous Generators

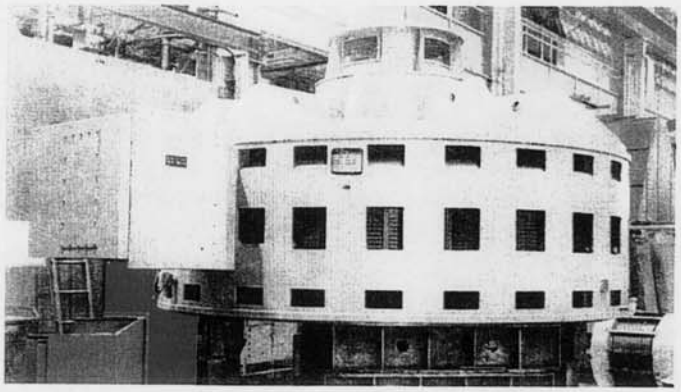
for Small Hydroelectric Applications

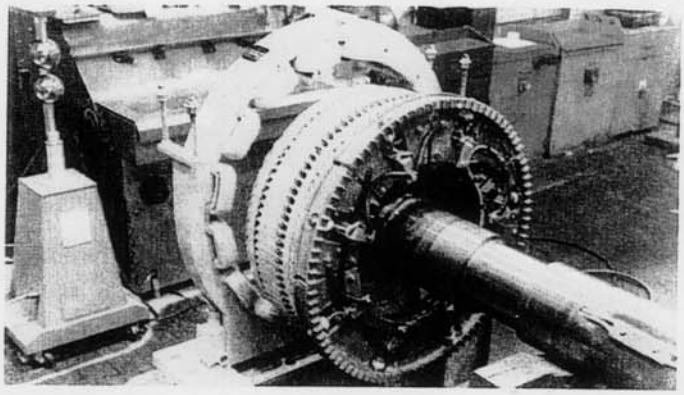


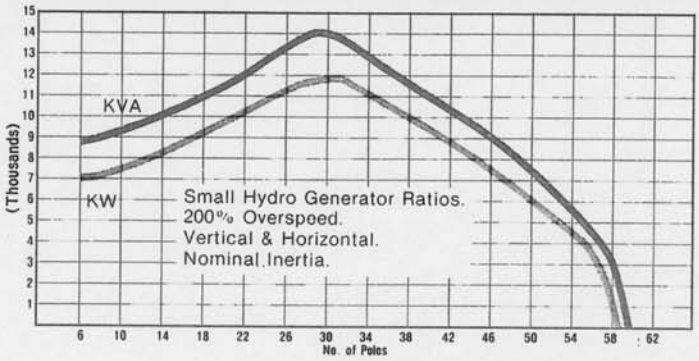
Canadian General Electric

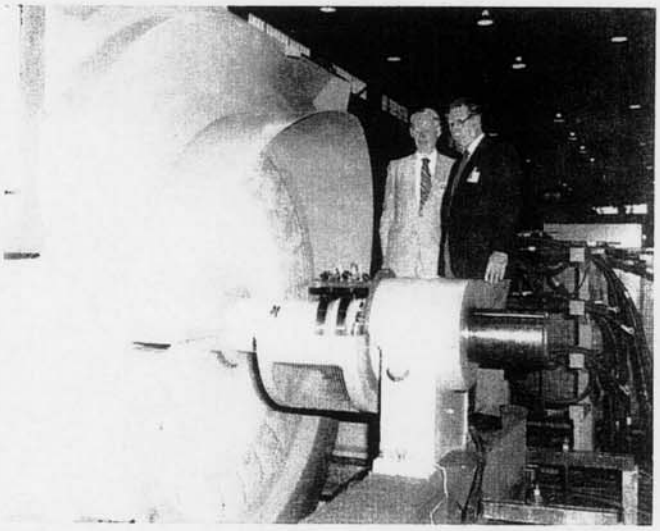
Introduction

Brushless Excitation System







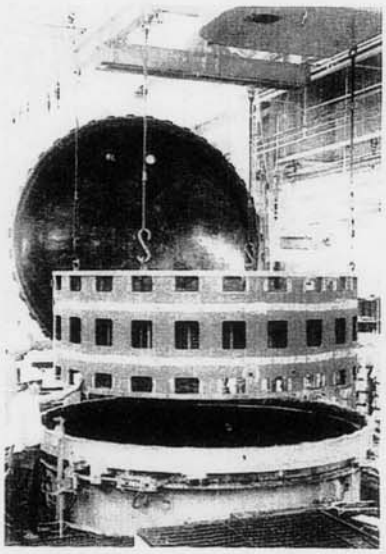


Horizontal and vertical generators designed to North American Industrial Standards (NEMA) are now being used on Small Hydro Electric applications. The small hydro generator is one that is completely factory assembled and tested. The stator is manufactured with a Class F VPI winding where site splicing and winding is not required. The designs are based on being able to withstand the centrifugal forces exerted by overspeed conditions, staying within size constraints to allow proper cooling and still be built as a completed factory unit. Generators exceeding these constraints will be referred to CGE Hydro Generator marketing.

Low Maintenance

Although Canadian General Electric has a full line of slip ring synchronous motors, the shaft mounted brushless excitation system is most generally used across all segments of industry. Brushless excitation requires less maintenance with no brushes to change and is ideally suited for hazardous or contaminated environments. The system includes the easily controlled stationary exciter field, the exciter rotating element in which multiphase ac power is generated, plus the rotor-mounted rectifier system consisting of silicon diodes, thyristors and static switching devices. The system is selected to be the simplest functional design for maxi reliability.

Insulation

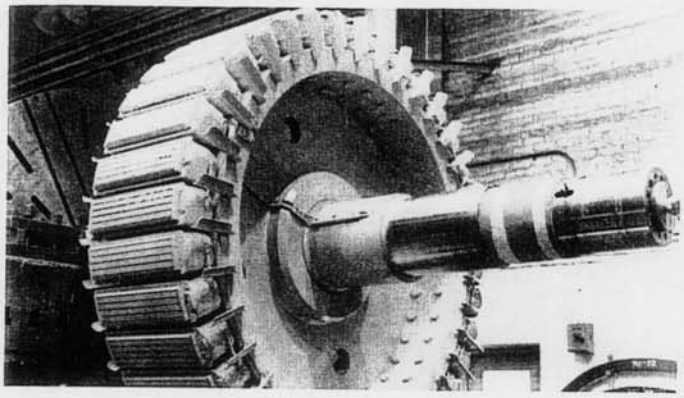


High Dielectric Strength, Stable, Contaminant Resistant

The stator coil insulation is rated Class F and features MICA MAT® ground wall insulation and epoxy vacuum-pressure impregnation. This MICA MAT® insulation provides the high dielectric strength needed between the coil and ground. All coils are over wrapped with a protective glass tape armor. Once the coils are inserted and locked into the stator slots, the entire core assembly is vacuum-pressure impregnated (VPI) with General Electric developed epoxy resin and is cured in a temperature controlled oven.

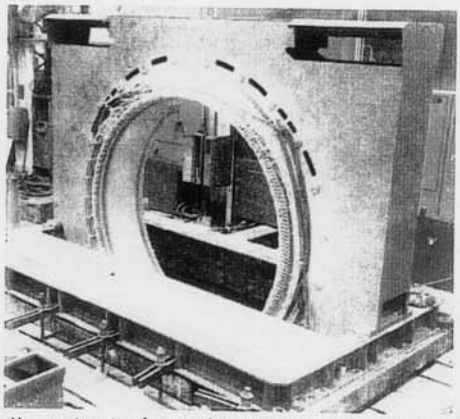
The process binds stator components into a solid, homogeneous structure with excellent dielectric strength, dimensional stability, mechanical strength and provides resistance to thermal shock and contaminants.

Synchronous Rotor



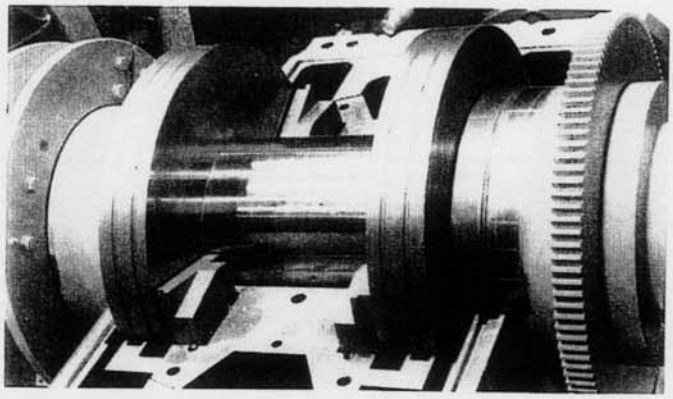
The salient pole synchronous rotor is performance designed primarily for high efficiency. Because of the overspeed requirements of a hydrogenerator some rotors will have a punched spider dovetail design rather than a rolled rim design. For smaller ratings, the field windings consist of rectangular sections of insulated copper wire wound directly on the insulated pole body and bonded by a high temperature, high strength, insulating epoxy resin. When cured, this results in a Class F insulated coil highly resistant to dirt, moisture and other contaminants. Field windings for larger motors are edge-wound copper strips with dimensionally stable insulating materials bonded between turns to form a high strength coil.

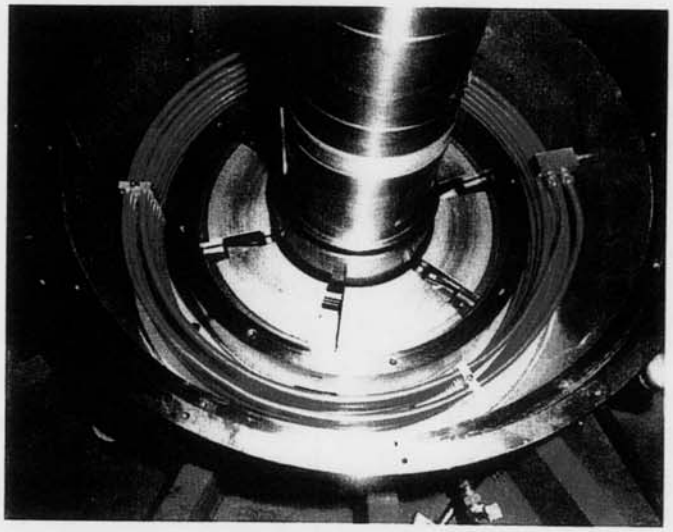
Stator Frame



Stator laminations are precision punched from high quality, low loss electrical sheet steel and coated with a thermally stable insulating film to minimize eddy current losses. The laminations are assembled in accurate alignment around a cylindrical mandrel of the correct diameter to form the stator core. At short intervals, ventilation ducts formed from sturdy "I" beams extending the full length of the teeth are electrically spot welded to the laminations. The core is clamped under heavy pressure between the two deep side plates of the frame by means of closely spaced through bolts. These plates are continuously welded to the substantial wrapper plate. Rectangular steel-block feet are continuously filet-welded to the side and wrapper plates to afford a sturdy, firm, stator support. This special-designed welded joint reinforces the critical mounting area to withstand the forces imposed on it. The resultant channel shaped frame, fabricated entirely of electrically welded steel sections, is extremely rigid and strong, yet comparatively light in weight. The strength of this frame maintains a uniform air gap under all operational stresses.

Bearings





A heavy cast iron pedestal supports the bearing in a spherical seat. The oil well is located in the center of the pedestal. The pedestal is horizontally split to facilitate easy removal for inspection and maintenance. Heavy cast steel, spherically seated shells ensure accurate alignment of the shaft and bearing. The babbitt lining is metallurgically bonded to the shell thus providing high mechanical strength and good heat transfer.

Oil rings, rotating through the oil well and over the shaft, carry oil to distribution grooves designed to supply adequate lubrication to the entire bearing surface. Split oil rings, together with a split shell, afford easy removal and replacement without disruption of installation alignment.

Because of the amount and duration of overspeed in hydrogeneration applications it is usual to have force flood lubricated bearings. On vertical assemblies, multi pad self-equalizing thrust bearings designed to meet the thrust requirement of the turbine generator set are incorporated.

Assembly

Rigid Support of Motor Components

The non-self supporting fabricated base on a horizontal generator is fabricated from rolled structural steel members electrically welded together to form a strong, rigid but lightweight structure. The base has sufficient strength to ensure rigidity and proper motor alignment when supported by a firm foundation.

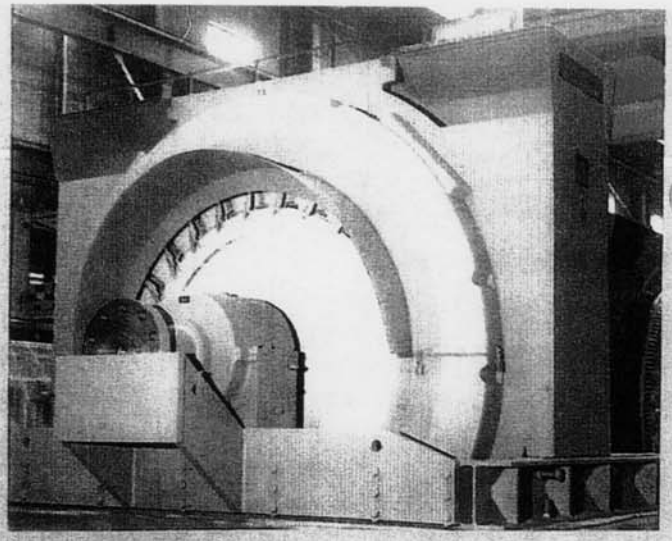
The completed rotor and stator are carefully assembled with the bearings on the base. They are aligned and firmly bolted to the base at the factory. Correct mounting positions are carefully marked. Liquid dowel kits are provided to permit final doweling after installation, thereby helping to ensure accurate permanent alignment of the main elements of the assembly.

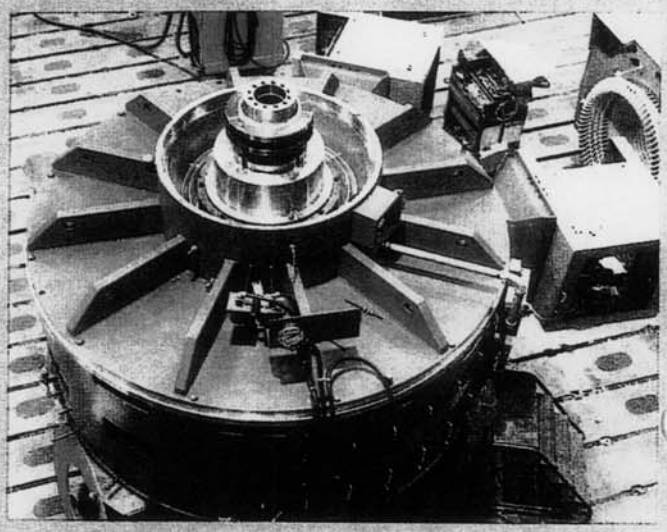
CGE experience recommends the inclusion of a non-self supporting fabricated base as factory standard.

However, for those customers who opt to install the horizontal generator components (i.e. the stator and bearing pedestals) directly on concrete foundations, sole plates and anchor bolts will be supplied in lieu of a non-self supporting fabricated base.

The vertical generator has a fabricated cylindrical stator frame which supports the upper thrust bearing.

Vertical generators are manufactured with a mounting flange as an integral part of the frame. Sole plates and anchor bolts can be supplied as an option, if requested.



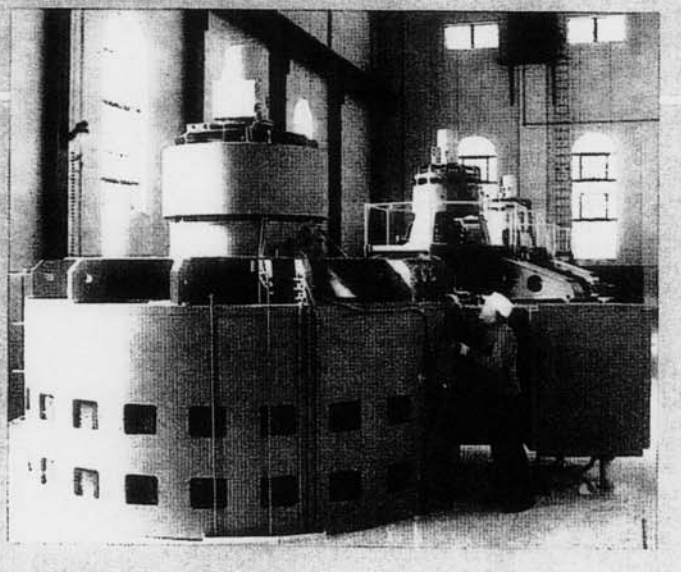


Service

From the time you begin planning a new installation, application assistance from the Canadian General Electric motor team will make your job easier and less time consuming.

Our field engineers can provide you with complete system installation start-up assistance, on-site maintenance services that include periodic inspections and tests, and training of your operating and maintenance personnel.

General Electric has more than 150 service shops worldwide, located near our customers. These service shops will provide complete "in or out of" warranty service, including preventive maintenance. In the event of an emergency, General Electric service shops — with factory backup — offer fast, expert repair service — world-wide — anytime, anywhere.



