Salt Water Intrusion Analysis for Post Panamax Locks – Report B, C, and D

Análisis de la intromisión de Agua Salada en Esclusas Pospanamax – Informe B, C y D

WL Delft Hydraulics

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Salt Water Intrusion Analysis
Panama Canal Locks

Future situation: Post-Panamax Locks

Report B: single-lift locks
Report C: three-lift locks
Report D: two-lift locks

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Salt Water Intrusion Analysis Panama Canal Locks
Future Situation: Post-Panamax Locks

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Comparison of salt water intrusion for three-lift, two-lift and single-lift configurations of Post-Panamax Locks

1 Introduction

The Panama Canal Authority (ACP) is developing a long-range master plan to augment the capacity of the Panama Canal and it's capability to transit vessels. To that purpose ACP has undertaken a study to evaluate the feasibility of constructing facilities and features to provide additional sources of water supply and associated hydropower generation, new sets of locks, alternate systems for raising / lowering vessels, channel improvements and maritime infrastructure. The study is designed to help the Canal meet future traffic demands and customer service needs and to continue providing efficient and competitive service for the next fifty years and beyond.

The available water resources for Canal operations have been analysed by the Canal Capacity Projects Division and several new water supply projects with potential for providing water for long-term Canal operation demands (including new locks) and for increased municipal and industrial needs have been identified. The Canal Capacity Projects Division has consequently initiated the conceptual development of new locks that would service Post-Panamax vessels. The tentative size of proposed Post-Panamax locks is 61 m wide by 457 m long by 18.3 m deep, which is significantly larger than the existing Panamax-size locks that measure 33.5 m wide by 305 m long by 13 m deep.

The proposed Post-Panamax locks could have several design configurations, ranging from a single-lift system to a three-lift system. It is expected that the new lock configuration and the number of lifts effect the transmission of salt sea water through the lock system to Gatun Lake and Miraflores Lake, and that the new locks will require a greater quantity of fresh water for Canal operation. In view of the latter the use of lateral water saving basins is considered.

The issue of possible salt water intrusion into Gatun Lake caused by the operation of the existing locks and proposed Post-Panamax locks is a very important environmental concern and will play a serious role in the evaluation of proposed Post-Panamax locks. The evaluation requires a comprehensive understanding of salt water intrusion through the lock operations and use of water saving basins. New tools are needed to perform an analysis of the physical and operational processes involved.

Autoridad del Canal de Panamá (ACP) has awarded WL | Delft Hydraulics the contract for 'Saltwater Intrusion Analysis for the Existing and Proposed Post-Panamax Locks at the Panama Canal' (contract SAA-74337). The formal Notice to Proceed, dated 18 October 2001, was received by fax on 19 October 2001.
The objectives of the services of WL | Delft Hydraulics were to analyse the salt water intrusion for the existing and proposed Post-Panamax locks and to develop the required tools. To that purpose the services included:

- review of present canal operation and data on salt water intrusion in the existing situation
- collection of field data on salt water intrusion, both in the wet and dry season

- numerical modelling, validation and analysis of salt water intrusion for the existing situation
- numerical modelling and analysis of salt water intrusion for three-lift and single-lift configurations of proposed Post-Panamax locks

In addition, the services included:

- development of specifications for further testing of salt water intrusion using physical scale models of the proposed locks and water saving basins

The contract was extended January 2003; the objective of this extension was:

- numerical modelling and analysis of salt water intrusion for two-lift configuration of proposed Post-Panamax locks

The present report presents the results of the salt water intrusion analysis for the future situation with new, third shipping lane and Post-Panamax locks. The first part of the report describes and compares the salt water intrusion for the three configurations of Post-Panamax locks, that was studied under the present contract. Comments of ACP to earlier draft reports, mainly on the set up of the salt water intrusion simulation model and the use of salt exchange coefficients in this model, are treated here and further explained. The next three parts of the report, indicated as Report B, Report C and Report D, present the numerical model and the results of salt water intrusion simulations for each of these three configurations of Post-Panamax locks separately. These reports can be read independently; each of them contains full information on the numerical simulation model for the specific lock configuration.

