Panama Canal Authority (ACP)

Integrated Water Resource Management Feasibility Study

Water Project Alternative Milestone Meeting Study A Final Report

Prepared in Partnership:
US Army Corps of Engineers, Mobile District
Panama Canal Authority, Panama

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1. EXECUTIVE SUMMARY

1.1 Background

Meeting Panama Canal operational needs, ensuring transits, municipal and industrial (M&I) water requirements and controlling salinity have created excessive demands on the Panama Canal watershed's limited water supply resources. This puts long-term sustainability of Panama Canal operations at risk, jeopardizes efficient and reliable navigation through the Canal, and impacts the Panama Canal's global competitiveness.

To address these concerns, the Autoridad del Canal de Panamá (ACP) and the US Army Corps of Engineers (USACE) entered an Implementing Arrangement partnership on 17 November 2021. The Implementing Arrangement objective is developing an economically justified and environmentally sustainable Integrated Water Resource Management (IWRM) Plan.

The Integrated Water Resource Management Feasibility Study, Water Project Alternative Milestone Meeting Study A Report presents the Alternative Milestone Meeting (AMM) outcomes and supporting analysis. The AMM Milestone Meeting identified the alternatives array, generally limited to measures within the Panama Canal basin and within ACP authority, to be analyzed as potential solutions to the ACP's long-term reliability goals in the next phase of the feasibility study.

1.2 Objective

The Panama Canal IWRM water project objective is optimizing the Panama Canal's reliability over a 50-year planning horizon. Optimization includes operating the Panama Canal at full system capacity while avoiding water shortages. A Study A goal is reducing or eliminating the frequency that Panama Canal navigation throughput is constrained by water supply in the future, allowing the ACP to consistently provide reliable navigation services and achieve vessel throughput at the maximum system capacity.

1.3 IWRM Water Project Study Details

The IWRM Study is a cooperative effort between ACP and USACE. The organizations have been working collectively to build analytical features, such as water demand through the study period.

The IWRM Study A uses a 50-year period of analysis (2025-2075) informed by a 57-year hydrologic period of record. It focuses on within Panama Canal basin and ACP authority opportunities to produce a plan with recommendations for maximizing navigation transits, maintaining water supply resources, reducing future water limitations, increasing operational reliability, and increasing system resiliency of the Panama Canal.

IWRM Feasibility Study B was identified as a potential option early in the planning process to separate feasibility studies by the location of primary measures being analyzed. Study B has the same goal and uses the same evaluation approach as Study A but focuses on outside Panama Canal basin and ACP authority opportunities to address Panama Canal water supply constraints.

IWRM Study A is informed by the Salinity Study (Study C). Study C is separate from and is being executed in parallel to Study A. It evaluates operational and mechanical ways to prevent, minimize and mitigate saltwater intrusion into Gatún Lake, such as maximizing use of water savings basins.

IWRM Study D is being conducted in parallel to assess the life safety, loss of Panama Canal service risk, and other risks associated with the Panama Canal System. Risk assessment will evaluate the existing and future with project conditions.

The IWRM Water Project Analytics flow chart in Figure 1-1 describes the analyses sequencing.

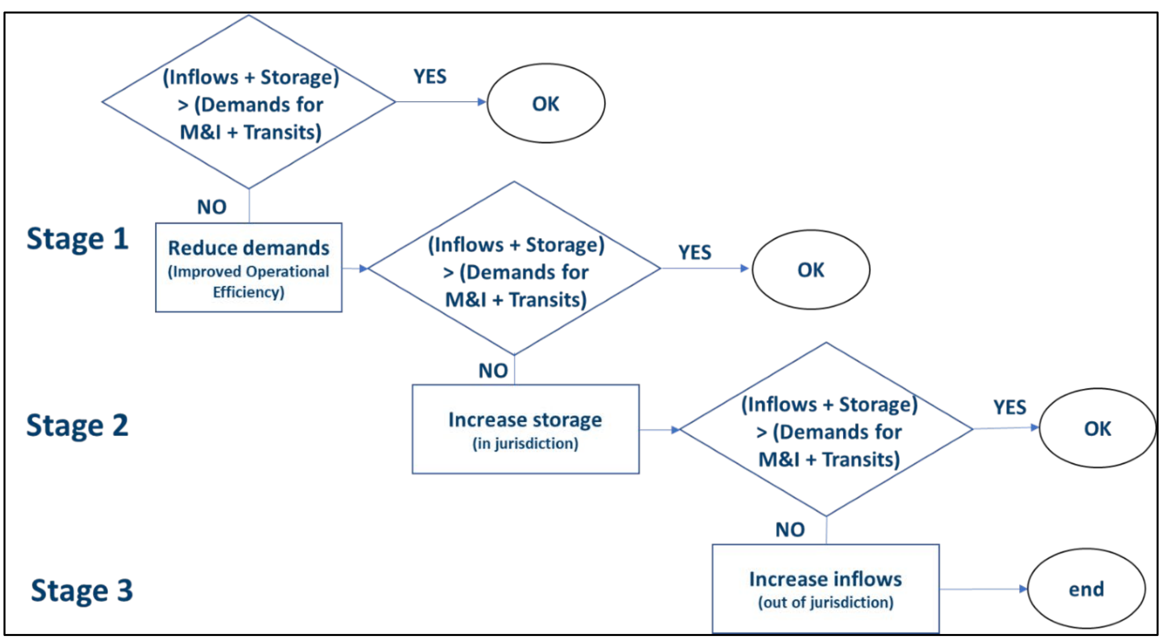


Figure 1-1: IWRM Water Project Analytics

1.4 Discussion

The Panama Canal system navigation capacity is 12.64 Neopanamax vessels per day and 26.34 Panamax vessels per day. The primary water demands are water for Neopanamax lockages, Panamax lockages, and M&I water supply with sources from Gatún and Alhajuela Lakes (Table 1-1).

Table 1-1: Water Supply Limit Variables

Variable	Existing Conditions (2025)	Future Without Project Conditions (2075)	Change
Gatún M&I Demands (ET[1])	3.433	10.043	+6.61
Alhajuela M&I Demands (ET)	4.545	4.545	NC
Panamax Transits	25.33	26.34	+1
Panamax Transit Water Demands (ET)	20.3	19.2	-1.1
Neopanamax Transits	9.53	12.64	+3.1
Neopanamax Transit Water Demands (ET)	22.2	30.2	+8
Neopanamax WSB[2] Use (Dry Season)	0%	0%	NC
Neopanamax WSB Use (Wet Season)	9.8%	9.8%	NC

[1]Equivalent Transits: Water volume (208,198 cubic meters or 55 million gallons) required to transit a vessel ocean to ocean through the Panama Canal.
[2]Water Savings Basin

Panama Canal basin water demands are projected to increase from 50.4 Equivalent Transits of water per day to 64.0 Equivalent Transits per day over the next 50 years. The ***future daily demands are anticipated to be greater than the average daily inflow of***

water into the Panama Canal basin, resulting in overallocation of water resources (Figure 1-2).

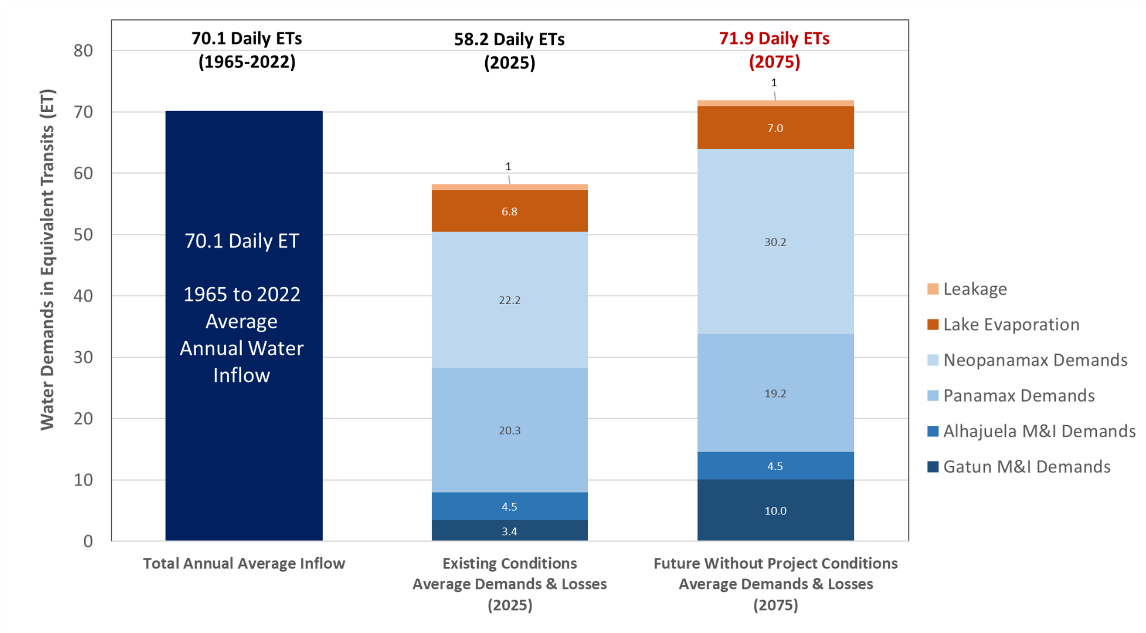


Figure 1-2: Water Supply Demands

(Reference Section 4.3, Water Demands for the Existing and Future Without Project Conditions for discussion)

The ACP's ability to consistently provide reliable navigation transits will be impacted if water demands are not addressed. Based on the current water supply***, increasing future water supply demands from the Panama Canal Watershed are incompatible with operating the Panama Canal system at full navigation capacity.***

Possible interventions (see Figure 1-3) to avoid future water overallocation while maximizing navigation throughput include:

1. **Decrease Water Volume Used per Lockage (Option 1).** This approach addresses navigation operational inefficiencies and could be achieved through increased use of the water savings basins or measures such as cross filling the Panamax locks.
2. **Decrease M&I Water Supply Demands (Option 2).** This measure could be a M&I water supply offset; decreasing water distribution losses, decreasing per capita water use; or capping future water supply withdrawals from the Panama Canal system.

3. **Increase Within Basin Water Storage (Option 3)**. This approach constructs or modifies dams and reservoirs to increase water stored during floods and uses this water during drought periods. This approach also includes accessing lower depths of Gatún Lake by lowering water intakes and dredging.
4. **Increase Water Available through Inter-Basin Water Transfers (Option 4).** This approach consists of inter-basin water transfers to bring water into the Panama Canal basin. This option is outside of ACP authority and the current IWRM Study A scope.
5. **Reducing Future Navigation Throughput (Option 5).** This approach limits the vessels transiting the Panama Canal based upon water availability. ***This option does not meet the IWRM study objective***.

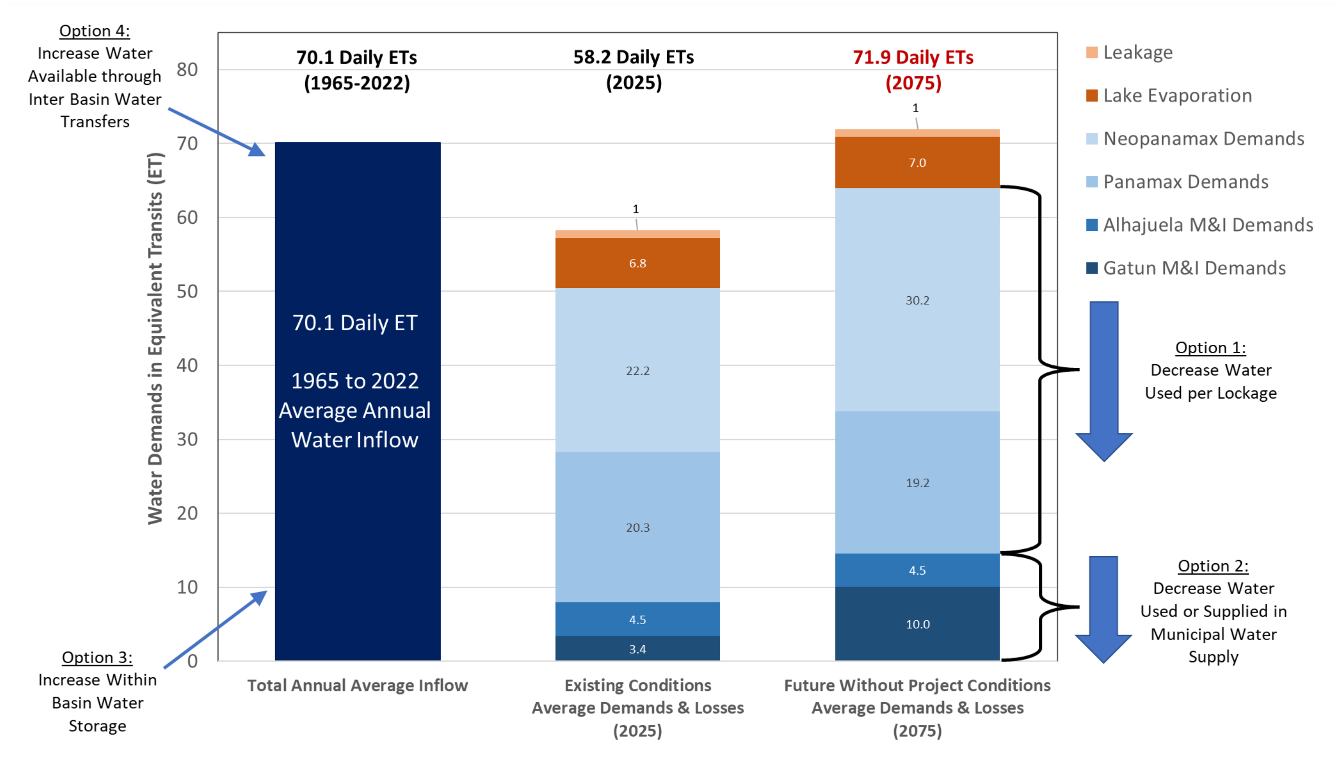


Figure 1-3: Water Supply Interventions

(Reference Section 5, Future With Project Measures for discussion)

Navigation throughput at full Panama Canal system capacity cannot be achieved with in-basin water resources without also addressing increasing M&I demands and salinity intrusion associated with the Neopanamax locks. The number of vessels transiting the Panama Canal in the future would be limited to less than the system capacity due to water supply limitations.

1.5 Study A Measures with Greatest Potential to Achieve the PC IWRM Study Objective

Study A assessed measures described in the ACP Administrator Letter to USACE South Atlantic Division dated January 20, 2022 (reference Attachment 1, Study A Report) and reports cited by the letter. Measures are physical, such as new construction, as well as operational actions. Measures described below are those from Study A providing the best cost benefits, appeared most likely to achieve the project objective and goals, and are recommended for further analysis.

1.5.1 Base Measures

Operational measures, identified as base measures, are recommended to be included in all alternatives. The base measures:

1. Provide greater operational flexibility to achieve water supply and navigation reliability targets.
2. Can be implemented in a shorter timeframe than other measures considered in Study A.
3. Provide significant improvements to future navigation reliability.

Base measures include:

1. **Salinity Study** – Study C identified water savings basins use and removing the Paraiso water intake and increasing water withdrawals at the Gamboa water intake as Salinity Study measures demonstrating some of the greatest opportunities for improving future navigation reliability.
2. **Municipal and Industrial Water Supply Withdrawal Cap** – Limiting future M&I water supply withdrawals is included in the base measures. Panamanian water resource regulations give ACP approval authority for water extraction permits within the Panama Canal Watershed.
3. **Cross-Filling** – Panamax locks cross-filling will be incorporated into future alternatives to the maximum extent possible to save water during drought periods. Understanding opportunities for cross filling implementation while maintaining salinity targets is necessary and will be investigated in the next phase of the feasibility study.
4. **Lowering Alhajuela Lake Operational Pool** – This measure modifies the Federico Guardia Conte Water Intake to allow withdrawal from lower pool elevations. It also gives the ACP greater flexibility for maintaining Alhajuela Lake's operational pool as low as EL 57.9 m PLD (190.0 ft PLD).
5. **Lowering of Gatún Lake Operation Pool** – This measure allows water withdrawal from lower portions of Gatún Lake such as converting M&I water intakes to floating intakes. This measure would lower Gatun Lake's operating limit to 21.34 m PLD (70.0

ft PLD). This provides additional flexibility for Gatún Lake's operational pool under the most severe droughts.

1.5.2 Within Basin Measures

Study A identified measures that should be further analyzed with other measures within alternatives to improve navigation reliability. These are:

1. **Dredging** – The dredging measure increases the navigation channel depth, allowing Neopanamax vessels to transit the Panama Canal at lower Gatún Lake pool elevations.
2. **Caño Quebrado** –The Caño Quebrado measure impounds water in the Caño Quebrado arm of Gatún Lake, making additional water available for release during drought.

1.5.3 Other Measures

1. **Bayano M&I Offsets** – This measure uses Bayano Lake to provide municipal water, allowing the Federico Guardia Conte Water Intake located in Alhajuela Lake to be decommissioned. This would be a municipal water supply offset to Panama Canal basin water withdrawals, reducing overall water demands on Panama Canal water resources. This measure was identified as a representative Study B measure for full evaluation to 5% design in Study A.
2. **Under Keel Clearance Policy** - A revision to under keel clearance policies could be included in any alternative. These policy revisions would provide modest benefits to draft reliabilities and could be implemented independently of the feasibility study.

1.6 Study A Key Findings

1.6.1 Study A Conclusions Regarding Water Supply Availability

1. Future conditions modeling shows Gatún Lake water resources will be overallocated. Without intervention, future water demands exceed the average available water.
2. Future water supply demands must be lowered relative to the available water. Panama Canal navigation throughput at system capacity cannot be maintained with increasing municipal water supply demands.
3. Bayano M&I water supply offsets provide significant water supply benefits compared to many other measures considered in this study. This suggests evaluation of a more comprehensive array of solutions to meet ACP water needs, including out of Panama Canal basin measures, is appropriate.

1.6.2 Study A Conclusions Regarding Navigation Reliability

1. Decreasing M&I water supply demands translates into the greatest opportunities for improved future navigation reliability.
2. Future Panama Canal navigation reliability goals cannot be achieved through implementation of a single measure.
3. Any viable IWRM plan requires a combination of inside and outside of basin solutions to ensure sufficient water supply demands are met for M&I and desired navigation reliability of the Canal.

1.6.3 Study A Conclusions Regarding Individual Measures and Alternatives

1. No single measure provides a complete solution.
2. Storage measures (Trinidad, Monte Lirio, and Caño Quebrado) are viable only after future demands are lowered relative to available water.
    a. Storage measures provide significant benefits only after the water demand imbalance is addressed.
    b. Combining storage measures alone will not avoid water limitations in the future.
    c. Increasing water storage (Option 3) provides modest and temporary benefits if not combined with measures reducing future demands or increasing water availability.
3. Dredging provides the greatest benefit within Option 3 measures.
4. Base measures alone provide $140 million - $260 million in annual benefits.
5. Base measures are recommended to be implemented as quickly as possible. Base measures represent a:
    a. Relatively lower capital investment.
    b. Relatively less complex implementation.
    c. Quicker return on investment.
6. Base measures combined with other in-basin Study A measures provide significant benefits but will not avoid future water supply limitations.

If Study A moves forward without consideration of Study B measures other than Bayano, six alternatives would be recommended for 15% design analysis. These are described in the Study A Alternatives Array Table 1-2 below. **The benefits provided by Study A's Bayano M&I Offsets measure supports expansion of the Alternatives Array to include Study B out-of-basin measures.**

Table 1-2: Study A Alternatives Array

No.	Alternative
Base	Salinity Study (WSB) + M&I Water Supply Cap + Lower Alhajuela Pool + Cross Filling Measures + Lower Gatún Water M&I Intakes
1	Bayano M&I Offsets* + Dredging + Caño Quebrado + Base
2	Bayano M&I Offsets* + Dredging + Base
3	Bayano M&I Offsets* + Caño Quebrado + Base
4	Bayano M&I Offsets* + Base
5	Dredging + Caño Quebrado + Base
6	Dredging + Base
* Representative Out-of-Basin Measure included in Study A	

Some measures outside of the Panamá Canal basin or ACP authority were analyzed for benefits for comparison purposes. These are referred to as Study B measures. Rio Indio Dam with Trans-basin Diversion and Caribbean Diversions measures, which are outside of ACP authority and were not evaluated for cost, provide greater benefit than any individual analyzed measure within ACP authority. Variations and combinations of Rio Indio Dam, Caribbean Diversions, and Bayano measures, including the Bayano offset measure, would be part of Study B.

1.7 Recommendations

- **Initiate Study B to assess outside of Panama Canal basin and ACP authority measures.** No measure or combination of measures within the ACP basin and authority analyzed in Study A avoids future water limitations. The deliverable will be an Alternatives Milestone Meeting and Report that considers measures within and outside ACP basin and authority in developing alternatives for further consideration. Alternatives developed from the Study A AMM may not be suggested in Study B and do not require immediate advancement to 15% design.

- ❑ **Advance the analysis of Study A´s measures defined as “base measures” to refine costs, benefits, and constructability.**

- ❑ **Conduct 15% Analysis and Design of Study B Alternatives Array following Study B AMM.** Completion of the Study B 5% Design analysis before 15% Study A analysis will allow alternatives re-formulation for a comprehensive array of in- and out-of-basin water solutions. It is recommended that the alternative array from the Study B AMM be evaluated to the 15% design level.

2. INTRODUCTION

2.1 ACP and USACE Partnership Overview

The Autoridad del Canal de Panamá (the Panama Canal Authority or ACP) and the US Army Corps of Engineers (USACE) entered a partnership known as an Implementing Arrangement on 17 November 2021. The objective of the Implementing Arrangement is described below:

> **Implementing Arrangement Objective:** Develop an economically justified and environmentally sustainable Integrated Water Resource Management Plan that includes specific measures to maximize the yield of water resources within the ACP watershed and potentially includes complementary solutions integrated from outside of the ACP watershed, resulting in increased operational reliability and resiliency of the system.

USACE supports this objective by providing Subject Matter Experts (SMEs) to work in the ACP headquarters in Panama on a full-time basis, as well as full-time and part-time support from USACE Districts and research laboratories in the United States.

The first task of the Implementing Arrangement is the development of an Integrated Water Resource Management (IWRM) Plan to support the Oficina de Proyectos Hídricos (Water Project Office). This IWRM Plan may consist of 2 phases:

Phase I: Integrated Water Resource Management Feasibility Study for the Water Project

Phase II: Tender Package Preparation and Support

This report represents the Alternative Milestone Meeting (AMM) and its supporting analysis. This report documents the 5% design and benefit evaluation of measures being recommended for inclusion in the next phase of the Water Project Feasibility Study. It also describes the plan formulation.

2.2 Summary of Reconnaissance Phase of USACE Support to ACP

In January 2022 USACE began a reconnaissance study phase of the Water Project Feasibility Study. This phase included three key objectives:

1. **Develop an understanding of the available data, studies, processes, and institutional framework that is expected to be relevant for the feasibility study.**

This objective was accomplished through a comprehensive literature review task as well as several workshops and interagency meetings between ACP and USACE. The literature review associated with the hydrologic conditions and engineering measures relevant to this study was provided to the ACP on 1 April 2022. Version 2.0 of the literature review (addressing comments received from the ACP) was provided on 31 July 2022.

2. **Development of a Scoping Level HEC-ResSim Model to Inform Study Scope:** The objective's purpose was to identify the overall opportunities and scale of processes that impact navigation reliability within the Panama Canal. The observed Gatún Lake level, and operational data associated with the Panama Canal system were used to calibrate a HEC-ResSim model. The long-term navigation reliability without a project in place was first estimated using the HEC-ResSim model. The model was then used to evaluate how much additional reliability could be obtained using additional storage of water and other measures within the watershed. Two key findings were made based on this preliminary scoping model:

    a. The water used for salinity intrusion mitigation is a significant process and should be addressed / prioritized in the separate Salinity Study as the ACP has recommended.
    b. Constructing additional storage within the ACP basin will provide some benefits but is unlikely to provide sufficiently high levels of navigation reliability on its own.

3. **Develop a scope of work for the feasibility study.** A scope of work for the feasibility study was provided to the ACP on 5 July 2022.

During initial project team meetings on 7 December 2021 the ACP requested separation of the design of salinity intrusion mitigation measures from the feasibility study. The salinity intrusion mitigation measures were requested to be treated as a separate design problem and the development of the specific measures associated with the Salinity Study are not directly described in this report. Instead, the expected Salinity Study results are incorporated in simulations of future conditions when evaluating the effectiveness of the expected salinity study results within the context of this feasibility study.

2.3 Planning Strategy

USACE and the ACP met in April, May, and August 2022 to discuss the USACE planning process and agree on which planning process features would be appropriate to the Panama Canal IWRM Study. The Panama Canal IWRM Study Project Delivery Team (PDT) agreed that planning elements specific to the United States federal project budgeting process, including the four Principles and Guidelines accounts were not applicable, because there is not a corollary at the ACP or in use in Panama; the planning process would guide and bound the development of measures, alternatives, and comparison of alternatives; economic analysis would focus on investments and income; and environmental analysis would begin after alternatives development. Technical analysis, hydrology and hydraulics modeling and engineering would adhere to relevant USACE and international standards.

2.4 Six-Step Planning Process

The USACE adheres to the six-step planning process defined in the 1983 Principles and Guidelines (P&G) and the Planning Guidance Notebook, dated 22 April 2000 (ER 1105-2-100). The 6-step planning process will be used as a framework to develop alternatives to address navigation reliability inside and outside the Panama Canal watershed. This process includes:

1. **Defining problems, opportunities, objectives, and constraints:** This step identifies goals and objectives for the study; opportunities for improving reliability; constraints to the study; and how problems may be addressed. This step is described in Chapter 2 of this AMM report.
2. **Inventorying the study area and forecasting future without project scenarios and conditions:** This step investigates relevant, existing data and uses the data to describe current conditions in the study area. It is also used to hypothesize the future without project conditions. The future without project conditions describe what circumstances are likely to exist if no action is taken to address the problems and opportunities. The future without project is also the circumstance against which alternative plans' positive and negative impacts will be assessed. The existing conditions and future without project conditions are described in Chapter 3.
3. **Formulating alternative plans:** Formulating alternative plans consists of identifying structural and non-structural measures that can be used to address problems and opportunities and combining the measures into a series of alternative plans. This step includes early elimination of measures because

they violate a constraint, do not support an opportunity, or do not contribute to problem solving. The description of the measures and their design and analysis are described in Chapter 4. The plan formulation elements of this step are described in Chapter 5. The development of the alternative plans is described in Chapter 6.

4. **Evaluating alternative plans:** The alternative plans will be assessed against criteria and key metrics to determine if a plan supports a problem solution or has a fatal flaw that indicates it should not be analyzed further. Individual measures are evaluated in Chapter 4 of this AMM report. The evaluation of alternative plans will be completed in the feasibility study report in the next phase of the study.
5. **Comparing alternative plans:** Each alternative plan is compared to other alternative plans, the future without project conditions and the existing condition using key metrics and criteria. The outputs of this analysis are compared and ranked to provide an array of alternatives from which the recommended plan can be selected. Comparisons of measures are included in Chapter 5 of this AMM report. The comparison of alternative plans will be completed in the feasibility study report in the next phase of the study.
6. **Selecting a recommended plan:** The ACP, with USACE support and recommendations, will choose an alternative for implementation. This step will be accomplished through the development of a Multi-Criteria Decision Analysis (MCDA) tool and will be described in the feasibility report. The preliminary information on the MCDA tool is described in Chapter 7 of this report.

2.5 Planning Process Framework and Guiding Principles

On 20 January 2022 the Administrator of the Panama Canal sent a letter to the USACE South Atlantic Division Commander (Attachment 1). This letter provided the guiding principles for the execution of the study. Some of the guiding principles listed in this letter include:

- Projects analyzed by USACE in 1999-2002 should be considered, as well as projects carried out by the ACP
- A single project to resolve the long-term reliability of the Panama Canal is not feasible.
- There should be a focus on within authority measures to the maximum extent possible and resorting to measures outside of the ACP authority should only be evaluated after all other considerations are made for in-basin measures.
- Saltwater intrusion mitigation measures can be reviewed and addressed independently from segmentation projects, operational changes to lake levels, and dredging projects.
- Finding a solution to offset water from Gatún and Alhajuela Lakes should be prioritized in this study.

Based on these guiding principles, the joint ACP and USACE team developed a workflow and strategy for implementation of the water project. This strategy is shown in Figure 2-1 and consists of three stages. These stages consist of 1) reducing water demands for navigation; 2) increasing storage; and 3) increasing inflows of water into the Panama Canal basin.

The first stage focuses on reducing the demands for water used in navigation – specifically the amount of water that is used to mitigate against salinity intrusion during Neopanamax lockages. This first stage is a parallel study called the Salinity Study, and the objective of that parallel study is to maximize the use of the water savings basins to increase efficiency of water used during Neopanamax lockages.

If there is not sufficient water available due to the implementation of Stage 1 measures, then Stage 2 measures would be designed and analyzed to improve system reliability. Initial analysis investigating the salinity intrusion mitigation measures and the Stage 1 measures are expected to be a significantly effective approach for improving system reliability. However, the initial findings also identified the salinity measures alone would not completely resolve the future reliability issues of the Panama Canal. Therefore Stage 2 measures are required for analysis and investigation.

The Stage 2 measures specifically include measures to increase storage of the water in the basin. This is called Water Project Feasibility Study A: In-Authority Measures. It should be noted Stage 2 also includes a project to offset M&I water usage from Gatún and Alhajuela Lakes (the Bayano M&I Offset measure). The Bayano project reduces demands instead of increasing storage and has been analyzed in parallel to Stage 2 in this study.

A third stage will be implemented if it is found that Stage 1 and Stage 2 measures are not viable or otherwise do not fully address the water needs of the basin. Stage 3 predominately focuses on measures that increase inflows into the basin through inter-basin water transfers. This is called Feasibility Study B: Outside Authority Measures. Stage 3 also includes other measures that are currently outside of ACP' authority, including additional storage of water via the construction of a new dam within the ACP basin in the Upper Chagres River. These measures would only be initiated if Stage 1 and Stage 2 measures are found to be inadequate to provide long-term sustainability of Panama Canal operations.

In each stage, a water resource management model (using the Hydrologic Engineering Center software HEC-ResSIM) was used to assess whether the objective of the water project can be achieved through the implementation of measures associated with a specific stage.

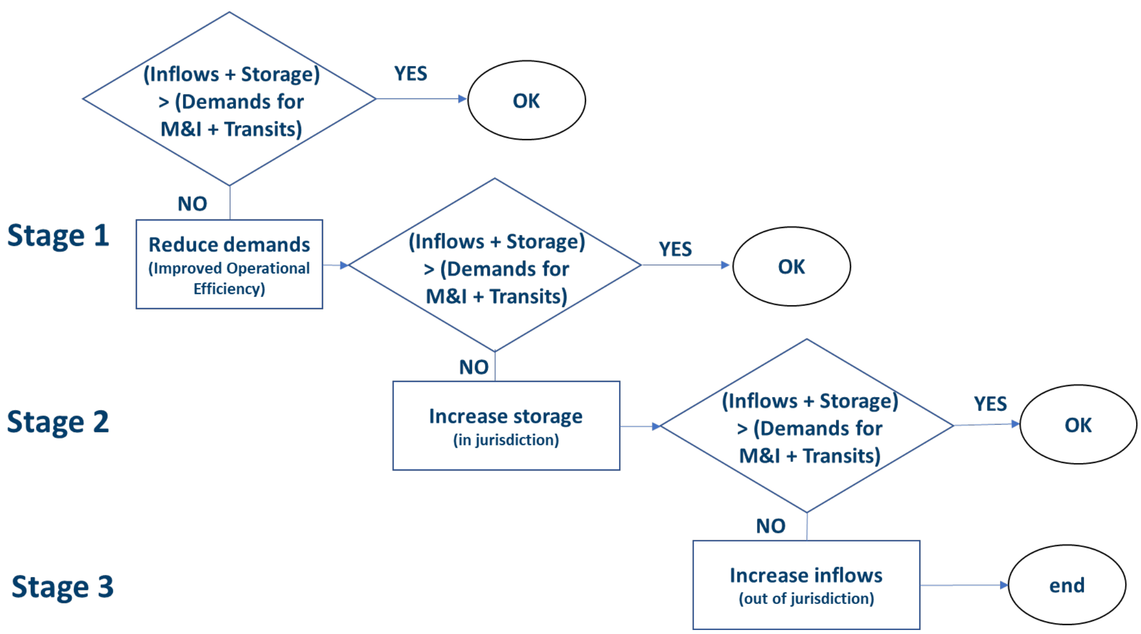


Figure 2-1: Three Stages of the Water Project

Key decision points, called milestones, have been identified to ensure the feasibility study's forward momentum, accommodate the Panama Canal study specifics, and meet the study's 2.5-year schedule; ensure vertical alignment with the ACP and USACE leadership; confirm concurrence regarding formulation, decisions, and risk evaluation; and define the way forward throughout the feasibility study.

Figure 2-2 presents the Planning Process Paradigm for the ACP-USACE Project Delivery Team (PDT) milestones and analysis inflection points for the PC IWRM Study.

Milestones are points where decisions affecting the study's direction are made. These are the Scoping Milestone (July 2022), when the PDT agreed on the study components and schedule and completed the scope of work for the study; the Alternatives Milestone Meeting (November 2022) when the 5% designed measures were reviewed to determine which measures would be combined into alternatives and presented to ACP for their concurrence; the 15% Scoping Meeting (March 2023) when the PDT will develop the scope of work for the 15% analysis; and the Tentatively Selected Plan (TSP) Milestone (March 2024) when alternative plans that have been carried to 15% design are compared, and the ACP selects the plan that will move forward into the tender package(s) development.

Work products that will be delivered to the ACP include the AMM Report and Appendices (May 2023); the Final Feasibility Study Report and Appendices (April 2024), including the Multi-Criteria Decision Analysis (MCDA) (March 2024). USACE may also support additional tasks, including development of the 35% Design Tender Package(s) for water management features of the selected plan. Tender packages may be developed during the study development as specific measures are identified for implementation.

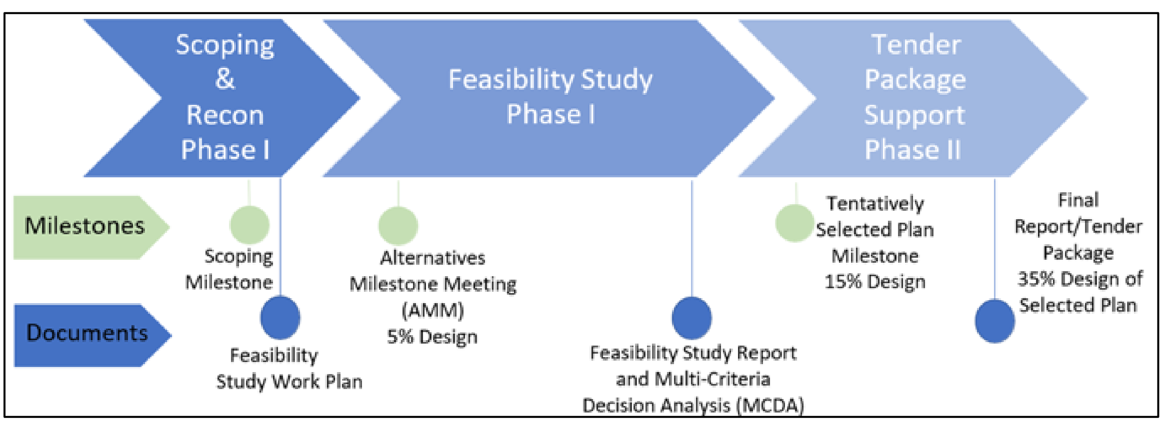


Figure 2-2: Planning Process Paradigm

2.6 Overview of the Panama Canal Site Features

The ACP manages water resources within the 3,338 square kilometer (km^2) Panama Canal watershed. The ACP operates the locks, reservoirs, and hydropower facilities within the basin, and is responsible for implementing any new measures for improving navigation reliability.

The original design of the Panama Canal was conceived by the French and construction began in 1881 based on the concept of a sea level crossing. This project was eventually abandoned due to technical, health, and financial challenges.

In 1907 the United States (US) began construction on the canal in the same vicinity as the French. The US design was a lock system, which was inaugurated on August 14, 1914. The original Panama Canal construction consisted of the Miraflores Locks, Miraflores Dam, Pedro Miguel Locks, Gatún Locks and Gatún Dam. Each of the locks have two lanes and each lane has three steps to raise vessels to Gatún Lake elevation. The Gatún Locks have three steps immediately in series. The Miraflores Locks have two steps at ocean level on the Pacific side, with Pedro Miguel completing the third step. Miraflores Lake is between the upper chamber of the Miraflores Lock and the Pedro Miguel Lock. The original locks are known as the Panamax Locks.

Gatún Dam has hydropower capacity up to 24 megawatts; however, hydropower is generated only occasionally during the wet season to conserve water use for other purposes. A key feature of the original locks' construction is the Culebra Cut (also known as the Gaillard Cut), which was a large and extremely challenging excavation across the continental divide located at the upper (southeast) end of the Gatún Lake.

Madden Dam construction began in 1931 and was completed in 1935. Madden Dam was constructed to manage the Chagres River – the largest river in the watershed – and provide water storage for navigation purposes and to meet the water demands required for a proposed third navigation lane. Madden Dam forms the Alhajuela Reservoir. Hydropower is generated at Madden Dam year-round and has up to 36 megawatts of hydropower capacity using three turbines (12-megawatt (MW) capacity each).

The Panama Canal Expansion Referendum was held in 2006, and the citizens of Panama approved the proposal to construct a third lane in the Panama Canal. This third lane consists of the Cocolí Locks and the Agua Clara Locks, known as the Neopanamax locks. Construction began in 2007 and was completed on June 26, 2016. Agua Clara and Cocolí Locks consist of three, in series steps. A key feature of Cocolí Locks and Agua Clara Locks is the water savings basins. The water savings basins are designed to recycle up to 60% of the water used in lockages to reduce total volumes associated with navigation operations. An overview of the existing Panama Canal system is shown in Figure 2-3.

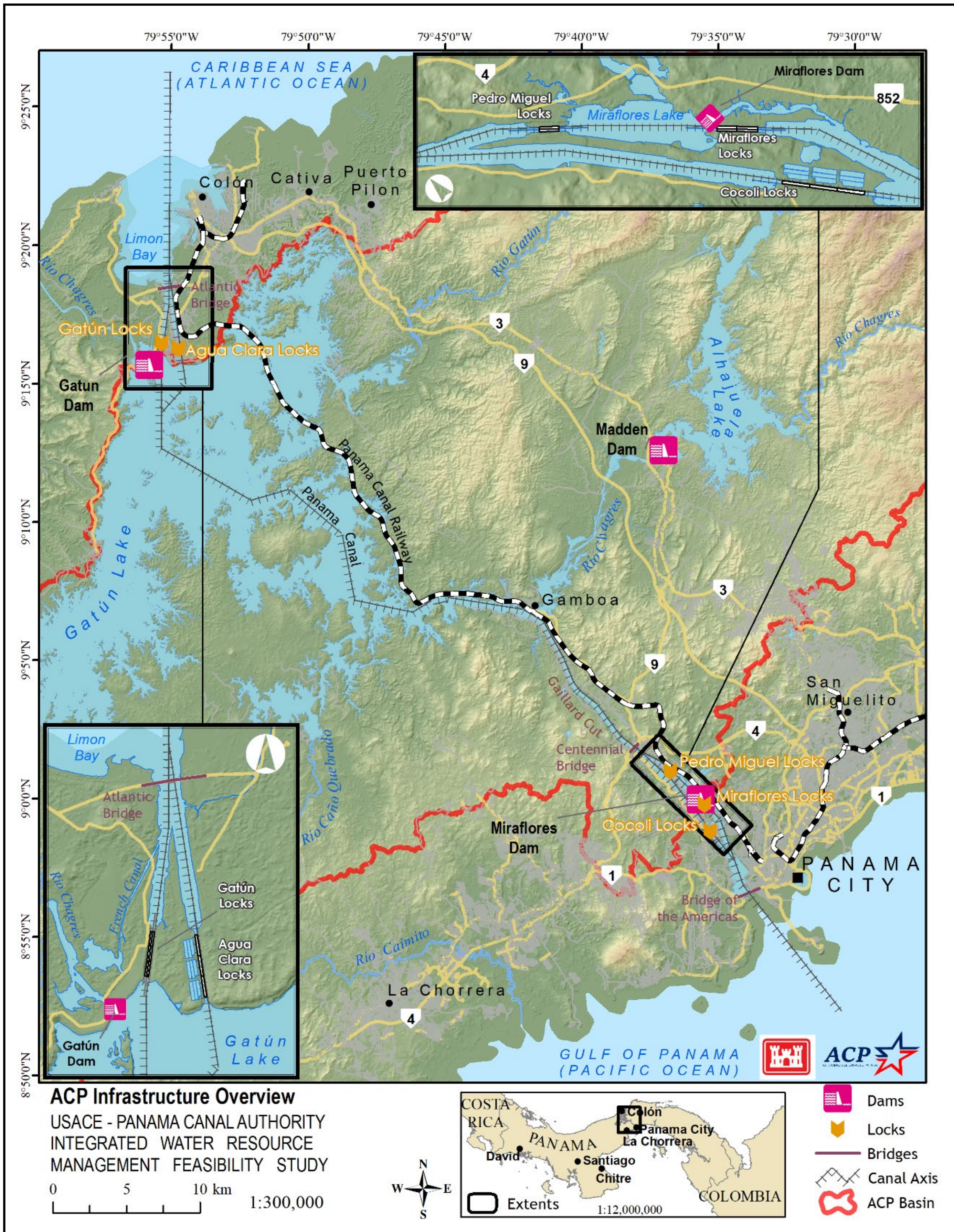


Figure 2-3: Overview Map of the Panama Canal

2.7 Governing Water Resource Policies and Laws Applicable to the Water Project

Various Republic of Panamá water resource policies guide the current study. These governing policies include the following:

1. Political Constitution of Panama – Title XIV
2. Organic Law Panama Canal Authority (1997)
3. Environmental Regulation, Hydrographic Basin and Inter-Institutional Commission on the Panama Canal Hydrographic Basin (2006)

The following sections describe key Articles and considerations of the water resource policies and a summary of their application to current Water Project.

2.7.1 Political Constitution of Panama

The Political Constitution of Panama (1972, rev. 2004), Title XIV includes provisions associated with the Panama Canal. Governing policies found in the Political Constitution of Panama that apply to Study A include the following Title XIV Articles:

- **Article 315**: The Panama Canal constitutes an inalienable patrimony of the Panamanian Nation; it shall remain open to peaceful and uninterrupted transit of vessels from all Nations and its use shall be subject to requirements, and conditions established by this Constitution, the Law, and its Administration.

- **Article 316:** An autonomous juridical entity under Public Law is hereby created with the name of the Panama Canal Authority, which shall have the exclusive administration, operation, conservation, maintenance and modernization of the Panama Canal and its pertinent activities, pursuant to constitutional and legal provisions to operate in a safe, continuous, efficient, and profitable manner. It shall have its own patrimony and the right to administer it.

  Per Article 316 "…The Panama Canal Authority, in coordination with other government agencies…shall be responsible for the administration, maintenance, use and conservation of the water resources of the Panama Canal watershed, which include the waters of the lakes and their tributary streams. Any plans for construction, the use of waters, and the utilization, expansion, and development of the ports, or any other work or construction along the banks of the Panama Canal shall require the prior approval of the Panama Canal Authority…".

There are two key guiding principles from the Title XIV Articles of the Panamanian Political Constitution applicable to the current study. These are:

- The Panama Canal Authority shall maintain uninterrupted transits of vessels into the future.
- The Panama Canal Authority is responsible for approving projects affecting water usage within the Panama Canal Watershed.

2.7.2 Organic Law of the Panama Canal Authority

The Organic Law of the Panama Canal Authority (Panama Legislative Assembly Law No. 19) was established on June 11, 1997. The purpose of this Law is to "…furnish the Panama Canal Authority with legislation for its organization, operation, and modernization to make the Canal a safe and profitable enterprise, a pillar in the human, social, and economic development of the country, open, without discrimination, to the participation of men and women and integrated to the national maritime strategy…". Key components of this legal framework applicable to the current study include:

- **Chapter 1, Article 4.** The Authority shall have the exclusive charge of the operation, administration, management, preservation, maintenance, improvement, and modernization of the Canal, as well as its activities and related services, pursuant to legal and constitutional regulations in force, so that the Canal may operate in a safe, uninterrupted, efficient, and profitable manner.
- **Chapter 1, Article 5.** The fundamental objective of the Authority functions is that the Panamá Canal always remain open to the peaceful and uninterrupted transit of vessels from all nations of the world, without discrimination, in accordance with the conditions and requirements established in the National Constitution, international treaties, this Law, and the Regulations.
- **Chapter 1, Article 6.** The Authority is responsible for the management, maintenance, use, and conservation of the water resources of the Canal watershed. To safeguard this resource, the Authority shall coordinate with the corresponding specialized governmental and non-governmental organizations which have responsibility for, and interests in, the natural resources of the Canal watershed, its management, preservation, and use of the natural resources of the watershed, and shall approve the strategies, policies, programs, and projects, both public and private, that may affect the watershed.
- Chapter 7, Article 120. The ACP shall manage water resources of the Panamá Canal hydrographic basin for the operation of the canal and water supply for consumption of the surrounding populations. The Authority will safeguard the natural resources of the hydrographic basin of the Canal watershed, especially critical areas, to prevent a reduction in the indispensable supply of water.

These Articles specifically note that the Panama Canal Authority must maintain operations, keep the canal always open to vessel transits, manage the Panama Canal hydrographic basin for consumptive water supply and prevent a reduction in water supply. The Panama Canal Authority is also the entity responsible for the management of water resources and is the entity that is responsible for approving the projects that may affect the watershed. The team interprets this to mean that the ACP is the entity that would ensure that future water expansion projects (for example future M&I water supply extractions) would require approval from the ACP and may include denial of future expansions if these projects are not compatible with maintaining sustainable navigation of the Panama Canal.

2.7.3 Environmental Regulation, Hydrographic Basin, and Inter-Institutional Commission on the Panama Canal Hydrographic Basin (2006)

According to Article 1 of the *Environmental Regulation, Hydrographic Basin, and Inter-Institutional Commission on the Panama Canal Hydrographic Basin* the purpose of this regulation is "to develop the general environmental regulations contained in the Organic Law of the Panama Canal Authority in matters of administration, protection, use, conservation, and maintenance of the water resources of the Panama Canal Basin, coordinate the administration, conservation, and use of the natural resources in these areas, establish the environmental regulations applicable to the patrimonial areas of the Panama Canal Authority and to the areas under its exclusive administration, as well as the environmental terms and conditions required by the Panama Canal Authority within the area of compatibility with the operation of the Canal and Hydrographic Basin of the Panama Canal." A key article that applies within the context of this current study is Article 2, which states:

- **Article 2:** The Panama Canal Authority is responsible for:
    - Managing, conserving, and maintaining water resources for the operation of the Canal and the supply of water for consumption of the surrounding populations, promoting its rational and sustainable use.
    - Coordinate the conservation of the natural resources of the Basin with the competent public and private organizations.
    - Approve the strategies, policies, programs, and projects, public and private, that may affect the Basin.

This article further highlights the Panama Canal Authority's responsibility to manage the water resources within the Panama Canal Watershed and identifies the Panama Canal

Authority as the entity responsible for approving projects that may affect the water resources of the Panama Canal Basin.

3. PROBLEMS, OPPORTUNITIES, OBJECTIVES, AND CONSTRAINTS

3.1 Problems

3.1.1 Problem Statement

A problem statement clearly describes existing, negative conditions; issues of concern; and objectives. The problem statement encompasses current and future conditions; reflects stakeholder priorities; and is a foundational description guiding analysis. The PC IWRM Study problem statement, developed by the ACP and USACE PDT is:

> Meeting Panama Canal operational needs, ensuring transits, municipal and industrial (M&I) water requirements and controlling salinity have created excessive demands on the Panama Canal watershed water supply resources. This puts long-term sustainability of Panama Canal operations at risk; jeopardizes efficient and reliable navigation through the Canal; and impacts the global competitiveness of the Panama Canal.

3.1.2 Water Availability

From 2017-2021, among the driest years on record in Panamá, Gatún Lake's average annual inflow was approximately 4.8 billion cubic meters (m^3) of total inflow (62.5 Equivalent Transits[1] per day). ACP manages the available water (see Figure 3-1 for an overview of the ACP water budget) for uses that include:

1. **Navigation (Lockages):** Lockages are the single, largest water resource demand on the system and maintaining water supply for sustainable future navigation is the key objective of the Water Project. Each Panamax vessel currently uses approximately 0.8 Equivalent Transits of water to transit from ocean to ocean. Each Neopanamax vessel uses between 1.0 and 2.4 Equivalent Transits of water to transit from ocean to ocean. The volume of water used to transit a vessel depends on the use of water savings basins or salinity mitigation measures.

2. **Municipal and Industrial Water Supply**: This is water supply for the cities of Panama City, Colón, and other communities.

[1] See Section 3.3.1 for definition of Equivalent Transit

3. **Hydropower**: The ACP generates hydropower at Gatún Dam when water resources availability allows. This is the most flexible use of water resources and is the first water use to be reduced or turned off when water availability is low.

4. **Saltwater Intrusion Mitigation**: Panamanian regulation establishes a limit of 250 Cl- mg/L, equivalent to 0.45 practical salinity units (psu), at water intakes for M&I. The ACP, through a decision memorandum, developed a 0.25 psu operational threshold that triggers implementation of mitigation measures to reduce the salinity intrusion in Gatún Lake. Ecological thresholds have yet to be a controlling factor determining when salinity intrusion mitigation measures are implemented in the system.

   Spillway Flow: Spillway flow is water released over the Gatún Spillway when Gatún Lake is relatively full and inflows exceed or are expected to exceed the outflows of the system (typically during flood events, in preparation for floods, to draw down the Gatún Lake elevation, or during spillway gate tests). Reducing volumes of spilled water and storing this water is one of the approaches used in the current study. During recent dry year (2017-2022) approximately 1% of the available water was released over the Gatún Spillway.

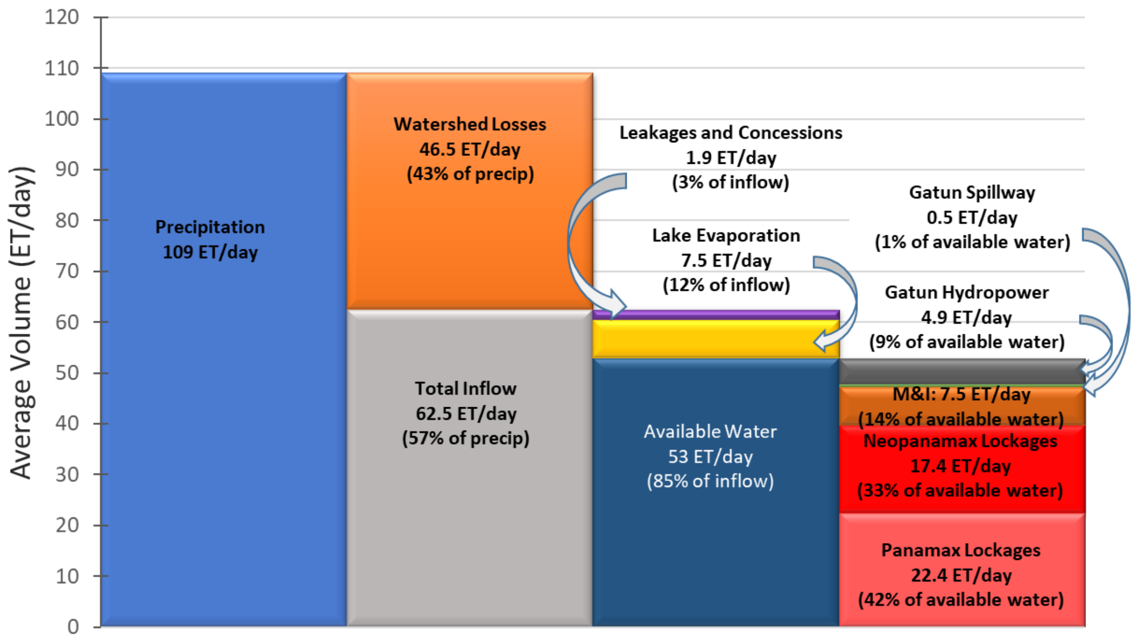


Figure 3-1: Observed Average Annual Water Budget from 2017-2021 (Note: The data represents a dry period.)

In Figure 3-1, the water used in lockages also includes water associated with the mitigation of salinity intrusion.

In Panama's referendum to expand the Panama Canal (ACP, 2006) municipal water supply demand was projected to reach approximately 340 million gallons per day in the year 2025. This volume of water is equivalent to that needed to perform approximately 6 ETs per day. The average M&I use from 2017-2021 was 7.5 ETs per day.

Currently, the water demands for M&I water supply are approximately 8 ETs per day (which is 33% greater than projected values for the year 2025). These projections were surpassed as early as 2012 due to water supply demands for human consumption, and other activities associated with a growing economy and population. There are also significant losses due to many unmetered water customers and distribution system leakage.

Future weather patterns are projected to be as or more intense than those experienced to date and characterized by extreme wet and dry weather events (see Section 4.4.1 and Appendix B Water Management, Attachment B1 for information regarding projected climate variability and climate change).

Exceptionally wet periods may challenge flood water storage.

Dry periods, when demands exceed inflows, will challenge availability of sufficient water to meet the Panama Canal's operational needs and Panama's increasing municipal water demands. The HEC-ResSim modeling conducted for this study demonstrates that navigation transits could be significantly impacted for weeks or months if 1) water supply demands continue to increase as forecasted and 2) droughts similar in magnitude to those in 1997-1998 or 2015-2016 occur.

Reliable navigation transits and drafts and increasing M&I water supply are fundamentally incompatible based upon forecasted Panama Canal system water volumes, the Republic of Panama's forecasted water use, and anticipated climate conditions. Given current trends, there will be insufficient water to support Panama Canal navigation at full operational capacity and M&I water supply in the future. The frequency of water supply limitations is expected to significantly grow. Meeting future navigation demands will be unsustainable if interventions to decrease water demands, increase system storage, or increase water supply are not put in place.

3.1.3 Operational Needs, Navigation and Shipping

The total navigation volume or throughput of the Panama Canal is constrained by three processes (see Table 3-1).

- Transit demand. For a given toll structure and other economic considerations, there is some global, navigation industry demand to use the Panama Canal system.
- System capacity. If the global demands exceed the Panama Canal system capacity, vessel throughput is constrained by the system's physical infrastructure. Under current Panama Canal queuing strategies, system capacity is limited by Culebra Cut's 14 kilometer (km), one-way channel. The Panama Canal's operational capacity is approximately 39.0 lockages (12.64 Neopanamax and 26.34 Panamax transits per day). Specifics of navigation and shipping in the Panama Canal are discussed in detail in Appendix D, Economics.
- Water availability. The Panama Canal operates on freshwater. Water available for future navigation continues to decrease (see Figure 3-2) as demand for freshwater grows (for example, due to expansion of M&I water supply or other non-navigation water demands).

Table 3-1: Processes Limiting Panama Canal Navigation Throughput

Process	Description	Additional Notes
Vessel Demand (Demand Limited)	**Based on economics**. This describes the global daily demand to use the system. For a given toll structure, the total vessel demand may be less than the physical system capacity.	The current study assumes there are always vessel demands equal to or exceeding system capacity. This is a reasonable assumption at the 5% design.
Operational (Capacity Limited)	**Based on the physical infrastructure in the system.** There is a ceiling on how many vessels can transit the Panama Canal each day. Currently this is limited by the one-way traffic in Culebra Cut.	Daily transit limits for the study: • Neopanamax: 12.64 transits • Panamax: 26.34 transits No system capacity expansion is assumed in Study A.
Water Availability (Supply Limited)	**Based on the water availability.** This describes if sufficient water is available to operate the system at full capacity.	Eliminating (or reducing) water availability as the limiting process to vessel throughput is the objective of this study.

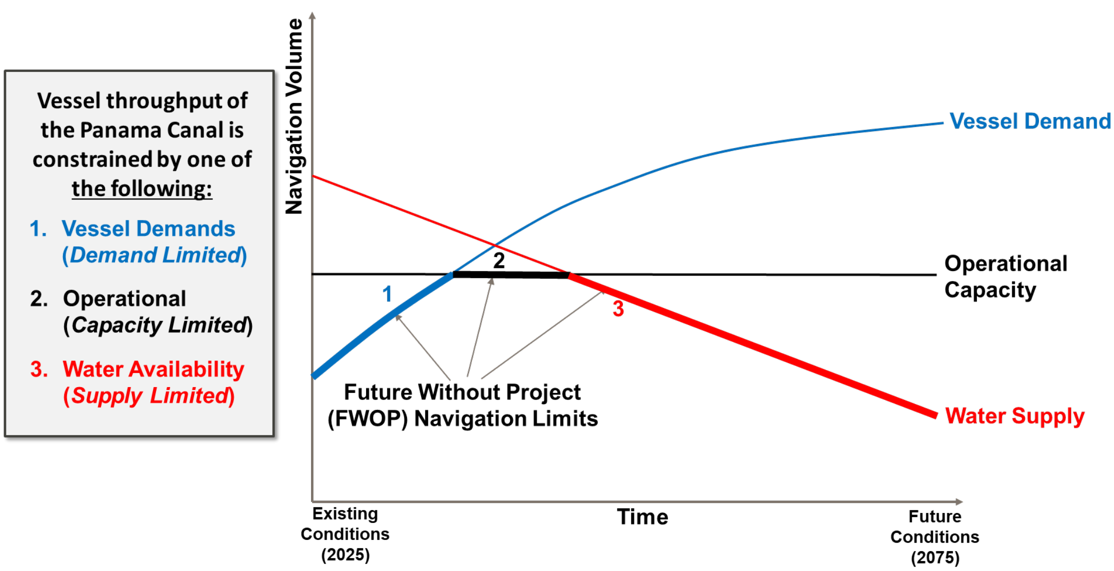


Figure 3-2: Panama Canal Navigation Volumes Limits

Panama has historically experienced severe droughts (for example, in 1976-1977; 1997-1998; and 2015-2016). Appendix B Water Management Modeling describes the drought conditions in the Panama Canal Watershed from 1950-2021. During drought periods, the elevation and operational volume within Gatún Lake are reduced. These conditions require special operations by the ACP to ensure uninterrupted service through the Panama Canal, particularly of larger Neopanamax vessels.

Operations during drought periods include crossfilling at the Panamax locks to save water and water savings measures at the Neopanamax locks[2]. ACP operations leading to water savings during droughts cause increased salinity values. A separate Salinity Study assessing salinity intrusion mitigation is being performed in parallel to the current feasibility study.

ACP sends a notice informing shippers of draft restrictions for sea-going vessels transiting Gatún Lake when the Panama Canal is operating at lower elevations. In response, Panama Canal customers typically take action, such as light loading to minimize draft. These reactions are time-consuming, negatively impact shipping efficiency, and could negatively impact the Panama Canal's marketability as a preferred route.

The Panama Canal watershed provides municipal water to the cities of Panama City, Colón, and other communities. M&I water withdrawals are not presently at risk due to lower water volumes because Gatún Lake M&I withdrawals are prioritized under current operating conditions. Existing and future without project analyses, discussed in greater depth in Chapter 4, indicate that M&I water supply could be threatened should a drought become so severe that water levels drop below water intakes currently installed at elevation (EL) 22.86 m (75 feet (ft)) or salinity in the vicinity of water intakes exceed the Panama Canal's operational M&I limit of 0.25 psu. A map of the locations and capacity of municipal water intakes are shown in Figure 3-3. The M&I water intake capacities correspond to the planned, maximum capacity of the water treatment plant.

[2] The water savings measures at the Neopanamax locks often lead to higher salinity values in the system, as salinity mitigation measures are reduced.

