# Salinity Intrusion in the Panama Canal

# Intromisión Salina en el Canal de Panamá

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Resumen y Conclusiones

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# 7 Summary and Conclusions

A review of salinity control measures at locks worldwide shows a variety of methods being employed, including salt water barriers, sumps to collect and drain salty water, and mixing devices to limit intrusion. A detailed evaluation of the Hiram Chittenden Locks in Seattle, Washington, USA, shows that a salt water sump with a hinged barrier is an effective approach to salt water intrusion control.

Salt water is slightly more dense than freshwater, causing it to flow under fresh water in a density current unless mixed by strong currents, ship propwash, or artificial mixing devices such as bubble screens. Density currents may lead to greater saltwater intrusion than would occur in well-mixed waters, but offers an opportunity to capture some of the salt water before it intrudes into the freshwater zone upstream of the locks.

A set of tools has been developed that supports evaluation of salinity intrusion and freshwater consumption through the Panama Canal locks for Gatun Lake. They include:

*a.* A simple mixing analysis coded in spreadsheet form that provides zero-dimensional models for the salinity of individual locks and for Miraflores Lake and Gatun Lake plus a freshwater consumption model for Gatun Lake.

*b.* A depth-integrated two-dimensional numerical model for dispersive transport of salt water into Gatun Lake.

*c.* A width-integrated two-dimensional numerical model for densimetric advection and dispersion of salty water from the locks into a channel.

The numerical models employ the graphical user environment of the U. S. Army Corps of Engineers Surface Water Management System (SMS) to manage the models and display their results. The zero-dimensional models have been adjusted to yield results roughly comparable to limited field observations of salinity in the Panama Canal. The two-dimensional models are physics-based and have been successfully employed in many applications; however, they have not been verified to field observations in Gatun Lake.

These tools have been applied in a feasibility-level evaluation of the following alternatives for expansion of Panama Canal capacity.

*a.* Use of holding ponds to conserve fresh water by recirculating lift water.

*b.* Installation of a Syncrolift lock chamber adjacent to the Miraflores and Gatun Locks.

*c.* A sump in the channel upstream of the locks to capture more dense salty water and drain it before it reaches the lake.

*d.* A gated chamber upstream of the locks to hold salty water while it is drained to the sea and replaced with freshwater.

Analyses using the tools listed above show that:

*a.* Freshwater consumption can be reduced by up to about 60% by recirculating lift water through holding ponds, albeit at the cost of increasing salinity in the ocean approach channels and ultimately in the uppermost locks. If this option is employed, the potential for increased salinity intrusion and necessary remedial measures should be addressed.

*b.* A sump in the channel upstream of the locks can capture salt water through selective withdrawal, and is most effective for higher salinity (and thus more dense) water in the locks; however, higher salinity in the locks (now about 0.1 ppt in the uppermost Miraflores and Gatun Locks) risks greater salinity contamination of the lake if any lock water escapes the sump. A sump requires some sort of confined channel upstream of the lock to train the densimetric flow out of the lock.

*c.* A salinity of greater than 0.3 ppt in the uppermost locks, including a Syncrolift lock, risks unsatisfactory buildup of salt water in Gatun Lake unless some means of capturing most of the salt water is incorporated in the facility.

*d.* A gated chamber on the lake side of the uppermost lock offers the option of draining salty water from the lock and replacing it with fresh water before opening for ship passage. This technique provides positive salinity control at the locks, either standard or Syncrolift, at the cost of a delay in the vessels' exit of the lock.

## Recommendations

We recommend:

*a.* Further consideration of recirculating lift water through holding ponds as a means of freshwater conservation.

*b.* Further consideration of a gated chamber at the uppermost lock entrance on each side to reduce salinity intrusion into Gatun Lake if either the

Syncrolift lock or the holding pond/recirculation alternatives are considered for design.

*c.* Use of the tools developed here in the design phase of any canal improvement plans. They should be verified to a comprehensive field data set of water levels, velocities, salinities, and temperatures before use in a design effort.

*d.* Addition of a model of the sea approaches to calculate the salinity there under any alternative that might alter the salinity, such as the recirculation/holding pond option.

*e.* Field data collection in support of further modeling should be synoptic to the maximum degree possible, should include acoustic Doppler current profiling, and should include salinity meters capable of measurements to hundredths of a ppt. If field instruments are not available to meet this requirement, water samples may be collected and analyzed in a laboratory to the required accuracy.