For Further Information Contact:

CANADIAN GENERAL ELECTRIC COMPANY LIMITED MOTORS AND DRIVES MARKETING
107 Park St. North Peterborough, Ontario K9J 7B5

Canadian General Electric

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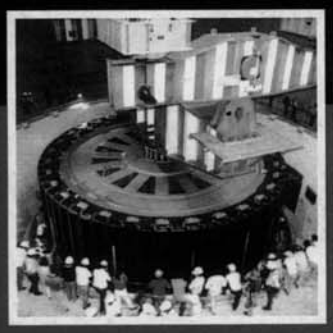
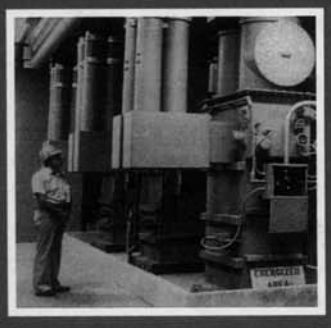
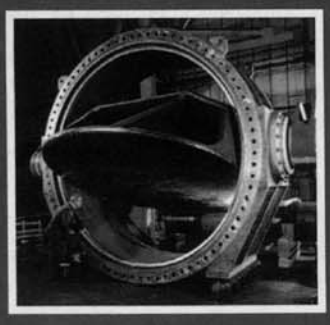
GE Hydro

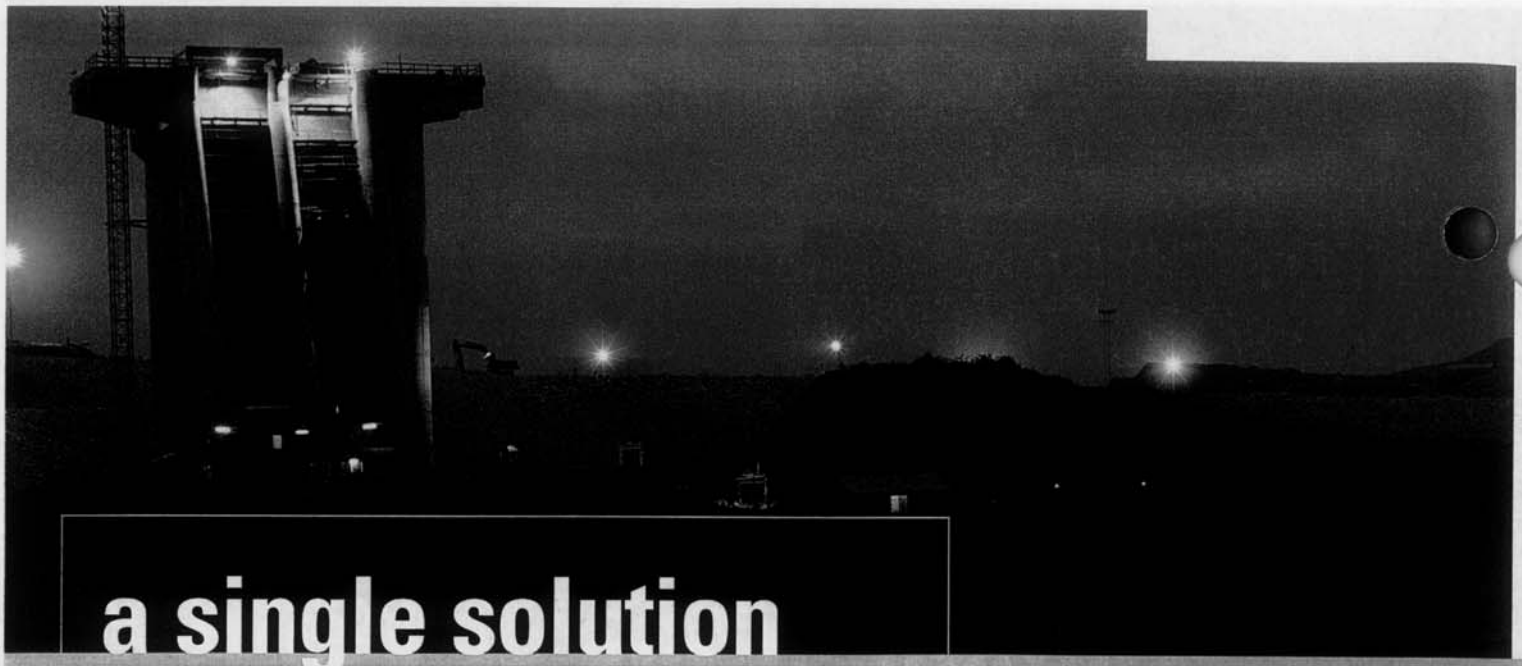
innovation

in water









a single solution

GE Hydro, a world leader in the utilisation and control of water, is a business unit of GE Power Systems (GEPS), which in turn is one of the eleven major business of the General Electric Company of U.S.A. (GE). GE is a world renowned, diversified engineering, manufacturing and service company with over 220,000 employees.

PSP30292-02

Not just a supplier of power generation technology, services and energy management systems, GEPS. with over 190 locations worldwide, is a company providing total energy solutions to its customers, "wellhead to consumer" is a proudly promoted GEPS business philosophy. GE Hydro applies the same best business practices, interpreting GEPS's business philosophy as "water to wire". As a world leader in the supply of equipment for hydro power and water control, GE Hydro benefits from its ability to supply this equipment and services through GEPS's global network of offices, service centres and workshops as well as their three regional headquarters in Asia, Europe and America.

GE Hydro, a world leader in the utilisation and control of water, has been manufacturing, supplying, installing and commissioning equipment for more than one hundred years. The continuing expansion of this business, through organic growth and successful acquisitions, has resulted in a company with unrivalled experience and a complimentary range of products and services. The synergy with the customer created by GE Hydro's position as a single source eliminates the necessity for the customer to deal with multiple suppliers and ensures efficient completion of projects using the most economic solutions.

GE Hydro designs, engineers, manufactures and supplies the full range of hydro power equipment. Its turbines and generators are some of the largest and most efficient in the world. Since 1848, when our first turbine was delivered, GE Hydro has delivered thousands of hydro turbines of all types, of the most modern designs for the smallest as well as the largest projects, totalling over 150,000 MW in output.

Continuous research and development, carried out in its laboratories located in America and Europe, enables GE Hydro to supply equipment to meet the most complex and rigorous operating regimes, onerous site conditions and increasingly demanding customer requirements.

PSP30292-03

GE Hydro's products include:

HYDRO TURBINES Francis, Pelton, Kaplan, propeller, bulb and single stage, reversible pump

HYDRO GENERATORS - MOTOR/GENERATORS Low to high speed. Air or watercooled. Up to 1,000 MVA

VALVES Spherical, butterfly, needle, multi port, and sliding sleeve, fixed cone

GOVERNORS All electro-hydraulic types

PENSTOCKS Surface mounted or covered, tunnel and pressure shaft linings, bifurcations and trifurcations

GATES All hydro power and water control types

TRASH RACK CLEANING EQUIPMENT Various types and sizes

ISOLATED PHASE DUCTS & ASSOCIATED EQUIPMENT Isolated phase bus duct. Min-I-phase bus duct. potential transformers and surge protection cubicles. Neutral grounding cubicles. Neutral ties. Disconnect switches (telescopic & blade type)

GE Hydro's services include:

REHABILITATION

Condition assessment repair, refurbishment, upgrading and uprating

CONSULTANCY

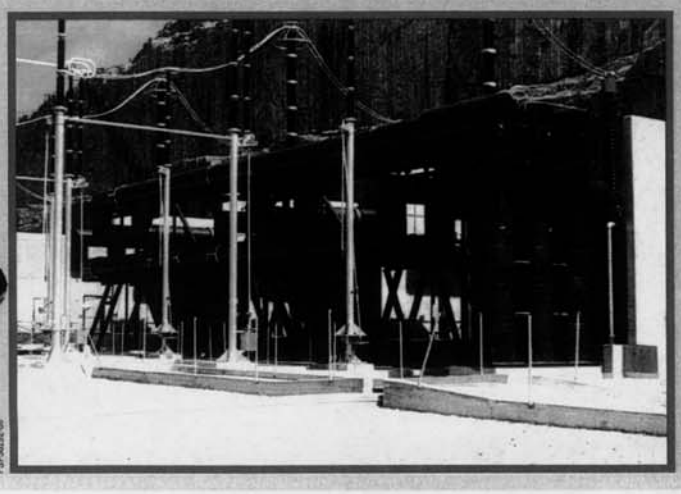
Services direct to utilities, generators, distributors and developer groups:

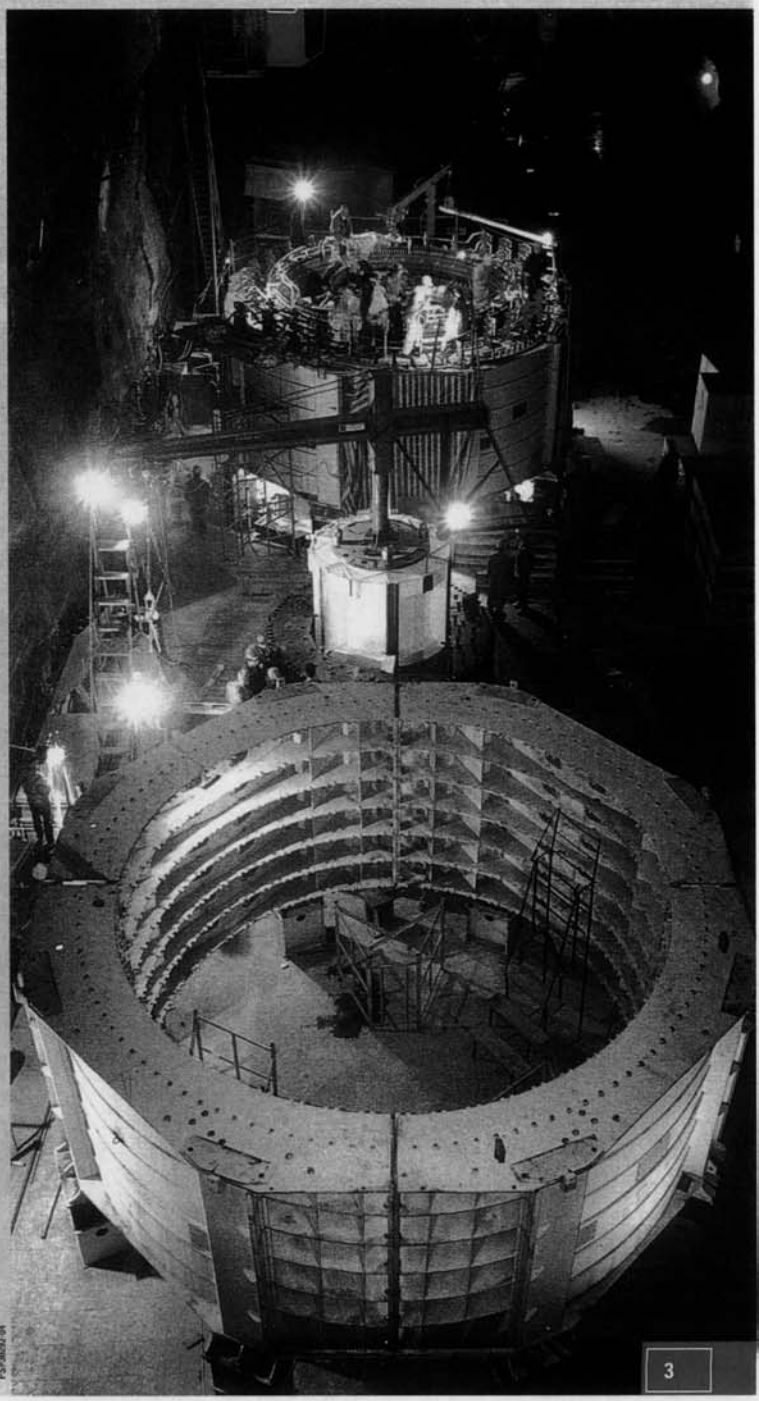
- Condition assessment
- Life time assessment
- Structural integrity
- Operation & maintenance studies
- Transient analysis
- Operating range improvement
- Energy production studies and optimisation
- Ampacity studies
- Field supervision

TRAINING

For past, existing and prospective customer:

- Complete hydro power design and engineering
- Project management
- Erection and commissioning
- Operation & maintenance





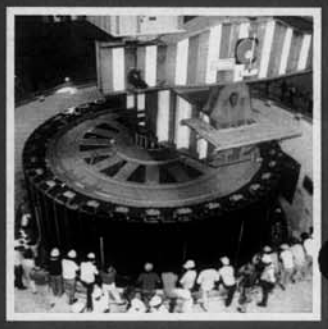
GE Hydro is a truly international organisation with its head office in Oslo administering operations located in all the major markets around the world.

a wealth of experience

GE Hydro with facilities in Canada, Sweden, Finland, UK, Australia ,USA. China, Brazil and the previously mentioned Norway offers potential, new and existing customers the opportunity to work with an organisation with an unrivalled history in the worldwide development in the control and utilisation of water.

Among these achievements are:

- The design, manufacture and installation of the world's first large Kaplan turbine
- The design, manufacture and installation of the world's first high head, single stage, reversible pump turbine
- The highest rated hydro-electric generators in the world
- World's largest self-cooled isolated phase bus duct

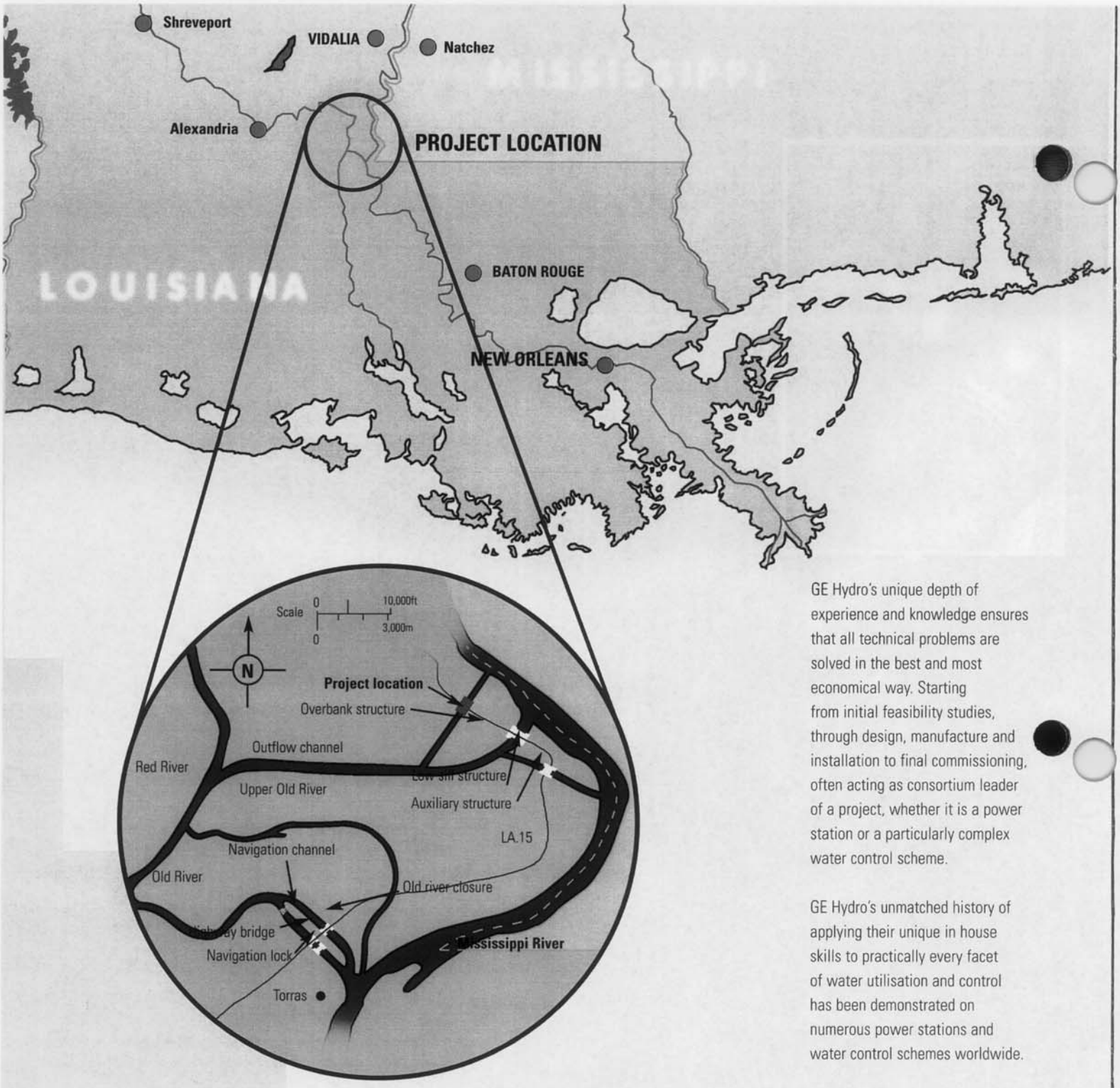


To complement these the group has been responsible for many record breaking developments in extending the barriers with regards to efficiency, size of machine, heads utilised, flows accommodated among others,

GE Hydro business philosophy ensures that the wealth of expertise, technical skills and experience in the design and construction of hydroelectric power stations and water control projects within the group is utilised on all projects.

It is this kind of international approach that enables GE Hydro to provide their unrivalled service.

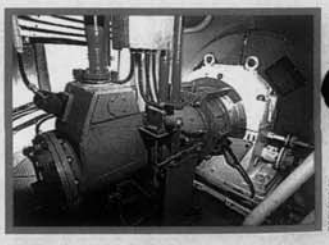
GE Hydro's policy is to share their knowledge with their potential and existing clients to help them to develop their businesses for greater efficiencies and growth.



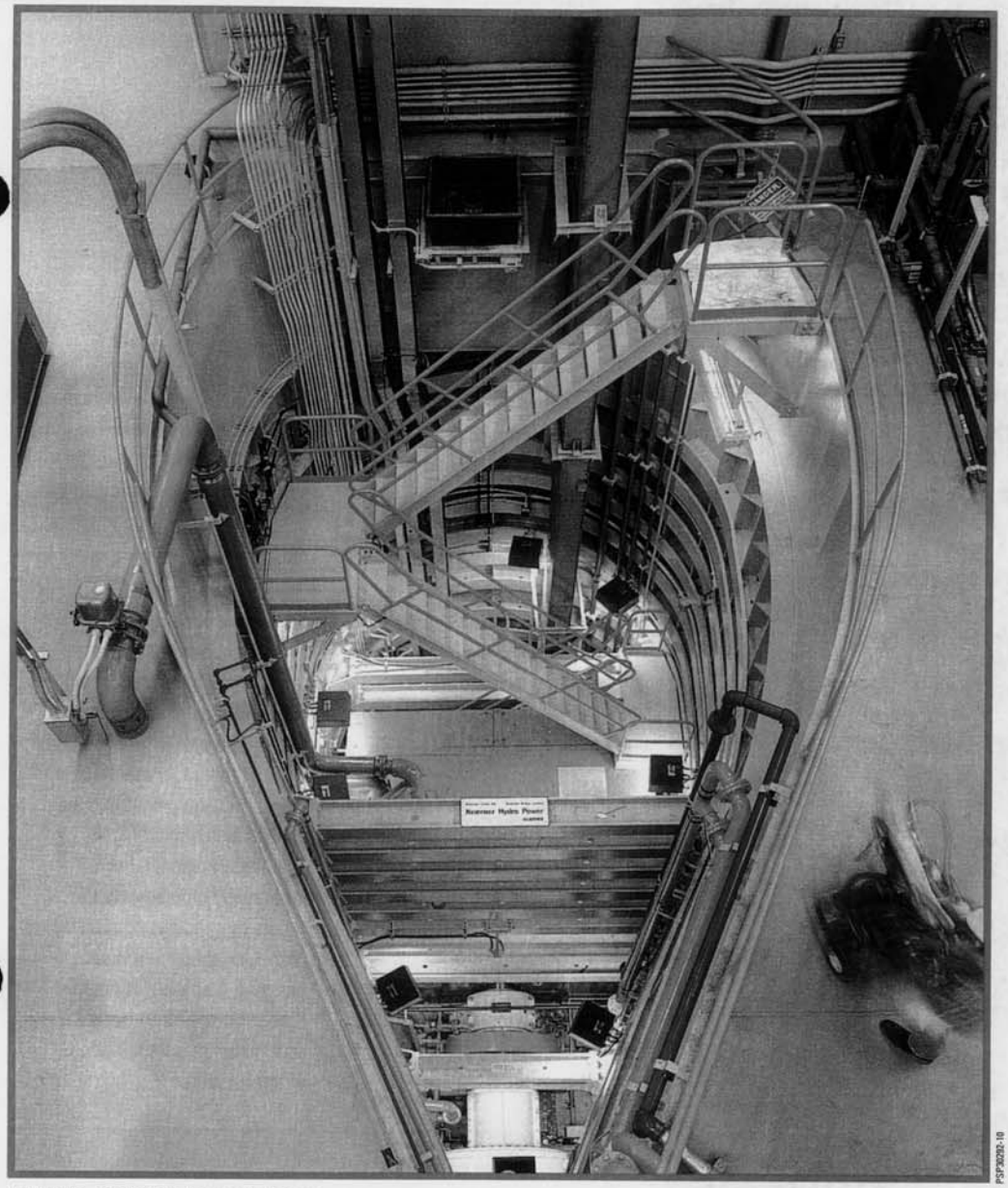
GE Hydro's unique depth of experience and knowledge ensures that all technical problems are solved in the best and most economical way. Starting from initial feasibility studies, through design, manufacture and installation to final commissioning, often acting as consortium leader of a project, whether it is a power station or a particularly complex water control scheme.