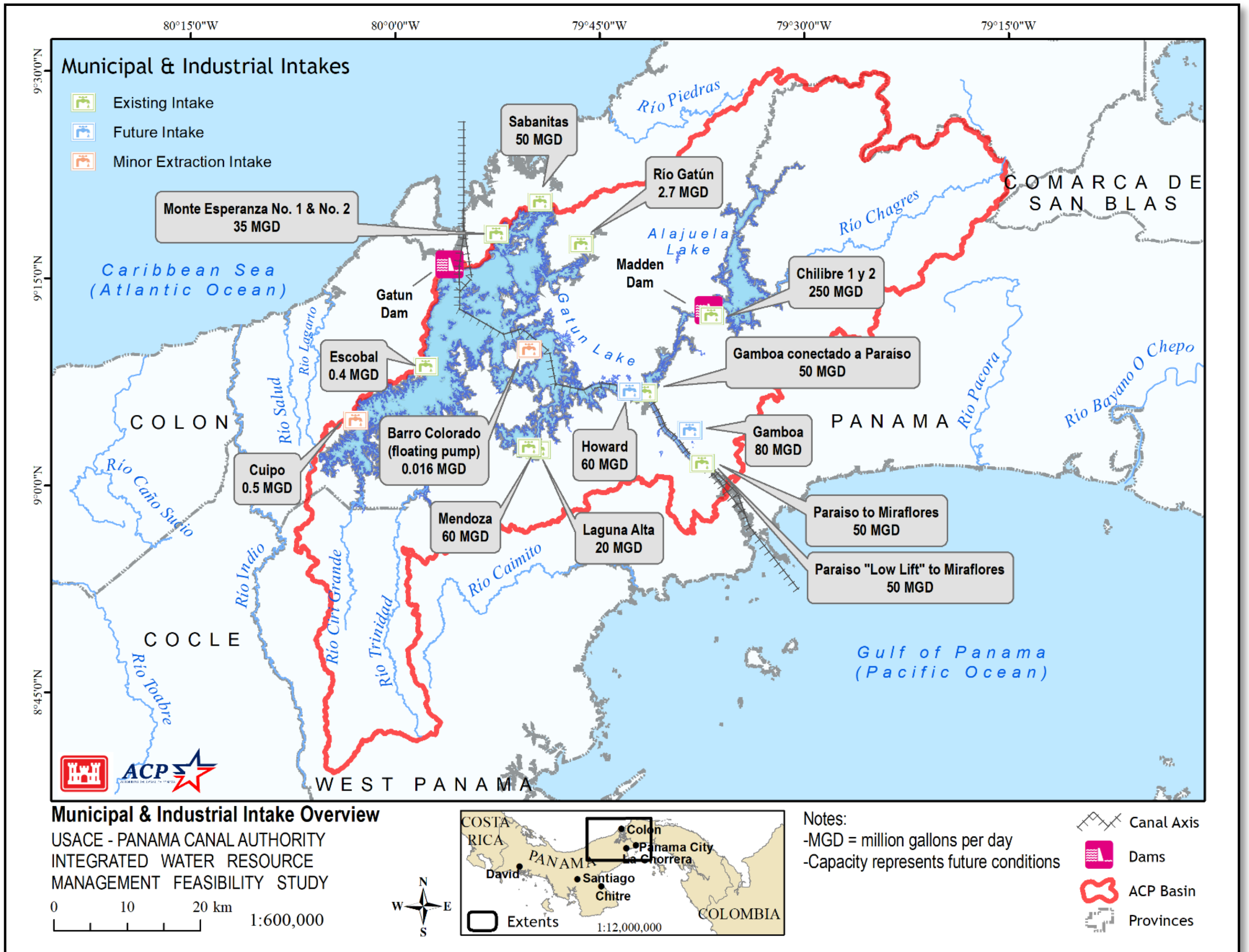


Figure 3-3: Water Treatment Plants Locations and Capacities within the ACP Basin

3.1.4 Water Quality (Salinity)

Neopanamax operations began in June 2016. Salinity intrusion rates into Gatún Lake have increased since Neopanamax operations began. Salinity intrusion occurs year-round under all hydrologic conditions; however, the Panama Canal Authority has managed the salinity intrusion through operational measures and maintains salinity values below threshold targets. The salinity intrusion mitigation measures include the use of a water barrier during Neopanamax lock operations and various flushing strategies. The greatest impact of incorporating salinity mitigation measures is the Panama Canal's inability to use the water savings basins (see Figure 3-4) to save water, leading to higher Neopanamax water volume use than originally designed.

Figure 3-4: Agua Clara Neopanamax Water Savings Basins

The Gatún and Agua Clara Locks are located on the northern, Caribbean-Atlantic Ocean boundary of the Panama Canal facilities. Saline water is released into Gatún Lake as vessels lock through the system, particularly in the ocean bound direction[3]. The saltwater is further distributed and mixed in the locks' vicinity and Gatún Lake by wave, wind, and prop action. Increased salinity negatively impacts Gatún Lake's freshwater ecosystem; raises concerns regarding invasive marine species found in Gatún Lake

[3] Salinity values increase at a greater rate when vessels are navigating in the ocean bound direction than the lake bound direction. This is due to displacement. As the vessel departs the lower chamber into the ocean side of a lock, the water that the vessel previously displaced in the chamber is replaced by the higher salinity water from the ocean entrance channel.

becoming permanently established; and affects the suitability of Gatún Lake’s for M&I uses.

The Cocolí and Miraflores Locks are located on the southern, Pacific Ocean boundary of the Panama Canal. Saltwater is released as vessels enter the Panama Canal. The saltwater wedge can migrate towards the Culebra Cut and has affected the water quality of withdrawals at the Paraiso Water Supply Intake. To date, elevated salinity values have not propagated through the Culebra Cut to Gamboa and the salinity wedge has been maintained within the Culebra Cut.

Currently Panamanian regulation establishes a limit of 250 Cl- mg/L, equivalent to 0.45 psu, at M&I water intakes; however, ACP, set a threshold of 0.25 psu that triggers the implementation of mitigation measures to reduce the salinity intrusion in Gatun Lake. Ecological thresholds have yet to be a controlling factor determining when salinity intrusion mitigation measures are implemented in the system. Ecological thresholds are being analyzed.

The ACP monitors salinity values using dozens of conductivity, temperature, and depth (CTD) sensors throughout the system. The ACP monitors practical salinity units throughout the Panama Canal system on a real-time basis. An example of a salinity monitoring dashboard is shown in Figure 3-5.

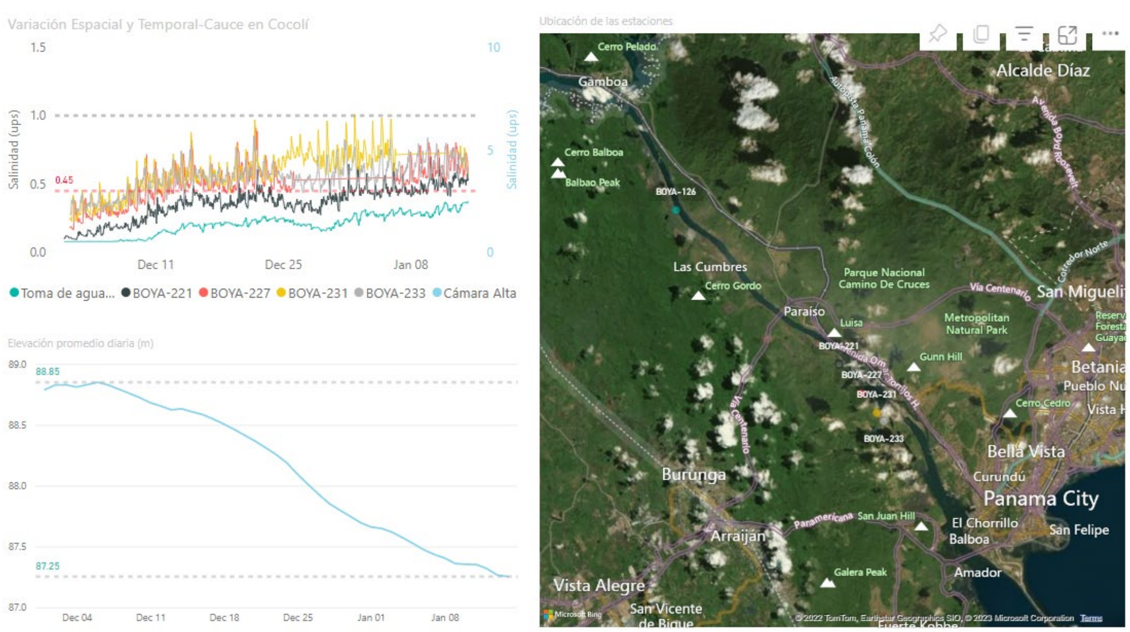


Figure 3-5: ACP Salinity Monitoring Dashboard

The ACP used, on average, 4.7 ETs of freshwater per day or approximately 258.5 million gallons per day (mgd) to control salinity from 1 January to 31 July 2020 The freshwater used to mitigate against salinity intrusion could be used to support Panama Canal transits.

A secondary impact of increased salinity is potential increased corrosion of facilities and infrastructure originally designed for use in freshwater.

3.2 Opportunities

The ACP and USACE PDT identified opportunities to support ACP strategic objectives and capitalize on ancillary outputs beneficial to the ACP. ACP's strategic objectives are described in Table 3-2.

Table 3-2: Panama Canal Authority Strategic Objectives (ACP, 2021a)

ACP Strategic Objectives Canal de Panama Annual Report 2021	
1	Grow Panama Canal business by increasing the tonnage to generate more revenue
2	Diversify revenues through strategic businesses
3	Maximize business profitability through efficiency, productivity, and effective risk management
4	Strengthen customer relations and business intelligence
5	Ensure water volume and quality for human consumption and for Panama Canal operations
6	Guarantee the use of best business practices and good corporate governance
7	Transform the organization by developing its capabilities and competencies
8	Proactively strengthen the Panama Canal's image, respect, and credibility

The opportunities that could be realized through the Water Project Feasibility Study relate to business, economic security, environment, climate change and social goals (reference Table 3-3).

Table 3-3: Opportunities, Panama Canal IWRM Feasibility Study

	Opportunities Panama Canal IWRM Feasibility Study								
	Opportunities / **ACP Strategic Objectives**	1	2	3	4	5	6	7	8
1	Improve water quality in Gatún Lake				X	X	X		X
2	Improve resiliency of the Panama Canal system by anticipating, preparing for, and adapting to changing conditions, and withstanding, responding to and recovering rapidly from disruptions	X		X	X	X	X	X	X
3	Improve water supply and sanitation for communities near the lakes				X	X	X		X
4	Provide additional freshwater storage, protected from salinity intrusion, for lock operations and M&I water use	X	X	X	X	X	X		X
5	Reduce flood risk in the basin by providing extra storage	X		X	X		X		X
6	Become a global reference for water management				X		X	X	X
7	Have more Panamanians on the front line of hydrology				X		X	X	X
8	Develop resource capacity in water stewardship and sustainability			X	X	X	X	X	X
9	Beneficial use of dredged material for planned projects within the basin and nearby civil projects			X	X		X		X
10	Use of dredged/excavated material as material on planned dams that will increase water storage to improve navigation use			X	X		X		X
11	Take advantage of dredged/excavated materials from projects to add value to the Canal		X	X	X		X		X

Opportunities Panama Canal IWRM Feasibility Study									
12	Increased hydropower generation		X	X	X		X		
13	2030 zero carbon emissions goal			X	X		X	X	X
14	Promote the cooperation/coordination between ACP and Instituto de Acueductos y Alcantarillados Nacionales (IDAAN, Panama's public water supply company)				X	X	X		X
15	Improved access road/transportation network			X	X		X	X	X
16	Enhanced understanding of life safety risks to communities in the study area			X	X		X		X

3.3 Objectives and Constraints

3.3.1 Panama Canal Authority Implementing Arrangement Objective

The ACP solicited the USACE for support in developing an economically justified and environmentally sustainable IWRM Plan that optimizes the Panama Canal's navigation reliability over the 50-year planning study horizon including specific measures to maximize water resources yields within the ACP watershed and when complementary, outside the ACP watershed. These measures will increase operational reliability and resiliency of the Panama Canal and watershed.

3.3.2 Study Objectives

A feasibility study objective describes the desired results from solving the problem(s) and capitalizing on opportunities. The ACP and USACE PDT identified the following planning objective for the PC IWRM Study:

Study Objective: Optimize the Panama Canal's navigation reliability over a 50-year planning horizon.

3.3.3 Planning Constraints

Alternative formulation is bound by planning constraints. Constraints are actions to be avoided; unalterable circumstances affecting the planning, project conditions that cannot be changed; and effects that should be avoided.

Constraints may be, but are not limited to, resources, conditions, known impacts, policy, or legal limitations. The Panama Canal IWRM Study PDT also agreed that measures violating constraints would be eliminated from further consideration. Constraints were re-visited throughout the study to ensure the constraint remained appropriate to the study and assess whether new information indicated a measure would violate a constraint.

Constraints identified by the ACP and USACE PDT in the August 2022 Planning Meeting are:

1. **Maintain or improve dam safety.** Measures that negatively affect dam safety or life safety risk at Madden Dam, Gatún Dam or Miraflores Dam will not be considered.
2. **Avoid increases to life safety risk.** Measures that may create circumstances or introduce hazards that increase susceptibility to life loss are unacceptable.
3. **Meet 100% of M&I requirements through the 50-year period of analysis.** M&I water supply is identified as one of the water uses in Panama within the context of Organic Law of the Panama Canal Authority. This law identifies the Panama Canal Authority is the entity responsible for managing the water resources within the ACP Basin, which includes approving or denying any future municipal water expansion projects. Any measure explored through the PC IWRM Feasibility Study must meet ACP approved M&I water supply demands. The PC IWRM Study PDT agreed that M&I water supply would be part of the base code in the HEC-ResSim Water Management model to guarantee this constraint.
4. **Maintain ACP operational salinity values to acceptable targets.** Measures will be excluded from further consideration if they are expected to result in salinity levels at drinking water salinity monitoring stations higher than 0.25 psu at drinking water intakes.
5. **Adherence to all applicable Panamanian laws and regulations.** Any measure that does not comply with Panamanian laws and regulations or creates conditions of non-compliance with Panamanian laws and regulations will not be considered.
6. **No significant impacts to railroad operations.** No measure will interrupt Panama Canal Railway (PCR) operations. The PCR is the only operational railroad in Panama providing passenger and freight service. The transcontinental railway generally follows the historic railway route used

during Panama Canal construction and provides transportation between Balboa/Panama City and Colón.

3.4 Study Assumptions

The PC IWRM Study PDT developed assumptions specific to the PC IWRM Feasibility Study analysis, with project conditions, and without project conditions. The USACE standard assumptions about with and without project conditions, adjusted to reflect the Panama Canal reality, also apply.

Specific study assumptions that underlie the PC IWRM Study plan selection are:

- The selected alternative should achieve future with project reliability metrics better than the existing system navigation reliability.
- The ACP's primary decision driver is investment assessed against anticipated navigation reliability. A project cost of approximately $2 billion or higher, while not a constraint, is beyond the planned expenditures of the ACP and will require additional consideration.

Specific study assumptions that underlie the PC IWRM Study plan analysis are described below.

To evaluate Panama Canal's navigation reliability and water supply solutions, the USACE developed an HEC-ResSim water management model. The HEC-ResSim model was designed to:

- Analyze measures that could improve water supply conditions; and
- Define how measures might be combined into effective alternatives.

The HEC-ResSim model outputs were used by the PDT to:

- Evaluate benefits, costs, impacts and risks of measures at approximately 5% design.
- Consider benefits of solutions in terms of:
  - Transits.
  - Available draft.
  - Economic benefits.
  - Under existing conditions and future conditions; and
  - In combinations that could achieve future levels of reliability like today's levels of reliability.

Characteristics of existing conditions used in the HEC-ResSIM model are:

- EL 22.860 m Precise Level Datum (PLD) (75 ft) water intake elevation/Gatún Lake operational level.
- EL 23.622 m PLD (77.25 ft) navigation cut off elevation to ensure adequate reserve water storage to meet current M&I water supply demands.
- Gatún Lake maximum normal operating pool EL 26.82 m PLD (88 ft).
- Year 2025 projections for M&I water supply withdrawals.
- Navigation demands of 25.33 Panamax vessels per day and 9.53 Neopanamax vessels per day

Characteristics of Future Without Project conditions used in the HEC-ResSim model are:

- EL 22.860 m PLD (75 ft) water intake elevation/Gatún Lake operational level.
- EL 24.232 m PLD (79.5 ft) elevation navigation cut-off required to meet increased M&I water supply demands and increased evaporation.
- Gatún Lake maximum normal operating pool EL 26.82 m PLD (88 ft).
- Increasing, uncapped M&I withdrawals.
- Navigation demands at full system capacity. This includes 26.34 Panamax and 12.64 Neopanamax vessels per day. Navigation demand will be independent of draft restrictions (i.e., there will always be vessels utilizing Panama Canal passage if water is available for transits).

The economics analysis assumes demand exceeds system capacity when the Panama Canal provides 100% transit and draft reliability. Once 100% reliability is not available, demand is adjusted by an elasticity estimate for vessels that are impacted by lack of available transits or draft.

USACE standard assumptions about with and without project conditions, adjusted to reflect the Panama Canal reality, also apply.

The following specific assumptions are part of the projected with and without project condition:

- All reasonably expected nonstructural practices within the discretion of the ACP are implemented at the appropriate time.
- Infrastructure and navigation channel improvements available over the planning period occur.
- Normal operation and maintenance practices are performed over the period of analysis.

- User toll fees are part of the without-project condition.
- Advances in technology affecting the transportation industry over the period of analysis are considered within reason.

4. EXISTING AND FUTURE WITHOUT PROJECT CONDITIONS

4.1 Hydrometeorological Setting

Precipitation runoff is the primary source of water stored in Alhajuela Lake and Gatún Lake for operational purposes. On average, approximately 60% of precipitation in the watershed arrives as inflow to the two reservoirs.

The Panama Canal region has well-marked seasonal variation in rainfall. The dry season typically begins in mid-December and lasts approximately four months until mid-April. The rainy season covers the remaining eight months of the year. The flood control season is typically from September to January. Mean annual rainfall from the last 20 years ranges from more than 3302 millimeters (mm) (130 inches (in)) in the Atlantic-Caribbean region to a low of 1876 mm (74 in) in the Pacific region (see Figure 4-1). The largest annual average volumes of precipitation within the ACP basin, 4852 mm (191 in), occur in the headwaters of the Chagres River above Madden Dam.

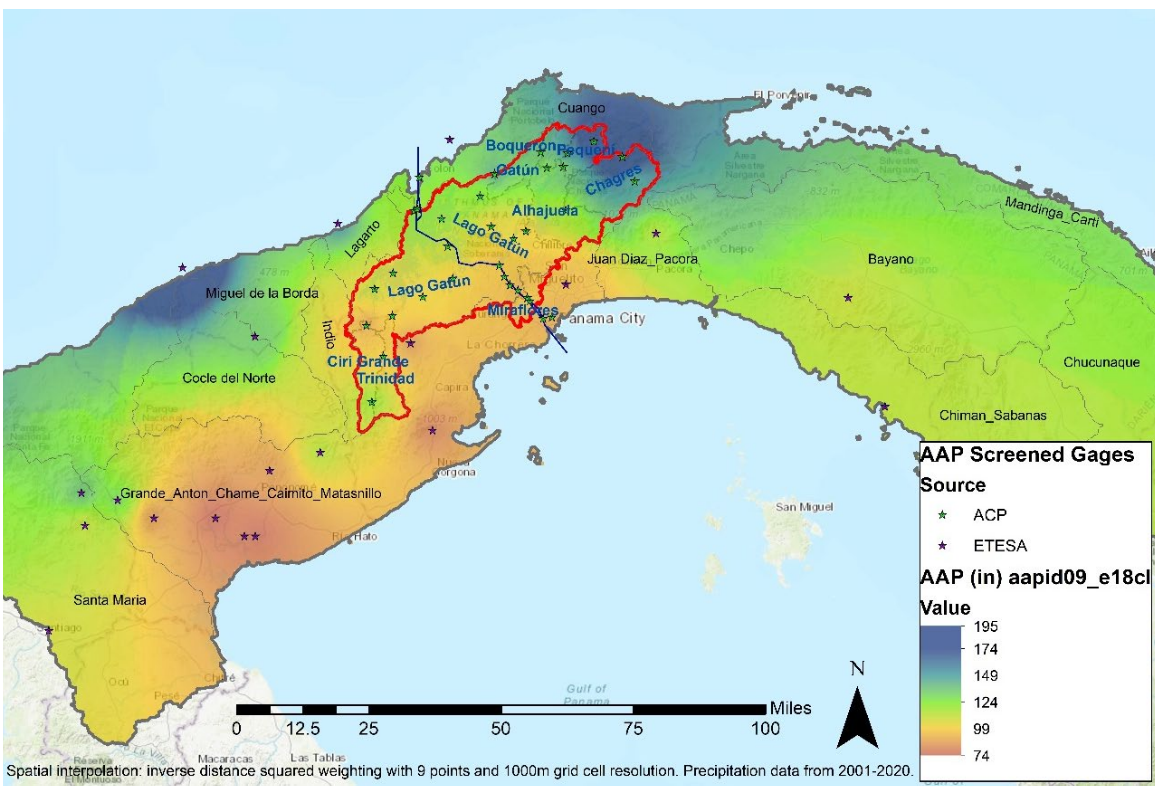


Figure 4-1: Republic of Panama Average Annual Precipitation, 2001-2020

Approximate, median annual rainfall for the Panama Canal Watershed based on 20 representative rainfall gages from 1950 through 2021 is 2630 mm (103.4 in). Figure 4-2 plots a computed average annual calendar year rainfall from 1950-2021 based on these 20 gages. Significant El Niño years (characterized by low rainfall) are highlighted in orange and red in Figure 4-2. The drought of record was in 1997. La Purisima, the flood of record occurred in December of 2010 (highlighted in green in Figure 4-2).

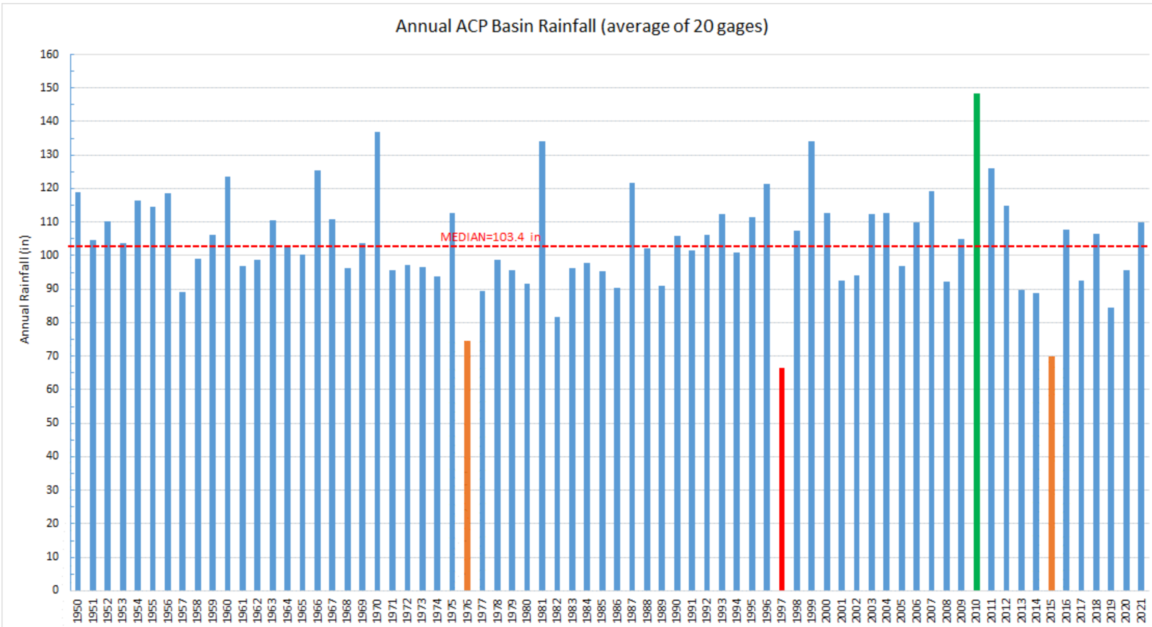


Figure 4-2: Panama Canal Basin Annual Average Rainfall

Since Neopanamax operations began in 2016, overall precipitation has been below average. Simultaneously, the use of water has increased and the Neopanamax locks are using more water than originally planned. For more information on the hydrometeorological setting of the ACP watershed, refer to Appendix B Water Management Modeling.

4.2 Planning Horizon

The planning horizon for this study is 50 years. The joint USACE and ACP team has identified the year 2025 as the starting point for the implementation of early measures and the year associated with the existing conditions for the study. The team identified the year 2075 as the future year for the evaluation of future conditions. These conditions are further defined below:

1. **Existing Conditions (EC):** This includes a series of assumptions based on an analysis of recent data and operational rules associated with the Panama Canal

system. The year 2025 will be used as the base year associated with the existing conditions.

2. **Future Without Project (FWOP):** The FWOP is a forecast of conditions that it is reasonable to assume would occur if a project is not put in place. The FWOP is the point from which alternatives are formulated and impacts are assessed. The FWOP is analyzed for the year 2075 in this study.

In addition to defining the existing conditions and future without project conditions, the team analyzed and investigated observed historic water demand and the system response to water demands. Typically, observed conditions represent the demands and system response from 1965 through 2022. The historically observed water demand conditions provide many useful insights; however, due to the short time duration associated with Neopanamax operations, historical trends have not been significantly used or have been used with caution in the current analysis.

4.3 Water Demands for the Existing and Future Without Conditions

4.3.1 Definition of Equivalent Transit

A unit of water used in this study is an Equivalent Transit (ET). One Equivalent Transit has historically been approximately equal to the amount of water necessary to fully transit a vessel from ocean to ocean using the Panamax locks. This value is equal to 208,198 cubic meters (m^3) (55 million gallons) and was defined in USACE (1999a).

The actual volume of water used today to transit from ocean-to-ocean under current conditions is typically 20-25% less than this volume. The ocean-to-ocean transit water volume is also variable based on the elevation of Gatún Lake and operational factors[4].

4.3.2 Water Demand Assumptions and Values

The ACP and USACE team jointly developed a set of assumptions associated with the water demands for both the existing conditions and the future without project conditions. These assumptions were developed through a series of meetings with the technical teams from the ACP and are calculated in ACP (2022). Table 4-1 lists the

[4] The size of the vessel does not impact the volume of water used for a lockage or an ocean-to-ocean transit.

assumptions for the demands of water for key water budget components of the Panama Canal. This table lists demands for lockages as well as M&I water supply.

In addition to the primary water demands, the ACP uses water at the Gatún Hydropower facility to generate electricity. This is not a primary economic driver for the Panama Canal Authority, and this current study prioritizes water to be used for navigation purposes over hydropower. Additional processes where water is removed from the water project include spilling over the Gatún Spillway, evaporation from Gatún Lake and Alhajuela Reservoir, Gatún leakages, and other smaller processes.

Based on historical inflows from 1965 through 2022, there are 61-62 daily equivalent transits of water (system inflows minus lake evaporation and Gatún Dam leakage) available for navigation, water supply, and other uses. This average is significantly greater than the average available water during the period of Neopanamax operations from 2017-2021, when only 53 ETs/days of water was available (refer to Figure 3-1). Under the existing conditions (reference Table 4-1), the total volumes required to meet navigation and water supply demands is approximately 50.4 ETs.

Future water demands are expected, on average, to exceed the water supply and navigation restrictions would occur in this water supply limited condition (see Figure 3-3). Future climate conditions will likely result in less available water (less than the average daily 61.1 ETs shown in Figure 3-3), which will exacerbate the predicted over-allocated situation. Climate change is not thought to be the primary driver of the future water over-allocation (see Section 4.4.1 and Appendix B, Attachment B1).

Table 4-1: Navigation Water Supply Demands, Existing and Future Without Project Conditions

Variable	Existing Conditions (2025)	Future Without Project Conditions (2075)	Change
Gatún M&I Demands (ET)	3.433	10.043	+6.61
Alhajuela M&I Demands (ET)	4.545	4.545	NC
Panamax Transits	25.33	26.34	+1
Panamax Transit Water Demands (ET)	20.3	19.2	-1.1
Neopanamax Transits	9.53	12.64	+3.1
Neopanamax Transit Water Demands (ET)	22.2	30.2	+8
Neopanamax WSB[2] Use (Dry Season)	0%	0%	NC
Neopanamax WSB Use (Wet Season)	9.8%	9.8%	NC

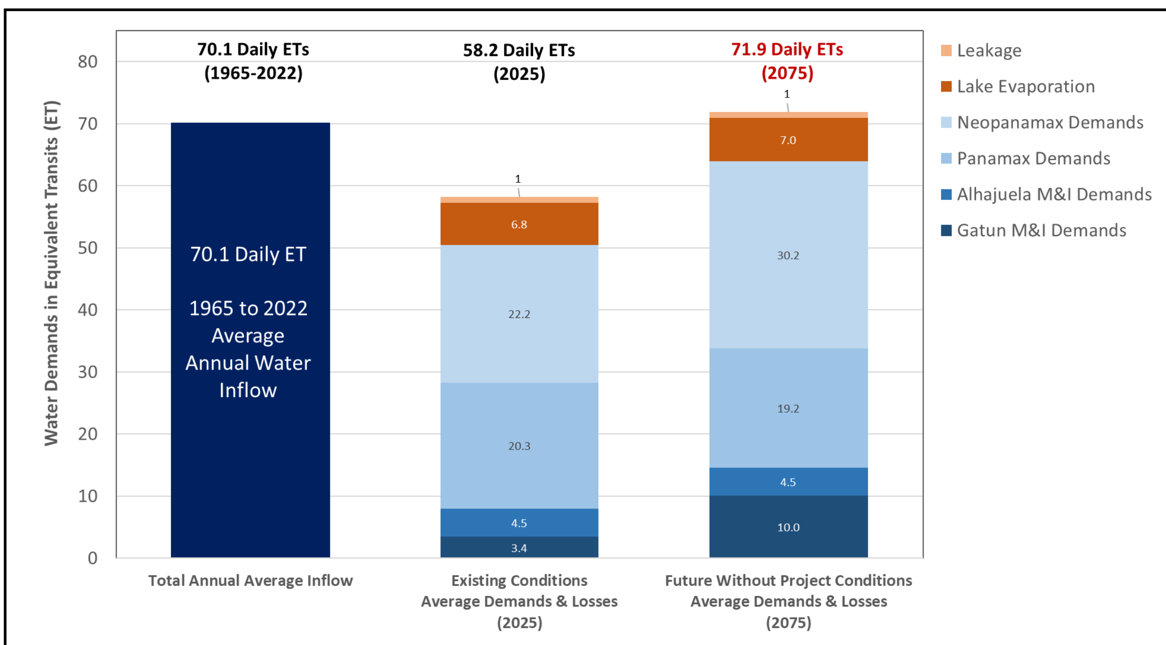


Figure 3-3: Existing Conditions and Future Without Project Water Demands (Note: These demands assume 100% of transits are supplied)

Water availability frequently limits navigation throughput in the Panama Canal because future without project conditions have a higher demand than the annual average inflow into the system (reference Figure 3-3). This demand-inflow imbalance is more pronounced during below average inflow years when future demands could far exceed available water entering the system (the 10 lowest inflow years since 1965 averaged less than 50 daily ETs). This would result in limitations to navigation transits.

The Panama Canal has not historically faced navigation transit limitations. In addition, expanding the system capacity for more vessel throughput (for example, adding a fourth lane or two-way traffic in Culebra Cut) would have limited benefits. Benefits of increasing the operational capacity of the Panama Canal is limited until the water availability issue is resolved.

4.4 Future Climate and Sedimentation Conditions

Within the context of the feasibility study analysis, the most significant difference between the existing conditions and the future conditions is anticipated increase in water demands, specifically navigation and municipal water supply demands.

Other processes also affect future navigation reliability in the future without project conditions analysis. These processes include:

- Climate Change
    - Future changes in evaporation
    - Future changes in inflows
- Reservoir Sedimentation

The following sections describe these processes and their relevance to the future conditions associated with this study.

4.4.1 Climate Change

Increased demands for vessel transits and M&I use have added stress to the Panama Canal system. Recent droughts, potentially exacerbated by climate change, have contributed additional stress on water supply resources and water quality. Now, and as the climate changes into the future, it is prudent to assess projected impacts to water resources and consider adaptive measures to increase operational resiliency of the system. See Appendix B, Water Management Modeling and Attachment B1 for information related to the climate change analysis associated with this study. The primary conclusions in the climate change analysis are:

- Results of future projected changes in precipitation rates based on various climate emission scenarios are inconclusive. Typically, lower emission scenarios predict a small percentage increase in mean precipitation, while higher level emission scenarios reflect a decreasing trend in precipitation.

- Historical temperature and evaporation observations are not stationary, suggesting historical data may not be good to use in future conditions analysis. This is supported by projected increases in temperatures, evapotranspiration, and lake evaporation. Based on the literature for evaporation projections 50 years into the future, the ACP could expect an approximate 10% increase in lake evaporation rates compared to average current rates. This annual volume equates to approximately 1 additional lockage per day of water lost with current demands (a future condition would likely include lower average pool levels and reduced pool area, which combined with higher evaporation rates, may balance evaporative volumes). These findings suggest it is prudent to incorporate numerical adjustment to future evaporation rates in reservoir modeling.
- Based on climate change analysis, the primary modification to the 5% evaluation of future without project conditions is an increased evaporation rate (see Table 4-3). The approximate expected annual evaporation rate increases from 1185 mm per year in the existing conditions scenario to 1302 mm per year in the future without project conditions scenario. Statistical tests of historical annual inflows suggest stationarity and promote the use of historical time series in water yield analyses for existing and future conditions. However, published literature for the region suggests projected decrease in runoff in the future, and droughts are likely to increase in severity and frequency. These findings indicate it is prudent for the feasibility 15% design to explore advanced climate change assessment to be able to compare climate resiliency metrics between alternatives.
- Climate change increases the likelihood of the occurrence of drought and extreme precipitation events. These phenomena may be more severe than any previously observed or occur with greater frequency and have the potential to adversely affect the Panama Canal System even with measures in place.
- Climate change has the potential to adversely impact constructed or implemented measures in various ways. A residual risk table is one way to identify triggers, hazards, potential harm, and qualitative likelihood. Table 4-2 provides a summary of preliminary residual risks associated with climate change for a range of potential measures categorized by type.
- Although sea-level is projected to rise on both coasts (approximately 0.3-0.6 meter (m)or 1-2 ft over the next 50 years), sea-level rise is not considered a significant factor in determining navigation reliability metrics for the future

conditions in this study because the operational range of the Panama Canal and Gatún Lake is greater than 15.24 m (50 ft) above sea level.

- In future phases, sensitivity of inflow volumes will be assessed, and a climate resiliency score developed. This will be used to evaluate alternatives among the range of probable future climate scenarios.

Table 4-2: Climate Change Residual Risks of Various Categories of Measures

Measure Type	Trigger (Variable which Causes Risk)	Environmental Hazard	Potential Harm to Project	Qualitative Likelihood (Low/ Moderate/ High)
Increase Storage (new dams, increase operating pool range at existing dams, lower M&I intakes)	Increase in extreme precipitation (future flood volumes may be larger than present; large flood volumes may occur more frequently)	Higher pool elevations at existing/ proposed reservoirs.	Inability to safely pass flood events could cause damage to locks, upstream and downstream population/structures	Moderate
	Increase in lake evaporation rates	Decrease in available water	Increased evaporation volume due to increased lake evaporation rates and increased lake surface area may reduce available water	Moderate
Increase System Inflow from Outside the Basin (trans-basin diversions and pumping)	Increase in drought frequency	Increase in low-flow frequency and decrease in baseflow in rivers	Increased periods in which environmental flows are not met leading to a reduction in the water available to divert/pump	Moderate
Water Quality and M&I Water Demand Reduction (salinity study, cross filling, Bayano M&I offsets, M&I Reduction)	Increase in drought frequency or occurrence of more severe droughts than the historical record	Reduced water quality	Reduced water quality causes the need to use unplanned stored water; not enough water is available to maintain minimum WQ standards; decreased transit reliability	Moderate
		Insufficient water for M&I supply	Buffer storage allocated for water supply based on historic droughts is inadequate leading to critical M&I shortages, transit stoppage, and Bayano hydropower reduction	Moderate
Dredging	Increase in extreme precipitation	Sediment loading increases with increased extreme event precipitation	Reduction in vessel draft and transit reliability; increased required dredging operations	Moderate

Table 4-3: Monthly Lake Evaporation for Panama Canal Region (mm)

Month	Lake Evaporation Percent of Annual	Existing Conditions (2025) Monthly Lake Evap. (mm)	Future Without Project Conditions (2075) Monthly Lake Evap. (mm)
Jan	9.9%	118	129
Feb	10.6%	126	138
Mar	12.3%	145	160
Apr	10.4%	123	136
May	8.1%	97	106
Jun	6.8%	81	89
Jul	7.0%	83	91
Aug	7.0%	82	91

Month	Lake Evaporation Percent of Annual	Existing Conditions (2025) Monthly Lake Evap. (mm)	Future Without Project Conditions (2075) Monthly Lake Evap. (mm)
Sep	6.9%	81	89
Oct	6.9%	82	90
Nov	6.4%	76	84
Dec	7.6%	91	99
Annual	100.0%	1185	1302

4.4.2 Reservoir Sedimentation

Since closure of the structures that contain Gatún Lake (1913) and Alhajuela Lake (1935), sediment delivered from the contributing watershed has played a role in the available water storage, management, and long-term life of each reservoir. Sedimentation is a chronic process, as sediment is transported from the watershed to the reservoir continuously. However, most sediment delivery is associated with high flow or acute flood events in the watershed.

The watershed slope, soil type, land cover and usage, and precipitation are major factors in the delivery of sediments to the reservoir pool. As these factors change throughout the life of a reservoir, sediment delivery can change. The total storage loss due to sediment in the water storage pool is the primary indicator of the reservoir's ability to deliver the necessary water supply for Panama Canal's' consumptive demands. The specific location of deposition may be a valuable indicator if there are any critical infrastructure that could be impacted or buried by sedimentation.

Analysis associated with reservoir sedimentation and its impact to the current study can be found in Appendix B, Water Management Modeling. Primary conclusions from the reservoir sedimentation assessment are as follows:

- Alhajuela Reservoir has a comprehensive history of hydrographic surveys, which provides strong insight into sedimentation rates and inform future reservoir elevation-storage-area (ESA) predictions. Survey techniques have varied. Therefore, the selected sedimentation rate applied for feasibility study future years leveraged the most reliable and consistent historic surveys. Ultimately a sedimentation rate from 1928-2012 was selected and applied to the latest 2018 survey to obtain future year ESA curves. This approach is consistent with USACE best practices.

- Gatún Lake does not have a comprehensive history of hydrographic surveys. There has been only one updated survey in 2022 since the original from 1914. Historically, various areas adjacent to the Gatún Lake navigation channel have been used for dredged material disposal. The two Gatún Lake surveys employed significantly different survey methods and computation techniques. This prohibited application of direct sediment rate estimates to determine future ESA.

  During the scoping of this 5% study the PDT decided to use the 2022 survey data for existing and future conditions and defer any further in-depth future sedimentation projections at Gatún Lake to 15% design. Future sedimentation is not included in this study phase due to changes in the survey methodology and taking Gatún Lake's large inactive storage into consideration. The inactive storage was designed to capture sediment without impacting the active storage of the reservoir.
- For new reservoir measures, cursory sedimentation analysis was initially conducted with follow-on Panama Canal reliability sensitivity testing. It was determined that reservoir sedimentation with baseline and estimated future ESA input data was not significant to navigation reliability at the new reservoirs. Additional exploration of sedimentation to inform future ESA was not pursued for the 5% effort. Any advanced sedimentation analysis of new reservoirs will be conducted in parallel to Gatún Lake sedimentation exploration efforts.

4.5 Water Management Model of the Panama Canal

The PDT developed a model of the Panama Canal water management system using HEC-ResSim version 3.5 (see Figure 4-3 for the graphical user interface associated with this model). The primary purpose of the HEC-ResSim model is to assess key navigation reliability metrics for the existing conditions, future without project conditions, and the future with project conditions. These metrics are used by the economics team to convert project reliability changes into economic benefits for that project. A general overview of the modeling approach includes:

- The team compiled relevant physical parameters of the system including the elevation-storage-area curves of the reservoirs (Gatún Lake and Alhajuela Lake), river alignments and dam, hydropower, spillway, navigation lock, and municipal water supply information.

- The model used the daily historical inflows from 1965 through 2021, with limited inflows from 2022. This 57-year period is known as the Period of Record (PoR) for the analysis.
- The model incorporated reservoir operations rules based on the 2021 operational strategies and guide curves. This includes a maximum operational pool of EL 26.82 m (88.0 ft).
- The model included water volumes associated with Panamax and Neopanamax lockages consistent with operational strategies described in ACP (2022). This included limited use of the Neopanamax water savings basins, as shown in Figure 3-4.
- The model was calibrated to 2010-2021. This time period included significant floods (La Purisima, 2010) and the 2015-2019 drought period. This calibration included before Neopanamax operations began (prior to 2016) and when Neopanamax operations were occurring (after June 2016). Figure 4-4 compares observed data (shown in red) and the simulated reservoir elevations (shown in green) over this calibration time-period.
- Codes (scripts) were written to investigate key navigation reliability metrics associated with the results of each simulation (these metrics are described in Section 4.6).

A detailed description of the full modeling approach, assumptions, and results are included in Appendix B of the AMM report.

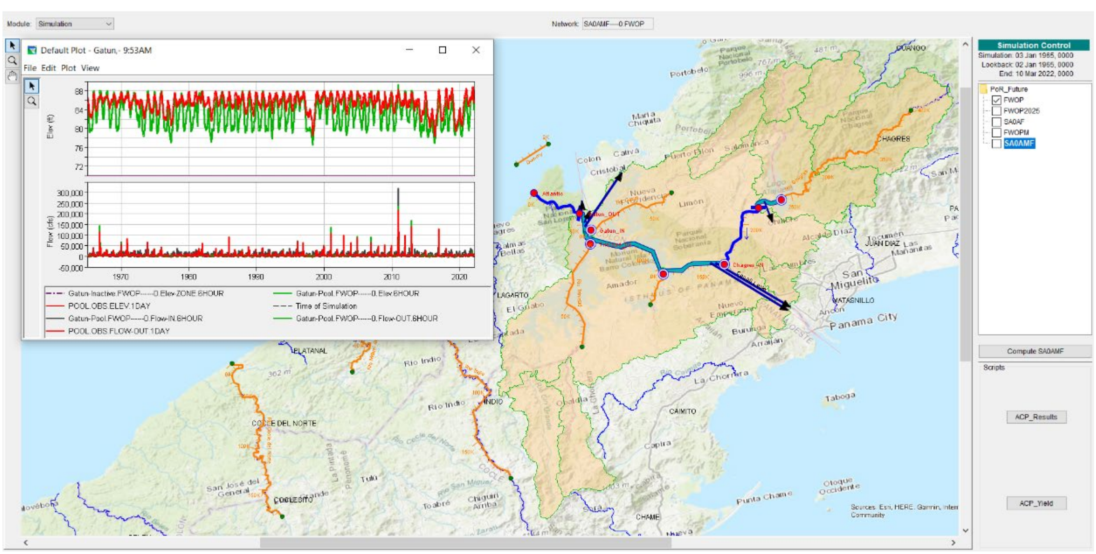


Figure 4-3: HEC-ResSIM model Interface Overview

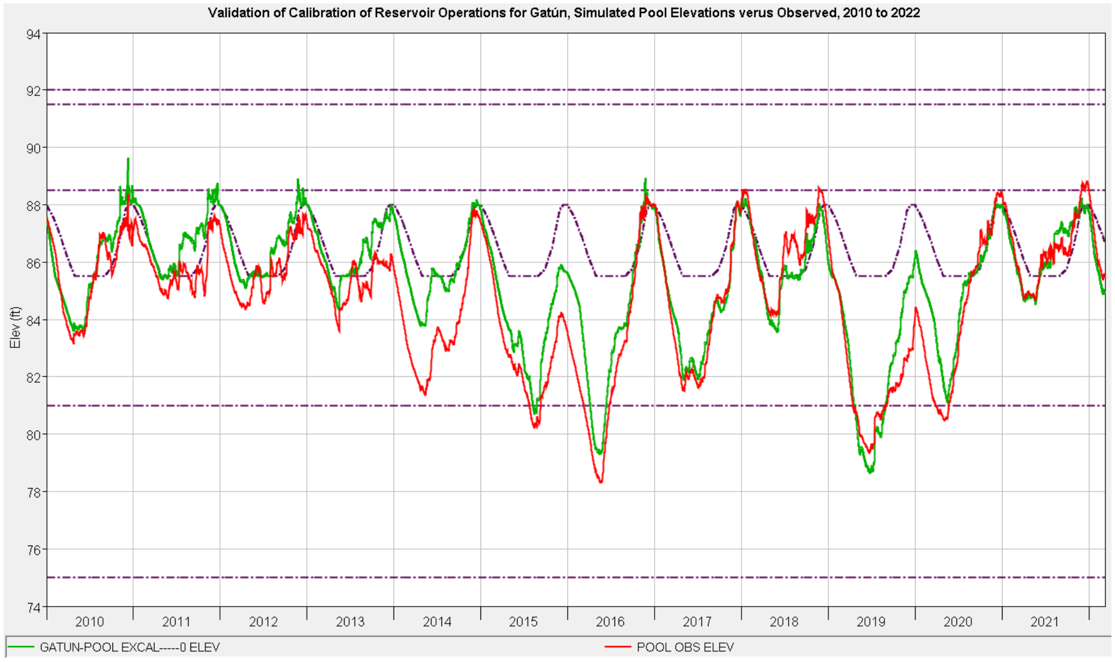


Figure 4-4: Gatún Reservoir Operations Calibration 2010-2021, Simulated (green) versus Observed (red)

Using the HEC-ResSIM model, investigations were made for a variety of "what-if" scenarios. The first investigation consisted of determining how the system would respond if the historical hydrology (inflows) occurred with the projected future navigation and municipal water demands. As an example of this comparison, Figure 4-5 shows the historically observed Gatún Lake levels from the end of 2009 until the beginning of 2022 in red (note these are observed values and not simulations from the model). From the observed 2009 through 2022 data there were 3 years where the Gatún Lake did not completely fill and 4 years where the elevation of Gatún Lake went below EL 24.69 m (81.0 ft) PLD.

The future without project model was simulated using HEC-ResSIM. This simulation included the historical inflow hydrology but with the future 2075 water demands including full Neopanamax lockages throughout the simulation. The FWOP simulation shows Gatún Lake would not have filled 7 of the 13 years and that in all 13 years, the lake would be below EL 24.69 m (81.0 ft, i.e., 46' drafts) for some portion of the year.

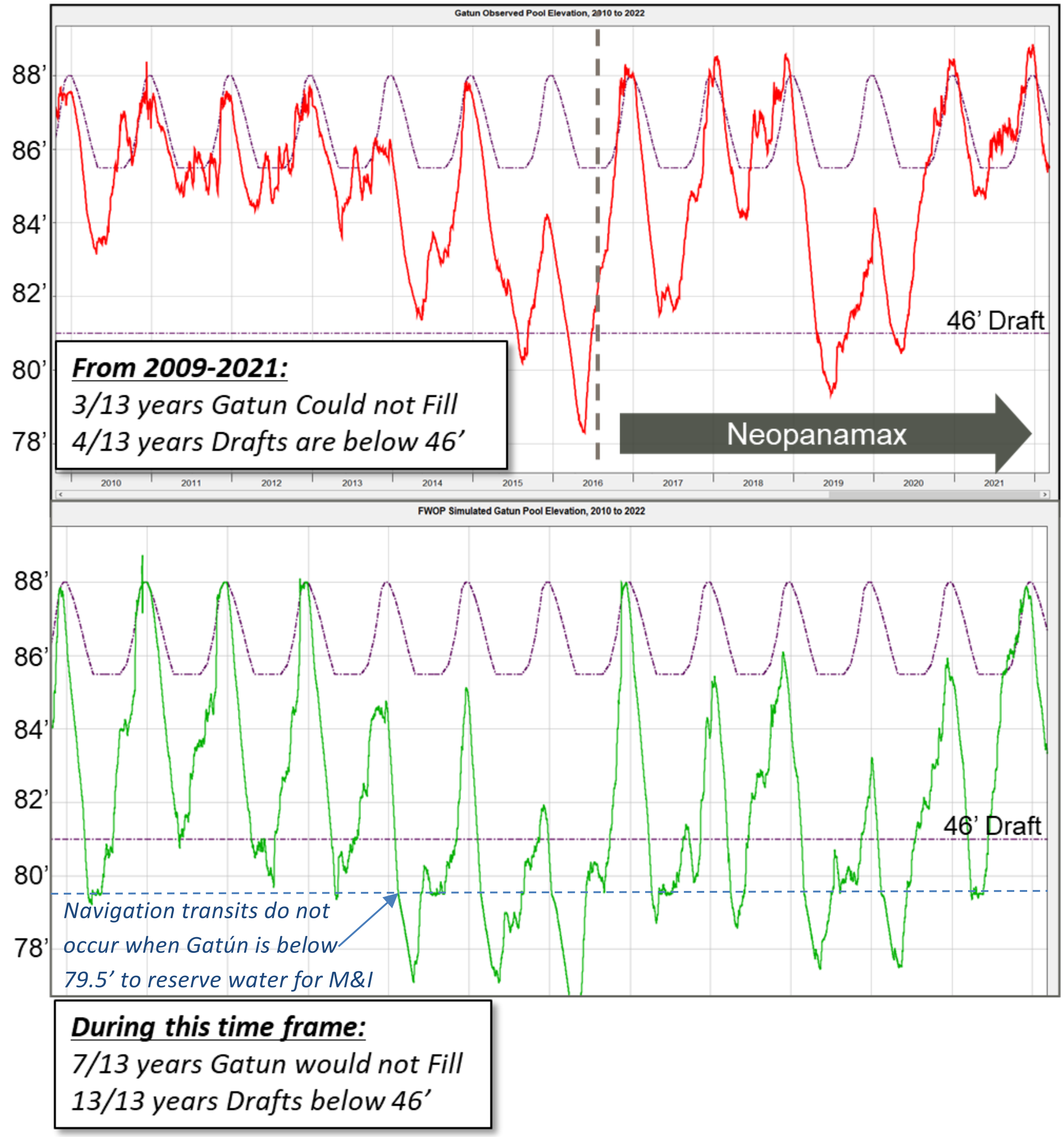


Figure 4-5: Comparison of Observed Gatún Lake Levels in 2009-2021 (top image) and Future Without Project Lake Levels in 2009-2021 using Historical Inflow Hydrology with Future Demands (bottom image)

In addition, the future without project condition simulation identifies significant durations when navigation would be restricted due to lack of water and the need to preserve water for M&I purposes. In the FWOP scenario, navigation transits could not occur when the Gatún Lake level is below 79.5 ft PLD, which occurs frequently in the FWOP scenario and in some cases, for long durations. This is further described in Section 4.6.3(1).

4.6 *Navigation Reliability Metrics*

In this water project study, "reliability" has several definitions. The PDT created a focus group to define the reliability metrics and select key metrics that will be used in the MCDA that will inform plan selection. This group identified three categories of reliability metrics that were used during the initial analysis of the existing and future without project conditions. These categories include ACP Leadership; Operational metrics; and Technical metrics (see Figure 4-6) and are described in the following sections. Additional information regarding the calculation of all the reliability metrics may be found in Appendix B, Water Management Modeling.

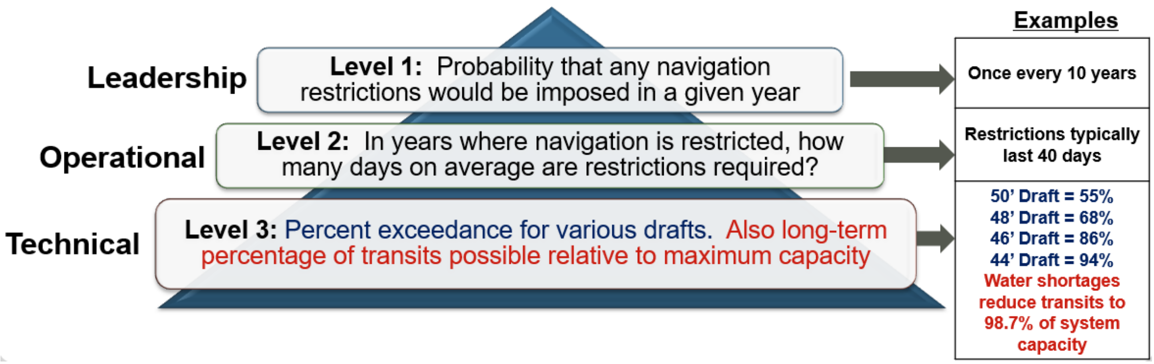


Figure 4-6: Navigation Reliability Categories

4.6.1 Level 1, Leadership

The *Leadership* navigation reliability metric level examines the problem of draft restrictions due to lack of sufficient water in the Canal system from a broad perspective. At this level there is one metric, the number of years within the Period of Record that contain draft restrictions below 14.02m (46 ft), which currently corresponds to a Gatún Lake elevation of EL 24.69 m (81 ft) PLD. The results of the existing and future without project simulations are shown in Table 4-4. Under the existing demands, it is projected that 1 out of every 3 years will have draft restrictions below 46'. With 2075 demands, and future conditions, it would be expected that these draft restrictions would occur approximately 19 out of 20 years (95% of the time).

Table 4-4: Level 1 Leadership Reliability Metrics Simulating Number of Years in the Period of Record with Drafts below 46'

Existing Conditions	Future Without Project	Difference
19 / 57 Years (33.3%)	54 / 57 Years (94.7%)	+ 35/57 Years + 61.4%

4.6.2 Level 2, Operational

The Operational navigation reliability level digs deeper into the simulation results with one metric that determines the average number of days that the Panama Canal system has navigation restrictions, but only in those years where navigation drafts were simulated to be below 14.02m (46 ft). Again, for the purposes of this metric, draft restrictions are defined when the Gatún Lake pool elevation is below 24.69 m PLD (81 ft PLD). The results of the Level 2 reliability metrics are shown in Table 4-5.

The Level 2 metric can result in non-intuitive results because it is intrinsically tied to the Level 1 metric (Level 1 metric is the number of years having draft restrictions below 81 ft PLD). The Level 2 metric builds on the Level 1 metric to provide the average number of days with a restriction in years that have draft restrictions. A measure that could decrease the Level 1 metric may increase the Level 2 metric because the average sample size is smaller and there could be more days of restrictions in years with draft restrictions, causing an increase in the Level 2 metric.

Table 4-5: Level 2 Operational Reliability Metrics Simulating the Average Number of Days for Each Year where there are Drafts below 46'

Existing Conditions	Future Without Project	Difference
105 days	146 days	+ 41 days

4.6.3 Level 3, Technical

The *Technical* level contains three metric sub-categories, with multiple individual metrics within each. The three sub-categories of metrics within the Technical level are *Transit Reliability, Draft Reliability*, and *System Firm Yield*.

(1) Transit Reliability

Transit Reliability defines how often transits are constrained by water supply limitations. The basis of this metric is that navigation will not occur when there is inadequate water to provide a lockage and navigation will not occur until there is enough water in Gatún Lake to meet lockage water demands.

All demanded transits are made in the simulation, and the resulting lockages release water from the Gatún Lake pool. However, all transits in the simulation stop when the Gatún Lake pool elevation drops below the elevation required to maintain M&I demands to preserve water supply for M&I purposes. The single elevation needed to ensure M&I demands are met (i.e., reserves) varies depending on the scenario being modeled and is determined by the worst drought on record (1997 to 1998).

M&I reserves elevation corresponds to EL 23.55 m PLD (77.25 ft) for existing conditions. Future without project conditions M&I reserves elevation is EL 24.23 m (79.5 ft). The future conditions elevation is higher because there is a higher demand for M&I water and more water reserves are necessary to meet the water supply demands through a dry season drought[5]. This is graphically represented in Figure 4-7. The results of the transit reliability metrics for the existing and future without project conditions are shown in Table 4-6.

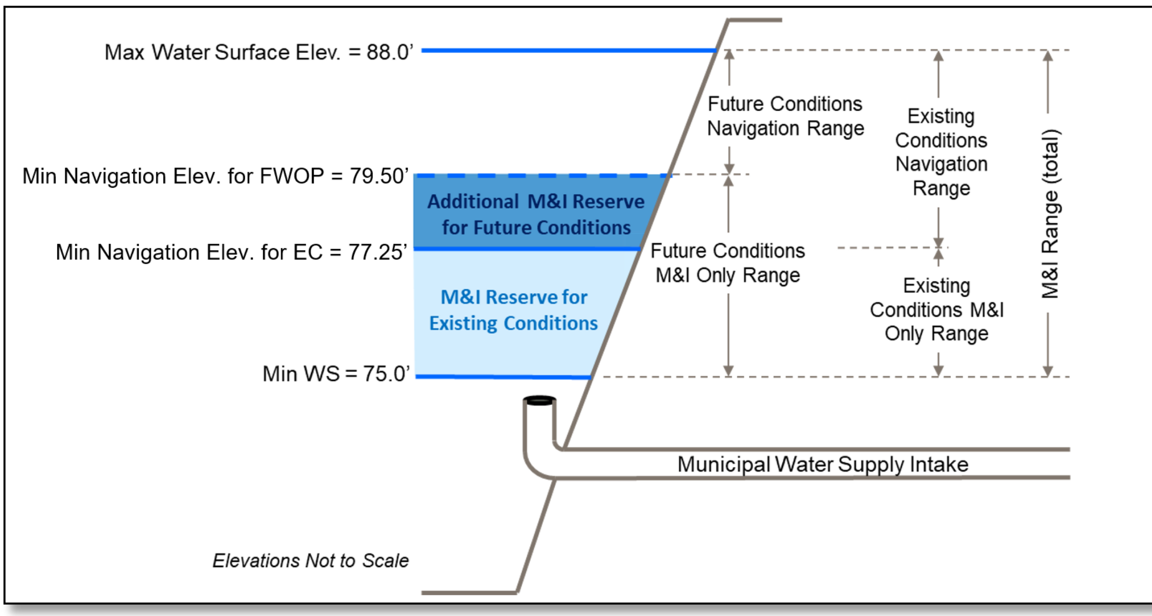


Figure 4-7: Gatún Lake Elevations when Navigation Transits are Turned Off in the HEC ResSIM Simulation to Ensure Municipal Water Supply Reserves

Draft Reliability

The *Draft Reliability* metric represents the frequency that Gatún Lake pool elevations are exceeded. These Gatún Lake elevations correlate with Neopanamax draft depths. The Neopanamax drafts analyzed and reported for draft reliability include:

- 15.24 m (50 ft). This corresponds to a Gatún Lake EL 25.91 m or 85 ft PLD.

[5] Alternatively, the municipal water intakes could be lowered to maintain the same elevation at which navigation is turned off in the simulation. This is a measure that is considered in the analysis (Measure #15).

- 14.63 m (48 ft). This corresponds to a Gatún Lake EL 25.30 m or 83 ft PLD.
- 14.02 m (46 ft). This corresponds to a Gatún Lake EL 24.69 m or 81 ft PLD.
- 13.41 m (44 ft). This corresponds to a Gatún Lake EL 24.08 m or 79 ft PLD.

Draft reliability of Panamax drafts of 12.04 m (39.5 ft) is also reported. Due to the elevation of the lock sills, draft restrictions below 12.04 m (39.5 ft) occur when the Gatún Lake elevation is EL 24.02 m (78.8 ft). The results of the draft reliability metrics for the existing and future without project conditions are shown in Table 4-6.

4.6.4 System Firm Yield

The *System Firm Yield* is a volume represented by emptying a full storage pool and re-filling the storage pool to full one time in the Period of Record critical drought. The critical drought period is from 1997 to 1998 in the HEC-ResSIM model. Within the context of this report, System Firm Yield is correlated to maintaining a specific draft. The lowest allowable draft used in this metric is 13.41 m (44 ft). The firm yield includes any releases from the system, including both M&I and navigation withdrawals. The results of the firm yield metrics for the existing and future without project conditions are shown in Table 4-6.

