GATES OF WSB OF THE MAGDEBOURG (ROTHENSEE) LOCK SYSTEM

Alternative Conceptual Design of Pacific and Atlantic Post-Panamax Locks – 3x2 WSB - Contract SAA-150551

PACIFIC LOCKS 3x2 wsb

TASK P4e-3x2 – CULVERT AND WSB CONDUIT GATES

Rev A

in association with

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PREAMBLE

This report is for a triple lift lock (55 m width) equipped with 3x2 water saving basins.

There are no major changes compared with the triple lift lock (also 55 m width) equipped with 3x3 water saving basins except the number of WSB conduit gates.

The size of the gates is the same:

- width 4.5 m x height 6 m for culvert gates,
- width 4.5 m x height 6 m for WSB conduit gates.

The maximum static heads (resulting from the hydraulic study) on the sills are slightly different:

- for the culvert gates : 38.81 m (for triple lift, 3x2 WSB) instead of 39.24 m (for triple lift, 3x3 WSB),
- for the WSB conduit gates : 43.79 m (for triple lift, 3x2 WSB) instead of 44.33 m (for triple lift, 3x3 WSB).

Nevertheless the weights of both culvert and WSB conduit gates have been computed for the static heads of the triple lift, 3x2 WSB configuration.

The weights are as follows:

- for one culvert gate : 26.3 T (for triple lift, 3x2 WSB) instead of 26.5 T (for triple lift, 3x3 WSB),
- for one WSB conduit gate : 28.6 T (for triple lift, 3x2 WSB) instead of 28.9 T (for triple lift, 3x3 WSB).

The number of culvert gates is the same.
The number of WSB conduit gates is reduced from 36 to 24.

Therefore the total weight for both the culvert and WSB conduit gates (including bulkheads and slots) is reduced from 7,419 T to 5,656 T.

1 SUITABILTY OF DIFFERENT TYPES OF GATES

1.1 GENERAL

Preliminary remark :
According to the normal wording practice, the term “valve” is only used in case of *butterfly valves* or of *cylindrical valves*. These types of valves have not been recommended neither for the culvert, nor for the Water Saving Basin conduit. Therefore, all other valves are called gates. As a consequence, the wording “culvert valves” and “conduit valves” used in previous reports have been replaced by *culvert gates* and *conduit gates*. The latter is also referred to as WSB gates (Water Saving Basins gates).

The analysis of the suitability of different types of gates is given in the report R4-E (Conceptual Design of Post Panamax locks – TASK 4 E - CULVERT AND CONDUIT VALVES), dated 15.11.2002.

In this report the different types of gates have been analyzed taking into account reliability, maintenance, manufacturing and construction costs, expected service life, design and construction, sensibility to cavitations and vibration.

In relation with the civil works, the overall size of the gates has also played a major role in determining the most suitable type of operating gate for filling and emptying the lock.

The types of gates/valves that have been examined are:

- Vertical-lift gates including:
    - fixed-wheel gates,
    - sliding gates
- Tainter gates including:
    - conventional tainter gates,
    - reverse tainter gates,
- Stoney gates,
- Butterfly valves,

- Cylindrical valves,

- Grid type gates.

To assess the most suitable type of gates/valves to be used for the Post Panamax locks, a comparative table has been elaborated. It is given in paragraph 1.2. below.

1.2 COMPARATIVE TABLE

The different types of lock gates/valves are listed in the table below. Several criteria are used to evaluate the gate/valve types. These criteria are linked with a weight factor, determined according to their importance.

The gates/valves are appraised on a 1 to 5 scale for each criterion. These scores are multiplied by the weight factor, resulting in a total evaluation for each type of gate/valve.

The fixed wheel gate obtained the best overall evaluation.

	weight factor	Fixed-wheel gate (FW)	Sliding Gate (Sl)	Grid Type Gate (GT)	Tainter Gate (Tt)	Butterfly Valve (Bt)	Cylindrical Valve (Cy)	Stoney Gate (St)
Reliability	0.20	4	4	2	4	4	3	3
Maintenance	0.20	4	4	2	3	3	3	2
Construction cost	0.15	5	4	3	3	3	3	3
Service life	0.15	4	3	2	4	4	3	2
Design and construction	0.15	4	3	2	4	3	3	3
Sensibility to vibration / cavitation	0.15	3	4	3	3	2	3	3
Total								
Total weight factors	1.00							
Total evaluation (max 5)		4.00	3.7	2.30	3.5	3.20	3.00	2.65
Total evaluation (%)		80	74	46	70	64	60	53

Note: the results of this comparative table remain valid for both flow directions through the gates/valves

1.3 CONCLUSIONS

The conclusions of the report R4E as referenced in §3 were as follows:

“Based on experience with Post Panamax locks and on engineering judgment there are only two types of gates that may realistically be used for the Post Panamax locks of the Panama Canal i.e. fixed wheel gates and sliding gates.

Nowadays vertical-lift gates are preferred for big locks because they are much cheaper to build and do not require the large space that is necessary (for example) for a tainter gate. Moreover, the hydraulic efforts are better distributed to the culvert walls and maintenance is easier.

Within this perspective the choice of fixed wheel gates seems obvious.

Another advantage of course is the actual know-how of ACP and the infrastructure for the maintenance of flat gates in use at the Panama Canal.”

Moreover, the vertical lift gates have proven well for designs where sealing in both directions of water flow is required, such as between the lock chambers and the water saving basins.

2 DESCRIPTION AND DIMENSIONING

2.1 GENERAL

The analysis of the suitability of different types of gates has led to the conclusion that the most suitable type of gate is the fixed-wheel type.

For the 55 m lock chamber width (instead of 61 m previously), the dimensions of the lock culverts and water saving basins (WSB) conduits have been determined in the hydraulic study (report P4C).

The culvert dimensions are **9 (width) x 6 (height) m** (instead of 9 x 7.5 m previously).

The WSB conduit dimensions are **4.5 (width) x 6 (height) m** (instead of 5.7 x 7.5 previously).

Redundancy (two gates for each culvert) has to be foreseen for the culvert gates, therefore the size of the culvert gates shall be **4.5 x 6m, which is the same as the ones of the WSB conduits**.

On the Pacific side all culverts and WSB conduits are equipped with gates of the same size.

The height to width ratio is 1.33 and quite acceptable.

For the culvert gates, the basic principle adopted for operation reliability is to work with two gates in parallel so that any incident to any gate will not stop the operation of the locks. Furthermore, it also reduces the required gate size.

However the **risk of an asymmetrical operation** of the gates (if one gate fails to open or remains open in an intermediate position) shall have to be assessed (in the preliminary and/or final design). If required, interlocking devices shall have to be foreseen.

Each of the six **water saving basins** is connected to the locks by four conduits. Two are connected on left hand (near to WSB) side of the corresponding lock chamber, two are connected to the right hand (far to WSB) side. **No** additional provision has been made for **redundancy** of the gates. In case of any trouble on a gate, one conduit will be out of order but the three remaining conduits of the concerned basin will be sufficient to operate the locks.

However the consequent **asymmetrical operation of the emptying and/or filling** of the lock chamber (if one gate fails to open or remains open in an intermediate position) shall have to be assessed during further design stages, especially as far as operating times and procedures are concerned.

2.2 LAYOUT OF CULVERTS AND WSB CONDUITS

Each culvert and conduit gate is equipped upstream and downstream with bulkhead gates allowing access to the gate(s) after emptying by pumping (by movable pumps) of the space on both sides.

The basins conduits have been arranged two by two (in total four per WSB). The arrangement, with one conduit located on top of the other as foreseen in the initial conceptual design has been abandoned. It makes the WSB gates arrangement much easier and the operation much more reliable

2.2.1 CULVERTS AND CULVERT GATES

There are two culverts running along each side of the locks. Their sill is at the sill level of the lock chamber. However, the bottom of the rolling gates chambers prevents the culverts from remaining horizontal. Therefore, the culverts are diverted under the rolling gates and the culvert gates are implemented between the main rolling gates.

As mentioned here above, the culvert dimensions are W x H = 9m x 6m. The culverts are locally divided into two sections of W x H = 4.5m x 6m where the culvert gates are to be installed. At full opening of the gate, the total size and thus the mean water velocity remains unchanged.

The next figure shows a basic layout for a culvert gate with two isolating bulkheads. **There is only one flow direction from the left to the right.**

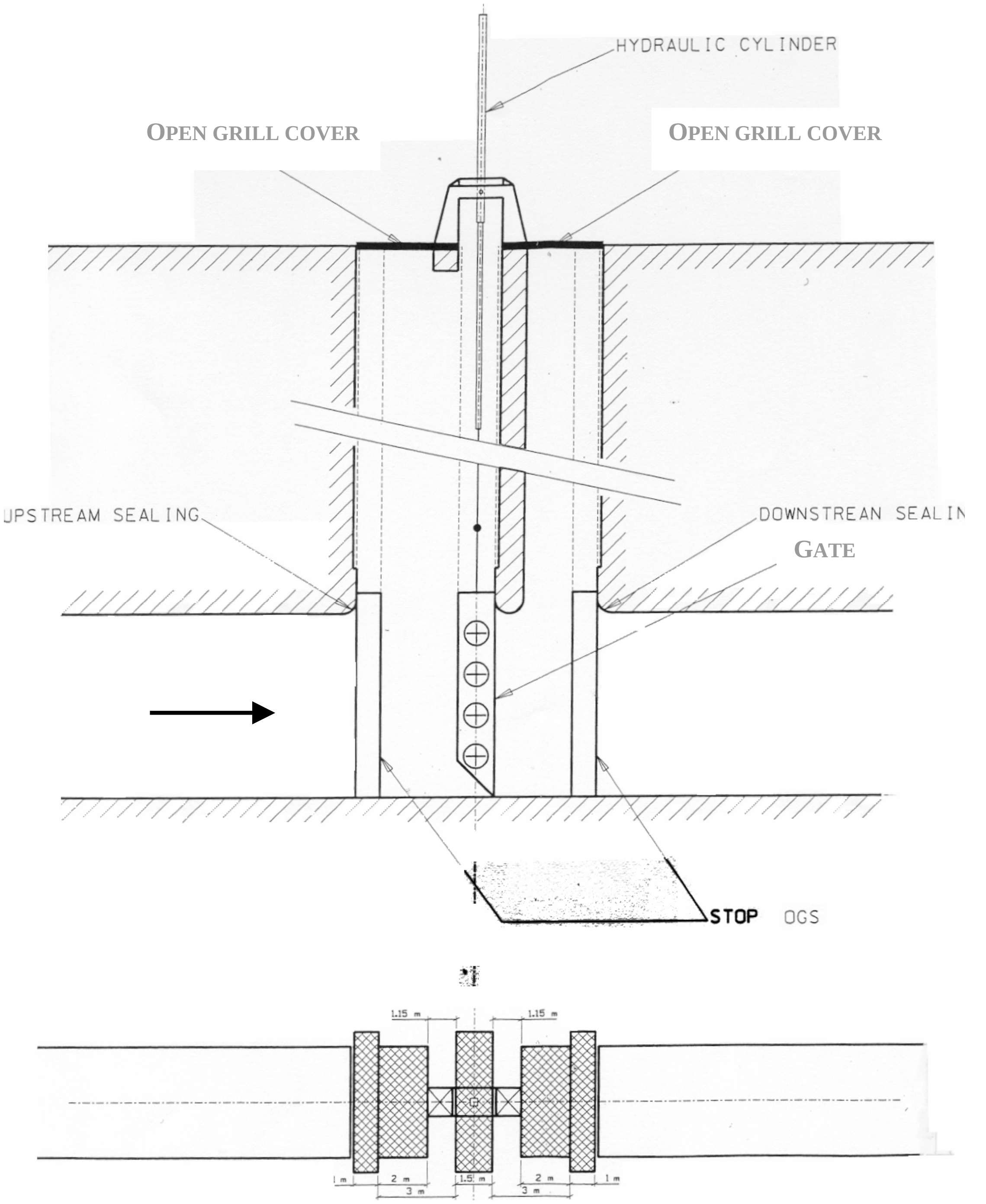

Figure 1 : basic layout for a culvert gate with two isolating bulkheads

For emptying both sides of the culvert gate, the **sealing conditions** are to be as follows:

- the upstream bulkhead has to be tight on its upstream side,
- the downstream bulkhead has to be tight on its downstream side,
- the gate has to be **tight on its downstream side**.

That design has the advantage (regarding civil works) that only one vertical separation wall is required.

2.2.2 WSB CONDUITS AND CONDUIT GATES

The arrangement of the gates and bulkhead gates is shown on the civil works drawing (ref D4-A-303).

The **fixed-wheel gates** are designed with **upstream and downstream sealing.**

Their leaf structures (and therefore the corresponding slots) are dimensioned to support the maximum static pressure on both sides corresponding to the following pressure conditions:

- maximum lock chamber level on one side and WSB completely empty on the other side,
- maximum WSB level on one side and lock chamber completely empty on the other side.

The hydraulic cylinders operating the gates have been pre dimensioned for two cases:

- for the normal operation with the locks and basins filled with water,
- for the maximum static head.

The power required for the gate operation in the most critical case, is the one taking into account maximum static head.

The bulkhead gate (WSB side) is of the sliding type in two or three elements and is designed with a double sealing system which allows to:

- empty the WSB while keeping the locks in operation,
- empty the space between the two bulkhead gates to give access to the conduit gate and slots for maintenance.

The bulkhead gate on the lock chamber side is also in two or three pieces and is designed with a sealing system which allows to:

- empty either the lock chamber or the WSB (for the emptying of the WSB it makes a redundancy while keeping the locks in operation),
- empty the space between the two bulkhead gates to give access to the conduit gate and slots for maintenance.

The basic data for designing the gates (dimensions and maximum static head) are the same as those of the bulkhead gates.

The bulkhead elements can be lowered or removed by means of a mobile gantry crane equipped with an automatic lifting beam.

The 24 conduit gates are also the same. They are dimensioned for the maximum head of 43.79m.

2.3 BASIC DATA FOR DESIGN

The values indicated below provide, for the culvert and WSB gates as well as for the bulkhead gates, the maximum static heads of water which have been taken into account for the estimation of the weight of the moving parts.

Maximum head on sill level of culvert gates:	38.81 m
Maximum head on sill level of WSB gates:	43.79 m

The values computed for the first conceptual design (61 m width lock chambers) were:

Maximum head on sill level of culvert gates:	40.03 m
Maximum head on sill level of WSB gates:	45.65 m

The weight of the gates has also been estimated taking into account the operating heads. The values indicated below provide the maximum operating heads of water which have been taken into account.

Maximum head on sill level of culvert gates:	25 m
Maximum head on sill level of WSB gates:	10 m

The operating heads used for the 61 m width lock chambers were:

Maximum head on sill level of culvert gates:	25 m
Maximum head on sill level of WSB gates (top):	30 m
Maximum head on sill level of WSB gates (top):	50 m

For each shaft (culvert or WSB conduit), the calculation of the weight of the gate and its related bulkheads has been computed using the same water heads.

2.4 ESTIMATED WEIGHTS

A reliable determination of the moving part of a fixed-wheel gate by a comprehensive study based on preliminary data and admissible stresses is a quite long and difficult exercise. To determine an approximate weight, it is common practice to make a comparison with existing gates, of course, of the same type.

Estimation of the weight is based on the main parameters, i.e.:

- the dimensions (width and height);
- water pressure on the sill.

It can be developed by a formula based on statistical data. The weight of the slot embedded fixed parts has then to be added.

This procedure gives an acceptable approach for conceptual design.

The formula used here (see Water Power and Dam Construction by P.C. Erbiste May 1984) is a function of W, h, and H where:

- W is the span,
- h is the gate height,
- H is the static head on the gate bottom seal.

The weight of the gate leaf is given by the formula (see abacus – annex 1):

Weight of a fixed-wheel gate: = $0.706 (W^2.h.H)^{0.7}$

Given the static heads are the highest ones (compared to the operating heads), only them have been taken into account for the calculation of the weights.
Span width, height, static head on seal bottom and weight of gate or bulkhead leaf are given in annex 3.

The estimated weight of the culvert gate is 26.3 tons and the estimated weight of the WSB conduit gate is 28.6 tons. The weights of the culvert and WSB conduit gates are very close to each other. At this conceptual stage, it clearly appears that the same design should be used for both gates.

The incurred costs/benefits that will result are the following :

- From the standardization point of view : same drawings, same manufacturing processes, erection procedures, …
- From the operational and maintenance point of view : reduced amount of spare parts, better material knowledge from the maintenance people, …

It is reminded that to check the procedure, a preliminary calculation of a WSB fixed-wheel gate structure has been performed (see Annex 2). The calculation has confirmed the results of the above formula.

Moreover, the weight of **one meter** of embedded fixed parts is estimated to:

- Culvert fixed-wheel gates at the bottom of the slot:	800 kg (last 12m[1])
- Culvert fixed-wheel gates at the upper part of the slot (only for guiding):	200 kg
- Culvert sliding bulkhead at the bottom of the slot:	500 kg (last 9m[2])
- Culvert sliding bulkhead (only for guiding)	200 kg
- WSB fixed-wheel gates at the bottom of the slot:	1,000 kg (last 12m)
- WSB fixed-wheel gates at the upper part of the slot:	200 kg
- WSB sliding bulkhead at the bottom of the slot:	500 kg (last 9m)
- WSB sliding bulkhead (only for guiding)	200 kg

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[1] *Two times the height of the gates (2x6=12m)*
[2] *One time first leaf plus two times second leaf (3+2x3=9m)*

Note: Lintel and sill embedded parts have been added separately. For the gates the weight of said parts is taken as 800 kg/m, for the bulkheads, it has been taken as 500 kg/m.