Report A, dated June 2003, presents the results of the salt water intrusion analysis for the existing situation, including a review of the present canal operation, a review of available data on salt intrusion in the existing situation, the collection of field data on salinity levels in the canal area in wet and dry season, the development of the numerical simulation model, and the analysis of salt water intrusion in the existing situation. It contains also specifications for further testing of salt water intrusion through the locks on the canal using physical scale models.

From the tables it appears that salt concentration values of most individual lock chambers of the existing locks (A – F, see also Reports B, C and D for names) do not importantly change when Post-Panamax Locks are in operation. The strongest effect occurs in Lock C (Pedro Miguel Locks) since the buffer function of the intermediate Miraflores Lake reduces when salt water directly intrudes Gatun Lake through the new locks.

For the salt intrusion into the lakes the phase of the lockage process with high water level in the upper lock chamber is of importance. This phase corresponds with the lower salt concentration values in the lock chambers. The lower values in the above tables are valid for uplockage of the last ship of a series of uplocking ships; these values are used for a mutual comparison of different lock systems:

Volume-averaged salt concentration in ppt.						
Side of canal	*Post-Panamax Locks Pacific side*			*Post-Panamax Locks Atlantic side*		
Lock system *Upper lock chamber*	*3-lift* *J*	*2-lift* *Q*	*1-lift* *N*	*3-lift* *M*	*2-lift* *S*	*1-lift* *O*
Scenario 1 wsb's in operation	0.2	2	16	0.5	2	15
Scenario 2 wsb's not in operation	0	1	7	0	1	6

Table 2.16 Post-Panamax Locks, upper lock chambers with high water level. Salt concentrations (in ppt) of individual lock chambers in year 50, end of dry season

Table 2.16 shows that the volume-averaged salt concentration of the upper lock chamber is smaller as the lock system has more upward steps in the floor. Salt concentrations are also smaller when wsb's are not in operation (scenario 2), but the differences between 1-lift, 2-lift and 3-lift locks remain. Since the salt concentration level in the upper locks is decisive for salt water intrusion, it appears that the greater the number of lifts the more effective salt intrusion in Gatun Lake is prevented.

2.4 Conclusions and recommendations

Both from the view point of salt water intrusion and extra water supplies to Gatun Lake the 3-lift Post-Panamax Lock system is the best alternative. The application of water saving basins helps to save water, but is also the cause of a somewhat greater salt water intrusion. The volume-averaged salt concentration of Gatun Lake remains far below the fresh-water limit, also when wsb's are in operation. However, areas with a higher salt concentration than the volume-averaged concentration will occur. Such areas may be Gaillard Cut, the shipping channel in the lake and the north-eastern area of the lake. This does not necessarily mean that the fresh-water limit in these areas is exceeded. A further study on the distribution of salt water in the lake is required to assess whether local salinity levels rise above the fresh water limit. If so, additional measures can be taken to reduce the salt water intrusion. The salt concentration level in Miraflores Lake is hardly effected and remains more or less as in the present situation.

The alternative 2-lift and 1-lift Post-Panamax Locks cause a much higher inflow of salt water into Gatun Lake. The volume-averaged salt concentration rises far above the fresh-water limit, also when wsb's are not in operation. These alternatives require additional measures to mitigate or prevent salt water intrusion.

Report B
Single-lift Post-Panamax Locks

I Introduction

The present Report B deals with the salt water intrusion of the *single-lift lock* configuration of Post-Panamax Locks on the future, third shipping lane. The salt water intrusion is additional to the salt water intrusion through the existing locks. The new single-lift locks may be provided with water saving basins.