Table 4-6: Level 3 Technical Reliability Metrics for Existing and Future Without Project Conditions

Metric	Existing Conditions	Future Without Project	Difference
Transit Reliability	Percentage of Vessels Transiting		
Transits	98.7%	86.1%	-12.6%
Draft Reliability	Frequency Draft is Exceeded		
50 ft Draft	52.5%	23.4%	-29.1%
48 ft Draft	78.9%	43.8%	-35.1%
46 ft Draft	90.4%	62.2%	-28.2%
44 ft Draft	96.0%	92.1%*	-3.9%
39.5 ft ft Draft	96.2%	93.6%*	-3.8%
Storage Pool Firm Yield	ET/day		
Firm Yield at 44 ft of Draft	36.8	35.7	-1.1
*** Note that 44 ft and 39.5 ft of draft for FWOP are below the M&I Cut-Off level guaranteeing M&I supply; the true draft reliability at these drafts is limited to the transit reliability.**			

4.6.5 Other Simulation Metrics

Additional reliability metrics that have been developed for this system include:

- Navigation (per transit) Water Usage
- Average Annual Residence Time
- Average Annual Hydropower Generation
- Minimum and M&I-Only Pool Elevations
- Average Annual Water Balance

The Average Annual Water Balance for the existing conditions and the future without project conditions are shown in Figure 4-8 and Figure 4-9 respectively. These figures demonstrate existing conditions will, on average, spill 9% of the available water and generate hydropower with 10% of the available water, resulting in 19% of available water used for non-navigation or M&I purposes. In the future without project simulations, this volume reduces from 19% to approximately 8%, primarily due to the increased water use for navigation and M&I purposes (in the future conditions, 5% of the water is predicted to be spilled over the Gatún Spillway and 3% is simulated to be used for hydropower purposes). This demonstrates that as demands for water continue to grow, there are less opportunities to store water to increase reliability due to the lack of available water to store in the future.

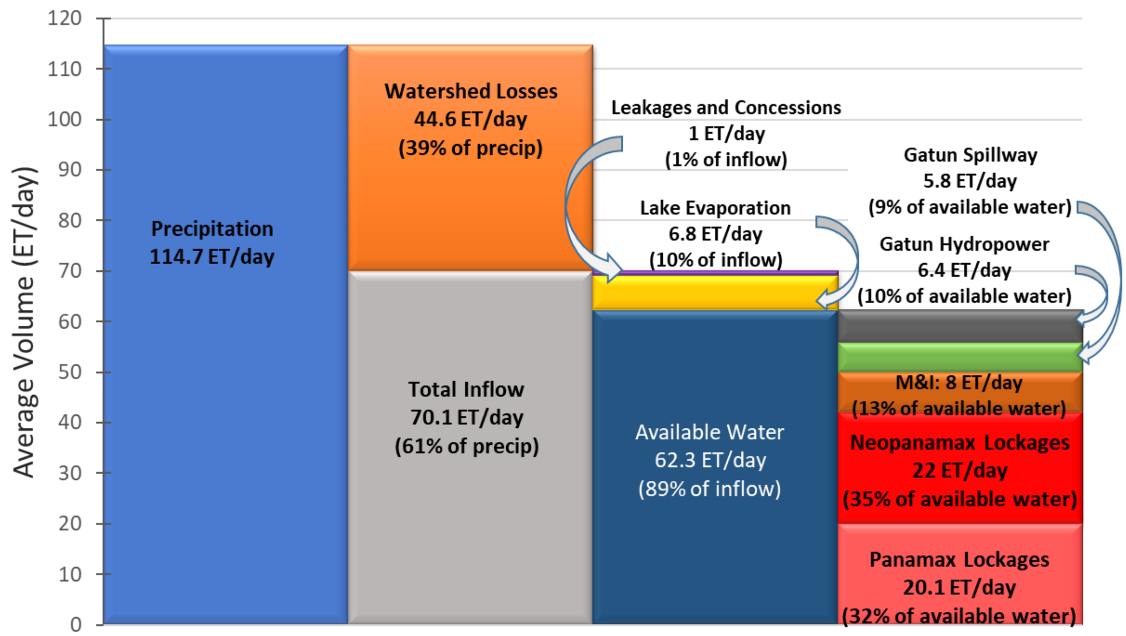


Figure 4-8: Simulated Average Annual Existing Conditions Full Water Budget

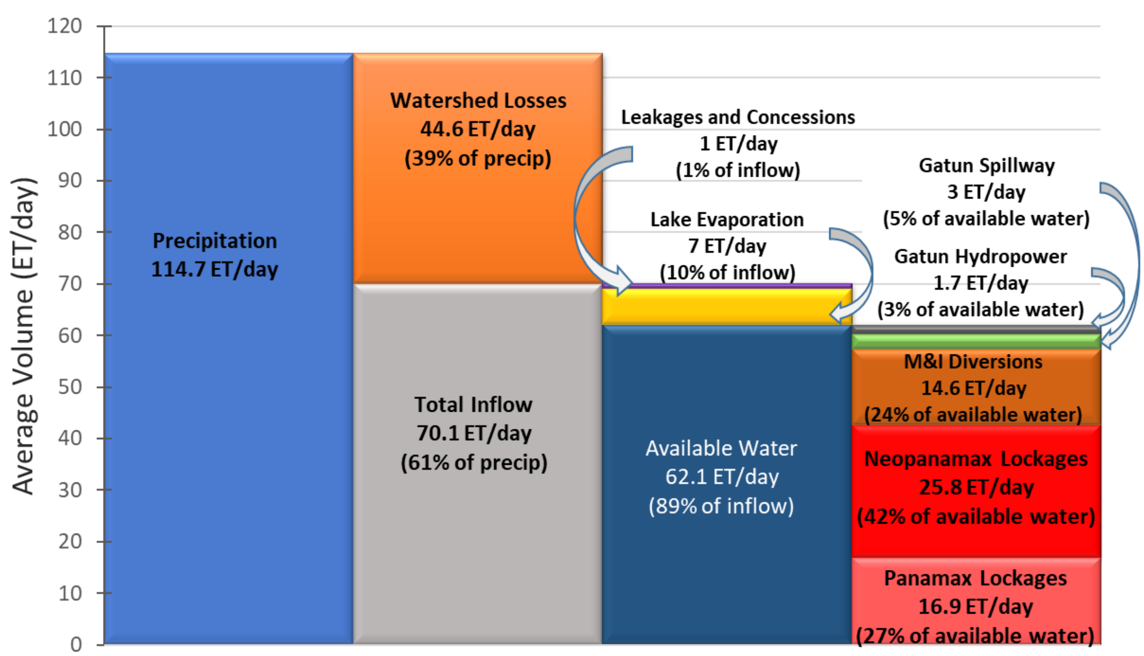


Figure 4-9: Simulated Average Annual Future Without Project Full Water Budget

Note the Neopanamax volumes and Panamax volumes in Figure 4-8 and Figure 4-9 are less than the demands previously shown in Table 4-1. This decrease represents reduced transit reliability, noting that full navigation demands up to the system capacity cannot be maintained resulting navigation restrictions in these simulations. The M&I and navigation demands, combined with the water supply and demands for each category are shown in Table 4-7. M&I demands are always supplied in these simulations.

Table 4-7: Water and Transit Demands and Supply for Existing and Future Without Project Condition

Variable	Existing Conditions (2025)			Future Without Project Conditions (2075)		
	Total Demands	Total Supplied	% Supplied	Total Demands	Total Supplied	% Supplied
Gatún M&I Demands (ET)	3.433	3.433	100%	10.043	10.043	100%
Alhajuela M&I Demands (ET)	4.545	4.545	100%	4.545	4.545	100%
Panamax Transits per Day	25.33	24.37	96.21%	26.34	22.67	86.07%
Panamax Transit Water Demands (ET)	20.3	20.1	99.0%	19.2	16.9	88.0%
Neopanamax Transits per Day	9.53	9.17	96.21%	12.64	10.88	86.07%
Neopanamax Transit Water Demands (ET)	22.2	22.0	99.1%	30.2	25.8	85.4%

Results for the existing conditions and future without project conditions metrics are shown in Appendix B (as well as the metrics associated with each project).

4.7 Analysis of Navigation Reliability Metrics for Existing and Future Without Project Conditions

4.7.1 Transit and Draft Reliability Assessments

The most relevant metrics for determining benefits of a project are the draft reliability and the transit reliability. The HEC-ResSIM model outputs for transit and draft reliability metrics are inputs to the economic model (see Section 4.9, 5.10, and Appendix D: Economics for the model description).

The draft and transit reliability for all Neopanamax drafts between 10.67 m (35 ft) and 15.24 m (50 ft) are shown in Figure 4-10. In Figure 4-10, the transit reliability is represented by the vertical line. Draft reliability does not increase beyond that line. The draft where this vertical line begins corresponds to the Gatún Lake Level where navigation is stopped to guarantee storage for M&I supply. As described elsewhere, the storage required to guarantee M&I supply is defined by the critical drought period for the system (1997 to 1998) and depends upon the amount of M&I demands. For example, in Figure 4-10, the Future Conditions curve stops at a higher draft. This indicates higher M&I demands require a larger storage guarantee and more frequent navigation interruptions throughout the PoR than under the Existing Conditions.

The results of the transit reliability are shown in Figure 4-11. Both figures include the historically observed data from 1965 through 2022 for comparison purposes. The observed data in Figure 4-10 is associated with the Gatún Lake levels. Neopanamax drafts are modeled because Neopanamax vessels transits did not begin until 2016.

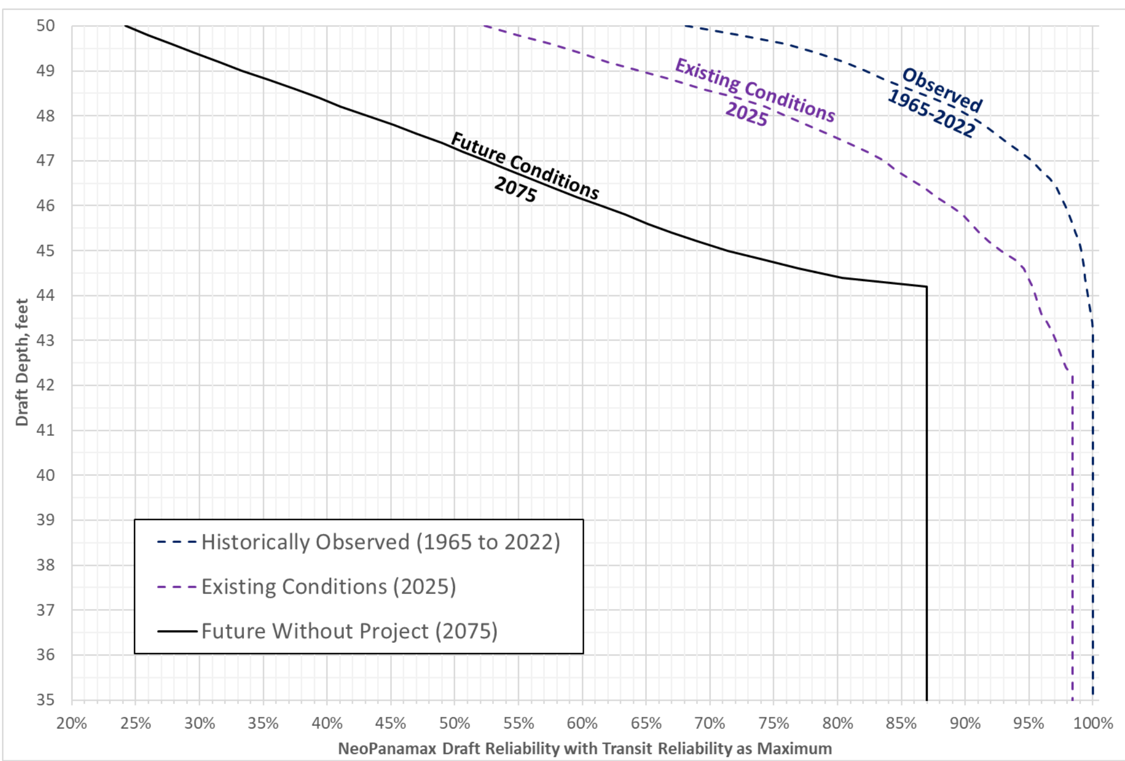


Figure 4-10: Draft and Transit Reliability for Existing and Future Without Project Conditions Compared to Historically Observed Reliability

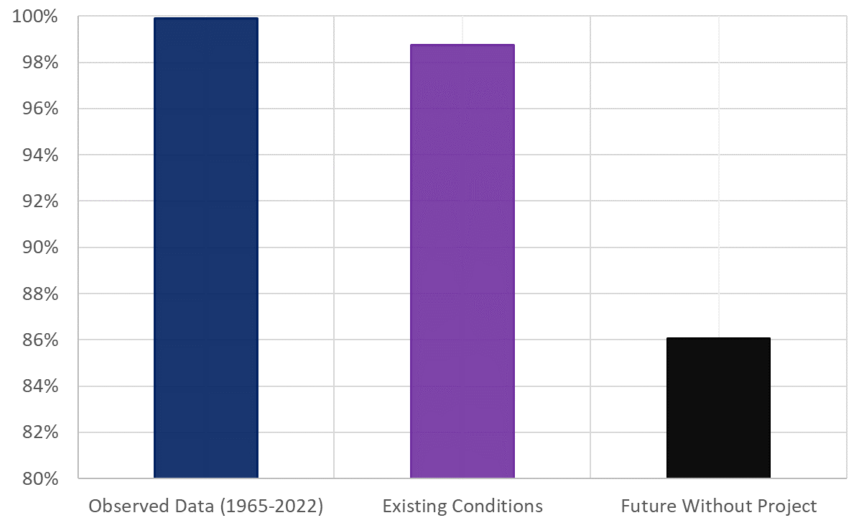


Figure 4-11: Transit Reliability for Historically Observed Conditions, Existing Conditions and Future Without Project Conditions

Figure 4-10 and Figure 4-11 demonstrate that future conditions provide less reliability for drafts and transits relative to transit demands when compared to the existing conditions. Because demand increases transits in the future, water restrictions will limit transits more frequently than under Existing Conditions.

The team developed a framework for observing the relationship between draft reliability and transit reliability. This is shown in Figure 4-12 and used throughout this report. The 13.41 m (44.0 ft) draft reliability was chosen because this is an extremely low Gatún Lake level that has occurred only 0.25% of the time between 1965 and 2022. There has been a total of 53 days since 1965 when Gatún Lake was below elevation EL 24.08 m (79.0 ft)[6], resulting in a 99.75% exceedance above this elevation. Any conditions that decrease 13.41 m (44.0 ft) drafts will be considered to have significant impacts to the Panama Canal operations.

Figure 4-12 shows a notable reduction in transit reliability and draft reliability at 13.41 m (44.0 ft) draft for the existing condition. This reliability significantly degrades when demands increase to predicted 2075 demands. Calendar Year 2075 demands result in 13.41 m (44.0 ft) drafts available only 92% of the time. This figure shows there is only enough water to operate the future navigation demands 86% of the time. If interventions are not put in place to improve reliability, navigation would not occur

[6] Gatún Lake was below 79.0' for 12 days 1998 and 41 days in 2016. This occurred during April and May in both years.

approximately 14% of the time in the future because the elevation at which navigation must be shut off to guarantee M&I supply is EL 24.2 m PLD (79.5 ft PLD) corresponding to a Neopanamax vessel draft of 43.5 ft.

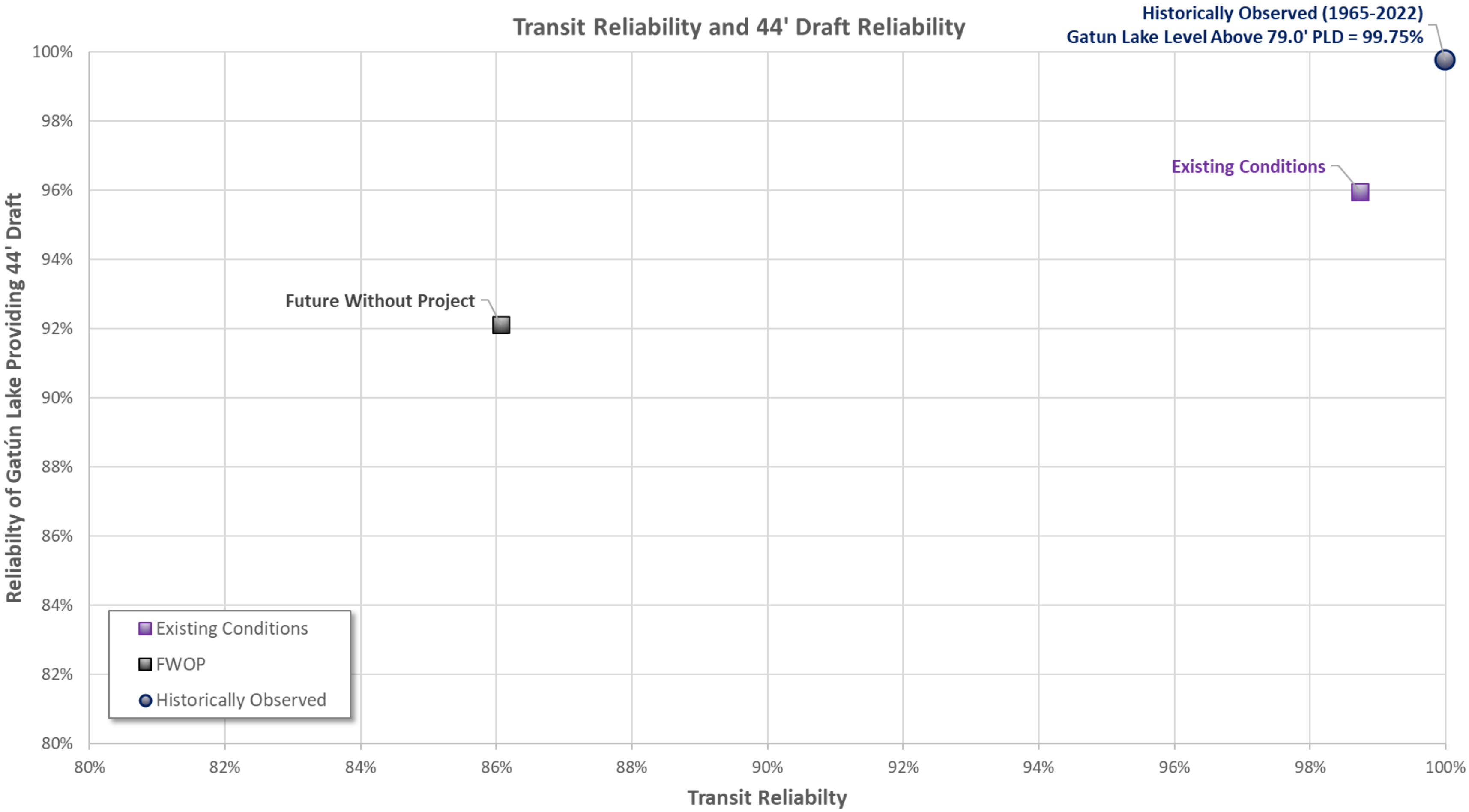


Figure 4-12: Transit Reliability and 44' Draft Reliability for Existing and Future Without Project Conditions (In the FWOP, the M&I-Only Level (79.5 ft PLD) is above the 44 ft Draft Level (79 ft PLD), limiting draft reliability to transit reliability)

4.7.2 *Transition of Reliability Metrics through the Planning Horizon*

Several assumptions about increased demands are necessary to assess how the transition between existing conditions and future without project conditions can be expected to occur over time. The following assumptions are used to assess the temporal transition in navigation reliability through the planning horizon:

- The full navigation demands will be reached in 2035, 10 years after the set point for existing conditions. These 2035 navigation demands include 12.64 Neopanamax vessels and 26.34 Panamax vessels per day.
- All currently planned M&I water expansion projects will be constructed and operational by 2035. These projects result in an additional 3.1 ET for M&I water supply and increases municipal water supply demand from 7.98 ET per day to 11.1 ET per day by 2035.
- After the initial water supply demand increases by the year 2035, it is assumed municipal water supply will grow at a constant rate from 2035 to 2075. This represents an increase of 0.8725 daily ET per decade to a total of 14.59 ET per day in 2075.

Based on these assumptions, approximately half of predicted, future reductions in reliability would occur between 2025 and 2035. Following 2035, the reductions in future navigation reliability reduce at a relatively constant rate. See Figure 4-13 for the results of this analysis.

Reliability in Year 2035 was simulated assuming full build out of currently planned M&I expansion projects, therefore it is the same as the M&I cap simulations. This simulation varied the M&I cut-off elevation in 0.25 feet increments, similar to the approach used to compute reliability for the FWOP and measures. The M&I cut-off elevation for the 2035 simulation was 78.5 ft PLD. Reliabilities for years 2035-2075 were interpolated and not simulated in HEC-ResSim.

The two processes that lead to significant reductions in reliability by 2035 are the increased M&I water supply demands (equivalent to 3.1 ETs) and increased navigation demands. Increased navigation demands cannot be sustainably met with a high level of reliability given the lack of available water. Each factor was investigated to determine the relative impact of each process. Figure 4-14 displays the results of the two additional simulations described below:

- **Increased M&I demands Without increased Navigation Demands**. This simulates M&I demands at the 2035 level (additional 3.1 ET for M&I) with existing conditions navigation demands. This investigates the sensitivity of M&I demands only on the 2035 reliability levels (reference Figure 4-14).

- **Increased Navigation Demands Without Increasing M&I Demands Above Existing Conditions**. This simulation increases navigation demands to the full system capacity with existing conditions M&I water supply demand. This investigates the sensitivity of the increased navigation demands only on the 2035 reliability levels (reference Figure 4-14).

In both simulations, reliability is notably decreased from the existing conditions. Lost reliability is less significant than when both navigation and water supply demands are increased simultaneously.

The previous analysis leads to four key observations:

1. **Existing Conditions:** The reliability associated with the existing conditions is notably less than historically observed conditions. For the existing conditions, the ACP may need to restrict navigation transits due to lack of water supply approximately 1.3% of the time. This situation has not occurred previously in the Panama Canal.
2. **2075 Conditions:** Without action, the future conditions preclude sustainable navigation. Navigation would not be able to occur approximately 14% of the time in the future because the elevation at which navigation must be shut off to guarantee M&I water supply is EL 2.42 m PLD (79.5 ft PLD). This corresponds to a vessel draft of 44.5 ft.
3. **2035 Conditions:** Approximately half of the predicted reliability reductions are expected to occur by 2035.
4. **Incompatibility of Increasing Navigation Transits while Increasing M&I Supply:** Increasing navigation throughput above existing conditions and continuing to increase M&I water supply from the Panama Canal Watershed are incompatible.

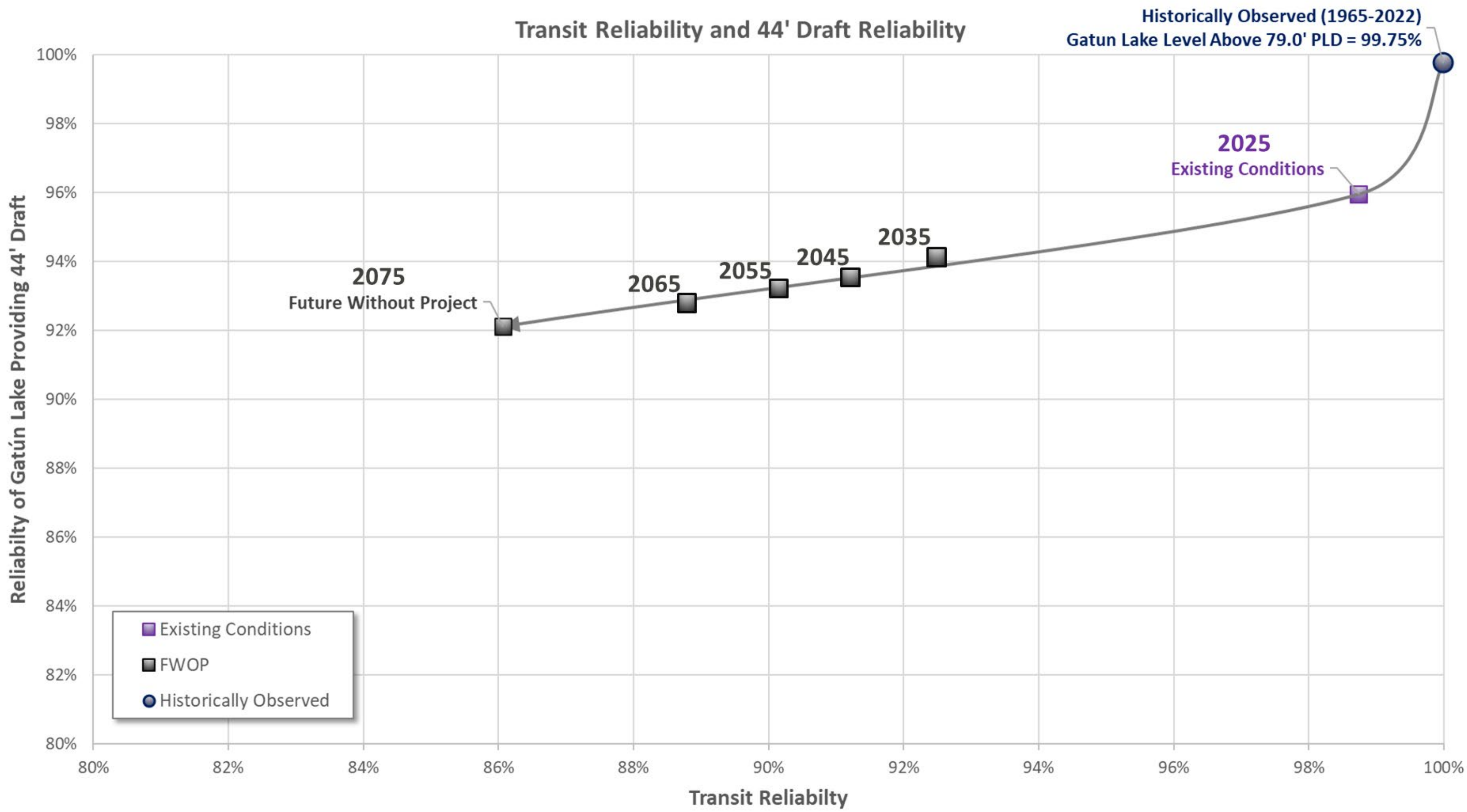


Figure 4-13: Temporal Transition of Transit Reliability and 44' Draft Reliability for Existing and Future Without Project Conditions (Draft reliability is limited to transit reliability because of reserve storage guaranteeing M&I supply)

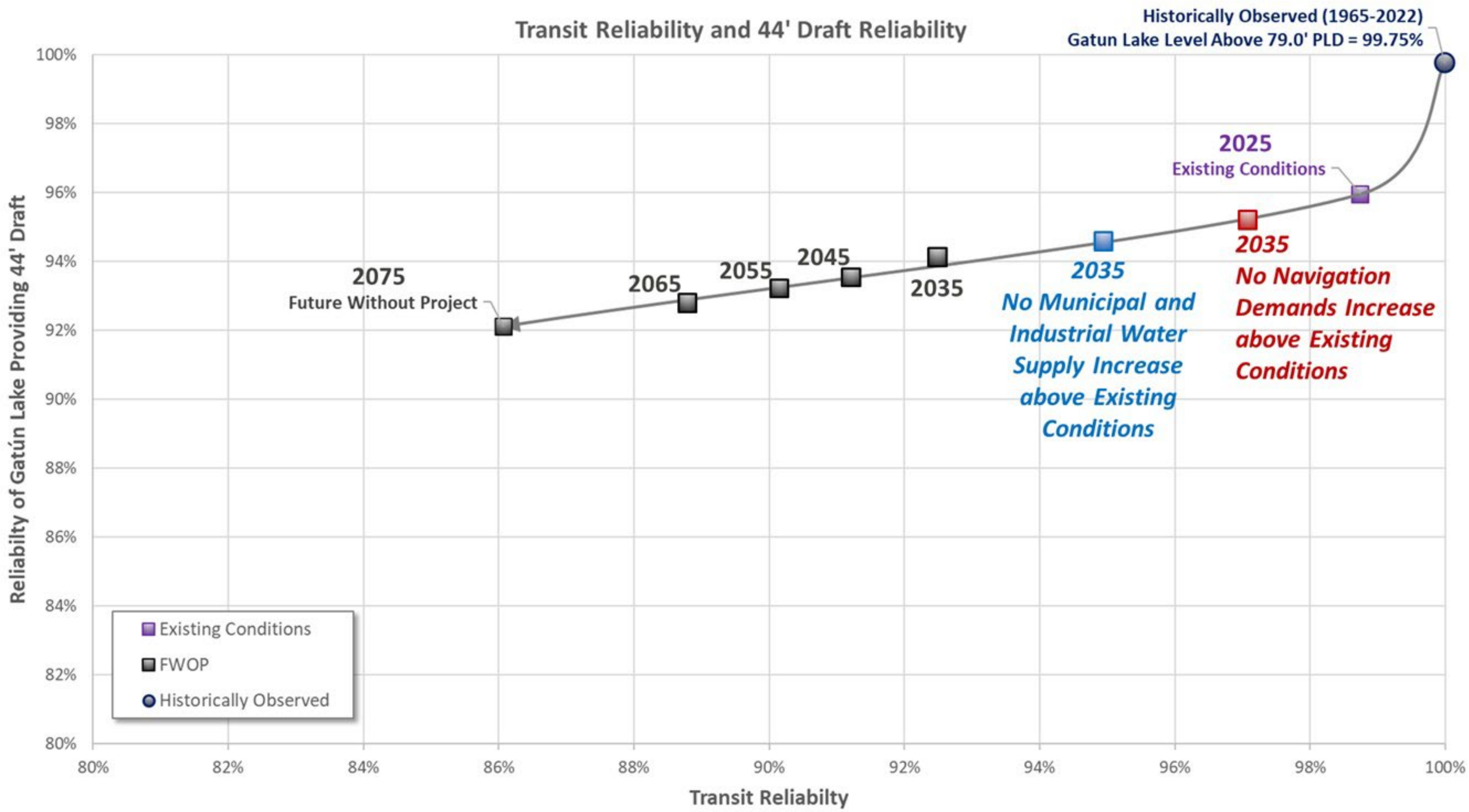


Figure 4-14: Navigation Demands and M&I Demand Increasingly Influences Temporal Transition of Transit Reliability and 44' Draft Reliability for Existing and Future Without Project Conditions (Draft reliability is limited to transit reliability because of reserve storage guaranteeing M&I supply)

4.8 Variability in Existing and Future Without Project Conditions Reliability Based on Operational Strategies

Future without project conditions preclude navigation 14% of the time (or navigation would occur 86% of the time) given the HEC-ResSIM model inputs. Under this scenario using existing operational rules, Gatún Lake's level is above EL 24.08 m (79.0 ft) approximately 92% of the time. Although the reliability of having the Gatún Lake elevation above EL 24.08 m (79.0 ft) is less than the existing conditions, this highlights that the current operational strategies focus on maximizing drafts in the operational rules more than on maximizing transits. In the face of water shortages, the ACP may decide to shift operational focus to maximize the transit reliability above draft reliabilities.

The ACP has control over its operations, and changes in operational strategies are commonplace in ACP's recent history. This operational flexibility allows the ACP to prioritize selected metrics in future conditions. The PDT analyzed several operational changes, including operating Gatún Lake at lower elevations and found a clear, inverse relationship between transit reliability and draft reliability for any given draft. The relationship and flexibility between draft reliability and transit reliability for the existing demands and the future demands is shown in Figure 4-15. These additional points were developed by lowering the M&I intake limit (limits of EL 23.5 m PLD / 77 ft PLD, EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD), which also lowered the elevation at which navigation is stopped to guarantee M&I supply.

The analysis leads to another key observation:

- **The ACP can choose between maximizing transit reliability or draft reliability.** The ACP can prioritize draft reliability or transit reliability through simple operational rule changes or relatively modest investments in lowering the elevations of municipal water supply intakes. Coordination with appropriate authorities would be necessary to modify municipal water supply intake elevations.

- This study acknowledges the transit-draft reliability trade off but does not make recommendations regarding the optimal transit-draft reliability balance. Future study will analyze operational changes to define impacts to transit and draft reliability.

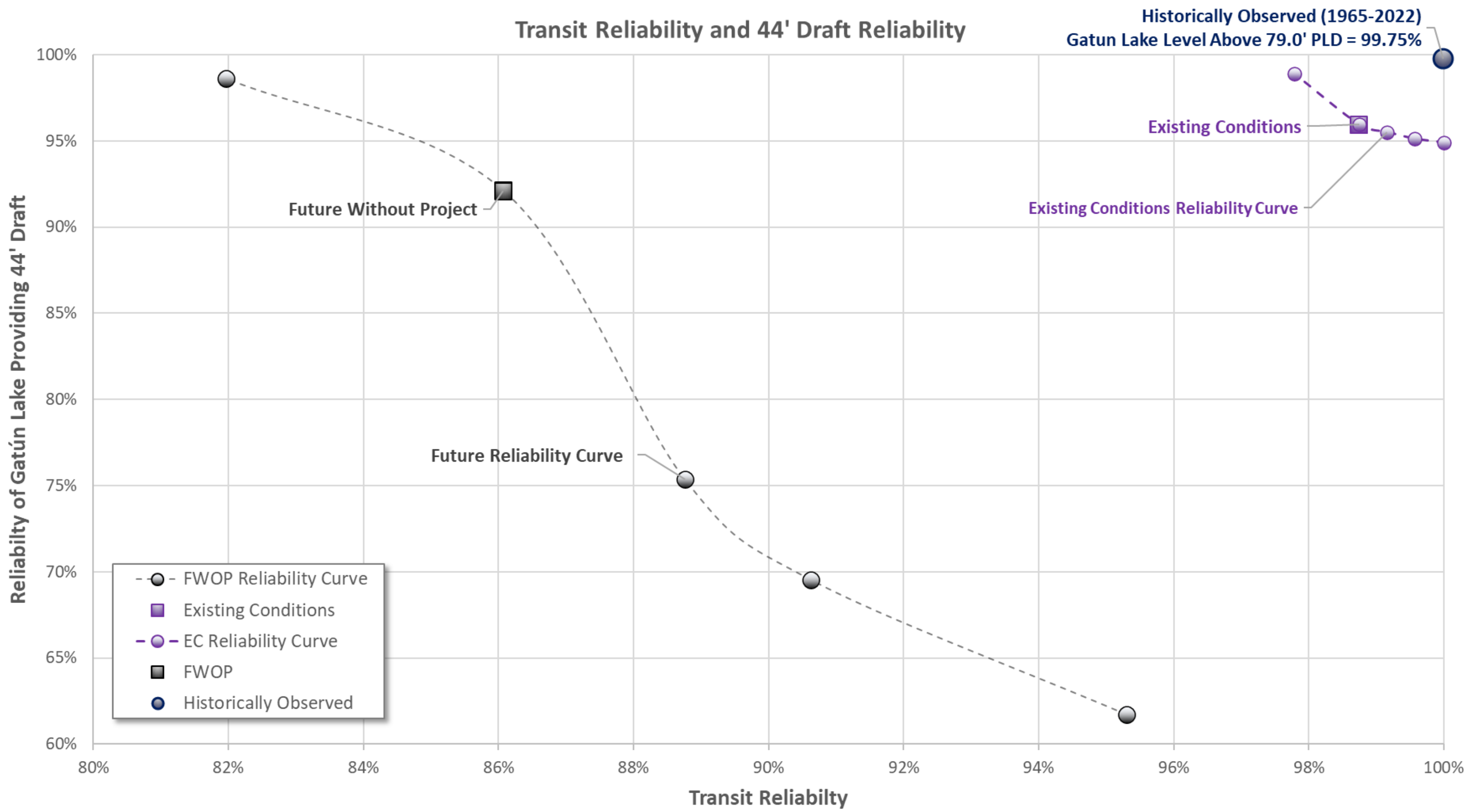


Figure 4-15: Existing and Future Conditions Reliability Curves

4.9 Existing and Future without Project Economics Analysis

The ACP primarily creates value through the commercialization of water resources for navigation[7]. The economic analysis defines project benefits as an increase in value[8] realized by the ACP accounting for all costs associated with implementation. This section summarizes the existing and future without project economic conditions to establish a baseline for the comparison of measures (Section 5.12).

4.9.1 Toll Structure

The Panama Canal toll structure uses pricing based on vessel capacity. The toll structure applied in fiscal year 2022 included more than 400 toll rates. These rates involved loyalty programs, special rates for return trips and various rate levels for vessels transiting in ballast. Average toll revenue per vessel from Fiscal Years 2017 through 2022 was $260,000[9]. This includes all vessel types loaded and in ballasted conditions.

In April 2022 the ACP released plans to update the toll structure to (1) reflect the value provided by the Canal to its users, (2) maintain relative value over time, and (3) uphold the competitiveness of the Panama route to maintain profitability. The new toll structure reduces the number of tariffs from over 400 to less than 60.

The new tolls will be implemented from 2023 through 2025 and periodically adjusted. The updated toll structure consists of the following components:

1. **Fixed Tariff:** This fee is determined by locks used (Panamax or Neopanamax), vessel type and size.
2. **Capacity Tariff:** The capacity tariff is assessed by vessel type, size and billing unit.
3. **Freshwater Surcharge:** The surcharge consists of a fixed fee based on vessel size and a variable fee determined by the Gatún Lake level.
4. **Transit Fee:** Panama imposes a transit fee for vessels using the canal. This amounted to 17% of total revenues from 2016 through 2021.

[7] Tolls and transit services constituted more than 95% of total revenue from Fiscal Year 2017-2021

[8] For the 5% level of analysis, the economic model uses the earnings before interest, taxes, depreciation, and amortization (EBITDA) margin from ACP's Long-term Financial Forecasts to estimate the benefit realized by the ACP of each vessel transit.

[9] The economics model uses ACP's financial forecast to estimate tolls and EBITDA per transit. These estimates will be further refined during the 15% level analysis. Economics will also work to include a freshwater surcharge forecast in the 15% level of analysis.

5. **Other Fees:** Booking fees for advanced reservations.

The toll structure that fully comes online in 2025 has been applied to the existing conditions analysis associated with this study and is held constant across the period of analysis. Appendix D includes additional information regarding the toll structure that applies to the current study.

4.9.2 Existing Economic Value of the Panama Canal

Annual toll revenues grew from $2.85 billion in Fiscal Year 2017 to over $3.95 billion in Fiscal Year 2021. The study uses changes in the ACP's interest, taxes[10], depreciation, and amortization (EBITDA) to estimate the economic value of project implementation. EBITDA (Earnings before interest, taxes, depreciation, and amortization) measures the ACP's operating performance (i.e., ability to convert toll revenue into earnings). For this study, EBITDA is useful for measuring the estimated benefit of a project after all associated costs. By multiplying additional toll revenue by the EBITDA margin, the study attempts to estimate the ACP's earnings after operating costs generated from project implementation. The ACP's EBITDA margin was 61% in Fiscal Year 2021.

4.9.3 Future Without Project Economic Value of the Panama Canal

In the future without project, the ACP will not be able to maintain 100% reliability of the Canal. Increased demand on the system will lead to transit and draft constraints, which impede ACP's operations and financial position. The economic value associated with the existing conditions and future without project conditions is shown in Table 4-8. For comparison, the EBITDA in Fiscal Year 2021 ($2,420 M) is also shown in this table. Fiscal Year 2021 benefit per transit is estimated by dividing actual EBITDA by total transits.

Table 4-8 shows that although the future without project demands would generate more economic value than in Fiscal Year 2021, there will be a reduction in total value generated over time. This conclusion is based on the increase in tolls for transiting vessels. Total transits decline due to the loss of transit and draft reliability in the Future

[10] The ACP is not taxed; however, the ACP contributes an annual payment to the Treasury

Without Project Condition[11] (Figure 4-16)[12]. This estimate of future without project value is the baseline for comparison of all measures.

Table 4-8: Economic Results of Existing and Future Without Project Conditions[13]

Condition	Transits	Benefit per Transit	EBITDA
Fiscal Year 2021	13,342	$ 181,500	$ 2,420 M
Existing Conditions (2025)	13,731	$ 259,620	$ 3,560 M
Future Without Project (2075)	12,237	$ 259,620	$ 3,160 M

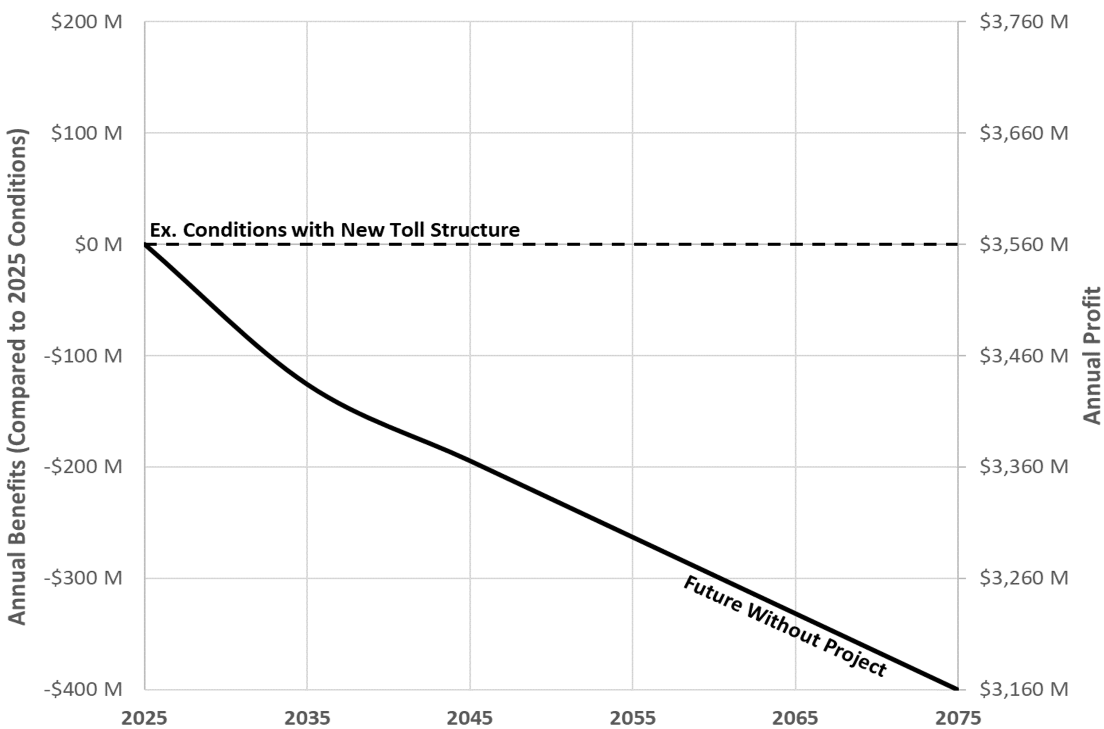


Figure 4-16: Impacts to Economics for the Future Without Project Condition

[11] Assumes constant EBITDA margin and revenue per transit by market segment over the period of analysis

[12] Estimated at $400 million in losses based on difference between Existing Conditions (2025) EBITDA and Future Without Project (2075) EBITDA

[13] The analysis presented in in Table 3-8 does not include increases in future tolls beyond the 2025 toll structure. The analysis was completed in this fashion to demonstrate the sensitivity associated with reliability restrictions associated with water. As a result, these results differ from those presented later in the report and are not for direct comparison.

5. FUTURE WITH PROJECT MEASURES

5.1 Future With Project Condition Objectives and Framework

Figure 3-3 shows that water supply demands exceed water supply in Year 2075 future without project conditions. This overallocation impacts navigation reliability. Navigation could occur at the Panama Canal's full system capacity more frequently and the ACP could avoid or reduce the frequency navigation throughput is limited by water availability by designing a project to increase water supply relative to the water demands. Increasing water supply relative to the water demands could include:

1. **Decreasing the water volume used per transit.** This approach addresses navigation operational inefficiencies and could be achieved through increased use of the water savings basins or other measures such as cross filling the Panamax locks. Based on the PDT's evaluation, the greatest opportunity for improving per lockage water use efficiency is maximizing use of the Neopanamax locks water savings basins[14].
2. **Increasing storage.** This approach constructs or modifies dams and reservoirs to store surplus water as it becomes available or make lower pool storage accessible. This would increase the amount of accessible water available for use during drought periods.
3. **Decreasing the demands for M&I water supply**. This measure could be a M&I water supply offset (such as extracting M&I water from Bayano Lake), decreasing water distribution system losses, decreasing per capita water usage, or negotiating caps on future growth of water supply withdrawals from the ACP system (i.e., M&I water caps). The ACP is responsible for approving permits for future M&I water supply expansion projects in the Panama Canal under current Panamanian water law.
4. **Increasing Inflows.** This approach consists of inter-basin water transfers. Interbasin transfers are currently outside the ACP's authority and the scope of Study A[15]. Study A analyzes some representative inter-basin water transfers projects have been developed and analyzed for benefits only. The HEC-ResSIM

[14] Maximizing the usage of the water savings basins is the primary objective of the parallel Salinity Study.
[15] These measures would be considered in Feasibility Study B: Outside Authority Measures and corresponds to Stage 3 in Figure 1-1.

benefits modeling is discussed in Appendix B, Water Management Modeling. Costs have not been evaluated for these out-of-authority measures.

Figure 5-1 shows the conceptual model of project benefits in Study A. In this figure, the water supply without a project limits navigation volumes below the existing system capacity in the future. The water supply with future project seeks to prevent navigation volumes being restricted by water availability. The difference in navigation volume between the water limited, future without project and the system capacity limited, future with a project are the benefits associated with the water project.

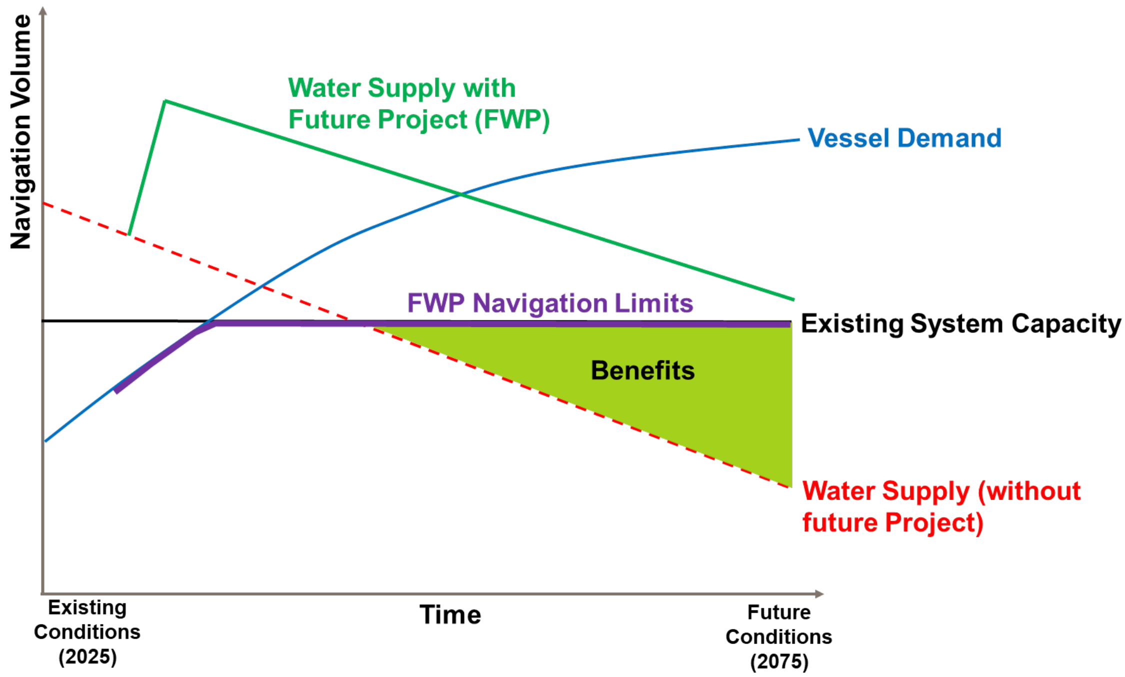


Figure 5-1: Conceptual Economic Model of the Future With Project Benefits to Navigation

5.2 *Measures Overview*

Measures are actions that, individually or in combination, address objectives, problems, or opportunities related to maximizing the Panama Canal's operational reliability and increasing system resiliency. These measures broadly fall into two categories: structural and nonstructural. Structural measures are expected to require significant construction activities; create or significantly modify existing infrastructure; or dredging. Nonstructural measures are primarily operational but may require minor construction, such as extending, modifying, or replacing existing water intake pipes. Descriptions of measures can be referenced in Section 4.5 of this document. Additional discussion of benefits analysis and 5% design are available in supporting appendices including Appendix A.

The measures can be further categorized into the following:

- **Parallel Measures** – Measures that are not directly included in the feasibility study but are being analyzed in parallel and may contribute or influence final plan selection.
- **Feasibility Study A Measures** – These are measures within ACP's authority to implement and generally correspond to Stage 2 of Figure 2-1.
- **Feasibility Study B Measures** – These are measures outside ACP's current authority and generally correspond to Stage 3 of Figure 2-1.

The list of Parallel Measures, Feasibility Study A Measures, and Feasibility Study B measures that were initially considered are listed in Table 5-1 and are described in the following sections. These are identified as either structural or nonstructural measures in this table. Some of the Feasibility Study A measures were pre-screened for various reasons, which are described in Chapter 6 - MEASURES SCREENING AND COMBINATION. The measures that were pre-screened from Feasibility Study A include the following:

- Lower Rio Chagres
- Panamax Water Savings Basins (Gatún Locks)
- Segmentation of the Entire Navigation Channel
- Pump Storage to Alhajuela Lake
- Tide Gates
- Lower Gatún Lake Elevation and Eliminate Upper Locks
- Reduce Seepage and Evaporation Losses
- Raise Miraflores Lake
- Airlocks

Table 5-1: PC IWRM Study Initial Measures Array

Name	Study Phase	Structural	Non-structural
Municipal Water Supply Caps	Parallel		X
Salinity Study	Parallel	X	X
Under Keel Clearance Policy Revisions	Parallel		X
Trinidad with and without pumping	Study A	X	
Caño Quebrado	Study A	X	
Raise Gatún Lake (elevations 89', 90', and 91')	Study A	X	
Navigation Channel Dredging (25' PLD and 27.5' PLD)	Study A	X	
Raise Alhajuela Operational Pool (256' and 260')	Study A	X	
Monte Lirio	Study A	X	
Alhajuela Lake Dredging	Study A	X	
Bayano Reservoir Municipal & Industrial Water Offsets	Study A	X	
Desalination Plant	Study A	X	
Drought contingency planning	Study A		X
Cross filling of Gatún Locks	Study A		X
Reduced M&I Demands	Study A		X
Lower Alhajuela Lake Operational Pool	Study A		X
Lower Municipal Water Intakes (Gatún)	Study A		X
Lower Rio Chagres	Study A	X	
Panamax Water Savings Basins (Gatún Lock)	Study A	X	
Segmentation of the navigation channel	Study A	X	
Alhajuela Lake pump storage	Study A	X	
Tide Gates	Study A	X	
Lower Gatún Lake Elevation and Eliminate Upper Locks	Study A	X	
Reduce seepage and evaporation losses	Study A	X	
Raise Miraflores lakes	Study A	X	
Airlocks	Study A	X	
Rio Indio	Study B	X	
Caribbean Diversions	Study B	X	
Upper Chagres Reservoir	Study B	X	

5.3 Parallel Measures

Several parallel efforts and measures to this feasibility study have been prioritized for consideration and inclusion in future with project condition alternatives. These measures include the following:

1. Capping municipal water supply extractions from the ACP Basin.
2. Increasing the use of the Neopanamax water savings basins (i.e., the Salinity Study).
3. Modifications to Under Keel Clearance Policies

These parallel efforts are being conducted because these measures are known to provide benefits to navigation reliability but could have accelerated timelines compared to other measures in the feasibility study. The parallel measures' benefits are well understood, do not require the feasibility study's completion for implementation, represent a relatively modest investment, can be quickly implemented, and will be carried forward for future analysis. The following sections describe the measures that have been analyzed in parallel to the feasibility study.

5.3.1 Municipal Water Supply Caps

Several simulations have analyzed reliability transitions through time (see Section 4.7.2). These simulations also inform the impacts assessment of M&I water supply extraction caps. This analysis assumes that all currently planned municipal water supply expansion projects will be constructed and online; no further expansion of M&I would occur into the future; and water sources outside the ACP basin will be used for future M&I water expansion. Planned new extractions or upgrades are listed in Table 5-2.

The existing municipal water supply provided by the Panama Canal watershed is 7.98 ET per day. The currently planned expansion projects would increase M&I demands by an additional 3.1 ET per day, bringing the total M&I water withdrawals to 11.07 ET per day. A M&I water withdrawal cap would limit water withdrawals 11.07 ET per day for the future condition.

With an 11.07 ET per day future condition, total future demands are approximately equal to the average volume of water available for withdrawal (see Figure 5-2). The 11.07 ET per day water withdrawal cap significantly reduces the water demand overallocation predicted to occur in the future. While this significantly reduces the overallocation of water within the system, M&I water supply withdrawal caps does not prepare the system for droughts or sufficiently increase reliability as a standalone project. These results are plotted on the transit reliability versus 44' draft reliability chart in Figure 5-7.

Table 5-2: Projected Municipal Water Supply Expansions

Potable Water Plant Name	Year 2025 Extraction (ET / day)	Year 2035 Extraction (ET/day)	Additional Extraction (ET/day)
Mendoza	0.73	1.09	0.36
Arraiján (Howard)	0	0.82	0.82
Cerro Tigre (Gamboa)	0	1.18	1.18
Sabanitas[16]	0.63	0.91	0.28
Laguna Alta	0.36	0.82	0.46
		TOTAL ADDITIONAL EXPANDED CAPACITY	**3.1**

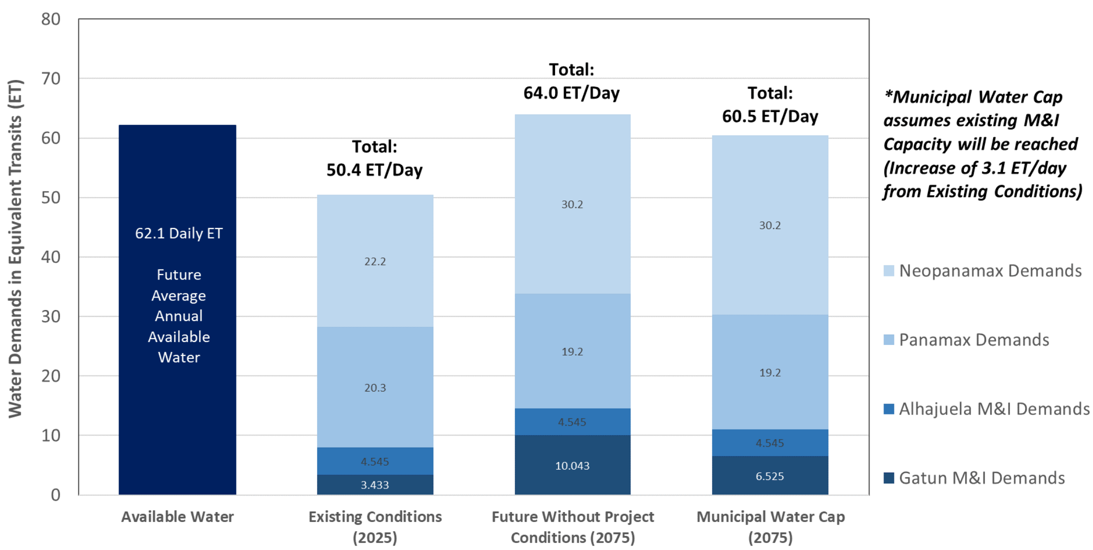


Figure 5-2: Water Demand for Existing Conditions, Future Without Project Conditions, and a Municipal Water Cap of 11.07 ET per Day

[16] The daily extraction from Sabanitas in 2022 was approximately 0.27 ET per day. The expansion of this treatment plant is expected to be completed in Calendar Year 2023 and this analysis assumes that additional planned extractions occur between 2025 and 2035

5.3.2 Salinity Study

During the initial project team meeting on 7 December 2021, the ACP requested a study be performed in parallel to the feasibility study to investigate salinity intrusion and mitigation of salinity intrusion. The Salinity Study (Study C) was requested because the ACP previously decided maximizing water savings basins utilization to reduce water use should be an objective within the water project future alternatives. Using the Deltares simulations of 2018 conditions and other assumptions, it was recognized that salinity measures, especially water savings basin use, provide some of the largest future navigation reliability benefits and these opportunities can be quickly implemented.

Currently, the water savings basins are used infrequently because system salinity values increase when the water savings basins are used. The water saving basins are used during the locking processes to create a water barrier against the saline density currents that propagate through the lock chamber after the rolling gates open in two adjacent equalized chambers (see Figure 5-3).

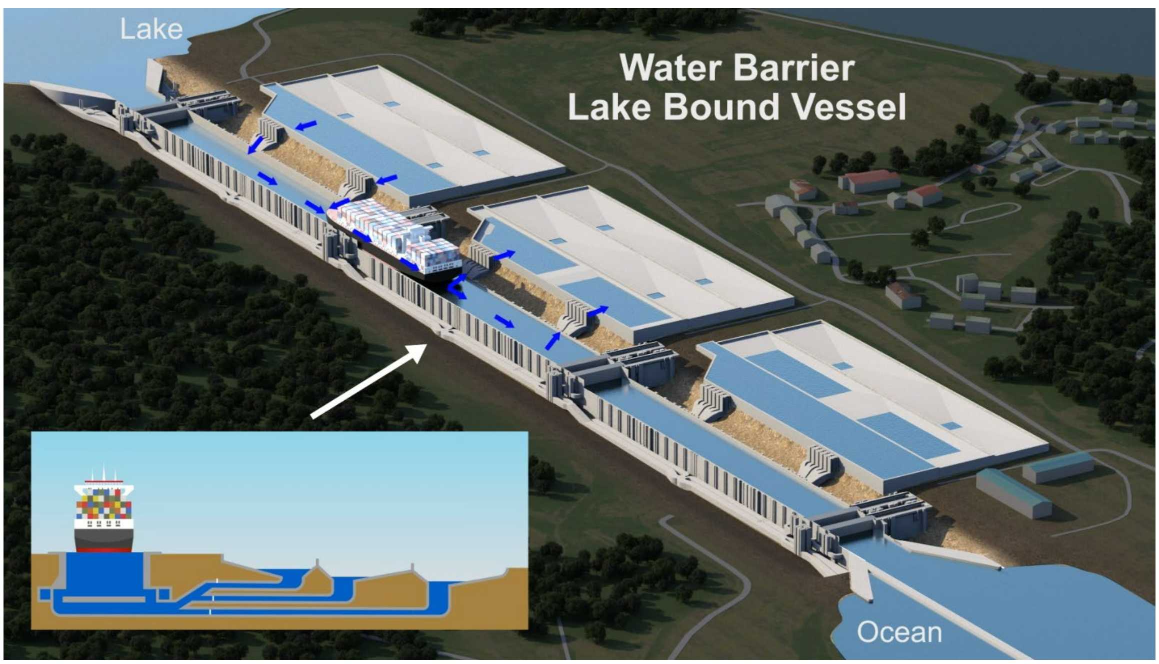


Figure 5-3: Water Barrier Process Used in the Neopanamax Locks

The Neopanamax locks were originally designed to use approximately the same amount of water as Panamax locks. Operational data shows the number of transits of each lock type compared to the amount of water used for each transit type. The data clearly demonstrates a significant increase in volumes of water have been used since the Neopanamax operations began (see Figure 5-4). For example, in the last quarter of calendar year 2021, there was an average of 37.1 total transits per day but an average of 51.6 Equivalent Transits of water volume used. This is approximately 14.5 ET of water volume per day more than the original operational design of the Neopanamax locks.