2.5 CONSTRUCTION DETAILS

Hydraulic servomotor operated, the fixed wheel gates are equipped with wheels revolving on fixed axles cantilevered from the gate frame (see annex 4 for typical example of a sectional view of one wheel of the Berendrecht culvert gates). Wheels can be of the flat type (rolling on stainless steel tracks) or of the flanged type (rolling on rails). Tracks must withstand the bearing pressures and distribute them to the concrete structure behind. The **number of wheels** will be based on the steel characteristics. It shall **not be less than 6 wheels.**

A typical horizontal sectional view of a gate (or bulkhead) welded structure is shown in Annex 5. Horizontal plate girders or standard T or I-shape beams are the main force resisting members of the gate.

The distance between horizontal girders may vary according to the hydrostatic pressure. Diaphragm plates and intercostals are also used as reinforcement to distribute loads more uniformly.

WSB fixed-wheel gates have to resist to water pressure and **be tight in both directions** as for the locks submitted to tidal effects.

The access shaft for maintenance will be used as **surge chambers** during operation of the gates.

Tolerances must be adequate to assure watertight seals. That is the reason why it is recommended to use very rigid U-shape steel guiding for the gates to avoid any movement during embedding of the fixed parts.

The gate and wheels are permanently under water. Maintenance of these wheels and bearings is possible by lifting the moving parts out of water. Wear of these elements can be considerably reduced by using **self lubricating** material.

SEALING SYSTEM

Seals are usually made of rubber with or without a PTFE (Teflon) overlay (**PTFE overlay is preferred**). The seals are often of the music note shape or lip type.

For the WSB gates being tight for water flowing in both directions, the lip seals adopted for Berendrecht (see sectional view of the wheel) should be convenient.

Lintel seal and side seals: can be of the upstream or downstream type (see figure - Annex 6)

Bottom seal can be flat or also of the J-shape type.(see figure – Annexes 6 and 7)

MAINTENANCE OF THE GATES AND BULKHEADS

Maintenance work on gates and bulkheads (as wheels and relevant slots) consists mainly in the replacement of rubber seals and painting. Overhaul and/or replacement of wheels could also be foreseeable. Moreover, the maintenance works will have to include the replacement of the sacrificial anodes whenever necessary.

During normal operation, any trouble with one culvert or WSB gate (blocking or incident on the oil system) will not interfere on the ship transit except concerning the operation time. Every gate can be isolated and maintenance people can reach the upstream or downstream side of the gate by use of bulkheads after emptying of the space between them.

In case of planned replacement of seals or painting, the gate will be lifted out by use of a 100 tons gantry crane moving on rails. This crane will be provided by truck, assembled and installed on the railway located above the gate slot. After dismantling of the gate, the work will be carried out in good conditions in the maintenance building. Two mobile cranes will be necessary for the 40 gates and 12 bulkheads. Rails will be installed between and outside of all the rows of WSB and culvert slots.

For the culverts, 8 (4 x 2) bulkheads are foreseen. It enables to close completely one culvert using 2 x 2 bulkheads at each of the culvert extremities.
For the WSB conduit, 6 (2 x 3) bulkheads are foreseen. It enables to close completely one conduit.

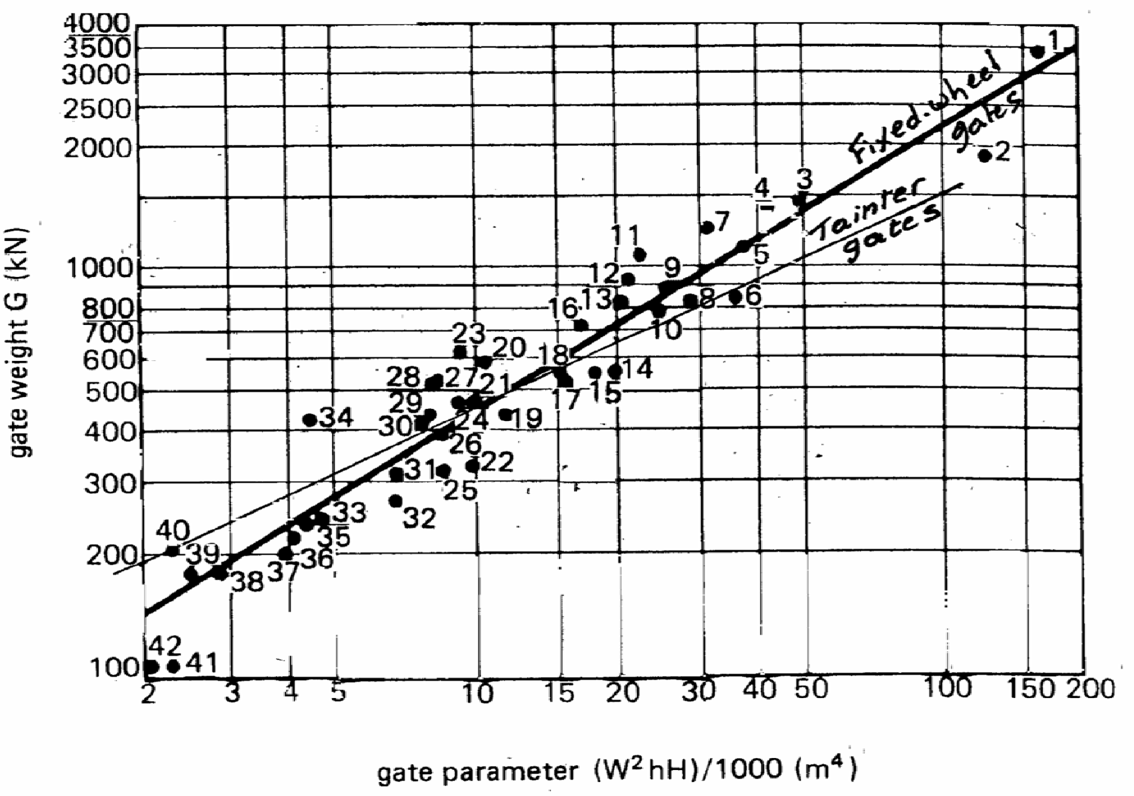
Bulkheads gates can be stored outside or suspended into the slots (one piece of bulkhead gate per slot). To remove a bulkhead gate, the cranes will be equipped with an automatic lifting beam. Planned maintenance will also be done in the maintenance building.

3 REFERENCES

- Hydraulic gates and valves in free surface flow and submerged outlets by Jack Lewin
- Water Power and Dam Construction (review)
- Final report of the International commission for the study of locks (PIANC)
- Engineer manuals
- CCP (2002) “Diseño conceptual de las esclusas Post Panamax – Triple Lift Lock System, Task 4”

ANNEX 1

Abacus of gate weight versus gate parameter (W, h, H)



Weight of large fixed-wheel gates ($W^2hH > 2000\ m^4$).

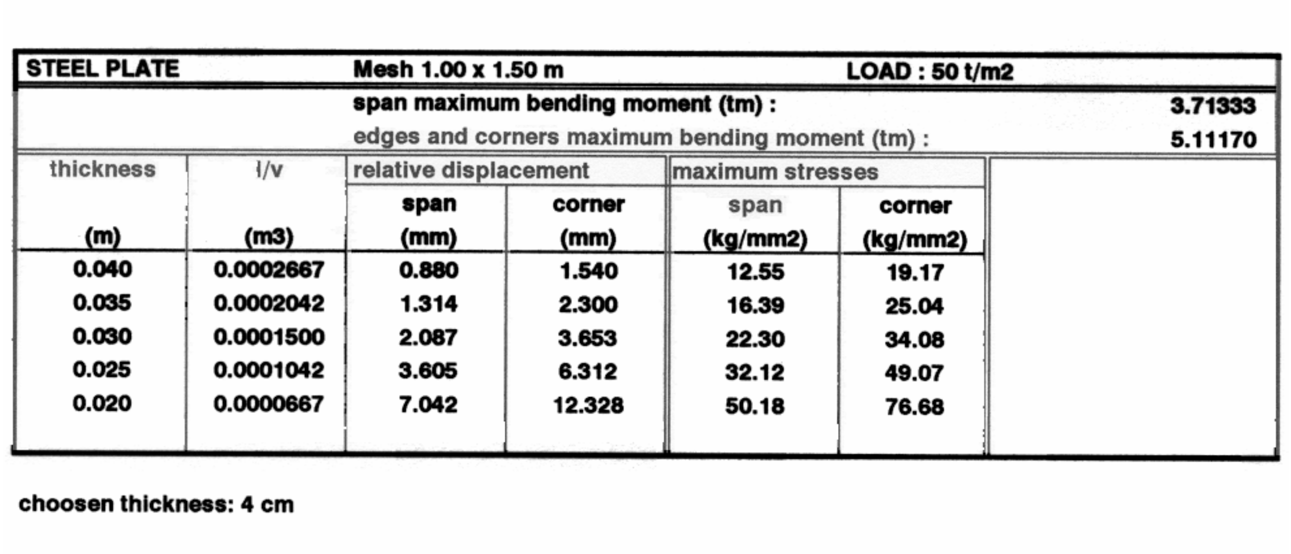
ANNEX 2 (Remind of report R4-E date 15.11.2002)

TYPICAL CALCULATION OF A WSB GATE (Hs = 50m)

This calculation is the same as the one included in the report mentioned at the beginning of paragraph 1.1 of this report. The only goal of this calculation is to prove that the use of the general formula (see page 2-6) is relevant for weight calculation.

SKIN PLATE

The estimated skin plate thickness corresponds to a distance of 1.5m between the horizontal I beams and 1m between the vertical T shape intercostals is 4cm



STEEL PLATE **Mesh 1.00 x 1.50 m** **LOAD : 50 t/m2**

span maximum bending moment (tm) : **3.71333**

edges and corners maximum bending moment (tm) : **5.11170**

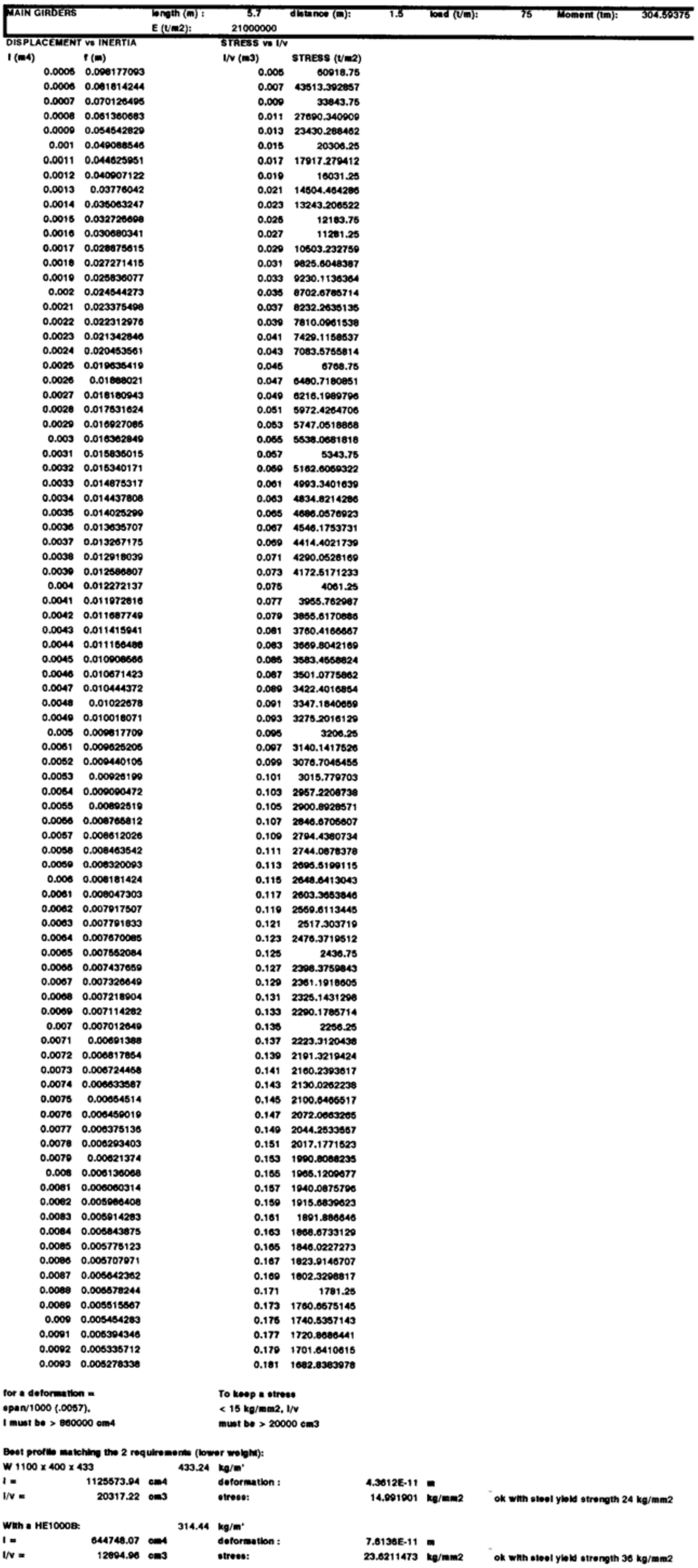
thickness	I/v	relative displacement		maximum stresses	
		span	corner	span	corner
(m)	(m3)	(mm)	(mm)	(kg/mm2)	(kg/mm2)
0.040	0.0002667	0.880	1.540	12.55	19.17
0.035	0.0002042	1.314	2.300	16.39	25.04
0.030	0.0001500	2.087	3.653	22.30	34.08
0.025	0.0001042	3.605	6.312	32.12	49.07
0.020	0.0000667	7.042	12.328	50.18	76.68

choosen thickness: 4 cm

MAIN BEAMS

The horizontal main beams size depends on the span between them and load. According to the I/v required, alternatives were investigated i.e.:

- HE 1000 A
- W 1100 x 400 x 433



MAIN GIRDERS length (m) : 5.7 distance (m): 1.5 load (t/m): 75 Moment (tm): 304.59375
E (t/m2): 21000000

DISPLACEMENT vs INERTIA		STRESS vs I/v	
I (m4)	f (m)	I/v (m3)	STRESS (t/m2)
0.0005	0.098177093	0.005	60918.75
0.0006	0.081814244	0.007	43513.392857
0.0007	0.070126495	0.009	33843.75
0.0008	0.061360683	0.011	27690.340909
0.0009	0.054542829	0.013	23430.288462
0.001	0.049088546	0.015	20306.25
0.0011	0.044625951	0.017	17917.279412
0.0012	0.040907122	0.019	16031.25
0.0013	0.03776042	0.021	14504.464286
0.0014	0.035063247	0.023	13243.206522
0.0015	0.032725698	0.025	12183.75
0.0016	0.030680341	0.027	11281.25
0.0017	0.028875615	0.029	10503.232759
0.0018	0.027271415	0.031	9825.6048387
0.0019	0.025836077	0.033	9230.1136364
0.002	0.024544273	0.035	8702.6785714
0.0021	0.023375498	0.037	8232.2635135
0.0022	0.022312976	0.039	7810.0961538
0.0023	0.021342846	0.041	7429.1158537
0.0024	0.020453561	0.043	7083.5755814
0.0025	0.019635419	0.045	6768.75
0.0026	0.01888021	0.047	6480.7180851
0.0027	0.018180943	0.049	6216.1989796
0.0028	0.017531624	0.051	5972.4264706
0.0029	0.016927085	0.053	5747.0518868
0.003	0.016362849	0.055	5538.0681818
0.0031	0.015835015	0.057	5343.75
0.0032	0.015340171	0.059	5162.6059322
0.0033	0.014875317	0.061	4993.3401639
0.0034	0.014437808	0.063	4834.8214286
0.0035	0.014025299	0.065	4686.0576923
0.0036	0.013635707	0.067	4546.1753731
0.0037	0.013267175	0.069	4414.4021739
0.0038	0.012918039	0.071	4290.0528169
0.0039	0.012586807	0.073	4172.5171233
0.004	0.012272137	0.075	4061.25
0.0041	0.011972816	0.077	3955.762987
0.0042	0.011687749	0.079	3855.6170886
0.0043	0.011415941	0.081	3760.4166667
0.0044	0.011156488	0.083	3669.8042169
0.0045	0.010908566	0.085	3583.4558824
0.0046	0.010671423	0.087	3501.0775862
0.0047	0.010444372	0.089	3422.4016854
0.0048	0.01022678	0.091	3347.1840659
0.0049	0.010018071	0.093	3275.2016129
0.005	0.009817709	0.095	3206.25
0.0051	0.009625205	0.097	3140.1417526
0.0052	0.009440105	0.099	3076.7045455
0.0053	0.00926199	0.101	3015.779703
0.0054	0.009090472	0.103	2957.2208738
0.0055	0.00892519	0.105	2900.8928571
0.0056	0.008765812	0.107	2846.6705607
0.0057	0.008612026	0.109	2794.4380734
0.0058	0.008463542	0.111	2744.0878378
0.0059	0.008320093	0.113	2695.5199115
0.006	0.008181424	0.115	2648.6413043
0.0061	0.008047303	0.117	2603.3653846
0.0062	0.007917507	0.119	2559.6113445
0.0063	0.007791833	0.121	2517.303719
0.0064	0.007670085	0.123	2476.3719512
0.0065	0.007552084	0.125	2436.75
0.0066	0.007437659	0.127	2398.3759843
0.0067	0.007326649	0.129	2361.1918605
0.0068	0.007218904	0.131	2325.1431298
0.0069	0.007114282	0.133	2290.1785714
0.007	0.007012649	0.135	2256.25
0.0071	0.00691388	0.137	2223.3120438
0.0072	0.006817854	0.139	2191.3219424
0.0073	0.006724458	0.141	2160.2393617
0.0074	0.006633587	0.143	2130.0262238
0.0075	0.00654514	0.145	2100.6465517
0.0076	0.006459019	0.147	2072.0663265
0.0077	0.006375136	0.149	2044.2533557
0.0078	0.006293403	0.151	2017.1771523
0.0079	0.00621374	0.153	1990.8088235
0.008	0.006136068	0.155	1965.1209677
0.0081	0.006060314	0.157	1940.0875796
0.0082	0.005986408	0.159	1915.6839623
0.0083	0.005914283	0.161	1891.886646
0.0084	0.005843875	0.163	1868.6733129
0.0085	0.005775123	0.165	1846.0227273
0.0086	0.005707971	0.167	1823.9146707
0.0087	0.005642362	0.169	1802.3298817
0.0088	0.005578244	0.171	1781.25
0.0089	0.005515567	0.173	1760.6575145
0.009	0.005454283	0.175	1740.5357143
0.0091	0.005394346	0.177	1720.8686441
0.0092	0.005335712	0.179	1701.6410615
0.0093	0.005278338	0.181	1682.8383978

