Study of Additional Combinations of Lock Water Saving Basins for Proposed Post-Panamax Locks at the Panama Canal

Estudio de Combinaciones Adicionales de Piletas Laterales para Esclusas Pospanamax Propuestas en el Canal de Panamá

Moffatt & Nichol Engineers

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Resumen Ejecutivo

EXECUTIVE SUMMARY

The Autoridad Del Canal De Panama (ACP) is conducting a study of the Panama Canal to evaluate the feasibility of constructing facilities and features to augment the Canal's capacity and capability to transit vessels. The proposed locks (~61m x 457m x 18.3m– 200' x 1500' x 60') will be significantly larger than the existing locks (33.5m x 305m x 13m – 110' x 1000' x 43'), and with the addition of these new larger locks, water demands from Gatun Lake are expected to increase dramatically. In fact, ACP estimates that the water volumes required by the new locks could approach 2.6 – 7.7 times the current lock volumes based on preferred new lock configurations. In light of the above, and coupled with the fact that operation of the current locks, municipal water consumption, hydropower generation, occasional spillage, and evaporation cause seasonal water level changes of up to 2.5 m (9') in Gatun Lake, a conceptual study for the design of new locks equipped with water saving basins was warranted.

However, the results of this study showed that the lock and water saving basin wall heights needed to meet the theoretical water saving percentages under the full range of water levels and lockage lengths were quite high. As a partial result of these substantial lock and basin wall heights, the total opinions of probable costs for the systems ranged from $357 million to $573 million which exceeded the ACP desired budget for the project. Furthermore, the preliminary study also showed that a stacked basin arrangement with placement of basins to only one side of the lock necessitated an "overlap" between the basins that could not be overcome if the theoretical water saving percentage was to be achieved always.

Based on the above findings of the preliminary conceptual study for the design of new locks' water saving basins, ACP commissioned an additional study with the goal of reducing the necessary lock and basin wall heights in hopes of reducing overall project costs. The purpose of this study is to investigate different alternatives for lock and water saving basin configurations and to design them for a smaller range of water levels and lockage lengths that occur most often. Specific lake and tide level combinations in addition to a single lockage length of 457.2 m (1500') would be used to set required lock and water saving basin floor elevations and wall heights, but the full range of lake and tide levels would be used to investigate the possible impacts (water spillage, additional water usage, etc.) of not designing for all operational conditions for the hydraulic analyses. More detailed sensitivity analyses would also be performed on the Pacific Ocean side to determine the effects of allowing the system to handle a wider range of operating conditions, as well as probabilistic analyses for the multi-lift options on the Pacific Ocean side to further optimize lock and basin wall height design.

The study options for this new work order were:

- OPTION 1 – Three-lift lock structure – side-by-side water savings basins to one side of lock – 50% water savings – Atlantic and Pacific Ocean sides,
- OPTION 2 – Three-lift lock structure – side-by-side water savings basins to one side of lock – 60% water savings – Pacific Ocean side only,
- OPTION 3 – Two-lift lock structure – side-by-side water savings basins to one side of lock – 50% water savings – Atlantic and Pacific Ocean sides, and

- OPTION 4 – One-lift lock structure – stacked water savings basins on both sides of lock – 75% water savings – Atlantic and Pacific Ocean sides.

As part of the study, a comprehensive data collection was completed along with a formulation of detailed design criteria. These criteria and design procedures were applied to determine basin and conduit layouts and associated sizes. These features were then conceptually designed hydraulically, structurally and geotechnically for Options 1 and 4.

As in the previous work order, an in-house spreadsheet model was used to complete the hydraulic analyses. This model was checked against the USACOE's LOCKSIM model and calibrated/verified to the existing locks with satisfactory results. A preliminary design of the lock Filling and Emptying (F/E) culverts (for Option 4 – the results from the previous work order were used for Option 1) was also completed to determine reasonable head loss estimates at the interface of the two systems and more importantly to determine the upper threshold of WSB conduit size (i.e., the WSB conduit should not be larger than the lock F/E culvert).

Hundreds of individual model runs were completed to create parametric curves which provided an opportunity to investigate "what-if" scenarios with a range of culvert sizes and arrangements. These curves were also plotted against the two most important design criteria which were equalization time and instantaneous maximum F/E rate. The explicit criteria for the lock F/E culverts were:

- the instantaneous maximum F/E rate should not exceed 2.28 m/min (7.5 ft/min) (the maximum for the existing locks with two culvert operations), and

- F/E times for a 3-lift system should be 8 – 9 min per lift (based on the existing system) and for a two-lift system, (3 lift x 8 – 9 = 24-27 min total)/2 lift = 12 – 13.5 min/lift. A factor of 3/2 was used to compute the F/E time for a two-lift system, assuming equal total operational times for the three-lift and two-lift systems. This factor was used only as a target in designing the preliminary F/E system.

In applying these criteria, the finalized lock F/E culvert sizes were found to be:

- Option 1– Atlantic Side (8.84m - 29'),
- Option 1 – Pacific Side (8.53m - 28'), and
- Option 4 – Pacific Side (6.40m - 21').