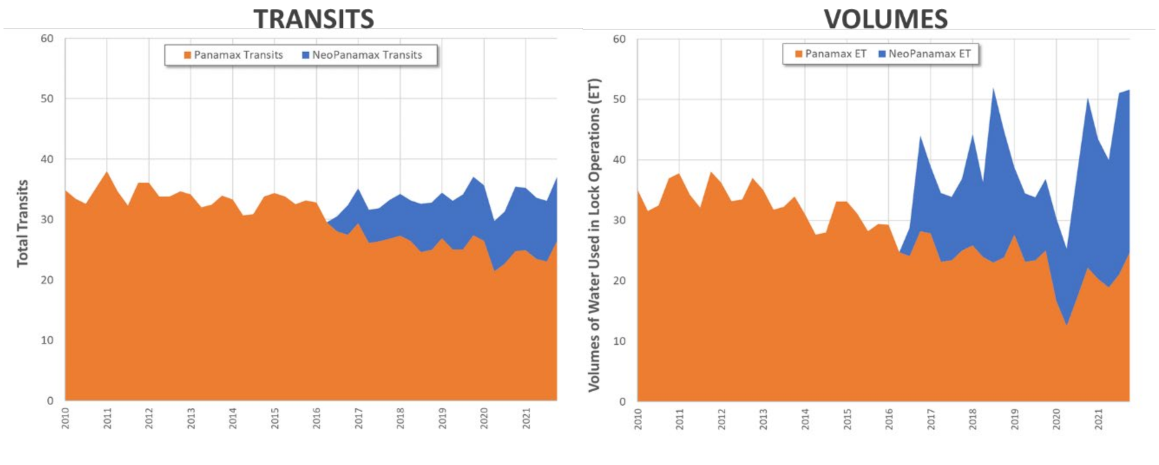


Figure 5-4: Comparison of Quarterly Averaged Transits and Water Volumes used for Panamax and Neopanamax Lockages

One objective of the Salinity Study is to maximize the use of the water savings basins (WSB). Other measures, such as salinity barriers and operational measures are also being investigated. To achieve higher utilization of the water savings basins, the initial salinity study findings identified the following interventions that potentially meet the Salinity Study objectives:

1. Operational improvements developed and tested by the ACP operators.
2. Upgrading the Gamboa Water Intake to also withdraw volumes currently extracted by the Paraiso Water Intake and taking the Paraiso Water Intake offline.
3. Bubble Screens and/or Flexible Barriers at the Neopanamax locks, especially the Agua Clara Locks.

The existing conditions and future without project conditions assume an average WSB utilization of 4.9% annually. With these Salinity Study interventions in place, 100% utilization of the Cocolí Locks WSBs and 50% utilization of the Agua Clara Locks WSBs could be achieved. The Salinity Study assumes an additional 70.1% utilization of the water saving basins above the current utilization.

The expected results of the salinity study demonstrate there is an opportunity to reduce future water demands from 64 ET to 56.3 ET, saving 7.7 ET of water per day. These results are shown in Table 5-3 and Figure 5-5. These results are also plotted on the transit reliability versus 44’ draft reliability chart in Figure 5-7.

Table 5-3: Neopanamax Water Demands for Existing Conditions, Future without Project, and Future with the Salinity Study Measures

Variable	Neopanamax Transits per Day	Neopanamax WSB Usage	Neopanamax Water Demands (ET / day)
Existing Conditions	9.53	4.9%	22.1
Future without Project Conditions	12.64	4.9%	30.2
Future with Salinity Measures in Place	12.64	75%	21.42

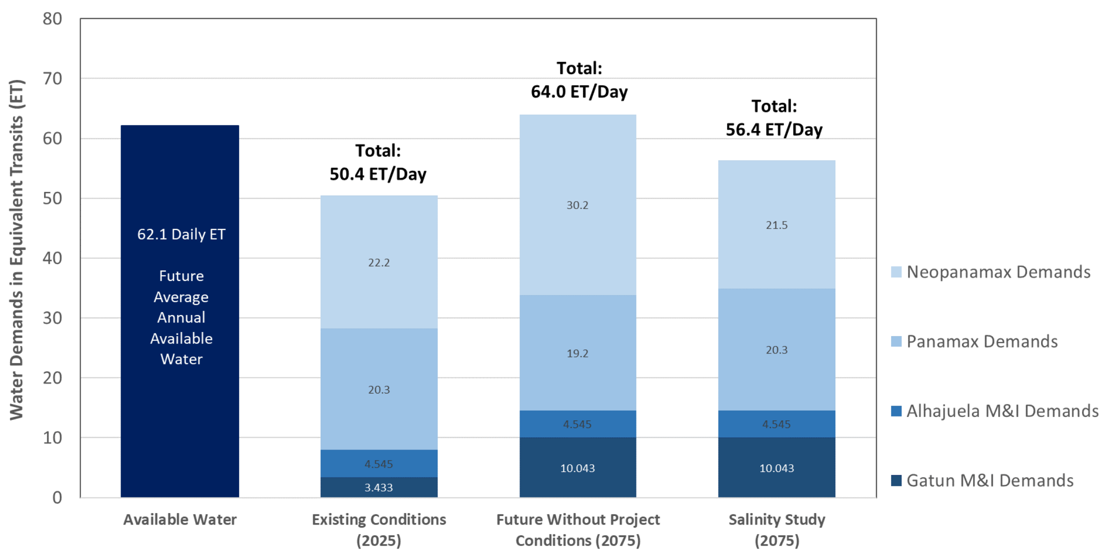


Figure 5-5: Water Demand for Existing Conditions, Future Without Project Conditions, and the Expected Results from the Salinity Study

5.3.3 Under Keel Clearance (UKC) Policy Modifications

The third parallel measure is modifications to ACP's Under Keel Clearance (UKC) policies. Current policies governing vessel dimensions, including vessel drafts are described in OP Notice to Shipping No. N-1-2023, Vessel Requirements (ACP, 2023) and Regulations for Navigation in the Water of the Panama Canal, Agreement No. 360, by which the Regulations for Navigation in the Waters of the Panama Canal are subrogated. The OP notice outlines two relevant UKC requirements relevant to the study. The first establishes the maximum allowable draft for Canal transits for Neopanamax and Panamax vessels; and the second establishes the process for determining draft restrictions beyond the maximum draft. These are included in the following three excerpts (ACP, 2023):

> "…The maximum permissible draft for Canal transits using the Panamax Locks has been set at 12.04 meters (39 feet 6 inches) Tropical Fresh Water (TFW) at a Gatún Lake level of 24.01 meters (78.8 feet) or higher..." (Reference Section 2.a.3.a., Page 10).

> "…The maximum allowable draft for Canal transits using the Neopanamax locks has been set at 15.24 meters (50.00 feet) Tropical Fresh Water (TFW) at a Gatún Lake level of 25.91 meters (85.0 feet) or higher..." (Reference Section 2.b.3., Page 13).

> "…During the rainy season (from May to December), Gatún Lake and Madden Lake, the upstream reservoir for the Canal and the municipal water supply of Panama City, are expected to be filled to capacity. During the dry season (from December to May), the Madden Lake reserve is drawn off to keep Gatún Lake at an optimum level. As the Gatún Lake level falls below 25.91 meters (85 feet) it becomes necessary to reduce the maximum allowable draft in the Neopanamax locks, and if the Lake level falls below 24.09 meters (79 feet), it becomes necessary to reduce the maximum allowable draft in the Panamax locks to preserve the safe navigation margin. The reductions are made in 15.24 cm (6 inch) decrements, with three-week advance notice, when possible, based on computer assisted lake level and precipitation forecasts made by the Authority's hydrologists and meteorologists. Ships already loaded to a prevailing draft limitation at the time of promulgation of a new draft restriction are waived for transit, subject to overriding safety considerations. Ships loading after promulgation of a new draft restriction are held to a tolerance of not more than 15.24 cm (6 inches) above that restriction and may be required to trim or off-load the ship to achieve a safe transit draft..." (Reference Section 2.c.10.b., Page 15).

In addition to these references, the Panama Canal Navigation channel is maintained to EL 9.144 m PLD (30 ft). Since the maximum drafts for Neopanamax vessels are defined when Gatún Lake is at EL 25.91 m PLD (85 ft) and the channel bed is maintained to an elevation of EL 9.144 m PLD (30 ft), the UKC associated with this condition is 1.524 m (5 ft). In practice, Neopanamax drafts have been restricted with a constant UKC of 1.524

m (5ft) as a function of the Gatún Lake level when it is below EL 25.91 m PLD (85 feet). For example, when the Gatún Lake level is at 24.69 m (81 ft) the navigation drafts are restricted to 14.021 m (46 ft), which maintains UKC of 1.524 m (5ft). The constant UKC assumption has been applied throughout the analysis for the determination of navigation reliability in this current AMM report.

International guidelines may warrant additional investigations into less restrictive UKC. PIANC (1997) establishes that "…minimum values of depth/draught ratio should be taken as 1.10 in sheltered waters, 1.3 in waves up to one metre in height and 1.5 in higher waves with unfavourable periods and directions…" The Panama Canal can be considered to have sheltered waters and therefore, a depth/draught ratio of 1.10 can be considered appropriate under the PIANC (1997) Guidance. PIANC and USACE have additional guidance that includes effects of freshwater, ship motion from waves, squat, and safety clearances, although the guidance of 1.10 depth/draft is within the expected range of analysis that would be appropriate for the Panama Canal and was used for first analysis at the AMM level. This assumption would allow for lower UKC when vessel drafts are less than 15.24 m (50 ft) and for small increases in drafts associated with various Gatún Lake elevations according to Table 5-4.

Table 5-4: Neopanamax Drafts and Associated Gatún Lake Elevations under Existing Practices and a Policy of 1.10 Depth/Draft Ratio

Vessel Draft	Allowable Gatún Lake Elevation under Current Practices	Allowable Gatún Lake Elevation Under Policy of 1.10 depth/draft Ratio
15.24 m (50 ft)	25.91 m PLD (85 ft)	25.91 m PLD (85 ft)
14.63 m (48 ft)	25.30 m PLD (83 ft)	25.24 m PLD (82.8 ft)
14.02 m (46 ft)	24.69 m PLD (81 ft)	24.57 m PLD (80.6 ft)
13.41 m (44 ft)	24.08 m PLD (79 ft)	23.90 m PLD (78.4 ft)

There is not an opportunity to improve navigation drafts for Panamax lockages under a policy of a 1.10 depth/draft ratio as part of Study A. The Panamax UKC is governed by the locks' sills at elevation EL 11.38 m (37.33 ft) and not the navigation channel bed. The UKC for the Panamax locks is already significantly less than 5.0 feet at the sill. The UKC for a 39.5 ft draft vessel when the lake is at 79 ft is 2.17 ft. Therefore, no additional analysis for reductions in UKC is considered for Panamax vessels.

The reliability improvements associated with a revised UKC policy for Neopanamax lockages were determined using the HEC-ResSIM model outputs. The draft reliability metrics associated with the revised Gatún Lake elevations listed in Table 5-4 were analyzed and are shown in Table 5-5.

Table 5-5: Change in Reliabilities of Drafts due to Revised UKC Policy

Vessel Draft	Future without Project Conditions (FWOP) Reliability	Future with Revised UKC Policy Reliability	Difference
15.24 m (50 ft)	23.4%	23.4%	0%
14.63 m (48 ft)	43.8%	45.7%	1.9%
14.02 m (46 ft)	62.2%	66.2%	4.0%
13.41 m (44 ft)	92.1%	95.6%	3.5%

Table 5-5 demonstrates there are not benefits for draft reliability at 15.24 m (50 ft) because this draft already has a depth/draft ratio of 1.10 and the new policy would not decrease the UKC value. The draft reliability associated with 14.63 m (48 ft) drafts increases 1.9% and the 14.02 m (46 ft) drafts and 13.41 m (44 ft) drafts increase in reliability by 4.0% and 3.5% respectively. These results do not impact the transit reliability, or the overall water demands. These results are also plotted on the transit reliability versus 44' draft reliability chart in Figure 5-7.

5.3.4 Parallel Measures Conclusions

Measures that have been assessed separately from the current study were initially analyzed individually. The two primary measures that reduce demands (salinity study and the municipal water caps) can be combined to further reduce demands in a simulation (reference Figure 4-6). If the expected Salinity Study results (50% use of Agua Clara Locks water savings basins and 100% use of Cocolí Locks water savings basins)) and a municipal water supply withdrawal cap are implemented, there would be further reduction of future demands of approximately 52.9 ETs of water per day. This is 2.4 ETs more than in existing conditions, representing 4 additional vessels per day.

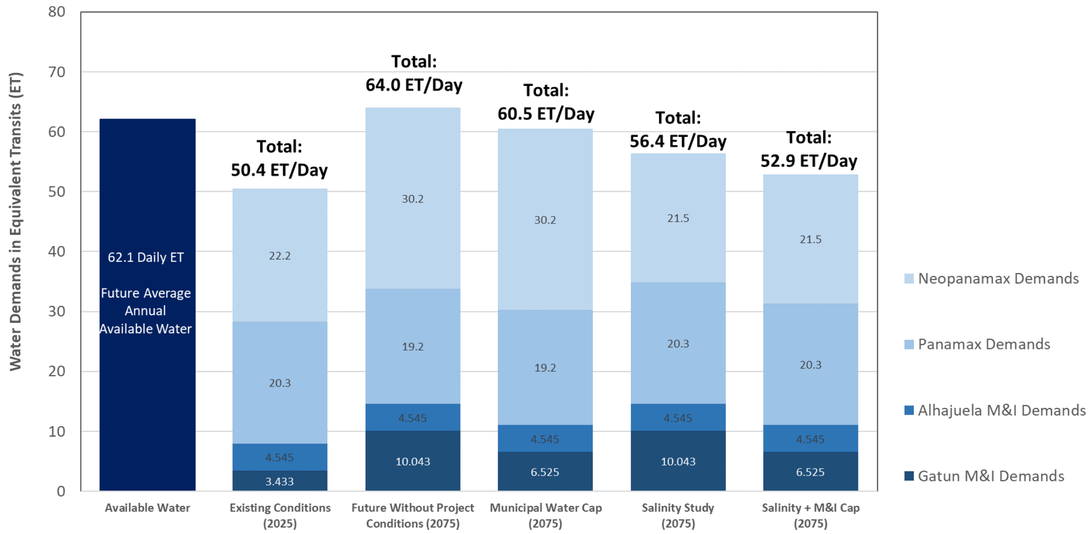


Figure 5-6: Year 2075 Water Demands with Municipal Water Caps and Expected Salinity Study Results

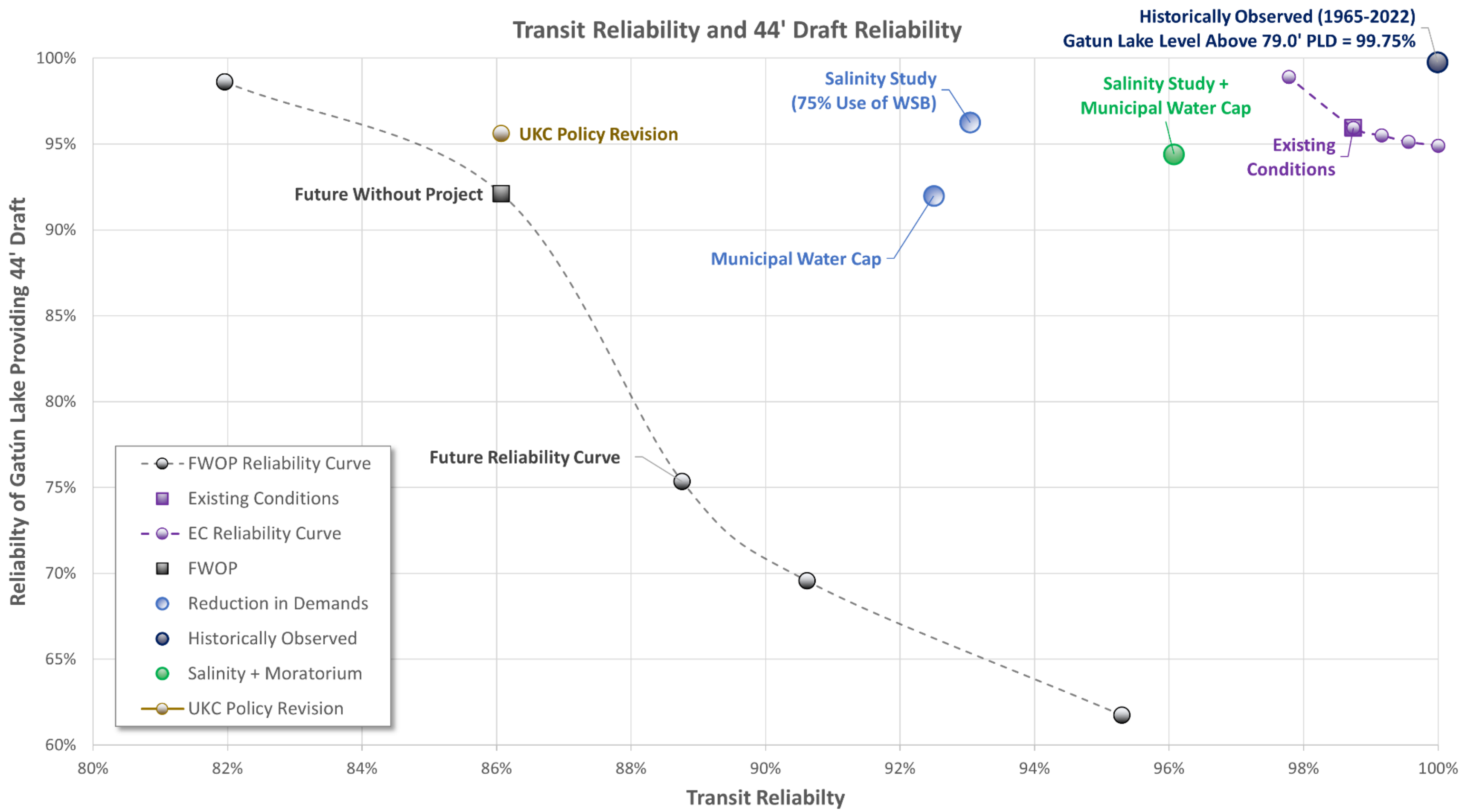


Figure 5-7: Transit and 44' Draft Reliability Associated with Parallel Measures (Municipal Water Caps, Salinity Study, and Under Keel Clearance Policy Revisions)

5.4 Guiding Design Principles for Measures Analysis in Study A

Appendix A, Engineering and 5% Design of this report describes the design of various measures to improve the Panama Canal operational reliability. The purpose of this analysis is to define which measures can be carried forwarded and combined into alternative plans. An appropriate level of analysis and design is necessary to provide sufficient information to make an informed decision. Several guiding principles were applied to the 5% design analysis.

Guiding Design Principle #1: The 5% Analysis Objective is a Rough Order of Magnitude Associated with Key Screening and Evaluation Criteria

The objective of the preliminary analysis to a 5% design is to develop an understanding of key screening and evaluation criteria to a rough order of magnitude. The primary screening criteria is related to the cost of the measure (discussed in Appendix A Engineering and 5% Design and Appendix C, 5% Design Cost Engineering) and the associated increases to system reliability associated with the measure (assessed in Appendix B, Water Management Modeling). Additional criteria used to inform the viability of a measure moving forward include operational impacts, associated risk, and other factors. Benefits of each measure are addressed in Appendix B, Water Management Modeling. Social and environmental impacts and benefits of measures will be addressed at the 15% design stage by the ACP. Preliminary economic feasibility (i.e., net present value) of measures are assessed in Appendix D, Economics.

Guiding Design Principle #2: 5% Analysis will be Conducted on a Representative Measure with Agreed upon Design Assumptions

Measures described at the 5% level are conceptual designs. The team has developed several design assumptions for each measure through a series of meetings with the PDT. The design assumptions are based on best available information and engineering judgement, but the assumptions are not optimized solutions. The design assumptions are intended to define a representative version of the measure to be analyzed to a 5% level design. A measure’s costs, impacts, and overall viability are based on the design assumptions made at the 5% level design. These design assumptions will be validated or optimized in the next study phase if the measure passes screening criteria and moves forward to the 15% design level.

An important component of this guiding principle is that if a measure was analyzed in studies performed by USACE in 1999 or 2002, the design assumptions used in the study will be used in the current analysis. Results from more recent studies and design analyses will be considered and incorporated as applicable during the 15% analysis for measures moving forward.

Guiding Principle #3: 5% Analysis is Based on Existing Information and Previous Reports

Design and analysis of all measures are based on existing information, data, and previous reports. No new data was collected as part of the 5% design analysis. If a measure was included in the previous USACE Reconnaissance Study in 1999 and 2002, the design assumptions used at that time were applied to the measure.

The ACP has advanced several designs originally listed in the USACE 1999 and 2002 study and significant improvements and advances that have occurred since that time. Design assumptions in the USACE 1999 and 2002 study were used to have the same level of analysis and allow information informing the USACE processes at that time to be leveraged. This decision was made to address the schedule constraints of the current study.

Other information and studies, including the Ingetec 2018 and 2020 reports and information described in the ACP Integrated Water Resource Management Study, Reconnaissance Phase: Literature Review Version 2.0 (31 July 2022) also inform Study A analysis. Some sections associated with a measure may have incomplete information, and this is described in each section. The team has identified assumptions that have higher uncertainties and will need to be verified in 15% design, 35% design or Pre-Construction Engineering & Design (PED).

5.5 Study A Projects (Measures) Overview

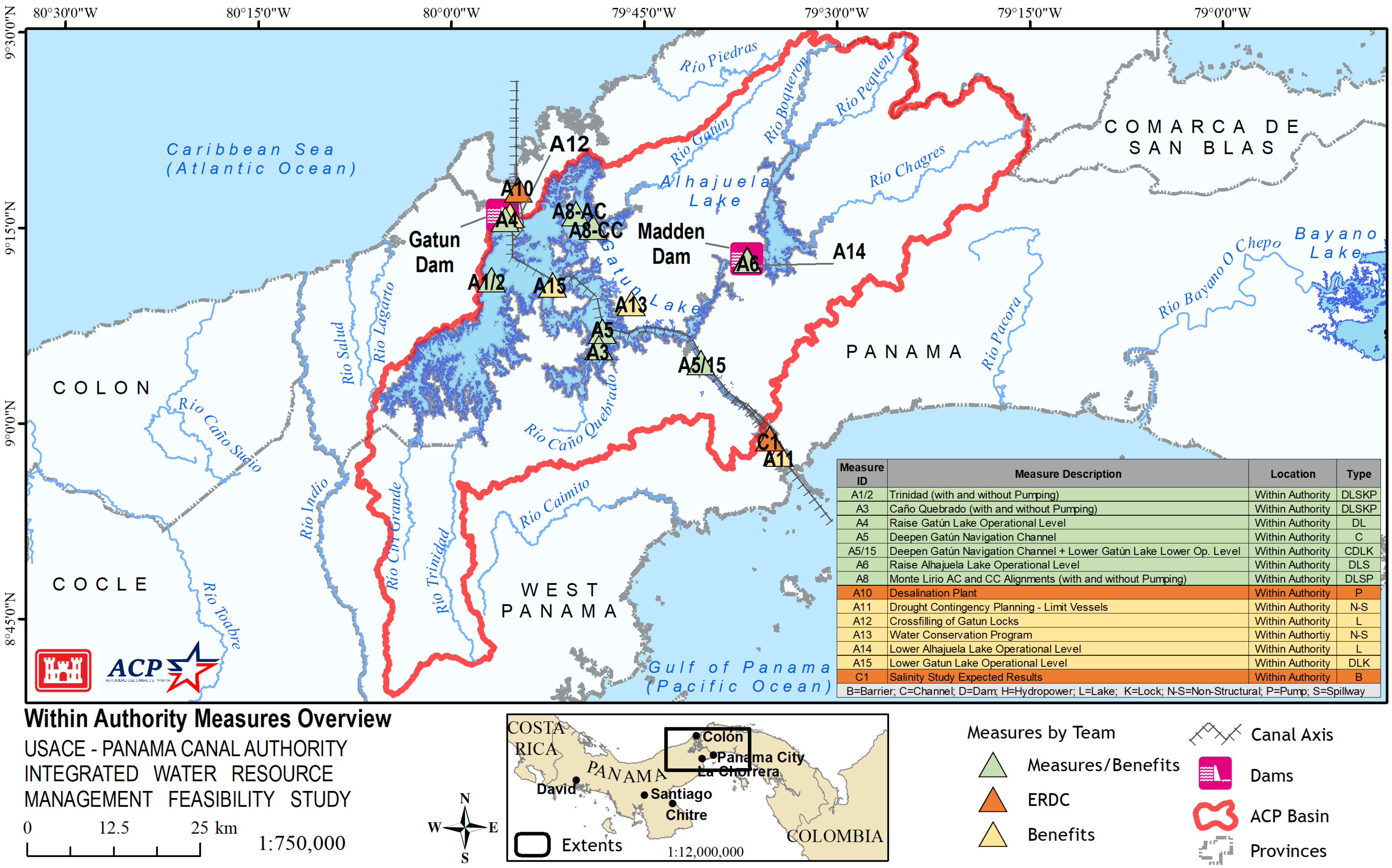
After initial pre-screening (see Chapter 5), a total of 15 measures were developed for analysis within the Water Project Feasibility Study A. These measures are listed below:

- Measure 1: Trinidad without Pumping
- Measure 2: Trinidad with Pumping
- Measure 3: Caño Quebrado
- Measure 4: Raise Gatún Lake Operating Pool
- Measure 5: Navigation Channel Dredging
- Measure 6: Raise Alhajuela Lake Operating Pool
- Measure 7: Alhajuela Lake Dredging
- Measure 8: Monte Lirio
- Measure 9: Bayano Reservoir M&I Offset

- Measure 10: Desalination Plant
- Measure 11: Drought Contingency Planning
- Measure 12: Cross Filling of Gatún Locks
- Measure 13: Reduced M&I Demands
- Measure 14: Lower Alhajuela Lake Operational Pool
- Measure 15: Lower Gatún Lake Municipal & Industrial Water Intakes

Locations of the proposed measures are shown in Figure 5-8 and design assumptions associated with each measure are listed in Table 5-6. These design assumptions are based on the Guiding Principles listed in Section 5.4 Table 5-6 also identifies if a measure was selected for a full engineering analysis and cost estimate; analyzed for benefits only; or screened after the initial measure array was developed.

The following sections briefly describe each measure. Additional information on the engineering analysis associated with each measure is in Appendix A and Appendix B Water Management Modeling. References used to develop individual measure write ups are listed at the end of each write up in Appendix A Engineering and 5% Design.



Measure ID	Measure Description	Location	Type
A1/2	Trinidad (with and without Pumping)	Within Authority	DLSKP
A3	Caño Quebrado (with and without Pumping)	Within Authority	DLSKP
A4	Raise Gatún Lake Operational Level	Within Authority	DL
A5	Deepen Gatún Navigation Channel	Within Authority	C
A5/15	Deepen Gatún Navigation Channel + Lower Gatún Lake Lower Op. Level	Within Authority	CDLK
A6	Raise Alhajuela Lake Operational Level	Within Authority	DLS
A8	Monte Lirio AC and CC Alignments (with and without Pumping)	Within Authority	DLSP
A10	Desalination Plant	Within Authority	P
A11	Drought Contingency Planning - Limit Vessels	Within Authority	N-S
A12	Crossfilling of Gatun Locks	Within Authority	L
A13	Water Conservation Program	Within Authortiy	N-S
A14	Lower Alhajuela Lake Operational Level	Within Authority	L
A15	Lower Gatun Lake Operational Level	Within Authority	DLK
C1	Salinity Study Expected Results	Within Authority	B

B=Barrier; C=Channel; D=Dam; H=Hydropower; L=Lake; K=Lock; N-S=Non-Structural; P=Pump; S=Spillway

Figure 5-8: Structural Measures Locations

Table 5-6: Feasibility Study A Measures Design Assumptions

No.	Name	Notes / Measures Design Considerations (Appendix A, Engineering and 5% Design[17] and Appendix B, Water Management Modeling can be referenced for details of analysis supporting finding presented in this table.)
1	Trinidad (Without Pumping)	This measure has been analyzed for the 5% design, Class 5 cost estimate, and determination of navigation reliability metrics. Design assumptions include: • Tudor Alignment (location) • No Pumping • Gated Spillway. Single direction discharge, only from Trinidad into Gatún. • Navigation Lock for Local Population • Top of Embankment: 103’ • Crest Width: 43’ • Side Slopes: 3:1 above water; 15:1 below water
2	Trinidad (Pumping)	This measure has been analyzed for the 5% design, Class 5 Cost estimate, and determination of navigation reliability metrics. Design assumptions include: • Tudor Alignment • Pump Station with pumping in both directions • Gated Spillway • Navigation Lock for Local Population • Top of Embankment: 103’ • Crest Width: 43’ • Side Slopes: 3:1 above water; 15:1 below water
3	Caño Quebrado	This measure has been analyzed for the 5% design, Class 5 Cost estimate, and determination of navigation reliability metrics. Design assumptions include: • Alignment #3 • Pumping • Gated Spillway • Navigation Lock for Local Population • Top of Embankment: 103’ • Crest Width: 43’

[17] 15:1 slopes were assumed for the 5% analysis in order to leverage work done during past studies in order to escalate costs as efficiently as possible since certain measures had been developed to a greater level than others (Trinidad vs. Monte Lirio or Cano Quebrado). Foundation improvements proposed during past Trinidad design efforts are generally discussed in the Appendix A segmentation measure write ups but were not incorporated into the design at the 5% phase since the same level of exploration or study has not historically been completed at all segmentation locations. It is acknowledged in the Appendix A write ups that steeper embankment slopes would likely be achievable with the use of foundation improvement, and this will be analyzed during later phases of design.

No.	Name	Notes / Measures Design Considerations (Appendix A, Engineering and 5% Design[17] and Appendix B, Water Management Modeling can be referenced for details of analysis supporting finding presented in this table.)
		• Side Slopes: 3:1 above water; 15:1 below water
4	Raise Gatún Lake Operating Pool	This measure has been analyzed for the 5% design, Class 5 cost estimate, and determination of navigation reliability metrics. Design assumptions include: • 88.0’ is the existing maximum normal operating pool elevation • Raising the Gatún Lake Elevation will be evaluated at an operational elevation of 91.0’ • The BEC Spillway, complementary to the Gatun Spillway, is assumed needed for additional discharge capacity • The miter gates at Gatún and Pedro Miguel locks are replaced • The flood gates at Gatún dam are replaced • Cursory hydrologic model of an assumed extreme flood event was performed and was determined that a top of pool of 92.9’ would apply during an event equivalent to the 1979 Probable Maximum Flood (PMF) study with initial conditions of 91.0’. Without the BEC spillway the resulting flood elevation would be 94.4’. • Additional impacts and modifications to Panamax and Neopanamax infrastructure to operate at 91.0’ that have not been assumed in this current phase are expected. These impacts and modifications will not be determined at the 5% but will need to be analyzed through a comprehensive diagnosis of the locks and system if this measure moves into the next phase. • Benefits and Costs will be analyzed at 91.0’
5	Navigation Channel Dredging	This measure has been analyzed for the 5% design, Class 5 Cost estimate, and determination of navigation reliability metrics. Design assumptions include: • A typical dredging prism will be applied for sand and rock • The Culebra Cut widening will not be included in costs. Instead, the navigation channel would be narrowed to address necessary slope stability issues. A navigation suitability analysis using PIANC Guidelines will be completed to verify this assumption has no impacts to navigation operations. • Will be analyzed for 27.5’ PLD (Option 1) and 25.0’ PLD (Option 2) scenarios • Option 1 will include a lowering of the M&I intakes to an elevation of 72.5’ PLD • Option 2 will include a lowering of the M&I intakes to an elevation of 70.0’ PLD • No drilling and blasting will be considered. Only rock cutter head suction dredging will be considered.
6	Raise Alhajuela Lake	This measure has been analyzed for navigation reliability metrics only. It was determined during the analysis that a baseline risk assessment will be required before the engineering analysis of a dam modification that would be

No.	Name	Notes / Measures Design Considerations (Appendix A, Engineering and 5% Design[17] and Appendix B, Water Management Modeling can be referenced for details of analysis supporting finding presented in this table.)
	Operating Pool	required for assessing this measure's engineering and costs. Modeling assumptions include: • Operational reliability benefits will be analyzed at 256' max normal operating pool and 260' max normal operating pool operations.
7	Alhajuela Lake Dredging	This measure has been recommended to be screened from the feasibility study due to low benefits, long execution time, and environmental and social concerns.
8	Monte Lirio	Will be analyzed for costs and reliability metrics at the 5% design. Design assumptions include: • AC Alignment • Will not include pumping • Gated Spillway • No Navigation Lock • Top of Embankment: 103' • Crest Width: 43' • Side Slopes: 3:1 above water; 15:1 below water
9	Bayano Reservoir M&I Offset	This measure has been analyzed for the 5% design, Class 5 cost estimate, and determination of navigation reliability metrics. Design assumptions include: • Intake from Bayano Reservoir • La Joya Water Treatment Plant • Constant 12 cubic meters per second (cms) offset. This flowrate is removed from Federico Conte Water Intake in Alhajuela • Minimum operations of Madden pool will lower to 190' in this measure.
10	Desalinization Plant	This measure has been pre-assessed in a White Paper from the USACE Engineer Research and Development Center. This measure was recommended to be screened as it is impractical when compared to other options based on cost and abundance of freshwater sources in the region.
11	Drought Contingency Planning	This measure has been analyzed for navigation reliability metrics only.
12	Cross Filling of Gatún Locks	This measure is known to reduce Panamax water usage and will be fully analyzed only in the 15% design phase of the current study, pending additional information from the ACP on the water volumes and effectiveness associated with this measure.
13	Reduced M&I Demands – Sensitivity Analysis	This measure has been analyzed for navigation reliability metrics only. The modeling assumptions associated with this measure include: • Option A: 5% Reduction in FWOP M&I Demands • Option B: 10% Reduction in FWOP M&I Demands

No.	Name	Notes / Measures Design Considerations (Appendix A, Engineering and 5% Design[17] and Appendix B, Water Management Modeling can be referenced for details of analysis supporting finding presented in this table.)

14	Lower Alhajuela Lake Operational Pool	This measure has been analyzed for the 5% design, Class 5 Cost estimate, and determination of navigation reliability metrics. Design assumptions include upgrades to the Federico Conte Water Intake including:
		• Supply and installation of 6 1,500 horsepower (hp) pumps and motors to replace existing pumps and motors:
		  ○ Three pumps running with soft starter.
		  ○ Three pumps working with the existing frequency variators.
		• Supply and installation of six 36'' check valves with slow opening and closing.
		• Supply and installation of six 36'' butterfly valves with electric actuator.
		• Supply and installation of six 4'' air valves.
		• Supply and installation of 2 induction flow meters.
		• Air conditioning of the area of electrical panels and variators and operator's room.
		• Supply and installation of a SCADA system.
		• Supply and installation of a vibration monitoring system.

15	Lower Gatún Lake Operational Level and Municipal and Industrial Water Intakes	This measure has been analyzed for the 5% design, Class 5 Cost estimate, and determination of navigation reliability metrics. Design assumptions include: • Costs will be made based on assuming the water intakes are able to be lowered to an elevation of 70' PLD. • Floating intake design will be applied • Electrical and mechanical upgrades will be incorporated

5.6 Study A Projects Measures Descriptions (Within Basin and ACP Authority)

5.6.1 Measure #1: Trinidad without Pumping

The development plan for the Lower Rio Trinidad Dam Project considers creating a dam and lake on the Trinidad basin, within the Panama Canal watershed at Gatún Lake, southwest of the Gatún Locks. Impounded water adds storage to the Panama Canal system and reduces spilling at the Gatún Dam. The water may be used as needed to support canal operations.

The Rio Trinidad watershed is located on the western side of the Panama Canal watershed. The proposed dam site is located within Gatún Lake across the Lower Rio Trinidad Lake arm approximately 4 km (2.5 miles) northeast of the town of Escobal and

10 km (6.2 miles) south-southwest of Gatún Locks. The proposed dam extends from Punta Mala on the west shore of Gatún Lake to Guacha Island, then to Isla Tern, and then straight across to the eastern shore of the Rio Trinidad Lake arm, just south of the South Range Point lighthouse. This alignment was adopted for 5% design and evaluation of measures and corresponds to the proposed alignment presented in the Study and Report on Increasing the Water Supply of the Panama Canal (Tudor, 1962).

The proposed structures for the Lower Rio Trinidad project consist of a rock fill dam constructed by underwater deposition of fill materials, a gated spillway constructed in the dry on Guacha Island and navigation lock currently proposed at the left dam abutment. The conceptual spillway is a concrete ogee with 8 radial gate bays, each measuring 18.3 m wide. The conceptual navigation lock interior dimensions are 9.1 m (30 ft) x 19.8 m (65 ft). The lock is intended to allow for transport of local traffic between the Trinidad impoundment area and Gatún Lake. This site can accommodate construction of a dam with a crest equal to EL 31.4 m PLD (103 ft) and a maximum normal operating lake level up to EL 29.6 m PLD (97 ft).

See Figure 5-9 for an overview of the site conditions of Trinidad without pumping measure.

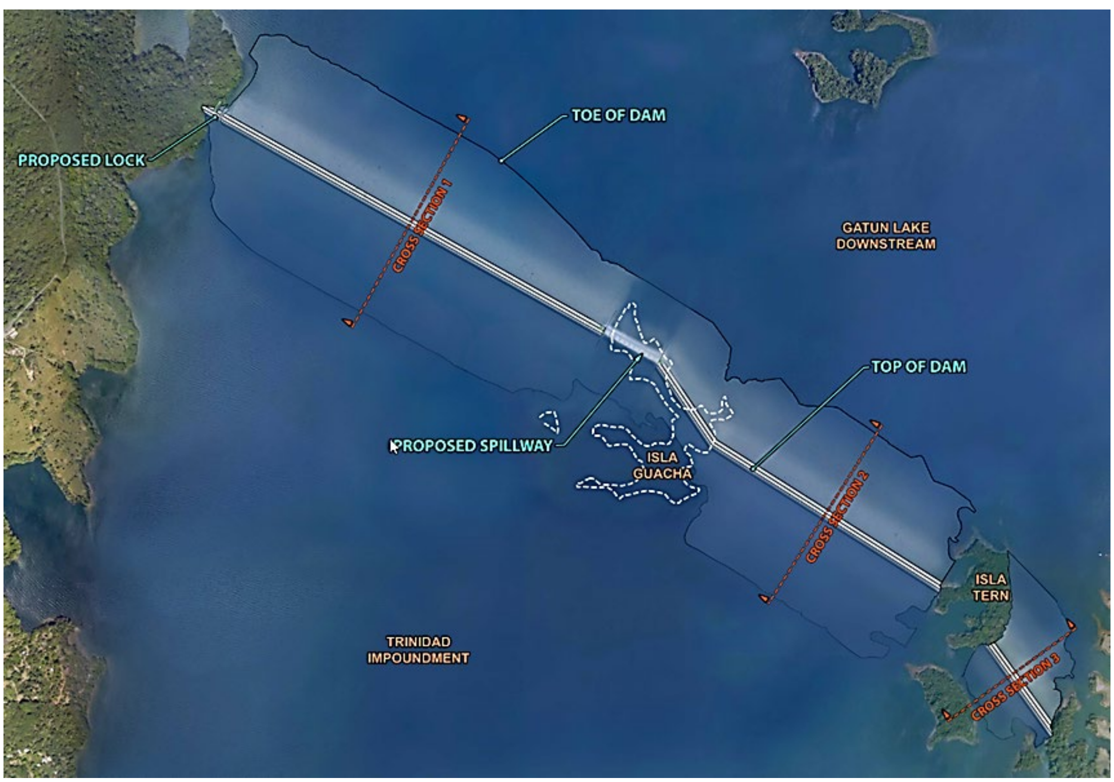


Figure 5-9: Trinidad Site Plan

5.6.2 Measure #2: Trinidad with Pumping

Measure #2 consists of the Trinidad Project with pumping. Water may be pumped between Gatún Lake and Trinidad Lake by a pumping station installed near the east end of Trinidad Dam. During the flood season, excess water can be pumped from Gatún Lake to Trinidad Lake. During the dry season, water stored in Trinidad Lake can be pumped from Trinidad Lake to Gatún Lake. Impounded water adds storage to the Panama Canal system and reduces spilling at Gatún Dam. The water may be used as needed to support canal operations. All other assumptions associated with Measure #1 apply to the Trinidad with Pumping measure. See Figure 5-10 for an overview of the site conditions of Trinidad with pumping measure.

Figure 5-10: Trinidad With Pumping

5.6.3 Measure #3: Caño Quebrado

The proposed Caño Quebrado dam site was recommended as a standalone measure in the 1999 Feasibility Study (USACE, 1999) but was previously screened in the 1999 study due to the limited benefit of the storage capacity identified in the 1999 Feasibility Study (0.54 lockages). Caño Quebrado was also analyzed as a measure in combination with other measures in the 2002 Feasibility Study (USACE, 2002). This location was re-evaluated as a potential measure for this study due to different selection criteria and revised economic conditions associated with the Neopanamax operations. The measure definition and description were developed with a view toward maximizing the water impounded, while minimizing the volume of material required for construction of the dam and minimizing the number of saddle dams required to contain the lake.

This measure originally did not include pumping. However, to maximize the benefits of this measure, a pumping station was added. During the flood season, excess water can be pumped from Gatún Lake to the Caño Quebrado Lake; and during the dry season, water stored in the Caño Quebrado Lake can be pumped to Gatún Lake. Impounded water adds storage to the Panama Canal system and reduces spilling at Gatún Dam. The water may be used as needed to support canal operations.

The proposed dam site would be located within Gatún Lake across the Caño Quebrado arm in the general location shown in Figure 5-11. The Caño Quebrado watershed comprises a portion of the western side of the Panama Canal watershed. This site would accommodate construction of a dam with a maximum normal operating lake level at EL 29.6 m PLD (97 ft). Storage would be accommodated above the normal operating levels for Gatún Lake, EL 26.8 m PLD (88 ft), and the normal maximum operation level of the proposed measure, EL 30.5 PLD (100 ft), resulting in 79 million m^3 (64 acre-feet (ac-ft)) of useable storage.

The structures for the proposed Caño Quebrado measure would consist of a rock fill dam, a gated spillway, a pumping station to pump water between this reservoir and Gatún Lake, a small lock, and three saddle dams. The spillway would be a gated ogee with 8 radial gates, each 18.3 m (60 ft) wide. The lock would be 9.1 m (30 ft) by 19.8 m (65 ft) and be designed to handle a vessel 9.1 m (30 ft) long and 2.7 m wide (9 ft) with a draft of 0.4 m (1.3 ft).

Figure 5-11: Caño Quebrado

5.6.4 Measure #4: Raise Gatún Lake

Raise Gatún Lake Operating Pool proposes a new maximum operational level for the Gatún Reservoir. The design assumption associated with this study is that Gatún Lake can be operated between 22.86 and 26.82 m PLD (75.0 and 88.0 ft). With this measure, the maximum operational level would be raised to 27.74 m PLD (91.0 ft), resulting in a new operational range of 22.86 – 27.74 m PLD (75.0 – 91.0 ft). The increased pool level would provide additional storage of 430 cubic hectometer (hm^3) (348,509 ac-ft). Freeboard at maximum operating level would reduce to 14 feet for the top of Gatún Dam elevation of 32 m PLD (105 ft PLD). Operational freeboard at Gatún and Pedro Miguel lock miter gates would be reduced to 0.5 foot.

Expected infrastructure modifications include the addition of the BEC Spillway (Ingetec, 2017), replacement of the Gatún Dam spillway gates, and replacement of the miter gates at Gatún and Pedro Miguel Locks (16 sets). Analysis of the 27.74 m (91.0 ft) contour for Gatún Lake shows that no saddle dams are required to support the increased pool level. The upcoming Risk Assessment will verify the design assumptions. Any increase in incremental risk will be documented and influence future project design. Study D, the Risk Assessment, will evaluate if and why additional spilling capacity is needed and define the spilling capacity volume.

Additional specifics of infrastructure affected by the increased maximum operating pool have not been determined at the 5% design level. The assumption is no modifications to Panamax and Neopanamax lock infrastructure beyond those described herein would be made.

5.6.5 Measure #5: Navigation Channel Dredging

There is one dredging measure with two configurations. Measure 5A is a 0.8 m (2.5 ft) deepening of the navigation channel. Measure 5B is a 1.5 m (5 ft) deepening of the navigation channel. The current navigation channel depth through the Culebra Cut (Gaillard Cut) is 9.1 m PLD (30 ft PLD). The dredging measures increase the navigation channel depth, allowing for deeper draft Neopanamax vessels to traverse the canal at lower Gatún Lake pool elevations.

Dredging will maintain the existing side slopes of the navigation channel. This will decrease the navigation channel width at lower Gatún Lake pool elevations. Widening of the Culebra Cut has not been associated with analysis of this structure. It is assumed the reliability benefit of this measure would apply only to Neopanamax vessels having drafts of less than 46 feet. Appendix B also presents benefits for this measure as if it were applied to all Neopanamax vessels.

These measures also include lowering the Gatún Lake M&I intakes by a commensurate depth (22.1 m PLD / 72.5 ft PLD for Measure 5A and 21.3 m PLD / 70 ft PLD for Measure 5B) to ensure water extraction at lower Gatún Lake levels.

5.6.6 Measure #6: Raise Alhajuela Lake Operating Pool

The USACE (1999b) reconnaissance study for water supply projects investigated raising the operational pool of the Alhajuela Reservoir (the pool associated with the Madden dam). The current maximum operational pool elevation is EL 76.8 m PLD (252 ft). In the USACE (1999b) study, two options were considered including raising the maximum operational pool to EL 77.4 m PLD (254 ft) and EL 78.0 m PLD (256 ft).

Raising the operational pool provides more storage and could contribute to improved navigation reliability. The USACE (1999b) study found that implementing the Raise Alhajuela measure could contribute between 0.97-1.2 Equivalent Transits per day.

The USACE and ACP discussed this measure as a possible candidate for inclusion in the Water Project Feasibility Study A. One key constraint that has been assigned to this study that applies for screening consideration is that no measure shall increase risk associated with dam safety. The current baseline level of risk associated with the Madden Dam has not been directly evaluated, and therefore any risk mitigation measures associated with changing the operational pool could not be designed until the baseline risk assessment is completed. The joint USACE and ACP team anticipates that this measure would have a benefit to cost ratio greater than 1.0 as was found in previous studies; however, due to the unknown level of risk associated with this measure, the PDT recommends deferring analysis of this measure until after the full baseline risk assessment of Madden Dam is completed. This approach is justified by the following considerations:

- The costs associated with the risk mitigation measures (if needed) are unknown until the baseline risk assessment has been completed
- The Raise Alhajuela measure is expected to provide modest benefits. It is not expected that the scale of the benefits would significantly impact the alternative plan that is ultimately selected for this project. The Raise Alhajuela measure could be implemented independently of the feasibility study following the completion of the risk assessment and may provide some additional benefits to any selected alternative. The benefit-cost ratio associated with this measure could be used to justify its implementation as an option to the tentatively selected plan associated with this current study.

Due to the unknown additional dam safety and life safety risks, this measure was pre-screened for the Study A, and it is recommended to revisit this measure following the completion of a baseline risk assessment for Madden Dam.

5.6.7 Measure #7: Alhajuela Lake Dredging

The construction of the Madden dam created the Alhajuela reservoir with the main objective of increasing the storage capacity of water to be used in the lockages of the Panama Canal. Since its creation in 1935, the reservoir has been subject to sedimentation processes. This measure considers the benefits to navigation reliability improvements through strategies of dredging and removal of accumulated sediments in the Alhajuela Reservoir.

The ACP has analyzed the effectiveness of dredging the Alhajuela Lake in ACP (2013). This study found dredging the sediments out of the operational pool of Alhajuela could provide an additional 0.07 to 0.11 equivalent transits volume per day. The dredging would include approximately 15.7 million cubic meters of dredging. The project could be executed using 4 cutter-head suction dredges simultaneously over 9 years of operation. Maintenance dredging would require 3 dredges working simultaneously to remove sediment entering the Alhajuela reservoir to maintain the improved navigation reliability. Dredged material disposal is not readily available to the project area; and the project footprint is within Parque Nacional Chagres boundaries; is outside ACP patrimony; and impacts indigenous people's communities.

Due to low benefits, long execution time, and environmental and social concerns, this measure was pre-screened and recommended to not be included in the analysis associated with the feasibility study.

5.6.8 Measure #8: Monte Lirio

The Monte Lirio measure was recommended due to the potential volume of water that could be stored with the construction of a new embankment dam across the Monte Lirio arm of Gatún Lake. The measure was developed with a view toward maximizing the water impounded while minimizing impact to the railroad crossing; the volume of material required for construction of the dam; and the number of saddle dams required to contain the impounded water.

The proposed dam site would be located within Gatún Lake in the general location shown in Figure 5-8 (labeled 8A-AC in this figure). This site would accommodate construction of a dam with a maximum operating lake level at EL 29.6 m PLD (97 ft). Storage would be accommodated above the normal operating levels for Gatún Lake, EL 26.8 m PLD (88 ft), and the normal maximum operation level of the proposed measure, EL 30.5 PLD (100 ft), resulting in 105M m^3 (85K ac-ft) of useable storage.

The location of the major components of the proposed measure are shown in Figure 5-12. The embankment structures within the footprint of Gatún Lake would consist of rock fill dams. There is one main embankment that spans most of the Monte Lirio arm of Gatún Lake (Segment 3). There is a shorter embankment that spans between Isla Zorro and Isla Banana (Segment 2), as well as three other significantly shorter embankments within the lake footprint (Segments 1, 4 and 5). This measure includes a gated spillway to the northwest end of the proposed dam alignment. The spillway would be a gated ogee with 11 radial gates, each 18.3 m (60 ft) wide. This measure does not include a pumping station to pump water between this reservoir and Gatún Lake or a navigation lock (since navigation would be blocked at the existing railroad embankment). No modifications to the existing saddle dams were assumed for this study, and no new saddle dams beyond the new embankment alignment would be required.

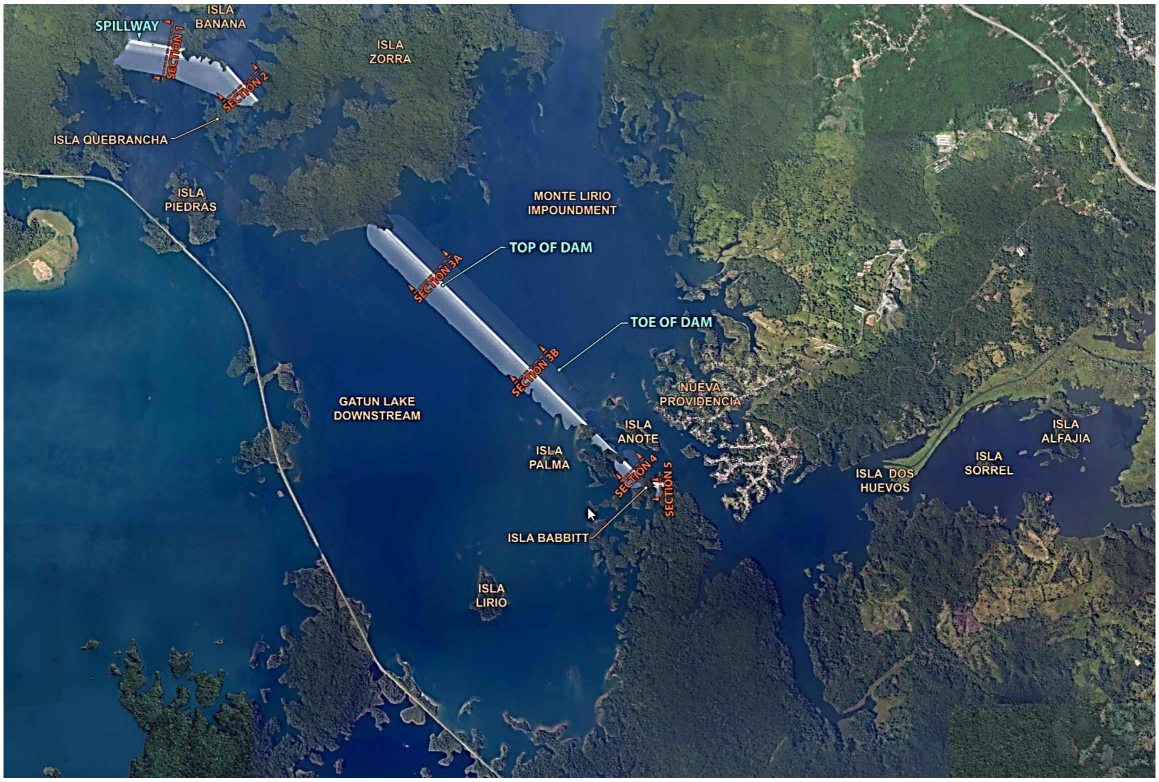


Figure 5-12: Monte Lirio

5.6.9 Measure #9: Bayano Reservoir M&I Offset

This measure considers using Bayano Lake as a source of potable water for eastern and metropolitan regions of Panama. The premise of this project is to provide a source of municipal water, allowing the Federico Guardia Conte Water Intake located in the Alhajuela Reservoir to be decommissioned. This would serve as a direct municipal water supply offset from the ACP basin to reduce overall demands of water on ACP water resources. Decommissioning the Federico Guardia Conte Water Intake would result in a reduced water demand for M&I of approximately 5 ET per day (12 cms).

The Bayano River basin is located 80 km east of Panama City in the Chepo District of the Panama Province. The total length of the Bayano River is 215 km with a predominantly east-west direction and a total drainage area of 4,980 km^2.

The Ascanio Villalaz Dam was constructed in 1976 creating Bayano Lake, the second largest lake in Panama, exceeded in size only by Gatún Lake. The Torti, Cañazas, Diablo, Ipeti, Maje, Aguas Claras, Majecito and Bayano Rivers contribute inflow to Bayano Lake. Bayano Dam is a straight axis concrete gravity dam and hydroelectric power plant with an installed capacity of 260 MW.

The Republic of Panama's Ente Regulador de Los Servicios Publicos (the Regulatory Entity of Public Services) entered a 50-year concession with Empresa de Generación Eléctrica Bayano (Bayano Electricity Generation Company, also known as AES Panama) on December 18, 1998. Clause 3a. Object of the Concession includes safeguarding people and property located in the Bayano Lake Basin; attenuating and controlling river floods; making water available for human consumption, domestic use by riverside populations; and irrigation. This concession authorizes AES Panama to provide public electricity generation service, including operation and maintenance of the Bayano electricity generation plant, connection to transmission networks and transformation equipment to produce and sell in the national electrical system and make international sales of energy.

The measure includes 6 structures to pump water from Bayano Lake and conduction needs to transfer the water for treatment and distribution through the existing IDAAN northern hydraulic ring. The measure evaluated is a combination of measures 2 and 10 from the pre-feasibility report completed by Ingetec Engineering Consultants on October 2020 as part of the Contract No. SAA 434910 with the ACP. The measures evaluated in the pre-feasibility report (Ingetec, Oct 2020) are shown in Figure 5-13. The measure for this evaluation includes a direct water intake from Bayano reservoir with a capacity of 12 cms, as assumed in alternative 2 and a water treatment plant located in La Joya, as assumed in alternative 10. Based on the evaluation by USACE and the reduced flow demand to offset M&I, it is recommended that an intake tower be evaluated for the intake at the reservoir. The cost estimate assumes the lake tap option evaluated by Ingetec although this option is likely more expensive than the recommended intake tower. This assumption was made for the 5% phase an represents only 5% of the total cost of the measure Reference Appendix A, Section 11.9.1. for greater detail. As in alternative 2 in the Ingetec study, there are no water transfers into the Panama Canal reservoir of Alhajuela Lake. No hydrologic engineering analysis was conducted by USACE pertaining to Bayano Reservoir or the Bayano River watershed at this phase of the study.

The following structures are included in the measure evaluated herein. Information on each feature has been compiled from the Bayano Pre-Feasibility (Ingetec, Oct 2020) and the Feasibility (Ingetec, Aug 2020) Reports as appropriate. The total length of water transfer is estimated to be approximately 66.2 km. The required features for this project include the following:

1. Raw water intake located at the Bayano Reservoir upstream of the Ascancio Villalaz Dam

2. Bayano Storage Tank
3. Water conduction route
4. La Joya Pump Station and Storage tank
5. La Joya Water Treatment Plant
6. Connection to the IDAAN northern hydraulic ring

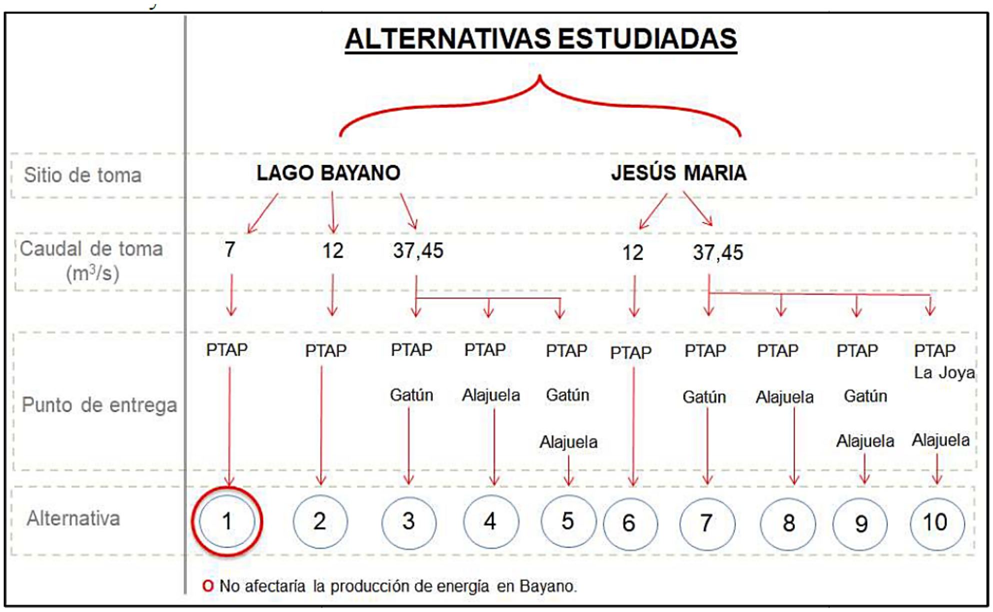


Figure 5-13: Bayano Alternatives, Pre-Feasibility Report (Ingetec, Oct 2020)

The conduction route is assumed based on the information provided in the Pre-Feasibility Report (Ingetec, Oct 2020) starting from the Bayano reservoir, transferring water to the La Joya Treatment Plant and connecting to the IDAAN northern distribution ring. The assumed route is a combination of Alternative 2 and 10 from the Ingetec Pre-Feasibility Report. All measure pipelines and structures are shown in Figure 5-14 and Figure 5-15 and the general location of La Joya Water Treatment Plant and Connection to IDAAN Northern Hydraulic Ring is shown in Figure 5-16. The cost estimate does not include the expansion to the IDAAN hydraulic network that was determined to be needed by Ingetec (Oct 2020).

The USACE recommends further evaluation of the intake type for this measure. Ingetec (2020) recommended an intake downstream of the dam due to required flow and the difficulties of a reservoir intake through a lake tap. Based on the required M&I offsets assumed at this time, an intake structure within the lake, similar to Chilíbre, would be feasible and could be more cost effective. Although this is reported in Appendix A, and assumed for the alignment of the measure, no engineering analysis has been performed to date to confirm and recommend this as a final solution. The Jesus y Maria intake downstream of the dam proposed by Ingetec (2020) may be analyzed in Study B (including a cost estimate), unless this measure is screened from future analysis in the Planning Charrette scheduled for June 2023.