GE Hydro's unmatched history of applying their unique in house skills to practically every facet of water utilisation and control has been demonstrated on numerous power stations and water control schemes worldwide.

project development



■ *Runner blade controls*



■ *Turbine, gearbox and generator layout*

A typical example of such a project was the Sidney A Murray. Jr. hydro power station for which GE Hydro's contract included the design of the waterways, bulb structures and downstream gates, and the supply of eight bulb turbines with step-up gear units, bearings, together with the installation and commissioning of all equipment supplied.

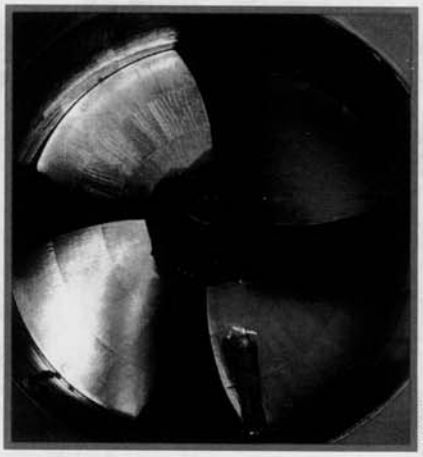
The 192 MW bulb turbine installation. Comprising a 24,000 tonnes prefabricated power house, which was built in a shipyard in New Orleans, USA then floated 320 kilometres up the Mississippi river to the power station site. This solution was selected for two main reasons:

1. The overall project construction time could be reduced by at least 12 months, with the civil work being carried out on site at the same time as the power house was being constructed in the shipyard.

2. The skills and crafts required for the construction of the power house were more readily available at the shipyard.

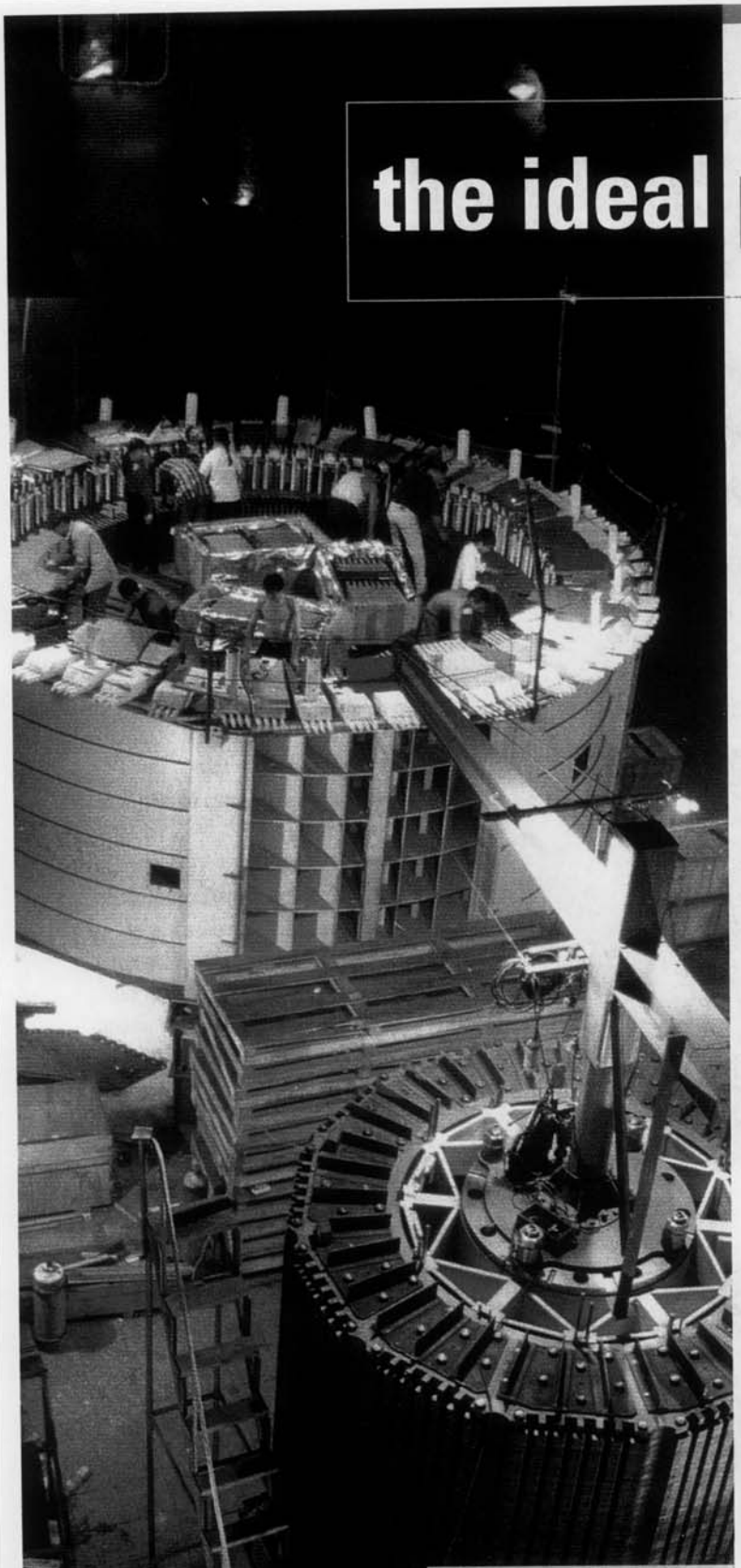
The end result was completion of the installation six months ahead of the projected completion date even taking into consideration this innovative solution.

■ *Transportation up the Mississippi River*



■ *Runner inspection*

the ideal partner

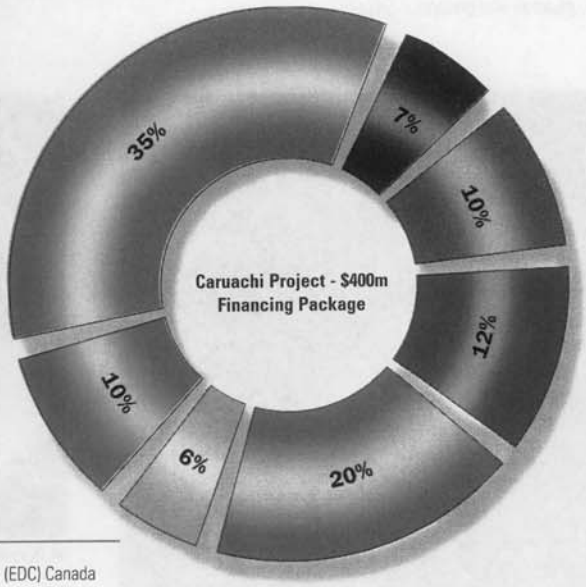


With locations in the world's major money markets and their highly skilled team of financial experts, GE Hydro are the ideal partner to raise finance for proposed projects.

This ability was demonstrated by the Caruachi project in Venezuela. GE Hydro as leader of an international consortium raised sufficient finance on the world market to allow this multi million dollar project to come to fruition.

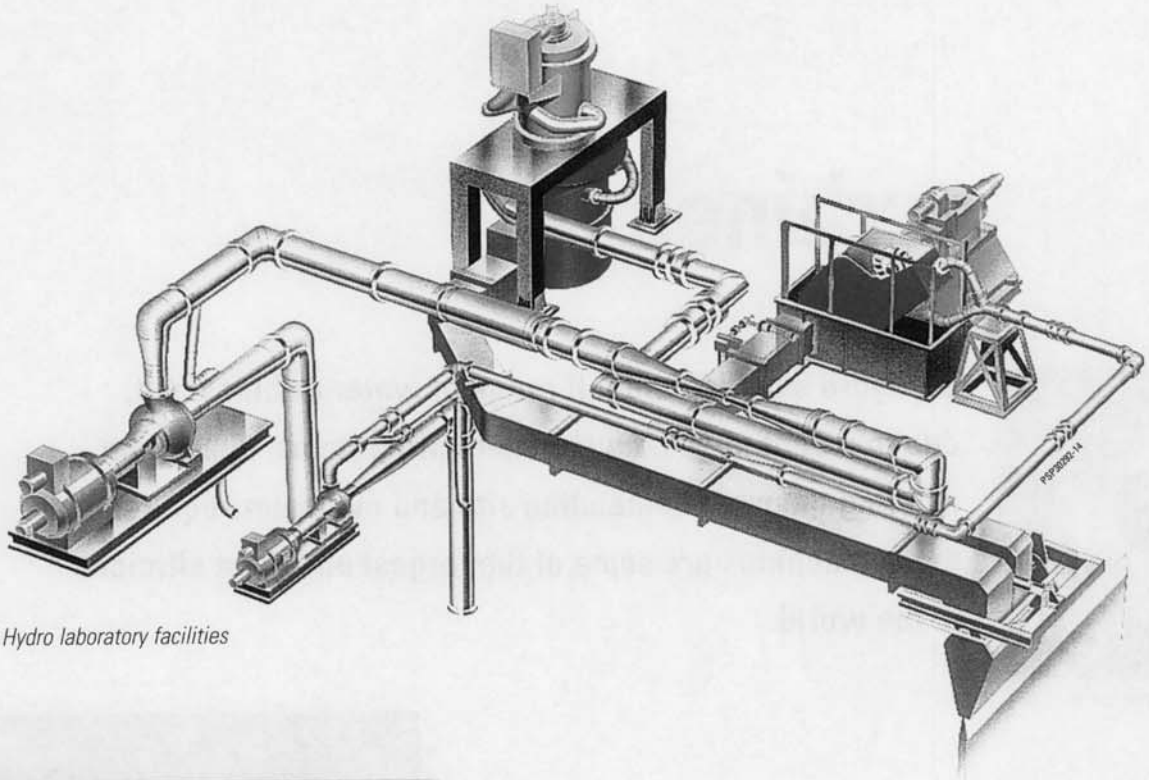
In addition to this GE Hydro is heavily involved in the financing and eventual ownership of hydropower projects. To this end GE Hydro has already invested a considerable amount of its own money and expertise in a number of schemes worldwide, to develop them from green field sites to completion often as full or partial owners/operators. This involvement is evidence of GE Hydro's confidence in its own ability to select suitable economical sites and to choose the correct equipment to extract the maximum output.

GE Hydro's wide range of hydraulic machines is backed by internationally recognised hydraulic machine laboratories. These laboratories use the latest, state of the art, computerised measuring equipment and are staffed by teams of highly qualified personnel. Each laboratory complements the others by specialising on different ranges of equipment, thus ensuring that there is no duplication of effort but a continuous cross pollination of information.

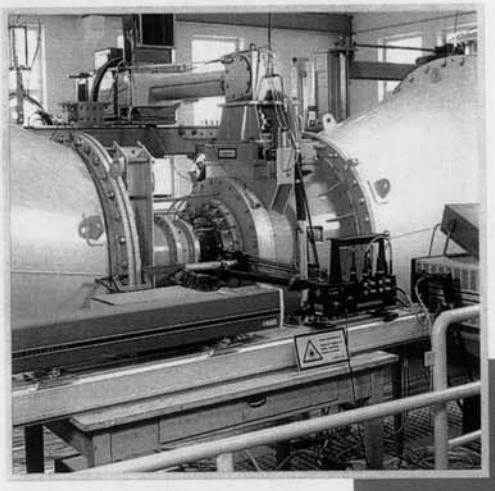


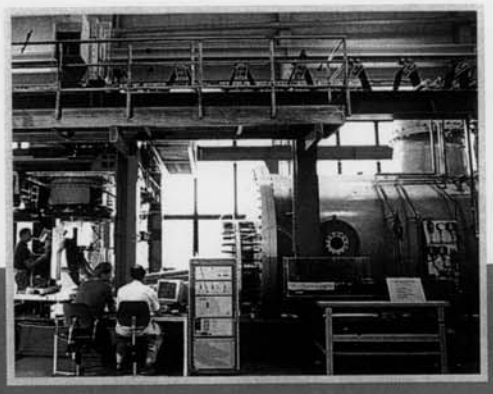
Key:

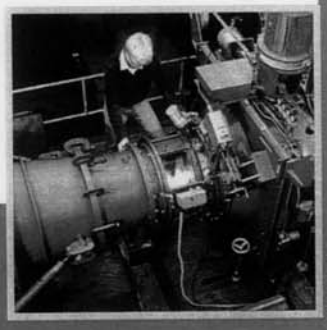
- Export Development Corporation (EDC) Canada
- Finnish Export Credit (FEC) Finland
- Skandinaviska-Enskilda Banken (SEB) Sweden
- Eksportfinans (Norway)
- Nordic Investment Bank (NIB)
- Corporacion Andina de Fomento (CAF)
- Creditanstalt Bankverein (Austria)

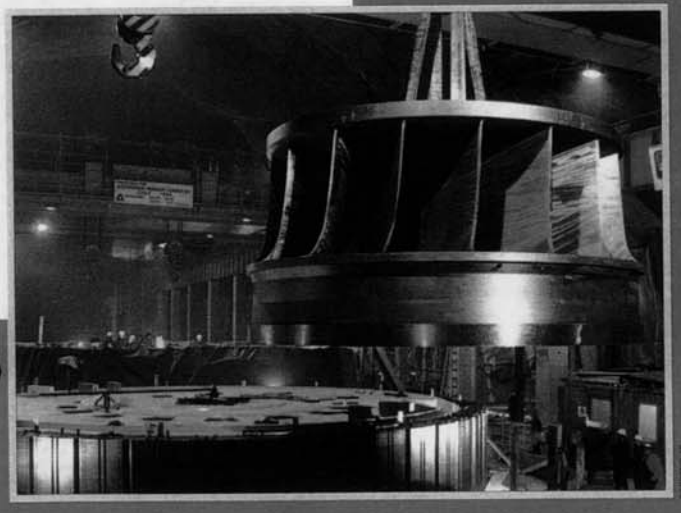


■ *GE Hydro laboratory facilities*









■ *Installation of 5.2 m Francis runner and rotor for 240MW generator*

turbines

■ *4.06m diameter runner*

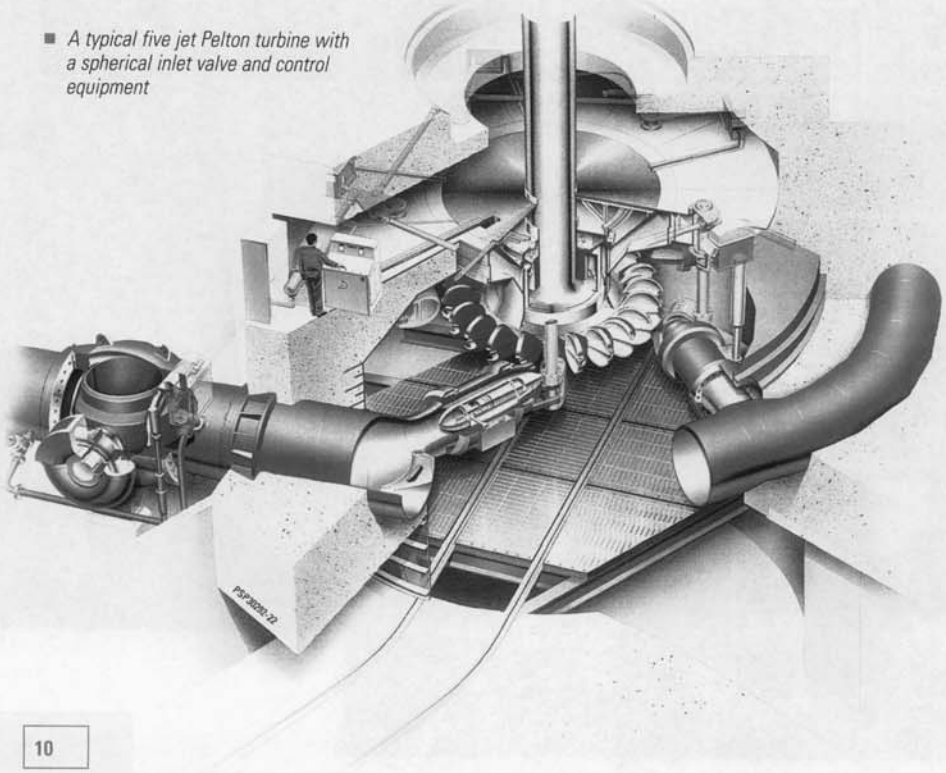
GE Hydro supplies the full range of water turbines and, due to a continuous development programme, apart from meeting the most demanding site and customer requirements these machines are some of the largest and most efficient in the world.

PELTON

Our Pelton turbines are among the largest installed in the world with outputs up to 500 MW, runners over 5.0m diameter and heads in excess of 1,200m.

