Engineering Consultants
Sint-Niklaas - Belgium

Enabling Delta Life

Fresh Water availability and impact on Lake Nicaragua levels - feasibility

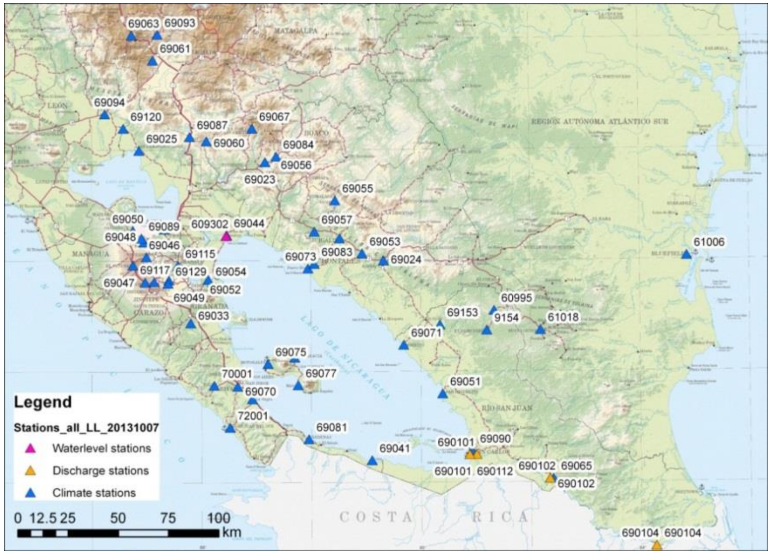
Salt intrusion - feasibility

Fresh water availability

- Calculate available fresh water
  - determine run off in the water basins (valleys, river etc.) linked to a canal route
  - study focus is on effect of the canal use (fresh water used for locking process) on the water level in Lake Nicaragua (LN)
  - at the time of this task routes 3 and 4 were both still considered

- Main sources of input data :
  - meteorological data (precipitation, evaporation)
  - water level and gauging stations
  - long term discharge data San Juan river
  - digital terrain (height) data Shuttle Radar Topography Mission (SRTM)
  - information on land use
  - data on LN: A(h) (surface) en Q(h) (discharge into San Juan)

Observation stations and routes

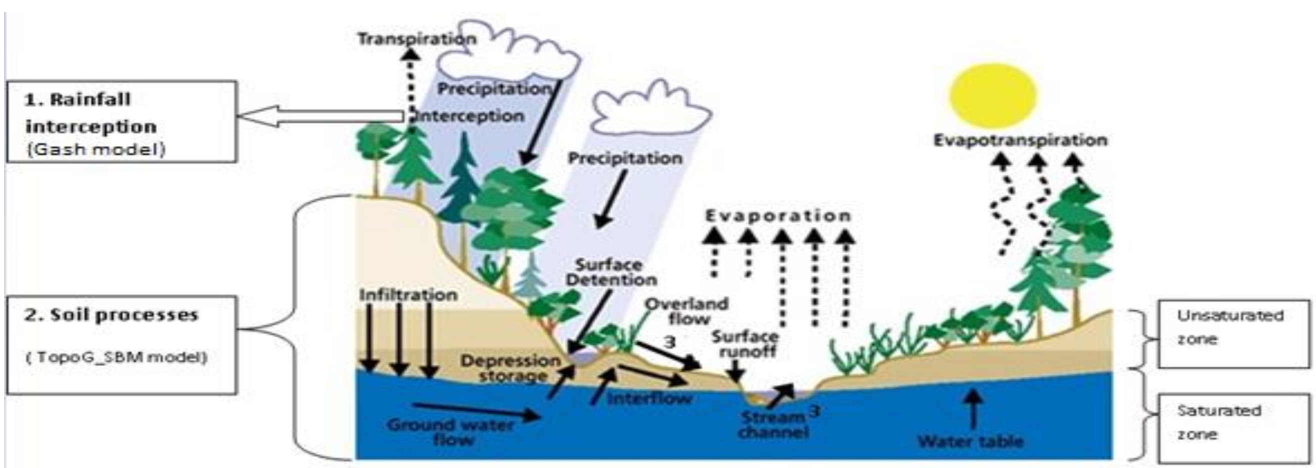



LN water balance model

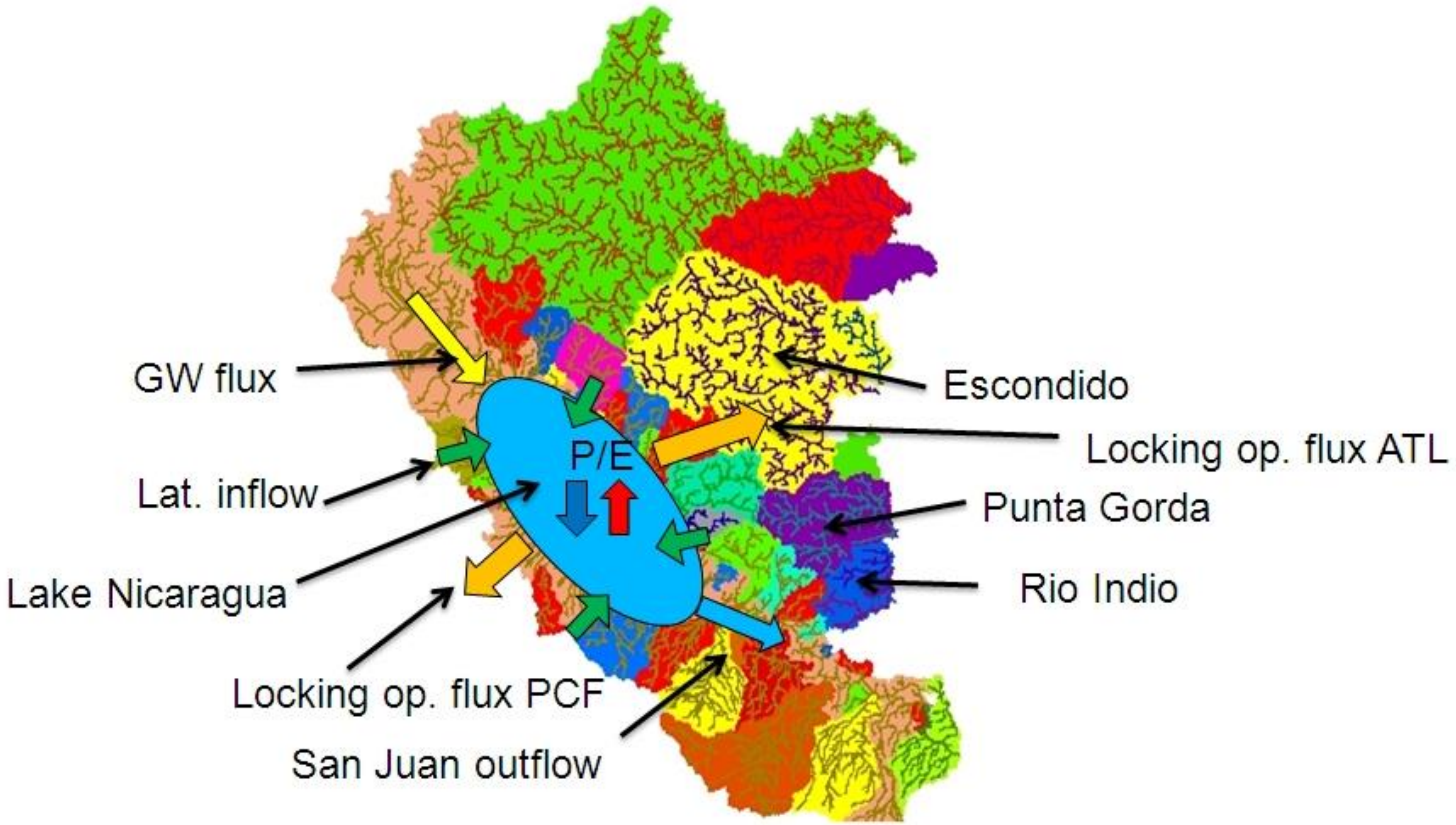
- ‘book keeping’ model of all inflows and outflows of LN; net result determines rising or lowering of the lake
- model provides first indication of long-term (steady state) equilibrium conditions
- monthly values of precipitation and evaporation
- calibration of model (inflows into the lake) **first for existing situation** without canal and for known present-day average lake level (+31.31 masl)