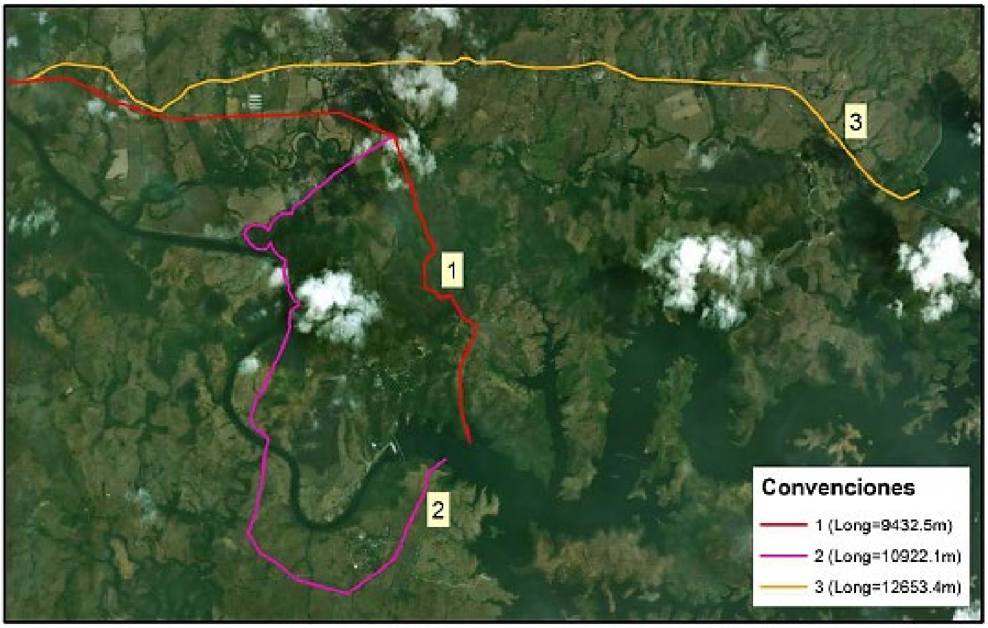


Figure 5-14: Locations of Bayano Raw Water Intake Locations (Ingetec, Oct 2020)

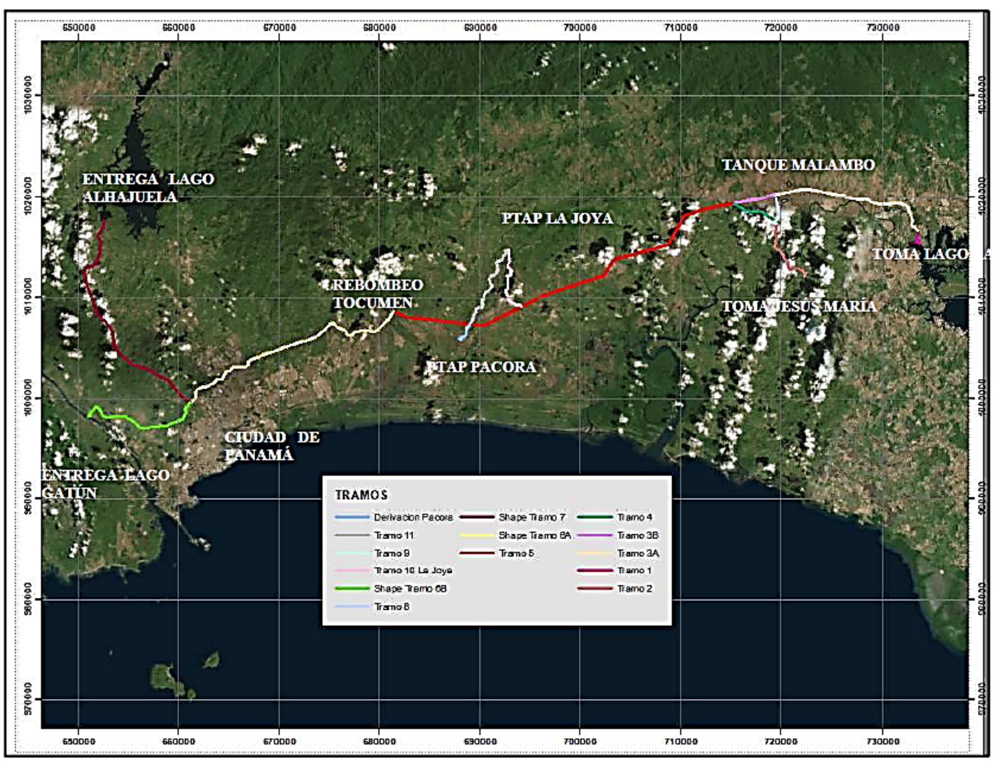


Figure 5-15: Bayano Pipeline Route (Ingetec, Oct 2020)

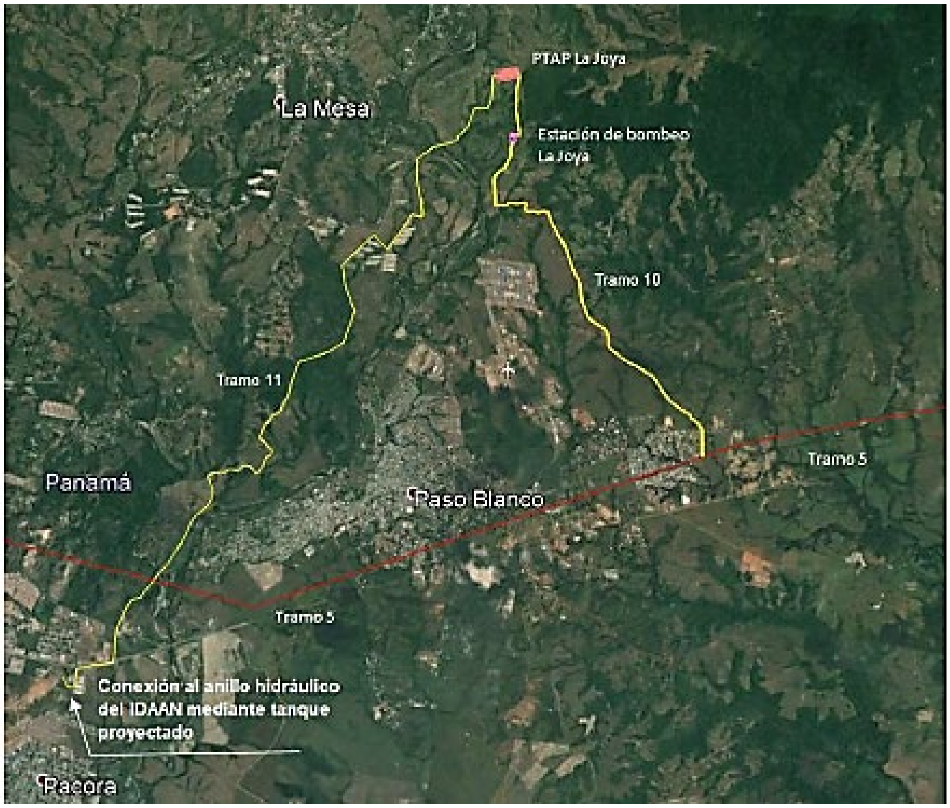


Figure 5-16: La Joya Water Treatment Plant and Connection to IDAAN Northern Hydraulic Ring (Ingetec, Oct 2020)

5.6.10 Measure #10: Desalinization Plant

Three proposed scenarios for desalination were developed on the behalf of the ACP. These include:

1. Pump and treat ocean water to Gatún Lake. This would include pumping 1 million (M) m^3d^{-1} of saltwater 4 km to a 27.1 m above sea level. The initial saltwater would be 30 psu, with the goal of 0.2 psu or lower post-processing after 1 day of treatment).
2. Treating the saline water in the ACP Water Savings Basins. This would include treating 200,000 m^3 in a batch process for a duration of 1 hour (hr), and this would occur 12 treatments d^{-1}. The water would be returned to the water savings basin (no head difference). Practical salinity units are initially 5 psu in this scenario with the goal to achieve 0.2 psu values.
3. Treating brackish water (1.0 psu) at a water intake. The water intake pumps 50 million gallons per day (190,000 m^3d^{-1}). Goal is to achieve psu values below 0.3 psu.

Table 5-7: Desalination Scenarios

Scenario	Description	Discharge (M m^3d^{-1})	Head (m)	Initial psu	Goal psu
A	Treat ocean water and pump to Gatún Lake	1	27.1	30	0.2
B	Treat water savings basin water and return	2.4	0	5	0.2
C	Treat water at the M&I Intakes	0.19	0	1	0.3

It is technically possible to implement desalination, but it has been recommended for pre-screening due to high costs and the overall availability of freshwater resources in Panama. In addition, this measure was found to be impractical compared to other options based on cost and abundance of freshwater sources according to ACP Stantec (2018) study. This measure will be considered in a future phase if all other measures are proven to provide insufficient reliability. This topic is also discussed in Attachment 2, Review of Three Desalinization Scenarios.

5.6.11 Measure #11: Drought Contingency Planning

Measure 11, Drought Contingency Planning, attempts to prevent a complete shut-down of Panama Canal navigation, including during the most extreme drought on record. This scenario was considered by assigning various minimum navigation demands and developing navigation rules as a function of water levels, limiting navigation demands gradually as the Gatún Lake level continues to fall. This measure does not result in an improvement in overall transit reliability but avoids stopping navigation when water supplies are low.

5.6.12 Measure #12: Crossfilling of Gatún Locks

Measure 12, Crossfilling of Gatún Locks is an alternative in Panamax lock operation that changes the base assumptions about how often the water savings basins are utilized and when crossfilling in the Panamax locks occurs. This is shown in Figure 5-17.

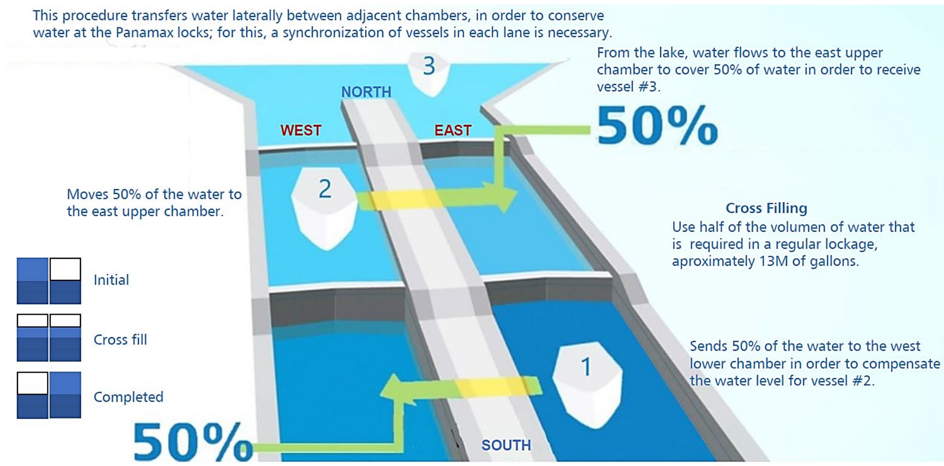


Figure 5-17: Crossfilling Procedure (ACP, 2021b)

ACP uses crossfilling in times of water scarcity. Crossfilling is a complex, situational operation affected by water availability, Gatún Lake salinity, transit throughput, queue lines, ship combinations, maintenance operations, etc. The ACP and USACE are jointly defining and documenting the crossfilling procedure.

This measure provides benefits to navigation reliability. Crossfilling will be considered as a non-structural measure when determining future navigation reliability. The process will be included in the next analysis phase and may be included in alternative plans.

This measure will be considered for inclusion in all alternative plans in the feasibility study. There is insufficient data to accurately assess the frequency that this measure can be implemented due to its relationship to navigation scheduling and impacts to salinity values in the Gatún Lake. The Cross Filling procedure will be further investigated in the next phase of the study.

5.6.13 Measure #13: Reduced M&I Demands (Sensitivity Analysis)

Measure 13, Reduction in Future M&I Demands, assumes that demands under future conditions will be reduced by 5% (Measure 13A) or 10% (Measure 13B). The exact method of reducing M&I demands is not specified; analysis of this measure focuses on how reliability responds to reductions in M&I withdrawals.

5.6.14 Measure #14: Lower Alhajuela Lake Operational Pool

Alhajuela Lake, via the Federico Conte water intake for the Chilíbre Water Treatment Plant, accounts for approximately 66% of the M&I water extractions in the Panama Canal watershed.

Chilíbre Water Treatment Plant's Federico Conte water intake extends approximately 600 m (2,000 ft) from the left abutment of Madden Dam Spillway along the southern bank of the reservoir and into Alhajuela Lake, as shown in Figure 5-18. The original design of the intake was to provide the full capacity of water withdrawals (270 MGD) with the reservoir as low as EL 57.92 m (190 ft) PLD, see Figure 5-19. Due to current operating conditions, including corrosion and cavitation damage, intake is restricted to a minimum elevation of EL 52.48 m (205 ft) PLD.

This measure would restore capacity across the full, original operating range by replacing all 6 pumps, adding check, butterfly, and air valves for each pump, adding a monitoring system for flow and vibrations, and a SCADA system for remote monitoring. If this measure is considered in the future, floating intakes may be considered.

Figure 5-18: Federico Conte Water Intake, Chilíbre Water Treatment Plant

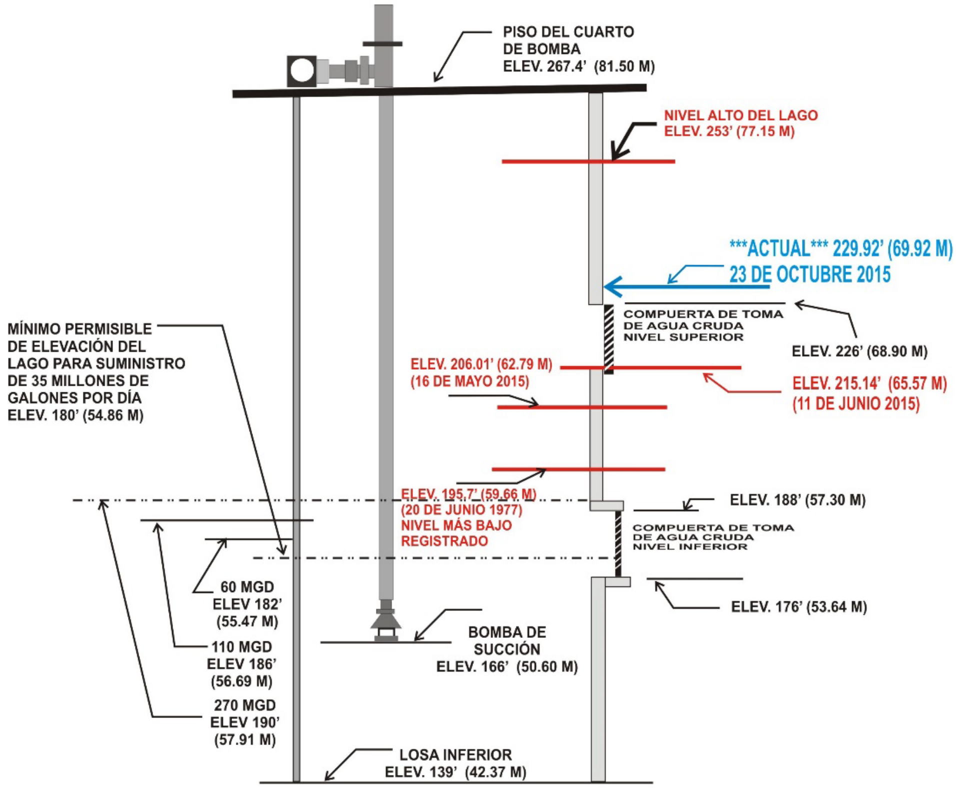


Figure 5-19: Federico Conte Water Intake, Chilíbre Treatment Plant

5.6.15 Measure #15: Lower Gatún Lake Operational Level and Municipal and Industrial Water Intakes

Lower Municipal Water Intakes in Gatún Lake proposes a new minimum operational level for the Gatún Reservoir. Presently, the reservoir is operated between 22.86 and 26.82 m PLD (75.0 and 88.0 ft). With this measure, the minimum operational level would be lowered to 21.34 m PLD (70.0 ft PLD), resulting in a new operational range of 21.43–26.82 m PLD (70.0–88.0 ft-PLD). Operating Gatún Lake to 21.34 m (70.0 ft) will activate an additional storage volume of 526.4 hm^3 (426,764 ac-ft).

A key infrastructure modification required to support this measure is lowering of M&I intakes within Gatún Lake. Modifications for all intakes within Gatún Lake were considered necessary for this measure at the 5% design level. The locations of the intakes were previously shown in Figure 3-3. Measure 15 is included in the base measures' set.

5.7 Study A Measures Descriptions (Outside Basin and ACP Authority)

Outside authority measures did not undergo 5% design. Analysis of the measures was limited to a general assessment of benefits for comparison to Study A measures.

5.7.1 Measure #16: Rio Indio

The Rio Indio Reservoir and Inter-Basin Transfer measure leverages design information from Ingetec (August 2020 and October 2020). The Ingetec reports explore water supply extraction from Rio Indio. Specifics developed for the Ingetec reports, such as volumes, general project components, etc. to inform the preliminary analysis of Measure 16. Measure #16 considers creating a dam and reservoir in the Rio Indio Basin, west of the Panama Canal watershed on Rio Indio, approximately 75 km northwest of Panama City. Storage on Rio Indio provides additional water to the Panama Canal Basin through releases to the Gatún Reservoir. Under normal operations, water passes from the Rio Indio Reservoir to Gatún Lake through a diversion tunnel, where releases vary with Gatún Lake elevations. The Rio Indio Reservoir is operated between minimum and maximum pool elevations of 40.0 and 80.0 m PLD (131.2 and 262.6 ft), respectively.

The Rio Indio watershed is located west of the Panama Canal watershed and includes the significant tributaries of Rio Indio, Rio Teria, Rio Uracillo, and Rio El Torito. The proposed dam site is at a location approximately 25 km (15.5 miles) above the mouth of the River at the Caribbean Sea. The main hydraulic features of the measure are a free-overflow (fixed crest) spillway and diversion tunnel.

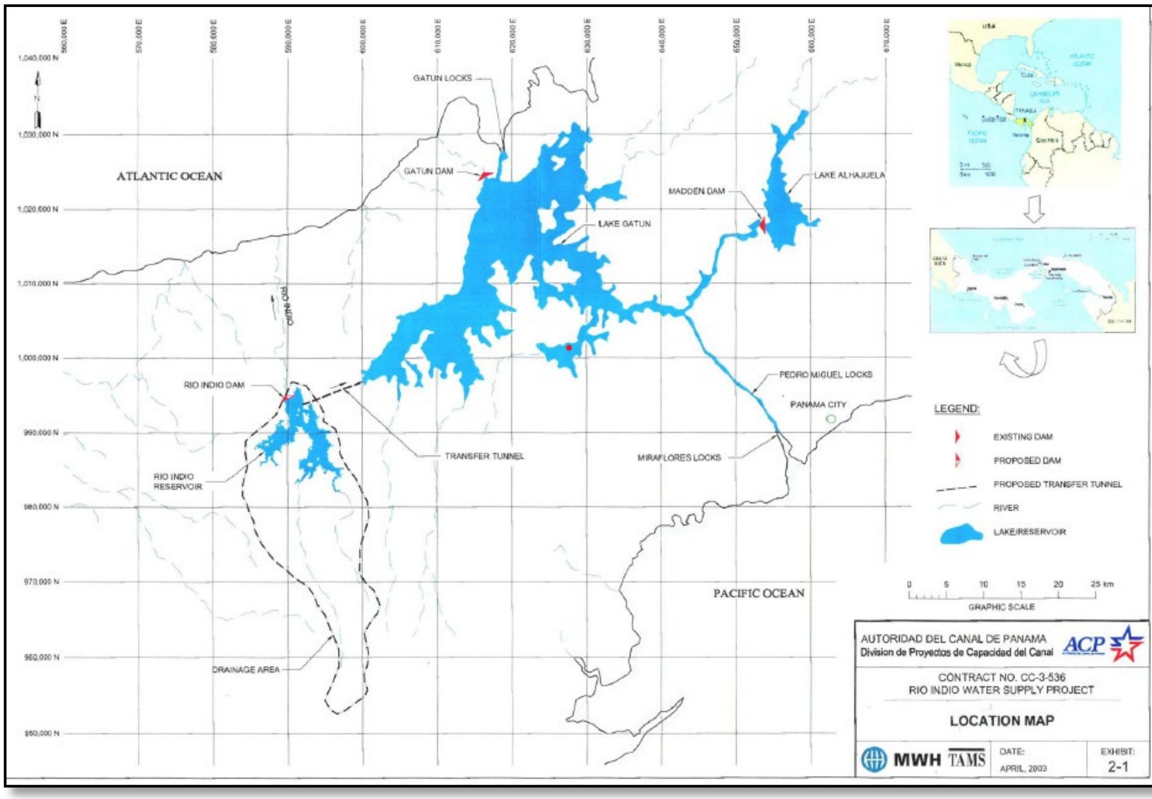


Figure 5-20: Rio Indio

5.7.2 Measure #17: Caribbean Diversions

The Caribbean Diversions measure includes features in watersheds west of the Panama Canal on Rio Indio, Rio Miguel de la Borda, and Rio Cocle del Norte that pump water across basin divides and into Gatún Lake. This measure includes component parts that have been described in past studies, but the measure analyzed herein is new, and therefore, design assumptions are highly conceptual. This measure is being analyzed for reliability and benefits only and not for design; only conceptual design assumptions required for the navigation reliability model were developed.

The Caribbean Diversions measure considers creating an approximately 25 m (82.0 ft) tall dam on Rio Cocle del Norte and low head run-of-river weirs on Miguel de la Borda and Rio Indio with the primary purpose of providing water for trans-basin pumping to Gatún Lake. The locations of the measure features are shown in Figure 5-21. Each measure feature prioritizes passing of environmental flows downstream with additional streamflow (or stored water if applicable) available to pump up to a maximum pump rate. Two sets of maximum pump rates were considered, of which the higher rates were assumed for full reporting. Dam details, pump configurations, piping, and other design components not required for a reliability model were not developed.

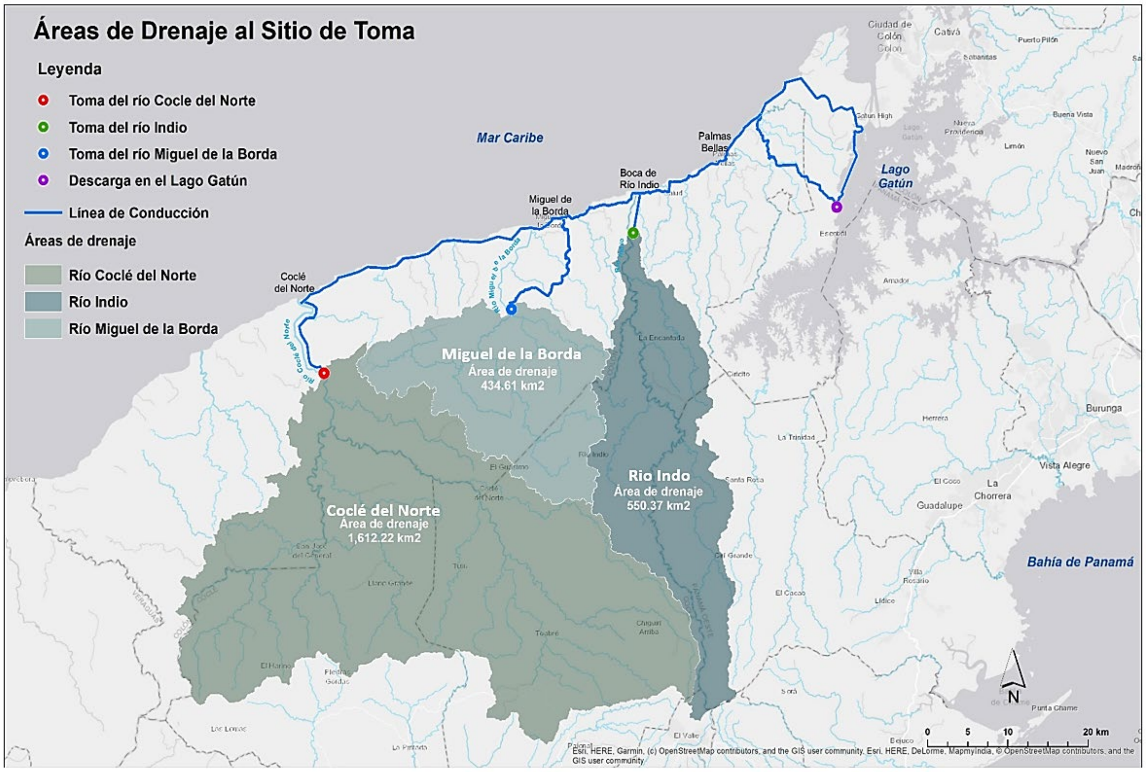


Figure 5-21: Caribbean Diversion

5.7.3 Measure #18: Upper Chagres

The Upper Rio Chagres Reservoir (also referred to as Alto Chagres) measure proposes the construction of a dam and reservoir in the Alhajuela Basin on the upper reach of the Rio Chagres, upstream of Alhajuela Reservoir. Storage on the Upper Rio Chagres reservoir provides additional water to the Panama Canal Basin through releases to the Alhajuela Reservoir. Under normal operations, water would pass from the Upper Rio Chagres Reservoir to Alhajuela Reservoir through a gated spillway and low-level outlet via a hydropower facility, where releases vary with Upper Rio Chagres Reservoir elevations and inflows. The Upper Rio Chagres Reservoir is operated between minimum pool elevation of 156.1 m PLD (512.2 ft) and maximum pool elevations of 213.0 m PLD (698.7 ft).

The Rio Chagres Basin is in the eastern portion of the Panama Canal watershed. The proposed damsite location provided by the ACP includes drainage from the significant tributary of Rio Las Palmas, and is approximately 3.0 km upstream of Alhajuela Lake, 15.5 km upstream of Madden Dam, and approximately 31 km north of Panama City.

Previous alignments of this measure analyzed by USACE (1999), and MWH (2003) are slightly upstream of the proposed location, at 9.0 km and 7.5 km, respectively. Figure 5-22 displays the current and past locations of the proposed dam. The main hydraulic features of the measure are a gated spillway and a hydropower facility.

Figure 5-22: Current (ACP 2022) and Past Locations of the Upper Chagres Dam Measure

5.8 Reliability Benefits of Measures (Future With Project)

As previously noted, three levels of reliability metrics were developed for this study. These reliability levels included 1) Leadership metrics; 2) Operational metrics; and 3) Technical metrics (see Section 4.6 for a description of these metrics).

A comparison of the modeling results associated with these three metrics categories are described in the following sections. Only a single representative version of each measure using the design assumptions are analyzed for comparison purposes. The Salinity Study results, M&I water cap, Salinity Study plus M&I water caps, and the outside authority measures are also included in these comparisons. A summary of the key reliability metric results is shown in Table 5-8 for each measure.

The types of metrics shown in Table 5-8 are intended for two purposes. First, metrics can be applied within the Multi-Criteria Decision Analysis that will be performed on the array of alternatives in the next phase of the analysis. The identification of key metrics to be used in the MCDA has initially been completed by the PDT and is described in Section 8.2.1. The initial MCDA metrics that have been prioritized include the Transit Reliability; the 48’ Draft Reliability; and the 44’ Draft System Firm Yield. Metrics will be revisited in the next phase of the analysis to confirm their use in the MCDA and weights assigned.

Second, navigation reliability metrics can be used as direct inputs into an economic model to assess how much additional economic benefits a project provides when it is compared to a future without project conditions. The economic modeling and how the reliability metrics are used to assess benefits of a specific measure is described in Section 5.10 of this report and in Appendix D, Economics.

Table 5-8: Reliability Metrics for Each Modeled Scenario

	Years in PoR with Draft Restrictions (below 81 ft PLD)	Mean Number of Restricted Days in Draft Restricted Years	Neopanamax 50' Draft Reliability	Neopanamax 48' Draft Reliability	Neopanamax 46' Draft Reliability	Neopanamax 44' Draft Reliability	Panamax 39.5' Draft Reliability	Transit Reliability	44' Draft System Firm Yield
Existing Conditions	19	105.1	52.5%	78.9%	90.4%	96.0%	96.2%	98.7%	36.8
Future Without Project	54	146.0	23.4%	43.8%	62.2%	92.1%	93.6%	86.1%	35.7
Salinity Study	42	114.2	37.4%	59.6%	77.0%	96.3%	96.8%	93.0%	35.7
Water Cap	51	147.4	26.2%	46.8%	64.0%	82.4%	84.9%	92.0%	35.7
Salinity Study + Water Cap	32	113.4	42.6%	65.9%	82.6%	92.6%	93.9%	96.4%	35.7
1 Trinidad (No Pumping)	49	144.1	23.5%	53.0%	66.2%	92.6%	93.8%	86.5%	39.4
2 Trinidad (Pumping)	43	144.1	22.7%	58.1%	70.3%	93.5%	94.4%	88.5%	42.0
3 Cano Quebrado (Pumping)	52	144.6	23.4%	46.4%	64.0%	92.3%	93.6%	86.7%	36.6
4 Raise Gatun (91')	46	150.9	29.2%	49.8%	66.8%	92.7%	93.9%	87.8%	39.7
5 Dredging (25' PLD)	34	98.5	17.7%	32.6%	84.0%	95.2%	63.0%	95.3%	40.5
6 Raise Alhajuela (260')	52	143.8	22.8%	44.5%	64.2%	92.6%	93.9%	87.0%	36.9
8 Monte Lirio (No Pumping)	52	148.7	22.4%	45.7%	63.0%	91.1%	92.5%	87.2%	36.5
9 Bayano	49	150.0	24.4%	44.4%	64.8%	84.8%	86.9%	94.0%	36.7
10 Desalination	34	104.3	43.8%	66.4%	83.0%	96.8%	97.3%	95.4%	35.7
11 Drought Contingency	54	140.5	24.5%	45.0%	63.7%	89.9%	91.2%	83.5%	35.7
13 Reduced M&I Demands (10%)	52	151.6	24.0%	44.5%	62.3%	88.4%	92.3%	89.0%	35.7
14 Lower Alhajuela Intake (190')	52	148.7	22.8%	43.2%	63.0%	92.5%	93.9%	86.9%	36.7
15 Lower Gatun Intakes (70')	54	202.4	17.7%	32.6%	47.7%	61.7%	63.0%	95.3%	35.7
16 Rio Indio	38	110.1	36.3%	61.1%	80.0%	92.4%	93.5%	96.1%	46.2
17 Caribbean Diversions (47cms)	29	98.6	46.2%	72.1%	86.3%	95.2%	95.7%	98.6%	47.1
18 Upper Chagres	48	147.7	18.3%	44.2%	66.1%	92.9%	93.9%	91.0%	45.5

Most Acceptable — Least Acceptable

5.8.1 *Level 1: Years in Period of Record with Draft Restrictions*

Level 1 reliability metrics are based on the number of years when draft restrictions less than 14.02 m (46.0 ft) would occur out of the 57-year simulation. For the existing conditions simulation, these drafts occur approximately 1 out of every 3 years (19 of 57 years). For the future without project conditions simulation, these restrictions occur 54 out of every 57 years.

Measures that reduce the number of years when draft restrictions below 14.02 m would occur are Dredging and the Salinity Study with a M&I water withdrawal cap. These results are shown in Figure 5-23.

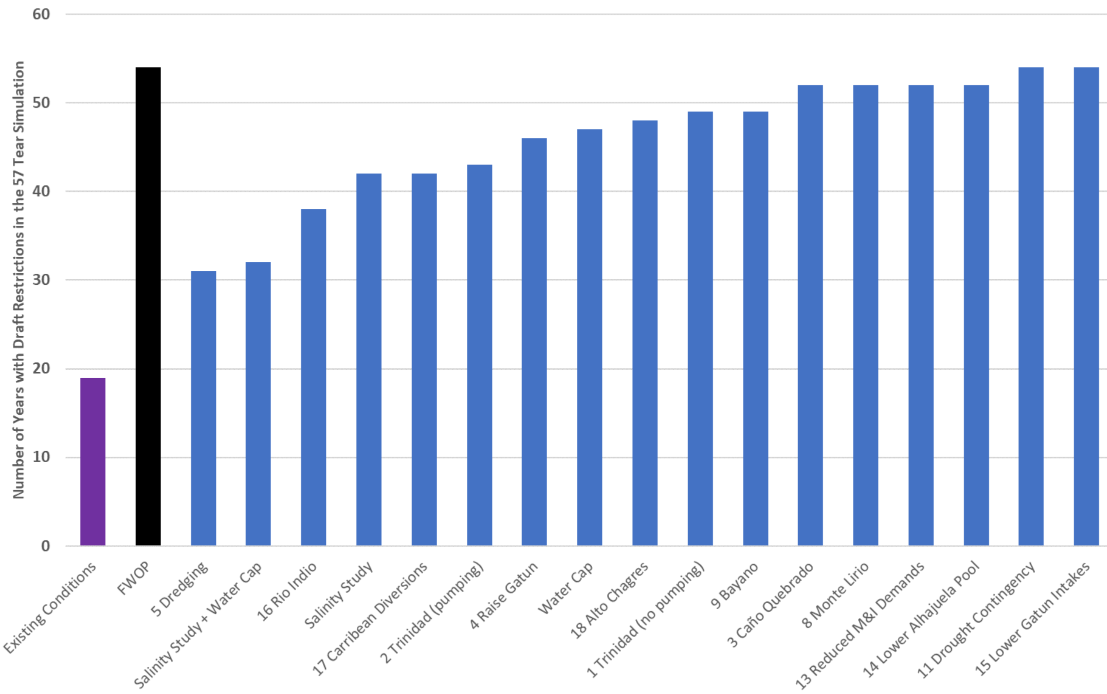


Figure 5-23: Number of Years in the PoR with Draft Restrictions below 46'

5.8.2 *Level 2: Number of Restricted Days in Draft Restricted Years*

Level 2 reliability metrics include the average number of days where drafts are below 14.02 m (46.0 ft) in years when draft restrictions occur. These results are shown in Figure 5-24. The measures that provide the greatest benefits in Study A are Dredging and the Salinity Study combined with a M&I water withdrawal cap.

Results of the Level 1 and Level 2 metrics must also be viewed simultaneously because they are related (as shown in Figure 5-25). For example, a larger Level 1 metric could result in a smaller Level 2 metric, because the total number of years in restriction could increase, thereby decreasing the average number of days in restriction in those years. The Study A measure that most closely achieves conditions like the existing conditions is Dredging.

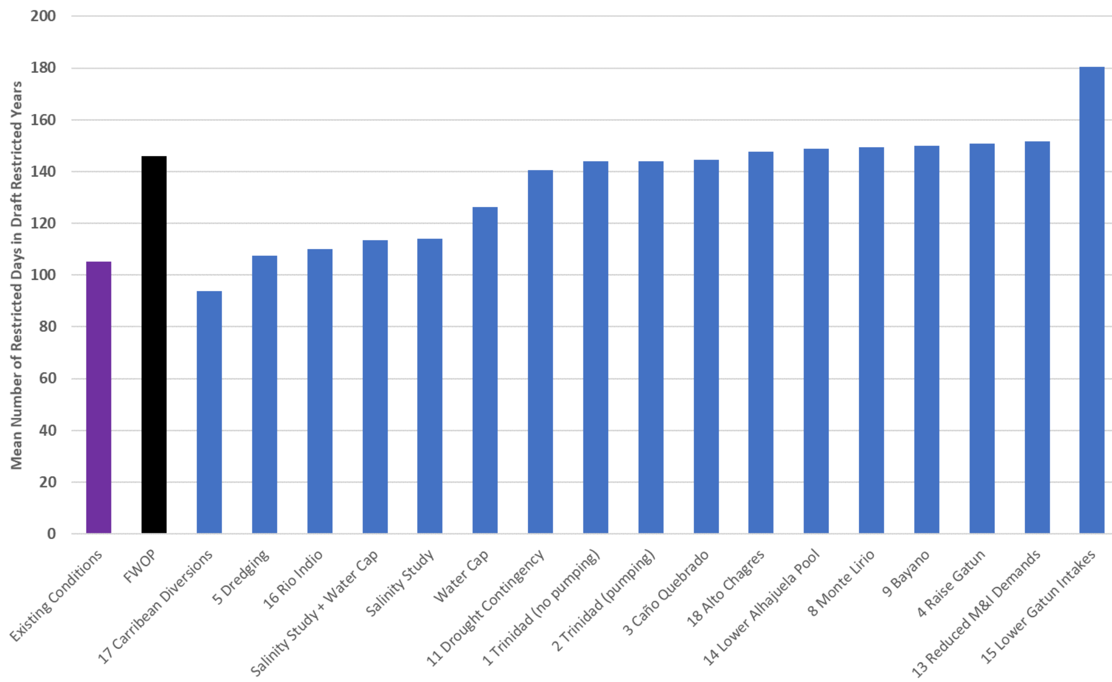


Figure 5-24: Mean Number of Days with Draft Restrictions below 46' for Years with Draft Restrictions

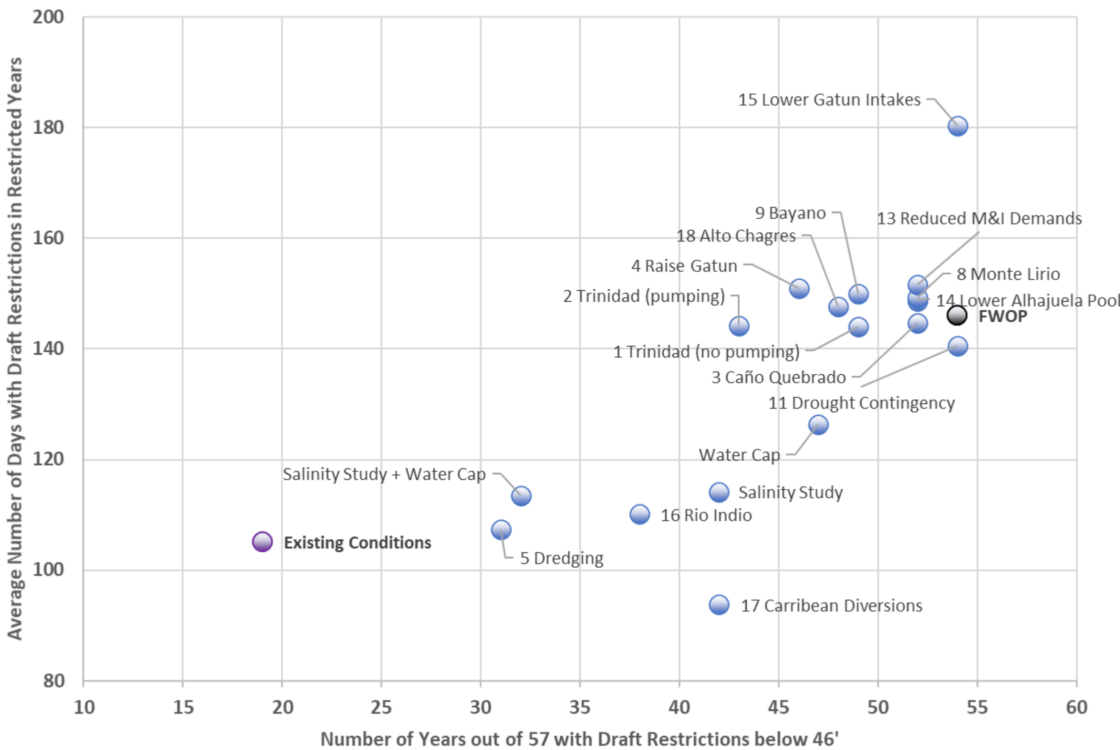


Figure 5-25: Level 1 and Level 2 Reliability Metrics showing the Number of Years of with Drafts below 46' and the Average Number of Days for those Years

5.8.3 Level 3: Neopanamax Draft Reliabilities

Four separate Neopanamax drafts for each measure were analyzed for draft reliabilities. These included:

- 15.24 m (50 ft) – see Figure 5-26
- 14.63 m (48 ft) – see Figure 5-27
- 14.02 m (46 ft) – see Figure 5-28
- 13.41 m (44 ft) – see Figure 5-29

Similar benefits patterns are shown for the array of measures analyzed across each draft. The measures within ACP authority that generally provided the most significant increases in draft reliability over the future without project conditions included the Salinity Study, a M&I water withdrawal cap, and combination of these measures. Dredging provides some of the highest benefits for 14.02 m (46 ft) and 13.41 m (44 ft) drafts.

Measures that include the lowering of intakes, lower demand, or significant changes in storage allocation can result in lower pool elevation exceedance values than the FWOP.

For example, lowering Gatun intakes (or dredging which includes lowering intakes) allows the Gatun pool elevation to lower before navigation is cut-off. That pulls down pool exceedance values throughout the period of record, because Gatun is drawn lower during drought periods and doesn't refill as much during subsequent years. Additionally, measures that decrease demands can have a similar effect by reducing the storage required to guarantee M&I demands, which then allows the pool to go lower and transits to continue for longer periods.

Several model improvements to be incorporated in the next phase of the study will diminish this effect to some extent, such as using a more sophisticated method to ensure M&I supply, rather than a fixed cut-off elevation.

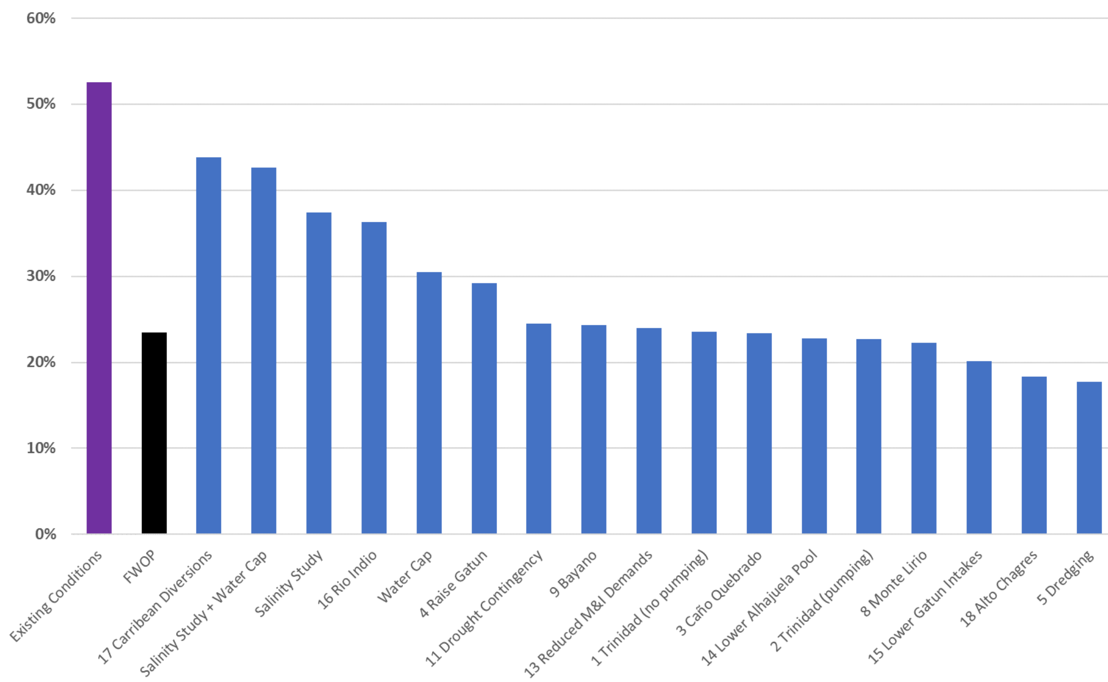


Figure 5-26: Percent Exceedance for 50’ Neopanamax Drafts

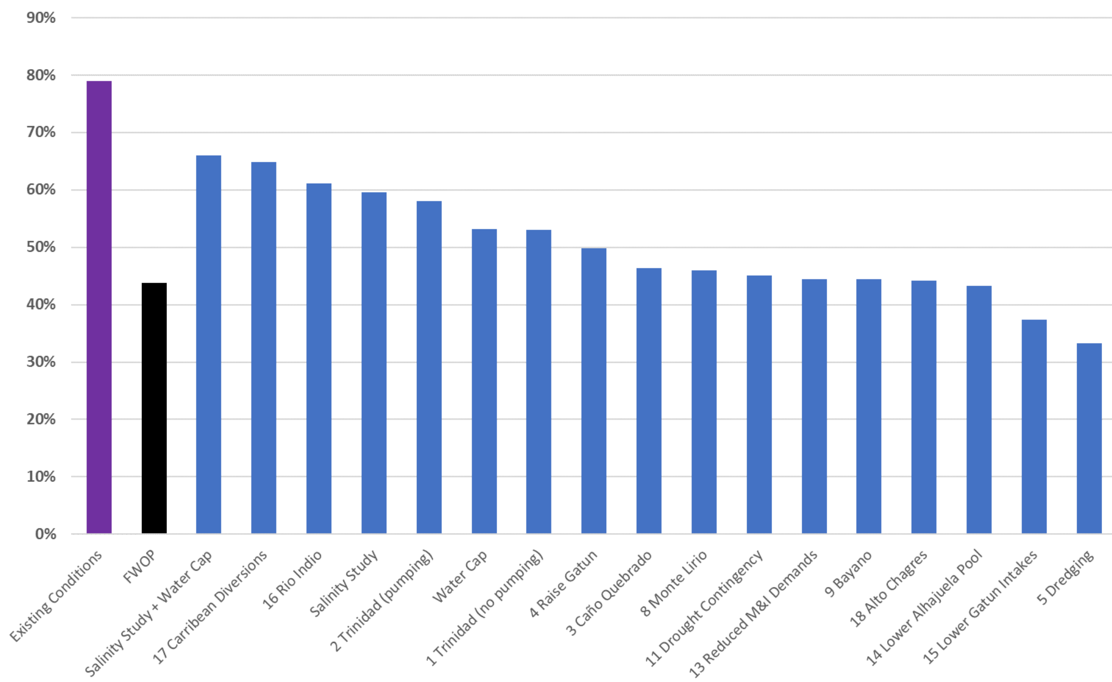


Figure 5-27: Percent Exceedance for 48' Neopanamax Drafts

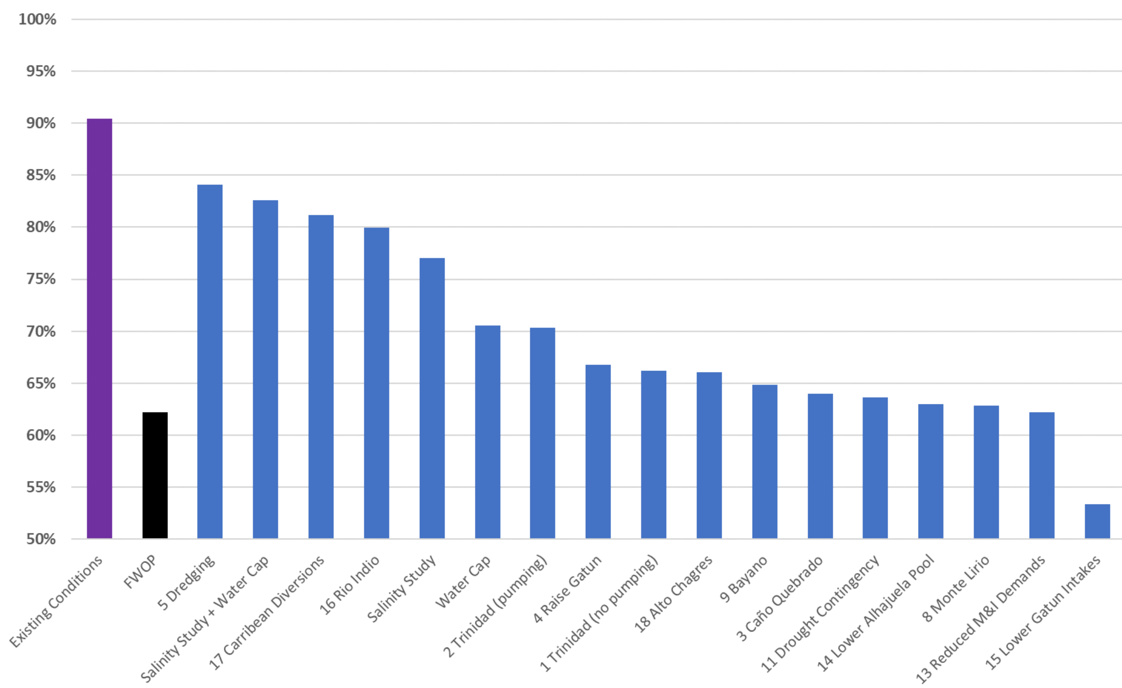


Figure 5-28: Percent Exceedance for 46' Neopanamax Drafts

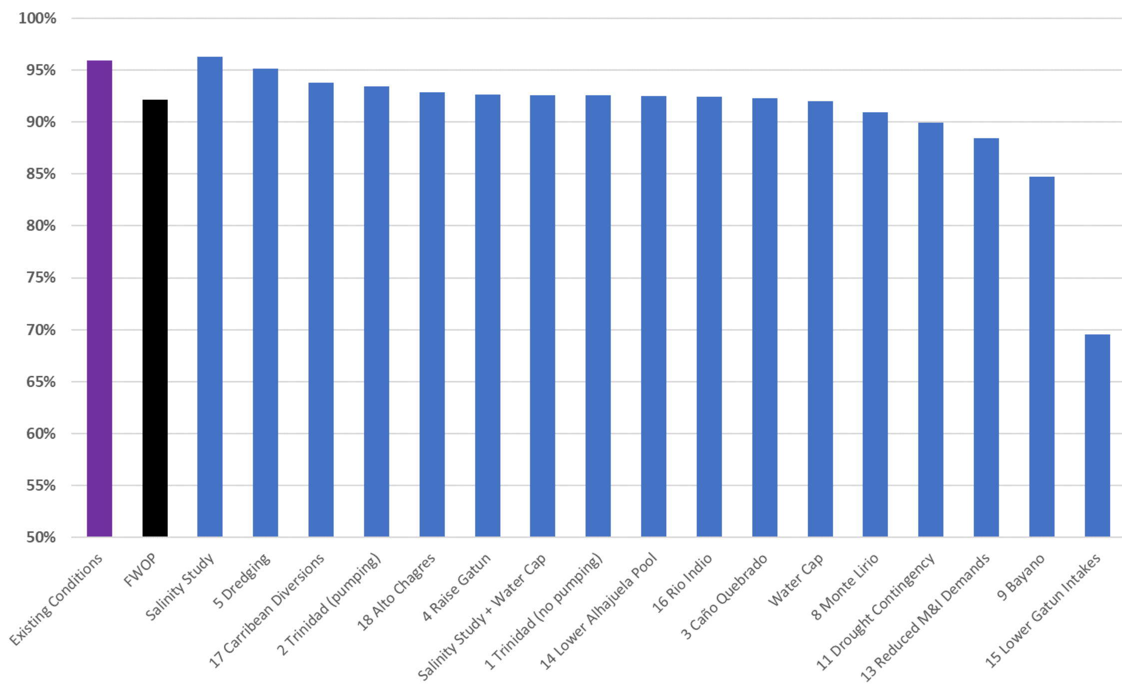


Figure 5-29: Percent Exceedance for 44' Neopanamax Drafts

5.8.4 Level 3: Panamax Draft Reliability

Panamax draft reliabilities for 12.04 m (39.5 ft) draft were analyzed for Level 3 metrics. The Salinity Study and Trinidad with pumping provide the greatest improvements to Panamax draft reliabilities when compared to the future without project conditions (see Figure 5-30).

5.8.5 Level 3: Neopanamax and Panamax Transit Reliability

Transit reliability was compared for each measure and against the future without project conditions. Within the ACP authority, the measures that provide the greatest improvement to transit reliabilities include the Salinity Study, Dredging, and Bayano M&I Water Withdrawal Offsets. Transit Reliability has been identified as one of the most significant metrics for maintaining sustainable navigation of the Panama Canal. Results of this analysis are significantly correlated with economic benefits associated with this study. The transit reliability of a given measure is directly impacted by the need to guarantee M&I water supply storage because no transits occur below the level corresponding to the top of the M&I-only storage (Figure 5-31).

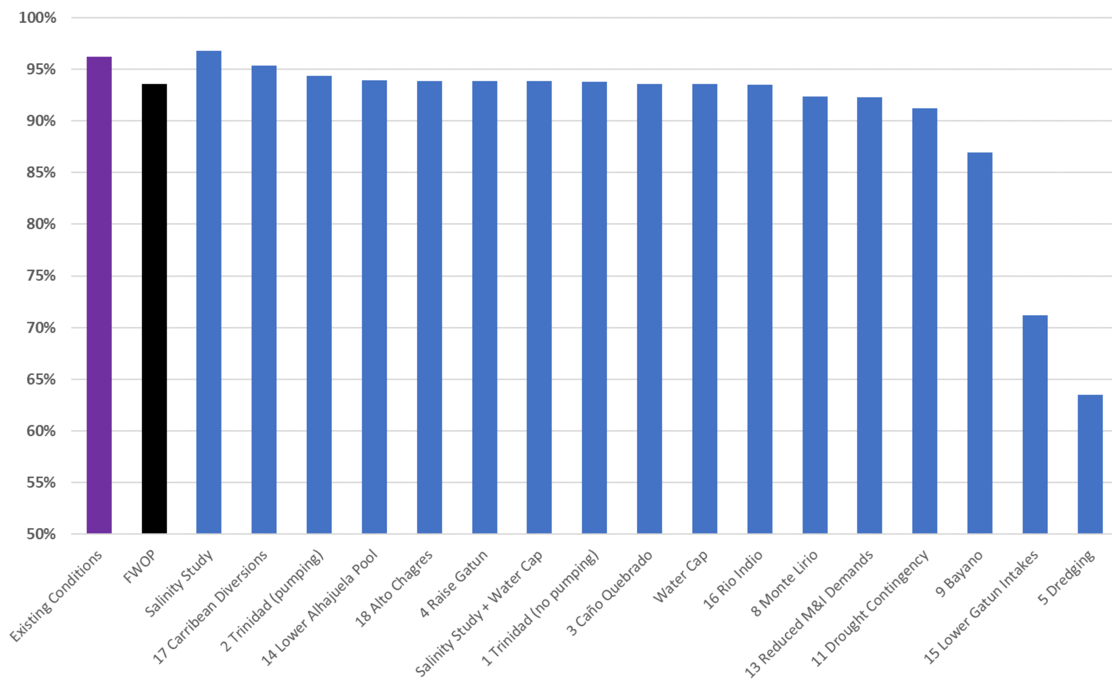


Figure 5-30: Percent Exceedance for 39.5' Panamax Drafts

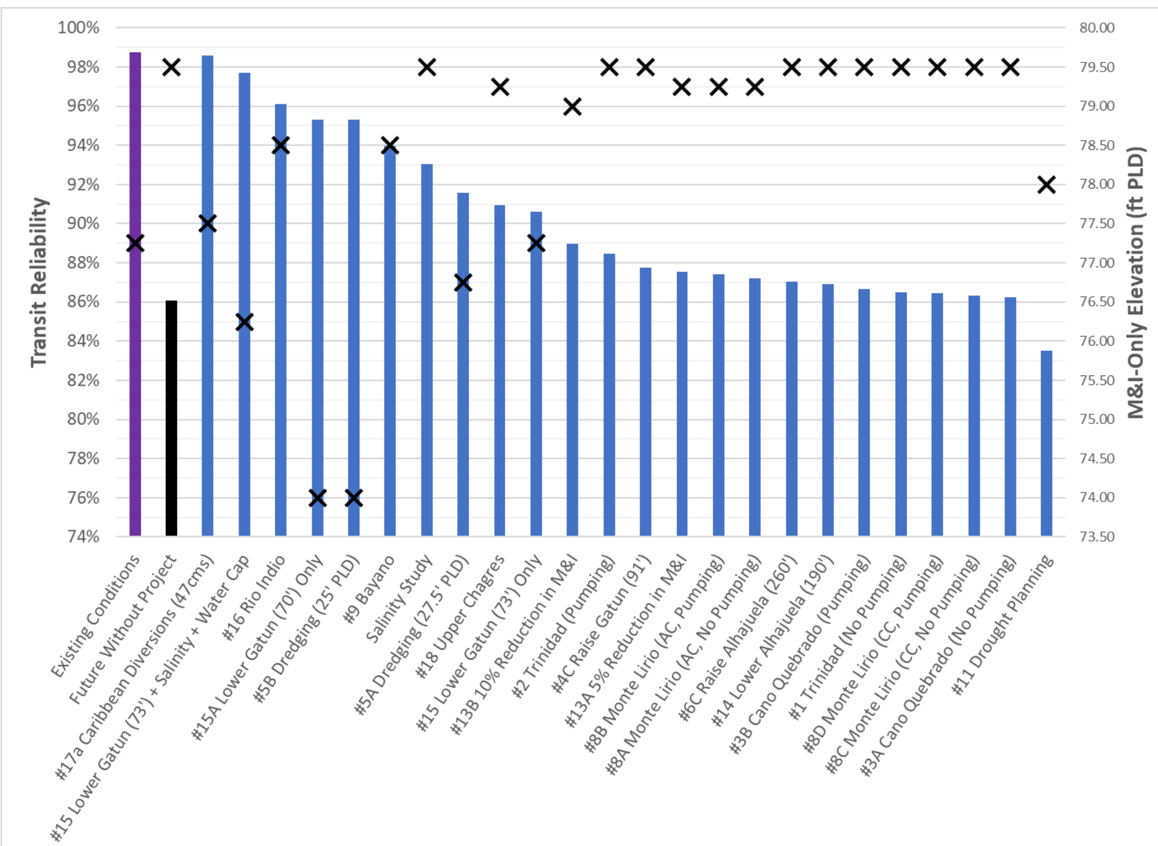


Figure 5-31: Neopanamax and Panamax Transit Reliability with M&I-only Elevations.

5.8.6 Level 3: 44' Draft System Firm Yield

System firm yield is the final metric analyzed in the Level 3 reliability metrics. Firm yield equals the maximum constant discharge that ensures minimum navigation drafts of 13.41 m (44 ft) are maintained throughout the period of record, which in practice is determined by the critical drought period (1997 to 1998). Measures within the ACP authority that maximize firm yield are Trinidad and Dredging (see Figure 5-32). Additional details about the system firm yield computation and results are included in Appendix B Water Management Modeling.

This metric does not credit measures that reduce future demands; measures that only reduce demands have the same firm yield as the future without project condition. The firm yield metric focuses on demands the system could withstand in the future and ensures navigation drafts will not drop below 13.41 m (based on the period of record analysis).

The average demands in the future conditions are significantly higher than the firm yields shown for each measure. The future without project conditions demands are approximately 64 ETs per day. This demonstrates no single measure provides sustained navigation of 13.41 m (44 ft) draft unless the measure includes reductions in future demands. The comparison of the firm yield to maintain 13.41 m (44 ft) draft and the average daily demand associated with each measure is shown in Figure 5-33.