■ *6 jet turbine installation*

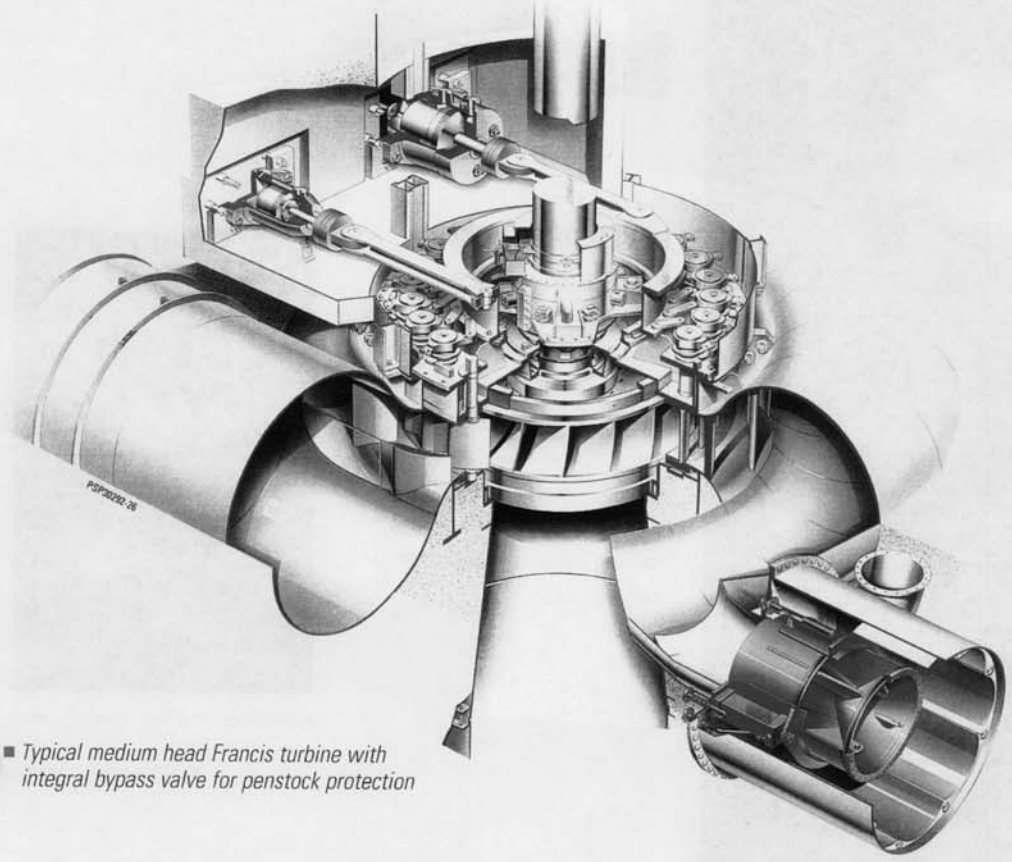
■ *A typical five jet Pelton turbine with a spherical inlet valve and control equipment*



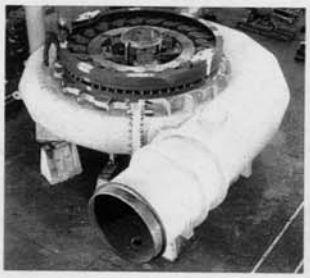
■ *Finishing Runner*

FRANCIS

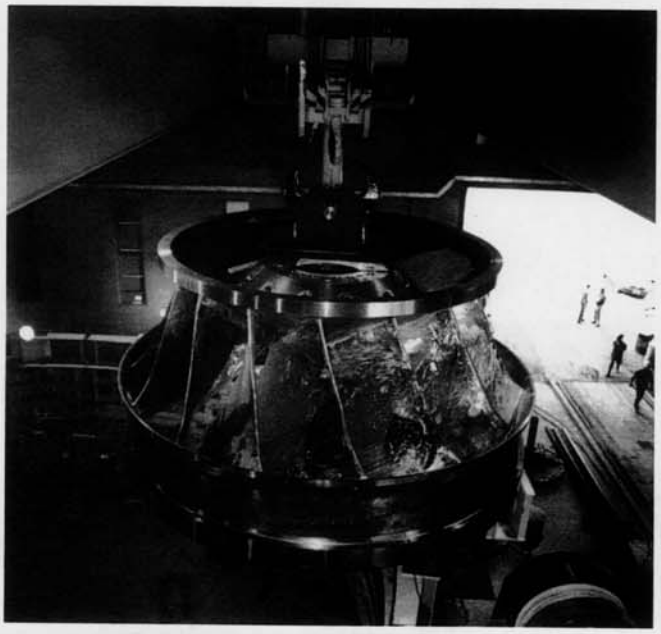
GE Hydro's Francis turbines suit the full range of heads and specific speeds associated with this type of turbine and are available for outputs over 800 MW, runner diameter in excess of 9.00m and heads up to 800m.



■ *Typical medium head Francis turbine with integral bypass valve for penstock protection*



■ *Shop assembly of one of four spiral casings and guide apparatus for a high head turbine installation*



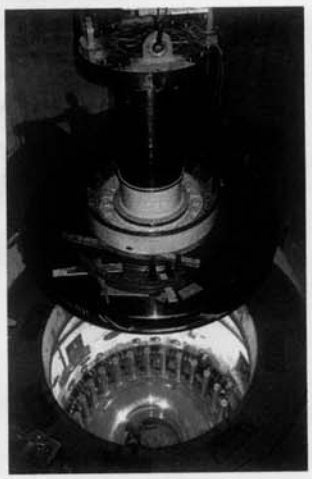
■ *Installation of 7.1m runner*

■ *Transporting one of the 9.4m diameter runners for the Three Gorges scheme in P.R. China*

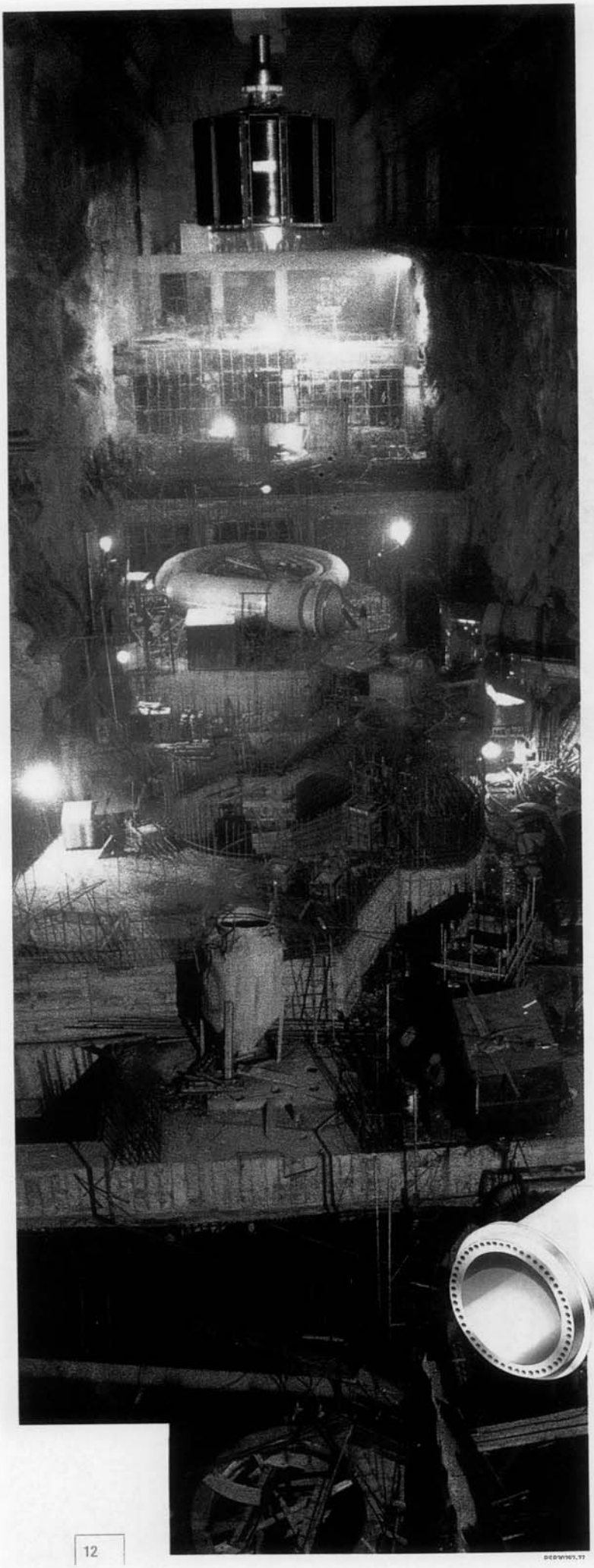
turbines

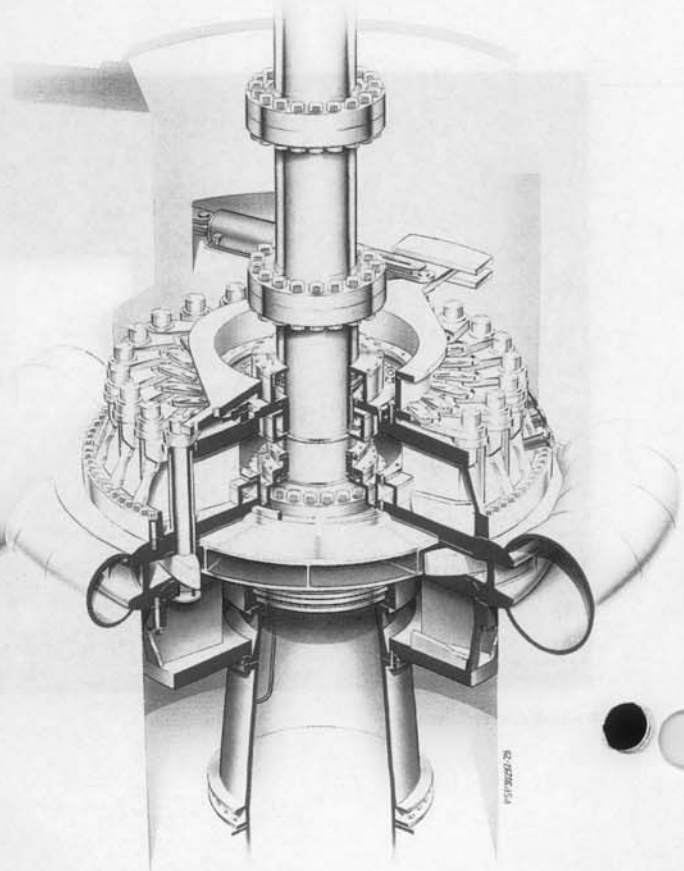
REVERSIBLE PUMP

Since designing, manufacturing and installing the worlds first high head, single stage, reversible pump turbine in 1961, continuous development has perfected this type of machine. Machines with outputs in excess of 500 MW, runner diameters over 5.0m and pumping heads up to 900m are now available.

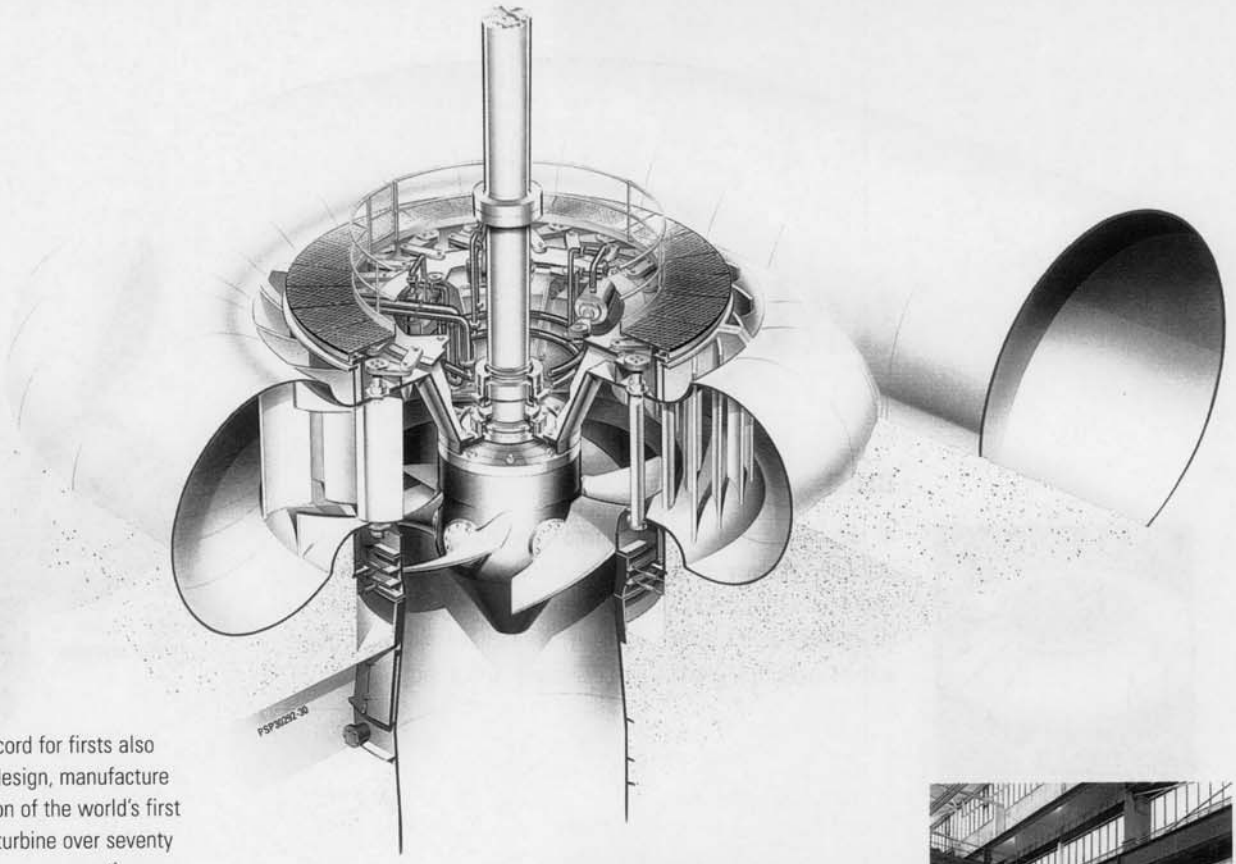


■ *Installation of 4.10m diameter runner*





■ *Typical high head reversible pump turbine*

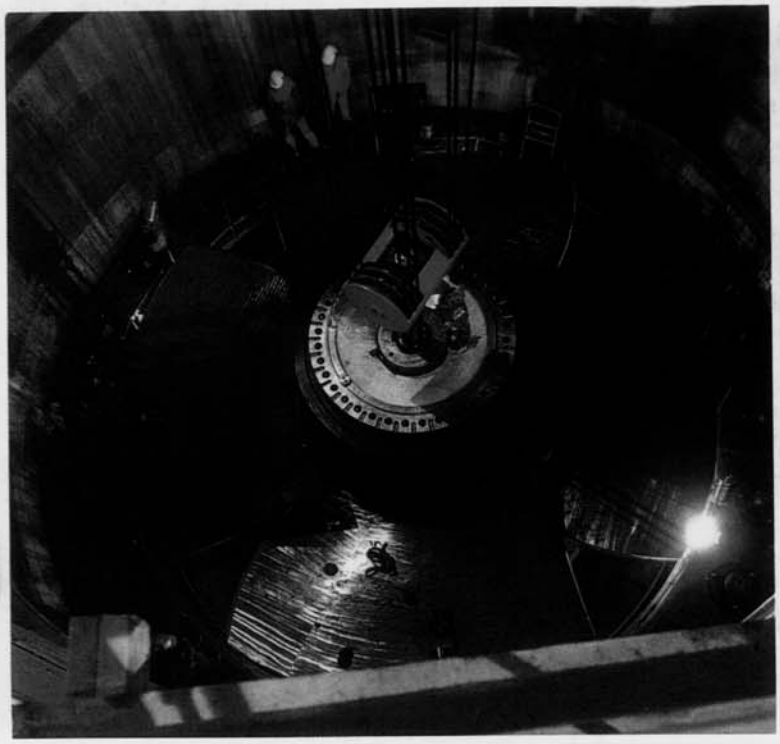


KAPLAN

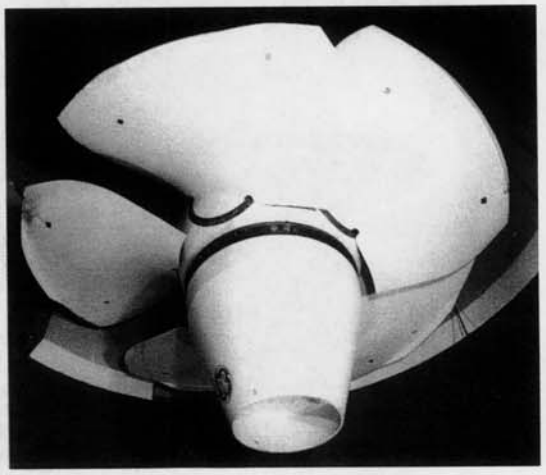
GE Hydro's record for firsts also includes the design, manufacture and installation of the world's first large Kaplan turbine over seventy years ago. Once more continuous development has improved the design of this type of machine and they are now available for outputs over 250 MW, runners over 8.0m diameter and heads in excess of 70.0m.

■ *Kaplan turbine*

■ *Draft tubes during manufacture*



■ *Installation of 8.3 m diameter runner*



■ *Five bladed runner installation*

turbines

BULB

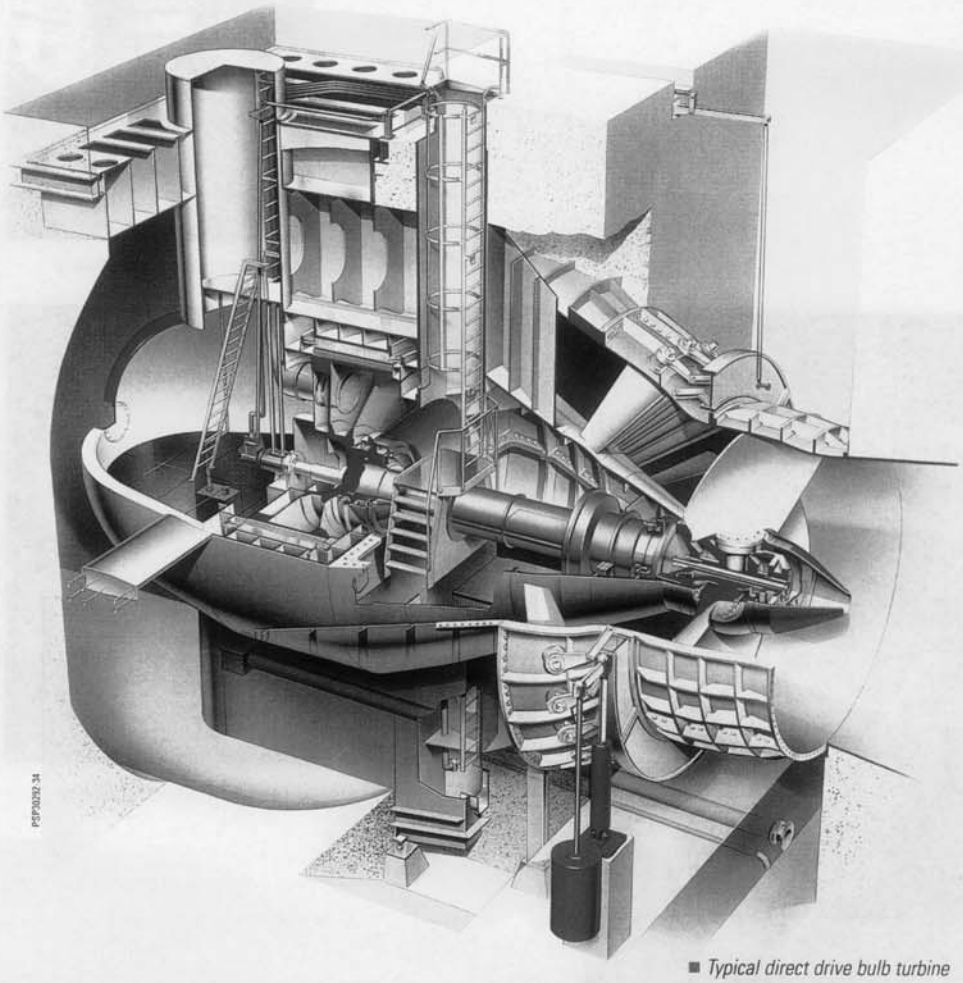
GE Hydro's bulb turbines are designed for reliable operation with high efficiency and easy access. Both direct drive and gearbox driven units have been supplied. Since delivering the first of these machines in the 1950's this type of machine has been manufactured and installed with outputs up to 45 MW and runner diameters up to 8.2m.