for a deformation =
span/1000 (.0057),
I must be > 860000 cm4

To keep a stress
< 15 kg/mm2, I/v
must be > 20000 cm3

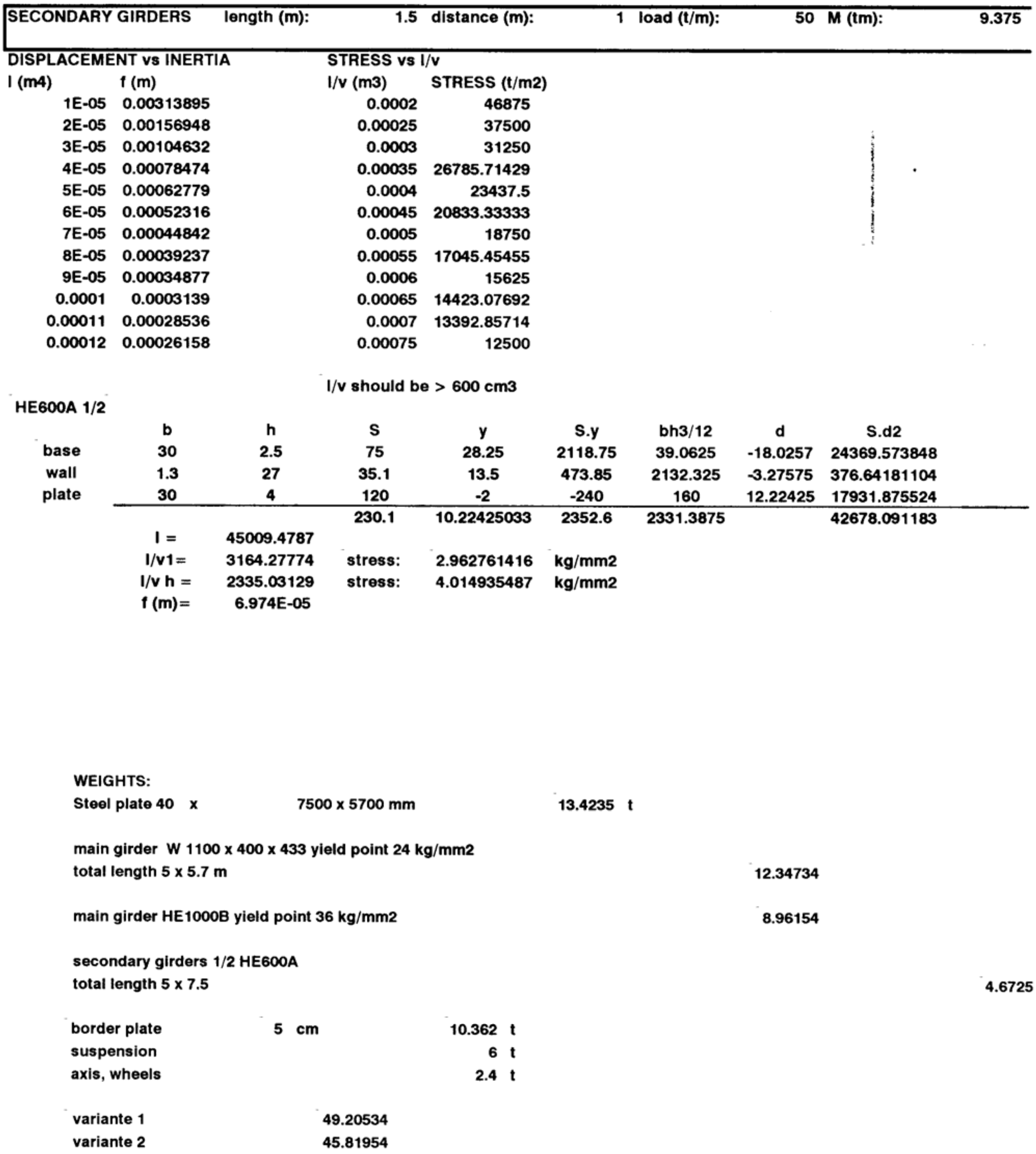
Best profile matching the 2 requirements (lower weight):

W 1100 x 400 x 433		433.24	kg/m'				
I =	1125573.94	cm4		deformation :	4.3612E-11	m	
I/v =	20317.22	cm3		stress:	14.991901	kg/mm2	ok with steel yield strength 24 kg/mm2

With a HE1000B:		314.44	kg/m'				
I =	644748.07	cm4		deformation :	7.6136E-11	m	
I/v =	12694.96	cm3		stress:	23.6211473	kg/mm2	ok with steel yield strength 36 kg/mm2

SECONDARY BEAMS

T beams coming from HE 600 A were considered



SECONDARY GIRDERS	length (m):	1.5	distance (m):	1	load (t/m):	50	M (tm):	9.375

DISPLACEMENT vs INERTIA		STRESS vs I/v	
I (m4)	f (m)	I/v (m3)	STRESS (t/m2)
1E-05	0.00313895	0.0002	46875
2E-05	0.00156948	0.00025	37500
3E-05	0.00104632	0.0003	31250
4E-05	0.00078474	0.00035	26785.71429
5E-05	0.00062779	0.0004	23437.5
6E-05	0.00052316	0.00045	20833.33333
7E-05	0.00044842	0.0005	18750
8E-05	0.00039237	0.00055	17045.45455
9E-05	0.00034877	0.0006	15625
0.0001	0.0003139	0.00065	14423.07692
0.00011	0.00028536	0.0007	13392.85714
0.00012	0.00026158	0.00075	12500

I/v should be > 600 cm3

HE600A 1/2

	b	h	S	y	S.y	bh3/12	d	S.d2
base	30	2.5	75	28.25	2118.75	39.0625	-18.0257	24369.573848
wall	1.3	27	35.1	13.5	473.85	2132.325	-3.27575	376.64181104
plate	30	4	120	-2	-240	160	12.22425	17931.875524
			230.1	10.22425033	2352.6	2331.3875		42678.091183

I =	45009.4787			
I/v1=	3164.27774	stress:	2.962761416	kg/mm2
I/v h =	2335.03129	stress:	4.014935487	kg/mm2
f (m)=	6.974E-05			

WEIGHTS:

Steel plate 40 x 7500 x 5700 mm 13.4235 t

main girder W 1100 x 400 x 433 yield point 24 kg/mm2
total length 5 x 5.7 m 12.34734

main girder HE1000B yield point 36 kg/mm2 8.96154

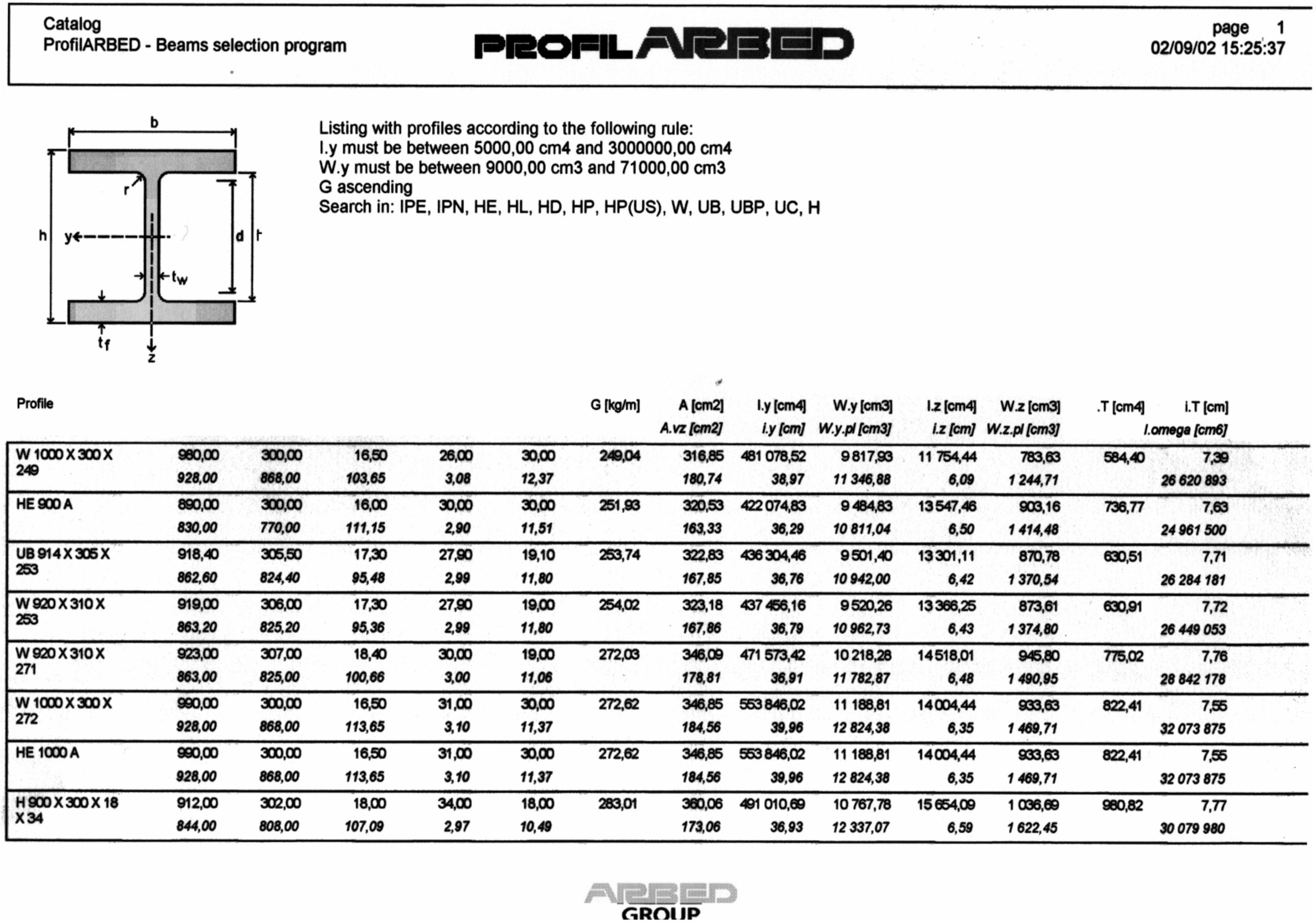
secondary girders 1/2 HE600A
total length 5 x 7.5 4.6725

border plate	5 cm	10.362 t
suspension		6 t
axis, wheels		2.4 t

variante 1	49.20534
variante 2	45.81954

CONCLUSION:

The estimated weight by 1st calculation is 46 or 49 tons according to the beam choice (HE 1000 A or W 1100 x 400 x 300 according to the ARBED catalogue (see extract hereunder). These values are to be compared with the 51 tons found by the above statistical formula.



Catalog
ProfilARBED - Beams selection program

PROFILARBED

page 1
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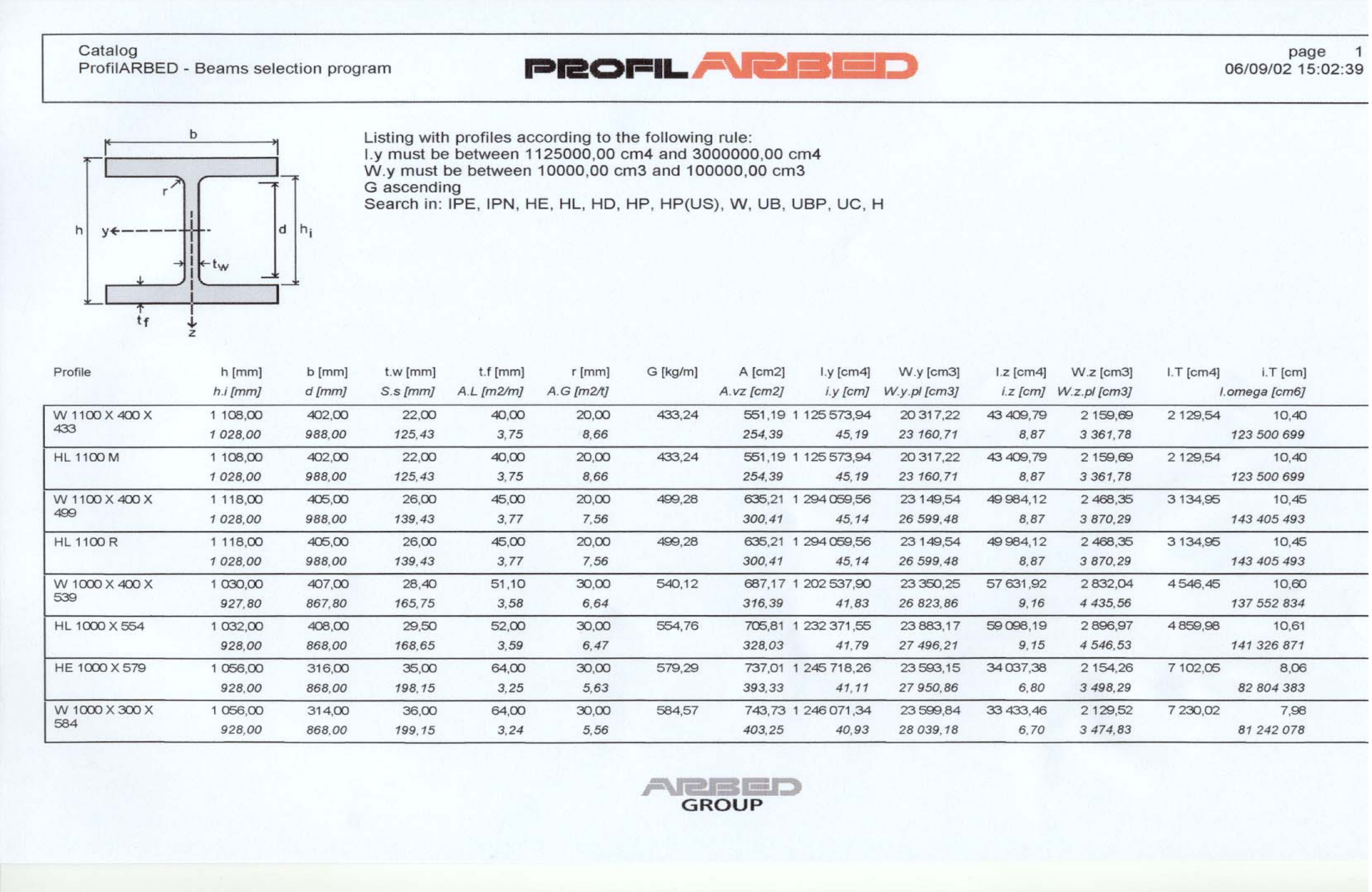
Listing with profiles according to the following rule:
I.y must be between 5000,00 cm4 and 3000000,00 cm4
W.y must be between 9000,00 cm3 and 71000,00 cm3
G ascending
Search in: IPE, IPN, HE, HL, HD, HP, HP(US), W, UB, UBP, UC, H

