Greetings,

The Panama Canal Expansion Project and known water-saving lock designs have been evaluated. Ways to further reduce water-use have been devised by modifying and combining previously known water-reducing methods.

Limited water availability held back canal expansion for over half a century, as did the ever-present problem of saltwater intrusion into freshwater Gatún Lake. Reducing water-use is very important. Obtaining more water is difficult and costly, and is typically ecologically damaging.

The lock system proposed in the attached document overcomes both problems. The locks currently selected for the canal expansion project overcome neither problem and create new ones.

The key benefits of upgrading the Panama Canal with the two-lane system that is proposed—which can be built in phases to reduce initial investment—instead of the planned single-lane system are that it will:

- Nearly double the new transits added using the same water.
- Eliminate the risk of single-lane closure by providing a second lane.
- Permit larger chambers for larger ships or multiple smaller ships to be used.
- Use structural & mechanical components much more efficiently.
- Fit two lanes vs. just the one and its three side-tanks, within a site of equal width.
- Reduce digging and dredging and eliminate having to change Gatún Lake levels.
- Maximize the use of the water "borrowed" from the existing, older locks.
- Guarantee both water and site availability for a subsequent expansion.
- Reduce environmental risks and damages.

These benefits are too compelling to ignore if the long-term viability of this important waterway is to be assured.

The current expansion plan uses a single-lane side-tank lock, a 19th century innovation, as its centerpiece. At minimum, the water-saving methods of the 20th century existing canal should have been considered. Now there are newer lock layouts that can increase the canal's capacity even more by combining several water-saving methods.

The existing Panama Canal was built after side-tank locks were invented. The locks of today's canal contain a water-saving feature that is a variant of side-tanks. Using that feature would considerably reduce the water needed for transits of today's locks as compared to what is conventionally used, and it would greatly simplify the project.

The controversial plan to obtain operating water by increasing the range over which Gatún Lake fluctuates would also be eliminated. That is significant because increasing the lake's fluctuation range requires lake-level channels to be deepened an extra 4ft. Increasing that range also forces facilities throughout the lake to be modified, and it negatively impacts the performance of both the new and the old locks.

Truly upgrading the Panama Canal using the latest lock technology will multiply transits and maximize return-on-investment through the efficient use of the canal's water resources. Doing so will also resolve controversial environmental issues. An alternative system, that combines water-saving and operational techniques optimally, and which fully employs the capabilities of the today's locks, will provide all that.

The Panama Canal is of great importance to world markets. This publicly funded expansion must be as effective as possible for the long-term. Building a short-term and limiting system—with a growth horizon of 10 years and no way to accommodate more—is illogical. It cannot be transformed to become efficient later.

Better lock designs were available before the project began, and even better designs are available now. It is still possible to choose better locks and change the plan to one that provides for growth in service for several generations. It would be an unconscionable tragedy not to build a more effective lock system.

Building a white elephant will irrevocably damage the legacy of the Panama Canal.

Respectfully yours,

Bert G. Shelton

A Superior Panama Canal Expansion Plan

By Bert G. Shelton, Research Scientist and Professional Engineer February 29, 2008

The Panama Canal Expansion Project can be greatly improved. It is not too late to make the changes needed to improve it. The expansion project as it stands today is to add ONE new lane with side-tank locks, which is to nearly double the present canal's cargo transiting capacity.

Were the project to use newer, state-of-the-art lock designs instead of an approach surpassed over a century ago, the cargo transiting capacity of the Panama Canal could be astoundingly increased using water already available in the present canal.

An alternative state-of-the-art TWO-lane lock system—that would double the cargo capacity to be added by the currently planned expansion—is presented in this document. That it can do using the same amount of water the currently chosen single-lane side-tank locks will use.

Building of the proposed two-lane alternative system can be phased to reduce initial investment. Its completed first lane would comparably increase the canal's cargo capacity to what the presently planned single-lane system will provide. The second lane could be added later with no need to obtain additional waters.

The alternative lock system uses technology proven in today's canal, in use elsewhere, and already approved for the project. Using it can preserve and protect the canal's fresh water resource, its ecosystems and the oceans it connects far more effectively than the planned side-tank locks with their related construction work.

It is not necessary to increase the range over which the level of Gatún Lake fluctuates in order to increase the lake's usable water-volume for operating the locks. The best way to obtain the water needed to operate the new locks is to implement another water-saving feature contained in the canal's original locks. The procedure for implementing that feature is described in this document.