PSP30292-35

■ *Shop assembly of guide apparatus*

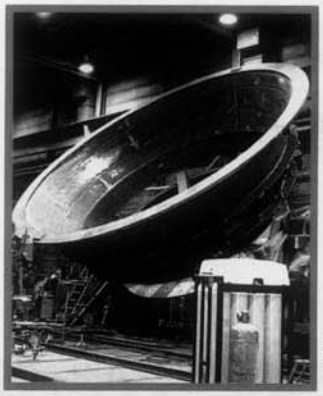
PSP30292-37

■ *6.0m diameter runner assembly*



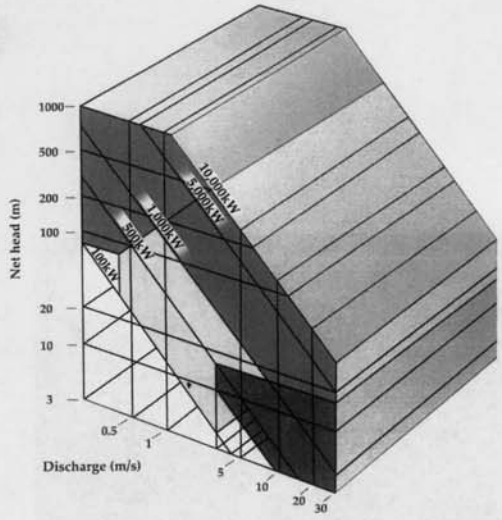
PSP30292-34

■ *Typical direct drive bulb turbine*



PSP30292-36

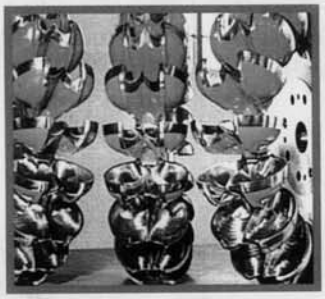
■ *Machining of distributor ring for a 24.3 MW turbine*



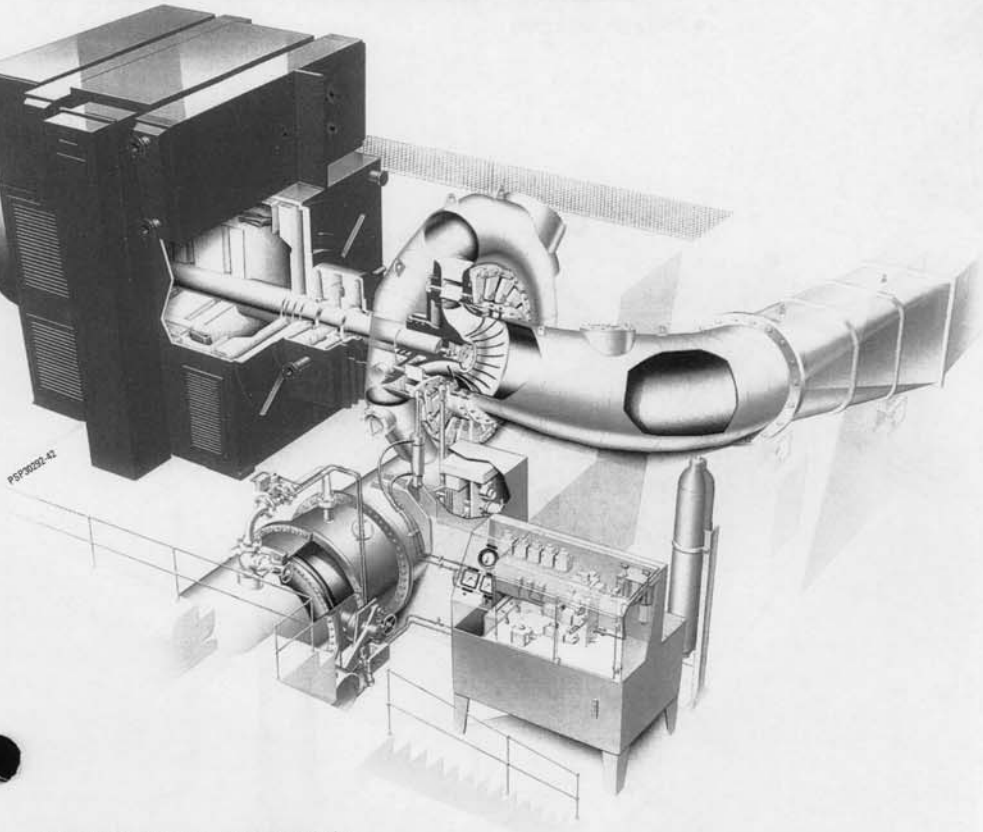
- Pelton Standard design. Adapted to requested site data.
- Francis Standard design. Adapted to requested site data.
- Francis Pre-designed standard.
- Tubular Pre-designed standard.

MINI OR SMALL-SCALE

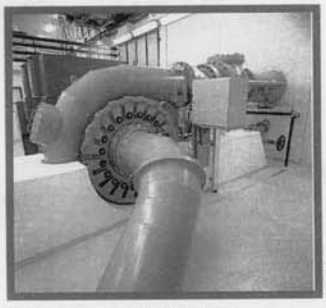
GE Hydro's flexible range of mini or small-scale turbines covers the output range from 0.5 to 10.0 MW and includes Pelton, Francis, Kaplan, semi-Kaplan and propeller turbines. These turbines are designed using the same criteria as for large-scale machines and therefore offer the highest possible reliability and optimum performance at the lowest cost.



■ *Pelton runners for turbines for South America*



■ *Small scale Francis turbine installation*



■ *Francis turbine installation*

■ *Grinding a Francis runner*

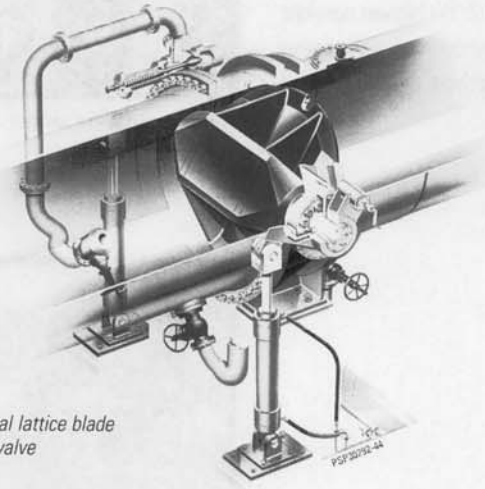
valves & gates

WATER CONTROL EQUIPMENT

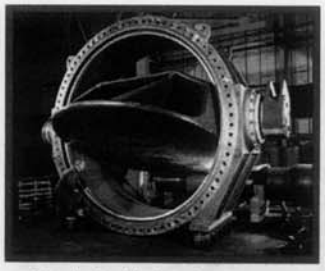
GE Hydro's range of hydraulic equipment extends outside turbines to various types of control equipment.

This equipment covers all types of gates, valves, trash rack cleaning equipment, penstocks, steel tunnel linings, bifurcations and trifurcations. The gate range extends from simple slide to high head roller gate, whereas the valve range covers butterfly, spherical and energy dissipating valves.

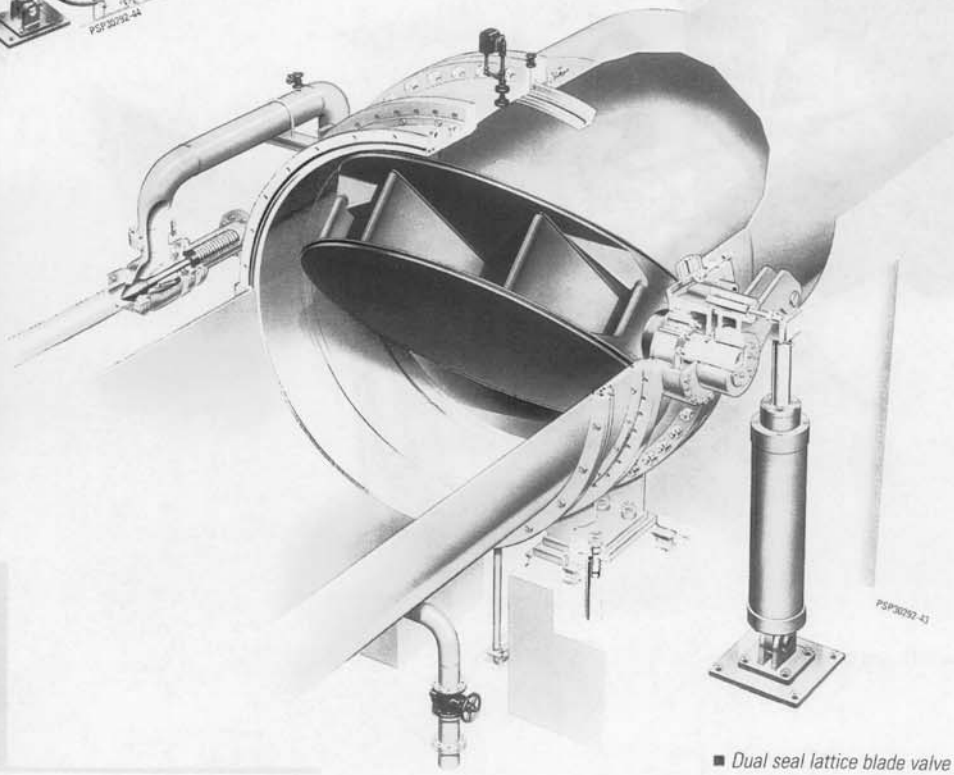
■ *7.5m x 8m radial gates*



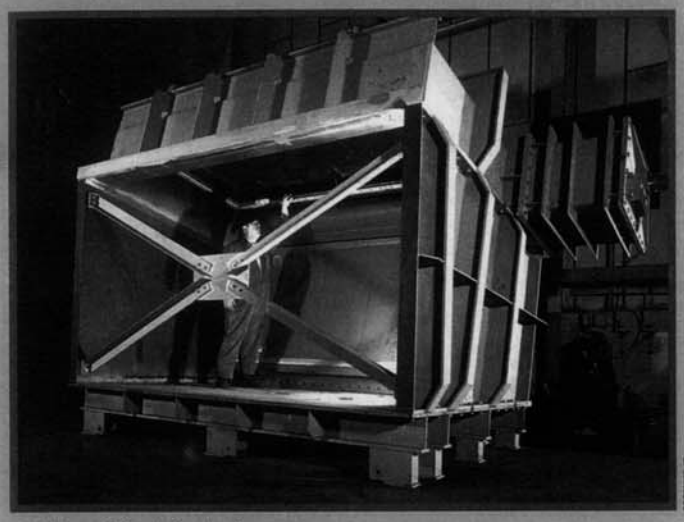
■ *Single seal lattice blade butterfly valve*



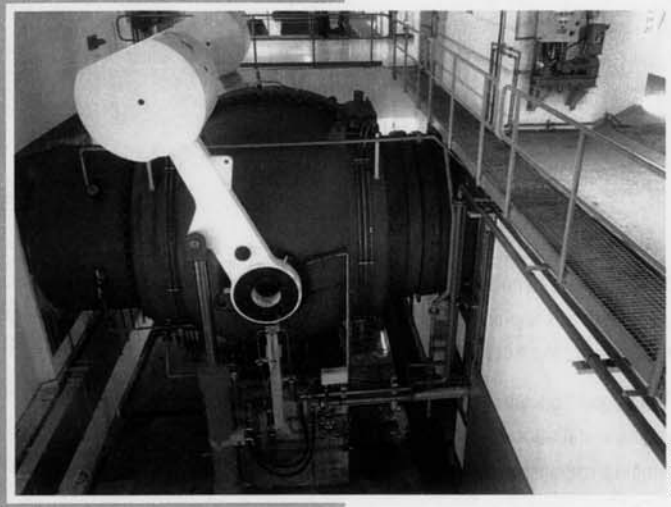
■ *4.0m lattice blade valve*



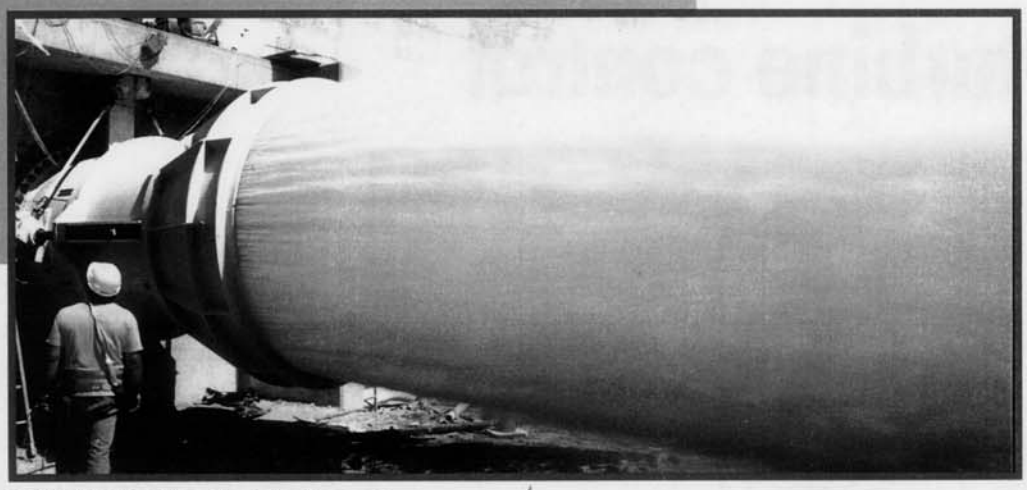
■ *Dual seal lattice blade valve*



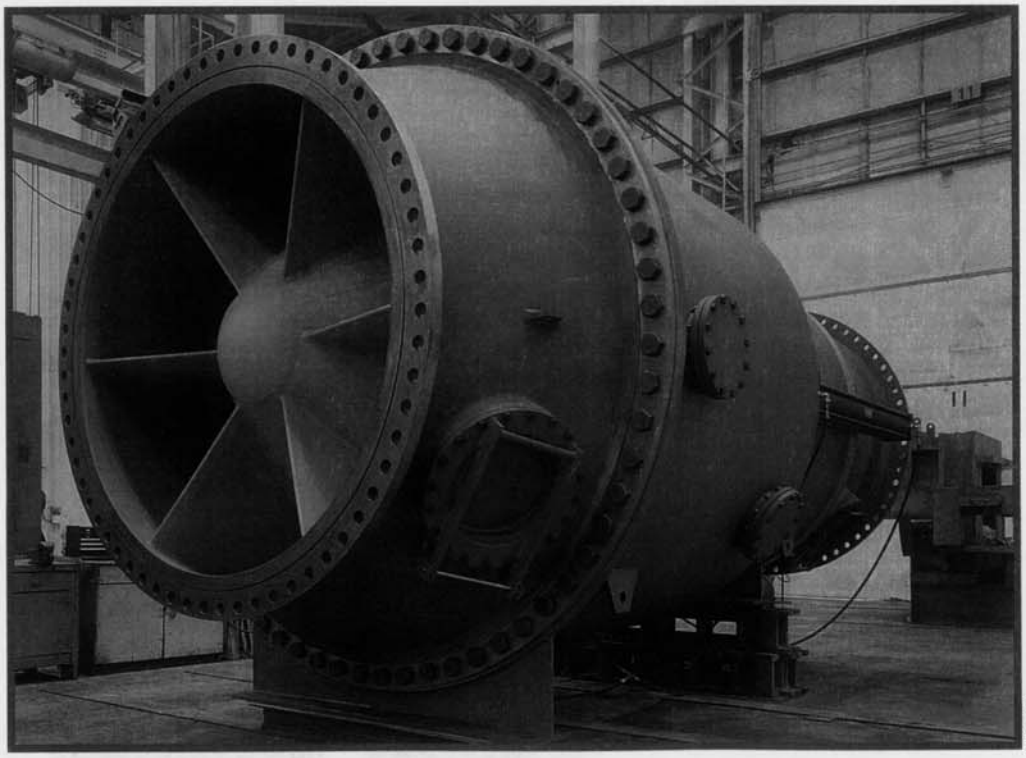
■ 2.47m x 3.68m draft tube flap gate



■ 2.75m Turbine a inlet valve



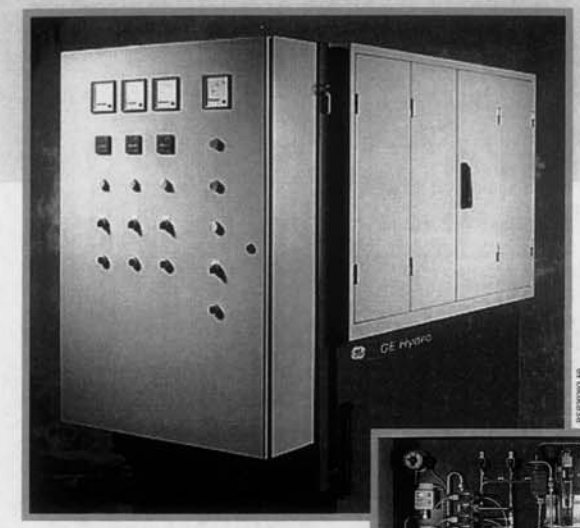
■ 1.6m diameter, sliding sleeve, fixed cone valve

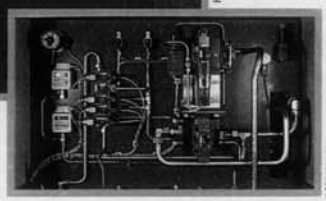


■ 2.13m diameter multi-port sleeve valve

GE Hydro have been supplying turbine governor and control systems for as long as they have been producing turbines.The first GE Hydro electro-hydraulic turbine governor was introduced in 1944.