Profile						G [kg/m]	A [cm2]	I.y [cm4]	W.y [cm3]	I.z [cm4]	W.z [cm3]	.T [cm4]	i.T [cm]
							A.vz [cm2]	*i.y [cm]*	*W.y.pl [cm3]*	*i.z [cm]*	*W.z.pl [cm3]*		*I.omega [cm6]*
W 1000 X 300 X 249	980,00	300,00	16,50	26,00	30,00	249,04	316,85	481 078,52	9 817,93	11 754,44	783,63	584,40	7,39
	928,00	*868,00*	*103,65*	*3,08*	*12,37*		*180,74*	*38,97*	*11 346,88*	*6,09*	*1 244,71*		*26 620 893*
HE 900 A	890,00	300,00	16,00	30,00	30,00	251,93	320,53	422 074,83	9 484,83	13 547,46	903,16	736,77	7,63
	830,00	*770,00*	*111,15*	*2,90*	*11,51*		*163,33*	*36,29*	*10 811,04*	*6,50*	*1 414,48*		*24 961 500*
UB 914 X 305 X 253	918,40	305,50	17,30	27,90	19,10	253,74	322,83	436 304,46	9 501,40	13 301,11	870,78	630,51	7,71
	862,60	*824,40*	*95,48*	*2,99*	*11,80*		*167,85*	*36,76*	*10 942,00*	*6,42*	*1 370,54*		*26 284 181*
W 920 X 310 X 253	919,00	306,00	17,30	27,90	19,00	254,02	323,18	437 456,16	9 520,26	13 366,25	873,61	630,91	7,72
	863,20	*825,20*	*95,36*	*2,99*	*11,80*		*167,86*	*36,79*	*10 962,73*	*6,43*	*1 374,80*		*26 449 053*
W 920 X 310 X 271	923,00	307,00	18,40	30,00	19,00	272,03	346,09	471 573,42	10 218,28	14 518,01	945,80	775,02	7,76
	863,00	*825,00*	*100,66*	*3,00*	*11,06*		*178,81*	*36,91*	*11 782,87*	*6,48*	*1 490,95*		*28 842 178*
W 1000 X 300 X 272	990,00	300,00	16,50	31,00	30,00	272,62	346,85	553 846,02	11 188,81	14 004,44	933,63	822,41	7,55
	928,00	*868,00*	*113,65*	*3,10*	*11,37*		*184,56*	*39,96*	*12 824,38*	*6,35*	*1 469,71*		*32 073 875*
HE 1000 A	990,00	300,00	16,50	31,00	30,00	272,62	346,85	553 846,02	11 188,81	14 004,44	933,63	822,41	7,55
	928,00	*868,00*	*113,65*	*3,10*	*11,37*		*184,56*	*39,96*	*12 824,38*	*6,35*	*1 469,71*		*32 073 875*
H 900 X 300 X 18 X 34	912,00	302,00	18,00	34,00	18,00	283,01	360,06	491 010,69	10 767,78	15 654,09	1 036,69	980,82	7,77
	844,00	*808,00*	*107,09*	*2,97*	*10,49*		*173,06*	*36,93*	*12 337,07*	*6,59*	*1 622,45*		*30 079 980*

ARBED GROUP



Catalog
ProfilARBED - Beams selection program

page 1
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Listing with profiles according to the following rule:
I.y must be between 1125000,00 cm4 and 3000000,00 cm4
W.y must be between 10000,00 cm3 and 100000,00 cm3
G ascending
Search in: IPE, IPN, HE, HL, HD, HP, HP(US), W, UB, UBP, UC, H

Profile	h [mm]	b [mm]	t.w [mm]	t.f [mm]	r [mm]	G [kg/m]	A [cm2]	I.y [cm4]	W.y [cm3]	I.z [cm4]	W.z [cm3]	I.T [cm4]	i.T [cm]
	h.i [mm]	*d [mm]*	*S.s [mm]*	*A.L [m2/m]*	*A.G [m2/t]*		*A.vz [cm2]*	*i.y [cm]*	*W.y.pl [cm3]*	*i.z [cm]*	*W.z.pl [cm3]*		*I.omega [cm6]*
W 1100 X 400 X 433	1 108,00	402,00	22,00	40,00	20,00	433,24	551,19	1 125 573,94	20 317,22	43 409,79	2 159,69	2 129,54	10,40
	1 028,00	*988,00*	*125,43*	*3,75*	*8,66*		*254,39*	*45,19*	*23 160,71*	*8,87*	*3 361,78*		*123 500 699*
HL 1100 M	1 108,00	402,00	22,00	40,00	20,00	433,24	551,19	1 125 573,94	20 317,22	43 409,79	2 159,69	2 129,54	10,40
	1 028,00	*988,00*	*125,43*	*3,75*	*8,66*		*254,39*	*45,19*	*23 160,71*	*8,87*	*3 361,78*		*123 500 699*
W 1100 X 400 X 499	1 118,00	405,00	26,00	45,00	20,00	499,28	635,21	1 294 059,56	23 149,54	49 984,12	2 468,35	3 134,95	10,45
	1 028,00	*988,00*	*139,43*	*3,77*	*7,56*		*300,41*	*45,14*	*26 599,48*	*8,87*	*3 870,29*		*143 405 493*
HL 1100 R	1 118,00	405,00	26,00	45,00	20,00	499,28	635,21	1 294 059,56	23 149,54	49 984,12	2 468,35	3 134,95	10,45
	1 028,00	*988,00*	*139,43*	*3,77*	*7,56*		*300,41*	*45,14*	*26 599,48*	*8,87*	*3 870,29*		*143 405 493*
W 1000 X 400 X 539	1 030,00	407,00	28,40	51,10	30,00	540,12	687,17	1 202 537,90	23 350,25	57 631,92	2 832,04	4 546,45	10,60
	927,80	*867,80*	*165,75*	*3,58*	*6,64*		*316,39*	*41,83*	*26 823,86*	*9,16*	*4 435,56*		*137 552 834*
HL 1000 X 554	1 032,00	408,00	29,50	52,00	30,00	554,76	705,81	1 232 371,55	23 883,17	59 098,19	2 896,97	4 859,98	10,61
	928,00	*868,00*	*168,65*	*3,59*	*6,47*		*328,03*	*41,79*	*27 496,21*	*9,15*	*4 546,53*		*141 326 871*
HE 1000 X 579	1 056,00	316,00	35,00	64,00	30,00	579,29	737,01	1 245 718,26	23 593,15	34 037,38	2 154,26	7 102,05	8,06
	928,00	*868,00*	*198,15*	*3,25*	*5,63*		*393,33*	*41,11*	*27 950,86*	*6,80*	*3 498,29*		*82 804 383*
W 1000 X 300 X 584	1 056,00	314,00	36,00	64,00	30,00	584,57	743,73	1 246 071,34	23 599,84	33 433,46	2 129,52	7 230,02	7,98
	928,00	*868,00*	*199,15*	*3,24*	*5,56*		*403,25*	*40,93*	*28 039,18*	*6,70*	*3 474,83*		*81 242 078*

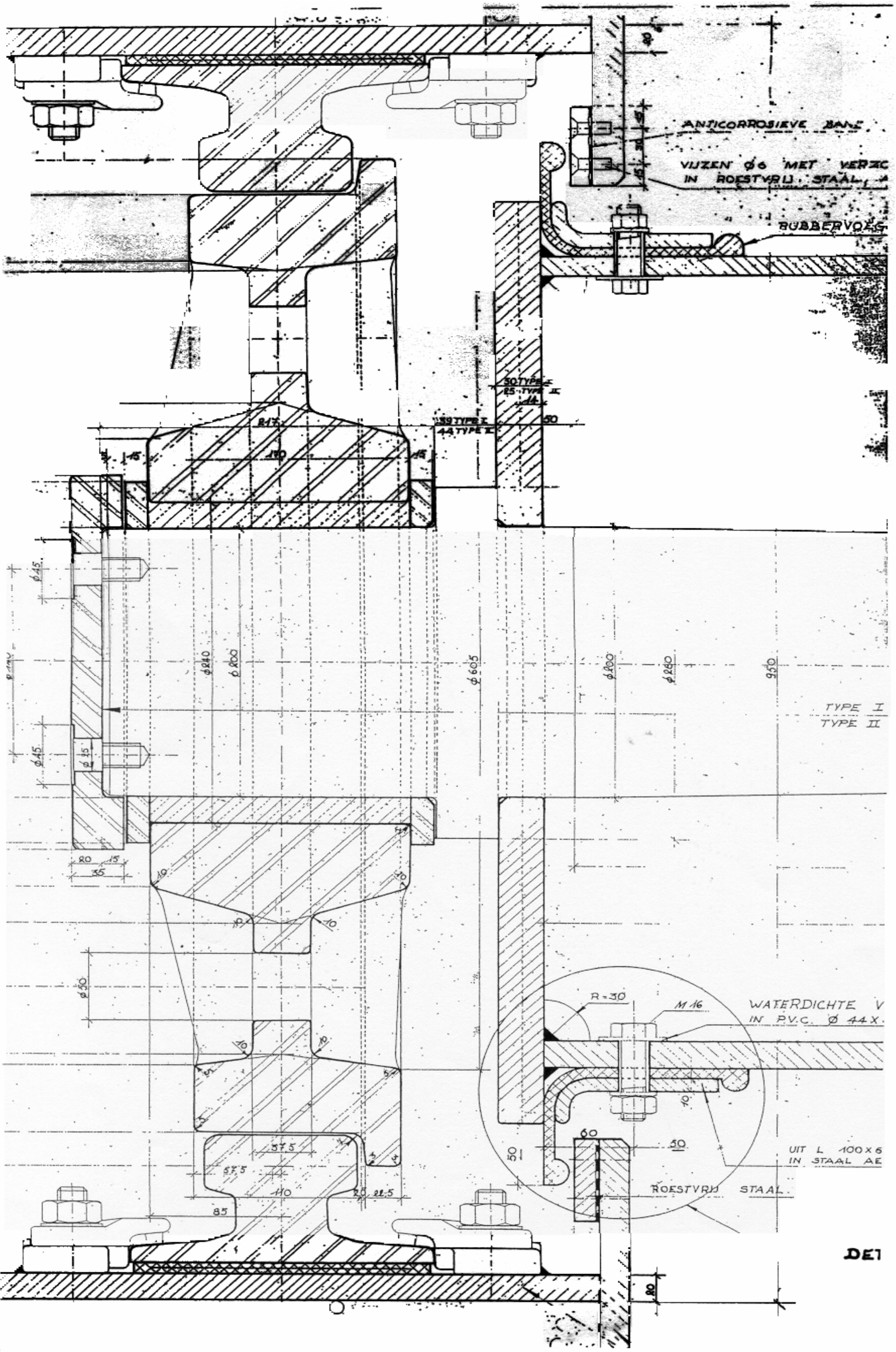
ANNEX 3

ESTIMATION OF WEIGHT FOR CULVERT AND CONDUIT GATES TAKING INTO ACCOUNT MAXIMUM STATIC HEADS

PACIFIC SIDE : TRIPLE LIFT (W=55m) 3 X 2 WATER SAVING BASINS

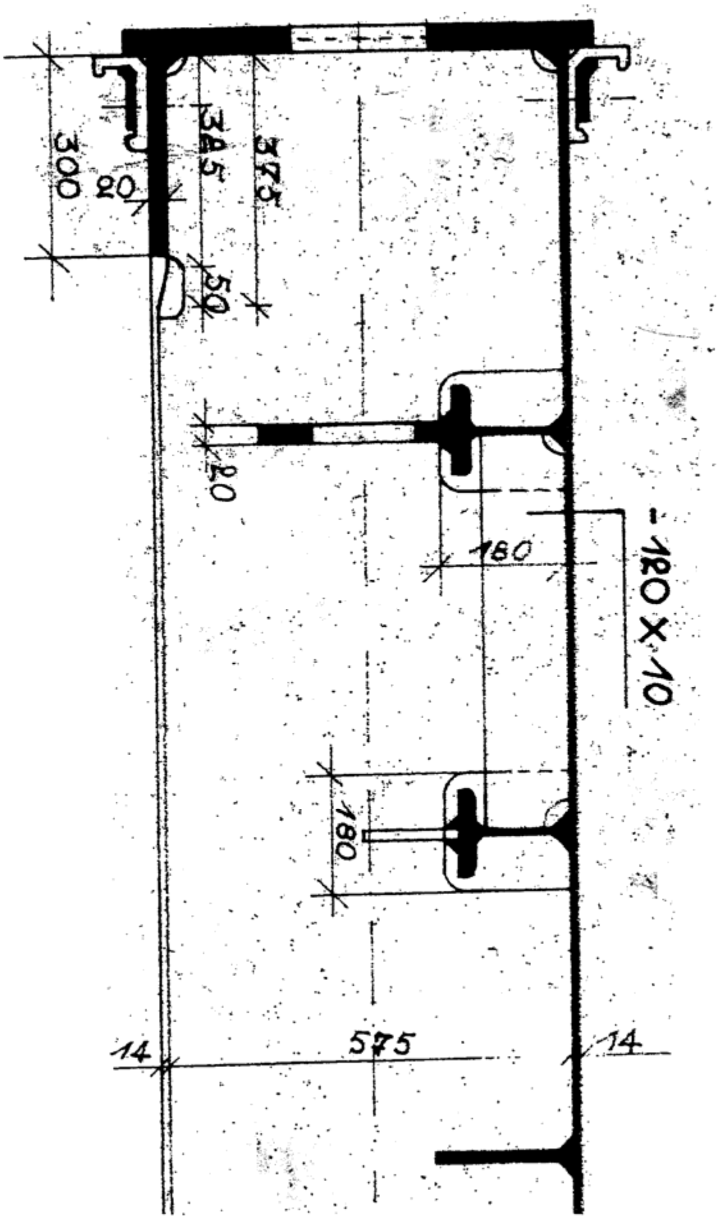
			Width(m)	height(m)	Hmwc(m)	Hsécurité	Htot	T/m	L tot(m)	**Estimated weight (T)**	n	**Total weight (T)**
CULVERT GATES	Culvert gates		**4,5**	**6**	**38,81**					**26,3**	16	421
	Culvert gates slots	2*2gate height		12				0,8	24	19,2	16	
		2*[Htot-(2gate height)]		12	38,81	1,5	40,31	0,2	56,62	11,3	16	
		2*width	4,5					0,8	9	7,2	16	
		tot culvert gates slots										604
	Culvert bulkhead	equal to culvert gate - 3T								23,3	8	187
	Culvert bulkhead slots	2*2bulkhead height		12				0,5	24	12	32	
		2*[Htot-(2bulkhead height)]		12	38,81	1,5	40,31	0,2	56,62	11,3	32	
		2*width	4,5					0,5	9	4,5	32	
		tot culvert bulkhead slots										890
CONDUIT GATES	Conduit gates		**4,5**	**6**	**43,79**					**28,6**	24	687
	Conduit gates slots	2*2gate height		12				1	24	24	24	
		2*[Htot-(2gate height)]		12	43,79	1,5	45,29	0,2	66,58	13,3	24	
		2*width	4,5					1	9	9,0	24	
		tot conduit gates slots										1112
	Conduit bulkhead	equal to conduit gate - 3T								25,6	6	154
	Conduit bulkhead slots	2*2bulkhead height		12				0,5	24	12	48	
		2*[Htot-(2bulkhead height)]		12	43,79	1,5	45,29	0,2	66,58	13,3	48	
		2*width	4,5					0,5	9	4,5	48	
		tot conduit bulkhead slots										1431

ANNEX 4 – CROSS SECTION OF A GATE WHEEL OF BERENDRECHT LOCK



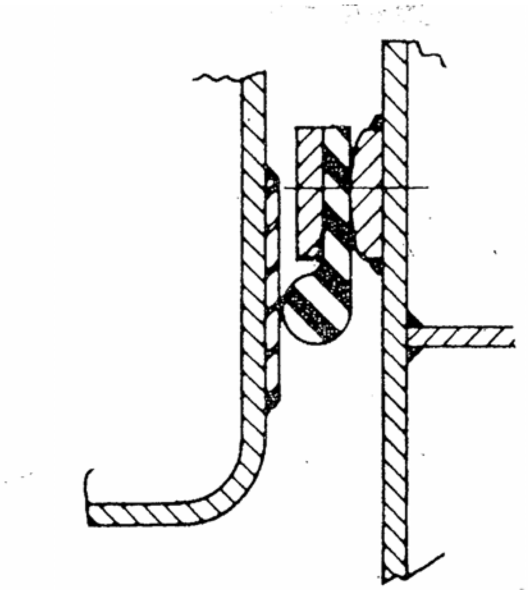
ANNEX 5

TYPICAL GATE STRUCTURE

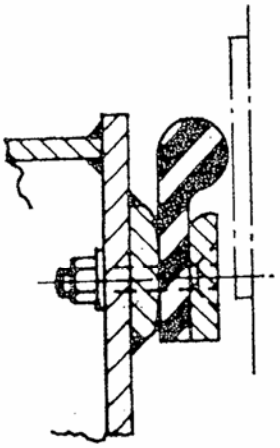


ANNEX 6

UPSTREAM AND DOWNSTREAM SEALING (Music not J-shape type)