State-of-the-Art Slave-Tank Lock Design

A new two-lane lock design is presented in this section. This state-of-the-art water-saving design combines two methods for saving water during lock operations.

One method is to transfer water laterally from one chamber to the adjacent chamber (one lane across to the other lane), a method available in the original Panama Canal Locks. The other method is to add water-saving tanks, similar to those presently selected for the Panama Canal expansion. By building a two-lane lock system having comparatively fewer tanks than the new canal's presently selected locks, per transit water-use can be notably reduced with the proposed combination.

The method of transferring water from side to side between chambers to reduce water-use requires that canal ship traffic be coordinated a specific way. That coordination of ship traffic is not particularly complicated.

To reduce water-use, every side-by-side pair of chambers of a two-lane lock system must be operated with one chamber being drained while the adjacent chamber is being filled. In the case of a lock set with multiple, contiguous steps, water movements between adjacent chambers of all steps must be completed simultaneously before proceeding with upstream to downstream water movements. This is why ship transits must be coordinated to take full advantage of the method.

The key to the newly developed state-of-the-art water-saving lock is the location of its water-saving tanks (to be referred to as slave-tanks). Its tanks are placed in the center-wall between the lanes of a two-lane lock unit.

A two-lane lock layout with two slave-tanks, one located at a distance above the other in the lock's center-wall, will be referred to as a "standard" slave-tank lock design in this document. The layout of the new standard slave-tank locks will be described shortly.

A standard slave-tank lock unit uses as little as one-third (33.3%) of the water per transit that a traditionally operated lock uses. On the same comparative basis, the triple-side-tank locks that are to be added to the Panama Canal use 40% of the water per transit. Both lock designs require four sequential water-moves to obtain their respective water-savings.

With fewer tanks and shorter pipe runs, per transit the two-lane slave-tank lock uses less water (83.3%) than the single-lane triple-side-tank lock uses. Note that the two lanes of a slave-tank lock share their two tanks to simultaneously obtain the greater water-savings.

Slave-Tank Lock Layout

The slave-tanks in the center-wall of a standard slave-tank lock must be arranged a specific uncomplicated way. To maximize water-savings, the vertical distance between chamber high and low water levels is divided into six equal layers. The upper and lower slave-tanks are respectively located within the center-wall at the level of the second and the fifth water-layers counting from the top.

The plan area of each slave-tank is made greater than that of the main chambers to insure an adequate height differential for flow between a chamber-layer and the slave-tank to which it drains; also insured is adequate flow between a slave-tank and the chamber-layer to which it subsequently drains. The extra height differential achieved by increasing the tank area saves time by chopping-off the slow flattening of the level equalization curve.

When the levels of the upper and lower waterways (joined by the locks) vary, the overall height of each slave-tank can be made larger and its vertical position adjusted so that the filled and drained levels can be adjusted. That allows the requisite water-use reduction to be maintained over the range of waterway level-variation.

It is important to note that it is necessary to do this with any water-saving tank arrangement if maintaining the percentage of water-savings over the full range of waterway level variation is desired. Therefore, it is best for all designs with water-saving tanks that waterway levels not vary greatly.

Slave-Tank Lock Operation

Once ship movements between lift operations have been completed and the chamber gates have been closed, water transfer operations to increase and decrease chamber water levels are to proceed simultaneously.

For maximum water-savings, the operations follow a specific sequence, which involves the chambers of both lanes and the slave-tanks. The requisite four-step sequence is described as follows, where the chamber's water-level change is figuratively divided into the six equal layers as was noted above.

First: Begin emptying the "full" first chamber by draining its top-most layer into the upper slave-tank, while concurrently draining the lower slave-tank into the "empty" second (adjacent) chamber's bottom layer to begin the filling of that chamber.

Second: Share water side-to-side between chambers, bringing the level in each to about mid-way. This entails draining the first chamber's second and third layers into the second chamber's fifth and fourth layers.

Third: Drain the first chamber's fourth layer into the lower slave-tank while concurrently draining the upper slave-tank into the second chamber's third layer.

Fourth: Drain the first chamber's bottom two layers to the lower waterway, or lock-chamber below, to complete the first chamber's draining process, while concurrently flowing water into the second chamber's second and top-most layers to fill it from the upper waterway, or lock chamber above.