Full hydrological model

- detailed modelling of run off in areas connected to the lake and/or the canal
- day-to-day variations instead of monthly steady-state variations (contrary to the basic balance model describe earlier)
- provides information of water availability of the basins that are crossed by the canal on both the Pacific and Atlantic ocean sides
- also extreme events are modelled (El Niño)
- computed with software developed by Deltares, WFLOW (modelled up to 0.5-1 m of soil depth)



Graphical representation of modelled area



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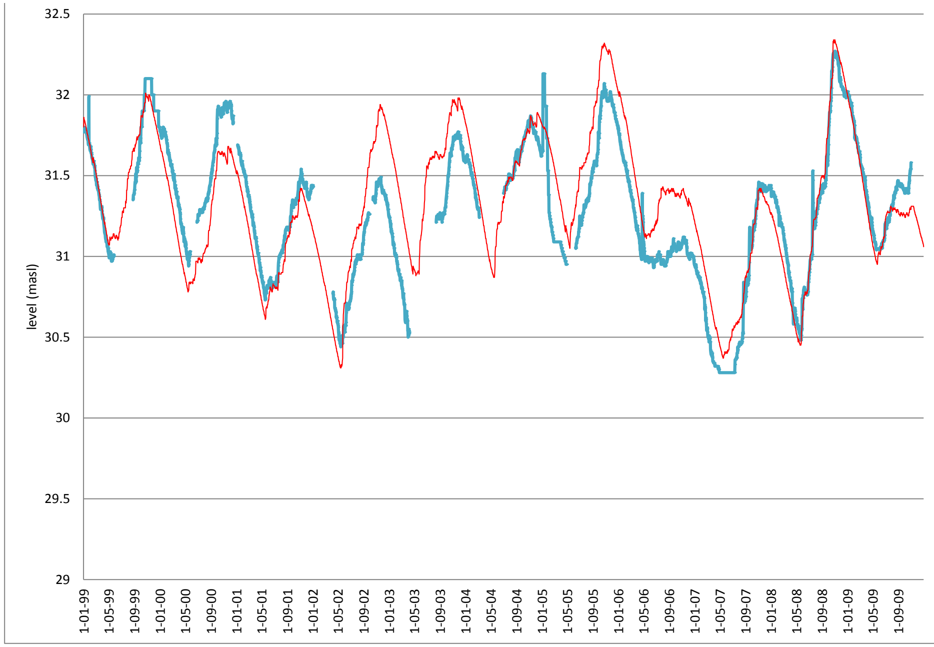
Validation of the full hydrological model

(existing situation)



Measured: blue
Computed: red

- simulation based on 10 years of archived data (available: 1999-2009)
- performance indicator (weighted average deviation from observations): 0.73 (in the range of typical values for consultancy with this type of model)
- deviations are present (<0.1-0.2 m), but model correctly represents average and dynamic behaviour of the system
- particularly good match for extremely dry years, which are most critical for canal operations

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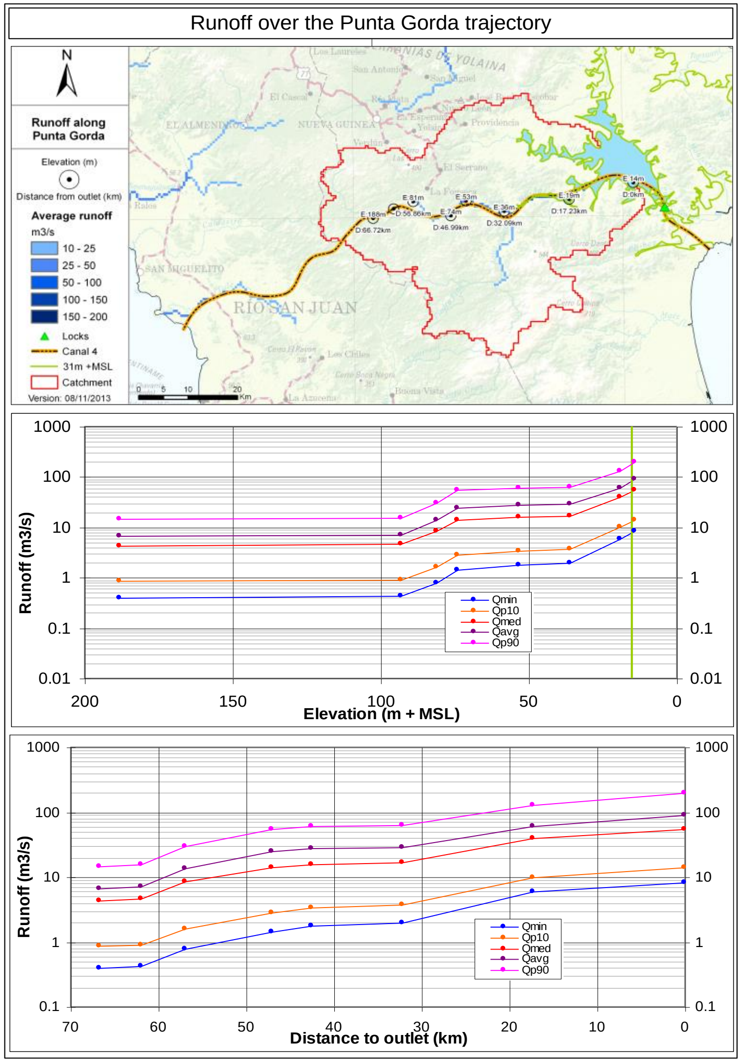
Water availability analysis Atlantic catchments

- Natural (gravity-based) run-off into the canal along the catchments it passes (applied approach after consultation with HKND)
- Mean annual flow estimated at 98 m^3/s in the Rio Escondido basin (including the Rio Rama and Rio Plata branches) and 94 m^3/s in the Rio Punta Gorda basin
- Large natural variations in time of fresh water run off
- Values determined for each catchment (Punta Gorda for Route 4, see example)