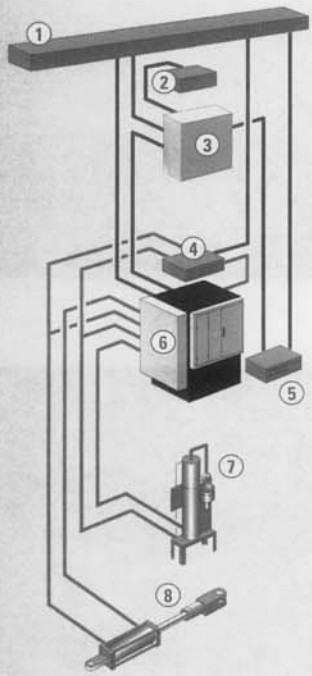
The range of governor and control systems covers all types of hydro turbine installations from the simplest to the most sophisticated computerised installations.





■ *Electro hydraulic control & oil pressure unit*

turbine control



1. Control and Protection Systems
2. Frequency Sensing Device
3. Computerised turbine controller
4. Mechanical Hydraulic Overspeed Device
5. Position Measurement Device
6. Electro hydraulic control & oil pressure unit
7. Accumulator Unit
8. Servomotor

SIGNAL CONNECTIONS

GOVERNOR MAIN PIPING

High pressure oil control system.

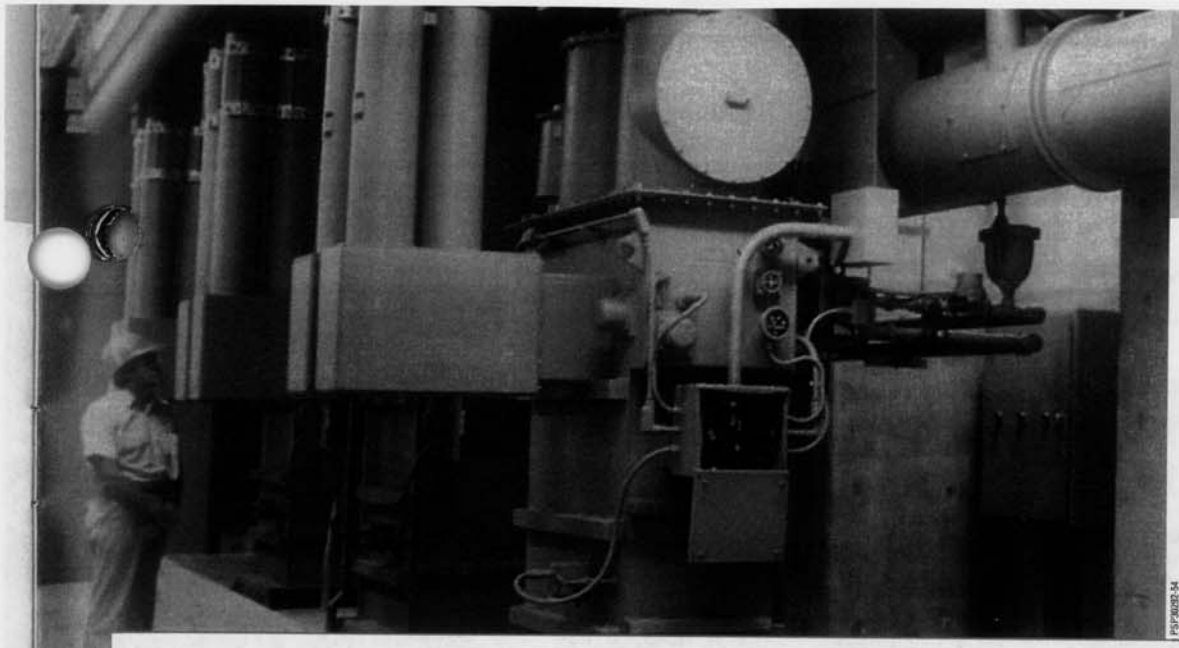
The TC100 turbine controller is based upon a standard industrial PC with 5x86 CPU or higher. The programme structure gives critical loops priority which is processed every 10 milliseconds.

This is a complete controller which incorporates a multitude of features and can be adapted for all types of turbines, therefore it is equally suitable for upgrading of existing plants as it is for new plants.

The controller's main features are:

- Automatic frequency control
- Automatic load control
- Water level control
- Dual control facility
- Manual/auto mode
- Turbine start and stop sequence

■ *Computerised turbine controller*



■ *Min-I-Phase connections to excitation cubicles*

isolated phase bus duct

Specifically designed for power plant and large switching station applications, the GE Hydro "Miniflux" all welded isolated phase bus provides reliable operation with a minimum of maintenance. The bus is designed for easy installation and meets all the applicable international safety standards.

The bus is shipped in single-phase sections in order to ease handling, alignment and installation at site. Size of sections is limited only by customers handling facilities and transportation restrictions.

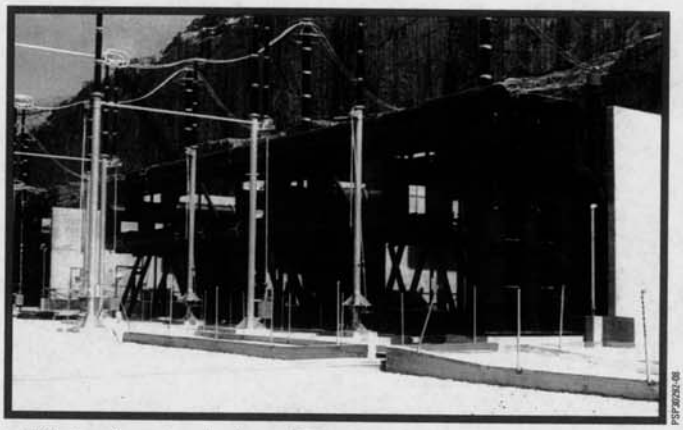
By combining the analysis and field testing along with years of experience and the introduction of new computer aids, we can provide unique ampacity studies on clients existing equipment in order to help you make an informed decision for upgrading projects.

GE Hydro's self-cooled and forced air designs cover the following ratings:

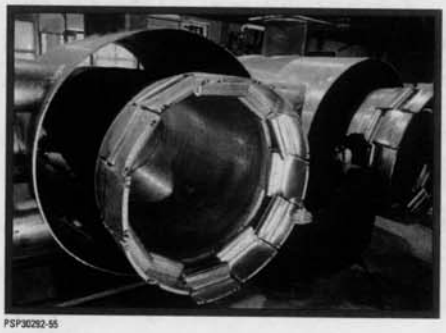
- 11 kv – 38.5 kv
- 110 kv – 150 kv
- 1,200 A – 40,000 A

GE Hydro entered the isolated phase bus duct market in the early 1950's. As a world class supplier with a fully integrated manufacturing plant, which is ISO - 9001 - 94 certified, we have been very active in the isolated phase bus duct equipment market both domestic and international.

During the past 20 years we have been a major supplier of isolated phase bus duct equipment to the utility market and this has led us to supplying what we believe is the world's largest self-cooled isolated phase bus duct (28,9800 A) and disconnect switches (30,000 A).



■ *Main transformer terminations at LG-4 power plant*



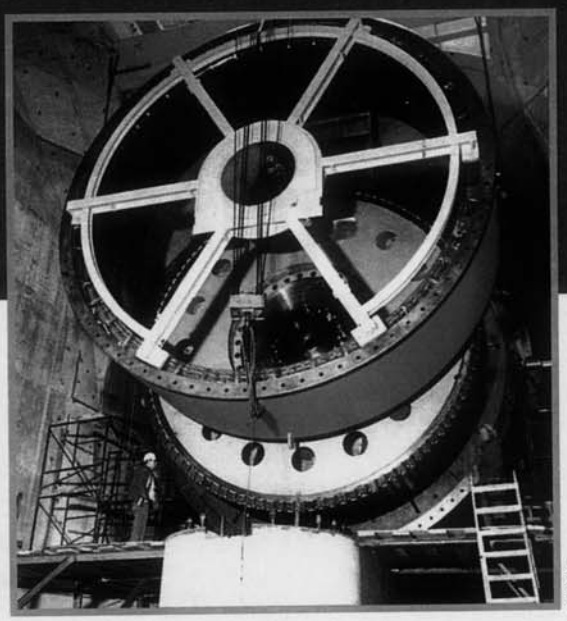
■ *Section of a 28,000 Amps self cooled bus duct with laminated bus connectors*

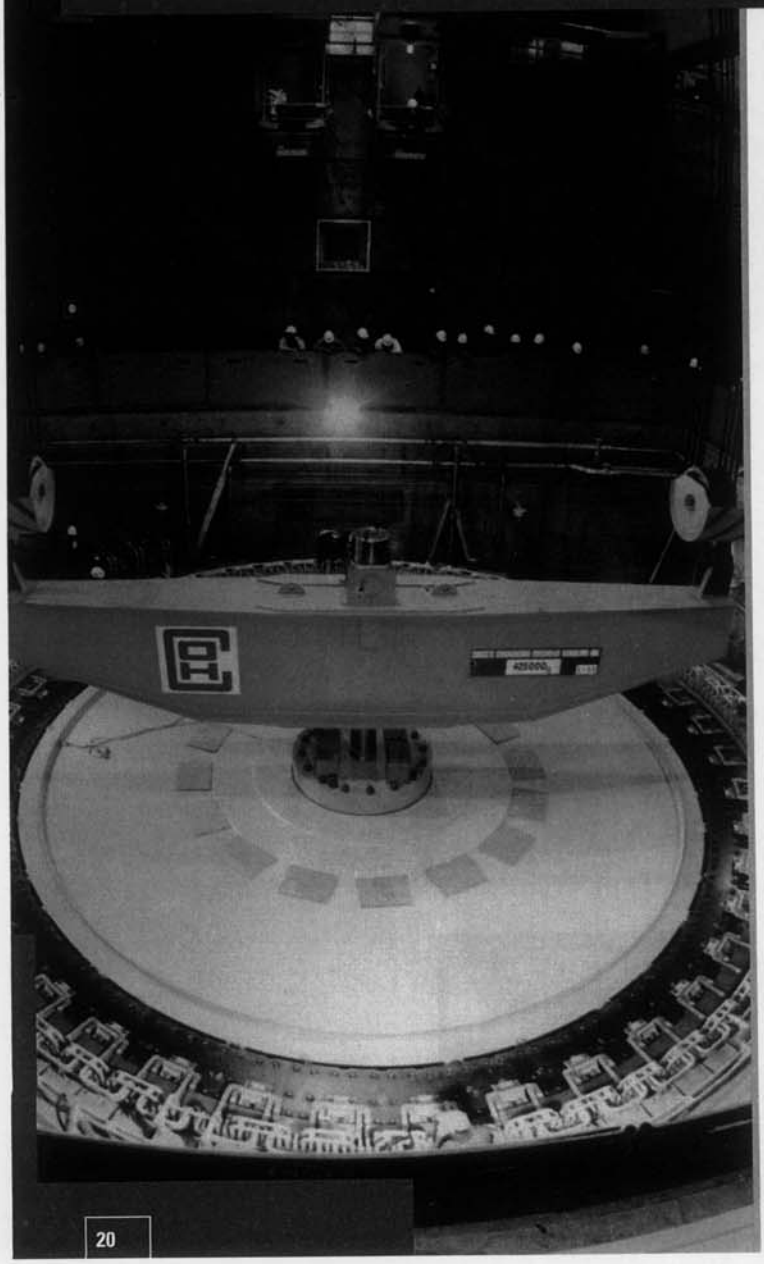
■ *Min-I-Phase bus duct*

generators

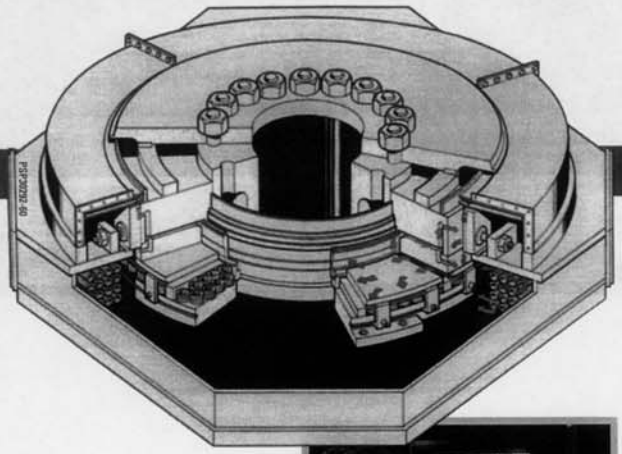
GE Hydro produces generators to suit the full range of hydro turbines.

- **Conventional**
  Designed for all types of vertical axis machines
- **Motor/Generator**
  Designed for single stage reversible pump turbines
- **Horizontal**
  Designed for conventional horizontal machines and bulb turbines. The bulb design incorporates GE Hydro's specific experience in air-gap stability, control of thermal distortion, unbalanced magnetic pull, frame stiffness and seal design.





- **1878** The Edison Electric Light Company was formed in the USA for the express purpose of developing a new source of light-the incandescent lamp
- **1882** the world's first hydro-electric plant was put into operation at Appleton, Wisconsin, using an Edison bipolar generator
- **1883** Thomas Edison installed the first electric generator in Canada in Sherbrooke Quebec where he later incorporated the Edison Electric Light Company which subsequently moved to Peterborough, Ontario in 1890
- **1892** The Toronto Construction and Electrical Supply Company merged with the Edison company to form the Canadian General Electrical Company, renamed General Electrical Canada Inc. in 1987
- **1900** The first Hydro-electric generators from the GE plant in Peterborough, Ontario installed on the Chaudiere River, Quebec
- **1979** Design of all GE Hydro Generators transferred to GE Peterborough

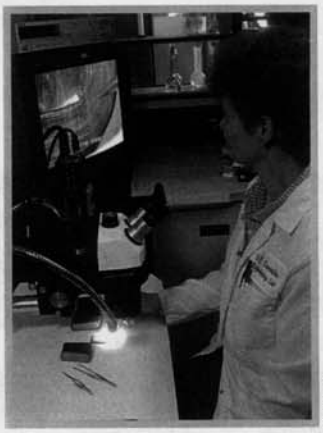


■ *Cutaway of combined thrust and guide bearing. Arrows show oil flow directions*

DESIGN

The design process determines the generator quality.
At GE Hydro, our design process stems from:

- Continuous applied research and development focussed on improving the analytical methods of performance evaluation
- Application of the latest and most sophisticated engineering analysis tools calibrated with actual generator performance site test results
- World class engineers and designers with unsurpassed experienced in machines with ratings from 10 MVA to 800 MVA
- Over 100 years of experience designing some of the world's largest and most technologically advanced generator/motor
- ISO 9001 design control procedures, and cost optimisation based on GE Hydro's ongoing commitment to improve the value provided with each successive generator.

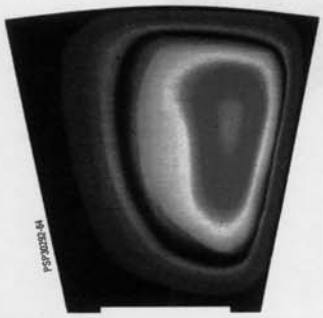


THRUST BEARING

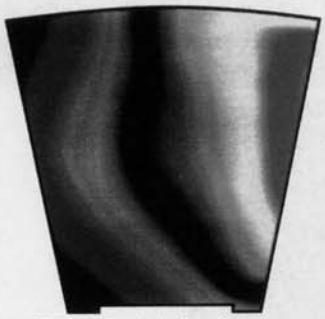
GE Hydro developed the spring loaded thrust bearing specifically for its hydroelectric generators. With over 800 thrust bearings in commercial service GE Hydro is committed to quality and superior design.

A distinctive feature of the bearing is the flexibility of its spring loaded segments which facilitate the development of a full hydrodynamic oil film under both steady state and transient conditions. This allows for dynamic load optimisation and promotes greater tolerance to misalignment.

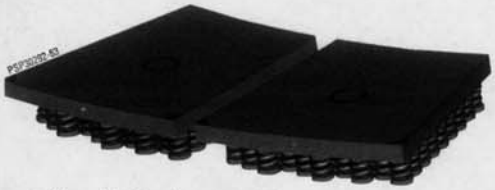
GE Hydro have specifically untilised the software program "GENMAT" to evaluate the performance of the bearing. The program simultaneously analyses the hydrodynamics, heat transfer and the mechanical and thermal distortion of the bearing elements. Bearing test information from actual field experience and data from the GE Hydro Thrust and Guide Bearing test facility is used to calibrate "GENMAT".



■ *"GENMAT" calculation of constant pressure contours on a thrust bearing segment*



■ *"GENMAT" calculation of constant temperature contours on a thrust bearing segment*



■ *Solid model of spring supported thrust bearing segments*

generators

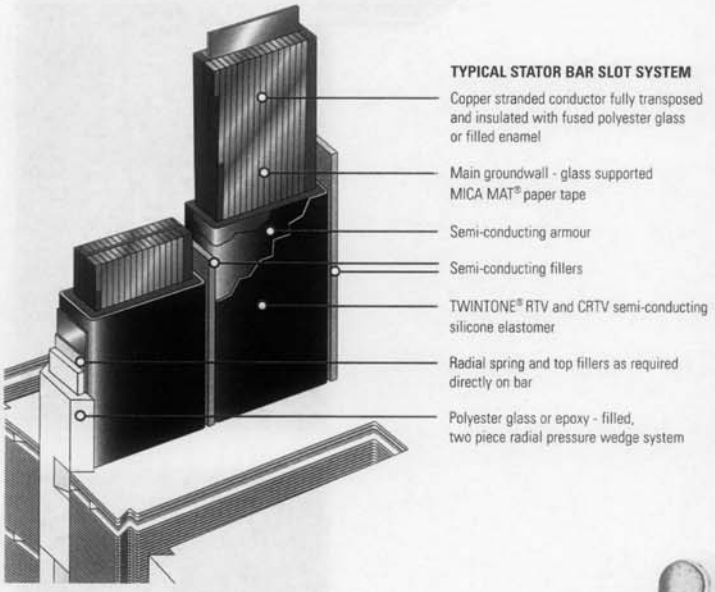
STATOR WINDINGS

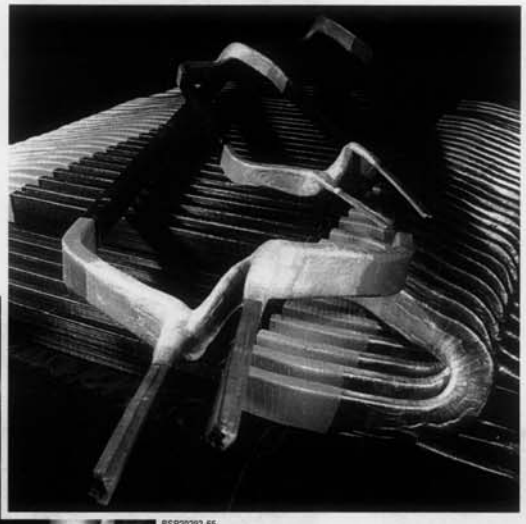
The design, manufacture and installation of stator windings is critical to unit reliability and performance. The design optimises the thermal loading, mechanical response and electrical stress distribution, consistent with the customers loss economics and operating environment. With over 240,000 stator bars and coils in commercial service GE Hydro has a proven record of supplying superior quality hydro-electric windings for all applications.