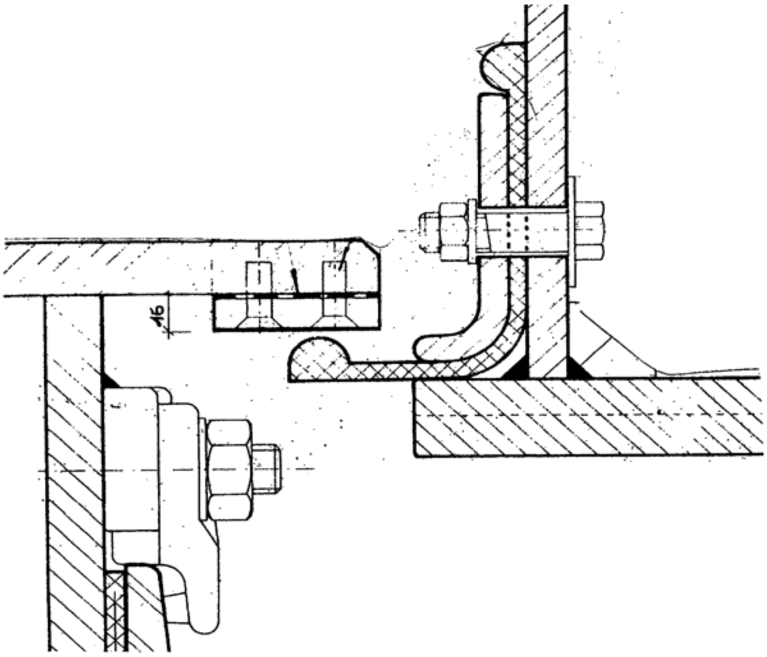
UPSTREAM SEALING

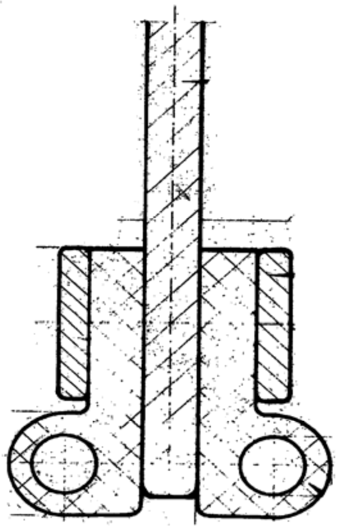


DOWNSTREAM SEALING

ANNEX 7

SIDE AND BOTTOM SEALS (BERENDRECHT)





ANNEX 8 : Pictures – typical seals view (Zandvliet lock, Belgium)

Side seal left position (angular music note type)

Front seal (simple music note seal)

Side seal right position (angular music note type)

Bended music note seal – Pressing plate and protecting device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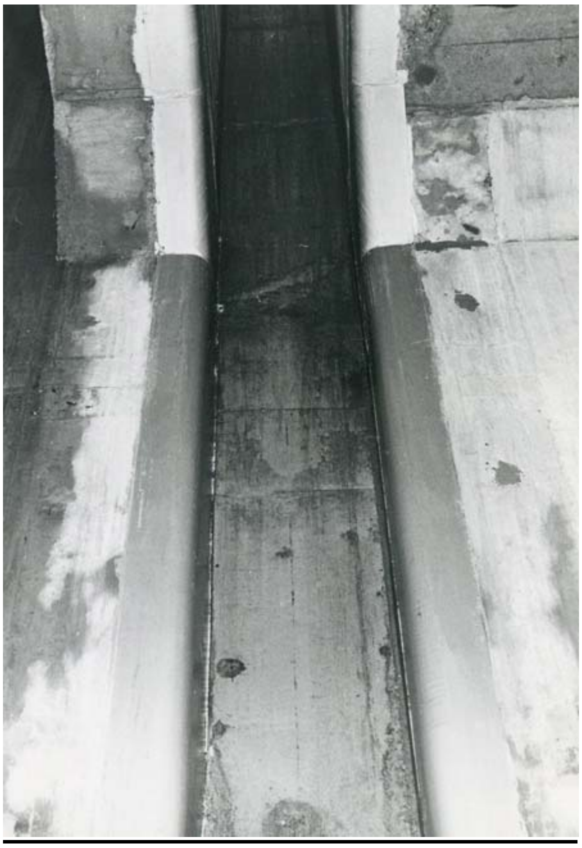
Double bottom seals

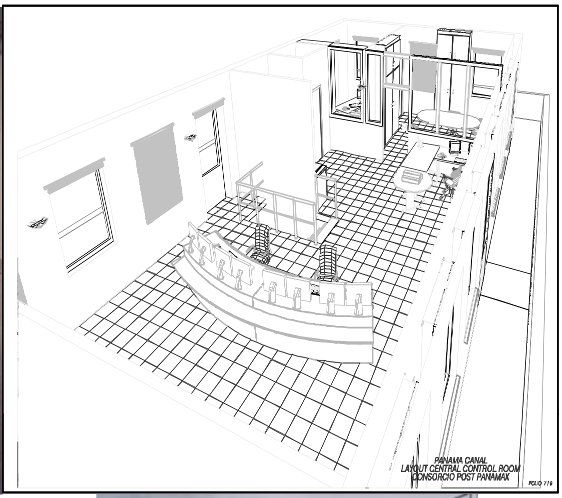


Detail of a gate slot

Handling device details

General view of culvert gate

CPP Consorcio Post-Panamax



Alternative Conceptual Design of Pacific and Atlantic Post-Panamax Locks – 3x2 WSB - Contract SAA-150551

PACIFIC LOCKS 3x2 wsb

Task P4f-3x2 – OPERATING MACHINERY
Task P4g-3x2 – LIGHTING
Task P4h-3x2 – ELECTRICAL AND POWER REQUIREMENTS
Task P4j-3x2 – OPERATING STRUCTURES

Rev A

in association with

TABLE OF CONTENTS

Annexes

1. Estimation of gate engine power for culvert and conduit gates taking into account operating heads
2. Estimation of gate engine power for culvert and conduit gates taking into account maximum static heads

1 INTRODUCTION

The **original conceptual design (CCP 2002)** has been made for a **triple lift lock with a width of 61 m** and **locomotive tracks** for the positioning of the ships inside the lock chambers.

For the actualization studies, the width of the lock chambers has been reduced by 6 m. Hence, the **actual lock width is 55 m**. Furthermore, the use of vessel positioning by tugboat assistance cancels the locomotives on the lock walls.

Both original conceptual design and actualization studies were for a triple lift lock equipped with 3x3 WSB.

The present document gives the impact on the previous study of the replacement of the 3x3 WSB option by the 3x2 WSB one on the following subjects:

- the gates and valves operating machinery (Task 4 F-3x2). This corresponds to the operating machinery of the main lock gates and of the culvert and conduit gates,
- the control system architecture (including SCADA[1]), which includes the monitoring of the whole lock system. The control system architecture is part of Task 4 F-3x2,
- the lighting system (Task 4 G-3x2),
- the electrical and power requirements (Task 4 H-3x2),
- the operating structures (Task 4 J-3x2), which deals with the arrangement of the various technical buildings[2].

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[1] ***SCADA = System Control And Data Acquisition***

[2] ***Electrical rooms, Maintenance building, Rolling gates technical rooms, WSB technical building, Culvert technical building, Emergency Diesel Room and (Main) Control room***

2 Operating machinery (Task P4f-3x2)

2.1 MACHINERY OF THE (MAIN) ROLLING GATES

The characteristics of the operating machinery for the 61m width lock has been determined taking into account the information available from the Berendrecht lock (Belgium) which has main gates of similar size to the ones foreseen for the 61 m Post Panamax locks. The power output of the main motor was foreseen to be 330 kW.

For the 55 m width lock chamber, the power output of the motor should be slightly less than 330 kW. The power output of the gate moving system (drums and gear boxes) should also be slightly less than that of the Berendrecht lock.
The impact on the costs is not significant.

In the 2002 report it was recommended to define the final value of the main motor. CPP recommends to proceed with physical model tests of the gates and to fix the various parameters (nominal speed, gate geometry, presence of mud, etc.).

The opening and closing times will be optimised based on model tests results.

There is no difference, regarding the machinery of the main rolling gates, between the triple lift lock with 3x3 WSB and the triple lift lock with 3x2 WSB.

2.2 MACHINERY OF THE CULVERT AND WSB CONDUIT GATES

The calculation of the rated output of the motor of the main oil pumps mounted on the hydraulic power pack is enclosed in Annexes 1 and 2, respectively for operating and maximum static heads. This calculation takes into account the actual dimensions of the culvert and WSB conduit gates (see P4e-3x2).

A summary of the output for different options is given hereafter:

61 m, (operating heads)	culvert gates:	75 kW,
	WSB conduit gates:	41 kW.
61 m, (maximum static heads)	culvert gates:	116 kW,
	WSB conduit gates:	166kW.
55 m (operating heads)	culvert gates:	53kW,
	WSB conduit gates:	23kW.

(see annex 1 – Estimate of the gate engine power taking into account operating heads)

55 m (maximum static heads)	culvert gates:	81kW,
	WSB conduit gates:	90kW.

(see annex 2 – Estimate of the gate engine power taking into account maximum static heads)

Regarding the two last values, standardization of the servomotors is possible if we consider the operation under maximum static heads.
But, regarding the design of the motors (two per gates), another alternative could be envisaged in the next step of the studies:

- for the operating heads, one motor will operate the gate, one will remain on stand-by (one redundancy degree).
- operation under maximum static heads should be with the two motors in operation (no redundancy).

Of course the power output of the motors will have to be slightly adapted to fit the above operation procedures.

2.3 CONTROL SYSTEM ARCHITECTURE

The control system architecture doesn't change at all. Nothing was foreseen for the operation, the control and the signalisation (I&C) of the locomotive tracks. There is a small impact on the control system. One redundant PLC is foreseen in each of the WSB conduit gate chambers 1, 2 and 3. As the numbers of WSB conduits is reduced from 12 to 8 per chamber, the estimated number of I/O is reduced by one third (to be about 70 instead of 100). Impact on the cost is really negligible. Reference is made to the 2002 report and its corresponding drawings.

3 Lighting (Task P4g-3x2)

3.1 OUTSIDE LIGHTING

3.1.1 LOCK CHAMBER WALLS

The dimensioning criterion is the height of the chamber and not the width. The lighting of the walls is essential (and not the water surface).
Reference is made to the 2002 report.

Vertical recess in the lock walls are equipped on the top of a turned-down lighting system fixed under a hinged plate with easy access from the working platform.
The inclined section at the top of the lock chamber wall is not important for the recess. There is no significant change to do to the system.

The impact on the price is negligible.

3.1.2 LIGHTING POLES

The location of the lighting poles is slightly easier without the locomotive tracks.
The philosophy of the lighting is to have a lighting level along the lock chamber (both side) and decreasing lighting level after the imaginary line running along the dead end of the main rolling gates recesses.

The length of the entrance walls for the triple lift lock with 3x2 WSB is the same as for the triple lift lock with 3x3 WSB. Therefore, the number of lighting poles is the same.

Given there are now only 3x2 water saving basins, the number of floodlights has decreased from 12 to 10 because 2 floodlights were foreseen for the lighting of the last water saving basin.

The external lighting arrangement is summarised hereafter :

Side WSB – Gatun lake entrance :
- 8 lighting poles.
- 60 m between two LP
- 6 floodlights of 1000 W

Side WSB – Chamber locks :
- 3 x 5 lighting poles.
- 90m between two LP
- 10 floodlights of 1000 W

Side WSB – Pacific Entrance :
- 8 lighting poles.
- 60 m between two LP
- 6 floodlights of 1000 W

Other side :
- 28 lighting poles
- 60 m between two LP
- 6 floodlights of 1000 W

The number of floodlights has slightly decreased. But there is no major impact on the price of the whole lighting because the most important part of the price is the mast.

Therefore no significant changes are to be taken into account for the triple lift lock with 3x2 WSB. As a consequence, no financial impacts have been considered. Reference is made to the 2002 report and its corresponding drawings.

3.2 INTERNAL LIGHTING

Reference is made to the 2002 report.
There is no significant change between the 3x3 WSB and 3x2 WSB options.
No financial impacts have been considered.

4 Electrical and power requirements (Task P4h-3x2)

Reference is made to the 2002 report.

A few changes in the electrical substation from HV1 through HV8 are to be foreseen (drawing D4-H-306).

As a reminder, it was foreseen to feed the locomotive from transformers exclusively dedicated to this purpose. Eight 630 kV transformers (one per substation) are to be removed as well as eight MV cubicles linked to the transformers. The removed transformers and linked cubicles incur a cost saving of around $700,000. It is just around 0.35% of the budgetary prices of the equipment and 0.08 % of the total costs of the works.

The number of WSB gates to be electrically fed decreases from 12 to 8 per chamber lock (in total from 36 to 24). The power switchboard consequently has a lower amount of feeders. The PC&M is reduced as well. The total cabling is slightly reduced.

Those changes can be summarized, for the 6 WSB, to a price reduction of the low voltage switchboards and cabling of about US$ 25,000.

5 Operating structures (Task P4j-3x2)

More space is available in the HV1 through HV8 electrical rooms due to the removal of the transformers and associated MV cubicles, originally foreseen for vessel positioning with locomotives.

The size of the HV buildings has been kept equal to the size foreseen in the first conceptual design.

Given the power switchboards are smaller (see P4h-3x2) for the water saving basin conduit gates, the electrical power and control rooms (two per lock chamber) dimensions could be reduced however this has not been considered.
No financial impacts have been considered.

Reference is made to the 2002 report and its corresponding drawings.

6 References

- CPP (2002). Diseño conceptual de las Esclusas Post Panamax. Triple Lift Lock System, task 4.
- PACIFIC LOCKS ACTUALIZATION (May 2005), Tasks P4f, P4g, P4h and P4j.

ANNEXES

ESTIMATION OF THE GATE ENGINE POWER
PACIFIC SIDE : TRIPLE LIFT (W=55m) 3 X 2 WATER SAVING BASINS
TAKING INTO ACCOUNT OPERATING HEADS

	LOCK	WSB
	CULVERT GATE	CONDUIT GATE
Maximum effort (T)	96	41
Oil pressure (bar)	200	200
Stroke (m)	6,00	6,00
Opening time (min)	2,00	2,00
Cylinder section (m^2)	0,048	0,021
Cylinder oil volume (m^3)	0,288	0,123
Oil flow (m^3/min)	0,144	0,062
mechanical efficiency	0,9	0,9
POWER (kW)	**53**	**23**

Calculus of the forces on the gate

Gate width (m)	4,5	4,5
length of horizontal seal (m)	4,9	4,9
Gate heigth (m)	6	6
length of vertical seal (m)	6,3	6,3
width of seal (cm)	3	3

OPENING

Sealing friction forces Fs			
Fs = f x 1,5 x p x A	f (friction coefficient)	0,15	0,15
	p (hydraulic pressure on the gate) (bar)	2,5	1,0
	A (Area of sealing contact) (m^2)	0,525	0,525
	Fs (kg)	2953	1181
Wheel friction Fw			
Fw = Q x (fd x d + fr) / D	Q (max load on the gate) (kg)	771750	308700
(six wheels have been foreseen)	fd (friction coeff of the wheel bushings)	0,12	0,12
	fr (friction coeff of wheels rolling on slot rails)	0,2	0,2
	d (diameter of wheel shaft) (cm)	20	20
	D (wheel diameter) (cm)	80	80
	Fw (kg)	25082	10033
Hydraulic load F1 on the top seal of the gate			
F1 = p x l x ls	p (hydraulic pressure on the gate) (bar)	2,5	1,0
	l (width of the seal) (m)	0,08	0,08
	ls (length of the seal) (m)	4,9	4,9
	F1 (kg)	9800	3920
Hydraulic load F2 on the top of the gate			
F2 = p x gt x ls	p (hydraulic pressure on the gate) (bar)	2,5	1,0
	gt (gate thickness) (m)	1	1
	ls (length of the seal) (m)	4,9	4,9
	F2 (kg)	122500	49000
Hydraulic load F3 under the gate			
F3 = F2 x dlc	F2 (kg)	122500	49000
	dlc (dynamic load coefficient)	0,8	0,8
	F3 (kg)	98000	39200
Weight W (under water)			
W = rw x 6.85/7.85 x 1.05	rw (real weight) (kg)	19345	10186
	W (weight under water) (kg)	17725	9333
Maximum opening load			
F = Fs + Fw + F1 + F2 - F3 + W	**F (T)**	**80**	**34**

CLOSING

Sealing friction forces F's			
F's = 0.1 x p x A	p (hydraulic pressure on the gate) (bar)	2,5	1,0
	A (Area of sealing contact) (m^2)	0,525	0,525
	Fs (kg)	1313	525
Wheel friction F'w			
F'w = Q x (f'd x d + f'r) / D	Q (max load on the gate) (kg)	771750	308700
	f'd (friction coeff of the wheel bushings)	0,08	0,08
	f'r (friction coeff of wheels rolling on slot rails)	0,1	0,1
	d (diameter of wheel shaft) (cm)	20	20
	D (wheel diameter) (cm)	80	80
	F'w (kg)	16400	6560
Hydraulic load F'1 on the top seal of the gate			
F'1 = 0.5 x F1	F1 (kg)	9800	3920
	F'1 (kg)	4900	1960
Hydraulic load F'2 on the top of the gate			
F'2 = 0.9 x F2	F2 (kg)	122500	49000
	F'2 (kg)	110250	44100
Hydraulic load F'3 under the gate			
F'3 = 0.5 x F3	F3 (kg)	98000	39200
	F'3 (kg)	49000	19600
Weight W'			
real weight of the gate	W' (kg)	19345	10186
Maximum braking force			
B = W' + F'1 + F'2 - F'3 - F'w - F's	**B (T)**	**68**	**30**