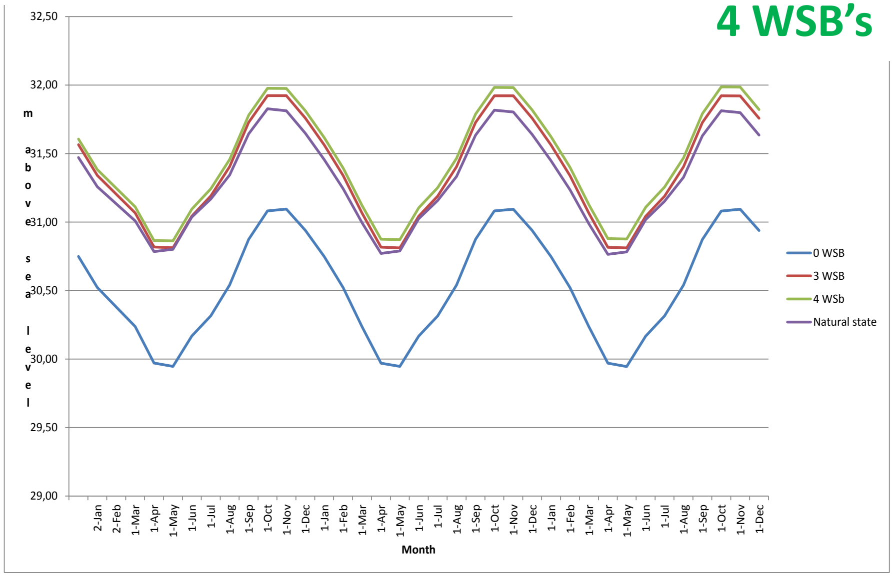
Results with canal (Route 4) for average year

Ship traffic prognosis for 2050

	Indicative equilibrium levels, 2050, Transits/day: 14			
Lock configuration	Canal 0 WSBs	Canal 3 WSBs	Canal 4 WSBs	Present situation
Water use locks [m³/s]	190.3	76.1	63.4	0
Eq. level [masl]	30.54	31.38	31.44	31.31
Min. level [masl]	29.95	30.81	30.88	30.76
Ave. water level LN [m]	-0.77	0.07	0.13	0.00
Max. lowering of water level LN [m]	-1.36	-0.50	-0.43	- 0.54
Ave. surface area [km²]	6717	8447	8581	8274
Q average San Juan [m³/s]	160	339	357	319

Present situation
0 WSB's
3 WSB's
4 WSB's

- Route 4, 2x3 lock steps
- Monthly run off values, so average seasonal influences are included
- Locks with or without Water Saving Basins (WSBs), which allow partly re-use of fresh water
- Only direct runoff (by gravity) included in canal-lake system



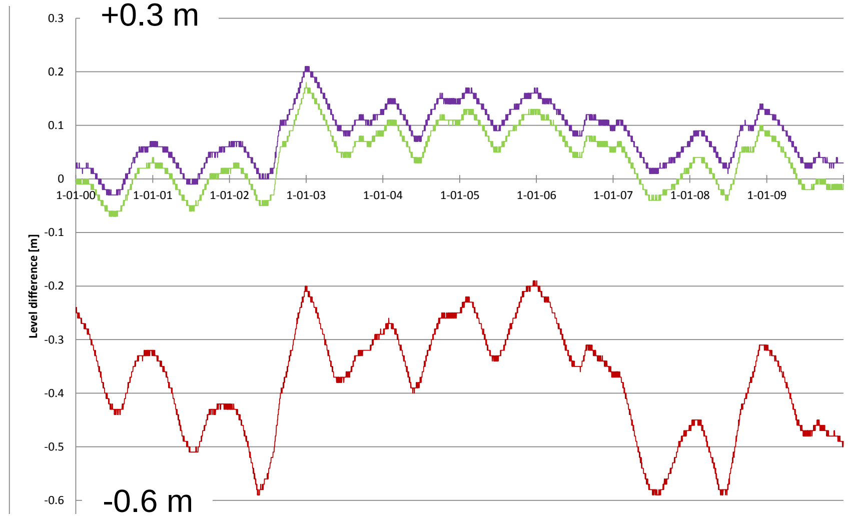
Full hydrological model with canal

with gravity-driven natural inflow from Atlantic catchments

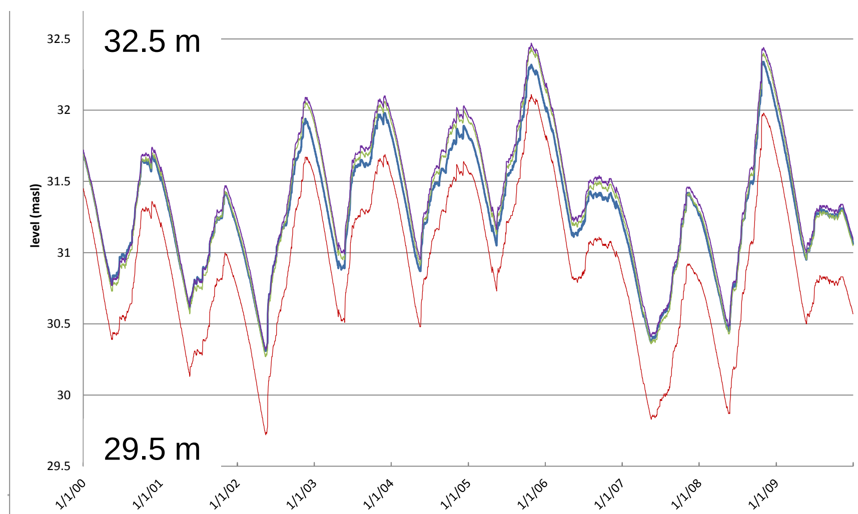
- Route 4, ship traffic 2050
- 10 year time interval simulated, using archived precipitation data (available 1999-2009)
- Daily values (precipitation, run off) for full time series
- Includes 2 extreme, dry years (El Niño): 2001-2002 and 2007-2009

	2050, Transits/day: 14			
	Canal 0 WSB	Canal 3 WSB	Canal 4 WSB	Present situation
Ave. level	31.03	31.41	31.45	31.33
Delta average [m]	-0.32	0.06	0.10	0.00
Min. level [masl]	29.78	30.31	30.36	30.31
Max. lowering in water level LN [m]	-1.58	-1.05	-1.00	-1.02

Difference relative to existing situation (m)



Absolute lake water levels (m)

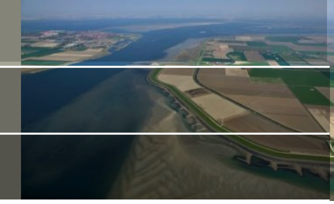


Present situation
0 WSB's
3 WSB's
4 WSB's

Conclusions fresh water availability study

- The water level of LN (average and seasonal variations) will be influenced by the canal operations, but influences may be limited when Water Saving Basins (WSBs) will be applied
- Largest fluctuations presently occur for extreme (El Niño) years, which could be influenced by the canal use, but with WSBs these fluctuations may remain of similar magnitude
- All water that flows from the catchments on the Atlantic side into the new canal will mean reduced water availability in other areas for irrigation, rivers (navigation), sediment transport
- Impacts of changes in water use and distribution should be studied in detail to identify and solve critical issues as part of the canal and lock designs