Our multi-staged and highly specialised stator winding uses only pre-tested and approved materials. The ISO 9001 approved process employed produces windings that surpass IEEE, IEC requirements and the requirements of all other approved standards.

Other specific products include:

- Class F epoxy MICA MAT® or HYDROMAT® Roebel bars and class F or B epoxy multi-turn coils
- RIPPLECOAT®, RIPPLECOAT II® or TWINTONE® elastomeric slot fitting for the ultimate in thermal, mechanical and electrical slot fit
- Retainer or ripple spring slot wedge systems

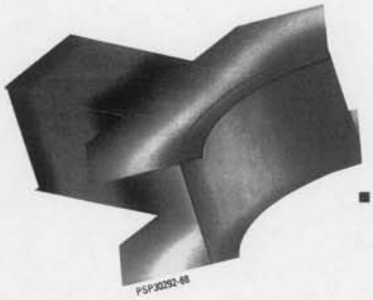



PSP30292-65

■ *Multi turn stator coil*

PSP30292-66

■ *Installed stator bar winding*



■ *Lower bracket finite element displacement analysis*

■ *Rotor pole body assembly*

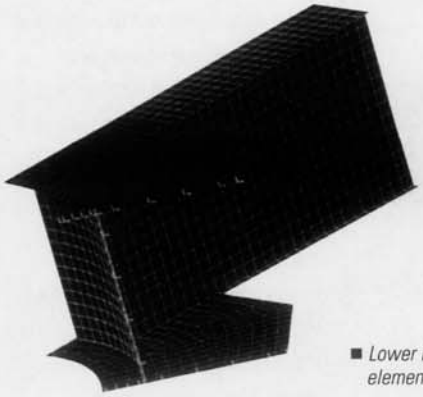
■ *Pole endplate element stress analysis*

HYDRO-ELECTRIC GENERATOR DESIGN

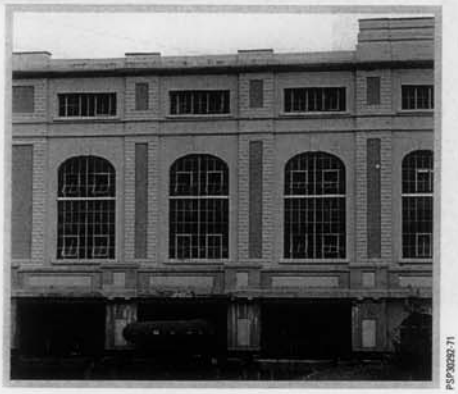
The process for optimum generator design continuously incorporates new capabilities of state-of-the-art design tools

- Custom designed software augmented by cutting edge CAE and CAD technology explores various design options and generator arrangements
- Advanced solid modelling and drafting design tools prevent possible design conflicts
- Knowledge based on design optimisation software uses the accumulated design experience and extends the limits of the design potential
- Structural vibration and heat transfer finite element analysis tools diagnose the mechanical integrity of generator components under the whole spectrum of the design potential
- Electromagnetic finite element programs simulate and analyse transients including the effects of transient rotor motion and inertia
- Both 2 and 3 dimensional magnestostatic, electrostatic and magnetodynamic finite element programs perform steady state analysis

■ *Insulating rotor field coil*



■ *Lower bracket finite element model*



PSP30292-71

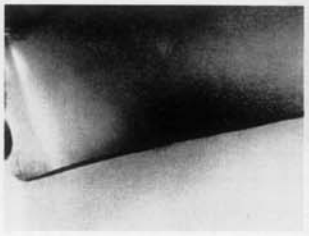
■ *Installation of replacement spiral casing*

services

refurbishment & uprating

PSP30292-76

PSP30292-75



PSP30292-74

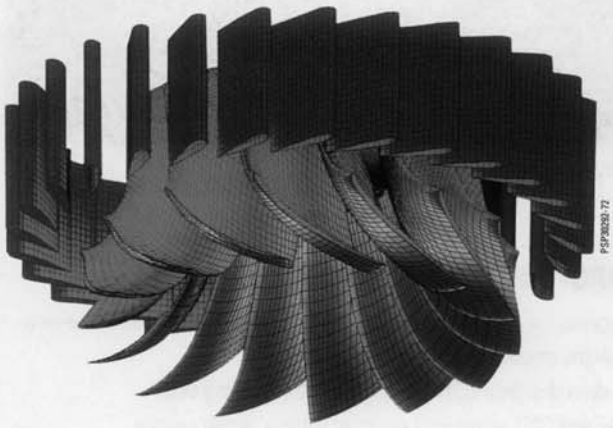
■ *Weld repair of a Francis Runner*

TURBINES

The evolution in the design of turbine runners and the subsequent improvement in the performance of turbines are the result of extensive development carried out in the fields of hydraulic and mechanical engineering and in governor technology.

GE Hydro's depth of experience together with its wide resources make it ideally suited to undertake the repair, refurbishment and uprating of existing turbines and associated equipment as well as water control equipment.

GE Hydro also offers periodical inspection and preventive maintenance programmes backed by a comprehensive spares facility. Please visit our website **www.gepartsedge.com**



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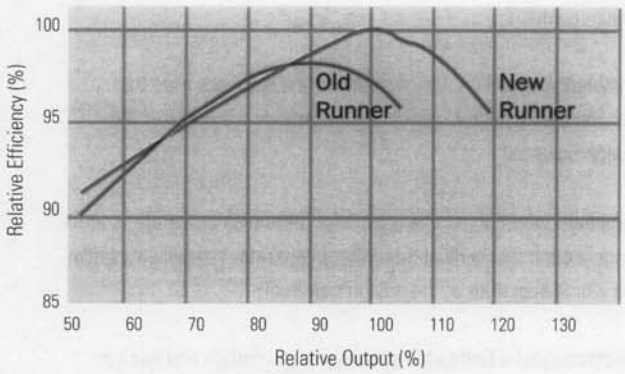


■ *Example of Typical improvement in performance after uprating*

services

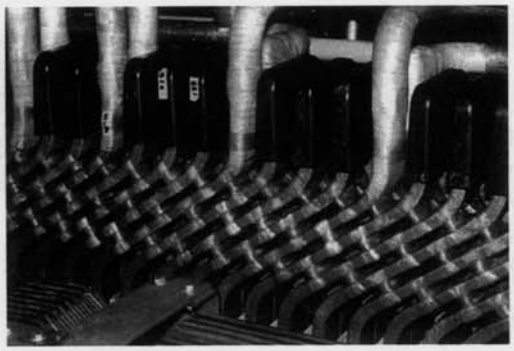
refurbishment & uprating

GENERATORS

The introduction of new sophisticated materials and GE Hydro's ongoing research and development has resulted in major improvements in reliability and performance of their generators.

With over 40 years experience in the installation, maintenance and repair of hydro-electric generators GE Hydro are ideally suited to carry out all forms of uprating and refurbishment on all types of these machines, both of their own manufacture and those manufactured by others.

GE Hydro also offers periodical inspection and preventive maintenance programmes backed by a comprehensive spares facility. Please visit our website **www.gepartsedge.com**



PSP30292-66

■ *Installed stator bar windings*

PSP30292-69

■ *Various stator coils*

PSP30292-73

■ *Test bearing assembly*

- **GENERATOR UPRATE STUDIES**
- **GENERATOR REWIND AND RE-CORE**
- **POLE REFURBISHMENT**
- **THRUST BEARING UPGRADE**
- **INSTRUMENTATION MODERNISATION**
- **FULL INSTALLATION SERVICES**

services

Carefully prepared programmes for operational and maintenance staff form an important part of GE Hydro's training programmes. These specially prepared programmes, are available for existing customers or as part of a contract for new equipment.

These programmes cover the whole spectrum of requirements for existing and potential owners and operators of hydro plants, from maintenance and operation of plants to detailed design and engineering.

The programmes assist the customers to increase their profits throughout the mechanical life cycle of their equipment. Additionally they teach the customers to develop functional solutions and optimise the performance of their equipment to ensure its maximum performance.

training

- **Operation & maintenance**
- **Project management**
- **Erection and commissioning**
- **Complete hydro power design and engineering**

GE Hydro

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www.gepower.com

BACK-UP TO

SECTION 3.3

"ANALYSIS OF TECHNICAL ALTERNATIVES"

Back-up to Section 3.3

A. Mathematical derivation of "reliability" values shown in Tables 3.3.1.1, 3.3.2.1, and 3.3.3.1 for Alternatives 1, 2 and 3, respectively are provided as follows:

- Table 3.3.1.1 (Alternative 1)

  Lock Water Recovery System (a series of components):
  0.999 (lock water recovery culvert) x 0.99 (gate valve) = **0.989**

  Lock Water Retention/Treatment System (a series integrated with parallel components):
  0.999 (retention reservoir) x [1 - (1 - 0.98)^3 (3 - level controls)] x [1 - (1 - 0.98)^3 (3 - variable weir gates valves)] x [(1 - (1 - 0.97 (aerator)) x (1 - 0.999 (mixing)) x (1 - 0.999 (sedimentation)))] = **0.999**

  Saltwater Intrusion Barrier System (a series integrated with parallel components):
  0.999 (retention reservoir) x [1- (1 - 0.98)^3 (3 - level controls)] x [1 - (1 - 0.98)^3 (3 - variable weir gates valves)] x [1 – (1 - 0.999 (retention reservoir discharge culvert)) x (1 – 0.97 (air compressor)) x (1 – 0.99 (bubbler header))] = **0.999**

  Potable Water Treatment System (a series of components):
  Phase I: 0.999 (retention reservoir) x 0.999 (mixing-feed sump) x 0.97 (filtration) x 0.97 (de-aerator) x 0.999 (RO) x 0.98 (disinfection) = **0.919**
  Phase II: 0.999 (retention reservoir) x 0.97 (aerator) x 0.999 (mixing) x 0.999 (sedimentation) x 0.97 (filtration) x 0.98 (disinfection) = **0.919**

  Treated Water Transport and Discharge System (a series integrated with parallel components):
  (1 – (1 - 0.98)^{30} (30 pumps – pump station)) x (1 – (1 – 0.99)^2 (2 – pipelines)) = **0.999**

  Hydroelectric Power Generation, Transmission and Interconnection (a series integrated with parallel components):
  (1 – (1 - 0.99)^{21} (9 – turbines for each facility)) x (1 – (1 – 0.97)^{21} (9 – generators for each facility)) x [1 – ((1 – 0.98) (switching gear @ substation)) x ((1 - 0.99) (transmission)) x ((1- 0.99) (interconnection))] = **0.999**

  Solid Waste Disposal System (a series integrated with parallel of components):
  (1 – (1 - 0.96)^4 (4 - sludge pumps)) x (1 – (1 – 0.999 (dewatering)) x (1 – 0.98 (filtrate recycle))) = **0.999**

  Composite Value (a series integrated with parallel of components):
  0.989 (Lock Water Recovery System) x 0.999 (Lock Water Retention/Treatment System) x 0.999 (Water Transportation and Discharge System) x [1 – (1- 0.999 (Saltwater Intrusion System)) x (1 – 0.919 (Potable Water Treatment System)) x (1 – 0.999 (Hydroelectric Power Generation, Transmission and Interconnection System)) x (1 – 0.999 (Solid Waste Disposal System))] = **0.987**

- Table 3.3.2.1 (Alternative 2)

  Lock Water Recovery System (a series integrated with parallel of components):

$(1 - (1 - 0.999)^4$ (4 - wet wells)) x $(1 - (1 - 0.98)^4$ (4 - variable weirs)) x $(1 - (1 - 0.98)^4$ (4 - level controllers)) x $(1 - (1 - 0.98)^{12}$ (12 - turbine pumps)) x $(1 - (1 - 0.99)^{12}$ (12 - gate valves)) x 0.99 (steel pipeline) = **0.989**

Lock Water Retention/Treatment System (a series integrated with parallel components):
0.999 (retention reservoir) x 0.98 (level controls) x [(1 - (1 - 0.97 (aerator)) x (1 - 0.999 (mixing)) x (1 - 0.999 (sedimentation)))] = **0.979**

Saltwater Intrusion Barrier System (a series integrated with parallel components):
1 – (1 – 0.97 (air compressor)) x (1 – 0.99 (bubbler header))] = **0.999**

Potable Water Treatment System (a series of components):
Phase I: 0.999 (retention reservoir) x 0.999 (mixing-feed sump) x 0.97 (filtration) x 0.97 (de-aerator) x 0.999 (RO) x 0.98 (disinfection) = **0.919**
Phase II: 0.999 (retention reservoir) x 0.97 (aerator) x 0.999 (mixing) x 0.999 (sedimentation) x 0.97 (filtration) x 0.98 (disinfection) = **0.919**

Treated Water Transport and Discharge System (a series integrated with parallel components):
$(1 - (1 - 0.98)^{18}$ (18 pumps – pump station)) x $(1 - (1 - 0.99)^2$ (2 – pipelines)) = **0.999**

Hydroelectric Power Generation, Transmission and Interconnection (a series integrated with parallel components):
$(1 - (1 - 0.99)^9$ (9 – turbines for each facility)) x $(1 - (1 - 0.97)^9$ (9 – generators for each facility)) x [1 – ((1 – 0.98) (switching gear @ substation)) x ((1 - 0.99) (transmission)) x ((1- 0.99) (interconnection))] = **0.999**

Solid Waste Disposal System (a series integrated with parallel of components):
$(1 - (1 - 0.96)^3$ (3 - sludge pumps)) x (1 – (1 – 0.999 (dewatering)) x (1 – 0.98 (filtrate recycle))) = **0.999**

Composite Value (a series integrated with parallel of components):
0.989 (Lock Water Recovery System) x 0.979 (Lock Water Retention/Treatment System) x 0.999 (Water Transportation and Discharge System) x [1 – (1- 0.999 (Saltwater Intrusion System)) x (1 – 0.919 (Potable Water Treatment System)) x (1 – 0.999 (Hydroelectric Power Generation, Transmission and Interconnection System)) x (1 – 0.999 (Solid Waste Disposal System))] = **0.967**

- Table 3.3.3.1 (Alternative 3)

Lock Water Recovery System (a series integrated with parallel of components):
$(1 - (1 - 0.999)^3$ (3 - wet wells)) x $(1 - (1 - 0.98)^4$ (4 - variable weirs)) x $(1 - (1 - 0.98)^3$ (3 - level controllers)) x $(1 - (1 - 0.98)^6$ (6 - turbine pumps)) x $(1 - (1 - 0.99)^6$ (6 - gate valves)) x 0.99 (steel pipeline) = **0.989**

Lock Water Retention/Treatment System (a series integrated with parallel components):
0.999 (retention reservoir) x 0.98 (level controls) x [(1 - (1 - 0.97 (aerator)) x (1 - 0.999 (mixing)) x (1 - 0.999 (sedimentation)))] = **0.979**

Saltwater Intrusion Barrier System (a series integrated with parallel components):
1 – (1 – 0.97 (air compressor)) x (1 – 0.99 (bubbler header))] = **0.999**

Potable Water Treatment System (a series of components):

Phase I: 0.999 (retention reservoir) x 0.999 (mixing-feed sump) x 0.97 (filtration) x 0.97 (de-aerator) x 0.999 (RO) x 0.98 (disinfection) = **0.919**

Phase II: 0.999 (retention reservoir) x 0.97 (aerator) x 0.999 (mixing) x 0.999 (sedimentation) x 0.97 (filtration) x 0.98 (disinfection) = **0.919**

Treated Water Transport and Discharge System (a series integrated with parallel components):

$(1 - (1 - 0.98)^9$ (9 pumps – pump station)) x $(1 - (1 - 0.99)^2$ (2 – pipelines)) = **0.999**

Hydroelectric Power Generation, Transmission and Interconnection (a series integrated with parallel components):

$(1 - (1 - 0.99)^9$ (9 – turbines for each facility)) x $(1 - (1 - 0.97)^9$ (9 – generators for each facility)) x [1 – ((1 – 0.98) (switching gear @ substation)) x ((1 - 0.99) (transmission)) x ((1- 0.99) (interconnection))] = **0.999**

Solid Waste Disposal System (a series integrated with parallel of components):

$(1 - (1 - 0.96)^3$ (3 - sludge pumps)) x (1 – (1 – 0.999 (dewatering)) x (1 – 0.98 (filtrate recycle))) = **0.999**

Composite Value (a series integrated with parallel of components):

0.989 (Lock Water Recovery System) x 0.979 (Lock Water Retention/Treatment System) x 0.999 (Water Transportation and Discharge System) x [1 – (1- 0.999 (Saltwater Intrusion System)) x (1 – 0.919 (Potable Water Treatment System)) x (1 – 0.999 (Hydroelectric Power Generation, Transmission and Interconnection System)) x (1 – 0.999 (Solid Waste Disposal System))] = **0.967**

B. Mathematical derivation of "operability" values shown in Tables 3.3.1.2, 3.3.2.2, and 3.3.3.2 for Alternatives 1, 2 and 3, respectively are provided as follows:

- Table 3.3.1.2 (Alternative 1)

Lock Water Recovery System (a series of components):

0.999 (lock water recovery culvert) x 0.98 (gate valve) = **0.979**

Lock Water Retention/Treatment System (a series integrated with parallel components):

0.999 (retention reservoir) x [1 - $(1 - 0.98)^3$ (3 - level controls)] x [1 - $(1 - 0.98)^3$ (3 - variable weir gates valves)] x [(1 - (1 - 0.98 (aerator)) x (1 - 0.999 (mixing)) x (1 - 0.999 (sedimentation)))] = **0.999**

Saltwater Intrusion Barrier System (a series integrated with parallel components):

0.999 (retention reservoir) x [1- $(1 - 0.98)^3$ (3 - level controls)] x [1 - $(1 - 0.98)^3$ (3 - variable weir gates valves)] x [1 – (1 - 0.999 (discharge box culvert)) x (1 – 0.98 (air compressor)) x (1 – 0.999 (bubbler header))] = **0.999**