ESTIMATION OF THE GATE ENGINE POWER
PACIFIC SIDE : TRIPLE LIFT (W=55m) 3 X 2 WATER SAVING BASINS
TAKING INTO ACCOUNT MAXIMUM STATIC HEADS

	LOCK	WSB
	CULVERT GATE	CONDUIT GATE
Maximum effort (T)	145	163
Oil pressure (bar)	200	200
Stroke (m)	6,00	6,00
Opening time (min)	2,00	2,00
Cylinder section (m²)	0,073	0,081
Cylinder oil volume (m³)	0,435	0,488
Oil flow (m³/min)	0,218	0,244
mechanical efficiency	0,9	0,9
POWER (kW)	**81**	**90**

Calculus of the forces on the gate

Gate width (m)	4,5	4,5
length of horizontal seal (m)	4,9	4,9
Gate heigth (m)	6	6
length of vertical seal (m)	6,3	6,3
width of seal (cm)	3	3

OPENING

Sealing friction forces Fs			
Fs = f x 1,5 x p x A	f (friction coefficient)	0,15	0,15
	p (hydraulic pressure on the gate) (bar)	3,9	4,4
	A (Area of sealing contact) (m²)	0,525	0,525
	Fs (kg)	4584	5173
Wheel friction Fw			
Fw = Q x (fd x d + fr) / D	Q (max load on the gate) (kg)	1198065	1351797
(six wheels have been foreseen)	fd (friction coeff of the wheel bushings)	0,12	0,12
	fr (friction coeff of wheels rolling on slot rails)	0,2	0,2
	d (diameter of wheel shaft) (cm)	20	20
	D (wheel diameter) (cm)	80	80
	Fw (kg)	38937	43933
Hydraulic load F1 on the top seal of the gate			
F1 = p x l x ls	p (hydraulic pressure on the gate) (bar)	3,9	4,4
	l (width of the seal) (m)	0,08	0,08
	ls (length of the seal) (m)	4,9	4,9
	F1 (kg)	15214	17165,68
Hydraulic load F2 on the top of the gate			
F2 = p x gt x ls	p (hydraulic pressure on the gate) (bar)	3,9	4,4
	gt (gate thickness) (m)	1	1
	ls (length of the seal) (m)	4,9	4,9
	F2 (kg)	190169	214571
Hydraulic load F3 under the gate			
F3 = F2 x dlc	F2 (kg)	190169	214571
	dlc (dynamic load coefficient)	0,8	0,8
	F3 (kg)	152135	171656,8
Weight W (under water)			
W = rw x 6.85/7.85 x 1.05	rw (real weight) (kg)	26319	28640
	W (weight under water) (kg)	24115	26241
Maximum opening load			
F = Fs + Fw + F1 + F2 - F3 + W	**F (T)**	**121**	**135**

CLOSING

Sealing friction forces F's			
F's = 0.1 x p x A	p (hydraulic pressure on the gate) (bar)	3,9	4,4
	A (Area of sealing contact) (m²)	0,525	0,525
	Fs (kg)	2038	2299
Wheel friction F'w			
F'w = Q x (f'd x d + f'r) / D	Q (max load on the gate) (kg)	1198065	1351797,3
	f'd (friction coeff of the wheel bushings)	0,08	0,08
	f'r (friction coeff of wheels rolling on slot rails)	0,1	0,1
	d (diameter of wheel shaft) (cm)	20	20
	D (wheel diameter) (cm)	80	80
	F'w (kg)	25459	28726
Hydraulic load F'1 on the top seal of the gate			
F'1 = 0.5 x F1	F1 (kg)	15214	17165,68
	F'1 (kg)	7607	8582,84
Hydraulic load F'2 on the top of the gate			
F'2 = 0.9 x F2	F2 (kg)	190169	214571
	F'2 (kg)	171152	193113,9
Hydraulic load F'3 under the gate			
F'3 = 0.5 x F3	F3 (kg)	152135	171656,8
	F'3 (kg)	76068	85828,4
Weight W'			
real weight of the gate	W' (kg)	26319	28640
Maximum braking force			
B = W' + F'1 + F'2 - F'3 - F'w - F's	**B (T)**	**102**	**113**

Alternative Conceptual Design of Pacific and Atlantic Post-Panamax Locks – 3x2 WSB
Contract SAA-150551

PACIFIC AND ATLANTIC LOCKS WITH 3x2 wsb

TASK P/A4c-3x2 – Emptying and Filling System
RevB

Final report

in association with

0 Executive summary

This hydraulics report deals with an alternative to the Pacific side Actualization and Atlantic side Harmonization studies performed previously under contract SAA-143351. It follows the logic of these studies, where three water saving basins per lock were used.
This alternative concerns the same configuration on both sides of the Panama Canal, a triple lift lock system, but in this case using **two water saving basins** per lock.

Following the recommendations, choices and Terms of Reference of the ACP, a system with three lock chambers, each equipped with 2 water saving basins, allowing to **save nearly 83 %** [1]**of the total water required to lock 1 ship** (semi convoy mode), has been retained.

The levels of chambers and water saving basins have been set up using the same software as used in previous studies. This software calculates minimum and maximum water levels in the chambers and the 6 basins and also provides figures for water usage and the water saving rate for each lockage, as well as to the daily number of up and down lockages.

Based on the results of former concept design studies, the emptying and filling system retained for this alternative is **a sidewall culvert & ports filling and emptying system.**

The system has been modeled and pre-designed using Flowmaster™ hydraulic calculation software.

The new calculations were undertaken with the same hydraulic system (i.e. culvert, conduit & port size, valve opening times, etc.) as the ones designed which were obtained in the study with 3x3 water saving basins.

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[1] *The three-step lock system saves 2/3 of the volume of a* ***single lock*** *chamber.*

Moreover, the water saving basins save: $e = \frac{n}{n+2}$ *= 50 % of the 1/3 remained (with the same area for WSB and lock chamber : m= WSB area / lock area = 1), where n= 2 is the number of water saving basins per lock*

So, the total water saving rate is e':

$$e' = \frac{2}{3} + \frac{1}{3}e = \frac{3n+4}{3n+6}$$

For n=2, e' = 0.83, i.e. 83 %

It is reminded that because of the smaller tidal amplitude in the Atlantic Ocean than in the Pacific Ocean, the maximum head between lock chambers and water saving basins is also smaller at the Atlantic side and thus the size of the WSB conduits has been reduced.
On the other hand, as the average head between Gatun Lake and the Ocean is nearly the same at both sides, and as the maximum head between two lock chambers remain nearly unchanged, the dimensions of the main longitudinal culverts have been kept unchanged

The calculated filling and emptying times are within those required by design values and/or guidelines. The velocities reached in culverts, conduits and ports are acceptable, taking into account that the maximum velocities could be reduced by firstly adapting the forms of the circuits' components (especially ports) and secondly by changing the opening and closing rates of the valves.

The system provides, after optimization, quite a uniform flow distribution and a balanced upstream-downstream / east-west filling. The remaining dissymmetry that could cause strain levels on the hawsers to exceed acceptable levels has been examined during the Pacific side actualization study. Due to the increased F/E times, the hydraulic conditions remain comparable in these 2-WSB configurations. A new hawser forces analysis has therefore not been run in this alternative.

Nevertheless, solutions to reduce these forces would be identical as those proposed for the Pacific side actualization study for 3 water saving basins per lock chamber:

- Modifying the valve opening diagram;
- Modifying the dimensions of the ports.
- Concentrating the ports along the 'centre of gravity' of the lock chamber

The next stage, defined as the preliminary filling and emptying system design phase, should mainly be aimed at:

- Optimizing the culvert, conduit and port dimensions, shape and number of ports;
- Optimizing the valve opening/closing timings;
- Defining the distribution of ports along the lock chamber, their position and orientation;
- Accurately evaluating the expected hawser forces.

This stage will require a detailed study using Flowmaster™ in conjunction with the 2D/3D Delft numerical model and finally studies using a physical scale model.

This conceptual design is set up for locks using Water Saving Basins, according to the TOR. If these WSBs are not used, the E/F times may have to be increased, or the E/F system may need to be adapted / modified to take into consideration the fact that under certain configurations the head will be much greater.

1 Foreword

1.1 CONTRACT

This report has been produced within the scope of the Contract n° SAA-150551 awarded in April 2005 to the Consortium CPP (Consorcio Post Panamax) by the client ACP (Autoridad del Canal de Panama).

This report concerns the alternative conceptual design of a Pacific side and Atlantic side triple lift lock system, operating with **two water saving basins** per lock chamber.

The purpose of this contract is to update the previous studies by integrating a triple lift lock system using two water saving basins per lock chamber instead of a triple lift lock system using three water saving basins per lock chamber. The technical modifications (lock dimensions, ship handling system, etc. (C.f.: Part 1 of the 'Pacific Locks Actualization' contract) remain valid for this report.

1.2 SCOPE OF WORK

This report deals with the alternative conceptual design of a Pacific side and Atlantic side triple lift lock system, 2 water saving basins per lock chamber.

It is based on the results of previous studies, and takes into consideration the choices made by the ACP:

- Using a triple lift lock system, each lock chamber being equipped with 2 water saving basins;
- Using tug boats instead of locomotives as a positioning system;
- Operating the locks with rolling gates;
- Using a filling and emptying hydraulic system with longitudinal side wall culverts and ports;
- Reduction of the lock width from 61.00m to 55.00m.

The scope of work of this study mainly consists of:

- Setting the levels of the chambers and the water saving basins, using the new data: Gatun Lake levels, tidal variations of the Pacific & Atlantic levels;
- Calculating the heads between the different pools (Gatun Lake, chambers, water saving basins, Pacific & Atlantic Oceans);
- Calculating the water usage and the water saving rate;
- Optimizing the F/E system using Flowmaster ™ and the 2D/3D Delft model;
- Designing at a conceptual level a hydraulic system of the above solution,
- Determining approximately the number of ships passing through the locks in semi convoy mode

2 Introduction

2.1 BACKGROUND

The existing locks of the Panama Canal will most probably reach saturationn less than ten years. In addition, new Post Panamax vessels are going to be built which cannot pass through the locks.

The "Autoridad del Canal de Panama" is conducting a study to evaluate the feasibility of a third lane of locks for bigger vessels. However, there is a shortage of water to operate these new locks, and consequently new solutions have to be found.

None of these kinds of locks have yet been designed. The engineering work starts with a conceptual design study. The purpose of this study is not to design the locks in detail, but to allow the ACP to choose the best solution according to the following subjects: hydraulic filling and emptying systems, water saving basins, type of gates, civil works, electro-mechanical equipment, …

2.2 BRIEF DESCRIPTION

The Panama Canal is equipped with a triple lift lock system at the Atlantic side, and a lock system at the Pacific side which is composed of a single and a double lift lock:

The Pacific side locks are composed of two distinct blocks,:

- A set of two, parallel double lift locks on the Pacific side - the Miraflores Locks, providing nearly two third of the head
- A set of two parallel single lift locks on the Gatun Lake side - the Pedro Miguel Locks, for the remaining head

The Atlantic side locks consist of two parallel triple lift lock system - the Gatun Locks

Each lock on both sides has following dimensions:

- Useful length : 305 m
- Useful width : 33.50 m
- Maximum vessel draft : 12 m (39.5 ft) in tropical fresh water

The maximum tidal range on the Pacific coast is nearly 7 m; whereas on the Atlantic side it is only 0.50 m. The level of the Gatun Lake can drop nearly 2 m during the dry season (from 26.67 m PLD to 24.84 m PLD). The ACP plans to raise maximum level of the Gatun Lake in order to improve the channel's transit capacity (see new levels further in this report).

All the locks are capable of handling 65,000 dwt ships (known as 'Panamax ships), sailing in semi-convoy mode, i.e. for 12 hours ships sail in one direction and for 12 hours in the other direction.

The current locks will be saturated in a few years. In addition they cannot be used to handle the larger ships: 105,000 dwt Container Vessels, 140,000 dwt Bulk Carrier, and further upto 200,000 dwt ships (known as 'Post Panamax'). The ACP (Autoridad del Canal de Panama) has thus decided to investigate construction of new, larger locks.

The main issue, from a hydraulic point of view, is the lack of water to operate these new locks. The existing locks supply resource is lower than demand and the level of the lake drops. In addition, some other needs (municipal and industrial), increase continuously, competing with the water demand required to operate the locks.

The present hydraulic project has two main purposes:

- ➢ Design an efficient hydraulic system for filling and emptying operations, and for limitation of the hawser forces.
- ➢ Propose water saving systems (in addition to new resources)

The present project, on both sides, consists in the stepping of the head at a single location by means of a triple lift lock system. These new locks will of course also need new by-pass channels.

3 Terms of reference

3.1 LEVELS

Note: PLD (Precise Level Datum) is the reference system used by the Panama Canal. All levels in this report refer to that reference.

3.1.1 GATUN LAKE

Maximum level: +27.13 m PLD (89 ‘)
Minimum level: +24.99 m PLD (82 ‘)

3.1.2 PACIFIC OCEAN

Ranging from – 3.44 m to +3.60 m PLD

The ACP has decided that the bottom levels of the chambers (sills) have to be designed with the Mean Low Water Spring (MLWS) level, i.e. a tidal range of –2.32 m to +2.40 m PLD

3.1.3 ATLANTIC OCEAN

Ranging from – 0.15 m to +0.41 m PLD

3.2 SIZES - DIMENSIONS

- Useful length of the locks : 426.72 m
- Useful width of the locks : 55.00 m
- Depth (minimum water over the sills) : 16.76 m
- Freeboard : 2.13 m (to be verified)

3.3 WATER SAVING RATE

A triple lift lock system with 2 water saving basins per lock chamber should save 50 % per lock chamber and 83 % * of the total water required to lock a ship.

** see footnote page C/0-1*

3.4 OPERATING TIME

It is desirable that the filling and emptying times are kept within an 8-10 min cycle without using the water saving basins for a single lift of the triple lift lock system. This time is given rather as a guideline than as a TOR, as the TOR of the study are set up for locks operating with water saving basins.

The time needed for a lockage using the water saving basins is not specified, nevertheless it must not increase too much the filling/emptying times without using water saving basins. The guidelines of the times are given in Chapter 5.1.

3.5 NUMBER OF SOLUTIONS TO BE STUDIED

Only one solution for the filling and emptying system has to be studied in this alternative project. It is the system with side wall culverts and ports, and two water saving basins per lock chamber.

3.6 COST AND MAINTENANCE OF THE SYSTEM

Special attention will be paid to these points:

- A compromise must be reached between the level of efficiency of the system and the corresponding costs.
- System redundancy is also very important to obtain a high level of reliability, minimizing traffic interruptions.

4 Design criteria and assumptions

4.1 DESIGN CRITERIA

Reference is made to the following reports:

R2 - A	: Part A General Design Criteria
R2 - B	: Part B Specific Design Criteria
R4 - C	: Filling and emptying system

4.2 ASSUMPTIONS

- Saving 83 % of the lockage water implies the use of 2 water saving basins per step or 6 water saving basins for the complete 3 step system (see 3.3), no additional recycling system has been retained by ACP.

- The water saving basins will be built only on one side of the locks

- Only two side-by-side water saving basins will be studied

- Considering the operating time, and to be in accordance with the results of the first study for a triple lift configuration, Pacific side, the target time for filling and emptying a lock chamber using the water saving basins is approximately 51 minutes. This has led to a reduction of culvert and conduit sizes in the previous actualization and harmonization studies. The same dimensions will be retained in this alternative design, as will be further explained.
- The surface area of the lock that is taken into consideration for the filling / emptying simulations is 27 500 m². This includes the surface between the adjacent gates, the surface of the gate recesses and part of the gate surface (95 %), as shown on the sketch below:

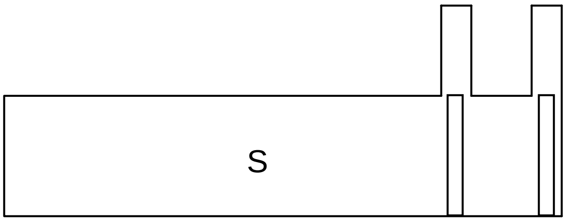


Figure 4.2-a

- The valves will be of the vertical plane valve type, rectangular, with rollers.

- Each valve will be surrounded by slots in order to insert stoplogs for maintenance or repair work. According to ACP’s request, these slots will be of the same size as the main valve slots so that they can be equipped with auxiliary valves if required. Access shafts for material and personnel will be provided on both sides of the main valves.

- The scheduling in semi convoy mode, which is the actual way to lock ships, will be retained for the 3rd lane of locks in that configuration.

The design of the filling system will take into consideration the possibility of smaller ships passing through the new lock. This will affect in particular the acceptable turbulence levels within the chamber: smaller ships can resist to higher water slopes inside the chamber, as the hawser forces are far smaller than for high displacement ships. On the other hand, smaller ships are more sensitive to local turbulence (created by the discharge jet flows from the ports for instance). According to the ship dimensions, recommendations will be provided about the valves opening rate and the positioning system (ships in the centre of the lock or on one side, etc.)

5 Levels in lock chambers and water saving basins

All elevations are in Precise Level Datum (P.L.D.)