Parametric curves were also created for the design of the water saving basin conduits. The design criteria for the WSB conduits were:

- the WSB conduits should not be larger than the preliminary F/E culvert sizes,
- no conduit solution should exceed an instantaneous maximum F/E rate of 2.28 m/min (7.5 ft/min) for basin to lock operations, and
- no conduit solution should have a single basin operation time of less than 2 minutes (which is the assumed shortest time needed to open and immediately close the valves).

Using these criteria, a myriad of solutions were available so methodologies were formulated to combine the results from the lock F/E culvert and the WSB conduit analyses to compute more meaningful statistics including total operation time, allowable transits/day, etc.

These results were then reviewed. Based on the selections from the previous study by ACP, the finalized WSB conduit arrangement and sizes chosen for illustrative purposes were:

- Option 1 – Atlantic Side - 4 conduits/basin (6.10m - 20'),
- Option 1 – Pacific Side - 4 conduits/basin (6.10m - 20'), and
- Option 4 – 4 conduits/basin (6.71m - 21').

The selections of the number and sizes of conduits for the above options were mainly based upon the selections made by ACP for the previous work order which were based upon the desire to obtain a range of price scales for the different options. Therefore, the conduit selections should be viewed as preliminary and for illustrative purposes only.

Throughout the conceptual design process, it became apparent that by designing the locks and water savings basins' system for a narrower range of hydrologic and hydraulic conditions, the required lock and basin wall heights would be substantially reduced. This conclusion is based on a comparison of lock and basin wall heights for Options 1-3 in this study to similar configurations (i.e. equivalent number of locks and overall percentage savings) studied in Work Order No. 1. The results of the comparisons are summarized in **Tables VII.1** and **VII.2**.

As shown in **Tables VII.1 & 2**, the percent reduction in **lock wall heights** ranged from approximately 5–10 %, while the percent reduction in **basin wall heights** was more significant, ranging from approximately 30-60 %. It should be noted that some percentage of the wall height reduction for the locks can be attributed to the exclusion of the 2 ft sill in this study. It should also be noted that a significant portion of the **basin** wall height reductions can be attributed to designing for only one lockage length (1500') versus three (1400', 1500', 1600'). In fact, it is very likely that this factor (which was applied to **each** lock level for Work Order No. 1) has a much more direct impact on required basin wall heights versus the water level variation effects which would be split among all locks.

An additional comparison made for Options 1-3, related to the limitation of hydrologic and hydraulic conditions designed for in this work order, was that of water usage. The results of the comparisons are summarized in **Table VII.3**.

As shown in **Table VII.3**, the overall trend is an increase in the water volume taken from the lake between Options 1-3 in this study and the corresponding options from the previous study. In fact, the Atlantic side Work Order No. 2 options require approximately **12%** more water volume than similar options designed under Work Order No. 1. This lost water volume equates to approximately 2 lockages a day (based on a current operating total of 16 lockages/day) or 700 lockages/year. The volumetric increase occurs as a result of the fixed lower lock equalization elevation set in this study (which in turn also lowers the required lock and basin wall heights).

Please recall that in the previous work order, the system was designed to meet all lake and tide elevations, so that there was no water spilled. The system was designed to fully handle all possible equalization levels based on the full range of lake and tide levels as well as lockage lengths. In this study, the forcing of a fixed lower lock equalization elevation requires the system to spill water under conditions where the lake and/or tide elevation result in lower lock equalization elevations which are higher than the fixed equalization elevation. Another consequence of these occurrences is that the upper and middle (where applicable) locks' elevations are lower than would exist if the system were allowed to achieve the theoretical equalization elevation (i.e. no spillage). Since these elevations are lower (artificially depressed by the fixed lower lock TOWSE), the lake must supply more water for the upper lock(s) operations.

As also shown in **Table VII.3**, the percent increases in water usage between the current and previous studies are higher for the Atlantic Ocean side options (~12% average) as compared to the Pacific Ocean side options (~3% average). This occurs because the chosen lower lock top of operating water surface elevations (TOWSE) for Options 1-3 on the Pacific Ocean side (based upon the ACP selections from the probabilistic analyses) are higher than those chosen from the hydraulic analyses where the theoretical TOWSEs were set using a lake elevation of 81.0 ft and the low tide elevation (-7.6 ft PLD). The higher elevations result in less water spilled overall (and a greater range of lower lock equalization elevations accommodated) and also decrease the volume of water taken from the lake. For the Atlantic Ocean side options (Options 1&3), the TOWSEs were set using a lake elevation of 81.0 ft and the low tide elevation (-1.25 ft PLD), since the sensitivity and probabilistic analyses were not required by ACP for these options. However, if a similar probabilistic analysis had been completed for the Atlantic side options and ACP had allowed for a increased lower lock TOWSE elevation (as was done for the Pacific side), the percent increase in water usage for the Atlantic side options would have decreased also.

The single lift, stacked basin arrangement (Option 4) with basins on both sides of the lock will eliminate the problem of overlap addressed in Work Order No. 1. The basins are arranged so that they are offset from one side to the other. On the Pacific Ocean side, it was necessary to increase the width of the basins (m>1.0) to a value greater than that of the locks to eliminate overlap. The m-factor by which the overall basin areas were increased was calculated as 1.21. This results in a 16 m (52.5') increase in the basin width from the typical basin width of 76.2m.