In practice, the action of sharing water between chambers would be stopped short of equalizing the chamber levels, because it is impractical to completely equalize the levels due to the long time required. To compensate for that shortfall in water transferred between chambers, the area of the slave-tanks can be increased to increase the volume of water moved to and from those tanks.

Making such adjustments or deciding how much to adjust is a trade-off between water-savings vs. time. Similarly, establishing the "cut-off flow-rate" for water-moves between tanks and chambers is a trade-off between water-savings vs. time that must be established for any water-saving system.

Where there are tides, as is the case at the Pacific entrance to the Panama Canal, an additional "tide-tank" can be located below the lower slave-tank between the lock unit's seafront chamber pair. Should such a tank be included for tide-mitigation, the First and Fourth actions described above would be amended as follows.

First: Drain the first chamber's top layer, to begin emptying it, into the upper slave-tank, while concurrently draining the tide-tank, located below the lower slave-tank, into the second chamber to begin filling it, followed by draining the lower slave-tank into the second chamber to continue filling it.

Fourth: Drain the first chamber's bottom two layers into the tide-tank until the cut-off flow-rate is reached, then drain the remaining first-chamber water to the lower waterway, while concurrently flowing water to fill the second chamber's second and top layers from the upper waterway, or lock chamber above.

In effect, incorporating a tide-tank adds one water-movement action before and another after the four standard water-movement actions, for a total of six actions. The added water manipulations must be assessed relative to operations at the other locks in a system in order to determine their impact on total system operation.

The function of the tide-tank—which could have remote tanks connected to it to better store (and also capture high-tide water for) fill-water—is to greatly attenuate the amplitude of tide extremes and to raise above mean tide the axis about which the reduced tide extremes oscillate. That in turn generates a water-savings.

Adding tide mitigation to the new Miraflores Locks of the state-of-the-art lock system proposed in this document could reduce water-use at those locks by up to 10%. That makes it a worthwhile option to investigate further, refine, and incorporate. It may even be possible to retrofit such a system into the old Miraflores Locks.

State-of-the-Art Lock System for the Panama Canal

At the canal's Atlantic entrance near the existing Gatún Locks it is proposed that two separate single-step standard (two-lane) slave-tank lock units, with a stretch of channel between them, be built—instead of the three-contiguous-step single-lane triple-side-tank locks selected by the Panama Canal Authority (ACP).

Such an alternative lock arrangement would operate using 62.5% of the water per lane that the ACP's side-tank lock selection would use.

That level of water-use is obtained by combining the two water-savings methods of the standard slave-tank lock design (center slave-tanks and side-to-side water-sharing between chambers) with a reversing of the transit direction through a lock chamber transit by transit. Such single-step-lock lane reversals cut water-use in half.

The Pacific lock layout would appear as a larger version of the original Panama Canal Locks. In other words, two lock units separated by Miraflores Lake are proposed for the Pacific entrance. The new lock unit next to the present-day Pedro Miguel Locks would have one step and that next to the present-day Miraflores Locks would have two steps.

The new two-step standard slave-tank locks placed next to the present-day Miraflores Locks would additionally have a state-of-the-art tide-tank system to maximize water-savings.

It is estimated that the new two-lane locks proposed at Miraflores would use about 72.5% of the water per lane that the locks the ACP is planning to build at the canal's Pacific entrance would use. Because the proposed new two-step slave-tank locks at Miraflores cannot take advantage of water-saving transit-by-transit lane reversals, the water that can be saved by them is less than what could be saved at the new two-lane single-step lock unit at Pedro-Miguel.

At Pedro Miguel, a single-step two-lane lock unit with interconnected chambers is all that is needed because, with lateral water-transfer between chambers and transit-by-transit lane reversals, the water used by those locks can be reduced to as little as 65% of what is used per transit by the ACP's chosen side-tank locks. Without slave-tanks the proposed new Pedro-Miguel Locks, which would be reversed transit by transit when operated, can save more water than the new slave-tank locks proposed for Miraflores, so adding tanks there is of no benefit.

Effect on Canal Transiting Time

Today's Panama Canal has three lock locations, one on the Atlantic (Gatún) and two on the Pacific (Miraflores and Pedro Miguel). The ACP's plan uses two, one at each ocean. The ACP's system is to transit 12 "post-Panamax" ships a day.

The herein proposed state-of-the-art two-lane alternative instead calls for four lock locations as compared to the original canal's three locations, and has fewer steps per lane. The proposed layout takes advantage of the tremendous water-saving benefit of reversing a lane transit by transit at several of the new locks locations.