The following items will be adressed in the present report:

- review of concept design of Consorcio Post-Panamax (CPP) for the *single-lift lock* configuration of Post-Panamax Locks;
- extension of the salt-water intrusion simulation model built for the existing situation with a new shipping lane; this new lane is is provided with *single-lift locks* and water saving basins at either side of the canal (the use of water saving basins is optional in the simulation model);
- selection of salt exchange coefficients that will be used in the simulation;
- simulation of salt water intrusion for the *single-lift lock* configuration of Post-Panamax Locks and analysis of results.

Section 3.8 (water releases from Miraflores Lake remain as in the existing situation). The various cases are numbered as shown in Table 7.2.

In the baseline scenario we assume that all extra water losses caused by lock operation in the new shipping lane are compensated by extra water supplies to Gatun Lake, but water spills at Gatun Dam are not reduced. When the wsb's of the single-lift locks in the new lane are in use (Case D1) the extra water supply amounts to $0.4x10^6$ m^3 water per transiting ship (leading to an extra water supply in year 50 of 6.10^6 m^3 per day). When the wsb's are not applied (Case D2) the extra water supply to Gatun Lake amounts to $1.6x10^6$ m^3 water per transiting ship (leading to an extra water supply in year 50 of 24.10^6 m^3 per day).

In the second scenario we assume that the water releases at Gatun Dam are reduced with the water losses caused by the new locks. Consequently, a lesser quantity of fresh water has to be supplied to Gatun Lake. In the dry season, however, the spilled quantities are small or nil and extra water supplies are still needed to compensate for the water losses of the new locks (see also Tables 3.14 and 3.15). When wsb's are used (Case D3) the water loss is 75% smaller than when the wsb's are out of use (case D4).
For reasons of comparison we have also simulated the salt water intrusion in the period 2011 – 2020 when no new shipping lane is realised. This case is indicated with A-10.

Simulation time	Existing Situation	Future Situation 1-lift locks **with** wsb's (baseline)	Future Situation 1-lift locks **without** wsb's	Future Situation 1-lift locks **with** wsb's and reduced water releases GL	Future Situation 1-lift locks **without** wsb's and reduced water releases GL
1 month		D1-1m	D2-1m		
1 year		D1-1	D2-1	D3-1	D4-1
5 years		D1-5	D2-5		
10 years	A-10	D1-10	D2-10	D3-10	D4-10
20 years		D1-20	D2-20	D3-20	D4-20
50 years		D1-50	D2-50	D3-50	D4-50

Table 7.2 Overview of cases

For the new shipping lane with alternative 2-lift locks we reserve the letter C (see Report D). The alternative 3-lift locks have been discussed in Report C. The simulations for this alternative design are indicated with the letter B.

7.3 Results of simulations and analysis

The computed salt concentrations (ppt) of Miraflores Lake and Gatun Lake in the period year 2016 – year 2020 (ending 10 years after opening of new lane) and the period year 2051 – year 2060 (ending 50 years after opening) are shown in Figures D1-10, 1 through D4-50, 2. The results for the existing situation (no new lane) for the period year 2011 – year 2020 are shown in Figures A-10, 1 and A-10, 2. As can be seen the salt concentrations of Miraflores Lake and Gatun Lake fluctuate as a function of wet and dry season; the salt concentration levels stabilize within a period of about 1- 2 years after a change in ship traffic intensity.

The maximum and minimum values of the salt concentration of Miraflores Lake and Gatun Lake in the last year of the considered period are presented in Table 7.3.