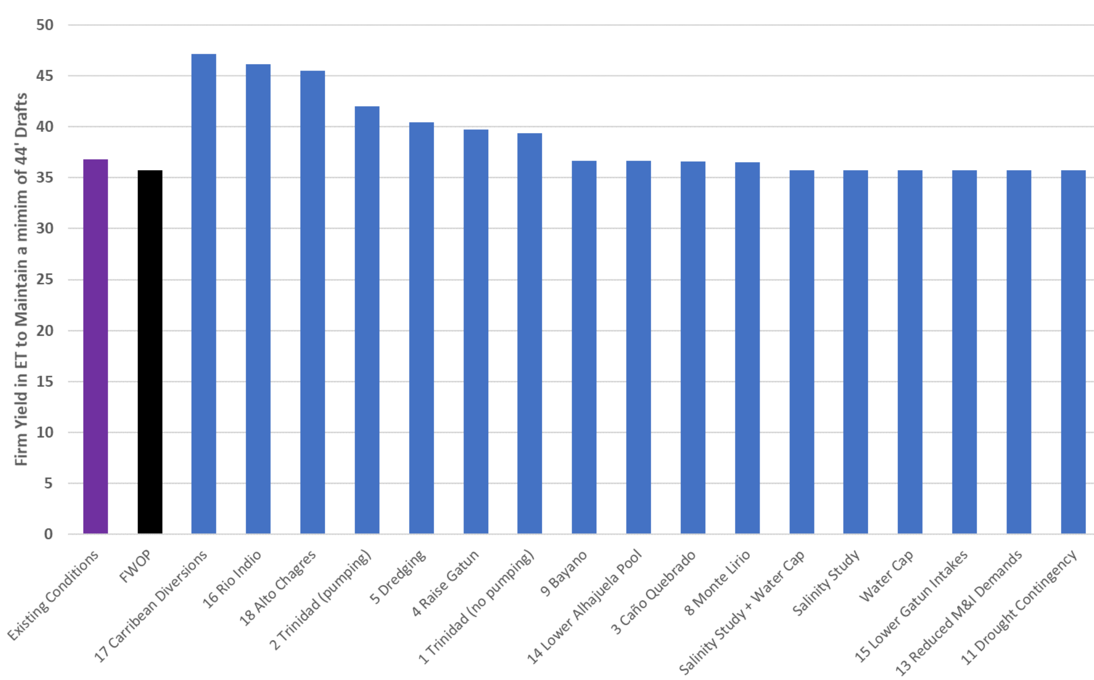


Figure 5-32: Firm Yield in ET Associated with a 44' Draft

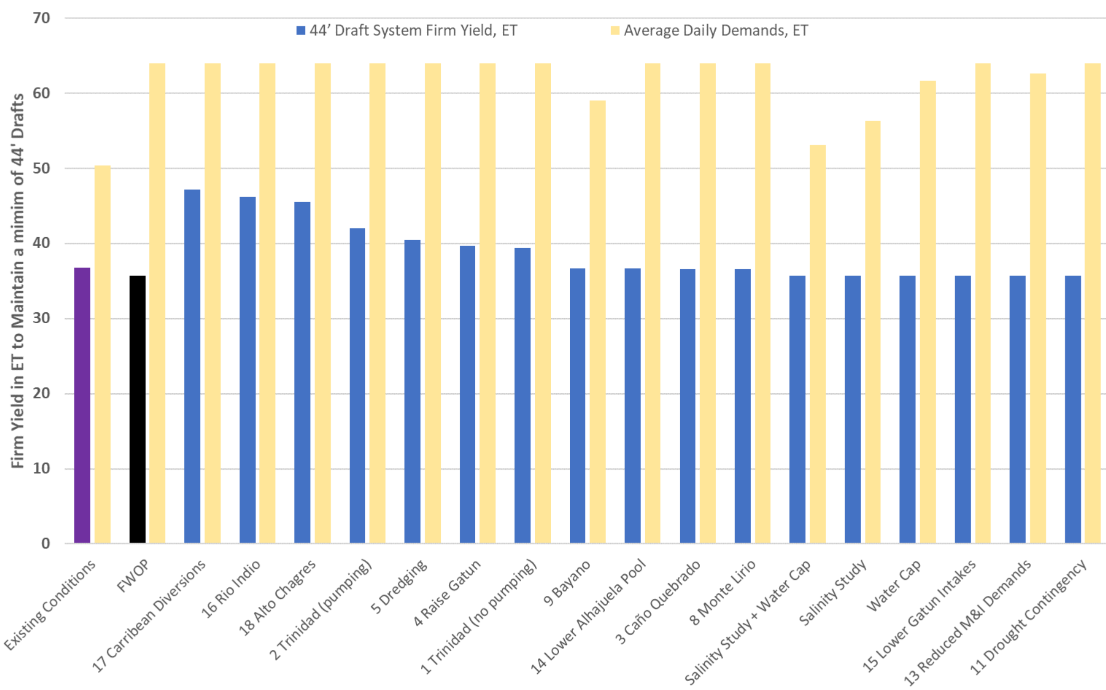


Figure 5-33: Firm Yield in ET Associated with a 44' Draft Compared with the Average Daily Demand Associated with the Measure

5.9 Reliability Results Grouped by Categories of Measures

Measures were categorized based on the solution type associated with each measure. The primary categories included:

- Measures Parallel to the Feasibility Study
- Feasibility Study A: Storage Measures
- Feasibility Study A: Measures that Reduce Demands
- Feasibility Study A: Dredging Measures
- Feasibility Study B: Outside Authority Measures

The following sections describe the results and observations for each category of measures.

5.9.1 Parallel Study Measures

The results of transit reliability and draft reliability at 13.41 m (44 ft) for the three parallel measures is shown in Figure 5-7. Figure 5-7 illustrates the following conclusions:

- The Salinity Study measures provide significant draft and transit reliability improvements. This is due to significant reduction in daily demands when water savings basins are more frequently utilized (Salinity Study are expected to be 75% utilization of the WSBs on average).
- The M&I water withdrawal cap provides a significant improvement to transit reliability due to the reductions in future daily water demands.
- Combining the Salinity Study with a M&I water withdrawal cap provides reliability metrics approaching the reliability of the existing conditions. Although the simulated reliability of combining these measures is less than existing conditions' reliability, this measures combination provides significant reliability improvements when compared to the future without project conditions.
- UKC policy revision would provide a modest increase in draft reliability for most drafts. However, this measure does not address water availability and will not affect transit reliability. UKC could be carried forward for additional analysis in future phases of the study or implemented independently of the feasibility study to gain additional value from the modest improvement in draft reliabilities.

5.9.2 Feasibility Study A: Storage Measures

Storage measures have been analyzed and plotted on the transit reliability versus 13.41 m (44 ft) draft reliability plot. This is shown in Figure 5-34, which includes the parallel measures of the Salinity Study and M&I water withdrawal cap water demands datapoints for comparison. When these measures categories are compared, it is observed that additional storage does not provide as much total reliability benefits as the Salinity Study or the M&I water supply cap, especially within the context of transit reliability.

Dozens of storage measures iterations were simulated with combinations of operational rules, design assumptions, and lowering existing municipal intakes. Results of these simulations are shown in Figure 5-34 and are the unlabeled datapoints in this figure.

Specific simulation results are described in Appendix B Water Management Modeling of this report. When evaluating simulation iterations, it was observed there is a limit on how much additional reliability can be gained through storage measures alone. The dashed lines in Figure 5-34 were developed by lowering the M&I intake limits and the level at which navigation is curtailed to guarantee M&I supply. The additional intake limits that were modeled were at EL 23.5 m PLD / 77 ft PLD, EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD.

A theoretical alternative was developed in the HEC-ResSIM simulations that included an infinite amount of storage to understand the limits of the benefits associated with the storage measures in the future conditions. Using various operational strategies and options, the PDT found that the benefit limits associated with storage measures is constrained relatively close to the reliability curve associated with the future without project conditions.

This limit of benefits associated with storage measures is due to water overallocation that occurs in the future conditions. The result is: **Storage measures provide only modest benefits until future water demands are reduced.** This is because future demands are greater than the available water on average, and any storage that would be realized during a very wet year would be quickly depleted. Storage benefits are temporary because the water volume leaving the basin is greater than average inflows under future demand conditions.

Storage measures provide additional benefit if combined with measures reducing the demands. This demonstrates the importance of any future alternative plan including measures reducing future water demands. Storage measures alone will not achieve acceptable levels of navigation reliability and must be combined with other measures to achieve reliability benefits.

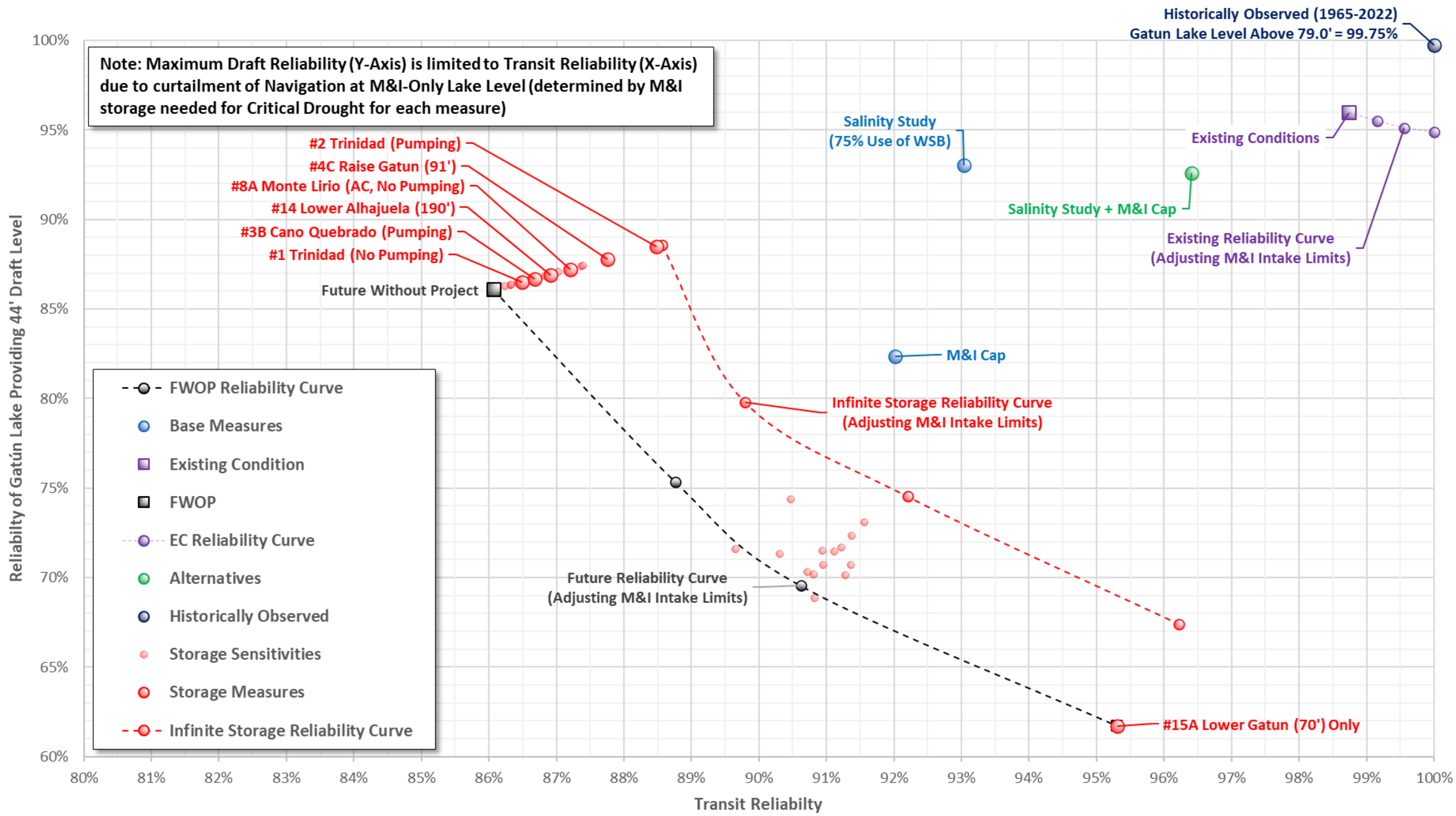


Figure 5-34: Transit Reliability and 44' Draft Reliability for Storage Measures (Note: Future, Infinite Storage, and Existing Condition Reliability Curves were generated using intake limits of EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD)

5.9.3 Feasibility Study A: Dredging Measures

Dredging provides significant benefits. Dredging to 25’ PLD is the only measure that shows more transit reliability benefits than the Salinity Study (75% Use of WSB). Dredging to 25’ PLD demonstrates over 95% transit reliability. Modeling results show the Salinity Study (75% Use of WSB) yields 93% draft reliability. Dredging to 25’ PLD draft reliability is 95% at 44’. This is 2% more than the 93% draft reliability associated with 75% water savings basins use.

There are many challenges associated with dredging. Dredging appears to be feasible only if a rock cutterhead dredge is used. Rock hardness and operational constraints may require use of a rock cutterhead dredge capable of quickly swinging in and out of the navigation channel to avoid placing drilling and blasting platforms to break the rock. The measure is believed to be feasible given ACP’s experiences with rock cutterhead dredges in the Neopanamax Expansion Project.

The dredging measure only provides benefits to Neopanamax reliabilities. Dredging allows for deeper draft Neopanamax vessels to navigate, even when Gatún Lake’s elevations is historically low. A design component associated with this measure includes lowering of water intakes to take advantage of lower pool elevations. Dredging does not provide benefits to Panamax vessels due to Panamax lock sill elevations (sills are the limiting elevation for Panamax drafts). Panamax and Neopanamax draft reliability would be decreased when Gatún Lake levels are lower than historical conditions.

Despite these challenges, dredging is being recommended for further analysis and may be used in several recommended alternatives.

5.9.4 Feasibility Study A: Measures that Reduce Demands

Several measures investigated reduction of water demands within the ACP Watershed. Two of these measures have been discussed in the Parallel Measures section – Salinity Study and a M&I water withdrawal cap.

Additional measures resulting in a reduction in water demand include Bayano M&I Offsets, Drought Contingency Planning, and Reduced M&I Demands. Another important measure that reduces water demands is crossfilling at Gatún Locks, which will be analyzed at the 15% design phase. Measures that reduce demands generally provide draft reliability equal to storage measures. Measures 13B (10% reduction of

M&I) and 9 (Bayano M&I Offset) are exceptions. Measures that reduce demands generally provide better transit reliability. Results are shown in Figure 5-36 and 4-37.

5.9.5 Feasibility Study B: Outside Authority Measures

The team conducted preliminary analysis on some Study B – Outside Authority measures. These measures have not been analyzed for costs, but there are significant opportunities for reliability improvements through Study B measures as shown in Figure 5-37. These measures are compared with all the studied measures in Figure 5-38.

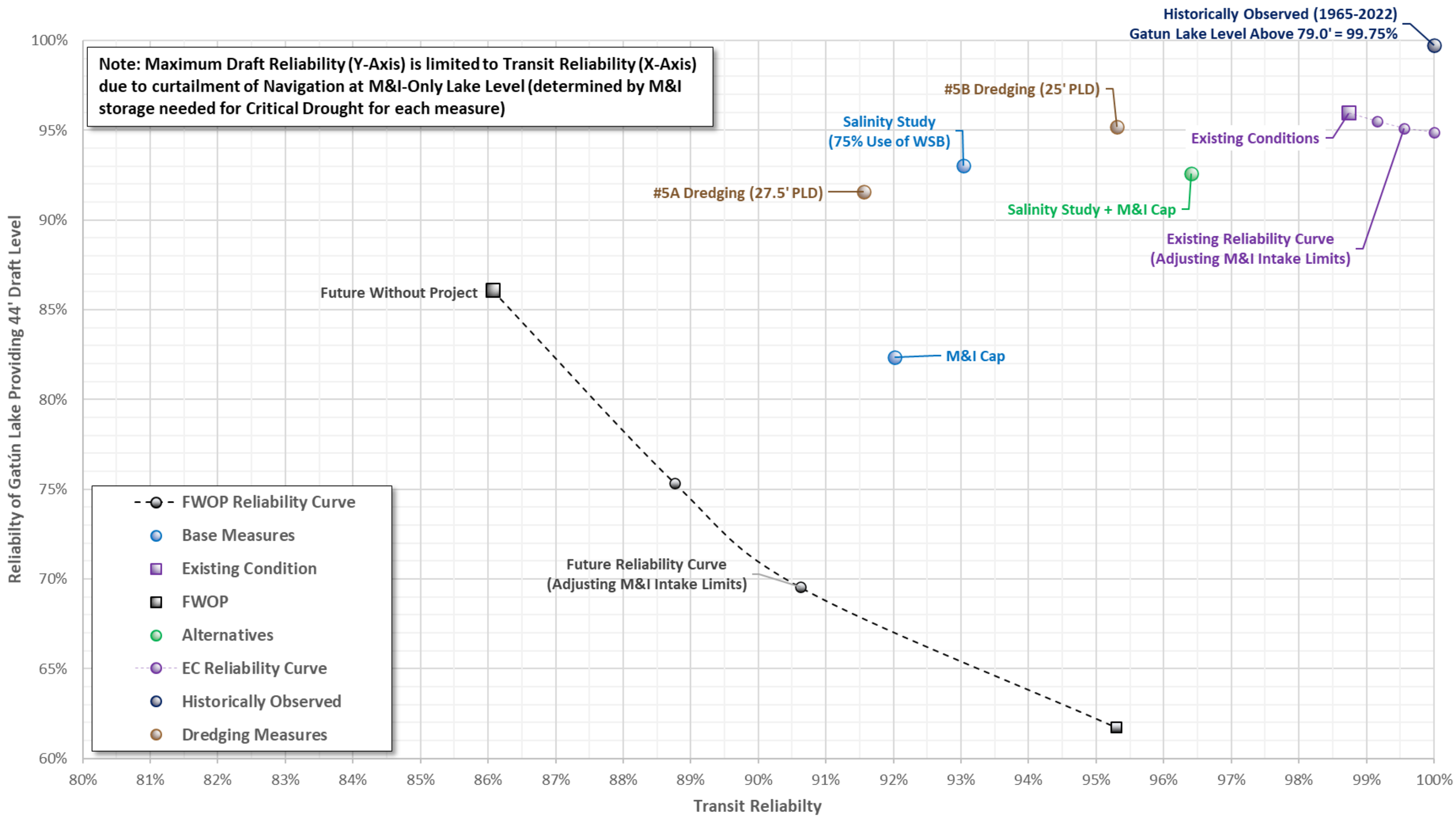


Figure 5-35: Transit Reliability and 44' Draft Reliability for Dredging Measures (Future and Existing Condition Reliability Curves were generated using intake limits of EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD)

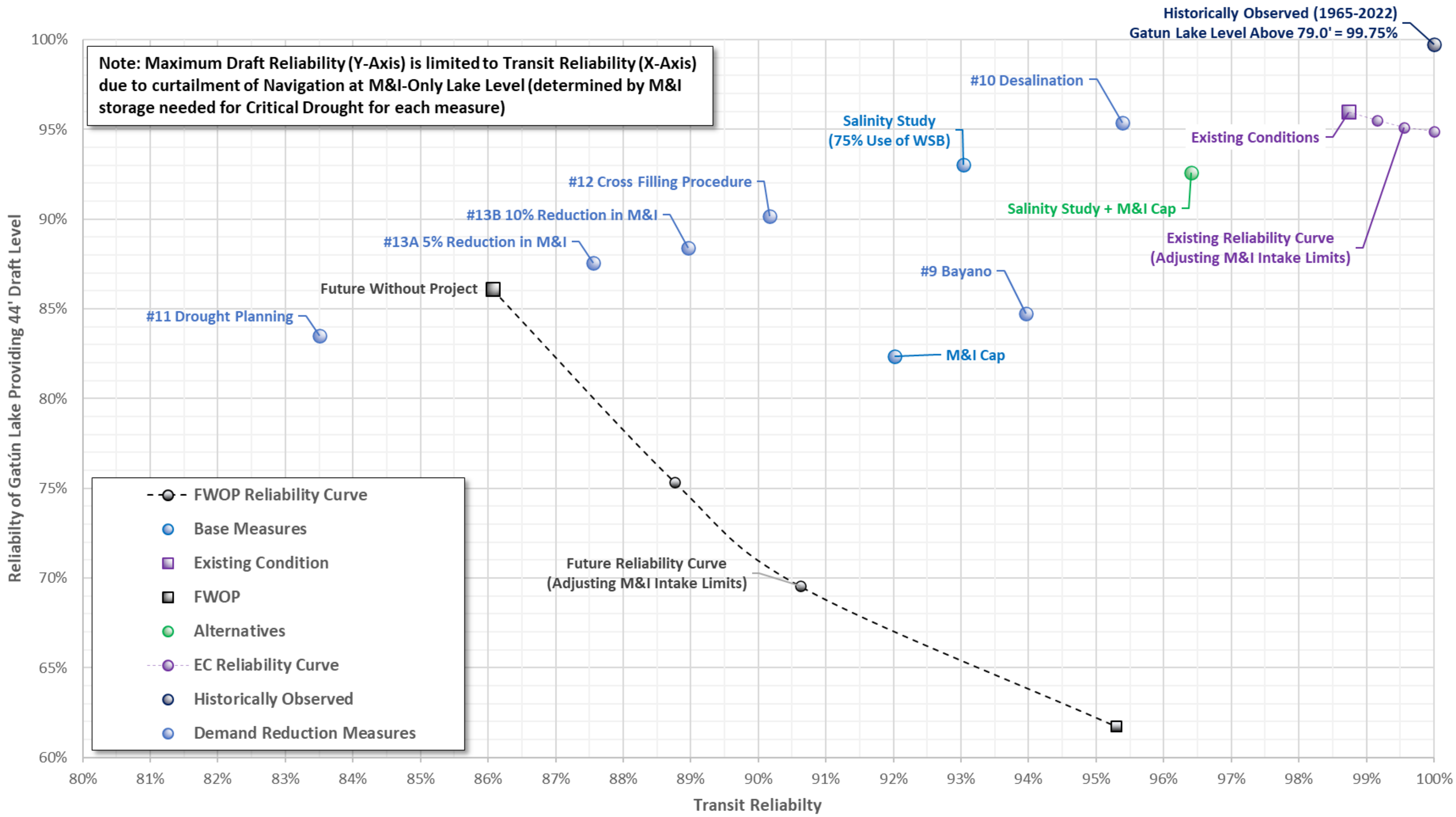


Figure 5-36: Transit Reliability and 44' Draft Reliability for Measures that Reduce Demands (Future and Existing Condition Reliability Curves were generated using intake limits of EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD)

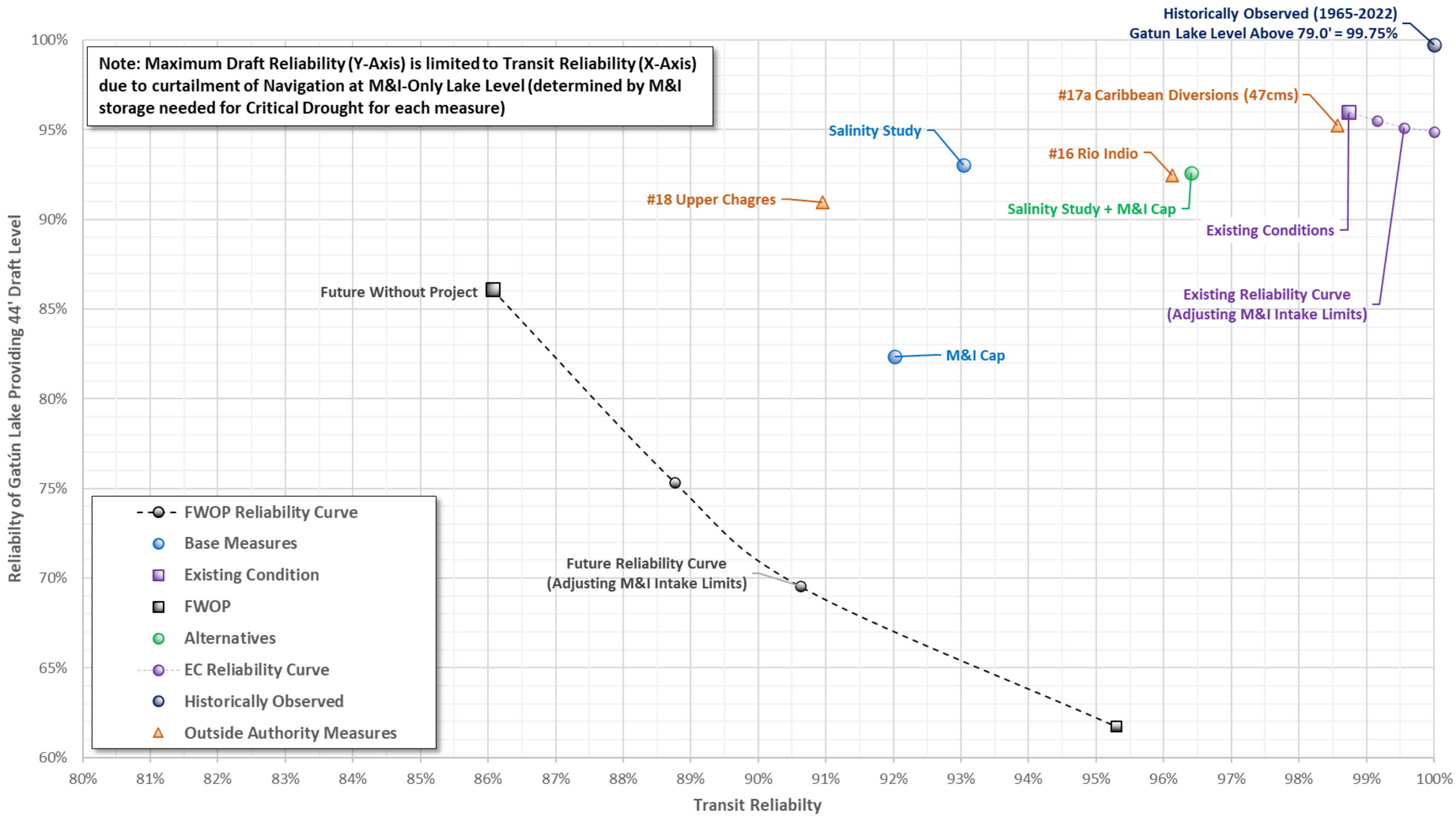


Figure 5-37: Transit Reliability and 44' Draft Reliability for Outside Authority Measures (Future and Existing Condition Reliability Curves were generated using intake limits of EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD)

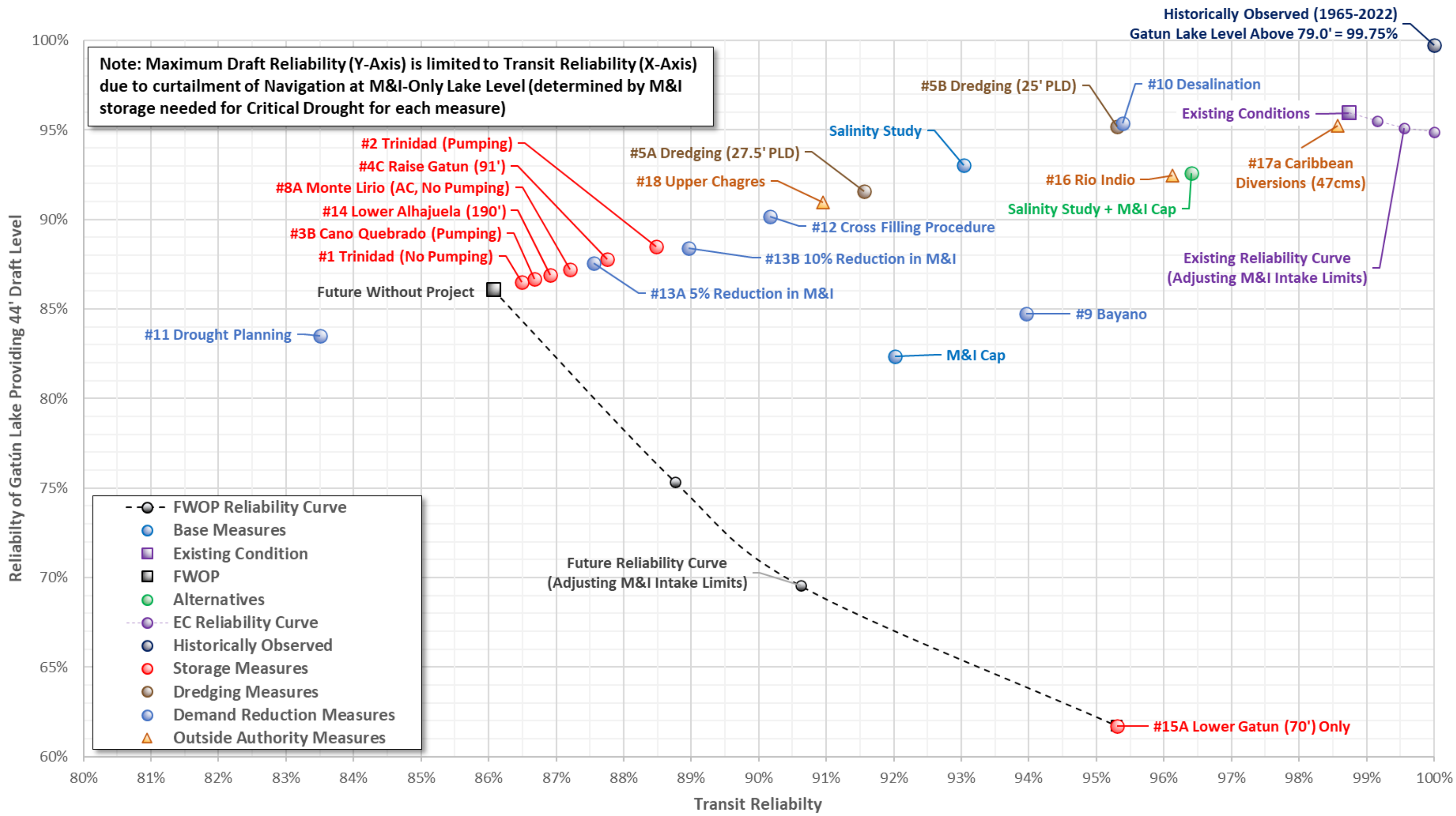


Figure 5-38: Transit Reliability and Draft Reliability for Measures Analyzed (Note: Future and Existing Condition Reliability Curves were generated using intake limits of EL 22.6 m PLD / 74 ft PLD, EL 22.3 m PLD / 73 ft PLD, and EL 21.3 m PLD / 70 ft PLD)

5.10 Economic Benefits of Measures

Project benefits derive from an increase in value realized by the ACP over the FWOP. The primary driver of value is an increase in water availability over the FWOP, which creates the opportunity for 1) increased transit reliability and/or 2) increased draft reliability.

Increased transit reliability benefits accrue when an alternative increases the transit capacity of the Panama Canal up to either operational capacity or transit demand. Increased draft reliability benefits occur either when an alternative restores lost demand or allows transit of higher value customers.

An overview of the relationship between the engineering outputs and the economic inputs (and their associated feedback) are shown in Figure 5-39. The economics model developed for the 5%-level-analysis uses the transit and draft reliability outputs of the 5% engineering model to estimate total transit demand in the Future Without-Project and Future With-Project conditions. The economic model converts the change in total transit demand into economic benefit. This methodology provides sufficient confidence for screening-level analysis (5%), but it does not fully account for the interdependency between reliability and demand.

Current reliability modeling assumes unconstrained transit demand. The economic model constrains transit demand based on reliability outputs from the HEC-ResSim model. The resulting total transit demand is typically less than the assumed transits in the HEC-ResSim model because transit demand in the economic model is sensitive to changes in reliability. As a result, there is feedback from the economic model that is not currently built into HEC-ResSim. At the 5% analysis the iterative feedback of updating transit demands in the HEC-ResSIM model based on the output of the economics model is not included. This model feature will be updated in the economic and navigation reliability tasks associated with analysis of alternatives. See Appendix D Economics for detailed description of methodology for the 5% economics analysis.

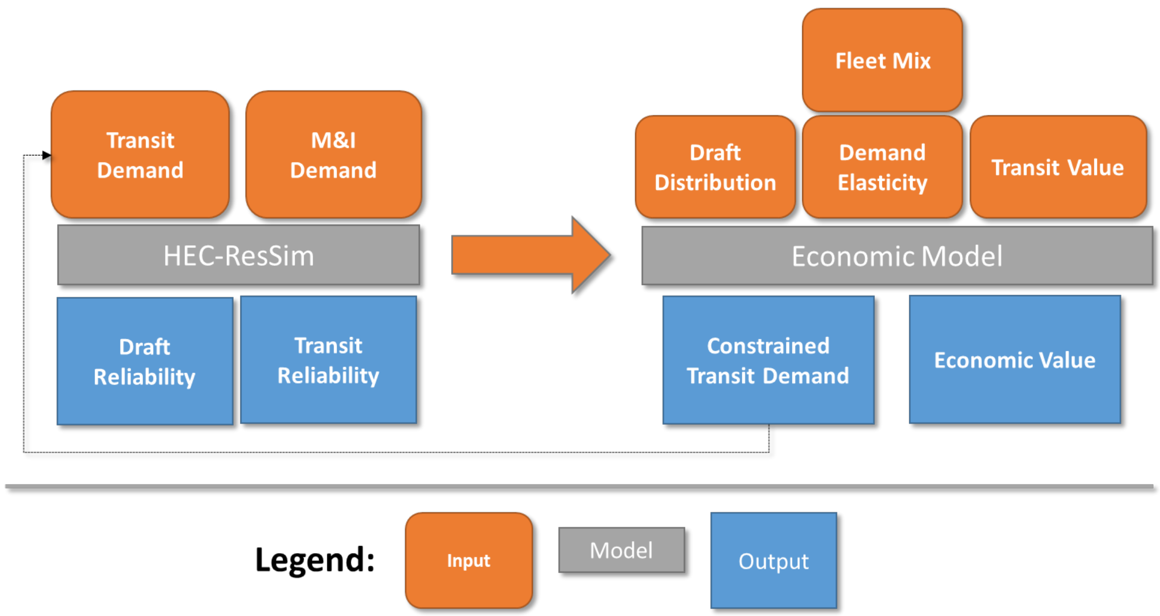


Figure 5-39: Navigation Reliability Modeling (HEC-ResSIM) and Economics Model Link

5.10.1 Transit Reliability Benefit Calculation

Transit reliability benefits equal the value of additional transits realized by a measure compared to the future without project condition. Total additional transits allowed by an alternative will be limited by the operational capacity of the Panama Canal System and total demand for vessel transits.

$$Transit\ Reliability\ Benefit = (Transits_{FWP} - Transits_{FWOP}) * (Value\ per\ Transit)$$

Where:

- **Transits$_{FWP}$** = Total annual transits in the Future With Project (FWP) condition based on 2075 HEC-ResSim outputs
- **Transits$_{FWOP}$** = Total annual transits in the Future Without Project (FWOP) condition based on 2075 HEC-ResSim outputs
- **Value per transit** = Value realized by the ACP per additional vessel transit

Table 5-9 shows the approach and sources used to estimate transit reliability benefits for the 5% level of analysis.

Table 5-9: Approach and Sources used to Convert Transit Reliability Improvements to Economic Benefits

Value	Detail	Source
Δ Transits	Future With-Project Transits – Future Without-Project Transits	HEC-ResSim
Value per Transit	Average Value per Transit (EBITDA Margin * Toll Revenues)	ACP Financial Projection (2030)

5.10.2 Draft Reliability Benefit Calculation

Draft reliability refers to the percent of time water elevation meets or exceeds a specific depth. Draft reliability creates value by ensuring the long-term competitiveness of the Canal (i.e., ensuring carriers will not change routes due to unreliable depths). The economic analysis uses the equation below to estimate the benefits of draft reliability.

$$\begin{aligned} &Draft\ Reliability\ Benefits \\ &\quad = (Reliability_{FWP} - Reliability_{FWOP}) * Impacted\ Transits \\ &\quad * Value\ per\ Impacted\ Transit * Demand\ Elasticity \end{aligned}$$

where:

- **$Reliability_{FWP}$** = Percent of time reference depth is available in the Future With Project (FWP) condition
- **$Reliability_{FWOP}$** = Percent of time reference depth is available in the Future Without Project (FWOP) condition
- **Impacted transits** = Percent of transits by market segment with a sailing draft exceeding the reference depth
- **Value per Impacted Transit** = Value of an 'impacted' vessel transit less the value of the most likely alternative vessel transit in the FWOP condition
- **Demand elasticity =** Percent change in demand for every percent change in draft reliability (e.g., for a 1% drop in draft reliability at 48 feet, the percent of vessels by market segment that would choose an alternate route)

Table 5-10 shows the approach and sources used to estimate economic benefits of draft reliability at the 5% level of analysis[18].

Table 5-10: Approach and Sources used to Convert Draft Reliability Improvements to Economic Benefits

Value	Detail	Source
Δ Draft Reliability	Future With-Project Draft Reliability – Future Without-Project Draft Reliability	HEC-ResSim Model
Impacted Vessels	Percent of vessels likely to draft at or above the limiting draft (% Exceedance).	ACP historical transit drafts (FY20-FY22)
Incremental Value per Transit	Incremental value per transit at or above reference draft compared to transit below the reference draft. Currently assumed equal to the value per transit.	ACP Financial Data
Demand Elasticity	Percent of vessels that will choose an alternate route without sufficient draft reliability.	USACE-ACP 5% level of analysis

Key assumptions used to estimate benefits at the 5% level of analysis include:

- 26.34 Daily Panamax Calls (9,614 Annual)
- 12.64 Daily Neopanamax Calls (4,614 Annual)
- Unrestricted Sailing Draft Distributions (i.e., when Gatún Lake is above 85 feet)
- Variable demand elasticity
- Value per transit by market segment based on 2035 ACP Financial Forecasting
- ACP transit forecast for 2035

5.10.3 Transit and Draft Reliability Modeling

The economic model accounts for the tradeoff between transit and draft reliability and the effect on total transits through the system by constraining total transits in the following order:

1. Estimate unconstrained transit demand across all transit drafts
2. Constrain transit demand using demand elasticity
3. Constrain transit demand by transit reliability
4. Convert transits to economic benefit

[18] For detailed description of inputs used and methodology, see Appendix D

This methodology reflects the need to optimize water use for transit and draft reliability within the system. Added draft reliability creates limited benefit if it is not supported by added transit reliability and vice versa. The most beneficial measures optimize draft and transit reliability.

Typically, transit reliability is gained at the expense of draft reliability and vice versa. Transit reliability benefits are generally constant because an additional transit tends to create the same value for the ACP on average. Added draft reliability benefits vary across levels of reliability based on demand elasticity and customer replacement (i.e., whether a lost customer is replaced by another customer).

Figure 3-2 of Appendix D, Economics depicts the trade-off between transit and draft reliabilities. Added draft reliability shows diminishing returns as the Panama Canal reliability increases. There is likely a 'tipping point' of draft reliability for each customer at which the draft reliability level is unacceptable. At this 'tipping point', the customer will not use the Panama Canal and their lost transit will not be replaced by another customer. At this point, the value of increased draft reliability equals the value of increased transit reliability because the added draft reliability recovers a lost transit.

The 'tipping point' is likely different for each customer and is based on multiple cost and operational considerations (reference Appendix D, Economics, Section 3.6). As a result, the 'tipping point' is not one draft or transit level of reliability. It is a minimum level of service acceptable to each customer. Reference Appendix D Economics for additional details.

5.10.4 Average Annual Equivalent (AAEQ) Benefits

The benefits associated with each Study A and Study B measure modeled in the Navigation Reliability and Economics model are shown in Table 5-14. The study normalizes costs and benefits into average annual equivalent (AAEQ) terms for comparison. The use of AAEQ accounts for the variation in the timing of costs and benefits by converting all costs and benefits over the 50-year period of analysis into a constant, annual value using a discount rate representing the time value of money[19].

The measures that provide the most average annual benefits from Study A include Navigation Channel Dredging ($135 million per year) and Bayano ($128 million per

[19] The ACP's discount rate for high-cost, high-risk water projects is currently 11% (FY2022)

year). The Caribbean Diversions project in Study B would provide an estimated $365 million per year of benefits and Rio Indio is estimated to provide $282 million of benefits.

The Salinity Study is estimated to have approximately $235 million in annual benefits and capping municipal water extractions is estimated to yield approximately $84 million in annual benefits. The Salinity Study has not been analyzed for costs, and a benefit-cost ratio cannot yet be determined for this measure.

Table 5-11. Average Annual Equivalent Economic Benefits above the FWOP for Each Measure Analyzed in Study A and Study B (Parallel Study Measures Benefits included for Reference)

Scenario*	Benefit (AAEQ)
Salinity Study	*$234,600,000*
Municipal Water Caps	*$83,700,000*
#1 Trinidad, without Pumping	$39,400,000
#2 Trinidad, with Pumping	$106,600,000
#3b Caño Quebrado	$15,000,000
#4c Raise Gatún, 91' PLD	$43,200,000
#5a Nav. Channel Dredging	$115,900,000
#5b Nav. Channel Dredging	$135,100,000
#6c Raise Alhajuela	$23,600,000
#8b Monte Lirio	$26,000,000
#9 Bayano M&I Offset	$128,200,000
#13a 5% Reduction in Future M&I Demand	$28,800,000
#13b 10% Reduction in Future M&I Demand	$42,500,000
#14 Lower Alhajuela	$19,400,000
#15 Lower Gatún	$(66,100,000)
#16 Rio Indio	$282,200,000
#17a Caribbean Diversions	$364,700,000
#18 Alto Chagres Reservoir	$108,400,000

*Measure #12 will be evaluated during 15% and is excluded from this summary table

5.11 *Costs of Measures*

The study considers both financial and economics costs. Financial costs are primarily used for capital planning and estimate the actual payments the ACP will make for project implementation. This report presents Total Project costs and Project First Costs. Total Project Cost is the constant dollar cost fully funded with escalation to the midpoint of construction. This cost differs from the estimated Project First Cost, which is the constant dollar cost at the current price level.

Economic costs represent financial costs plus opportunity costs of investment. For water resource projects, opportunity cost is represented by Interest During Construction (IDC). IDC represents the opportunity cost of investment and equals the hypothetical interest carried over the duration of construction activities calculated at the 11% discount rate. Economics uses the Project First Cost to convert economic costs to AAEQ terms for comparison to economic benefits. The following equations define the relationships between costs:

$$Total\ Project\ Cost = Project\ First\ Cost + Inflation\ to\ midpoint\ of\ construction$$

$$Total\ Ecoomic\ Cost = Project\ First\ Cost + IDC$$

5.11.1 Total Project Cost

In addition to the benefits previously described, several measures were advanced to a 5% Design Cost estimate. Appendix C includes the cost engineering summary conducted on each measure that was analyzed to a Class V cost estimate. A summary of the project total costs with the final associated contingencies are included in Table 5-12.

Table 5-12: Summary of Total Project Costs

Measure	Contingency %	Total Project Cost
#1 Trinidad, without Pumping[20]	84.6%	$2,212 M
#2 Trinidad, with Pumping	84.0%	$2,305 M
#3b Caño Quebrado, with Pumping	68.1%	$170 M
#4c Raise Gatún, 91' PLD	41.0%	$851 M

[20] Additional review of Trinidad, including the cost estimate is ongoing. The results of this will be incorporated prior to the final report.

Measure	Contingency %	Total Project Cost
#5a Nav. Channel Dredging, 27.5' PLD		Not Costed
#5b Nav. Channel Dredging, 25' PLD	34.0%	$696 M
#6c Raise Alhajuela, 260' PLD		Not Costed
#8b Monte Lirio, AC without Pumping	98.8%	$1,790 M
#9 Bayano M&I Offset, with Alhajuela M&I removal	49.4%	$1,220 M
#13a 5% Reduction in Future M&I Demand		Not Costed
#13b 10% Reduction in Future M&I Demand		Not Costed
#14 Lower Alhajuela, 190' PLD	57.9%	$23.3 M
#15 Lower Gatún, 73' PLD	46.4%	$62.4 M
#16 Rio Indio with Inter-Basin Transfer		Not Costed
#17a Caribbean Diversions, 47 cms		Not Costed
#18 Alto Chagres Reservoir		Not Costed

5.11.2 Average Annual Equivalent (AAEQ) Cost

The study compares all relevant costs of project implementation to project benefits by converting costs and benefits into AAEQ terms using a 50-year period of analysis. Project costs used to estimate net economic benefit include all economic and financial costs of implementation:

- Construction costs (Project First Cost)
- Associated construction costs
- Operation, maintenance, repair, rehabilitation, and relocation (OMRR&R)[21]
- Interest During Construction (IDC)

The study team completed a Class V cost estimate for each measure (reference Appendix C, Cost Engineering), which includes an estimate of construction cost and IDC based on the construction duration of each project. The study converts each measure's costs to an average annual equivalent (AAEQ) value at October 2022 prices for

[21] OMRR&R will be estimated during the 15% level of analysis

consistent comparison to AAEQ project benefits. Table 5-13 summarizes the costs for each measure. Some measures are not costed during the 5% level of analysis.

Table 5-13. Measure Average Annual Equivalent (AAEQ) Cost Summary

Scenario	Project First Costs	IDC	Total Economic Cost	Total AAEQ Cost
#1 Trinidad, without Pumping	$1,888.1 M	$892.1 M	$2,780.2 M	$290.1 M
#2 Trinidad, with Pumping	$1,967.0 M	$929.3 M	$2,896.3 M	$302.3 M
#3b Caño Quebrado	$156.4 M	$27.2 M	$183.6 M	$24.0 M
#4c Raise Gatún, 91' PLD	$751.2 M	$234.6 M	$985.8 M	$115.4 M
#5a Nav. Channel Dredging	*Measure not costed*			
#5b Nav. Channel Dredging	$617.6 M	$148.5 M	$766.1 M	$72.0 M
#6c Raise Alhajuela	*Measure not costed*			
#8b Monte Lirio	$1,560.1 M	$607.6 M	$2,167.7 M	$239.7 M
#9 Bayano M&I Offset	$1,128.8 M	$439.6 M	$1,568.4 M	$173.5 M
#13a 5% Reduction in Future M&I Demand	*Measure not costed*			
#13b 10% Reduction in Future M&I Demand	*Measure not costed*			
#14 Lower Alhajuela	$22.6 M	$8.8 M	$31.4 M	$3.5 M
#15 Lower Gatún	$55.2 M	$6.2 M	$61.4 M	$6.8 M
#16 Rio Indio	*Measure not costed*			
#17a Caribbean Diversions	*Measure not costed*			
#18 Alto Chagres Reservoir	*Measure not costed*			

5.12 Summary of Benefits and Costs of Measures

Table 5-14 presents AAEQ benefits, costs, net benefits, the benefit-cost ratio (BCR), and Net Present Value (NPV) for each Study A measure. Moreover, benefits-only associated with Study B, non-structural measures, or measures that were not selected for a full design are also included in this table at the 5% level of analysis. These measures will be combined into alternatives and cost estimates for the alternatives further refined during the 15% level of analysis.

Table 5-14. Measures Benefit-Cost Summary

Measure*	Annual Benefit (AAEQ)	Annual Cost (AAEQ)	Net Benefit (AAEQ)	BCR	NPV
Salinity Study	*$234,600,000*	*Measure not costed*			
Municipal Water Caps	*$83,700,000*	*Measure not costed*			
#1 Trinidad, without Pumping	$39,400,000	$290,149,000	$(250,749,000)	0.1	$(1,700,000,000)
#2 Trinidad, with Pumping	$106,600,000	$302,271,000	$(195,671,000)	0.4	$(1,485,400,000)
#3b Caño Quebrado	$15,000,000	$24,041,000	$(9,041,000)	0.6	$(49,900,000)
#4c Raise Gatún, 91' PLD	$43,200,000	$115,443,000	$(72,243,000)	0.4	$(496,900,000)
#5a Nav. Channel Dredging	$115,900,000	*Measure not costed*			
#5b Nav. Channel Dredging	$135,100,000	$71,962,000	$63,138,000	1.9	$211,500,000
#6c Raise Alhajuela	$23,600,000	*Measure not costed*			
#8b Monte Lirio	$26,000,000	$239,738,000	$(222,538,000)	0.1	$(1,445,200,000)
#9 Bayano M&I	$128,200,000	$173,467,000	$(45,267,000)	0.7	$(485,700,000)
#13a 5% Reduction in M&I Demand	$28,800,000	*Measure not costed*			
#13b 10% Reduction in M&I Demand	$42,500,000	*Measure not costed*			
#14 Lower Alhajuela	$19,400,000	$3,471,000	$15,929,000	5.6	$71,500,000
#15 Lower Gatún	$(66,100,000)	$6,782,000	-	-	$(2,261,500,000)
#16 Rio Indio	$282,200,000	*Measure not costed*			
#17a Caribbean Diversions	$364,679,000	*Measure not costed*			
#18 Alto Chagres Reservoir	$108,400,000	*Measure not costed*			

*Measure #12 will be evaluated during 15% and is excluded from this summary table

From Table 5-14 it can be observed that the measure that provides the highest net benefits and net present value, from the measures costed, is the Navigation Channel Dredging. The measure providing the highest BCR is Lower Alhajuela Pool. Bayano and Caño Quebrado have the next highest BCR values, although both are estimated to be less than 1.0-to-1.0 at this initial phase. Trinidad without Pumping and Monte Lirio were found to have the lowest BCR values in the measures that were analyzed for a full 5% design.

Various measures within the authority of the ACP were combined into categories of measures based on their size and complexity. This was useful in determining which measures will be recommended for screening; which measures can be combined into alternatives; and which measures cannot be combined. The screening and alternatives development are included in Chapter 6 and Chapter 7 respectively.

A summary of findings is:

1. The salinity and non-structural measures were categorized as potentially near-term, low-cost, and high-benefit measures. These are also the candidate measures that could contribute to the avoidance of significant navigation restrictions in the next severe drought. Some of these may require significant governmental negotiations or policy approvals (for example municipal water caps) but should certainly be investigated for inclusion in virtually any alternative being considered. The estimates of benefits and costs for these measures are shown in Table 5-15.

2. Five major measures were identified. These include Trinidad, Monte Lirio, Bayano, Raise Gatún, and Dredging. These are the most expensive measures with the longest execution times. Most have construction schedules of 7 years or more. The summary of estimated project costs and average annual equivalent benefits associated with the major measures are shown in Table 5-16.

3. Minor measures were identified and include measures that could be constructed in approximately 5 years or less. These measures also have some of the lowest costs, but also some of the lowest total benefits. These results are shown in Table 5-17.

A summary of the draft reliability, transit reliability, and costs are shown in Figure 5-40. This figure shows many of the storage measures on their own provide minimal benefits to transit and draft reliability when compared to the future without project condition.

This figure also shows that the most expensive measures (Trinidad and Monte Lirio) do not significantly improve transit reliability when compared to other measures. Also, measures that reduce demands generally provide more transit reliability than the measures that provide additional storage. The figure also shows that dredging provides more draft reliability at 44' drafts and more transit reliability than most of the storage measures. Finally, this plot shows that there is not a single measure that will provide reliability metrics equivalent to or greater than the existing conditions, and measures must be combined into alternatives to achieve future reliability targets with the system at full navigation capacity[22].

Table 5-15: Estimated Costs and Benefits for Salinity Study and Non-Structural Measures (Measures in Italics are Parallel Study Efforts)

Measure Name	Estimated Total Project Cost	Estimated Annual Benefits (AAEQ)
Salinity Study Measures	*$200 M*[23]	*$235 M*
Municipal Water Cap	*$0 M*	*$84 M*
Cross Filling	$0 M	Greater than $50 M[24]
Under Keel Clearance Revisions	*$0 M*	*Modest Benefits*

[22] The cost scale presented in Figure 4-39 correspond with estimated Total Project Costs detailed in Table 4-15, Table 4-16, and Table 4-17. See Appendix C for full cost estimates.

[23] Salinity study measures have not been assessed to a Class V Cost Estimate and are based solely on initial findings and engineering judgement. The salinity study is an on-going, parallel study to this current effort and the cost estimate has greater uncertainty than other measures.

[24] Benefits of the Cross Filling measure have not been fully analyzed in the HEC-ResSIM model and estimate of benefits is based on preliminary findings only.

Table 5-16: Estimated Costs and Benefits for Major Measures

Measure Name	Estimated Total Project Costs	Estimated Annual Benefits (AAEQ)
Trinidad without pumping	$2,212 M	$39 M
Trinidad with pumping	$2,305 M	$107 M
Monte Lirio	$1,790 M	$26 M
Bayano M&I	$1,220 M	$128 M
Raise Gatún Pool	$851 M	$43 M
Dredging (Measure 5B),	$696 M	$135 M

Table 5-17: Estimated Costs and Benefits for Minor Measures

Measure Name	Estimated Project Costs	Estimated Annual Benefits (AAEQ)
Caño Quebrado	$170 M	$15 M
Lower Gatún M&I Intakes	$62.4 M	$0 M[25]
Lower Alhajuela Pool	$23.3 M	$19 M

[25] Lowering intakes transfers benefits from draft reliability to transit reliability.

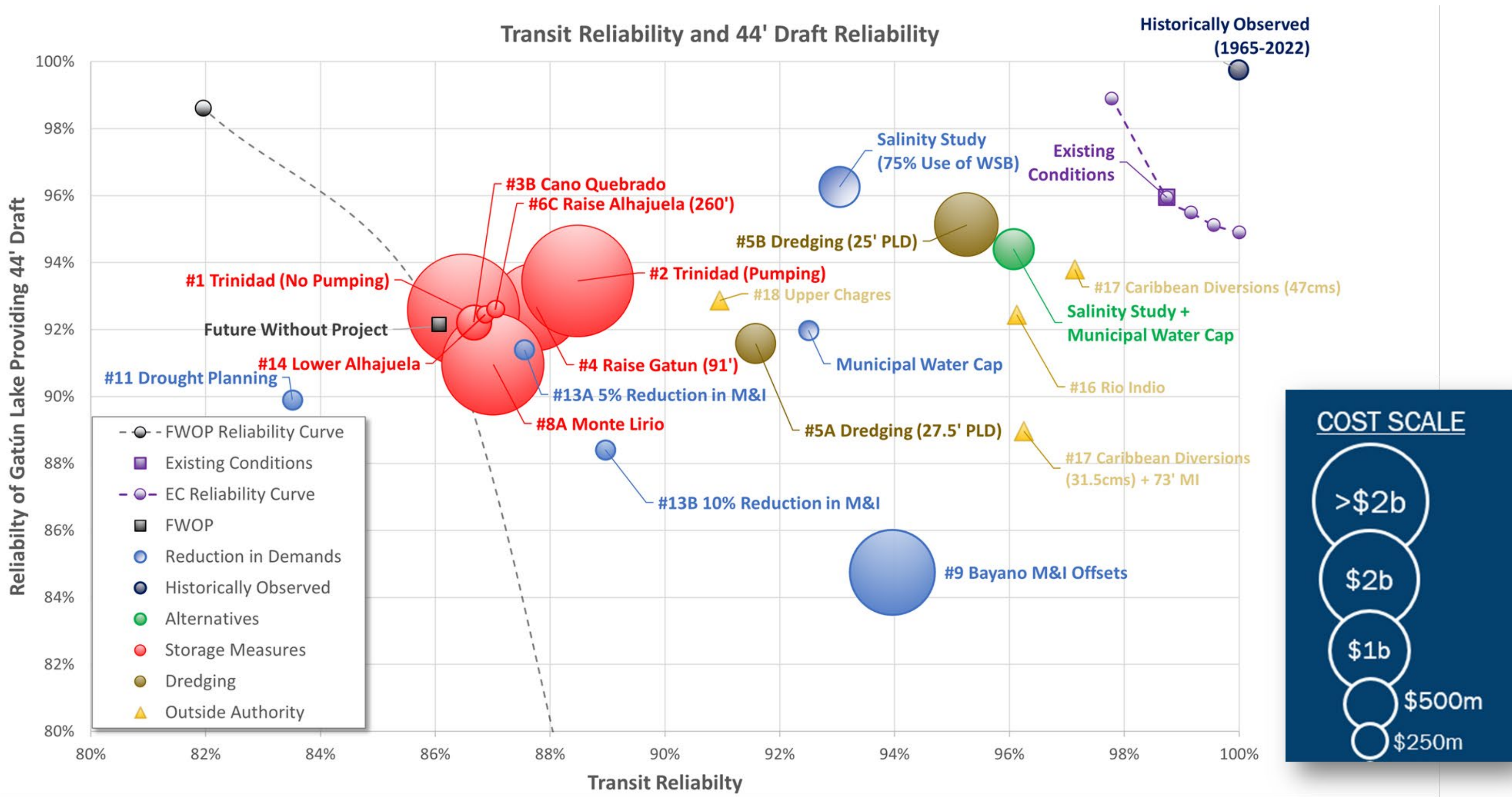


Figure 5-40: Transit Reliability and Draft Reliability with Estimated Costs for Measures Analyzed

6. MEASURES SCREENING AND COMBINATION

6.1 Measures Screening, Elimination and Preliminary Combination

Measures and alternatives development and assessment is an iterative process that is revisited with finer granularity and informed by new data as it becomes available throughout the project. This includes a general, qualitative assessment to confirm a measure or combination of measures is suitable for additional consideration and analysis.

6.2 Initial Measures Screening

The PC IWRM Study PDT cooperatively developed a series of measures. Measures sourcing included earlier engineering studies; engineering judgement; field investigations; proposed and ongoing ACP operations; opportunities to cooperate with other Panamanian agencies with related missions, such as IDAAN; new technologies and best engineering practices. These measures were qualitatively screened at the August 2022 Planning Meeting held in Panama and the Alternatives Milestone Meeting (AMM) held at the Mobile District, USACE on 14-18 November 2022.

The PC IWRM Study PDT agreed Study A would focus on measures within the Panama Canal hydrologic basin and ACP's patrimony. This was broadened to include measures that could directly affect water supply and resiliency in Gatún Lake, such as Bayano M&I water offsets and capping M&I water supply withdrawals. The PC IWRM PDT also agreed certain out of basin measures would be analyzed for benefits to support a general comparison of costs and benefits between within basin and out of basin measures.

6.3 Qualitative Measures Screening

The typical USACE qualitative standards for early screening of measures and alternatives are completeness, effectiveness, efficiency, and acceptability. As part of the Planning process, the PC IWRM Study PDT defined additional qualitative standards to refine which measures should be combined into alternatives and move forward for analysis. Table 6-1 describes the PC IWRM Study qualitative screening criteria.

Table 6-1: PC IWRM Study Measures Qualitative Screening Criteria

Screening Criteria	Definition
Acceptable	The measure is acceptable in terms of applicable laws, regulations, and public policies.
Effective	The measure could contribute to achieving the study objectives, including significantly increasing water storage and supply.
Efficient and Economically Viable	The measure appears to be cost-effective and is likely to be economically justified (i.e., the benefits will exceed the costs)
Technically feasible	It appears the measure can be successfully implemented using existing engineering, design and construction methodologies and materials are available on a timely schedule and are reasonably priced.
Environmentally viable and acceptable	It appears the measure is or can be with mitigation, environmentally acceptable in terms of impacts, applicable laws, public policies, and institutional tolerance.
Socially viable and acceptable	It appears the measure is or can be with mitigation, socially acceptable in terms of impacts, applicable laws, public policies, and institutional tolerance.
Operationally Acceptable	The measure is practical and doesn't appear to unacceptably impact Panama Canal operations or cause extended shutdowns of the Panama Canal.
Provides Secondary Benefits, Positive Outcomes or Supports Opportunities	The measure seems to provide benefit in one or more problem areas or to one or more opportunity.
Avoids Constraints	The measure does not violate an identified constraint.
Associated Risk	The measure avoids increased life safety risk, flood management or other risk.
Within ACP Authority or Influence	Can the measure be implemented without external coordination/permission.

6.3.1 *First Qualitative Measures Screening*

The first qualitative measures screening was informed by the study literature review, engineering studies and the PC IWRM PDT's professional judgement. Measures that, on balance, did not meet the qualitative screening criteria were excluded from additional analysis.

The nonstructural measures qualitative screening did not recommend any nonstructural measures be removed from consideration. A discussion of the final nonstructural measure array is in Section 6.4.2.

Table 6-3 visually describes structural measures that were qualitatively screened early in the study process, followed by brief descriptions of why they were screened. The definitions of categories used in Table 5-3 and other screening tables is shown in Table 6-2.

Table 6-2: Qualitative Screening Legend[26]

Color	Description
Red	The measure does not appear to conform with the qualitative criteria.
Yellow	The measure conforms with qualitative criteria, but minimally contributes to the study's objectives and solution.
Amber	There is insufficient information to determine if a measure conforms to the qualitative criteria, or the measure does not completely conform to the qualitative criteria.
Green	The measure conforms with the qualitative criteria

[26] This legend applies to all qualitative screening tables.

Table 6-3: PC IWRM Study, First Structural Measures Qualitative Screening

	Lower Rio Chagres	Panamax Water Savings Basins (Gatún Lock)	Segmentation of the navigation channel	Pump Storage to Alhajuela Lake	Tide Gates	Lower Gatún Lake Elevation and Eliminate Upper Locks	Reduce seepage and evaporation losses	Raise Miraflores Lake	Airlocks
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Effective	Yes	Yes	No	No	No	No	No	No	No
Efficient and Economically Viable	No	No	No	No	No	No	No	No	No
Technically feasible	Yes	No	No	No	Yes	No	No	Yes	No
Environmentally viable and acceptable	Unknown	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Socially viable and acceptable	Unknown	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Operationally Acceptable	Yes	No	No	Yes	Yes	No	No	Yes	No
Provides Secondary Benefits, Positive Outcomes, or Supports Opportunities	Yes	Yes	No	No	Yes	Yes	No	Yes	No
Avoids Constraints	Yes	Unknown	Yes	Yes	Yes	Yes	Yes	No	Yes
Associated Risk	Yes	Yes	No	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Within ACP Authority or Influence	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Will the Alternative be carried forward	No	No	No	No	No	No	No	No	No

The rationale for removing measures from further analysis by the first qualitative screening are below.

Lower Rio Chagres: The Lower Rio Chagres measure is a dam upstream of Gambon, Guayabalito and Autopista Panama-Colón and downstream of Madden. The dam would create a new reservoir to capture Madden Dam hydrogeneration releases. The captured water would be released as needed to maintain Gatún Lake water levels and avoid navigation draft restrictions. Lower Rio Chagres was screened from further analysis because:

- Preliminary analysis indicated the Lower Rio Chagres would result in minimal benefits, especially when compared to other measures.