The proposed state-of-the-art system will make 20 transits per day possible, using the same amount of water as the 12 transits of the ACP's system. Additional time is needed to accommodate water-saving transit-by-transit lane reversals; that results in 10 transits a day for each of the two lanes.

In order to efficiently use the water resource, routine transits of the canal segment between entering the first chamber at one end and exiting the last chamber at the other end of the lock system proposed herein, will take about 25% more time that with the system the ACP plans to use. However, fast transits, possibly faster than through the ACP's locks, could be done in case of emergency; optimum water-savings would be set-aside in those instances.

As an added benefit, reversing lanes transit by transit will permit less saltwater to intrude into the level of Gatún Lake, which will be discussed next.

Controlling the Intrusion of Salt

It must be noted that, with locks, there is no way to avoid the intrusion of salt. However, the amount of salt that gets in via the locks can be controlled by choice of lock system and of operating procedure followed.

The choice of lock type and how the chosen lock system is to be operated is key to reducing the intruding volume of salt to an amount that the available mitigation capacity of a freshwater lake can remove.

To select the appropriate lock system for a given canal requires that the lake's salt mitigation capacity be estimated for when the new lock system is in operation. Then, a lock system must be designed that permits that amount of salt, or less, to intrude; obviously such a lock system design process must be an iterative one.

In this lock and lock system development effort it was found that, not only does reversing a chamber transit by transit allow one ship's lift water be used to lower a second ship, that lane reversal also cuts in half the number of salty water inputs to the canal simply because two ships are handled by one lift-volume of water. Plus, those fewer salty-water inputs always contain the least amount of salt, because there is always a ship in the chamber to reduce the volume of salty water that the lifting-water must dilute.

Key to reducing the salt that intrudes into a canal is to eliminate the process of exiting ships in a series through the locks to the sea. That is the lock transiting operation that introduces the most saltwater into the lock unit and that causes the most to reach the lake, as is explained below.

As a seaward bound ship exits the lowest chamber of a set of locks, the volume that ship occupied in that chamber is back-filled by water from the sea. Thus, that lowest chamber ends up full of saltwater with the highest salt concentration possible.

That lowest chamber is then filled to raise its level to receive the next exiting ship. The fill-water usually comes from the chamber above, and it typically will have a lower salt concentration than the water in the lowest chamber. As the fresher water from above fills the lowest chamber, clearly the concentration of salt in the lowest chamber will be reduced. However, if part of the fill-water comes from tanks in which it was saved for re-use when the previous chamber-full was drained, rather than all the fill-water coming from the chamber above, the final salt concentration in that lowest chamber will be greater.

Once the lowest chamber is full, the next ship headed to sea can enter it. As that ship enters that full chamber, a volume of salt-containing water equal to the ship's displacement volume will be pushed into the chamber one step up. As the described sequence repeats with each exiting ship, progressively saltier volumes are pushed up the locks and into the upper waterway.

The large volumes of a salty mixture that move up through the lock chambers as ships exit in series do get diluted at each step, but the salt concentration in each lock step progressively increases with each exiting ship. With each ship that exits, some amount of salt will have reached the upper waterway; and, that amount will increase with each successive ship. The use of water-saving tanks will augment the salt concentration that arrives at the upper waterway.

In other words, how much salt reaches the lake will depend on how much saltwater began the journey and on the details of the journey.

It so happens that the least amount of salt enters a canal when ships are entering the locks from the sea. When ships enter a canal from the sea in series, water is expelled from the first or lowest chamber to the sea with each entering ship. This operation, then, introduces the least possible salt into the set of locks. Because water gets pushed out of each successive chamber in the direction of the sea as ships move up the locks, each chamber up is only exposed to salt that incidentally mixes into it.

The ability for saltwater to mix forward as the ship moves forward into the next chamber is limited by the water that flows around the ship opposing the salt's progress and by the short time the gate between chambers stays open. While the use of water saved in tanks will increase chamber salt concentration, the amount of salt that mixes forward as ships enter the locks will still be small as compared to what is pushed in by a ship headed out to sea.

Reversing the locks transit by transit permits capitalizing on that lowest intruding saltwater volume situation.

When each lane of each single-step lock unit of the proposed state-of-the-art lock system is reversed transit by transit, the saltwater volume introduced with each ship, that enters from the sea and initiates a new transit cycle, will be the least. When an outbound ship (headed to sea) takes the place of the lifted inbound ship that just exited the chamber, the chamber water the outbound ship displaced toward the canal will contain relatively little salt. Furthermore, only one volume of water having a low salt concentration will intrude for every two ships that pass through the set of locks.