Case	*Considered year*	*Salt conc. (ppt) Miraflores Lake*		*Salt conc. (ppt) Gatun Lake*	
		minimum	*maximum*	*minimum*	*maximum*
A-10	10	0.64	1.42	0.010	0.027
D1-1month	-	0.63	1.01	0.009	0.049
D1-1	1	0.63	1.66	0.009	0.36
D1-5	5	0.84	2.22	0.35	0.99
D1-10	10	0.87	2.32	0.42	1.18
D1-20	20	0.97	2.68	0.56	1.53
D1-50	50	1.14	3.56	0.95	2.59
D2-1month	-	0.63	1.00	0.009	0.031
D2-1	1	0.63	1.57	0.009	0.18
D2-5	5	0.72	1.81	0.16	0.45
D2-10	10	0.75	1.82	0.19	0.54
D2-20	20	0.79	2.02	0.25	0.67
D2-50	50	0.82	2.33	0.39	1.02
D3-1	1	0.63	1.87	0.009	0.70
D3-10	10	1.00	2.55	0.65	1.52
D3-20	20	1.22	3.08	0.99	2.13
D3-50	50	2.00	4.80	2.45	4.17
D4-1	1	0.63	1.65	0.009	0.45
D4-10	10	1.15	2.34	0.92	1.07
D4-20	20	1.31	2.64	1.16	1.30
D4-50	50	1.37	2.88	1.38	1.56

Table 7.3 Maximum and minimum values of salt concentration of Miraflores Lake and Gatun Lake

The maximum and minimum values are also shown in Figures 7.1 (Miraflores Lake) and 7.2 (Gatun Lake).
From Figure 7.1 it appears that depending on the scenario the salt concentration of Miraflores Lake increases with a factor up to 3.4 in year 50 compared to the present situation (scenario D3 is most unfavourable). Though Miraflores Lake is by-passed by the new lane, the new lane with Post-Panamax Locks has still an impact on the salinity of Miraflores Lake: extra salt water is spilled from Gatun Lake through Pedro Miguel locks into Miraflores Lake.
The salt concentration of Gatun Lake (Figure 7.2) changes considerably: the salt concentration increases from the present very low, negligible salinity level to a salinity level that raises above the fresh-water limit, similar as in Miraflores Lake. Notice that a value of 200 mg/l chloridity is used in the Netherlands as a fresh-water limit value; this corresponds to about 400 mg/l or 0.4 ppt salinity. In the USA a value of 250 mg/l cloridity (about 0.5 ppt salinity) is used as an upper limit for drinking water (Environmental Protection Agency

standard). The fresh-water limit line shown in the graphs is set on a value of 0.45 ppt salinity.

From Figures 7.1 and 7.2 it appears that Scenario D2 (no wsb's, no reduction of water releases at Gatun Dam) is most favourable in view of salt-water intrusion. The reason is that large quantities of fresh-water are supplied to Gatun Lake to maintain the water level of the lake. When wsb's are in operation (Scenario D1) a 75% smaller fresh-water supply is required and we see that the salt concentration levels increase. The salt concentration levels increase further when the water releases at Gatun Dam are reduced (Scenarios D3 and D4).

It should be noted that the computed concentration values are volume-averaged values, which means that local salt concentration values may be higher.

From the results of the simulations we conclude that the single-lift locks are unfavourable both from the view point of fresh water supply to Gatun Lake and salt water intrusion.

7.4 Sensitivity analysis

In a sensitivity analysis we have studied the effects of a variation of exchange coefficients for the single-lift locks in the new shipping lane. Most important coefficients are those which determine the exchange of salt water in step II of the uplockage and downlockage process (movement of ship between lock chamber and tailbay or forebay). These coefficients have been varied in cases Sens1 and Sens2. The exchange coefficients which determine the salt water transfer in step I of the uplockage and downlockage process (equalize water levels tailbay – lock or lock – forebay) have been varied in Sens3 and Sens4. For the values of exchange coefficients see Sections 5.1 and 5.2. The exchange coefficients of the existing locks have been kept constant (they are such selected that the salinity levels of Miraflores Lake and Gatun Lake in the present situation are correctly predicted, see also Report A).

The results of the sensitivity analysis are shown in Figure 7.3 (Miraflores Lake) and Figure 7.4 (Gatun Lake). These figures present the salt concentration of the lakes for the base exchange coefficients and for variations of the exchange coefficients. The figures demontrate that the salt concentration of the lakes varies with the exchange coefficients, but this variation is relatively small compared to the effects of the single-lift locks on the salinity of, in particular, Gatun Lake. The tendency of a much higher salinity level of Gatun Lake in the case of single-lift locks (with or without wsb's) is therefore reliable.