Preliminary salt intrusion assessment



- Task 1: preliminary salt intrusion (in absence of mitigation)
  - basic assessment for salt intrusion through locks
  - calibrated based on measurements, combined with expertise and experience of SBE-Deltares in earlier lock projects
  - Route 4 (selected route)

- Task 2: propose and evaluate applicability of mitigating measures
  - literature review
  - expertise and experience of SBE-Deltares

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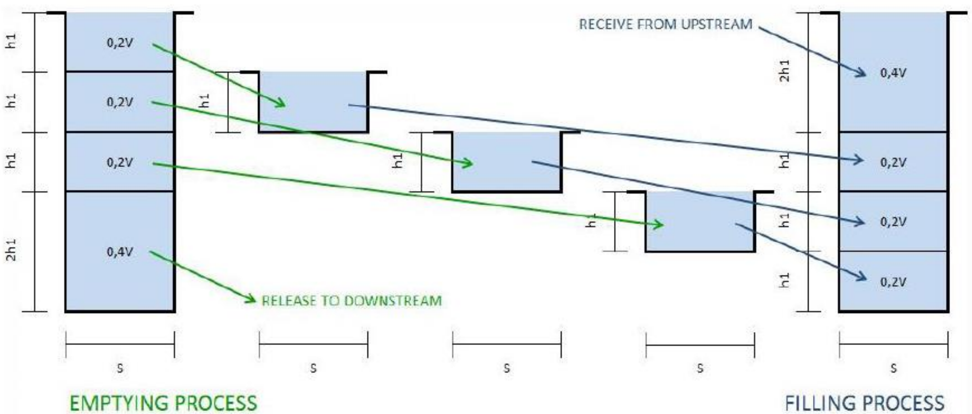
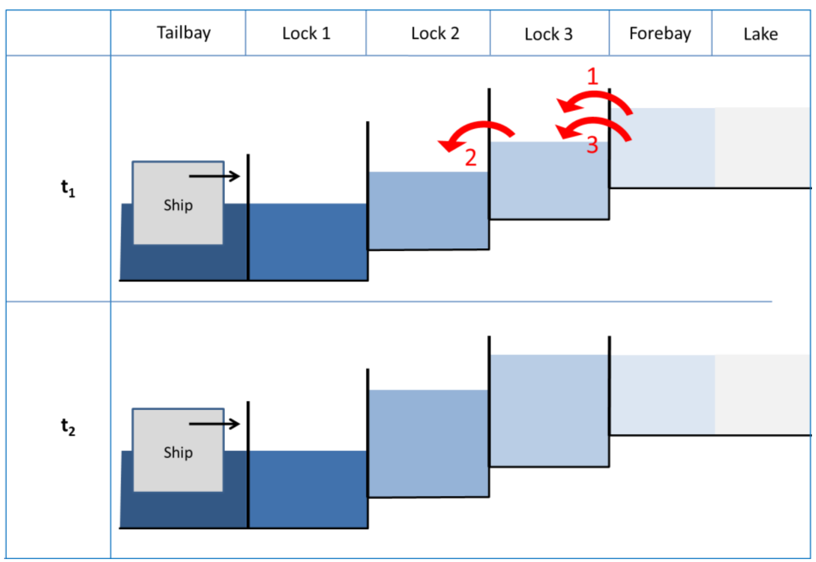
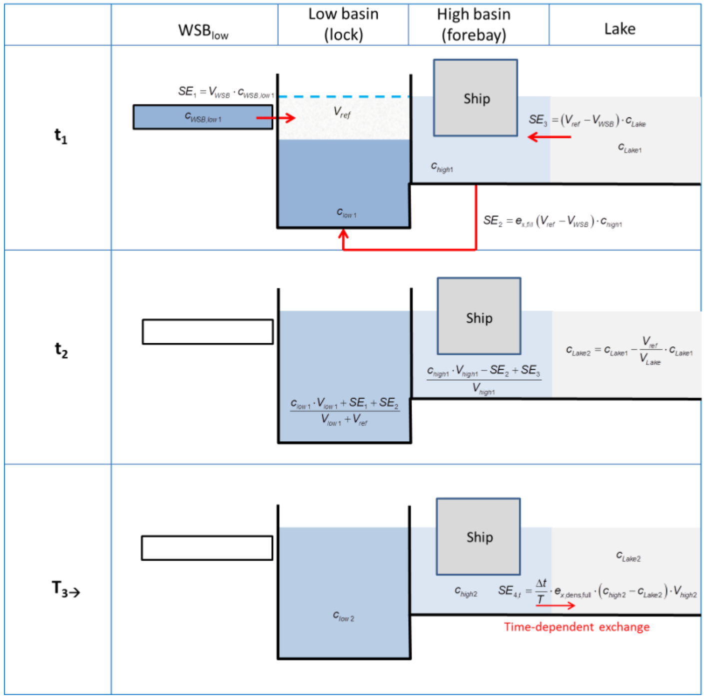
Salt intrusion, Task 1

- Input data:
  - Results hydrology study
  - Bathymetry of LN
  - Ocean salinity (estimated from in-house values known by Deltares)
  - Discharge data San Juan River
  - Lock dimensions and vessel data
  - Approach: assess salt load on one side and multiply by two to cover the two sets of locks (Atlantic + Pacific side)
  - Different options have been evaluated, 2 remaining scenarios are presented here:
    - 1) design vessel draught 19 m (lock chambers 20 m deep);
    - 3) design vessel draught 24 m (lock chambers 25 m deep)

Description of salt intrusion assessment







Discharge of San Juan assumed to contain 50% of mean lake salt concentration

Example lock scenarios

2070 forecasted traffic intensity,
combinations of Large Vessels (LV) and Small Vessels (SV)

	TYPE	DIRECTION	ATL SIDE
Day 1	LV	PCF -> ATL	1 x LV : ATL -> LN
			1 x LV : ATL -> LN
			1 x LV : ATL -> LN
	SV		2 x SV : ATL -> LN
			2 x SV : ATL -> LN
			2 x SV : ATL -> LN
	LV	ATL -> PCF	1 x LV : LN -> ATL
			1 x LV : LN -> ATL
			1 x LV : LN -> ATL
	SV		2 x SV : LN -> ATL
			2 x SV : LN -> ATL
			2 x SV : LN -> ATL
Day …			

Similar lock scenarios for other years (traffic intensities)