That is why the proposed state-of-the-art lock system—while doubling the cargo that the side-tank lock system would add—will protect Gatún Lake far better than the ACP's lock selection.

The bottom line is that the increased residence time of a ship in the canal that comes with using the transit-by-transit lane reversal procedure not only improves the use of water to allow a 67% increase in transits, it also goes a long way toward conserving lake water quality, which increases the value of the longer ship residence time.

With this state-of-the-art system, many more ships will be able to cross the isthmus that would otherwise not cross or would have to sail around South America or use the Suez Canal. Those extra transits will increase the Panama Canal's revenues.

Businessmen traditionally assume that protecting the environment will negatively impact profits. There is a rightful concern that this philosophy is driving the Panama Canal Expansion Project. Open and frank discussions of the impact the project will have on the environment have been avoided, and instead unsubstantiated assurances that impacts will not be significant are being given.

There are state-of-the-art lock systems that can increase transits of an expanded Panama Canal and do so with far less damage to the environment, as has been shown in this document.

It is unclear how much salt will intrude into Gatún Lake though the ACP's planned locks, thus it is unclear how the lake will ultimately be affected. However, what can be said with certainty is that by just changing the lock selection from a side-tank lock system to a state-of-the-art lock system, the intrusion of salt can demonstrably be reduced along with the substantial increase in number of transits.

Also, the salt-mitigation capacity that Gatún Lake presently has will not be reduced with the herein proposed plan, but it will with the ACP's plan.

Lock Design Comparative Discussion

Hydraulically speaking, shorter pipe runs in the more compact slave-tank locks make for faster flow times for same diameter pipes as compared to the more spread out triple-side-tank locks the ACP is slated to build. Therefore, smaller pipes and valves could be used to move water equally fast or the same diameter valves and pipes could be used to move the water faster. Either way, using slave-tank locks offers secondary benefits over the ACP's side-tank locks for the Panama Canal.

Structurally speaking, slave-tank locks, with water-saving tanks located in the lock unit's center-wall along with the pipes that connect them to the chambers, will be less affected by the differential settlement between the tanks and chambers. Differential settlement is known to cause problems to connecting elements like pipes. Element strengthening and foundation stiffening are often needed to resolve problems, which add cost.

Also with regard to structural design, the two separated lock-step lock arrangement proposed for the Atlantic entrance to the Panama Canal in this document would have chambers about 15ft taller than those of the ACP's side-tank locks. They would also be about 15ft taller than those of the canal's existing Gatún Locks.

Structural design estimates indicate that chambers and gates of that height are manageable. That extra height should already be acceptable for the project, assuming that the locks the ACP is planning to use at the canal's Pacific entrance are to maintain optimum water-savings at all tide conditions.

The proposed state-of-the-art locks for the Panama Canal as compared to the ACP's side-tank locks has:

- TWO lanes for 20 transits per day with service reduced to one lane during the overhaul of a lane vs. ONE lane for 12 transits per day and no service during chamber overhaul
- 10 chambers vs. 6 chambers
- 8 to 9 water-saving tanks vs.18 water-saving tanks
- 18 culvert valves vs. 8 culvert valves
- 21 to 23 tank and chamber interconnect valve sets vs. 18 tank to chamber interconnect valve sets
- 6 tallest gates vs. 2 tallest gates
- 8 shortest gates vs. 4 shortest gates
- 4 average gates vs. 10 average gates

- 4 short emergency gates vs. no such gates for the side-tank system due to its double gate design.

A detailed cost analysis is needed to properly compare the proposed state-of-the-art lock system to the side-tank lock system the ACP has chosen. However, it is clear from the above list of the main elements of each system that there is no more than two-thirds more in the way of lock structure to build and equipment to install in order to add a second lane and increase the new lock transit cargo capacity by a factor of 1.67.

Yet, such a simplistic comparison doesn't make fully apparent the value of what would be gained.

Not only are 20 transits obtained with the proposed state-of-the-art lock system using the same water needed for 12 transits of the ACP's side-tank lock system, the per-transit cost should be lower with the state-of-the-art system which uses water more efficiently.

Also, the proposed two-lane alternative should remove concerns that shippers may have with the single-lane solution should it have to close for maintenance.