Report C
Three-lift Post-Panamax Locks

1 Introduction

The present Report C deals with the salt water intrusion of the *three-lift lock* configuration of Post-Panamax Locks on the future, third shipping lane. The salt water intrusion is additional to the salt water intrusion through the existing locks. The new three-lift locks may be provided with water saving basins.

The following items will be adressed in the present report:

- review of concept design of Consorsio Post-Panamax (CPP) for the *three-lift lock* configuration of Post-Panamax Locks;
- extension of the salt-water intrusion simulation model built for the existing situation with a new shipping lane; this new lane is is provided with *three-lift locks* and water saving basins at either side of the canal (the use of water saving basins is optional in the simulation model);
- selection of salt exchange coefficients that will be used in the simulation;
- simulation of salt water intrusion for the *three-lift lock* configuration of Post-Panamax Locks and analysis of results.

Gatun Lake, see Section 3.8 (water releases from Miraflores Lake remain as in the existing situation). The various cases are numbered as shown in Table 7.2.

In the baseline scenario we assume that all extra water losses caused by lock operation in the new shipping lane are compensated by extra water supplies to Gatun Lake, but water spills at Gatun Dam are not reduced. When the wsb's of the three-lift locks in the new lane are in use (Case B1) the extra water supply amounts to 2.10^5 m^3 water per transiting ship (leading to a water supply in year 50 of 3.10^6 m^3 per day). When the wsb's are not applied (Case B2) the extra water supply to Gatun Lake amounts to 5.10^5 m^3 water per transiting ship (leading to a water supply in year 50 of $7.5.10^6$ m^3 per day).

In the second scenario we assume that the water releases at Gatun Dam are reduced with the water losses caused by the new locks. Consequently, a lesser quantity of fresh water has to be supplied to Gatun Lake. In the dry season, however, the spilled quantities are small or nil and extra water supplies are still needed to compensate for the water losses of the new locks (see also Tables 3.18 and 3.19). When wsb's are used (Case B3) the water loss is 60% smaller than when they are out of use (case B4).

For reasons of comparison we have also simulated the salt water intrusion in the period 2011 – 2020 when no new shipping lane is realised. This case is indicated with A-10. The results for year 10 are in fact also valid for year 1, 5, 20 and 50, since these values are stable, equilibrium values for the given ship traffic intensity in the existing locks.

Simulation time	Existing Situation	Future Situation 3-lift locks **with** wsb's (baseline)	Future Situation 3-lift locks **without** wsb's	Future Situation 3-lift locks **with** wsb's and reduced water releases GL	Future Situation 3-lift locks **without** wsb's and reduced water releases GL
1 month		B1-1m	B2-1m		
1 year		B1-1	B2-1	B3-1	B4-1
5 years		B1-5	B2-5		
10 years	A-10	B1-10	B2-10	B3-10	B4-10
20 years		B1-20	B2-20	B3-20	B4-20
50 years		B1-50	B2-50	B3-50	B4-50

Table 7.2 Overview of cases

For the new shipping lane with alternative 2-lift locks or 1-lift locks we reserve the letters C and D respectively for designation of the cases.

7.3 Results of simulations and analysis

The computed salt concentrations (ppt) of Miraflores Lake and Gatun Lake in the period year 2016 – year 2020 (ending 10 years after opening of new lane) and the period year 2051 – year 2060 (ending 50 years after opening) are shown in Figures B1-10, 1 through B4-50, 2. The results for the existing situation (no new lane) for the period year 2011 – year 2020 are shown in Figures A-10, 1 and A-10, 2. As can be seen the salt concentrations of Miraflores Lake and Gatun Lake fluctuate as a function of wet and dry season; the salt concentration levels stabilize within a period of about 1- 2 years after a change in ship traffic intensity.