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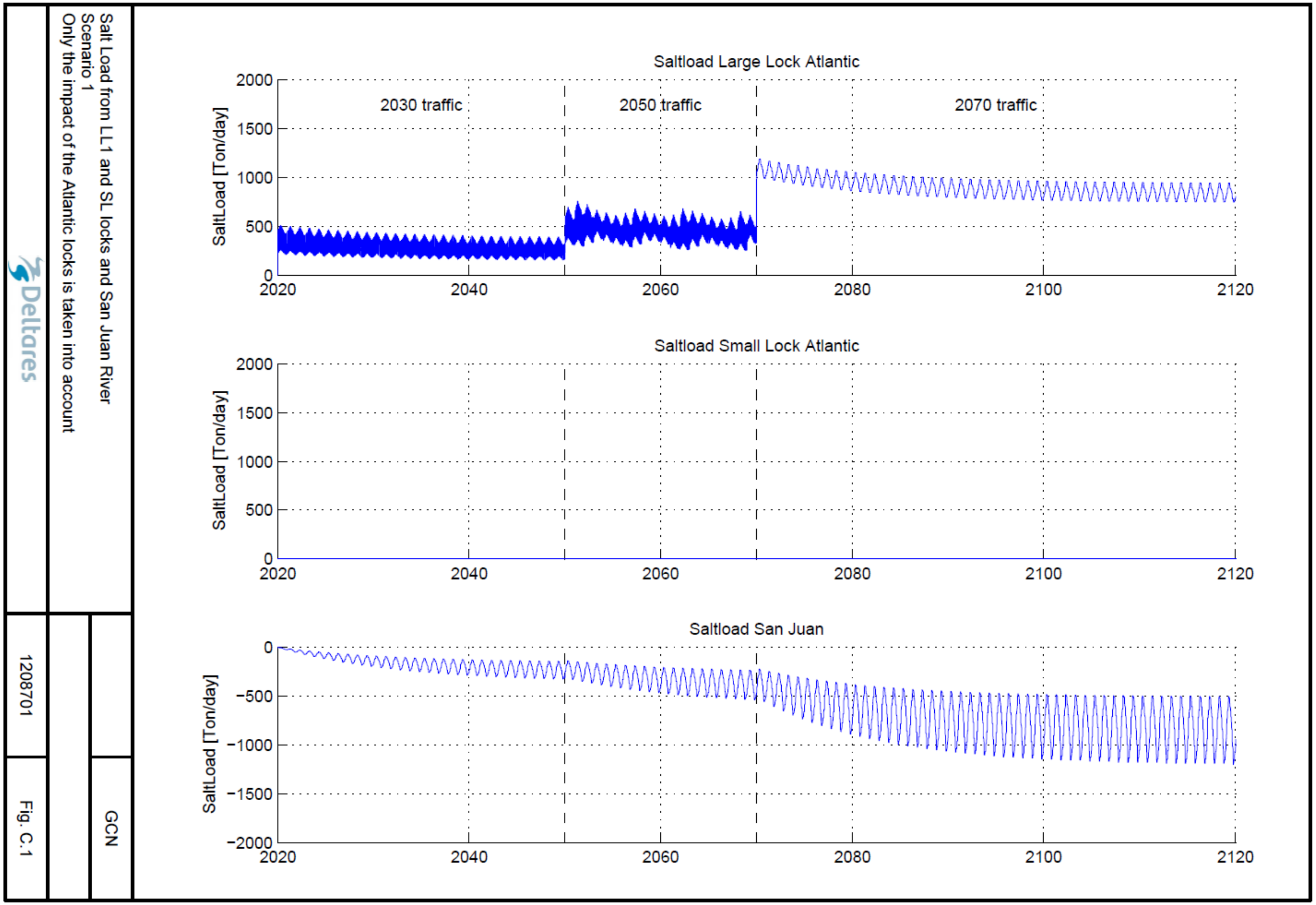
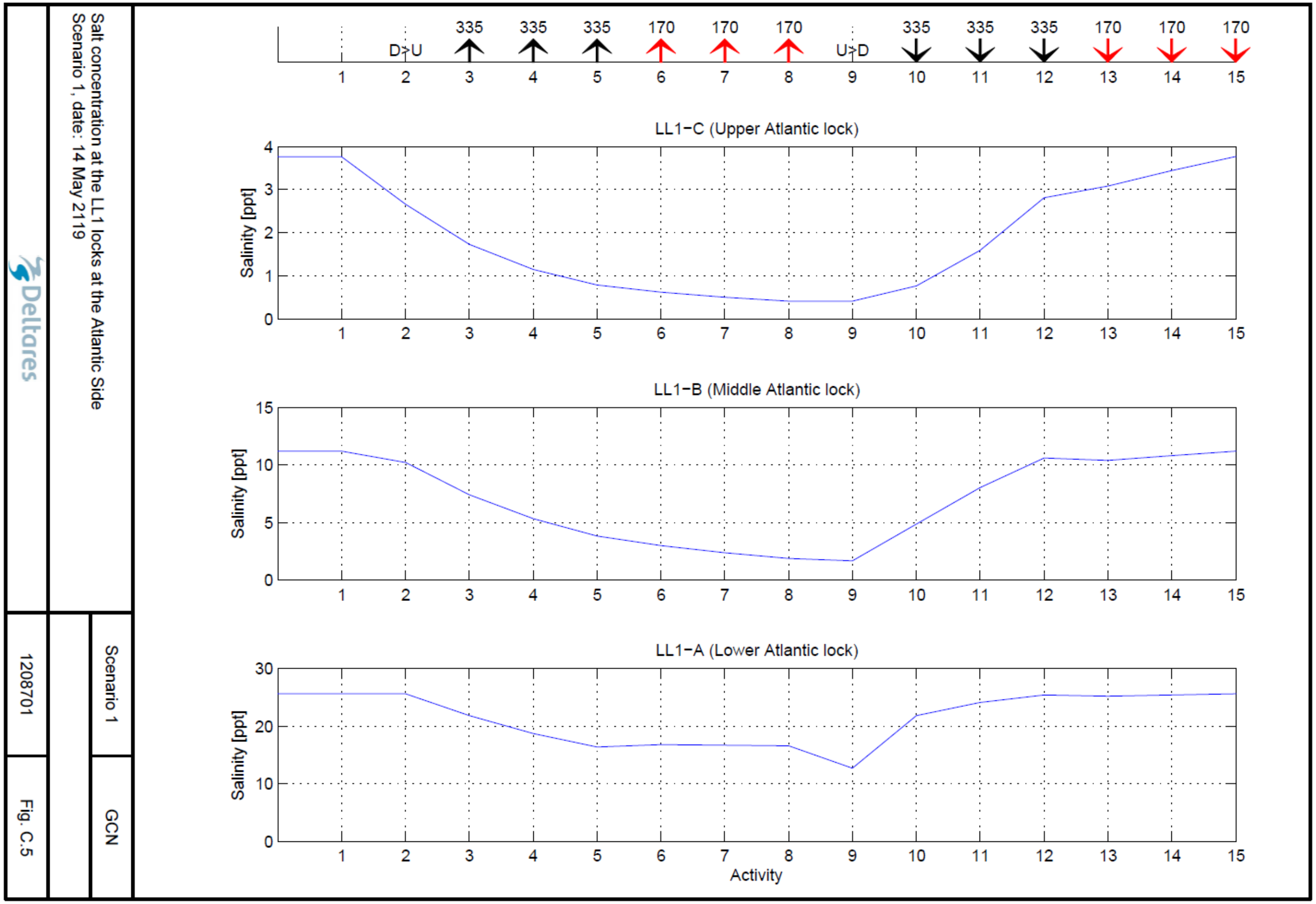
Results assessment salt loads through locks on Atlantic side (to be multiplied by 2 for total loads)