Furthermore, the proposed state-of-the-art lock system plan calls for the activation of the water-saving capabilities of the existing locks to get the water needed to operate the new locks, as will be discussed in greater detail in the next section

That would eliminate costly changes all around Gatún Lake needed to accommodate the planned lake level fluctuation range change, along with the time and cost of digging lake-level channels 4ft deeper. That extra digging could be reserved for the consideration of bigger ships with deeper draft in the future. Also eliminated would be the need to further reduce the cargo ships carry in order to transit the old-lock when lake water levels drop below the lake's original low-water level.

Obtaining Water to Run the Enlarged Canal

It has been published that the enlarged canal is to transit 42 ships a day. It has also been published that the new locks will transit 12 post-Panamax ships a day. That implies there will be 30 transits of the old locks per day.

Reducing transits through the old locks to 30 from their average 38 per day (as reported by the ACP for the year 2003), suggests that the plan is to "borrow" water from the "less efficient" older locks for use in the newer "more efficient" locks. Doing that significantly increases the service the water provides, as the new locks for the Panama Canal are to move ships with up to three times the cargo using about the same volume of water per transit. That in principal is a good plan.

However, despite having obtained water by "borrowing" about 8 transits-worth of it from the old locks, more water is needed to fully operate the ACP's chosen system. To remedy that shortfall the ACP will increase the lake's usable water reserves by changing the range over which Gatún Lake fluctuates from 2.5 ft to 8 ft.

That change is unnecessary as there is a far better way to get more water.

Once existing lock transits are reduced from 38 to 30 a day there will be 8 transits-worth of <u>time</u> that the old locks will stand idle in addition to the 8 transits-worth of water they will no longer use.

It is strongly recommended that the slower method of operating those old locks to save more water be used. The plan to borrow water from the old locks provides the time needed to activate the water-saving lateral transfer capability of those locks.

There is a large culvert within the center-wall of the present-day locks. That culvert is connected to half of the water-distribution ports that penetrate the bottom of each chamber on each side of the center-wall by pipes with valves; and, those valves are routinely operated during transits following a prescribed sequence.

To reduce the water used to lift and lower ships, that center-wall culvert and its valves, pipes and ports could be operated in a sequence different to what is routinely followed. That requires changing the sequence in which the lock's side culverts are used, as well.

Operating the locks using the alternative operating procedure referred to here, requires revising ship transit schedules in addition to changing valve-operating sequences. And doing so takes more time, which, it would seem, is to be made available in the new lock-operating plan.

Up to 50% of the water typically used per transit in today's canal can be saved if chamber pairs are operated in tandem. This means that when a chamber to one side of the center-wall is being emptied, the chamber directly on the other side is filled about half way with water drained into it from its pair. That amount of savings can be obtained whether transits in both lanes are going the same direction or in opposite directions.

As noted by the ACP, the side-tank locks will use about 92% of the water per transit that the old Panama Canal locks traditionally use per transit given the selected chamber size.

Built with chambers of the same size the ACP has selected, the state-of-the-art lock system proposed herein would use about 62% the volume of water the old lock system uses per transit. (That is based on an average of the water-use estimates given earlier for the proposed Atlantic entrance and Pacific entrance alternative new locks.)

To obtain from the old locks the water needed for 20 transits of the proposed state-of-the-art lock system, it is necessary to eliminate some of the old-lock transits to gain the time needed to perform water-saving operations on the balance of the old lock transits.

Using the year 2003's 38-daily transits of the old locks as the assumed point of departure for the calculation, the number of old-lock transits need only be reduced to about 34 to obtain the time needed to perform chamber-to-adjacent-chamber water transfers on selected transits. The target would be to on-average save about 26% of the water that 34 old-lock transits would normally use, and add that to the 4 transits-worth of water "borrowed". The water saved there would then be used to operate the new, state-of-the-art lock system.

Thus, the 20 transits of the state-of-the-art lock system could be obtained with old lock transits only reduced by 4. That means the added cargo capacity offered by the ACP's side-tank lock system can be fully doubled by the alternative system using the same amount of water; and actually less water than that when the extra water used to reverse the single-lane side-tank locks is taken into account.

If in the future two more lanes were to be added using this same state-of-the-art lock system, the 40 transits of the four added lanes could be operated with water supplied by "borrowing" more, with transits of the old locks reduced to 26 ships a day, each using just over 50% of the water traditionally used per transit.