The maximum and minimum values of the salt concentration of Miraflores Lake and Gatun Lake in the last year of the considered period are presented in Table 7.3.

Case	*Considered year*	*Salt conc. (ppt) Miraflores Lake*		*Salt conc. (ppt) Gatun Lake*	
		minimum	*maximum*	*minimum*	*maximum*
A-10	10	0.64	1.42	0.010	0.027
B1-1month	-	0.65	0.99	0.009	0.011
B1-1	1	0.62	1.05	0.011	0.024
B1-5	5	0.63	1.49	0.012	0.032
B1-10	10	0.65	1.43	0.012	0.034
B1-20	20	0.66	1.53	0.013	0.036
B1-50	50	0.61	1.52	0.018	0.044
B2-1month	-	0.66	0.99	0.009	0.011
B2-1	1	0.62	1.05	0.009	0.025
B2-5	5	0.63	1.49	0.009	0.026
B2-10	10	0.64	1.42	0.009	0.026
B2-20	20	0.65	1.52	0.009	0.025
B2-50	50	0.61	1.51	0.009	0.026
B3-1	1	0.62	1.48	0.009	0.032
B3-10	10	0.65	1.43	0.015	0.039
B3-20	20	0.66	1.53	0.017	0.042
B3-50	50	0.62	1.53	0.025	0.057
B4-1	1	0.62	1.47	0.009	0.030
B4-10	10	0.65	1.43	0.016	0.035
B4-20	20	0.66	1.53	0.019	0.038
B4-50	50	0.62	1.53	0.032	0.046

Table 7.3 Maximum and minimum values of salt concentration of Miraflores Lake and Gatun Lake

The maximum and minimum values are also shown in Figures 7.1 (Miraflores Lake) and 7.2 (Gatun Lake). From Figure 7.1 it appears that the salt concentration of Miraflores Lake remains more or less as in the present situation (in all four cases B1-B4), but the salt concentration of Gatun Lake (Figure 7.2) changes. The increase of salt concentration is up to a factor 3.2 in year 50 for the most unfavourable case B4, but still the salinity level remains far below the fresh-water limit. (Note: A value of 200 mg/l chloridity is used in the Netherlands as a fresh-water limit value; this corresponds to about 400 mg/l or 0.4 ppt salinity. In the USA a value of 250 mg/l cloridity (about 0.5 ppt salinity) is used as an upper limit for drinking water (Environmental Protection Agency standard)).

It appears that Case B2 (no wsb's) is most favourable in view of salt-water intrusion (a small reduction of the salt concentration levels is predicted). This is caused by the large fresh-water supply to Gatun Lake. When wsb's are applied (Case B1) a 60% smaller fresh-water supply is required and we see that the salt concentration levels increase with a factor 1.7. The salt concentration levels increase further (factor 2 – 3) when the water releases at Gatun

Dam are reduced (Cases B3 and B4). Again, the computed salt concentration level of about maximum 0.06 ppt of Gatun Lake in year 50 is very low compared to fresh-water standards (see Figure 7.2a)

It should be noted that the computed concentration values are volume-averaged values, which means that local salt concentration values may be higher.

Conclusions

The main conclusions that can be drawn from the salt-water intrusion simulations are:

- The salt concentration of Miraflores Lake (Figure 7.1) is hardly effected by the new shipping lane (provided that the water releases at Miraflores Dam will be maintained).
- The volume-averaged salt concentration of Gatun Lake (Figures 7.2 / 7.2a) generally increases, in particular when wsb's are applied and water releases at Gatun Dam are reduced, but remains far below fresh-water limit values.

Report D
Two-lift Post-Panamax Locks

I Introduction

The present Report deals with the salt water intrusion of the *two-lift lock* configuration of Post-Panamax Locks on the future, third shipping lane. The salt water intrusion is additional to the salt water intrusion through the existing locks. The new two-lift locks may be provided with water saving basins.