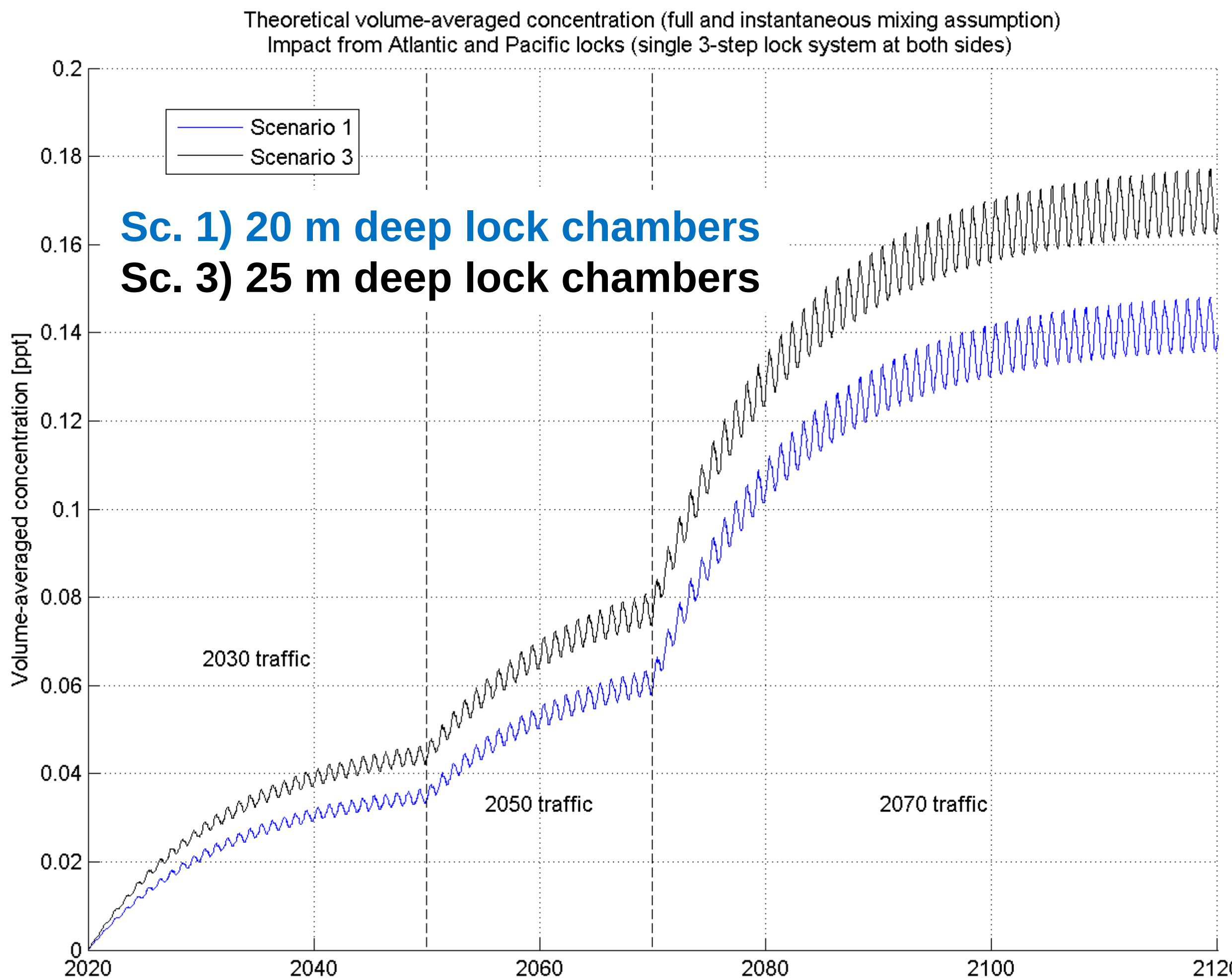
Detail of results of one day (3-step lock)



Preliminary result salt intrusion (uniform assumption)
(including factor 2 to cover influx via Pacific locks)

Rule of thumb:
0.75 kg/m^3 added density for each ppt, for a typical ambient water temperature (20º C), so 1 ppt then corresponds to 1000.75 kg/m^3

Periodic fluctuations in the trends are seasonal influences



Note: theoretical lake-volume-averaged salt concentration, for relative comparison uses only

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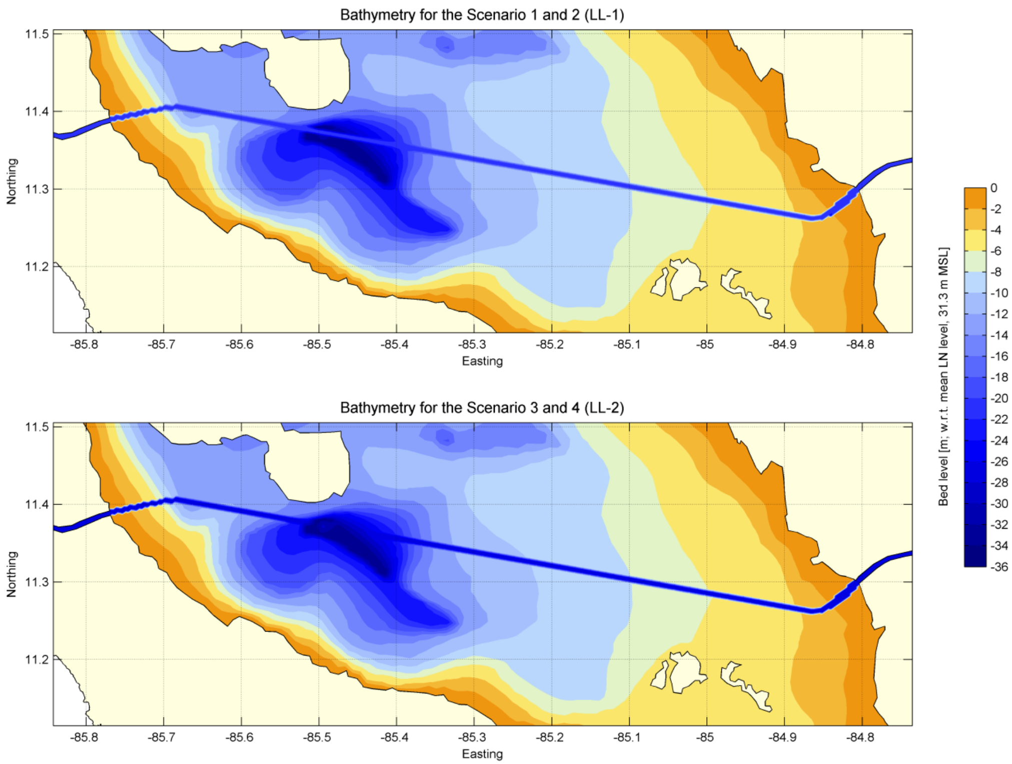
Lake bathymetry influences salt distribution



- Perfectly mixed uniform lake salt concentration is only calculation/comparison parameter
- Will <u>not</u> occur in reality
- Higher concentrations around inflow areas
- Deeper sections will collect more of the heavier salt water → salt ‘hotspots’ (natural pits but also inside the canal)