The results of the hydraulic analyses are summarized and compared for all options in the following tables. The volumes presented in the tables are per lockage.

System Layout and Theoretical Water Savings Percentages for all Options

OPTION	# Lifts	# WSBs per Lift	# Conduits per WSB	Conduit Diameter	Theroretical Water Savings Percentage
Option 1	3	2	4	6.10 m (20')	50%
Option 2	3	3	#N/A	#N/A	60%
Option 3	2	2	#N/A	#N/A	50%
Option 4	1	6	4	6.40 m (21')	75%

Overall Water Usage and F/E Times per Lockage for Atlantic Side Options

Metric Units

OPTION	Water Intake Volume With Basins (thousand m^3)			Water Spillage Volume With Basins (thousand m^3)			% Water Savings With Basins			Avg. Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	115.4	118.3	130.2	0.0	12.1	27.0	46.1%	49.1%	50.0%	32.68
Option 2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Option 3	169.4	177.4	202.3	0.0	7.9	40.8	46.8%	49.5%	50.0%	#N/A
Option 4	164.1	185.4	188.5	0.0	0.0	0.0	74.3%	74.9%	75.0%	#N/A

English Units

OPTION	Water Intake Volume With Basins (million gal)			Water Spillage Volume With Basins (million gal)			% Water Savings With Basins			Avg. Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	30.48	31.25	34.41	0.0	3.20	7.12	46.1%	49.1%	50.0%	32.68
Option 2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Option 3	44.74	46.88	53.44	0.0	2.08	10.77	46.8%	49.5%	50.0%	#N/A
Option 4	43.36	48.98	49.79	0.0	0.0	0.0	74.3%	74.9%	75.0%	#N/A

Overall Water Usage and F/E Times per Lockage for Pacific Side Options

Metric Units

OPTION	Water Intake Volume With Basins (thousand m^3)			Water Spillage Volume With Basins (thousand m^3)			% Water Savings With Basins			Avg. Total F/E Time per Lockage (min)
	min	mean	max	Min	mean	max	min	mean	max	
Option 1	101.0	121.5	156.8	0.0	4.2	40.0	39.3%	50.0%	50.0%	32.68
Option 2	77.7	96.2	131.7	0.0	0.2	18.6	49.1%	59.9%	60.0%	#N/A
Option 3	147.0	182.5	219.6	0.0	4.9	44.7	39.2%	50.0%	50.0%	#N/A
Option 4	137.2	171.5	188.5	0.0	0.0	0.0	75.0%	76.2%	76.7%	32.52

English Units

OPTION	Water Intake Volume With Basins (million gal)			Water Spillage Volume With Basins (million gal)			% Water Savings With Basins			Avg. Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	26.69	32.10	41.43	0.0	1.10	10.56	39.3%	50.0%	50.0%	32.68
Option 2	20.54	25.42	34.81	0.0	0.06	4.91	49.1%	59.9%	60.0%	#N/A
Option 3	38.84	48.22	58.01	0.0	1.30	11.80	39.2%	50.0%	50.0%	#N/A
Option 4	36.25	45.30	49.81	0.0	0.0	0.0	75.0%	76.2%	76.7%	32.52

As stated previously, by designing for a smaller range of water levels and lockage lengths, the required lock and basin wall heights were considerably reduced for this work order when compared to the results of the previous work order. However, this benefit is not without serious consequences. For one, these options will require considerably more water from the lake over time than the systems designed for Work Order No. 1. Also, there may be safety and possible downtime issues with this revised system as now overfillage of locks and basins will be a real concern since the full range of lake and tide levels as well as lockage lengths are not being accommodated in this new design. It is true that the cost of the basins will now be lower, but necessary spillage and possibly recirculation systems may nullify this cost savings in the long run especially if one also includes the likelihood of lost time due to accidents (overfillage) that may occur even with elaborate "fail-safe" control systems in place. It should also be noted that the footprint reduction that was incorporated in this work order (bringing the basins closer to the locks by fitting the first in between the gate recesses) could also be applied to the previous work order arrangements for a considerable cost savings which may also make them economically viable. Finally, as can be seen in above tables, with these new systems, the target water savings percentage is not always achieved. In fact, when the lake levels are the lowest (below 81.0'), the water savings percentage is at its worst given that the WSB's were designed to fully operate at lake levels of 81.0' and higher.

In conclusion, Option 2 consumes the least water and spills the least water, but would likely be the most costly option given the number of lifts and basins. Options 3 and 4 consume similar

volumes of water, but cost differentials are hard to estimate given the complexity of constructing a single-lift, six stacked basin arrangement (Option 4) versus a two-lift, two side-by-side basins arrangement (Option 3). Option 1 falls in the middle as far as water usage and would also likely fall in the middle of comparative total costs. Therefore, weightings of costs, overall water usage, lock operating characteristics, safety, maintenance, and vessel throughput goals should be considered when deciding which options warrant further investigation.