Panamax Water Savings Basins (Gatún Locks): The Panamax Water Savings Basins measure consists of constructing and operating water savings basins at Gatún Locks. The water savings basins would be similar in construction and operation to those previously discussed in this document (reference Section 3.1.4 Water Quality (Salinity)) and currently in use at the Cocolí Locks and Agua Clara Locks. The Panamax Water Savings Basins (Gatún Locks) was screened from further analysis because:

- Physical constraints (inadequate property, configuration of the property and existing development) make construction and operation technically infeasible.
- Construction would significantly hinder Gatún Locks operations, affecting the ACP's ability to transit Panamax vessels safely and efficiently.
- Use of the water savings basins, by releasing salt water through lockages may impact salinity values at M&I water supply intakes or in Gatún Lake.

Segmentation of the Entire Navigation Channel: This measure is a physical barrier isolating the Panama Canal navigation channel from Gatún Lake's main body. Segmentation of the Entire Navigation Channel was screened from further analysis because:

- A rough order of magnitude analysis indicated navigation channel segmentation would be cost prohibitive and have minimal benefits.
- A navigation channel barrier's size, nature, scale, construction methodologies and time to operation are insurmountable engineering issues.
- Panama Canal transit options and operations would be unreasonably affected.
- The barrier would be a new and serious safety risk during construction and operations.

Pump Storage to Alhajuela Lake: Pump storage modifies Madden Dam with pumpback capability or installs another pumpback mechanism to transfer water from Gatún Lake to Alhajuela Lake. Pump Storage to Alhajuela Lake was screened because:

- Preliminary analysis indicates Alhajuela Lake and Madden Dam operations can optimize the water balance in Gatún Lake for navigation at less cost than a pumpback system.
- Pump storage does not provide additional net water for storage in Gatún or Alhajuela Lake.

Tide Gates: Tide gates are control structures that maintain an optimal operating pool for lockages. Tide Gates were screened because:

- Preliminary analysis indicated tide gates would result in minimal benefits, especially when compared to other measures.
- The measure did not realize significant net water savings or gains.

Lower Gatún Lake Elevation and Eliminate Upper Locks: This measure is a complex plan that lowers the water surface elevation using dams parallel to the navigation channel from Culebra Cut through Gatún Lake to Gatún Dam; deepens the navigation channel; and removes all or part of the existing locks. Lower Gatún Lake Elevation and Eliminate Upper Locks was screened out because:

- Preliminary analysis indicates this measure would result in minimal benefits, especially compared to other measures.
- Extreme operational difficulties including shutdowns during construction would impact Panama Canal navigation transits.
- A rough order of magnitude analysis indicates lowering Gatún Lake and Eliminating Upper Locks would be cost prohibitive.
- The measure is unlikely to increase water supply reliability.

Reduce Seepage and Evaporation Losses: The measure includes various methodologies to preclude Panama Canal hydrologic basin water losses through seepage and evaporation. Reduce Seepage and Evaporation Losses was removed as a measure because:

- Preliminary analysis indicates this measure would result in minimal benefits.
- The measure is unlikely to increase water supply reliability.

Raise Miraflores Lake: Raising Miraflores Lake raises the normal operating pool of Miraflores Lake to 55.5 ft (16.92 m) MSL. Raising Miraflores Lake was removed as a measure because:

- Preliminary analysis indicates Raising Miraflores Lake would result in minimal benefits.
- The measure is unlikely to increase water supply reliability.

Airlocks: The airlocks measure is an alternative locking concept that uses a piston to raise the water level in lock chambers instead of filling the full chamber with water, resulting in more efficient locking water use and preclude transit interruptions in high water conditions. Airlocks was removed as a measure because:

- The measure is not considered technically viable.
- The measure would be too expensive to implement.
- The measure would impact operations of the Panama Canal.

6.3.2 Second Qualitative Measures Screening

The second measures screening was part of the AMM held at the Mobile District, USACE in November 2022. Measures not eliminated in the first qualitative screening were reassessed against the qualitative screening criteria. Engineering and economics analysis prepared for the AMM informed the second qualitative screening.

Table 6-4 visually describes the PDT’s recommendations for screened structural measures. Several of these measures were further analyzed to confirm the PDT’s recommendation.

Table 6-4: PC IWRM Study, Second Structural Measures Qualitative Screening

	Trinidad (with and without pumping)	Caño Quebrado (without pumping)	Raise Gatún Lake and BEC Spillway	Raise Alhajuela Lake/Madden Dam (256' & 260')	Monte Lirio (AA & CC, with and without pumping	Desalination Plant	Alhajuela Lake Dredging
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Effective	Minimal	Minimal	Minimal	Minimal	Minimal	Yes	Minimal
Efficient and Economically Viable	No	No	No	Yes	No	No	Minimal
Technically feasible	Yes	Yes	Yes	Yes	Yes	Yes	No
Environmentally viable and acceptable	Unknown	Unknown	Yes	Yes	Unknown	Yes	No
Socially viable and acceptable	Yes	Yes	Yes	Yes	Yes	Yes	No
Operationally Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	No
Provides Secondary Benefits, Positive Outcomes, or Supports Opportunities	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Avoids Constraints	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Avoids Increasing Risk	Unknown	Unknown	Unknown	No	Unknown	Yes	Yes
Within ACP Authority or Influence	Yes	Yes	Yes	Yes	Yes	Yes	No
Will the Alternative be carried forward	No	No	No	No	No	No	No

The rationale for recommending measures be removed from further analysis by the second qualitative screening is described below.

Trinidad Segmentation Project: The Trinidad measure(s) segments the Trinidad arm of Gatún Lake to create a water supply impoundment either without pumping or with a two-way pump system to ensure water exchange with the Gatún Lake main body. Trinidad with pumping was recommended to be removed as a measure because:

- Trinidad does not yield sufficient benefits when compared to other measures of similar scale. The highest BCR was estimated at 0.4.
- The first cost investment in Trinidad segmentation without pumping or with 2-way pumping potentially exceeds $2B.
- Trinidad did not yield sufficient benefits when compared to other measures.
- Increased water elevations in the Trinidad impoundment could pose unacceptable risks to saddle dikes and appurtenances in the area.

The PDT elected to do additional analysis to quantitatively validate removal of Trinidad as a measure.

Trinidad segmentation has been considered a potential solution to water supply issues since the 1960's. This measure had significant opportunities for improving navigation reliability in the Panamax system due to opportunities that storage could provide.

Trinidad segmentation significantly reduces flood storage available in the Gatún Lake. The PDT analyzed impacts to flood storage associated with an extreme hydrologic event equal to the Probable Maximum Flood (PMF) that was calculated in 1979[27] with the Trinidad project in place. This analysis and underlying modeling assumptions are described in Appendix B, Attachment B5 Gatún Lake Extreme Event Flood Assessment.

The 5% analysis found that if the operational pool was set to EL 88.0 ft PLD that an extreme event would result in a flood elevation of 93.90 ft PLD with the Trinidad project in place without additional spillway capacity. Without the Trinidad measure, the extreme event would result in a maximum pool elevation of 92.29 ft PLD. This means that an additional 1.61 feet of elevation would be associated with the extreme event

[27] The PDT does not consider the USACE 1979 PMF to be the PMF if calculated today due to updates in methodologies and additional data and storms, including the 2010 Purisima storm. A precomputation of the PMF is being conducted in a parallel risk assessment study.

described in the USACE 1979 Probable Maximum Flood analysis if Trinidad were to be constructed without a significant spillway. These results are shown in Figure 6-1.

This measure would require additional spillway capacity or a reduction in the maximum pool elevation of Gatún Lake in to decrease the expected maximum pool to that with existing conditions. The additional spillway capacity is a cost that has not been included in the analysis of Trinidad. Reducing the Gatún Lake's operational pool would further reduce the reliability of navigation, resulting in lower annual net benefits and lower BCR.

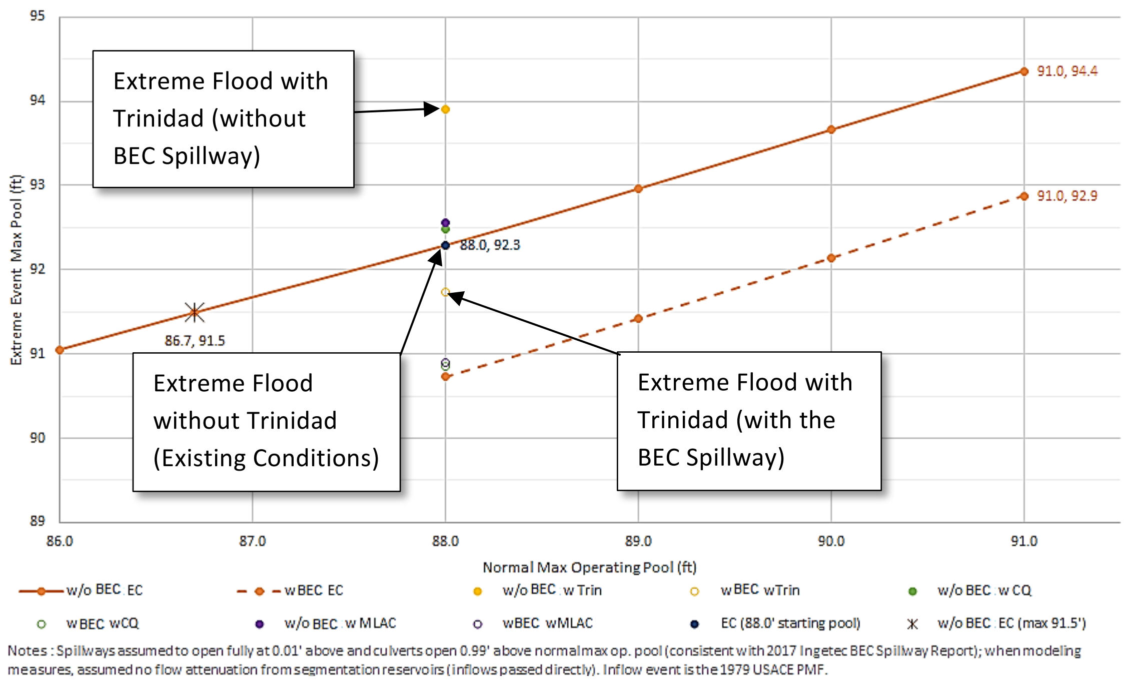


Figure 6-1: Trinidad Extreme Flood Elevation With and Without Additional Spillway Capacity

There were several discussions related to assumptions used to calculate the benefits during the Trinidad analysis. An important question is whether the elevation where navigation "turns off" is penalizing Trinidad's benefits.

Navigation turns off at EL 79.5 ft PLD for the Trinidad measure. The simulation assumption that turns off navigation at higher elevations for Trinidad is due to higher system water demands requiring more M&I storage reserves. The additional M&I storage reserves are to prevent violating the study constraint requiring 100% of M&I requirements be met through the 50-year period of analysis.

Water budget analysis demonstrates lowering the elevation where navigation is turned off has minimal impact on the overall amount of water used for navigation purposes in the Trinidad measure. Trinidad with pumping was analyzed with navigation turned off at EL 79.5 ft PLD and the water budget is shown in Figure 6-2. On average, 26.5 ET of water is used per day for Neopanamax lockages and 17.6 ET of water is used per day for Panamax lockages.

Another simulation set navigation to turn off at EL 77.25 ft PLD by lowering the M&I water intakes to 73 ft PLD. In this scenario, the total water used for navigation was 26.7 ET for the Neopanamax lockages and 17.6 ET for the Panamax lockages (see Figure 6-3). This is roughly equivalent to water volumes used for lockages when navigation is turned off at a higher elevation.

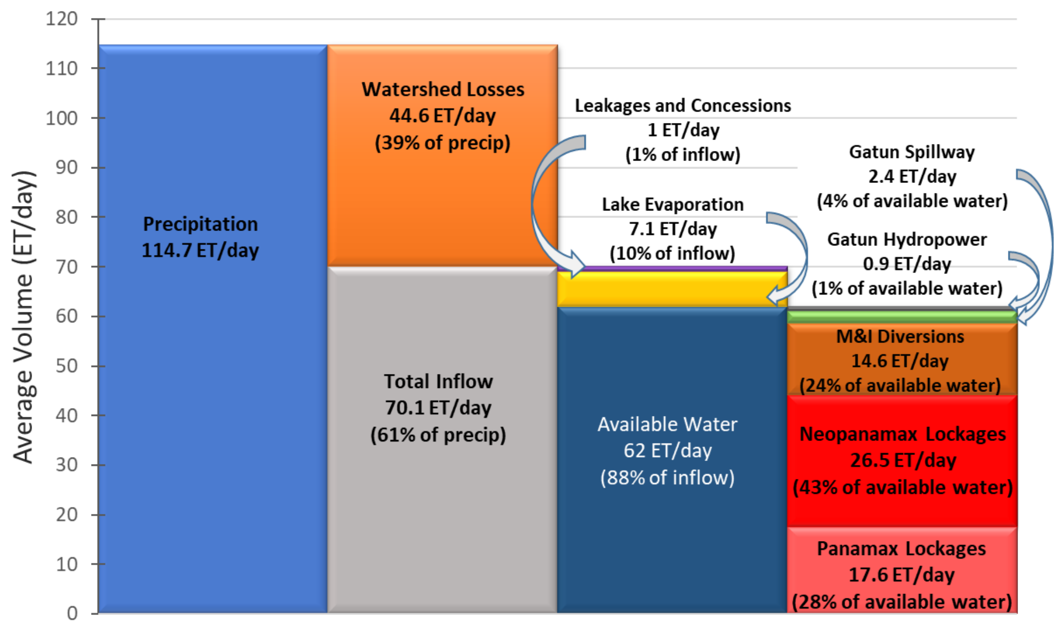


Figure 6-2: Average Annual Water Balance for Trinidad with Pumping (Measure Analyzed in this Study)

Storage added by the Trinidad measure has a modest impact on reliability due to the limited volume of water that is spilled or released as hydropower under the Future Conditions. Appendix B, Section 6 contains the water balance data used to develop this figure.

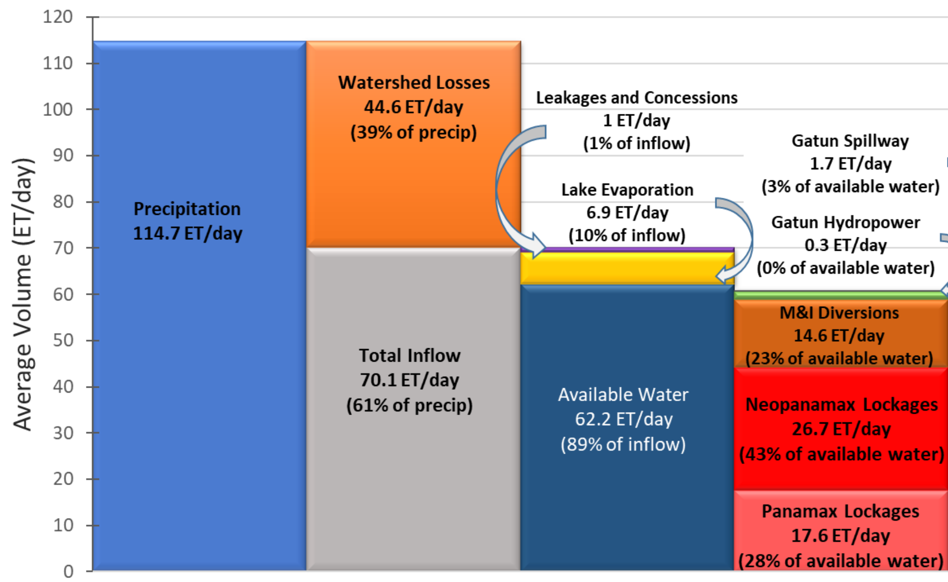


Figure 6-3: Average Annual Water Balance for Trinidad with Pumping and Lowering the M&I Intakes to 73'

Storage added by the Trinidad measure has a modest impact on reliability due to the limited volume of water that is spilled or released as hydropower under the Future Conditions. Appendix B, Section 6 contains the water balance data used to develop this figure.

The Trinidad measure stores most of the water that is available to be stored. The existing conditions modeling showed that approximately 19% of the water available to be stored is spilled or used to generate hydropower. In the future without project conditions, this value is reduced to approximately 8% of the total available water. For the Trinidad measure, 5% of the total available water is spilled or used to generate hydropower. This measure reduces spilling and hydropower generation more than any other single measure (i.e., maximizes storage to nearly the maximum extent possible), but it does not provide as much economic benefit as a measure that reduces demands.

The recommendation to screen Trinidad is based on its limited merits for storing water in the ACP basin under the context of future demands that include Neopanamax demands. Future water demands are projected to exceed available inflow and storage will provide limited or temporary benefits. This further contributes to the recommendation to screen Trinidad as a measure for Study A – In Authority Measures.

This recommendation does not preclude the Trinidad measure from being combined with measures that could be considered in Study B. Based on preliminary extreme event analysis conducted to date, an improved understanding of baseline and with-project risk will be necessary to better define operational or structural requirements tied to this measure. If the USACE risk assessment finds the BEC spillway or other spillway capacity is required under the existing conditions and guide curve, there could be an opportunity to address future with project risk more efficiently.

Caño Quebrado without pumping: This measure segments the Caño Quebrado arm to create a water supply impoundment in Gatún Lake.

- Caño Quebrado without pumping did not yield sufficient benefits compared to other measures. Without pumping, Caño Quebrado volumes are almost entirely used to meet the M&I demands from intakes located within the Caño Quebrado arm.
- Caño Quebrado with pumping was retained as a measure.

Raise Gatún Lake Operational Pool: This measure would raise Gatún Lake Lake's surface elevation. Existing Gatún Dam features would be modified or expanded to accommodate the increased elevation. Raise Gatún Lake was removed as a measure because:

- Preliminary analysis indicates this measure results in minimal benefits; other measures yield more benefits for comparable first cost investment.
- Raising Gatún Lake's surface elevation and the stresses it might pose on Gatún Dam, the Panama Canal locks, saddle dams and other appurtenances is an unknown, unacceptable risk.
- Raise Gatún Operational Pool assumes additional spillway capacity or other spilling mechanism is required, and the cost of this measure includes constructing the BEC spillway. Due to the limited benefits associated with the Raise Gatún Operational pool, the costs to construct this measure (including the BEC spillway) could not be justified.

Raising Gatún Lake and BEC Spillway has been considered a potential solution to water supply issues in the Panama Canal for decades. The ACP has already implemented this measure as a function of the Expansion Project by raising the guide curve from a maximum operational pool of 87.5 ft PLD to a maximum pool elevation of 88.0 ft PLD. During the study process, the ACP has raised the guide curve again, to 89.0 ft PLD under certain hydrologic conditions. Raising the guide curve reduces the potential benefits associated with this measure.

Raise Gatún Operational Pool is recommended for screening from the current study. This recommendation does not preclude the Raise Gatun measure from being combined with measures that could be considered in Study B. Based on preliminary extreme event analysis conducted to date, an improved understanding of baseline and with-project risk will be necessary to better define operational or structural requirements tied to this measure. If the USACE risk assessment finds the BEC spillway or other spillway capacity is required under the existing conditions and guide curve, there could be an opportunity to address future with project risk more efficiently.

Raising Alhajuela Operational Pool: This measure would raise the surface elevation of Alhajuela Lake and modify Madden Dam features to accommodate the increased operating elevation. Raising Alhajuela Operational Pool was removed as a measure because:

- Preliminary analysis indicates this measure would result in minimal benefits, especially when compared to other measures.
- Raising Alhajuela Lake's surface elevation and the stresses it might pose on Madden Dam, the adjacent saddle dams and other appurtenances is an unknown, unacceptable risk.

Raise Alhajuela Operational Pool is recommended for screening from the current study. This recommendation does not preclude the measure from being combined with measures that could be considered in Study B. The Semi-Quantitative Risk Assessment will improve understanding of the baseline and with-project risk. This will better define operational or structural requirements tied to this measure to mitigate risk.

Monte Lirio Segmentation: This measure consists of segmenting Gatún Lake's Monte Lirio arm to create a storage impoundment and includes four scenarios. Two scenarios include pumping to ensure water exchanges with Gatún Lake. Two scenarios do not include pumping. Monte Lirio was removed as a measure because:

- Preliminary analysis indicates this measure would result in minimal benefits and high costs, especially when compared to other measures.
- Social complexities include limited site access, disturbing local communities and potentially affecting the railroad or railroad operations.
- Increased water elevations in the Monte Lirio impoundment could pose unacceptable risk to saddle dikes in the area.

Desalination Plant: A desalination plant would desalinate sea water or brackish water. The treated water would be released into Gatún Lake. Desalination was removed as a measure because:

- It is technically possible to implement the desalination plant measure, but it is recommended for pre-screening due to the high costs.
- This measure was found to be impractical because of the overall availability and abundance of freshwater sources in the region (Stantec (2018)).

This measure may be considered in a future study if other measures do not provide sufficient reliability.

Alhajuela Lake Dredging: This measure includes dredging Alhajuela Lake to a lower bottom elevation to increase lake water storage. Alhajuela Lake dredging was removed as a measure because:

- The increased storage benefits were minimal.
- Dredging required for project implementation is estimated to take 9 years.
- Continual dredging into perpetuity would be required to maintain the benefits.
- The project footprint, including dredge disposal areas, is within the boundaries of Parque Nacional Chagres, includes communities of indigenous people, and is outside ACP patrimony.

6.4 Measures Retained for Further Analysis

6.4.1 Structural Measures Carried Forward

Table 6-5 displays the results of measures screening criteria for each of the remaining structural measures in the study.

Table 6-5: PC IWRM Final Structural Measures Array

	Caño Quebrado (with pumping)	Navigation Channel Dredging		Bayano Reservoir M&I Water Offsets
		27.5’ PLD	25’ PLD	
Acceptable	Yes	Yes	Yes	Yes
Effective	Minimal	Yes	Yes	Yes
Efficient and Economically Viable	Minimal	Yes	Yes	Yes
Technically feasible	Yes	Yes	Yes	Yes
Environmentally viable and acceptable	Unknown	Yes	Yes	Unknown
Socially viable and acceptable	Unknown	Yes	Yes	Unknown

	Caño Quebrado (with pumping)	Navigation Channel Dredging		Bayano Reservoir M&I Water Offsets
		27.5’ PLD	25’ PLD	
Operationally Acceptable	Yes	Unknown	Unknown	Yes
Provides Secondary Benefits, Positive Outcomes, or Supports Opportunities	Yes	Yes	Yes	Yes
Avoids Constraints	Yes	Yes	Yes	Yes
Avoids Increasing Risk	Unknown	Yes	Yes	Yes
Within ACP Authority or Influence	Yes	Yes	Yes	No
Will the Alternative be carried forward	Yes	Yes	Yes	Yes

Structural measures recommended to be carried forward are listed below.

Caño Quebrado (Alignment 3 with pumping): This measure segments the Caño Quebrado arm of Gatún Lake to create a water storage impoundment. The measure includes pumping to ensure water exchange between Caño Quebrado and Gatún Lake.

- Caño Quebrado has relatively low first costs and provides modest benefits when pumping is included with this measure.
- The average annual water balance resulting from the implementation of this measure is shown in Figure 6-4.

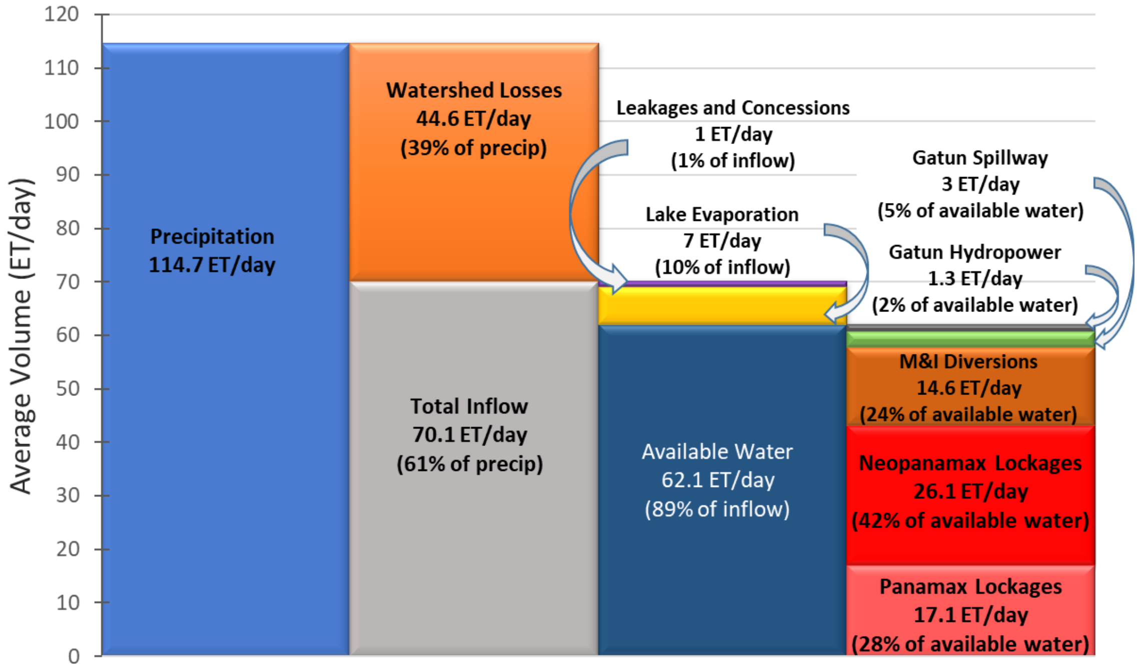


Figure 6-4: Average Annual Water Balance for the Caño Quebrado Measure

Appendix B, Section 6 contains the water balance data used to develop this figure.

Navigation Channel Dredging: This measure(s) deepens the existing navigation channel.

- Lowering the navigation channel bottom elevation allows Neopanamax transits to occur when Gatún Lake's water levels are stressed.
- The average annual water balance resulting from the implementation of this measure is shown in Figure 6-5.

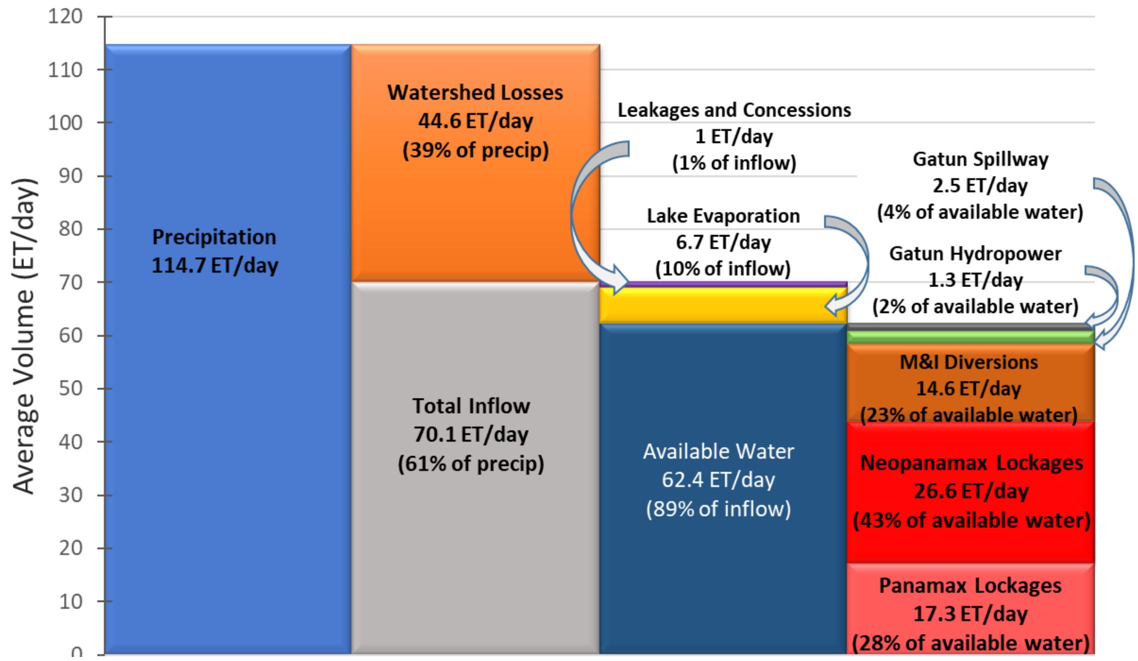


Figure 6-5: Average Annual Water Balance for the Dredging Measure

Appendix B, Section 6 contains the water balance data used to develop this figure.

Bayano Reservoir Municipal & Industrial Water Offsets: This measure withdraws and distributes water from Bayano Lake or Bayano Lake hydropower discharges to offset M&I water supply that would no longer be withdrawn from the Panama Canal hydrologic basin.

- Under this measure, water currently withdrawn for water supply would be retained in the Panama Canal system. This would increase within basin water supply and make more water available to support navigation transit.
- The average annual water balance resulting from the implementation of this measure is shown in Figure 6-6.

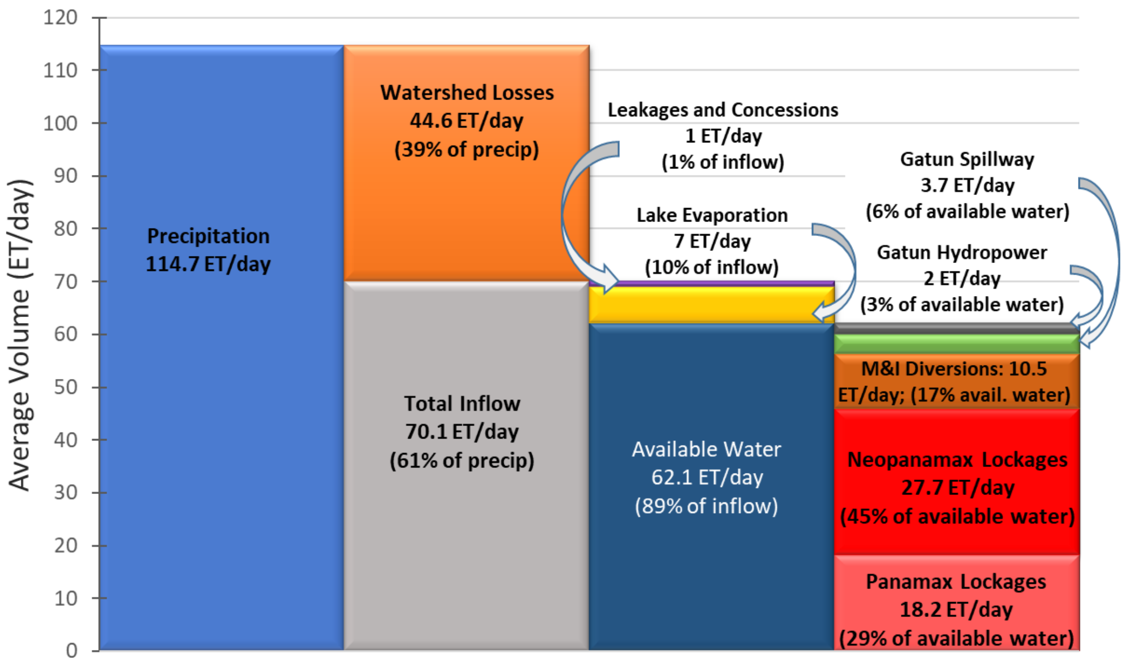


Figure 6-6: Average Annual Water Balance for the Bayano M&I Offset Measure

Appendix B, Section 6 contains the water balance data used to develop this figure.

6.4.2 Nonstructural Measures Carried Forward

Table 6-6 displays the results of measures screening criteria for each of the remaining non-structural measures in the study.

Table 6-6: PC IWRM Final Nonstructural Measures Array

	Drought contingency planning	Crossfilling Panamax Locks	Capping M&I Water Withdrawal	Lower Alhajuela Operational Pool to 190'	Lower Gatún Lake Operational Level
Acceptable	Yes	Yes	Yes	Yes	Yes
Effective	No	Yes	Yes	Minimal	Yes
Efficient and Economically Viable	Yes	Yes	Yes	Yes	Yes
Technically feasible	Yes	Yes	Yes	Yes	Yes
Environmentally viable and acceptable	Yes	Yes	Yes	Yes	Yes
Socially viable and acceptable	Yes	Yes	Yes	Yes	Yes
Operationally Acceptable	No	Yes	Yes	Yes	Yes
Provides Secondary Benefits, Positive Outcomes, or Supports Opportunities	Yes	Yes	Yes	Yes	Yes
Avoids Constraints	Yes	Unknown	Unknown	Yes	Yes
Avoids Increasing Risks	Yes	Yes	Yes	Yes	Yes
Within ACP Authority or Influence	Yes	Yes	Not Completely	Not Completely	Not Completely
Will the Alternative be carried forward	Yes	Yes	Yes	Yes	Yes

Nonstructural measures recommended to be carried forward are listed below.

Drought contingency planning: The drought contingency measure limits the number of vessels transiting the Panama Canal under drought conditions.

- The measure does not address Panama Canal water reliability. Drought contingency planning adjusts Panama Canal operations under reduced water conditions but does not affect water supply.

Cross filling of Gatún Locks: Gatún Locks cross filling recycles water between lock chambers during transits, allowing the water to be used several times before release.

- The water used in cross filling typically has elevated salinity levels and is ultimately released into Gatún Lake. Additional analysis is needed to determine if release violates Constraint 4, Maintain ACP operational salinity values to acceptable targets.

Capping M&I Water Withdrawals: This measure establishes a maximum amount of water that can be withdrawn from Gatún and Alhajuela Lakes for M&I water supply and avoids increasing water supply withdrawals over time. This will increase water storage in Gatún Lake and make that water available for navigation reliability.

- For Study A analysis, it is assumed Panama Canal operations includes meeting 100% of current and future M&I requirements. It is unknown if accommodating increasing, future demands is a Panama Canal responsibility.
- This measure requires coordination with IDAAN.

Lower Alhajuela Lake's Operational Pool to 190': Lowering the Alhajuela M&I operational depth makes more water available for release through Madden Dam into Gatún Lake while ensuring M&I water supply quantity and quality are met.

- This measure will not provide enough benefits to stand alone but has low first costs and can supplement water supply reliability in combination with other measures.
- This measure requires coordination with IDAAN.

Lower Gatún Lake Operational Level: Lowering the Gatún Lake operational level ensures water in the Gatún Lake pool is available to support navigation transits while M&I water supply quantity and quality are met.

- This measure requires coordination with IDAAN.

6.5 Preliminary Measures Combinations

The PDT agreed a high level, semi-quantitative assessment to confirm engineering feasibility and validate the qualitative screening would reduce risk, introduce rigor, build confidence in the findings and process, and jumpstart alternatives development.

Before combining measures for future consideration, the PDT:

- Determined no single measure provides sufficient benefits to be a stand-alone solution.
  - A viable selected plan that addresses the project objective will have to combine measures.
- Developed initial investment costs of measure combinations. The initial investments were used to compare the estimated total cost of combinations, cost effectiveness of combinations and compare one combination to another.
  - Measure combinations costs that exceeded $2,000,000,000 were eliminated from future consideration or annotated for more in-depth analysis if it appeared benefits might be substantial.
- Generally assessed which measures combinations are technically feasible.
- Measures were considered technically feasible if the measure could be executed using existing construction methodologies, were not redundant, were compatible, and materials could be obtained at reasonable cost.
- Generally assessed the risk posed by a combination of measures based on available information and risk professionals' judgement, including a cursory evaluation of possible life-safety impacts in the event of failure.
  - Trinidad and Monte Lirio segmentation are high risk measures. Raising surface elevations above Gatún Lake normal operating elevations potentially stresses existing infrastructure within the impoundments. Failure of Panama Canal infrastructure would affect communities and populations in the project vicinity.
  - Caño Quebrado segmentation with pumping is considered medium risk. Surface elevations in the Caño Quebrado impoundment would be raised above Gatún Lake normal operating elevations. However, it is considered an acceptable, lower-level risk because Panama Canal infrastructure, populations and developed areas in the Caño Quebrado project footprint are limited.
  - Raise Gatún Lake/BEC Spillway is a high-risk measure. Raising surface elevations potentially stresses existing Panama Canal infrastructure.

Infrastructure modifications will be necessary to reduce risk to acceptable levels based on currently available information.

The PDT agreed that a formal life-safety risk assessment quantifying and describing the nature, likelihood and magnitude of risk associated with Panama Canal's infrastructure is needed. The findings of the Semi-Quantitative Risk Assessment may affect which measures that are considered acceptable or can be combined.

6.5.1 Preliminary Measures Combinations Assessment

(1) Combined Measures First Semi-Quantitative Assessment

Table 6-8 visually represents the results of the first combined measures, semi-quantitative screening. It includes all possible combinations of any two structural measures that were retained, recommended for elimination, and the salinity study measure. This exercise's objective was a high-level comparison of two-measure combinations. Table 6-7 is the legend used in each semi-quantitative assessment.

Table 6-7: Combined Measures Semi-Quantitative Assessment Legend[28]

Color	Description
Red	The combination is recommended for elimination.
Yellow	The combination is not technically feasible, initial investment exceeds $2B, or is high risk. These combinations are recommended for additional analysis to determine the level of benefits that could be realized before they are eliminated from future consideration.
Green	The combination is technically feasible, the initial investment is =/< $2B, and is medium or low risk. These combinations should be further analyzed and be included in alternatives.
Grey	This combination of measures is represented elsewhere in the table.

[28] Legend applies to all semi-quantitative assessment tables.

Table 6-8: Combined Measures First Semi-Quantitative Assessment

	Caño Quebrado with pumping ($170M)	Raise Gatún Lake/BEC Spillway ($850M)	Navigation Channel Dredging ($700M)	Monte Lirio ($1.8B)	Bayano Reservoir M&I Water Supply Offsets ($1.2B)	Lower Alhajuela, 190' (Federico Guardia intake extension) ($23M)	Lowering Gatún Lake Operation Level ($62M)	Salinity Study Measures ($200M)
Trinidad ($2.3B)	Technically feasible Cost >$2B ($2.5B) High Risk	Not technically feasible Cost >$2B (~$3.2B) High Risk	Technically feasible Cost >$2B (~$3B) High Risk	Not technically feasible Cost >$2B (~$4.2B) High Risk	Technically feasible Cost >$2B (~$3.6B) High Risk	Technically feasible Cost >$2B (~$2.4B) High Risk	Technically feasible Cost >$2B (~$2.4B) High Risk	Technically feasible Cost >$2B (~$2.6B) High Risk
Caño Quebrado with pumping ($170M)		Not technically feasible Cost <$2B (~$1.0B) High Risk	Technically feasible Cost <$2B (~$870M) Medium Risk	Technically feasible Cost ~ $2.0B High Risk	Technically feasible Cost <$2B (~$1.4B) Medium Risk	Technically feasible Cost <$2B (~190M) Medium Risk	Technically feasible Cost <$2B (~$230M) Medium Risk	Technically feasible Cost <$2B (~$370M) Medium Risk
Raise Gatún Lake/BEC Spillway ($850M)			Technically feasible Cost <$2B (~$1.5B) High Risk	Not technically feasible Cost >$2B (~$2.6B) High Risk	Technically feasible Cost >$2B (~$2.1B) High Risk	Technically feasible Cost <$2B (~$870M) High Risk	Technically feasible Cost <$2B (~$910M) High Risk	Technically feasible Cost <$2B (~$1.1B) High Risk
Navigation Channel Dredging ($700M)				Technically Feasible Cost >$2B (~$2.5B) High Risk	Technically feasible Cost <$2B (~$1.9B) Low Risk	Technically feasible Cost <$2B (~$720M) Low Risk	Technically feasible Cost <$2B (~$760M) Low Risk	Technically feasible Cost <$2B (~$900M) Low Risk
Monte Lirio ($1.8M)					Technically feasible Cost >$2B (~$3.0B) High Risk	Technically feasible Cost <$2B (~$1.8B) High Risk	Technically feasible Cost <$2B (~$1.9B) High Risk	Technically feasible Cost ~ $2.0B High Risk
Bayano Reservoir Municipal & Industrial Water Offsets ($1.2)						Technically feasible Interim measure pending Bayano M&I offsets Cost <$2B (~$1.2B) Low Risk	Technically feasible Cost <$2B (~$1.3B) Low Risk	Technically feasible Cost <$2B (~$1.4B) Low Risk
Lower Alhajuela, 190' (Federico Guardia intake extension) ($23M)							Technically feasible Cost <$2B (~$86M) Low Risk	Technically feasible Cost <$2B (~$220M) Low Risk
Lowering Gatún Lake Operation Level ($62M)								Technically feasible Cost <$2B (~$260M)

(2) Combined Measures Second Semi-Quantitative Assessment

The second semi-quantitative screening incorporated more in-depth analysis. The PC IWRM Study PDT, using 5% analysis findings, recommended excluding Trinidad segmentation, Monte Lirio segmentation and Raise Gatún Lake from future alternatives. Table 6-9 visually represents the results of the second semi-quantitative screening.

Table 6-9: Combined Measures Second Semi-Quantitative Assessment

	Caño Quebrado with pumping ($170M)	Raise Gatún Lake/BEC Spillway ($850M)	Navigation Channel Dredging ($700M)	Monte Lirio ($1.8B)	Bayano Reservoir M&I Water Supply Offsets ($1.2B)	Lower Alhajuela, 190' (Federico Guardia intake extension) ($23M)	Lowering Gatún Lake Operation Level ($62M)	Salinity Study Measures ($200M)
Trinidad ($2.3B)	Technically feasible Cost >$2B ($2.5B) High Risk	Not technically feasible Cost >$2B (~$3.2B) High Risk	Technically feasible Cost >$2B (~$3B) High Risk	Not technically feasible Cost >$2B (~$4.2B) High Risk	Technically feasible Cost >$2B (~$3.6B) High Risk	Technically feasible Cost >$2B (~$2.4B) High Risk	Technically feasible Cost >$2B (~$2.4B) High Risk	Technically feasible Cost >$2B (~$2.6B) High Risk
Caño Quebrado with pumping ($170M)		Not technically feasible Cost >$2B (~$1.0B) High Risk	Technically feasible Cost <$2B (~$870M) Medium Risk	Technically feasible Cost ~ $2.0B High Risk	Technically feasible Cost <$2B (~$1.4B) Medium Risk	Technically feasible Cost <$2B (~190M) Medium Risk	Technically feasible Cost <$2B (~$230M) Medium Risk	Technically feasible Cost <$2B (~$370M) Medium Risk
Raise Gatún Lake/BEC Spillway ($850M)			Technically feasible Cost <$2B (~$1.5B) High Risk	Not technically feasible Cost >$2B (~$2.6B) High Risk	Technically feasible Cost >$2B (~$2.1B) High Risk	Technically feasible Cost <$2B (~$870M) High Risk	Technically feasible Cost <$2B (~$910M) High Risk	Technically feasible Cost <$2B (~$1.1B) High Risk
Navigation Channel Dredging ($700M)				Technically Feasible Cost >$2B (~$2.5B) High Risk	Technically feasible Cost <$2B (~$1.9B) Low Risk	Technically feasible Cost <$2B (~$720M) Low Risk	Technically feasible Cost <$2B (~$760M) Low Risk	Technically feasible Cost <$2B (~$900M) Low Risk
Monte Lirio ($1.8M)					Technically feasible Cost >$2B (~$3.0B) High Risk	Technically feasible Cost <$2B (~$1.8B) High Risk	Technically feasible Cost <$2B (~$1.9B) High Risk	Technically feasible Cost ~ $2.0B High Risk
Bayano Reservoir Municipal & Industrial Water Offsets ($1.2)						Technically feasible Cost <$2B (~$1.2B) Low Risk	Technically feasible Cost <$2B (~$1.3B) Low Risk	Technically feasible Cost <$2B (~$1.4B) Low Risk
Lower Alhajuela, 190' (Federico Guardia intake extension) ($23M)							Technically feasible Cost <$2B (~$86M) Low Risk	Technically feasible Cost <$2B (~$220M) Low Risk
Lowering Gatún Lake Operation Level ($62M)								Technically feasible Cost <$2B (~$260M)

6.6 *Measures Recommended for Alternatives Development*

Measures recommended to be carried forward are:

- Caño Quebrado with Pumping
- Navigation Channel Dredging
- Bayano Reservoir M&I Water Supply Offsets
- Lower Alhajuela Operating Level (190’, Federico Conte Guardia Intake Upgrades)
- Lower Gatún Lake Operating Level (70’ Water Intakes)
- Salinity Study Measure (75% Use of Water Savings Basins)

Nonstructural measures recommended for combination into alternatives in the 15% design and analysis include the following:

- Municipal and Industrial Water Withdrawal Cap
- Crossfilling
- Modifications to Under Keel Clearance Policies

Structural and nonstructural measures will be combined into alternatives in the 15% design phase. The development of a preliminary alternative array is described in Chapter 7 of this report.

7. PRELIMINARY ALTERNATIVE ARRAY DEVELOPMENT

7.1 Base Measures to be Included in All Alternatives

Previous sections have described measures identified by the PDT for inclusion in all future alternatives. These measures were identified to be included because they have either been prioritized for early implementation (for example, Salinity Study measures) or because they are non-structural measures that can be implemented without any additional costs or coordination with outside stakeholders. Other measures were identified to be included in the base set of measures due to the modest investment and clear benefits. The base measures that are included in all recommended alternatives include:

- **Salinity Study** – The measures in the parallel Salinity Study are anticipated to provide 75% utilization of the water savings basins.
- **Municipal and Industrial Water Withdrawal Cap** – Limiting future growth of water extraction for municipal supply purposes was included in the base set of measures. This assumes the measure is acceptable and viable for implementation within current Panamanian water resources policies and laws.
- **Crossfilling** – Crossfilling at Panamax locks is incorporated into future alternatives to the maximum extent possible to save water during drought periods. An understanding of the opportunities for implementation of this measure while maintaining salinity targets is necessary for its implementation.
- **Lowering of Alhajuela Operational Pool** – This measure was identified to have a small investment and a high benefit-cost ratio. If this measure can be implemented through coordination with the appropriate agencies, it is recommended to be included in the base set of measures.
- **Lowering of Gatún Operation Pool** – Lowering Gatún Lake's operational pool by converting existing, fixed intakes to floating intakes allows operational flexibility under the most severe drought condition. It is included in the base set of measures.

Policy modifications establishing Under Keel Clearances can also be included in the base measure list, although changing UKC policies provides modest benefits to some Neopanamax vessels. This measure can be implemented independently of the feasibility study and will not have significant influence on the selection of an alternative plan.

7.2 *Preliminary Alternatives Development*

Alternative measures have been developed in addition to the base set of measures identified in Section 7.1. Each preliminary alternative includes the set of base measures because base measures provide significant benefits for low cost and can be implemented in the near term. Preliminary development focused on identifying alternatives that could achieve desirable levels of navigation reliability for an acceptable investment. Measures assumed to be eliminated in measures screening were included in the preliminary alternatives analysis to quantitatively confirm their exclusion was appropriate.

The PDT used navigation reliability, cost, and best professional judgement to gauge potential alternatives performance. The actual performance of the measures will be assessed in the next phase of the feasibility study. This information was compared to assumptions regarding plan selection (reference Section 3.4 of this document). The plan selection assumptions are that the selected plan should yield navigation reliability equal to or better than existing navigation reliability and a solution's cost should not exceed $2,000,000,000.

Reference Table 7-1 for a visual representation of the preliminary alternatives analysis. Preliminary risk assessment determinations are discussed in Section 5.5.

Table 7-1: Preliminary Alternatives Assessment

Alternative Description	All Measures Necessary	Cost	Expected Navigation Reliability	Risk	Alternative Carried Forward
Trinidad + Monte Lirio + Bayano + Raise Gatún + Dredging + Base Measures	No	$7,210,000,000	~100%	High	No
Monte Lirio + Bayano + Raise Gatún + Dredging + Base Measures	No	$4,840,000,000	~100%	High	No
Trinidad + Dredging + Base Measures	Yes	$3,350,000,000	80-90%	High	No
Bayano + Dredging + Raise Gatún + Base Measures	No	$3,050,000,000	~100%	High	No
Monte Lirio + Raise Gatún + Base Measures	Yes	$2,930,000,000	80-90%	High	No

Alternative Description	All Measures Necessary	Cost	Expected Navigation Reliability	Risk	Alternative Carried Forward
Monte Lirio + Dredging + Base Measures	Yes	$2,770,000,000	>90%	High	No
Monte Lirio + Dredging + Base Measures	Yes	$2,770,000,000	>90%	High	No
Trinidad + Base Measures	Yes	$2,660,000,000	80-90%	High	No
Bayano + Raise Gatún + Caño Quebrado + Base Measures	Yes	$2,530,000,000	>95%	High	No
Bayano + Raise Gatún + Base Measures	Yes	$2,360,000,000	>95%	High	No
Bayano + Dredging + Caño Quebrado + Base Measures	Yes	$2,270,000,000	>95%	Medium	Yes
Bayano + Dredging + Base Measures	Yes	$2,200,000,000	>95%	Low	Yes
Monte Lirio + Base Measures	Yes	$2,100,000,000	80-90%	High	No
Raise Gatún + Dredging + Caño Quebrado + Base Measures	Yes	$2,000,000,000	>95%	High	No
Raise Gatún + Dredging + Base Measures	Yes	$1,830,000,000	>95%	High	No
Bayano + Caño Quebrado + Base Measures	Yes	$1,680,000,000	>90%	Medium	Yes
Bayano + Base Measures	Yes	$1,510,000,000	>90%	Low	Yes
Raise Gatún + Caño Quebrado + Base Measures	Yes	$1,310,000,000	80-90%	High	No
Dredging + Caño Quebrado + Base Measures	Yes	$1,150,000,000	>90%	Medium	Yes
Raise Gatún + Base Measures	Yes	$1,140,000,000	80-90%	High	No
Dredging + Base Measures	Yes	$982,000,000	>90%	Low	Yes
Caño Quebrado + Base Measures	Yes	$456,000,000	<80%	Medium	No

Alternative Description	All Measures Necessary	Cost	Expected Navigation Reliability	Risk	Alternative Carried Forward
Base Measures	Unknown	$286,000,000	Unknown	Low	Yes[29]

Conclusions of the analysis presented in Table 7-1 and additional findings from the evaluation of measures include the following:

- Due to cost constraints, two major measures, at most, can be combined into an alternative. The base measures and Caño Quebrado can be added to a maximum of two major measures.
- Trinidad with or without pumping
  - Trinidad with or without pumping cannot be effectively combined with another major measure due to high costs.
  - Trinidad does not achieve reliability targets as a single measure.
  - It is expected, based on today's information, that Trinidad will require additional spillway capacity on the order of magnitude of the BEC spillway. Alternatively, the operational pool storage would have to be significantly reduced at the end of the rainy season to ensure sufficient flood storage. Both options would result in a significantly lower benefit-cost ratio than is reported in this study, further contributing to the recommendation for screening Trinidad as a measure.
  - Trinidad is a high-risk measure. Pursuing high risk measures is unreasonable given other alternatives can achieve the project objectives at lower cost.
  - Trinidad is recommended to be screened from Study A – In Authority Measures. This recommendation does not preclude the Trinidad measure from being combined with measures that could be considered in Study B.
- Monte Lirio
  - The Monte Lirio measure does provide sufficient levels of reliability benefits on its own.

[29] The Base Measures alternative is advancing into the feasibility study. Feasibility Study B (outside the ACP Authority) measures will be added to it in future phases if it is determined that reliability targets cannot be achieved using within authority measures.

- The measure cannot be effectively combined with other measures such as Bayano or Dredging due to high cost.
- Monte Lirio would require additional spillway capacity.
- Monte Lirio is a high-risk measure. Pursuing high risk measures is unreasonable given other alternatives can achieve the project objectives at lower cost.
- Monte Lirio is recommended for screening from Study A – In Authority Measures.

- Raise Gatún Operational Pool
  - The evaluation assumes that additional spillway capacity is required. The cost of this measure, including the requirement to construct the BEC spillway is cost prohibitive.
  - The limited benefits associated with the Raise Gatún Operational pool could not be justified.
  - Raising Gatún Operational Pool is a high-risk measure. Pursuing high risk measures is unreasonable given other alternatives can achieve the project objectives at lower cost.
  - If the future USACE risk assessment finds that the BEC or other spillway capacity is required under the existing conditions and guide curve, then there would be an opportunity to re-evaluate raising Gatún Lake pool as part of any future spillway design.
  - Raising Gatún Lake's operational pool is recommended for screening from Study A – In Authority Measures.
- Caño Quebrado with pumping can be effectively combined with other measures to yield alternatives that achieve project objectives. Future references to Caño Quebrado assume pumping is part of the measure.

7.3 Final Measures Array

Individual measures that will be combined into alternatives are listed in Table 7-2. The base measures are called out in this table, and the measures are listed in order of estimated annual benefits.

Table 7-2: Final Measures Array

Measure	Estimated First Costs	Estimated Annual Benefits (AAEQ)
Salinity Study Measures (Base)	$200,000,000	$235,000,000
M&I Water Supply Cap (Base)	$0	$270,000,000
Dredging	$696,000,000	$135,000,000
Bayano M&I Water Offsets	$1,220,000,000	$128,000,000
Cross Filling Measures (Base)	$0	TBD in 15% Analysis
Lower Alhajuela Pool (Base)	$23,300,000	$19,400,000
Caño Quebrado with pumping	$170,000,000	$15,000,000
Lower Gatún Water M&I Intakes (Base)	$62,400,000	$0

Lower Gatún Lake M&I Intakes measure will be included in future alternatives, despite an apparent lack of annual monetary benefits. This is because the lowered M&I intakes provides operational flexibility and translates into converting draft reliability into increased transit reliability when water supply is stressed.

7.4 Initial Alternatives Array

Using the information from previous sections, the initial alternatives array developed from the final measures array is shown in Table 7-3.

Table 7-3: Initial Alternatives Array

No.	Alternative
Base	Salinity Study (WSB) + M&I Water Supply Cap + Cross Filling + Lower Alhajuela Pool + Lower Gatún Water M&I Intakes
1	Bayano M&I Offsets + Dredging + Caño Quebrado + Base
2	Bayano M&I Offsets + Dredging + Base
3	Bayano M&I Offsets + Caño Quebrado + Base
4	Bayano M&I Offsets + Base
5	Dredging + Caño Quebrado + Base
6	Dredging + Base

It is assumed that the ‘Base’ measure combination will be included in all alternatives because the combination of Water Savings Basins use, a cap on M&I water supply, Lowering Alhajuela pool, cross filling, and lowering the Gatún Water M&I intakes provide significant benefits at a relatively low cost.

8. OTHER WORK STATUS

8.1 Environmental and Social

8.1.1 Environmental and Social Impacts Analysis and Documentation

Republic of Panama Law 41 of July 1, 1998 (the Environmental Law) created a legal framework for protection, conservation and recovery of the environment and established that activities that may generate environmental risk must be assessed in an Environmental Impact Study (EIS). The Environmental Law and subsequent amendments and executive decrees include definitions of activities that require an EIS; EIS categories; defines significant, adverse impact and synergistic effects; specifies an EIS lifespan; requires an Environmental Management Plan (EMP); and outlines what and how an EIS can be modified.

ACP's environmental and social objectives are to efficiently operate the Panama Canal while managing and conserving water resources within the Panama Canal's hydrographic basin.

The ACP's environmental assessment process for projects within the ACP's patrimony is described in the Environmental Assessment Technical Manual, Revision 4, 2021 (Technical Manual). The Technical Manual thoroughly documents procedures to identify, analyze, address, and mitigate environmental and social impacts within the ACP's patrimony (the 100-foot contour surrounding Gatún Lake and the 260-foot contour of Alhajuela Lake).

The PC IWRM Study PDT and leadership agreed:

- ACP's Environmental Policy and Protection Division will lead the environmental and social impacts analysis and execute an EIS, should their Preliminary Environmental Assessment indicate an EIS is needed.
- An EIS and its coordination will be completed before the work assessed in the EIS is contracted.
- The USACE will provide technical support.

The PC IWRM Study PDT has defined environmental investigations needed to prepare an EIS. Those investigations are being contracted by ACP. The planned way forward for environmental and social impacts analysis and documentation is described in Table 8-1.

Table 8-1: Environmental and Social Impacts Analysis Way Forward

Measure	Within ACP Patrimony	Effort	Project Type	Details
Salinity Study/Use of Water Savings Basins	Yes	None	Nonstructural (Operational)	It is assumed an EIS is not required for operational changes that do not affect areas outside ACP's patrimony.
Lock Crossfilling and Operational Modifications	Yes	None	Nonstructural (Operational)	It is assumed an EIS is not required for operational changes that do not affect areas outside ACP's patrimony.
M&I Water Supply Cap	No	Unknown	Nonstructural (Operational)	It is assumed an M&I withdrawal cap would not require an EIS, but this will be re-assessed as the measure progresses.
Bayano M&I Offsets	No	Unknown	Structural	The Bayano environmental preliminary assessment will start in April 2023.
Navigation Channel Dredging	Yes	EIS II or III	Structural	This work is expected to begin in 2024 and will be completed before any contracting action.
Caño Quebrado	Yes	EIS II or III	Structural	This work is expected to begin in 2024 and will be completed before any contracting action.
Relocated Paraiso Intake; Lower Gatún Intakes	Yes	EIS II	Structural	Removing Paraiso Intake and relocating the intake to Gamboa will begin as soon as possible, with contracting expected no later than Quarter 4, Fiscal Year 2023. A Market Survey is ongoing in the Paraiso vicinity to inform the EIS. Analysis of lowering other Gatún Lake water intakes will begin closer to 2024 after the analytical scale is better defined.
Upgrades to water intakes at the Federico Guardia Conte Treatment Plant in	Yes	EIS II or III	Structural and Nonstructural (Operational)	A Socioeconomic, Ecosystem and Local Structures Survey was completed in January 2023. ACP is finishing specifications for a Socioeconomic and Environmental Impacts Evaluation for impacts associated with an

Measure	Within ACP Patrimony	Effort	Project Type	Details
Alhajuela Lake and updated lake management regime				updated water regime that includes lowering the lake elevation to 190' PLD.

As detailed earlier in this document, considering only Study A, it is unlikely the Trinidad segmentation, Monte Lirio segmentation and Raising Gatún Lake Operational Pool will be further analyzed.

8.1.2 Environmentally and Socially Acceptable

The PC IWRM PDT made a preliminary assessment of potential environmental and social impacts in site visits and reviewed earlier studies (reference Ingetec 2020, August 2020; Ingetec 2020, October 2020; USACE 1999a, Volume 1; and USACE 1999b, Volume II) to develop a preliminary assessment of potential environmental and social impacts. The preliminary findings were reviewed with the ACP, Environmental Policy and Protection Division, Office of Water Protection and their input incorporated. Table 7-2 describe the preliminary findings. These findings will be refined as the EIS more fully defines the environmental and social resources. Impacts will also be more fully defined as design moves forward. Mitigation will be detailed when this information is available.

Environmental impacts include effects to the natural environment within the physical project area, including biota. Social impacts include possible impacts to communities and individuals within the potentially affected area, as well as potential political and societal implications.

Table 8-2: Preliminary Assessment of Environmental and Social Impacts

Measure	Potential Impacts	Environmental		Social	
		Impacts	Mitigatable	Impacts	Mitigatable
Paraiso Intake Relocation	The Gamboa intake to Paraiso treatment facility distribution feature is partially off ACP owned land	None to Low	This is unlikely to have environmental effects because it is on previously disturbed property in a relatively developed area. It is unlikely to require mitigation.	Low to Medium	Typically, it is possible to get legal right-of-way or other legal covenant allowing a distribution pipeline crossing
Salinity Study/ Use of Water Savings Basins	Use of Water Savings Basins concentrates salinity in the locking water resulting in water above salinity operational levels being released into the Panama Canal System	Moderate to High	Cocolí Locks: Standardizing Panama Canal operations to control migration of high saline water into Culebra Cut and Gatún Lake would minimize impacts. Agua Clara Locks: The viability of measures to preclude sea water from entering Gatún Lake are being examined in a separate Salinity Study. The outputs of this analysis will inform the final report.	None	This measure is within ACP authority and boundaries. It is unlikely to have social effects.
Lock Crossfilling and Operational Modifications	Cross filling concentrates salinity in the locking water resulting in water above salinity operational levels being released into the Panama Canal System.	Moderate to High	Miraflores Locks: Standardizing Panama Canal operations to control migration of high saline water into Culebra Cut and Gatún Lake would minimize impacts. Gatún Locks: The viability of measures to preclude high saline	None	The measure is within ACP authority and boundaries. It is unlikely to have social effects.