Taken to the extreme, if the older locks were someday eliminated, the water used today to operate the older locks is enough to provide for three proposed state-of-the-art lock systems with chambers of the size presently planned for a total of 60 new-lock transits.

This is about 4.5 times the cargo capacity of the original canal provided by the same water.

Obtaining water to transit more cargo is clearly not a problem; solving the water "issue" is simply a matter of choosing to use the available water more efficiently.

The ACP has the analysis and planning capacity, plus the tools, to manage the ship scheduling and operational changes necessary to optimally operate the canal as outlined.

The administration of the Panama Canal should be challenged to change their procedures and to adopt state-of-the-art designs. This includes modifying the old lock operating protocols and using a combination of the side-tank water-saving technique already decided on and other water-saving techniques within the new locks.

Failure to make prudent changes now will result in a permanent loss of significant financial opportunities.

Improving Project Financing & Return-on-Investment Potential

The proposed state-of-the-art lock system offers a financially attractive option of phasing construction—not available with the ACP's single lane selection, which cannot be expanded later to make it more efficient.

One lane of the proposed alternative, built with just the lower slave-tank completed at the locks that include them, can be put into operation to generate revenue while the second lane and upper slave-tanks are completed.

Such a cost-reducing Phase I lock system would itself already result in nearly the same (as much as 97% of the) canal cargo capacity that the presently planned side-tank lock and old lock combined system would provide when completed. This 3% reduction in capacity is negligible, and a small price to pay, while waiting for the highly efficient two-lane system to be completed.

For Phase I, the number of old lock operations also need to be reduced to 34, as was estimated for when the two lanes are completed. In this case it would be necessary to save about 29% of the water normally used per old lock transit to provide for the 10 daily transits of the proposed state-of-the-art lock system with first lane completed. While waiting for the second lane to be completed, a ship's canal residence time as it transits the Phase I system would be about 25% longer than when Phase II is completed. This is due to the wait for the single-lane reversal-cycle to complete; the lane reversal-cycle wait for two lanes is half as long as for one lane.

Having established that water really is not a limiting factor, another improvement to the canal expansion project could be to build bigger chambers.

Bigger chambers would permit the transit of multiple ships of some typical smaller size, which would increase the usefulness of the new lane(s). The chamber's dimensions and shape could be optimized to best suit that possibility, which is another way by which water-use can be maximized when a vessel of optimum size doesn't appear over the horizon.

Besides leaving the door open for the possibility of yet bigger ships to transit the canal in the future, bigger chambers would also facilitate the entering and exiting of the large ships that are to transit the new locks.

Roomier chambers would make both the personnel charged with handling the ships and the owners of the ships more comfortable with the new locks.

<u>Some Lock Design Knowledge, History, and Added Recommendations</u>

There are three ways to reduce the water needed to raise and lower ships that transit a system of locks:

1) Divide a lift into more steps. The lift water volume needed is the fraction obtained by dividing the volume for a full-height lift by the number of steps.
2) Drain water by layers from a chamber being emptied, such that the water drained from higher layers can be re-used in lower layers during the process of re-filling a chamber, all by gravity flow. This is similar to dividing the lift into more steps; but, by using water-saving tanks, only the water is moved to or from the "in-between steps" to respectively lift or lower a ship inside a chamber. Transferring water laterally between the side-by-side chambers of a two-lane lock unit is a variant of this method.
3) Have a transiting vessel inside a chamber every time that chamber is filled or drained. Transiting a ship each time maximizes the use of the lift-water. In multiple-step lock systems, this method can only be capitalized upon if a channel segment, within which ships can pass, separates the steps.

The benefits of laterally connecting adjacent chambers—to permit water to be transferred between them—was already recognized in their day. So, the designers of the original Panama Canal Locks included that option in the two-lane system they designed. But they did not refine that option since its routine use was not a design requirement. That option was forgotten over the years, as the need to use it did not arise.

While several "hands-on" old timers still alive know of the procedure—and they also know many other lock tricks not on the books—those who documented operating procedures only documented the routine lock operations.

Forgetting that water-saving capability recently resulted in additional costs to shippers and consumers when there was a shortage of water during an unusually long dry season. Avoided could have been the lightening of ships by up to 5 ft of draft to permit transit, where cargo was unloaded, railed across the isthmus, and reloaded.

The present canal expansion plan includes bypassing Miraflores Lake with the new side-tank locks and, in so doing, that lake's western watershed area will be cut off.