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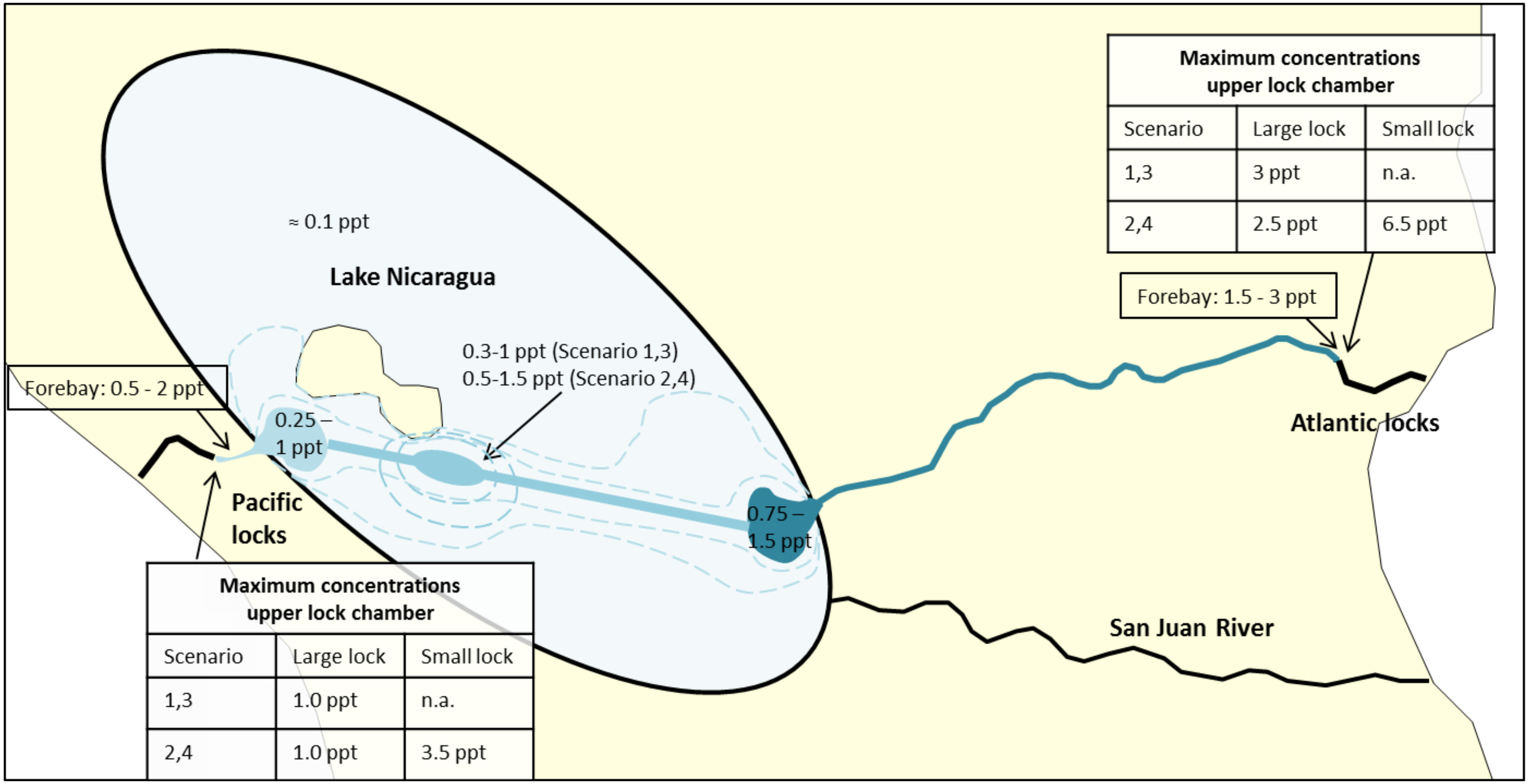
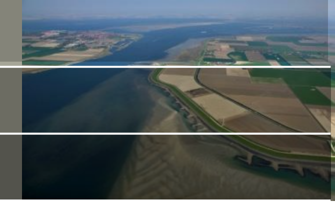
Very crude first interpretation of salt distribution in lake



Maximum concentrations upper lock chamber		
Scenario	Large lock	Small lock
1,3	1.0 ppt	n.a.
2,4	1.0 ppt	3.5 ppt

Maximum concentrations upper lock chamber		
Scenario	Large lock	Small lock
1,3	3 ppt	n.a.
2,4	2.5 ppt	6.5 ppt

- Based only on expert judgement expectations and interpretations
- Large uncertainty bands
- Requires detailed 3D hydrodynamic modelling to reach accurate and definitive results

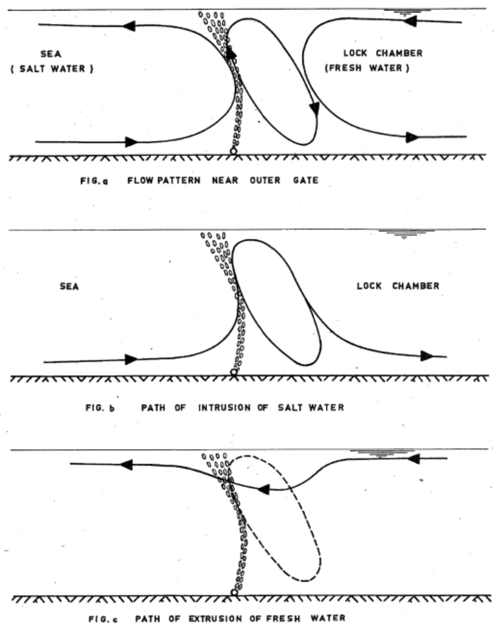
Salt intrusion, Task 2

- provide overview of possible mitigating measures from other locations/studies by Deltares and from literature

- evaluate to which extent these options will be suitable and effective for the Nicaragua Canal

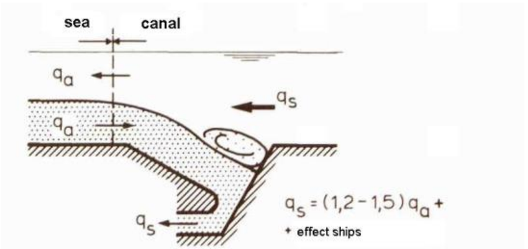
Potential mitigating measures and their effectiveness, I

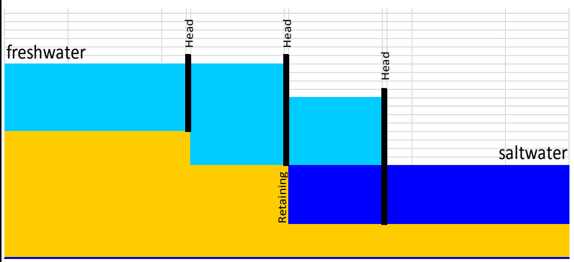
measure	Effectiveness of prevention of salt intrusion	range	remarks
Lock operations management	Additional to structural measures	N.A.	Limiting the convoy length is very effective in reducing the salt intrusion
No further measures	N.A.	Salt intrusion = 80 – 90% of upper lock chamber content above the level of the upward step in the bottom (1008 kg/m^3, brackish water) Freshwater loss = 80 – 90% of lock chamber content. idem	
Flushing mixed brackish water	Low effectiveness	Salt intrusion = 70 – 85% of upper lock chamber content above the level of the upward step in the bottom (1008 kg/m^3, brackish water) Freshwater loss = 160 – 200% of lock chamber content. idem	No time loss
Pneumatic barriers	Low effectiveness	Salt intrusion = 60 – 80% of upper lock chamber content above the level of the upward step in the bottom (1008 kg/m^3, brackish water) Freshwater loss = 60 – 80% of lock chamber content. idem	No time loss Effective in reducing forces