The following items will be adressed in the present report:

- review of concept design of US Army Corps of Engineers (USACE) for the *two-lift lock* configuration of Post-Panamax Locks;
- extension of the salt-water intrusion simulation model built for the existing situation with a new shipping lane; this new lane is provided with *two-lift locks* and water saving basins at either side of the canal (the use of water saving basins is optional in the simulation model);
- selection of salt exchange coefficients that will be used in the simulation;
- simulation of salt water intrusion for the *two-lift lock* configuration of Post-Panamax Locks and analysis of results.

In the baseline scenario we assume that all extra water losses caused by lock operation in the new shipping lane are compensated by extra water supplies to Gatun Lake, but water spills at Gatun Dam are not reduced. When the wsb's of the two-lift locks in the new lane are in use (Case C1) the extra water supply amounts to 4.10^5 m^3 water per transiting ship (leading to a water supply in year 50 of 6.10^6 m^3 per day). When the wsb's are not applied (Case C2) the extra water supply to Gatun Lake amounts to 8.10^5 m^3 water per transiting ship (leading to a water supply in year 50 of 12.10^6 m^3 per day).
In the second scenario we assume that the water releases at Gatun Dam are reduced with the water losses caused by the new locks. Consequently, a lesser quantity of fresh water has to be supplied to Gatun Lake. In the dry season, however, the spilled quantities are small or nil and extra water supplies are still needed to compensate for the water losses of the new locks (see also Tables 3.18 and 3.19). When wsb's are used (Case C3) the water loss is 50% smaller than when they are out of use (case C4).
For reasons of comparison we have also simulated the salt water intrusion in the period 2011 – 2020 when no new shipping lane is realised. This case is indicated with A-10. The results for year 10 are in fact also valid for year 1, 5, 20 and 50, since these values are stable, equilibrium values for the given ship traffic intensity in the existing locks.

Simulation time	Existing Situation	Future Situation 2-lift locks **with** wsb's (baseline)	Future Situation 2-lift locks **without** wsb's	Future Situation 2-lift locks **with** wsb's and reduced water releases GL	Future Situation 2-lift locks **without** wsb's and reduced water releases GL
1 month		C1-1m	C2-1m		
1 year		C1-1	C2-1	C3-1	C4-1
5 years		C1-5	C2-5		
10 years	A-10	C1-10	C2-10	C3-10	C4-10
20 years		C1-20	C2-20	C3-20	C4-20
50 years		C1-50	C2-50	C3-50	C4-50

Table 7.2 Overview of cases

For the new shipping lane with alternative 3-lift locks or 1-lift locks we reserve the letters B and D respectively for designation of the cases.

7.3 Results of simulations and analysis

The computed salt concentrations (ppt) of Miraflores Lake and Gatun Lake in the period year 2016 – year 2020 (ending 10 years after opening of new lane) and the period year 2051 – year 2060 (ending 50 years after opening) are shown in Figures C1-10, 1 through C4-50, 2. The results for the existing situation (no new lane) for the period year 2011 – year 2020 are shown in Figures A-10, 1 and A-10, 2. As can be seen the salt concentrations of Miraflores Lake and Gatun Lake fluctuate as a function of wet and dry season; the salt concentration levels stabilize within a period of about 1- 2 years after a change in ship traffic intensity.

The maximum and minimum values of the salt concentration of Miraflores Lake and Gatun Lake in the last year of the considered period are presented in Table 7.3.