Bypassing Miraflores Lake is not a good plan. Although the water the lake adds to the canal system is small, its function as a salt intrusion barrier is invaluable.

Eliminating Miraflores Lake's western watershed also goes against the goal of gaining operating water. During the routine operation of today's Panama Canal, it is possible to fully incorporate Miraflores Lake's watershed inputs to the canal's operating water reserves. That can be done with additional lock reversals at the Pedro Miguel Locks.

It is recommended that the western watershed of Miraflores Lake not be eliminated. And, it is further recommended that the Mocambo and Cardenas Rivers to the east of Miraflores Lake be diverted into it both to increase the canal's water reserves and increase the salt mitigation function of that lake.

The Panama Canal Authority (ACP) claimed that side-tank locks—being built at Hohenwarthe and Rothensee—were discovered through an exhaustive search for water-saving locks. Having found those, the ACP apparently decided to adopt the design and look no further. In the campaign for the canal expansion go-ahead vote the concept was called "the only possible" lock solution.

Considering what could have been done using other water-saving methods—such as those described in this document, most of which were in existence prior to the selection and design of the locks in Germany—it now seems that expediency won out in the selection processes that each party followed.

As the situation of the locks in Germany is decidedly different from the situation of the locks in Panama, the impact of expediting the lock choice is relatively minor with respect to what lock improvements could have been found with additional research and development in the German case. That is to say, while the lock choice could have been improved with more effort, expediting it in that particular situation can be proven appropriate.

The situation of the Panama Canal is altogether another matter.

Such oversights can needlessly increase system development, construction, and operating costs; plus, result in a product with reduced revenue generating potential.

The now-available slave-tank design—developed by way of an independent review of water-saving methods used in locks already in existence, methods with which better solutions for the Panama Canal's new locks could have been devised—magnifies the importance of performing a diligent review of existing technology before moving forward with major and costly projects.

Summary and Conclusions

The state-of-the-art lock system proposed in this document for the Panama Canal uses combinations of older, newer, and the latest lock layouts and water-saving techniques, which employ only proven equipment in maximizing the use of water.

This proposed lock system permits many more transits of the Panama Canal for a given amount of water compared to the lock system to be added to the canal per the present expansion plan, a system based on a 19th Century water-saving lock arrangement.

As compared to the ACP's chosen side-tank lock design, the proposed state-of-the-art lock system employs superior water-management techniques that permit:

- Building of a two-lane lock system that
  - increases the canal's cargo transit capacity,
  - uses water more efficiently, and
  - provides continued, though reduced, service during scheduled lock chamber maintenance.
- Cancelling the change to Gatún Lake's level fluctuation range which
  - eliminates associated modifications to lake-level facilities,
  - reduces lake-level channel dredging by 4ft, and
  - avoids the negative effects it would have on new and old lock performance.
- Reducing of the intrusion of salt into Gatún Lake, protecting that freshwater resource.

- Phasing of the construction of the locks, reducing the initial investment.
- Adding yet more locks in the future without having to find more water.
- Improving use of real-estate and benefiting from using more compact structures, where the
  - same space for one lane with three side-tanks can fit two lanes with a two-tank stack, and the
  - potential for differential settlement to crack pipes running between tanks and chambers is reduced.

The herein proposed state-of-the-art lock system, which incorporates the new water-saving slave-tanks where applicable and uses non-traditional lock operating sequences, is not the only plausible alternative lock arrangement for the Panama Canal using such new methods and method combinations. It is simply the lock arrangement that resulted from an attempt to consider existing site conditions and the full capabilities of the old locks to maximize the transit capacity of the canal while minimizing new construction, digging, dredging, and incidental changes.

With additional effort even this proposal could be further improved.

It is not too late to change the lock system choice for the present Panama Canal Expansion Project. It is only now that bids for detailed design of the locks have been requested; the design and build contracts are not to be issued until early next year. However, now is the last chance to steer the project onto a much better path.

The benefits of making changes like those proposed are overwhelming for all parties concerned.

By simply adjusting the scope of the elements of the project, adding a bit here and taking a bit away there, the resulting system's value and potential is greatly increased with respect to the investment made. And, the system leaves room available for future growth in terms of water resources plus physical real estate on which to build.

It is imperative the Panama Canal's new locks be more efficient, less damaging, and less restrictive.

Not to change the lock design is to choose to create a system that is inferior to the original. Choosing to stay the course is to knowingly limit this and future canal expansions and maximize damage to the environment.