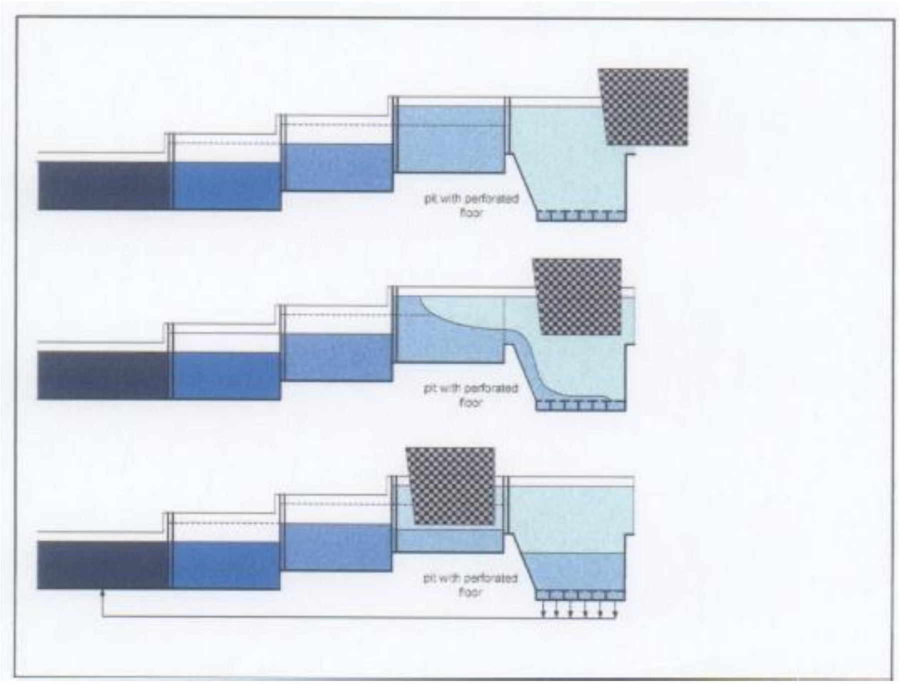
Potential mitigating measures and their effectiveness, II

measure	Effectiveness of prevention of salt intrusion	range	remarks
Flushing collected water, selective withdrawal	Good effectiveness	Salt intrusion max 20 – 30% of upper lock chamber content above the level of the upward step in the bottom (1008 kg/m^3, brackish water) Freshwater loss = 180 - 220% of lock chamber content. idem If combined with pneumatic barrier: salt intrusion max 15– 20%; about same freshwater loss.	Probably no time loss. Result very much depends on a well-designed and well-operated flushing system.
Retaining wall concept	High effectiveness	Salt intrusion 5 – 15% of (double head) lock chamber content (1024 kg/m^3, salt water) Freshwater loss = 10 – 20% of (double head) lock chamber content.	Probably no additional time loss for a single passing vessel, but the frequency of lockages of lower lock will be lower. Forces on vessels need attention (pneumatic barriers are advised) Still requires significant efforts in development and for verification of feasibility.

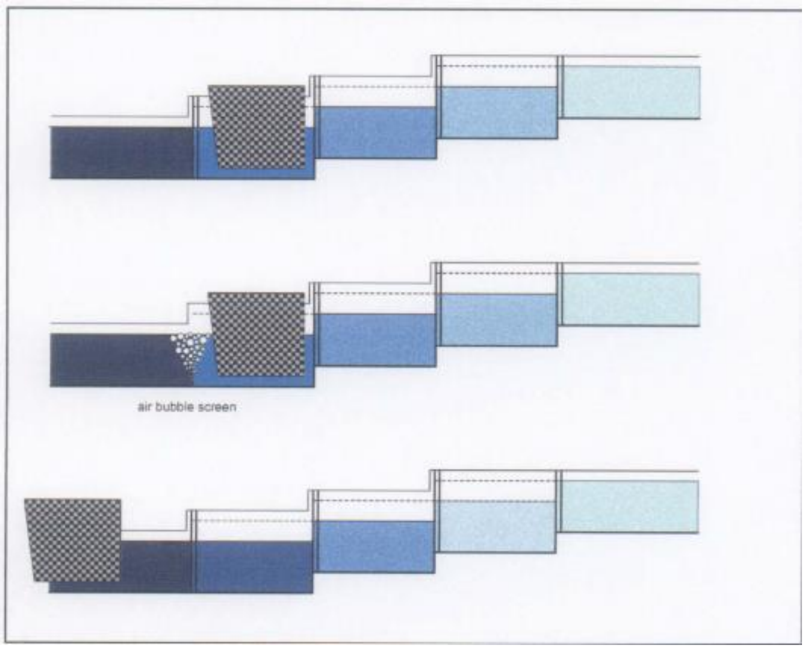




Potential mitigating measures and their effectiveness, II



Flushing of salt water from pit with perforated floor



Pneumatic barrier at the entrance to lower and upper lock chamber

Conclusions preliminary salt intrusion study

- The multiple step lock system and reversal of ship directions, aids in reducing the salt loads into Lake Nicaragua (LN)
- Results depend strongly on assumed concentration of San Juan River discharge (for now 50% of average lake concentration), possibly the river will not carry out any salt, leading to accumulation of salt
- Locally higher concentrations will be present in LN due to bathymetry effects: the heavier salt water will sink to the deepest lake and canal sections
- Some mixing may occur due to vessel transits, but no fully mixed situation is expected
- Requires fully 3D modelling for accurate and more detailed results
- Different mitigation measures are available that are suitable for the Nicaragua Canal, some well proven, others more experimental

Recommended further work I

Hydrology:

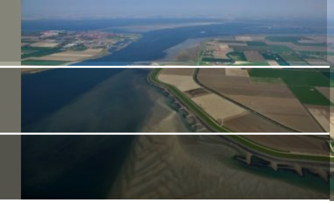
- Extended hydrological modelling (depending on data availability)
    - Improved Q(h) and A(h) relationships are required → extensive field measurement campaign
    - Study the effect of low water levels *and* high water levels in LN
    - Effects of climate change
    - Interaction with ground water bodies (data availability allowing, geology), possible flow into lower water bodies dissected by the canal
- Monitoring the areas crossed by GNC, discharge measurements (by local parties? Or archive data available?)

Recommended further work II

Hydrology:

- (Ecological) effects of water withdrawal from system by canal operations: Water Allocation Model
  - different water uses
  - additional influences of canal (growth of population, wealth, industry) all influence fresh water requirements
  - risk of salt water intrusions in the river in the near-coastal zone, increase of salt water content in the coastal lagoons due to less freshwater availability
  - climate change
- Effects of sediment influx into the canal
  - Highly dependent on local situation and soil characteristics
  - Requires extensive study and detailed local measurements
  - In absence of data only relative assessments

Recommended further work III



Salt intrusion:

- **full 3D (process-based) modelling of salt intrusion into the system and into LN is required**
- Requires that details of locks and lock operations are known
- Delft3D software tool
- capable of describing the relevant processes
    - density-driven flows
    - dispersion of salt water
    - influences of the non-uniform bathymetry
    - calculate the salt concentration of the inflow into San Juan River
- Calculate in detail salt loads trough locks
- Evaluate requirement and effectiveness of mitigating measures