Case	*Considered year*	*Salt conc. (ppt) Miraflores Lake*		*Salt conc. (ppt) Gatun Lake*	
		minimum	*maximum*	*minimum*	*maximum*
A-10	10	0.64	1.42	0.010	0.027
C1-1month	-	0.63	0.99	0.009	0.017
C1-1	1	0.63	1.10	0.009	0.09
C1-5	5	0.66	1.67	0.08	0.24
C1-10	10	0.70	1.66	0.11	0.33
C1-20	20	0.75	1.85	0.17	0.47
C1-50	50	0.82	2.30	0.38	1.03
C2-1month	-	0.63	0.99	0.009	0.013
C2-1	1	0.63	1.07	0.009	0.05
C2-5	5	0.65	1.55	0.04	0.11
C2-10	10	0.67	1.53	0.06	0.16
C2-20	20	0.70	1.69	0.10	0.26
C2-50	50	0.72	1.94	0.21	0.57
C3-1	1	0.63	1.56	0.009	0.18
C3-10	10	0.74	1.72	0.18	0.43
C3-20	20	0.83	1.98	0.31	0.66
C3-50	50	1.17	2.83	1.00	1.69
C4-1	1	0.63	1.50	0.009	0.09
C4-10	10	0.72	1.60	0.15	0.27
C4-20	20	0.83	1.86	0.31	0.46
C4-50	50	1.15	2.47	0.98	1.10

Table 7.3 Maximum and minimum values of salt concentration of Miraflores Lake and Gatun Lake

The maximum and minimum values are also shown in Figures 7.1 (Miraflores Lake) and 7.2 (Gatun Lake). From Figure 7.1 it appears that the salt concentration of Miraflores Lake increases slowly compared to the present situation (in all four cases C1-C4). Case C4 is most unfavourable with an increase up to a factor 2 in year 50. Though Miraflores Lake is by-passed by the new shipping lane, the new lane with Post-Panamax Locks has still an impact on the salinity of Miraflores Lake because extra salt water is spilled from Gatun Lake through Pedro Miguel locks into Miraflores Lake.

The salt concentration of Gatun Lake raises considerably: the salt concentration increases from the present very low, negligible salinity level to a salinity level in year 50 that is above the fresh water limit (a salinity level of 0.45 ppt can be regarded as fresh water limit). Note: A value of 200 mg/l chloridity is used in the Netherlands as a fresh-water limit value; this corresponds to about 400 mg/l or 0.4 ppt salinity. In the USA a value of 250 mg/l cloridity (about 0.5 ppt salinity) is used as an upper limit for drinking water (Environmental Protection Agency standard).

It appears that Case C2 (no wsb's, no reduction of water releases at Gatun Dam) is most favourable in view of salt-water intrusion. This is caused by the large fresh-water supply to Gatun Lake. When wsb's are in operation (Case C1) a 50% smaller fresh-water supply is required and we see that the salt concentration levels increase. The salt concentration levels increase further when the water releases at Gatun Dam are reduced (Cases C3 and C4).

It should be noted that the computed concentration values are volume-averaged values, which means that local salt concentration values may be higher.

7.4 Sensitivity analysis

In a sensitivity analysis we have studied the effects of a variation of exchange coefficients for the two-lift locks in the new shipping lane. Most important coefficients are those which determine the exchange of salt water in step II of the uplockage and downlockage process (ship movements between tailbay and lower lock, lower lock and upper lock, upper lock and forebay). These coefficients have been varied in cases Sens1 and Sens2. The exchange coefficients which determine the salt water transfer in step I of the uplockage and downlockage process (equalize water levels between tailbay and lower lock, lower lock and upper lock, upper lock and forebay) have been varied in Sens3 and Sens4. For the values of exchange coefficients see Sections 5.1 and 5.2. The exchange coefficients of the existing locks have been kept constant (they are such selected that the salinity levels of Miraflores Lake and Gatun Lake in the present situation are correct predicted, see also Report A).

The results of the sensitivity analysis are shown in Figure 7.3 (Miraflores Lake) and Figure 7.4 (Gatun Lake). These figures present the salt concentration of the lakes for the base exchange coefficients and for variations of the exchange coefficients. The figures demontrate that the salt concentration of the lakes varies with the exchange coefficients, but this variation is relatively small compared to the effects of the two-lift locks on the salinity of, in particular, Gatun Lake. The tendency of a higher salinity level of Gatun Lake in the case of two-lift locks (with or without wsb's) is therefore reliable.