Measure	Potential Impacts	Environmental		Social	
			water from entering Gatún Lake are being examined in a separate Salinity Study. The outputs of this analysis will inform the final report.		
M&I Water Supply Cap	Minimal direct negative physical, environmental impacts from capping, but impacts from an alternate source of water supply for increasing future may result.	Low	Capping M&I withdrawals would minimally affect the Panama Canal hydrologic system environment because it would, in effect, be no change to the existing condition.	Moderate to High	As mitigation for this action, ACP or another Panamanian agency would have to locate or develop a viable water source for future, increasing water needs, and ensure the water could be treated and distributed.
Bayano M&I Offsets	Direct physical impacts would be associated with development of water treatment facilities and distribution infrastructure. Operations may change the existing water regime. Social impacts may be associated with changes in operations at Bayano Lake.	High	Methods to control, mitigate, minimize, or compensate impacts may include infrastructure siting to avoid environmentally sensitive areas; compensation for property acquisition, hydropower generation impacts, etc.; relocations; water release protocols to ensure and balance downstream flows meeting hydropower, water supply and environmental purposes; and implementing water conservation programs, including upgrades to distribution infrastructure.	High	The Guna and Emberá indigenous groups have traditional lands in the Bayano Lake area. Impacts to these groups should be avoided or compensated.

Measure	Potential Impacts	Environmental		Social	
Navigation Channel Dredging	Deepening the existing navigation channel would have temporary impacts within the existing channel footprint.	Low to Moderate	Dredging may require special operations to minimize impacts during execution, such as scheduling when activities can occur given transits. Preliminary evaluation is that existing dredged disposal areas have adequate volume to accept dredged material. Impacts and mitigation will be revisited if further analysis reveals there is inadequate dredged material disposal.	None	The measure is entirely within ACP authority and boundaries. It is unlikely to have social effects.
Caño Quebrado	Significant permanent and temporary physical impacts would be associated with construction and operation of the project. Communities and individuals in the vicinity could be affected.	High	Water quality could be impacted when direct water exchange with Gatún Lake is interrupted. A water pumping or other protocol could be implemented to ensure water quality is maintained; features designed as part of the proposed infrastructure could facilitate water exchange and continued natural function (habitat, nurseries, etc.).	Moderate	Private property and established communities adjacent to Caño Quebrado could be impacted by this measure. Mitigation would be specific to the impacts, but could consist of property acquisition, relocations or rebuilds; infrastructure design features to ensure passage to Gatún Lake and Caño Quebrado upper reaches are not interrupted, such as a lock allowing small vessels to transit; and financial reimbursement for losses (income, property, etc.).

Measure	Potential Impacts	Environmental		Social	
Lower Gatún M&I Water Intakes	Minimal environmental and social impacts are expected to result from lowering water intakes.	Low	As currently conceptualized, the effort would temporarily affect existing infrastructure on previously disturbed property. Mitigation is unlikely to be needed.	Low	Permanent social impacts are unlikely because project effects are localized, temporary, and do not change the current conditions, the existing project footprint or land use. Temporary impacts associated with construction are possible. If necessary to accommodate the surrounding area, construction mitigation such as dust control, limiting activities to daylight hours, etc. could be implemented
Lower Alhajuela M&I Water Intakes and updated lake management regime	Minimal environmental and social impacts are expected to result from lowering water intakes. Regularly drawing down Alhajuela Lake to elevations 190' or 205' PLD may impact water quality in the lake.	Low Medium-High	Alhajuela Lake has had water quality issues in the past that resulted in eutrophication and low dissolved oxygen. An investigation into water quality concerns and conditions that might impact water quality and a Standard Operating Procedure that acknowledges and manages for water quality concerns could mitigate this potential issue.	Low	Permanent social impacts are unlikely because project effects are localized, temporary, and do not change the current conditions, the existing project footprint or land use. Impaired water quality could have social effects if it interferes with water withdrawal, treatment or distribution.

8.2 Multi-Criteria Decision Analysis

The Multicriteria Decision Analysis (MCDA) in the PC IWRM Feasibility Study will be used to assist decision-makers in selection of a recommended plan. MCDA is a tool to evaluate and compare alternative plans based on their ability to achieve project objectives. MCDA helps evaluate trade-offs between study objectives and associated criteria that cannot be directly compared (e.g., monetary benefits and environmental impacts).

Criteria measure an alternative plan's ability to meet objectives. The study will estimate a score for each alternative plan's performance in each criterion during the 15% design analysis. MCDA modeling combines the alternative plan's performance scores with subjective criteria weights that quantify the relative value of each criterion in plan selection. The resulting totals allow the study to compare and rank alternative plans.

The flowchart in Figure 8-1 below outlines the MCDA process.

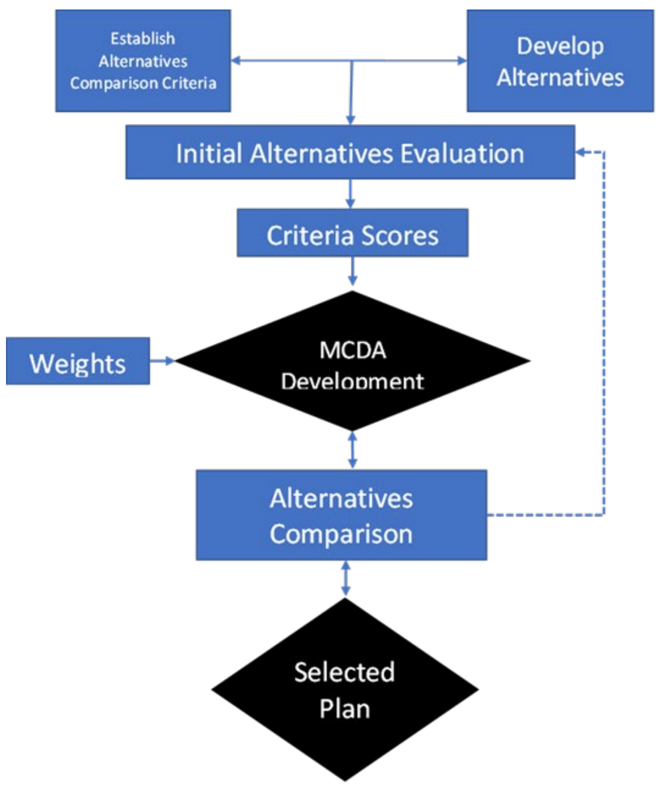


Figure 8-1: Multi-Criteria Decision Analysis Model Flowchart

The study team developed measures, combined the measures into alternatives and developed alternatives comparison criteria during the 5% analysis. Following ACP leadership concurrence on the alternatives array, the study team will score each alternative's performance and develop criteria weights. As shown by the dashed blue line in Figure 7-1, the MCDA process is iterative. As the list of alternatives narrows through further analysis and screening, the study team will compare plans with increasing granularity. The steps and specifics of the MCDA process are provided in the following table.

Table 8-3: Multi-Criteria Decision Process and Timeline

Step	Detail
Establish Alternatives Comparison Criteria	• Select alternatives comparison criteria. • Develop direct and swing weight questionnaire. • Finalize metrics to measure performance on each criterion. • Finalize calculation for how each metric will be measured.
Develop Alternatives	• Combine screened measures into alternatives for comparison.
Alternatives Milestone Meeting	• Final ACP concurrence on (1) criteria and (2) alternatives for evaluation and comparison.
Initial Alternatives Evaluation	• Alternatives 15% Analysis. • Begin ResSim analysis, assemble economic, environmental, and social metrics data for input into MCDA model.
Weighting	• Preliminary alternative criteria direct and swing weighting.
Criteria Scores	• Initial evaluation scoring each alternative on all criteria. • Normalize initial evaluation scores for consistent comparison.
MCDA Development	• Incorporate economic analysis maximum net present values. • Calculate weighted sum performance score for each alternative.
Alternatives Comparison	• Rank alternatives in order of preference (optional: refine criteria and alternatives and perform MCDA again). • Validate weighting using direct weight survey results.
Selected Plan	• Select preferred alternative.

8.2.1 MCDA Criteria

At the 09 August 2022 Measures Criteria and MCDA Workshop the study team developed MCDA criteria for 5 categories that align with organizational and study objectives. Subsequently, individual subject matter expert teams refined and finalized the list and developed metrics and calculations for each. Analysis completed for the Selected Milestone (15% analysis) will use this information to feed performance scores for each alternative across all criteria. Table 8-4 lists the initial criteria, their metrics and metric calculations developed by the study team for use in the PC IWRM Feasibility Study MCDA. These will be re-visited to ensure the PDT remains confident they are complete, reasonable, and applicable before weighting.

Table 8-4: Multi-Criteria Decision Analysis (MCDA) Categories, Criteria, Metrics and Calculations

Category	Criteria	Metrics	Calculation
Reliability Objective: To compare alternatives in terms of ensuring the Panama Canal's ability to reliably transit a variety of shipping vessels. Goal: Compare frequency and length of navigation restrictions for vessels with different draft depths.	Neopanamax/ Panamax Draft Reliability	Draft Reliability for 83' PLD (48' Draft)	Percentage of days from the period of record (57 years) in which the Gatún Lake level was above 83' PLD (48' Draft) based on the HEC-ResSim Model
	Transit Reliability	Neopanamax Transit Reliability	Simulated Transits / Total Demand in percentage based on the HEC-ResSim Model.
	System Total Yield	Firm Yield 79' (44' Draft)	Total Water Demand in number of equivalent transits (water yield based) that emptied the Gatún Lake for a specific level of 79' (44' draft) for the inflow data of 1997-1998, with the Gatún Lake starting at 88' PLD based on the HEC-ResSim Model.
Construction Objective: To compare conditions that might influence an alternatives' construction feasibility or time to operation. Goal: Compare physical conditions, cost, schedule, and uncertainty of alternatives' construction.	Construction Schedule	Maximum time required for the development and construction of the alternative.	Methodology applied to obtain execution time for each alternative, to be detailed by the USACE Measures Team. Number of days or years of duration of the construction of the alternative.
	Construction Cost	Cost required for the construction of the alternative.	MCACES Class 3 Cost Estimate based on USACE Regulation No. 1110-2-1302 "Engineering and Design Civil Works Cost Engineering"
Operations and Maintenance Objective: To compare alternatives' resource investments (time, money, others) throughout the lifetime of the project. It is assessed as investments required after the project is operational and separate from initial investments associated with planning, design, construction, etc. Goal: Represent ACP's investments to ensure an alternative's operability and safety throughout its lifespan.	Operating and Maintenance Costs	Costs of operations and maintenance on an annualized basis.	Class 3 Cost Estimate of Operations and Maintenance Costs based on USACE Regulation No. 1110-2-1302 "Engineering and Design Civil Works Cost Engineering"
	Impacts to Panama Canal operations	Qualitative impacts of the ability for vessels to navigate during the construction, normal operations, and extreme events.	A qualitative rubric will be developed to identify categories of impacts to Panama Canal operations with clear definitions of the categories used. The categories may include NEGLIGIBLE, LOW, MODERATE, HIGH. A team will define how these categories will be defined for impacts during construction of the measure, operations, and extreme conditions (for example floods).
Water Benefits and Sustainability of Future Demands Objective: To compare alternatives' costs and benefits to ascertain each alternative's rate of return on investment. Goal: Analyze revenues and benefit-cost ratios associated with alternatives and ACP investments.	Maximize net present value	Net present value of an alternative	Future cash flows based on an alternative's draft reliability, transit reliability and associated benefits (hydropower, etc.)

Category	Criteria	Metrics	Calculation
Climate Resiliency Objective: To evaluate the system's resiliency to future climate change. Goals: Ensure that navigation reliability is not impacted by future climate change.	System Resiliency to Future Climate Variability	Future Climate Resiliency Score	A quantitative rubric will be developed to assess the resiliency of an alternative plan to meet future navigation reliability targets across a range of future climate scenarios
Environmental Impacts Objective: To identify unacceptable environmental impacts within an alternative's project area. Goals: Assess potentially impacted environmental resources associated with an alternative and if impacts can be mitigated.	Carbon Emissions	Carbon emissions associated with increased transits and effects on local air pollution; estimated temporary increases in carbon emissions associated with construction	Estimated carbon emission increases attributable to increased transits
	Aquatic Habitat and Species	Impacts to aquatic habitat and species	Estimated hectares of permanently impacted water bottom, wetlands, and shoreline; estimated hectares of temporarily impacted water bottom, wetlands, and shoreline (construction, staging) and the area's recovery capacity
	Upland Habitat and Species	Impacts to upland habitat and species	Estimated hectares of permanently impacted upland habitat; estimated hectares of temporarily impacted upland habitat and the area's recovery capacity;
	IUCN Red Listed species and a species IUCN Red List Extent of Occurrence (EOO).	Presence of at-risk species or habitat in the project area	Potentially significant/listed species in the project area; hectares of potentially impacted significant habitat
Social impacts Objective: To identify unacceptable social impacts within an alternative's project area. Goals: Assess potential social impacts to individuals and communities associated with an alternative and if impacts can be mitigated.	Human Health and Safety in the study area	Probability of introducing pollutants, pathogens, unsafe conditions or creating conditions that increase risk to health or safety in the project vicinity	Types and pathways of pathogens and pollution that may affect human populations in the project vicinity
	Economic vitality in the study area, including subsistence fishing and farming and tourism related activities	Interruption of local population's ability to be self-sustaining; interruption of business activities	Populations or communities with subsistence activities that may be permanently or temporarily interrupted in the project area; businesses that may be permanently or temporarily unable to operate in the project area; ability of population, communities, or business to recover from disruption
	Social Connectedness, Vulnerability and Sense of Identity in the study area	Isolation of individuals or communities that identify with or have a heritage in a specific location	Presence of indigenous people, ethnic groups, or at-risk populations in the project area

8.2.2 Weighting

Weights and scores will be combined in the MCDA model to determine a final, aggregate score for each alternative. The study team will survey decision-makers within the ACP on the relative importance of each criterion. Surveys will be used to develop aggregated criteria weights for use in the MCDA model. A final alternative score is the sum of weighted criteria scores. This score can be used to compare and rank each alternative's performance.

The MCDA will result in a list of 'best' alternatives by numerical ranking and show an alternative's performance relative to the performance of other alternatives. The ACP can use these scores to inform plan selection.

9. RECOMMENDATIONS AND CONCLUSIONS

The primary milestone associated with this report is development of an array of alternatives from Study A within authority measures and Bayano M&I offset for further assessment in the next phase of study that better enables the ACP to provide more reliable navigation services and achieve improved vessel throughput consistency at the maximum system capacity.

The proposed array of alternatives within the confines of Study A measures includes the following:

- **Base Measures for Alternatives:** Five measures and 1 optional measure were combined to create a set of base measures for consideration and implementation in any future alternative. The recommended base measures include:
  - Salinity Study
  - Municipal and Industrial Water Withdrawal Cap
  - Crossfilling
  - Lowering Alhajuela Operational Pool
  - Lowering Gatún Operation Pool
  - Under Keel Clearance Policies Revision (Optional)

- **Alternatives:** In addition to the base measures, 6 alternatives were developed and are recommended to be included in the next phase of the feasibility study if Study A is to move forward without consideration of Study B measures. These alternatives include:
  - Bayano M&I Offsets + Dredging + Caño Quebrado + Base
  - Bayano M&I Offsets + Dredging + Base
  - Bayano M&I Offsets + Caño Quebrado + Base
  - Bayano M&I Offsets + Base
  - Dredging + Caño Quebrado + Base
  - Dredging + Base

Recommendations:

- **Initiate Study B to assess outside of Panama Canal basin and ACP authority measures.** No measure or combination of measures within the ACP basin and authority analyzed in Study A avoids future water limitations. The deliverable will be an Alternatives Milestone Meeting and Report that considers measures within and outside ACP basin and authority in developing alternatives for further consideration. Alternatives developed from the Study A AMM may not be suggested in Study B and do not require immediate advancement to 15% design.

- **Advance the analysis of Study A base measures to refine costs, benefits, and constructability.**

- **Conduct 15% Analysis and Design of Study B Alternatives Array following Study B AMM.** Completion of the Study B 5% Design analysis before 15% Study A analysis will allow alternatives re-formulation for a comprehensive array of in- and out-of-basin water solutions. It is recommended that the alternative array from the Study B AMM be evaluated to the 15% design level.

Key Findings:

- **Water Resource Policy of Panama:** Water resource policies and laws require the Panama Canal Authority to maintain sustainable navigation and to keep the canal always open to vessel transits. The ACP is also responsible for managing and safeguarding the Panama Canal hydrographic basin water resources for consumption and to prevent a reduction of supply. The Panama Canal Authority approves any projects that may affect the watershed and water uses.
- **Existing Conditions:** The existing conditions reliability is notably less than historically observed conditions. Approximately 1.3% of the time, the ACP may be restricted from being able to provide transits due to lack of water available for navigation. Historically, the ACP never faced transit restrictions due to lack of water.
- **2075 Conditions:** Without action, the future conditions preclude sustainable navigation. Navigation would not be able to occur approximately 14% of the time, and draft restrictions below 44' would be put in place approximately 8% of the time.
- **2035 Conditions:** Approximately half of the reliability reductions anticipated through 2075 are expected to occur by 2035.
- **Incompatibility of Increasing Navigation Transits while Increasing M&I Supply Withdrawals:** There is an incompatibility between increasing navigation throughput above existing conditions and continuing to increase M&I water supply withdrawals from the Panama Canal Watershed.
- **ACP may Prioritize Draft Reliability or Transit Reliability:** Through simple operational rule changes (Section 4.8) or modest investments in adjusting the

elevations of municipal water supply intakes (Section 5.6.15) the ACP can choose to prioritize draft reliability or transit reliability.

- **Loss of $400 million per year in the Future Conditions**. Without any interventions the reduction in reliability associated with the future conditions would be approximately $400,000,000 per year when compared to the existing conditions, given the 2025 toll structure.

- **Salinity Study Benefits:** The Salinity Study measures provide a significant improvement in the transit reliability. This is due to the significant reduction in daily demands when the water savings basins are utilized more frequently (expected results from the Salinity Study is to achieve 75% utilization of the WSBs, on average).

- **Municipal and Industrial Water Withdrawal Cap Benefits:** Water caps provide a significant improvement to transit reliability due to reductions in future daily water demands.

- **Combining Salinity Study and Municipal and Industrial Water Withdrawal Cap Benefits:** Combining the Salinity Study with a water withdrawal cap in the future provides reliability metrics approaching the reliability of existing conditions. Although the simulated reliability of combining these measures remains less than the existing conditions reliability, this combination of measures provides significant reliability improvements when compared to the future without project conditions.

- **Under Keel Clearance Policy Revision Benefits**: A modification to the Under Keel Clearance would provide a modest increase in draft reliability for most drafts. However, this measure does not address the water availability concerns, and will not affect transit reliability. This measure could be carried forward for additional analysis in future phases of the study or could be implemented independently of the feasibility study to gain additional value from the modest improvement in draft reliabilities.
- **Storage Measures:** Benefits to navigation reliability associated with in-basin storage measures is modest. Until the future overallocated water demands are reduced, the storage measures can only provide a modest benefit and the result is limited benefits. Future demands are greater than the available water on average, and any storage that would be realized during a very wet year would be quickly used up. Benefits of this storage is temporary because the volume of

water leaving the basin is greater than the inflows on average in the future demand condition.

The storage measures do provide additional benefit if combined with measures that reduce demands. This conclusion demonstrates the importance of any future alternative plan including measures that result in a reduction in future demands. Storage measures could only be combined with other measures and will not achieve acceptable levels of navigation reliability on their own merits.

- **Trinidad Measure**: The measure Trinidad with or without pumping does not provide sufficient levels of reliability benefits on its own. Combined with a high cost, the measure cannot be effectively combined with other measures such as Bayano or Dredging. Since Trinidad cannot be combined with another major measure and it cannot achieve reliability targets on its own, Trinidad is confirmed to be recommended for screening in Study A – In Authority Measures. and is not recommended to be advanced to the next phase of the study. The recommendation for screening Trinidad is based on its limited merits for storing water within the ACP basin. However, this recommendation does not preclude the Trinidad measure from being combined with measures that could be considered in Study B.

- **Monte Lirio Measure**: The measure Monte Lirio does not provide sufficient levels of reliability benefits on its own. Combined with a high cost, the measure cannot be effectively combined with other measures such as Bayano or Dredging. Since Monte Lirio cannot be combined with another major measure and it cannot achieve reliability targets on its own, Monte Lirio is confirmed to be recommended for screening. It is not recommended to be advanced to the next phase of the study. However, this recommendation does not preclude the measure from being combined with measures that could be considered in Study B.

- **Raise Gatún Measure:** The Raise Gatún Operational pool currently assumes that additional spillway capacity is required, and the cost of this measure includes the requirement to construct the BEC spillway. Due to the limited benefits associated with the Raise Gatún Operational pool, the costs to construct this measure (including the BEC spillway) could not be justified. The Raise Gatún Operational Pool is recommended for screening as part of this current study. However, if the future USACE risk assessment finds that the BEC spillway (or other spillway) capacity is required under the existing conditions and guide curve, then there would be an opportunity to re-evaluate the raise Gatún Pool measure as part of the spillway design.

- **Single Measure will not Achieve Reliability Goals:** This phase of the study has confirmed that the reliability goals of the future Panama Canal cannot be achieved through the implementation of a single measure. This was described in the letter from the ACP Administrator (Attachment 1). There is not a single measure within the Authority of the ACP that will achieve the current conditions level of reliability in the year 2075. Therefore, several measures will be required to be combined into alternatives to achieve future reliability targets.

- **Study B Measures:** In addition to the full development of the Bayano measure, benefits (without 5% design and cost) were developed for three Study B measures (Rio Indio, Caribbean Diversions, and Upper Chagres). The Study B measures found to be effective at significantly improving navigation reliability are the Rio Indio and Caribbean Diversions. The Rio Indio project has been developed through other studies in the past and was shown to provide greater benefit than any other single measure analyzed in Study A. The Caribbean Diversions project would also provide significant benefits, although this project is still highly conceptual.

- **Base Measures Analyzed for Combinations in Study B:** The base measures are also recommended to be analyzed alone in the next phase of the feasibility study. The base measures should be included in an independent analysis, and Study B measures (outside of the authority of the ACP) could be added to the base measures to achieve improved future reliability metrics.

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11. GLOSSARY AND ACRONYMS

Alternative Milestone Meeting (AMM): The first key milestone in the feasibility study. This milestone identifies the list of recommended alternatives that will be analyzed in the feasibility study.

Autoridad del Canal de Panama (ACP): The administrative body responsible for operation and maintenance of the Panama Canal.

Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA): The EBITA is used as the proxy for annual value generated in this current study.

Environmental Impact Study (EIS): A Panamanian document prepared to identify and assess environmental and social impacts and risks that might result from implementation of a project or action. This document should not be confused with an Environmental Impact Study.

Equivalent Transit (ET): A standardized unit of volume equal to 208,000 m^3 (55 million gallons). This volume is approximately equal to the total amount of water used to fully transit a vessel from ocean to ocean in the Panamax locks.

Instituto de Acueductos y Alcantarillados Nacionales (IDAAN): The National Institute of Aqueducts and Sewers is the Panamanian agency responsible for municipal and industrial water supply, distribution, and treatment.

Integrated Water Resources Management (IWRM): A holistic approach to development and management of water, land and related resources that equitably maximizes economic and social welfare and supports sustainability of affected ecosystems.

Mean Sea Level (MSL): The average surface elevation of global, coastal water bodies.

Millions of Gallons Per Day (mgd): A water standard of measure that typically indicates use or yield.

Municipal and Industrial (M&I): Relating to a product or services provided by a government body or for a process creating or changing raw material into another form. In the context of this report, it primarily refers to making water available for domestic consumption.

Neopanamax Vessel: Vessels with maximum allowable dimensions of 168-foot beam x 1,214-foot length overall x 50-foot draft.

Panamax Vessel: Vessels with maximum allowable dimensions of 168-foot beam x 966 length overall x 39.5-foot draft.

Period of Record (PoR): The 57-year record of conditions within the Panama Canal being used in analysis.

Practical salinity unit (psu): A unit of measure of dissolved salt content in water as a function of electrical conductivity to estimate ionic content.

Precise Level Datum (PLD): Level of the plane that is used as a reference to measure heights and elevations. For the Panama Canal, the 0.00 PLD adopted was the mean sea level as determined in the pre-construction period. "Atlantic Mean Low Water (MLW)" is equal to –0.4 feet (-0.12 meters) PLD; "Pacific Mean Low Water Springs (MLWS)" equals –7.6 feet (-2.32 meters), PLD; "Gatun Mean Lake Level (MLL)" is equal to 85 feet (25.91 meters) PLD; and "Miraflores Mean Lake Level (MLL)" is equal to 54 feet (16.46 meters) PLD.

Probable Maximum Flood (PMF): A hypothetical flood event utilizing a combination of the most severe critical meteorologic and hydrologic conditions reasonably expected in a region.

Project Delivery Team (PDT): The Autoridad del Canal de Panama and U.S. Army Corps of Engineers professionals involved in developing and producing the final IWRM Feasibility Study deliverables.

Attachment 1:

ACP Administrator Letter to USACE South Atlantic Division Commander

CANAL DE PANAMÁ

January 20, 2022

Brigadier General Jason E. Kelly
South Atlantic Division Commander
US Corps of Engineers (USACE)

Dear Brigadier General Kelly:

Following up to our last communication, I wish to share with you that we are eager to take on this endeavor with USACE.

I detail below specifics I wanted to discuss during our postponed January 10, 2022 meeting in Atlanta, amidst the limitations imposed by COVID.

As we take on this joint effort, we hope to build from prior experience and information. We must consider projects analyzed by USACE from 1999 – 2002, as well as those carried out by the ACP, as we face realities that should shape how we pursue future tasks.

Among the facts to be considered, we must note that we are currently extracting an increasing amount of water from our lakes for potable water production for municipal and industrial activities (M&I) and for Canal operations. In the meantime, we concurrently consume fresh water to maintain water quality in Gatun Lake and we face greater rain pattern unpredictability. Furthermore, we foresee that efforts to expand water sources beyond current Canal watershed limits will face difficulties that could threaten the schedule and even their viability.

On the positive side, as can be seen in Figure 1 below, on average, rainfall within the existing watershed allows for potable water production and transits, leaving enough water for quality control, electrical generation and spilling at the end of the rainy season. Validating these figures, during calendar year 2021 rain levels were slightly higher than average, making it possible to use over 2,000 Hm^3 for hydrogeneration and water quality control, while satisfying all freshwater extractions for M&I and Canal transits. If we could save the surplus or a portion of it in rainy years (water used for quality control, hydrogeneration and spilling), the reserves should help with the shortcomings in case of drought.

These elements allow and impose the need to find solutions within our control, understanding that, we will require several complementary answers to reach the desired long run sustainability results. We have determined that a single project to provide our water needs will not be economically feasible. We should reduce, as much as possible, the need to resort to solutions beyond the Panama Canal's authority that may face external resistance or interference, leaving such alternatives, if needed, for whatever amounts of water are not obtained within our current jurisdiction.

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Brigadier General Jason E. Kelly
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January 20, 2022

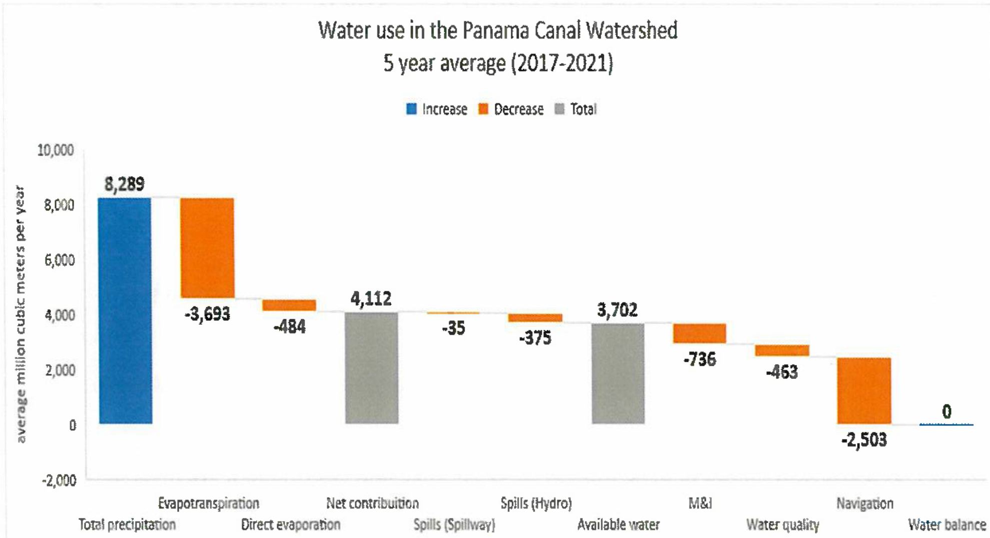

Figure 1: Average water yields and uses from 2017 to 2021 within the Panama Canal Watershed.

Taking this into account, we would like to implement an agile selection process which will allow to proceed expeditiously with projects found to add significant value without having to wait for results and comparisons with other projects.

We are confident that the following solutions would provide added value and significant yields and may be reviewed independently:

- Saltwater migration mitigation: The Canal is using about six (6) equivalent transits per day to maintain Gatun Lake water quality. We should reduce the amount of water currently used for this purpose, without negatively affecting Gatun Lake's water quality. In theory, electro-mechanical solutions may be implemented relatively quickly with reasonable investment and operating costs. We could consider managing and operating the Neopanamax Locks water saving basins in an innovative manner.

- Segmenting Gatun Lake (*figure 2*): These projects were considered in the USACE studies in 1999, the larger of these segments being the lake that may be created with the construction of the Trinidad Dam Project. New construction technology or a revised alignment may help overcome the challenges originally found associated with geological/soft soil and the need to build the dam in a flooded condition.

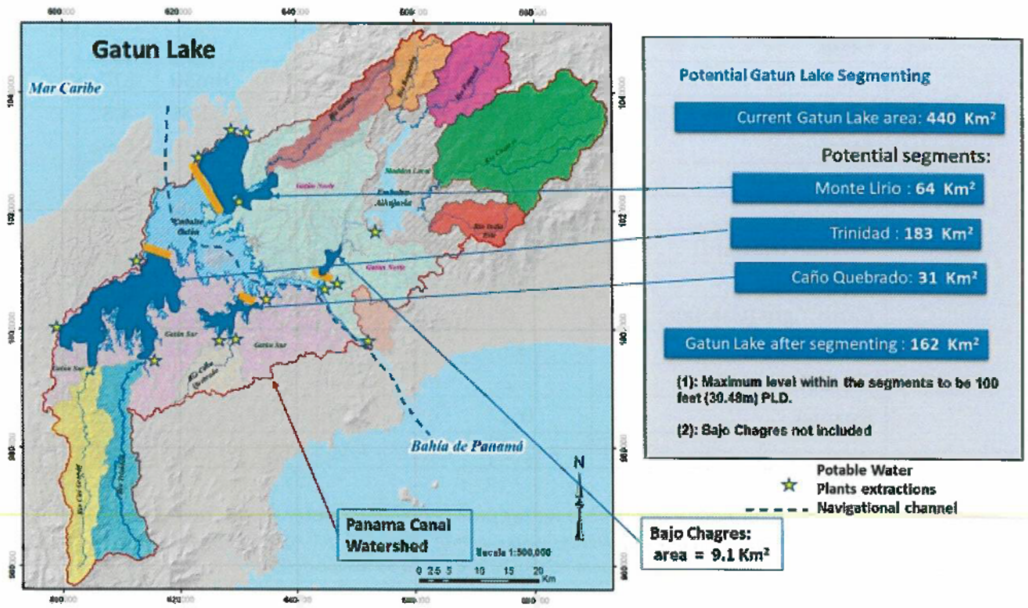

Figure 2: Gatun Lake segmenting projects

- Raising and/or lowering the Alhajuela Lake level limits. This potential solution will add water storage capacity available for drier years. It may require improvements in existing ACP and IDAAN (Institute of Water Supply and Sewer Systems) facilities, but the cost of such improvements may be small in comparison with the benefits to be achieved if the project is implemented.

- Deepening the navigational channel, particularly to reduce or shorten the periods for draft restrictions.

We would also like to explore and fast track the possibility of finding alternate sources suitable for relocating potable water extraction currently extracting within the Gatun and Alhajuela Lakes, particularly the Federico Guardia Conte potable water treatment plant, which extracts water from Alhajuela Lake for close to five (5) equivalent transits per day. Freshwater extraction for potabilization from our two lakes is significant and is increasing rapidly (see Table 1 below). The production capacity of these plants is expected to reach close to 12 equivalent transits soon, straining the system significantly.

Water extraction relocation to areas other than the Canal lakes implies solutions out of our watershed, but they may leave a significantly smaller footprint than other efforts and may be easier to implement than building infrastructure to transfer water to the Canal.

Potable water plants drawing water from Canal Lakes	Current			Projected		
	MGD	Hm3D	ET*	MGD	Hm3D	ET*
Federico Guardia (Chilibre)	250	0.95	4.55	265	1.00	4.82
Miraflores	50	0.19	0.91	50	0.19	0.91
Mount Hope	35	0.13	0.64	35	0.13	0.64
Mendoza	40	0.15	0.73	60	0.23	1.09
Arraiján (Howard)	0	0.00	0.00	65	0.25	1.18
Laguna Alta	20	0.08	0.36	45	0.17	0.82
Cerro Tigre (Gamboa)	0	0.00	0.00	85	0.32	1.55
Sabanitas	15	0.06	0.27	50	0.19	0.91
Río Gatún	2	0.01	0.04	2	0.01	0.04
Escobal	0.1	0.00	0.00	0.1	0.00	0.00
Total	412.1	1.56	7.49	657	2.49	11.95

Table 1: Capacity of potable water plants drawing water from Canal Lakes
**ET: Equivalent transits, average water quantity used for a full Panamax transit through the Panama Canal equivalent to 55 million gallons*

I am confident that, together, we will be able to find quality solutions that may produce quick, cost-effective, socially and environmentally acceptable operations. Some of these opportunities have already been discussed among USACE and ACP technical teams. Our mutual support conveying our urgency will make this effort even more effective.

Thank you once again for your support and I hope to be able to meet with you soon.

Sincerely,

Ricaurte Vásquez M.
Administrator

Attachment 2:

Desalination White Paper (ERDC)

Title: Review of three ACP Desalination Scenarios

INTRODUCTION

Need

The ACP completed the design and construction of the Cocolí and Agua Clara Locks in 2016. The expansion included a widening and deepening of the Gaillard Cut in the Panama Canal and the sea entrances, the construction of large shipping locks adjacent to the existing locks, and the construction of water saving basins. The expanded canal services large vessels of the Neopanamax ship category. A three-lift lock configuration with each of the three lock chambers is connected to three separate water saving basins (WSBs), was constructed. These WSBs reduce the loss of water caused by lock operation.

Since the construction of the new locks, salt water from the ocean intrudes into the canal system through normal lock operations. This intrusion is the result of water density flows (that is density differences between the tail bay, lock chambers, and forebay), mixing processes, ship-induced flows when ships sail into or out of the successive lock chambers, and lock chamber filling and emptying (F/E) processes. Some of the intruded salt water is also drawn back when the upper locks are levelled up with water from the forebays and when ships exit the lock chambers into the forebays.

Presently, Gatún Lake has a freshwater quality. Possible saltwater intrusion into Gatún Lake caused by the operation the Neopanamax locks is a very important societal and environmental concern for the ACP. The freshwater quality at the drinking water intakes of Panama City and Colón must be preserved at levels suitable for human consumption. The ACP requires salinity values to be less than 0.30 psu (practical salinity units) at those intakes and no more than 1.0 psu within Gatún Lake.

As part of a separate salinity study, the U.S. Engineer Research and Development Center (ERDC) is assisting the ACP in the evaluation of the effectiveness of salinity barriers proposed as measures to reduce saltwater intrusion into the Agua Clara Locks' chambers (Atlantic side) of the Panama Canal. The study is comprised of several components that include the development of physical and numerical modeling efforts of salinity intrusion processes and mitigation measures within the Neopanamax system.

While the above tasks are addressing many of the current needs, ACP requested an examination of desalination as an option to improve navigation reliability.

Scenarios

There are three (3) proposed scenarios that were developed on the behalf of ACP for consideration:

1. Pump and treat ocean water to Gatún Lake. This would include pumping 1 mil m^3d^{-1} of saltwater a distance of 4 km to a stage of 27.1 m above sea level. The initial saltwater would be 30 psu, with the goal of 0.2 psu or lower post-processing (1 day).

2. Treating the saline water in the ACP Water Savings Basins. This would include treating 104,000 m^3 in a batch process at two locations (one at Agua Clara and one at Cocolí) for a duration of 1 hour, and this would occur 12 treatments·d^{-1}. The water would be returned to the water savings basin (no head difference). PSU values are initially 5 psu. The goal is to achieve 0.2 psu values.

3. Treating brackish water (1.0 psu) at a water intake. The water intake pumps 50 million gallons per day (190,000 m^3d^{-1}). Goal is to achieve psu values below 0.3 psu. This would serve as an alternative design to relocation the Paraiso water intakes.

Table 1. Summarized in the table are the three scenarios that were used in the follow-on analyses.

Scenario	Description	Discharge (M m^3d^{-1})	Head (m)	Initial PSU	Goal PSU
A	Treat ocean water and pump to Gatún Lake	1	27.1	30	0.2
B	Treat water savings basin water and return	2.5	0	5	0.2
C	Treat water at the M&I intake	0.19	0	1	0.3

To address these scenarios, we first conducted a brief state-of-the-art census for desalination technologies, efficiencies, and status of desalination plants. Most desalination plants and scientific literature focuses on desalination for drinking water using electrical conductivity as a measure of saltiness (µS/cm) rather than a ppm, ppt or PSU. The drinking water range is variable by country and water source: 0-800 µS/cm. The World Health Organization's drinking water limit is 500 ppm. Because of this point of view, the data gathered is biased towards a stricter salinity standard than in consideration here.

BACKGROUND

(General) Desalination is any process that removes salts from water by separating the saline water into two parts – a low concentration of water (defied by the user, "product" water) and a high concentration of water ("brine" or "concentrate"). Desalination is often used in municipal, industrial, or commercial applications for the propose of creating drinking water or for water-reuse. The process also requires energy for operations, but energy to break the strong chemical bonds that are formed when salt (easily) dissolves into water (WHO 2011).

(Similarities of desalination processes) Generally, there are several processes that are included in desalination which tend to be in common for both technological approaches. First, the “raw” water must be extracted from a local source (i.e., river mouth, river, ground. Next, the water must be filtered for biota and large particles, such as suspended solids, to ensure that follow-on processes can be more efficient and reduce long-term operation and maintenance costs (Soliman *et al* 2021). Once the water has been pre-filtered, it goes through one of the established desalination processes (i.e., thermal or membrane), and the post-processed where the water quality is adjusted to meet drinking water or industrial use standards. The byproduct water or concentrate consists of dissolved compounds (i.e., metals, minerals, etc.) that are highly dependent on source water and thus the last step is the disposal of concentrates (El-Ghonemy 2018, Abdel-Jabbar et al 2007).

(Technology options) There are several commercial technologies on the market that can handle the requirement for desalination plants. The commercial-scale technologies are primarily centered around 2 principles: thermal (i.e., multi-stage flash, multiple-effect) and membrane (i.e., reverse osmosis [RO]), though there are other developing techniques that are limited thus far, such as vapor compression (VC; Table 1). The thermal technologies use heat for vaporization and condensation cycles to desalinate water. The membrane technologies use separation process via a semi-permeable membrane to desalinate the water. The top three (3) desalination technologies (noted by 1, 2, 3 in Table 1) represent 94% of the operational desalination facilities according to Soliman *et al* 2021. Reverse osmosis is used in 69% of the documented desalination facilities, followed by MSF at 18%, and then MED at 7% (Curto et al 2021).

Table 1. Commercially available desalination technologies (Saadat *et al* 2018, Curto *et al* 2021).

Thermal	Membrane	Others
Multi-stage flash distillation (MSF)[2]	Reverse osmosis (RO)[1]	Solar humidification (SH)
Multi-effect distillation (MED)[3]	Electrodialysis (ED)	Freezing distillation (FD)
Vapor compression (VC)	Forward Osmosis (FO)	Ion exchange (IE)

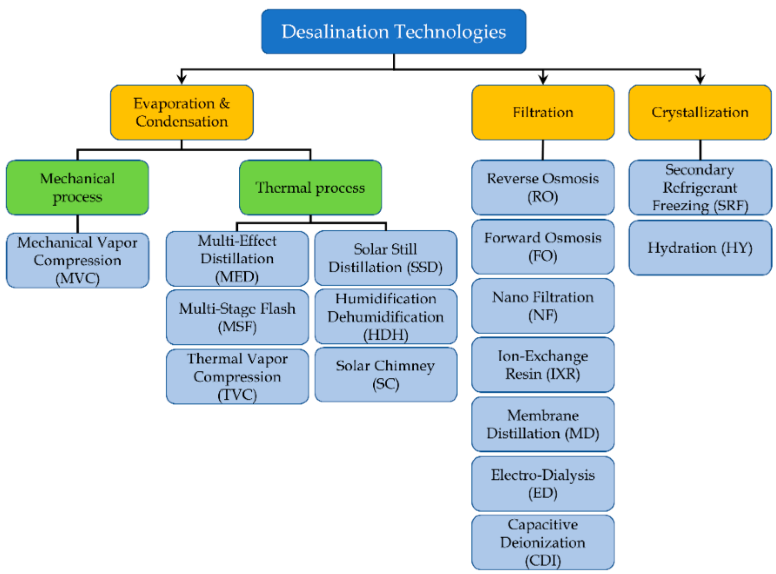

Figure 1. *The classification of desalination technologies by working principle. The idea of Evaporation and Condensation technologies is to supply thermal energy to seawater, producing a vapor, and then condensate it. Generally, filtration technologies are essentially based on a semipermeable membrane, i.e., a layer that shows a different mode of crossing behavior according to the sizes or nature of molecules. Finally, the Crystallization category comprises techniques that extract freshwater producing ice as intermediate product. (Curto et al 2021; Accessed 18 JAN 2023)*

(MSF) Multi-stage flash, a thermal process, requires a high energy requitement and thus commonly found installed with power plant for providing the needed energy. The common heating requirement is usually between 250–330 kJ/kg of products with electricity usage of 3–5 kW h/m^3 (El-Ghonemy 2018, Soliman et al 2021). As global perspective on climate change has shifted, the MSF technology has an advantage of combined cycle of heating and cooling internal streams that contribute to lower greenhouse gas emissions, and higher thermal efficiency (Soliman et al 2021). It is currently in use on ships and along coastlines like in USA, Middle East and Korea.

(MED) Multiple Effect Distillation (MED) process is designed to produce distilled water with steam or waste heat from power production or chemical processes, and/or to produce potable water. MED evaporator consists of several consecutive cells (effects) maintained at decreasing levels of pressure (and temperature) from the first (hot) cell to the last one (cold). The source water is heated in tubes with steam, usually by spraying saline water on them. Portion of the water evaporates, and afterward the steam enters the tubes. Each effect mainly reuses the energy from the prior stage, with consecutively lower pressures and temperatures after each one (Polat et al 2018). If high-pressure steam is available, for example, from a power plant, the efficiency of a MED plant can be further enhanced by using a steam ejector (Lange 2013). Due to low energy demand, multi-effect distillation system is equipped with thermal vapor compression (MED–TVC) and it is especially more interested than other thermal desalination processes. MED–TVC is known for its high-performance ratio, easy operation, and low maintenance (Polat et al 2018).

(RO) Reverse Osmosis is different from other water purification processes because of its use of a water permeable membrane for contaminant removal. This method utilizes the pressure differential created by the pressure of the feed water and the product water, and is known for removing dissolved solids, organic material, colloidal material, and some microorganisms (Saadat et al, 2018). Most of the RO plants, the system is divided into pretreatment, pumping, reverse osmosis, and post-treatment processes. Reverse osmosis is known better for treating brackish water ranging from 100-10,000 ppm but this process is also considered to be the most cost and energy efficient process for the desalination of seawater (Khan et al, 2021 and Saadat et al, 2018). The energy requirement of this desalination technique comes from pressurizing the saline feed, unlike thermal techniques that requires heating and enough latent energy for phase change to occur. The membrane must withstand the natural osmotic pressure of seawater, which is about 24 bar (350 psi). Efficacy of the process can be improved through a low salinity feed or low-pressure membrane and thus, lower operational costs.

Table 2. A brief overview of the advantage and disadvantages of desalination technologies (Eltawil et al 2009, Ibrahim et al 2020, Soliman et al 2021).

Process	Recovery & TDS	Advantages	Disadvantages
MSF	25–50% recovery in high temperature recyclable MSF plant <50 mg·L^{-1} TDS	• Lends itself to large capacity designs • Reliable technology w/ long operating life • Flashing rather than boiling reduces incidence of scaling • Minimal pre-treatment of feed water required • High quality product water • Plant process and cost independent of salinity level • Heat energy can be sourced by combining with power generation	• Large capital investment required • Energy intensive process • Larger footprint required (land and material) • Corrosion problems if materials of lesser quality used • Slow start-up rates Maintenance requires entire plant to shutdown • High level of technical knowledge required • Recovery ratio low
MED	0–65% recovery possible <10 mg·L^{-1} TDS	• Large economies of scale • Minimal pre-treatment of feed water required • Very reliable process • Minimal requirements for operational staff • Tolerates normal levels of suspended and biological matter • Heat energy can be sourced by combining with power generation • Very high-quality product water • Very low electrical consumption (<1.0 kWh m−3) • Operates at low temperature (<70 °C) and at low concentration (<1.5) • Produces steadily high purity distillate • Does not need complex pretreatment of seawater and are tolerant to variations of seawater conditions • Is highly reliable and simple to operate • Reduces civil works cost • Is simple to install • Has a low maintenance cost • Operates 24 h a day with minimum supervision • Ideal for coupling with power plants • Can be adapted to any heat source • Allows very high thermal efficiencies and savings in fuel costs (NAS 2008)	• High energy consumption • High capital and operational cost • High quality materials required as process is susceptible to corrosion • Product requires cooling and blending before potable water use
RO	30–60% recovery possible for single pass (>recoveries w/ multiple pass) <500 mg·L^{-1} TDS for seawater possible	• Lower energy consumption • Relatively lower investment cost • No cooling water flow • Simple operation and fast startup High space/production capacity • Removal of contaminants other than salts achieved • Modular design • Maintenance does not require entire plant to shutdown	• Higher costs for chemical and membrane replacement • Vulnerable to feed water quality changes • Adequate pre-treatment a necessity • Membranes susceptible to biofouling • Mechanical failures due to high pressure • Appropriately trained personnel recommended Membrane life expectancy around 5–7 years

	<less 200 mg·L^{-1} for brackish water		
ED	85–94% recovery possible 140–600 mg·L^{-1} TDS	• Energy usage proportional to salts removed not volume treated • Higher membrane life of 7–10 years • Operational at low to moderate pressures	• Leaks may occur in membrane stacks • Bacterial contaminants not removed by system and post-treatment required for potable water use
VC	~50% recovery possible <10 mg·L^{-1} TDS	• Developed process with low consumption of chemicals • Economic with high salinity (>50,000 mg/L) • Smaller economies of scale (up to 10,000 m3/d) • Relatively low energy demand Lower temperature requirements reduce potential of scale and corrosion • Lower capital and operating costs • Portable designs allow flexibility	• Start-up require auxiliary heating source to generate vapor • Limited to smaller sized plants • Compressor needs higher levels of maintenance

(Energy Consumption) The operations and maintenance economic costs associate with any facility is essential for consideration to evaluate associate risks and economics for a project. For this evaluation, facility operating cost, that is the energy requirement, is a good starting point for this refer and ability to compare the technologies under the proposed scenarios. Energy consumption of a desalination plant is influenced by numerous factors that are not addressed in the effort (e.g., design of the unit, quality of the raw seawater stream, material in use, and waste disposal). The energy consumption of MSF, MED, and VC re not sensitive to the amount of PSU in the water compared to the membrane desalination processes, such as RO and ED, that are extremely affected by the concentration of salt. When comparing the total consumed energy amount for seawater desalination methods to acceptable drinking limits (seawater) RO process with an energy recovery system requires less energy with around 4–6 kW h/m^3 (for the processing of 24,000 m^3/day for seawater, whereas, for brackish water it is about 2.1 kW h/m^3 (Manju and Sagar, 2017)), in contrast to MED and MSF methods with an amount of 14.45–21.35 kW h/m^3 and 19.58–27.25 kW h/m^3 of water, respectively.

Table 3. The estimate energy consumption of desalination technologies (Semiat 2008, Al-Karaghouli and Kazmerski 2013, Manju and Sagar, 2017, Pearson *et al* 2021, Curato *et al* 2021, Soliman *et al* 2021)

Process	Average Capacity (10^3 m^3d^{-1})	Input	Recovery Ratio	Water Quality (ppm)	Consumed Electrical Energy (kWh/m^3)	Consumed Thermal Energy (MJ/m^3)	Water Cost ($US/m^3)	Equivalent amount of electrical to thermal energy (kW h/m^3)	Total electricity consumed (kW h/m^3)
MSF	50-70	SW	0.22	10	2.5-6	190-390	0.56-1.75	15.8-23.5	19.6-27.3
MED	0.6-30	SW	0.25	10	1.5-2.5	230-390	0.52-1.5	12.3-19.1	14.5-21.4
RO (saltwater)	Up to 320	SW	0.42	400-500	3-6	--	0.45-1.72	--	4-6 with energy recovery system
RO (brine)	Up to 98	BW	0.65	200-500	1.5-2.5	--	0.26-1.33	--	1.5-2.5
ED	Up to 145	BW	0.9	150-500	2.6-5.5	--	0.6-1.33	--	2.6 for high TDS 0.7-2.5 for low TDS
TVC	10-35	SW	0.25	10	1.5-2.5	145-390	0.87-0.95	14.5	16.3
MVC	0.1-3	SW	--	10	6-12	--	2.0-2.6		

(Vulnerabilities) Desalination facilities are vulnerabilities and should include risk assessment of potential factors and steps for decreasing the risk to the plants. (Islam *et al* 2018, Tahir *et al* 2019)

Possible vulnerabilities:

- (Biological) T&E species entrainment, HABS, impacts on populations and community ecology
- Air and water quality impacts
- Natural disasters
- Localized spills of gas/oil/TIC/TIMS, and leakage of pipe/pipelines
- Drives increased energy consumption
- Component failure and need for redundancy
- Local footprint, co-location of desalination

Possible resilience measures:

- Security and emergency measure
- Water supply resilience through treatment ponds, reservoirs, aquifers, treated water
- Addition of pre-treatment technologies
- Portable RO systems
- Reduce freshwater demand through conservation actions (i.e., seawater or brackish water for toilet flushing)
- Increase awareness
- Floating desalination plants

RESULTS

(Combinations) Combination facilities or renewable energy sources were not reviewed. The subject matter is already quite complex, and more complex to account for increased variability by inclusion of more than one type of desalination effort. The below Figure 2 indicates possible options (Curto *et al* 2021), however we did not find substantial literature to extract actual operational costs.

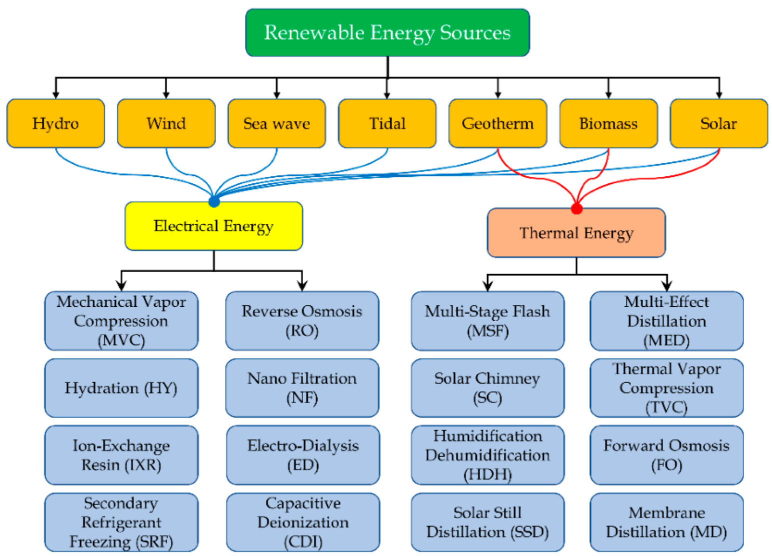

Figure 2. Possible coupling between desalination technology and renewable energy sources.

(Costs Estimations) The cost estimation is an important variable for moving forward on scenario selection. The chart below details the various cost parameters that are considered when determining an estimation. The individual factors causing and contributing to the overall cost of a project are largely the same regardless of the project. However, the magnitude of these factors vary amongst differing projects resulting in significant cost differences. Figure 3 shows factors or aspects of desalination facilities, in particular, focuses on seawater reverse osmosis; though many of these aspects are central to each type desalination facility regardless of the type. Each aspect is presented below along with qualitative estimates of costs. After that are a series of tables that detail costs associated with RO (sea water) estimate in USD, using 2012 data from California, US.

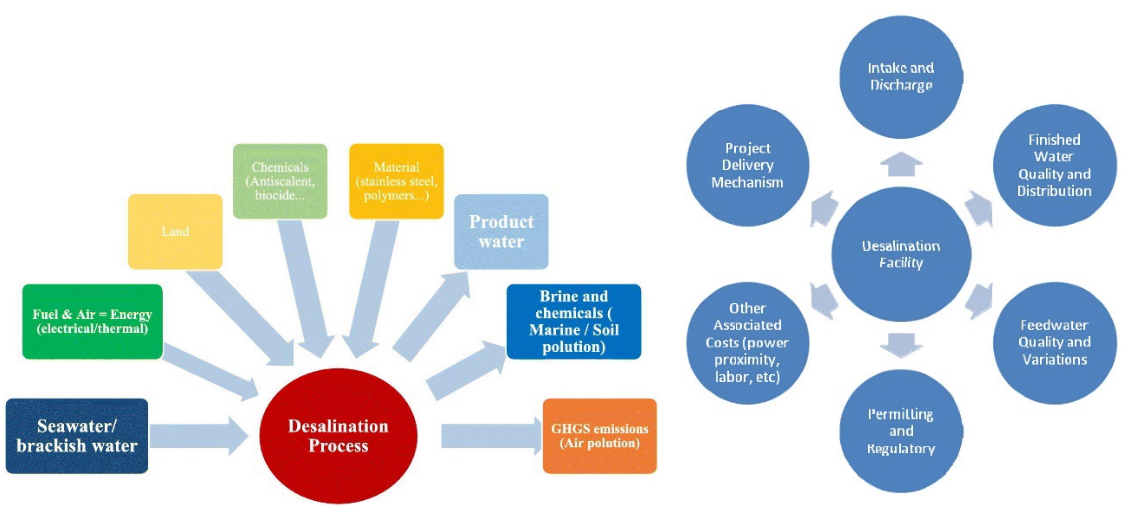

Figure 3. This is a figure of the categories that contribute to cost of an RO (seawater) project. Accessed 17JAN2023. https://watereuse.org/wp-content/uploads/2015/10/WateReuse_Desal_Cost_White_Paper.pdf

Table 4. Comparative water quality, costs, and reliability from various intake types. Accessed 17JAN2023 https://watereuse.org/wp-content/uploads/2015/10/WateReuse_Desal_Cost_White_Paper.pdf

Intake Type	Replace Cost (For equal capacity)	Relative Intake Space Requirements	Relative Pretreatments Space Requirements	Reliability
Beach Wells	Low	High	Theoretically Less	Variable based on subsurface lithology
Horizontal directional-drilled wells	Medium	High	Theoretically Less	Unknown
Radial wells	Medium	High	Theoretically Less	Unknown
Construction seabed/ infiltration gallery	High		Theoretically Less	Unknown
Submerged open intake	Medium-low	Low	More	High
Surface- open intake	Low	Low	More	High
Co-located intake	Low	Low	More	High

Table 5. Concentrate disposal costs (estimated from 2012, US Dollars). Accessed 17JAN2023. https://watereuse.org/wp-content/uploads/2015/10/WateReuse_Desal_Cost_White_Paper.pdf

Disposal Method	Construction Costs	
	MM / MGD (US$)	MM / acre-foot/day (US$)
New outfall w diffusers	2.0 – 5.5	07. – 1.8
Powerplant outfall	02. – 0.6	0.07 – 0.20
Sanitary sewer	01 – 0.4	0.03 – 0.13
WWTP outfall	0.3 – 2.0	0.1 – 0.7
Depp well injection	2.5 – 6.0	0.8 – 2.0
Evaporation ponds	3.0 9.5	1.0 – 3.1
Zero-liquid discharge	5.5 – 15.0	1.8 – 4.9

Table 6. Target Finished Water Quality (estimated from 2012, US Dollars). Accessed 17JAN2023. https://watereuse.org/wp-content/uploads/2015/10/WateReuse_Desal_Cost_White_Paper.pdf

Target Finish Water Quality	Construction Costs (MM / MGD)	Operation and Maintenance Costs (MM / MGD)	Cost of Water (MM/ MGD)
TDS: Cl = 500:250 mg/L	1.0	1.0	1.0
TDS: Cl = 250:100 mg/L	1.15 – 1.25	1.05 – 1.10	1.10 – 1.18
TDS: Cl = 100:50 mg/L	1.27 – 1.38	1.18 – 1.25	1.23 – 1.32
TDS: Cl = 30:10 mg/L	1.40 – 1.55	1.32 – 1.45	1.36 – 1.50

(Scenario A_ACP) Pump and treat ocean water to Gatún Lake. This would include pumping 1 mil m^3d^{-1} of saltwater a distance of 4 km to a stage of 27.1 m above sea level. The initial saltwater would be 30 psu, with the goal of 0.2 psu or lower post-processing (1 day). In order to evaluate an estimated cost and timeline, a preexisting desalination plant, similar to the proposed scenario was studied.

The Carlsbad saltwater reverse osmosis (SWRO) plant in California finished construction in 2015 with a final estimated cost of $537 million. This plant takes seawater and removes suspended particles with a sand/anthracite filtration process before being pumped through reverse osmosis membranes to remove remining salt and other dissolved particles. The Carlsbad plant is capable of producing up to 54 million gallons of potable water per day (or approximately 204,000 m^3 per day, or approximately 1 Equivalent Transit of water per day). San Diego county estimated water costs to be $2,513 to $2,796 per acre-foot ($2.04 to $2.27 per m^3) where the money from the first 48,000 acre-feet (5.9 million m^3) is used to pay the fixed costs from the project. The Carlsbad SWRO plant only produces 20% of the treated water needed for this proposed scenario.

Given this range, the cost to treat one Equivalent Transit of water (208,000 m^3) is equal to approximately $424,320 to $472,160. This value is greater than the average revenue generated by one equivalent transit of water, and is not considered financially viable for use in the Panama Canal.

(Scenario B) Treating the saline water in the ACP Water Savings Basins. This would include treating 208,000 m^3 in a batch process for a duration of 1 hr, and this would occur 12 treatments·d-1. The water would be returned to the water savings basin (no head difference). PSU values are initially 5 psu. The goal is to achieve 0.2 psu values. Given the range of $0.26 - $1.33 per m^3 to treat brackish water (shown in Table 3) the total cost to treat approximately 1 equivalent transit of water is $54,000 to $276,640.

(Scenario C) Treating brackish water (1.0 psu) at a water intake. The water intake pumps 55 million gallons per day (208,000 $m^3\ d^{-1}$). Goal is to achieve psu values below 0.3 psu. Given the range of $0.26 - $1.33 per m^3 to treat brackish water (shown in Table 3) the total cost to treat approximately 1 equivalent transit of water is $54,000 to $276,640.

(source for Carlsbad: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://sdcwa.org/sites/default/files/desal-carlsbad-fs.pdf)

DISCUSSION

In the economic modeling associated with this study, the average revenue per transit is estimated to be $ 259,620. All scenarios of desalination processes assessed would result in costs greater than this revenue in order to treat saline water, resulting in a fiscally unfeasible approach. Desalination of brackish water volumes equal to one equivalent transit of water (208,000 m^3) would cost between 21% to 107% of the revenue generate from a vessel transit for energy costs alone. Even under brackish water conditions, it is not considered financially viable to pursue desalination further in this current study given the freshwater sources within the general location of the Panama Canal.

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