Potable Water Treatment System (a series of components):

Phase I: 0.999 (retention reservoir) x 0.999 (mixing-feed sump) x 0.98 (filtration) x 0.98 (de-aerator) x 0.999 (RO) x 0.98 (disinfection) = **0.938**

Phase II: 0.999 (retention reservoir) x 0.98 (aerator) x 0.999 (mixing) x 0.999 (sedimentation) x 0.98 (filtration) x 0.98 (disinfection) = **0.938**

Treated Water Transport and Discharge System (a series integrated with parallel components):
$(1 - (1 - 0.97)^{30}$ (30 pumps – pump station)) x $(1 - (1 - 0.99)^2$ (2 – pipelines)) = **0.999**

Hydroelectric Power Generation, Transmission and Interconnection (a series integrated with parallel components):
$(1 - (1 - 0.98)^{21}$ (9 – turbines for each facility)) x $(1 - (1 - 0.98)^{21}$ (9 – generators for each facility)) x [1 – ((1 – 0.99) (switching gear @ substation)) x ((1 - 0.97) (transmission)) x ((1- 0.99) (interconnection))] = **0.951**

Solid Waste Disposal System (a series integrated with parallel of components):
$(1 - (1 - 0.97)^4$ (4 - sludge pumps)) x (1 – (1 – 0.999 (dewatering)) x (1 – 0.98 (filtrate recycle))) = **0.999**

Composite Value (a series integrated with parallel of components):
0.979 (Lock Water Recovery System) x 0.999 (Lock Water Retention/Treatment System) x 0.999 (Water Transportation and Discharge System) x [1 – (1- 0.999 (Saltwater Intrusion System)) x (1 – 0.938 (Potable Water Treatment System)) x (1 – 0.951 (Hydroelectric Power Generation, Transmission and Interconnection System)) x (1 – 0.999 (Solid Waste Disposal System))] = **0.977**

- Table 3.3.2.2 (Alternative 2)

Lock Water Recovery System (a series integrated with parallel of components):
$(1 - (1 - 0.999)^4$ (4 - wet wells)) x $(1 - (1 - 0.98)^4$ (4 - variable weirs)) x $(1 - (1 - 0.98)^4$ (4 - level controllers)) x $(1 - (1 - 0.97)^{12}$ (12 - turbine pumps)) x $(1 - (1 - 0.98)^{12}$ (12 - gate valves)) x 0.99 (steel pipeline) = **0.99**

Lock Water Retention/Treatment System (a series integrated with parallel components):
0.999 (retention reservoir) x 0.98 (level controls) x [(1 - (1 - 0.98 (aerator)) x (1 - 0.999 (mixing)) x (1 - 0.999 (sedimentation)))] = **0.979**

Saltwater Intrusion Barrier System (a series integrated with parallel components):
1 – (1 – 0.98 (air compressor)) x (1 – (0.999 (bubbler header))] = **0.999**

Potable Water Treatment System (a series of components):
Phase I: 0.999 (retention reservoir) x 0.999 (mixing-feed sump) x 0.98 (filtration) x 0.98 (de-aerator) x 0.999 (RO) x 0.98 (disinfection) = **0.938**
Phase II: 0.999 (retention reservoir) x 0.98 (aerator) x 0.999 (mixing) x 0.999 (sedimentation) x 0.98 (filtration) x 0.98 (disinfection) = **0.938**

Treated Water Transport and Discharge System (a series integrated with parallel components):
$(1 - (1 - 0.97)^{18}$ (18 pumps – pump station)) x $(1 - (1 - 0.99)^2$ (2 – pipelines)) = **0.999**

Hydroelectric Power Generation, Transmission and Interconnection (a series integrated with parallel components):
$(1 - (1 - 0.98)^9$ (9 – turbines for each facility)) x $(1 - (1 - 0.98)^9$ (9 – generators for each facility)) x [1 – ((1 – 0.99) (switching gear @ substation)) x ((1 - 0.97) (transmission)) x ((1- 0.99) (interconnection))] = **0.999**

Solid Waste Disposal System (a series integrated with parallel of components):
$(1 - (1 - 0.97)^3$ (3 - sludge pumps)) x (1 – (1 – 0.999 (dewatering)) x (1 – 0.98 (filtrate recycle))) = **0.999**

Composite Value (a series integrated with parallel of components):
0.99 (Lock Water Recovery System) x 0.979 (Lock Water Retention/Treatment System) x 0.999 (Water Transportation and Discharge System) x [1 – (1- 0.999 (Saltwater Intrusion System)) x (1 – 0.938 (Potable Water Treatment System)) x (1 – 0.999 (Hydroelectric Power Generation, Transmission and Interconnection System)) x (1 – 0.999 (Solid Waste Disposal System))] = **0.968**

- Table 3.3.3.2 (Alternative 3)

Lock Water Recovery System (a series integrated with parallel of components):
$(1 - (1 - 0.999)^3$ (3 - wet wells)) x $(1 - (1 - 0.98)^4$ (4 - variable weirs)) x $(1 - (1 - 0.98)^3$ (3 - level controllers)) x $(1 - (1 - 0.97)^6$ (6 - turbine pumps)) x $(1 - (1 - 0.98)^6$ (6 - gate valves)) x 0.99 (steel pipeline) = **0.99**

Lock Water Retention/Treatment System (a series integrated with parallel components):
0.999 (retention reservoir) x 0.98 (level controls) x [(1 - (1 - 0.98 (aerator)) x (1 - 0.999 (mixing)) x (1 - 0.999 (sedimentation)))] = **0.979**

Saltwater Intrusion Barrier System (a series integrated with parallel components):
1 – (1 – 0.98 (air compressor)) x (1 – (0.99 (bubbler header))] = **0.999**

Potable Water Treatment System (a series of components):
Phase I: 0.999 (retention reservoir) x 0.999 (mixing-feed sump) x 0.98 (filtration) x 0.98 (de-aerator) x 0.999 (RO) x 0.98 (disinfection) = **0.938**
Phase II: 0.999 (retention reservoir) x 0.98 (aerator) x 0.999 (mixing) x 0.999 (sedimentation) x 0.98 (filtration) x 0.98 (disinfection) = **0.938**

Treated Water Transport and Discharge System (a series integrated with parallel components):
$(1 - (1 - 0.97)^9$ (9 pumps – pump station)) x $(1 - (1 - 0.99)^2$ (2 – pipelines)) = **0.999**

Hydroelectric Power Generation, Transmission and Interconnection (a series integrated with parallel components):
$(1 - (1 - 0.98)^9$ (9 – turbines for each facility)) x $(1 - (1 - 0.98)^9$ (9 – generators for each facility)) x [1 – ((1 – 0.99) (switching gear @ substation)) x ((1 - 0.97) (transmission)) x ((1- 0.99) (interconnection))] = **0.999**

Solid Waste Disposal System (a series integrated with parallel of components):
$(1 - (1 - 0.97)^3$ (3 - sludge pumps)) x (1 – (1 – 0.999 (dewatering)) x (1 – 0.98 (filtrate recycle))) = **0.999**

Composite Value (a series integrated with parallel of components):
0.99 (Lock Water Recovery System) x 0.979 (Lock Water Retention/Treatment System) x 0.999 (Water Transportation and Discharge System) x [1 – (1- 0.999 (Saltwater Intrusion System)) x (1 – 0.938 (Potable Water Treatment System)) x (1 – 0.999 (Hydroelectric Power Generation, Transmission and Interconnection System)) x (1 – 0.999 (Solid Waste Disposal System))] = **0.968**

C. Mathematical derivation of "constructability" values shown in Tables 3.3.1.3, 3.3.2.3, and 3.3.3.3 for Alternatives 1, 2 and 3, respectively are provided as follows:

- Table 3.3.1.3 (Alternative 1)

Lock Water Recovery System:

Lock water recovery culvert tunneling, construction and installation -	9
Appurtenances -	+1
Total/Average:	10/**5**

Lock Water Retention/Treatment System:

Retention reservoir excavation and construction -	3
Variable weir construction and installation -	3
Aeration system construction and installation -	1
Mixing basin construction -	1
Sedimentation basin construction -	1
Sludge removal system -	1
Sludge conveyance system -	1
Appurtenances -	1
Process control -	+2
Total/Average:	14/**1.6**

Saltwater Intrusion Barrier System:

Reservoir discharge culvert tunneling, construction and installation -	9
Air compressor station construction and installation -	1
Appurtenances -	1
Bubbler conveyance and header construction -	+5
Total/Average:	16/**4**

Potable Water Treatment System:

Phase I -

Installation of RO (desalinization) plant -	1
Disinfection system installation -	1
Appurtenances -	1
Process control -	+2
Total/Average:	5/**1.3**

Phase II -

Filtration system installation -	1
Disinfection system installation -	1
Appurtenances -	1
Process control -	+2
Total/Average:	5/**1.3**

Treated Water Transport and Discharge System:

Pump station construction and installation -	1
Appurtenances -	1
Pipeline construction -	3
Process control -	+2
Total/Average:	7/**1.8**

Hydroelectric Power generation System:

Hydroelectric turbine installation -	9
Electric generator installation -	3
Electrical substation construction and installation -	2
Transmission system construction -	2
Interconnection electrical facilities tie-in -	+2
Total/Average:	18/**3.6**

Solid Waste Disposal System:

Dewatering facility construction -	1
Appurtenances -	1
Filtrate recycling system installation -	+1
Total/Average:	3/**1**

Composite Weighted Value of Averages (as in order above):
(5 x 0.2) + (1.6 x 0.1) + (4 x 0.2) + (1.3 x 0.1) + (1.8 x 0.05) +
(3.6 x 0.3) + (1 x 0.05) = **3.3**

- Table 3.3.2.3 and Table 3.3.3.3 (Alternatives 2 and 3)

Lock Water Recovery System:

Wet well construction -	10
Variable weir construction and installation -	3
Tunneling and pipeline construction -	9
Appurtenances -	1
Process control -	+2
Total/Average:	25/**5.0**

Lock Water Retention/Treatment System:

Retention reservoir excavation and construction -	3
Aeration system construction and installation -	1
Mixing basin construction -	1
Sedimentation basin construction -	1
Sludge removal system -	1
Sludge conveyance system -	1
Appurtenances -	1
Process control -	+2
Total/Average:	11/**1.4**

Saltwater Intrusion Barrier System:

Air compressor station construction and installation -	1
Appurtenances -	1
Bubbler conveyance and header construction -	+5
Total/Average:	7/**2.3**

Potable Water Treatment System:

Phase I -	
Installation of RO (desalinization) plant -	1
Disinfection system installation -	1
Appurtenances -	1

Process control -		+2
	Total/Average:	5/**1.3**
Phase II -		
Filtration system installation -		1
Appurtenances -		1
Disinfection system installation -		1
Process control -		+2
	Total/Average:	5/**1.3**

Treated Water Transport and Discharge System:

Pump station construction and installation -		1
Pipeline construction -		3
Appurtenances -		1
Process control -		+2
	Total/Average:	7/**1.8**

Hydroelectric Power generation System:

Hydroelectric turbine installation -		10
Electric generator installation -		3
Electrical substation construction and installation -		2
Transmission system construction -		2
Interconnection electrical facilities tie-in -		+2
	Total/Average:	19/**3.8**

Solid Waste Disposal System:

Dewatering facility construction -		1
Appurtenances -		1
Filtrate recycling system installation -		+1
	Total/Average:	3/**1**

Composite Weighted Value of Averages (as in order above):
(5.0 x 0.25) + (1.4 x 0.1) + (2.3 x 0.2) + (1.3 x 0.1) + (1.8 x 0.05) +
(3.8 x 0.25) + (1 x 0.05) = **3.1**

D. Mathematical derivation of "adaptability" values shown in Tables 3.3.1.4, 3.3.2.4, and 3.3.3.4 for Alternatives 1, 2 and 3, respectively are provided as follows:

- Table 3.3.1.4 (Alternative 1)

Lock Water Recovery System (Operations):

Lock water recovery culvert -		1
Appurtenances -		+1
	Total/Average:	2/**1**

Lock Water Retention/Treatment System (Operations):

Retention reservoir -	2
Variable weirs -	2
Aeration system -	2
Mixing basin -	2
Sedimentation basin -	2
Sludge removal system -	2

Sludge conveyance system -		3
Appurtenances -		3
Process control -		+2
	Total/Average:	20/**2.2**

Saltwater Intrusion Barrier System (Operations):

Reservoir discharge culvert -		1
Air compressor station -		3
Appurtenances -		3
Bubbler conveyance and header -		+5
	Total/Average:	12/**3**

Potable Water Treatment System (Operations):

Phase I -		
RO plant -		3
Disinfection system -		2
Appurtenances -		3
Process control -		+2
	Total/Average:	10/**2.5**
Phase II -		
Filtration system -		3
Disinfection system -		2
Appurtenances -		3
Process control -		+2
	Total/Average:	10/**2.5**

Treated Water Transport and Discharge System (Operations):

Pump station -		3
Pipeline -		5
Appurtenances -		3
Process control -		+2
	Total/Average:	13/**3.3**

Hydroelectric Power generation System (Operations):

Hydroelectric turbines -		1
Electric generators -		2
Electrical substation -		3
Transmission system -		1
Interconnection electrical facilities -		+2
	Total/Average:	9/**1.8**

Solid Waste Disposal System (Operations):

Dewatering facility -		2
Filtrate recycling system -		2
Appurtenances -		+3
	Total/Average:	7/**2.3**

Composite Weighted Value of Averages (as in order above):
(1 x 0.2) + (2.2 x 0.1) + (3 x 0.2) + (2.5 x 0.1) + (3.3 x 0.05) +
(1.8 x 0.3) + (2.3 x 0.05) = **2.1**

- Table 3.3.2.4 (Alternatives 2)

Lock Water Recovery System (Operations):		
Wet well -		5
Variable weir -		3
Pipeline -		5
Appurtenances -		3
Process control -		+2
	Total/Average:	18/**3.6**
Lock Water Retention/Treatment System (Operations):		
Retention reservoir -		3
Aeration system -		3
Mixing basin -		3
Sedimentation basin -		3
Sludge removal system -		2
Sludge conveyance system -		3
Appurtenances -		3
Process control -		+2
	Total/Average:	22/**2.8**
Saltwater Intrusion Barrier System (Operations):		
Air compressor station -		3
Appurtenances -		3
Bubbler conveyance and header -		+5
	Total/Average:	11/**3.7**
Potable Water Treatment System (Operations):		
Phase I -		
RO plant -		3
Disinfection system -		2
Appurtenances -		3
Process control -		+2
	Total/Average:	10/**2.5**
Phase II -		
Filtration system -		3
Disinfection system -		2
Appurtenances -		3
Process control -		+2
	Total/Average:	10/**2.5**
Treated Water Transport and Discharge System:		
Pump station -		3
Pipeline -		5
Appurtenances -		3
Process control -		+2
	Total/Average:	13/**3.3**
Hydroelectric Power generation System (Operations):		
Hydroelectric turbines -		1
Electric generators -		2

Electrical substation -		3
Transmission system -		3
Interconnection electrical facilities -		+2
	Total/Average:	9/**1.8**

Solid Waste Disposal System (Operations):

Dewatering facility -		3
Filtrate recycling system -		3
Appurtenances -		+3
	Total/Average:	9/**3.0**

Composite Weighted Value of Averages (as in order above):
(3.6 x 0.2) + (2.8 x 0.1) + (3.7 x 0.2) + (2.5 x 0.1) + (3.3 x 0.05) + (1.8 x 0.3) + (3.0 x 0.05) = **2.8**

- Table 3.3.3.4 (Alternatives 3)

Lock Water Recovery System (Operations):

Wet well -		5
Variable weir -		3
Pipeline -		5
Appurtenances -		4
Process control -		+2
	Total/Average:	19/**3.8**

Lock Water Retention/Treatment System (Operations):

Retention reservoir -		4
Aeration system -		4
Mixing basin -		4
Sedimentation basin -		4
Sludge removal system -		3
Sludge conveyance system -		4
Appurtenances -		4
Process control -		+2
	Total/Average:	29/**3.6**

Saltwater Intrusion Barrier System (Operations):

Air compressor station -		4
Appurtenances -		4
Bubbler conveyance and header -		+5
	Total/Average:	13/**4.3**

Potable Water Treatment System (Operations):

Phase I -		
RO plant -		4
Disinfection system -		3
Appurtenances -		4
Process control -		+2
	Total/Average:	13/**3.3**
Phase II -		
Filtration system -		4

Disinfection system -		3
Appurtenances -		4
Process control -		+2
	Total/Average:	13/**3.3**

Treated Water Transport and Discharge System:

Pump station -		4
Pipeline -		5
Appurtenances -		4
Process control -		+2
	Total/Average:	15/**3.8**

Hydroelectric Power generation System (Operations):

Hydroelectric turbines -		1
Electric generators -		2
Electrical substation -		3
Transmission system -		3
Interconnection electrical facilities -		+2
	Total/Average:	9/**1.8**

Solid Waste Disposal System (Operations):

Dewatering facility -		4
Filtrate recycling system -		4
Appurtenances -		+4
	Total/Average:	12/**4.0**

Composite Weighted Value of Averages (as in order above):

$(3.8 \times 0.2) + (3.6 \times 0.1) + (4.3 \times 0.2) + (3.3 \times 0.1) + (3.8 \times 0.05) + (1.8 \times 0.3) + (4.0 \times 0.05) =$ **3.2**

COMPARISON OF

DISCOUNTED INVESTMENT

Comparison of Discounted Investment

Technical Alternative 1

By project year 18 (15 years of operations) the total discounted value of capital investment for Technical Alternative 1 is approximately $107.09 million:

$$(\$420M + \$45M) \times (0.2303^{1}) = \$107.09M$$

Technical Alternative 2

On or about project year 18, if the facilities of Technical Alternative 2 are to be modified to accommodate the 100 percent lock water discharge diversion scenario as presented in Alternative 1 the total discounted value of capital investment for Technical Alternative 2 is approximately $147.01 million:

$$((\$338M + \$45M) / 0.6^{2}) \times (0.2303) = \$147.01M$$

Technical Alternative 3

On or about project year 18, if the facilities of Technical Alternative 3 are to be modified to accommodate the 100 percent lock water discharge diversion scenario as presented in Alternative 1 the total discounted value of capital investment for Technical Alternative 3 is approximately $254.10 million:

$$((\$303M + \$28M) / 0.3^{3}) \times (0.2303) = \$254.10M$$

Notes:

1: Discount factor in project year 18; see Table 3.5.3.1 in Table 3.5.3 for Scenarios C & D.
2. 60 percent diversion of lock water discharge in Technical Alternative 2.
3. 30 percent diversion of lock water discharge in Technical Alternative 3.