5.1 PRESENTATION OF THE METHOD AND INPUT DATA

This study consists in the calculation of the water surface elevation, within both the lock chambers and the water saving basins (WSB), at all times during a lockage, and takes into account the tidal variation of the oceans. It allows to determine the lock chamber and WSB main dimensions (bottom and top elevation, gate height, etc.).

All the calculations are carried out with the software developed by the Consultant and already presented in the previous studies. All the data entered in the program are detailed hereafter:

- **The Pacific Ocean levels**

To carry out the simulations, the tides of the Pacific Ocean have been taken into account, considering both daily and monthly variations in the tide:

- Daily variations are represented over a 12.47 hours period. This value was determined using data from 1991 (resolution with Statgraphics software)
- Monthly variations are represented over a 14.4 days period.

As it has been specified in the TOR, two tidal ranges have been considered:

- Maximum range from -3.44 m to +3.60 m PLD
- Mean Low Water Spring range from -2.32 m to +2.40 m PLD

The resulting equations entered in the software are shown below:

$$Z_{ocean}(t) = a + \sin\left(\frac{2\pi t}{12.47*60}\right) * \left(b + 0.6 * \sin\left(\frac{2\pi t}{14.4*24*60}\right)\right)$$

with t in minutes
a = 0.08 b = 2.92 for the maximum range
and a = 0.04 b = 1.76 for the MLWS range

The curves resulting from this equation are given in annex 2.

➢ The Atlantic Ocean levels

Data concerning the tides on the Atlantic side has been taken by the consultant from the web site of the SHOM (Service Hydrographique et Océanographique de la Marine) since September 20th at Cristobal.

The observation period runs over 105 days (20/09/04 to 03/01/05). This data is given in annex 8.1.

From the data collected, it appears:

- The maximum value is : + 0.44 m PLD
- The minimum value is : - 0.11 m PLD
- Tides have a period of 12.47 hours (high tide to high tide or low tide to low tide)
- There is a second variation of the amplitude of the tides, with a period of 14 days

The ACP has also provided the Consultant with data on the tides at the Coco Colo station (See Annex 8.2).

The extreme values (year extremes 1909-1991) were ignored (they were possibly due to atmospheric phenomena). Only the 19 year mean values over the period 1973-1991 have been taken into account.

The table below summarizes the values in feet PLD and m PLD

19 year means 1973 - 1991	feet PLD	m PLD
mean monthly highest high water	1.341	**0.409**
mean high water	0.973	0.297
mean sea level	0.355	0.108
mean low water	-0.171	-0.052
mean monthly lowest low water	-0.480	**-0.146**

Table 5.1-a

It appears that the values collected via the web are 3 to 4 cm higher than the data furnished by the ACP. This difference may be due to the difference between the 'PLD' reference and the reference used by the SHOM site (The zero value is roughly equivalent to the Lowest Astronomical Tide on the area). It was finally decided to retain the values highlighted in yellow in the chart

Consequently, to carry out the simulations, the tide of the Atlantic Ocean has been taken into account considering both its daily and monthly variations:

- Daily variations are represented over a 12.47 hours period.
- Monthly variations are represented over a 14 day period.

The resulting equation entered in the program is shown below:

$$Z(t) = \mathrm{a} + \frac{1}{2} * b * \sin\left(\frac{2\,\pi\,t}{per\,1 * 60}\right) * \left(c + \mathrm{d} * \sin\left(\frac{2\,\pi\,t}{per\,2 * 24 * 60}\right)\right)$$

Where:

- ➢ t is the time in minutes
- ➢ Z(t) is the level of the Caribbean sea (or Atlantic Ocean) in m PLD
- ➢ a = 0.1315 is the mean sea level value in m PLD
- ➢ b = 0.555 m is the maximum tide amplitude
- ➢ per 1 = 12.47 is the period of daily variations in hours
- ➢ per 2 = 14 is the period monthly variations in days
- ➢ c = 0.68 and d =0.32 are coefficients of the second sinusoidal curve.

The curve produced by this equation does not match exactly the actual tidal variations of the Atlantic Ocean (See Appendix 1.3).

Nevertheless, this equation provides the extreme levels, and the differences observed between real and calculated tides are of no consequence to the minimum and maximum levels reached in the lock chambers and water saving basins.

➢ The Gatun Lake levels

According to the TOR, the maximum and minimum values are:

Maximum level: .... +27.13 m PLD (89 ')
Minimum level: .... +24.99 m PLD (82 ')

The maximum level results from another study ("Raising Gatun Lake. The minimum level is from an examination of the variations in the lake levels over 18 years (period 1980 – 1997), see annex 1.1.

Annex 1.2 shows variations in the level of Gatun Lake between 1966 and 2000.

- **Freeboard and minimum water depth**

Freeboards and minimum water depths taken into account for the design of the structures are the following:

	Water depth (m)	Freeboard (m)
Chamber	18.30	1.50
Water saving basins	1.00	0.80

Table 5.1-b

The minimum water depth of 18.30m in the lock chambers is higher than specified in the terms of reference. This is due to the fact that it was shown that the corresponding UKC of 1.50m affects too much the hawser forces.

The freeboard of 1.5 m is confirmed both in the PIANC report on locks and in Dutch literature on lock design (Ontwerp van Schutsluizen – RWS 2000). In Berendrecht the maximum water level is +7.50 m above the sea level and the lock heads are at +9.00 m above sea level.

Freeboard depends on the water oscillation amplitudes in the chamber during lockage. A scale model is required to get precise values of these oscillations, and the same remarks are to be taken into account for the freeboard in the water saving basins. As far as the water saving basins are concerned, the minimum water depth of 1 meter can be further optimized during further studies.

NB: Adopted values do not affect the results of calculation.

- **Scheduling**

The simulations are undertaken with the ‘’semi convoy mode’’ scheduling.

- **Characteristic operating times**

Operating times in the simulations are as follows:

	duration time (min)
Gate opening or closing	5
Chamber filling or emptying time (using WSB)	6
Water saving basin filling or emptying	5
Inner cycle ship displacement	12
Mean value for entry of 1st ship and exit of last ship	20
Re-initialization of water levels at the turn around	30

Table 5.1-c

Taking into account the increase of unitary water volumes to be transferred in the case of 2 WSB compared to 3 WSB, the filling and emptying times have been increased too, from 4 to 5 minutes for WSB operations and from 5 to 6 minutes for lock to lock operations. These increases do not affect the global operation time, as there are only 2 WSB operations instead of three.

Note: the purpose of the software is to set the bottom levels of the chambers and the water saving basins; the values above are indicative and do not affect these levels when modified.

Nevertheless, it gives information about the mean daily water usage and the number of ship transits through the locks in both directions.

- **Generic names for locks and water saving basins**

The 3 lock chambers are identified as: upper, middle and lower

Water saving basins are identified as: top and bottom

So, when the upper-bottom WSB is addressed, it would mean the bottom water saving basin of the upper chamber.

5.2 WATER LEVELS CALCULATION

Specific software was developed to calculate the water levels in the chambers and the water saving basins during the different stages of a lockage in the case of **a triple lift lock with two water saving basins per lock chamber**.

The software allows simulating cycles scheduled in semi convoy mode:

- From Gatun Lake to the ocean for 12 hours
- From the ocean to Gatun Lake for 12 hours

The software also gives the water saving rate and the water usage during lockage and calculates the head for each filling or emptying operation.

The equations used in the software are based on the equalization of water levels between the chamber and the water saving basins (see the explanation below).

5.2.1 DESCRIPTION OF THE CALCULATION METHOD

- **Equalization of the levels between a chamber and a WSB**

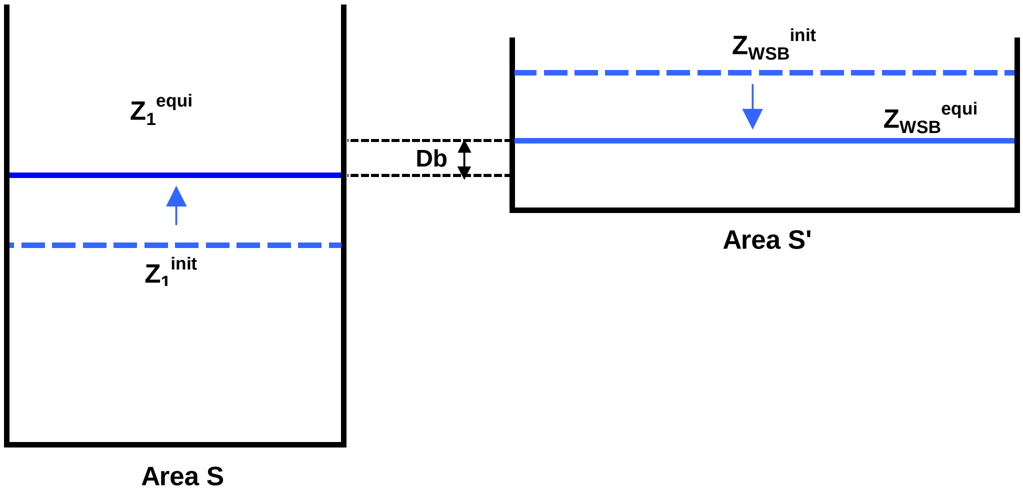


Figure 5.2.1-a

Equation system

$$\begin{cases} \left[Z_{WSB}^{init} - Z_{WSB}^{equi}\right]S' = \left[Z_{1}^{equi} - Z_{1}^{init}\right]S \\ Z_{WSB}^{equi} = Z_{1}^{equi} + Db \end{cases}$$

System solution

$$Z_{1}^{equi} = \frac{Z_{1}^{init} * S + Z_{WSB}^{init} * S' - Db * S'}{S + S'} = \frac{Z_{1}^{init} + m * \left(Z_{WSB}^{init} - Db\right)}{1 + m} \quad \text{with} \quad m = \frac{S'}{S}$$

$$Z_{WSB}^{equi} = \frac{Z_{1}^{init} + m * Z_{WSB}^{init} + Db}{1 + m}$$

Remark: Db (residual filling depth) is usually about 0.10 m to 0.20 m, based on CPP's experience. This residual filling depth was adopted in coordination with electromechanical experts, in order to save time (the last 0.10 m to 0.20 m would need too much time to be filled or emptied). The valves are closed before equalization. In this case the water saved is slightly smaller than the theoretical goal as it was shown during the first presentations in 2002 (e.g. for Db = 0.1 and m = 1, water saving rate = 58.7 % instead of 60% for the case with 3 WSB). The correct value can be reached by increasing slightly the area of the WSB, which is reflected in the civil drawings. Anticipated valve closure is taken into account by Flowmaster™ software.

- **Equalization of the levels between two chambers**

1- First stage : filling of lower chamber from middle chamber, or middle chamber from upper chamber

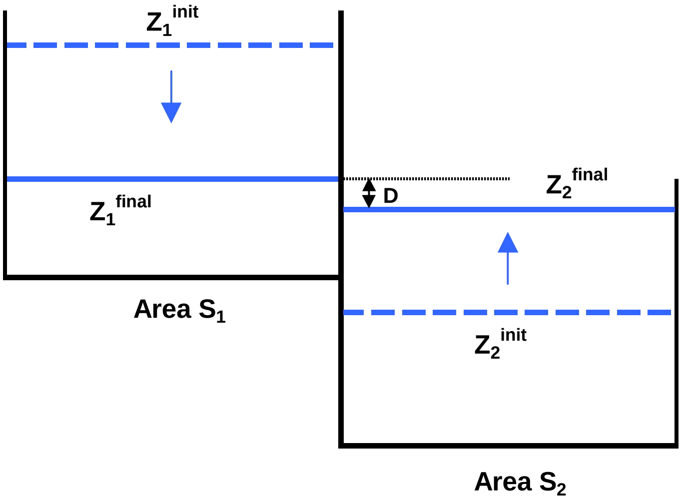


Figure 5.2.1-b

Equation system

$$\begin{cases} \left[Z_1^{init} - Z_1^{final}\right]S_1 = \left[Z_2^{final} - Z_2^{init}\right]S_2 \\ Z_1^{final} = Z_2^{final} + D \end{cases}$$

System solution

Before the opening of the gate, the levels are:

$$Z_2^{final} = \frac{Z_1^{init} * S_1 + Z_2^{init} * S_2 - D * S_1}{S_1 + S_2}$$

$$Z_1^{final} = \frac{Z_1^{init} * S_1 + Z_2^{init} * S_2 + D * S_2}{S_1 + S_2}$$

Remark : in the case of a rolling gate, D is equal to zero, i.e. .$Z_2^{final} = Z_1^{final}$
In the PIANC report on locks - part 6 : gates and valve § 2.4 : rolling gates
it is indicated that the gates are usually operated with equalization of levels
but are so heavily constructed that it is possible to move them before equalization
A device to detect the breaking of the gate seals at equalization will be installed, allowing to start opening of the gates.

2- Second stage : opening of the gate

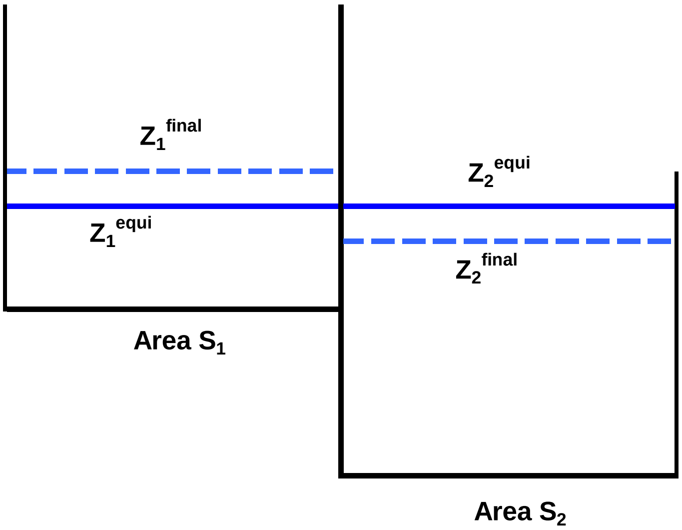


Figure 5.2.1-c

$$Z_1^{equi} = Z_2^{equi} = \frac{Z_1^{final} * S_1 + Z_2^{final} * S_2}{S_1 + S_2}$$

5.2.2 INITIALIZATION OF WATER SURFACE ELEVATION IN THE CHAMBER AND WATER SAVING BASINS

At the beginning of a simulation, the initialization of the water surface elevation in the chambers and water saving basins depends on the head between Gatun Lake and Pacific (or Atlantic) Ocean levels and on the direction of the lockage.

The drawings below illustrate the method of initializing the water surface elevations (drawings made for *m* = 1).

- **Lockage from Lake to Ocean (downlockage)**

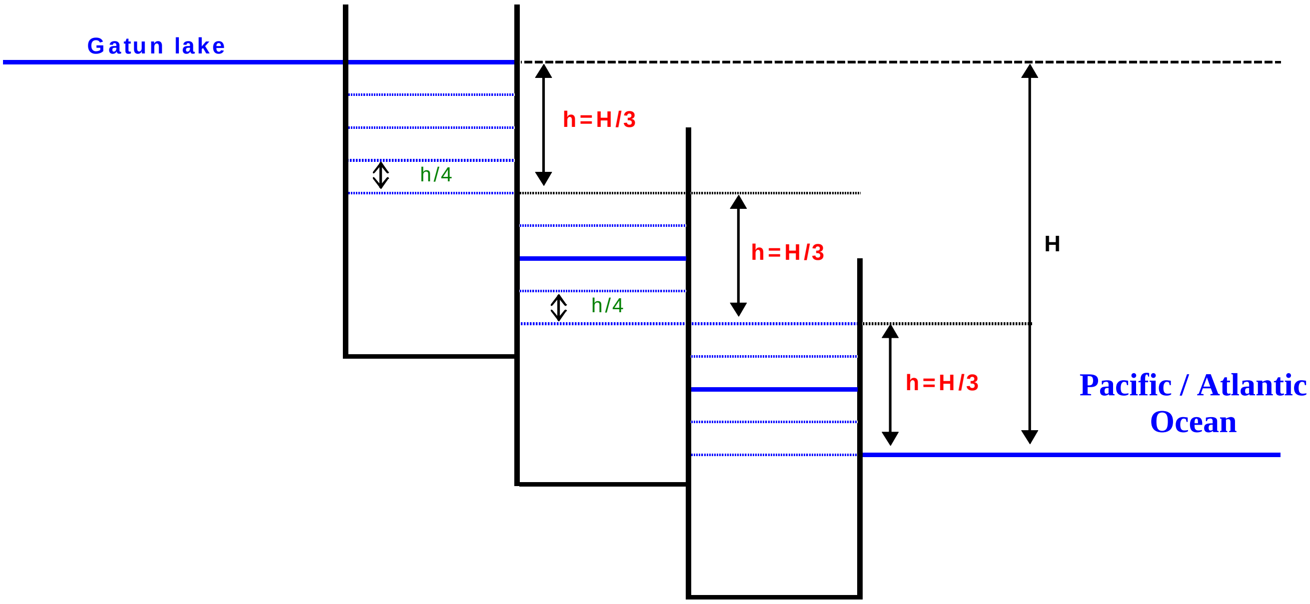


Figure 5.2.2-a

When the simulation starts, the water surface elevations are initialized as below:

- Upper chamber :........... Z_{lake}
  Upper-top WSB : .... $2h/4 + 2H/3 + Z_{mean\ ocean}$
  Upper-bottom WSB : ... $h/4 + 2H/3 + Z_{mean\ ocean}$

- Middle chamber : .... $2h/4 + H/3 + Z_{mean\ ocean}$
  Middle-top WSB : ..... $2h/4 + H/3 + Z_{mean\ ocean}$
  Middle-bottom WSB : .. $h/4 + H/3 + Z_{mean\ ocean}$
- Lower chamber :........... $2h/4 + Z_{mean\ ocean}$
  Lower-top WSB : ...... $2h/4 + Z_{mean\ ocean}$
  Lower-bottom WSB : ... $h/4 + Z_{mean\ ocean}$

With $Z_{mean\ ocean}$ = 0.30 m PLD, Pacific side

And

- Upper chamber : Z_{lake}
  Upper top WSB: $2h/4 + 2H/3 + Z_{mean\ ocean}$
  Upper bottom WSB: $h/4 + 2H/3 + Z_{mean\ ocean}$

- Middle chamber $2h/4 + H/3 + Z_{mean\ ocean}$
  Middle top $2h/4 + H/3 + Z_{mean\ ocean}$
  Middle bottom $h/4 + H/3 + Z_{mean\ ocean}$

- Lower chamber: $2h/4 + Z_{mean\ ocean}$
  Lower top WSB: $2h/4 + Z_{mean\ ocean}$
  Lower bottomWSB: $h/4 + Z_{mean\ ocean}$

With $Z_{mean\ ocean}$ = 0.13 m PLD, Atlantic side

➢ **Lockage from Ocean to Lake (uplockage)**

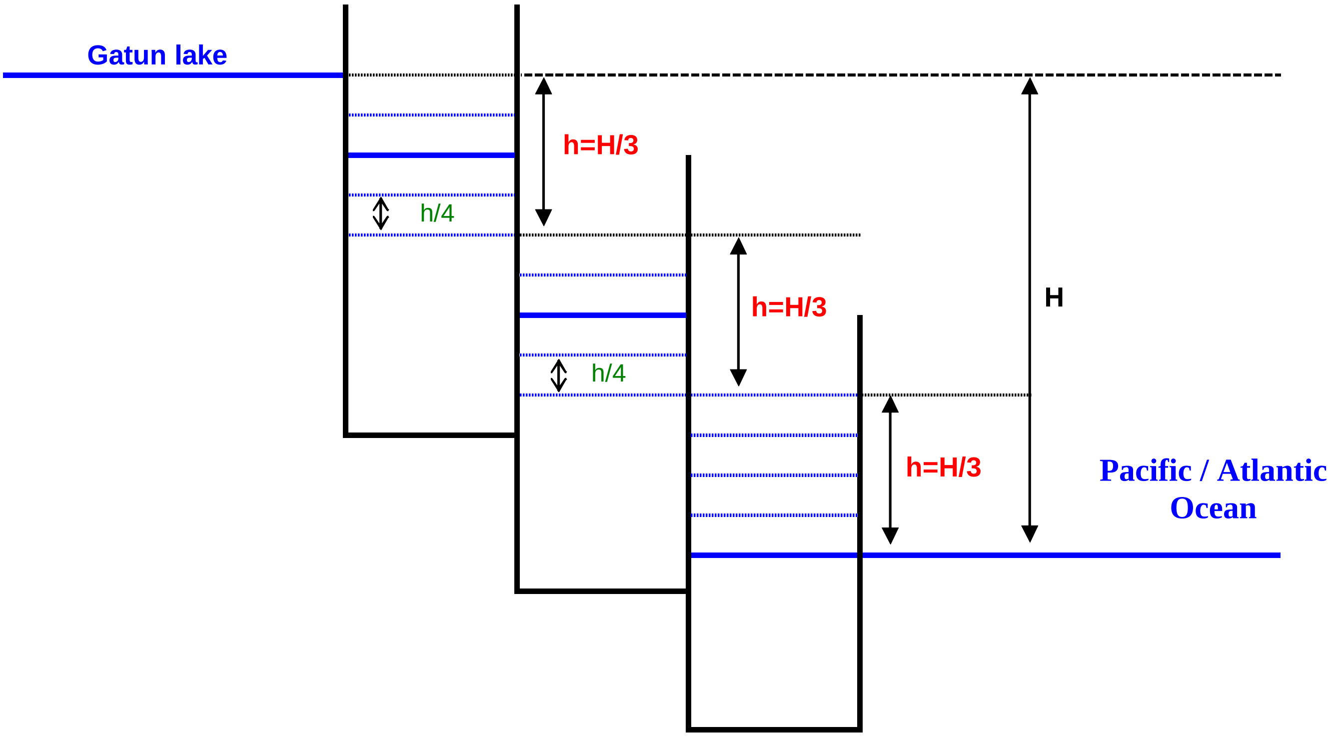


Figure 5.2.2-b

When the simulation starts, the water surface elevations are initialized as below:

- Upper chamber : .... $2h/4 + 2H/3 + Z_{mean\ ocean}$
  Upper-top WSB : .... $3h/4 + 2H/3 + Z_{mean\ ocean}$
  Upper-bottom WSB : . $2h/4 + 2H/3 + Z_{mean\ ocean}$

- Middle chamber : .... $2h/4 + H/3 + Z_{\text{mean ocean}}$
  Middle-top WSB : ..... $3h/4 + H/3 + Z_{\text{mean ocean}}$
  Middle-bottom WSB : $2h/4 + H/3 + Z_{\text{mean ocean}}$

- Lower chamber : .... $Z_{\text{ocean}}(t_0)$
  Lower-top WSB : ...... $3h/4 + Z_{\text{mean ocean}}$
  Lower-bottom WSB : $2h/4 + Z_{\text{mean ocean}}$

With $Z_{\text{mean ocean}} = 0.30$ m PLD

And $Z_{\text{ocean}}(t_0)$ level of Pacific Ocean at the beginning of the cycle

Or

- Upper chamber : .... $2h/4 + 2H/3 + Z_{\text{mean ocean}}$
  Upper WSB : .... $3h/4 + 2H/3 + Z_{\text{mean ocean}}$
  Lower WSB : .... $2h/4 + 2H/3 + Z_{\text{mean ocean}}$

- Middle chamber : .... $2h/4 + H/3 + Z_{\text{mean ocean}}$
  Middle-top WSB : ..... $3h/4 + H/3 + Z_{\text{mean ocean}}$
  Middle-bottom WSB : $2h/4 + H/3 + Z_{\text{mean ocean}}$

- Lower chamber : .... $Z_{\text{ocean}}(t_0)$
  Upper WSB : .... $3h/4 + Z_{\text{mean ocean}}$
  Lower WSB : .... $2h/4 + Z_{\text{mean ocean}}$

With $Z_{\text{mean ocean}} = 0.13$ m PLD

And $Z_{\text{ocean}}(t_0)$ level at Atlantic Ocean at the beginning of the cycle

5.3 DEFINITION OF THE BOTTOM SETTING SCENARIOS

The levels of the chambers and the water saving basins given below have been set according to the two simulations defined hereafter:

- The levels of the bottom floor and top of the chambers have been set using combinations of the following values :
  - Gatun Lake : + 27.13 m PLD ; + 24.99 m PLD
  - Pacific Ocean : ranging from +2.40 m PLD to – 2.32 m PLD
  - Atlantic Ocean : ranging from +0.41 m PLD to – 0.15 m PLD
- The levels of the bottom floors and tops of the water saving basins have been set with the combinations of the following values :
  - Gatun Lake : + 27.13 m PLD ; + 24.99 m PLD
  - Pacific Ocean : ranging from + 3.60 m PLD to – 3.44 m PLD
  - Atlantic Ocean : ranging from +0.41 m PLD to – 0.15 m PLD

- **For this study**, the water saving basins and lock chamber have the same area ($m = 1$),
- **For this study**, the residual filling depth was set to Db = 0.0 m

For the simulation, the initial levels have been calculated using the mean Ocean level values. The scenarios have been tested over a 160 cycles period (1 cycle corresponding to 12 hours of downlockage or 12 hours of uplockage), i.e. the total duration of the simulation represents nearly 80 days.

5.4 RESULTS

5.4.1 LEVELS

The results obtained according to the scenarios defined above for the levels of the upper, middle and lower chambers, and the water saving basins, are presented in the following tables:

Pacific side

Case			Level in m PLD								
Gatun lake level (m PLD)	Ocean amplitude (m PLD)		Upper chamber	Top WSB	Bottom WSB	Middle chamber	Top WSB	Bottom WSB	Lower chamber	Top WSB	Bottom WSB
27.13	[-3.44 ; +3.60]	maxi	27.13	24.95	22.77	18.44	16.29	14.19	10.10	8.17	6.40
		mini	17.78	22.48	20.14	8.08	13.06	10.64	-3.44	2.94	0.01
27.13	[-2.32 ; +2.40]	maxi	27.13	24.92	22.71	18.32	16.13	13.98	9.74	7.71	5.77
		mini	17.88	22.52	20.21	8.40	13.22	10.85	-2.32	3.46	0.74
24.99	[-3.44 ; +3.60]	maxi	24.99	22.98	20.98	17.01	15.04	13.12	9.38	7.64	6.04
		mini	16.36	20.70	18.54	7.37	11.99	9.74	-3.44	2.59	-0.17
24.99	[-2.32 ; +2.40]	maxi	24.99	22.96	20.93	16.89	14.89	12.91	9.03	7.17	5.41
		mini	16.46	20.74	18.60	7.68	12.15	9.96	-2.32	3.10	0.57

Table 5.4.1-a

Atlantic side

Case			Level in m PLD								
Gatun Lake level in m PLD	Atlantic tide range in m PLD		Upper chamber	Top WSB	Bottom WSB	Middle chamber	Top WSB	Bottom WSB	Lower chamber	Top WSB	Bottom WSB
27.13	[-0.15 ; +0.41]	**maxi**	**27.13**	**24.88**	**22.64**	**18.15**	**15.91**	**13.67**	**9.21**	**6.98**	**4.77**
		mini	18.10	22.61	20.36	9.05	13.59	11.32	-0.15	4.51	2.20
24.99	[-0.15 ; +0.41]	maxi	24.99	22.92	20.86	16.73	14.66	12.60	8.49	6.45	4.42
		mini	**16.68**	**20.83**	**18.75**	**8.34**	**12.52**	**10.43**	**-0.15**	**4.15**	**2.02**

Table 5.4.1-b

5.4.2 HEADS

5.4.2.1 Lock to lock operations

The tables below represent the heads obtained after 160 cycles of 12 hours in semi convoy mode (i.e. 80 days simulations), for the lock to lock operations.

Pacific side

lake Gatun	Ocean amplitude		Gatun / upper lock	upper lock / mid lock	mid lock / lower lock	lower lock / ocean
maxi 27.73	max	max	4,65	9,45	10,47	9,07
		min	4,37	8,58	7,55	0,39
	min	max	4,61	9,32	10,00	7,57
		min	4,42	8,74	8,05	1,89
mini 24.99	max	max	4,29	8,74	9,75	8,71
		min	4,01	7,87	6,83	0,03
	min	max	4,25	8,60	9,28	7,22
		min	4,07	8,02	7,34	1,53
synthesis		**maxi**	**4,65**	**9,45**	**10,47**	**9,07**
		mini	**4,01**	**7,87**	**6,83**	**0,03**

Table 5.4.2.1-a

Atlantic side

Gatun lake		Gatun / upper lock	upper lock / mid lock	mid lock / lower lock	lower lock / ocean
maxi 27.73	max	4.52	9.03	9.11	4.85
	min	4.49	8.97	8.88	4.27
mini 24.99	max	4.16	8.32	8.40	4.49
	min	4.13	8.25	8.17	3.92
synthesis	**max**	**4.52**	**9.03**	**9.11**	**4.85**
	min	**4.13**	**8.25**	**8.17**	**3.92**

Table 5.4.2.1-b

It can be clearly seen that at the Atlantic side, the range of heads is much less than at the Pacific side

5.4.2.2 Wsb to lock & lock to wsb operations

Note : the head is defined as the difference of water levels between an upper pool and a lower pool before operating (gravity operations). **By convention**, Flowmaster gives positive values for emptying lock into wsb and negative values for filling locks from wsb, but **real heads are always positive (or as low to 0) :**

Pacific side

Gatun lake	24.99	UPPER LOCK		MIDDLE LOCK		LOWER LOCK		extreme values
Ocean amplitude	min	top WSB	bottom WSB	top WSB	bottom WSB	top WSB	bottom WSB	
filling lock from wsb	max	-4.05	-4.01	-3.86	-3.47	-2.75	-1.52	
	min	-4.27	-4.30	-4.46	-4.76	-5.56	-7.29	
emptying lock into wsb	max	4.25	4.26	4.38	4.40	4.89	5.07	
	min	4.07	4.06	3.93	3.92	3.17	3.10	

Gatun lake	24.99	UPPER LOCK		MIDDLE LOCK		LOWER LOCK		
Ocean amplitude	max	top WSB	bottom WSB	top WSB	bottom WSB	top WSB	bottom WSB	
filling lock from wsb	max	-3.98	-3.93	-3.70	-3.13	-2.04	-0.02	**-0.02**
	min	-4.32	-4.37	-4.60	-5.08	-6.24	-8.84	
emptying lock into wsb	max	4.29	4.31	4.48	4.51	5.32	5.58	
	min	4.01	4.00	3.80	3.79	2.64	2.56	**2.56**

Gatun lake	27.13	UPPER LOCK		MIDDLE LOCK		LOWER LOCK	
Ocean amplitude	min	top WSB	bottom WSB	top WSB	bottom WSB	top WSB	bottom WSB
filling lock from wsb	max	-4.40	-4.37	-4.21	-3.82	-3.11	-1.88
	min	-4.63	-4.66	-4.81	-5.12	-5.92	-7.65
emptying lock into wsb	max	4.61	4.62	4.74	4.76	5.25	5.43
	min	4.42	4.41	4.29	4.28	3.52	3.46

Gatun lake	27.13	UPPER LOCK		MIDDLE LOCK		LOWER LOCK		
Ocean amplitude	max	top WSB	bottom WSB	top WSB	bottom WSB	top WSB	bottom WSB	
filling lock from wsb	max	-4.34	-4.29	-4.05	-3.49	-2.40	-0.37	
	min	-4.68	-4.72	-4.95	-5.44	-6.60	-9.19	**-9.19**
emptying lock into wsb	max	4.65	4.66	4.83	4.87	5.68	5.94	**5.94**
	min	4.37	4.36	4.16	4.15	3.00	2.92	

Table 5.4.2.2-a

Atlantic side

Gatun lake 24.99 m PLD		UPPER LOCK		MIDDLE LOCK		LOWER LOCK		extreme values
		top WSB	bottom WSB	top WSB	bottom WSB	top WSB	bottom WSB	
filling lock from wsb	max	-4.13	-4.13	-4.11	-4.07	-3.98	-3.89	-3.89
	min	-4.16	-4.16	-4.18	-4.22	-4.31	-4.51	
emptying lock into wsb	max	4.16	4.16	4.16	4.17	4.20	4.24	
	min	4.13	4.13	4.10	4.11	4.00	4.00	4.00

Gatun lake 27.13 m PLD		UPPER LOCK		MIDDLE LOCK		LOWER LOCK		
		top WSB	bottom WSB	top WSB	bottom WSB	top WSB	bottom WSB	
filling lock from wsb	max	-4.49	-4.48	-4.46	-4.43	-4.34	-4.25	
	min	-4.51	-4.52	-4.54	-4.58	-4.66	-4.86	-4.86
emptying lock into wsb	max	4.52	4.51	4.52	4.52	4.56	4.60	4.60
	min	4.49	4.49	4.46	4.47	4.36	4.36	

Table 5.4.2.2-b

The same remark can be made for the water saving basins: the range of heads is once again much less for the Atlantic side than for the Pacific side

5.4.2.3 Comparison Pacific heads vs. Atlantic heads

Annexes 3 and 9 show the head distribution for various operations, lock to lock, wsb to lock and lock to wsb, for both sides. These annexes confirm the observation made in §§ 5.4.2.1 & 5.4.2.2: the variation in head is relatively small at the Atlantic side, and the actual height of the heads themselves is smaller than at the Pacific side.

Another remark: at the Atlantic side, heads are always largely positive :

- Lock to lock operations : 3.92 m to 9.11 m
- Water saving basin to lock operations : 3.89 m to 4.86 m
- Lock to water saving basin operations : 4.00 m to 4.60 m

At the Pacific side on the contrary the heads can be as low as 0, either in lock to lock operation as in WSB to lock operation.

Consequently the Atlantic locks can be operated in an easier way than the Pacific locks, and the expected hawser forces will be lower.

5.4.2.4 Comparison 3 WSB vs. 2 WSB

The following tables show the head differences obtained for the Pacific and the Atlantic side locks.

- Lock to lock operations

PACIFIC SIDE		**3 WSB**			
		Gatun / upper lock	upper lock / middle ock	middle lock / lower lock	lower lock / ocean
synthesis	**mini**	**3,26**	**6,43**	**5,73**	**0**
	maxi	**3,66**	**7,46**	**8,09**	**8,28**

2 WSB			
Gatun / upper lock	upper lock / middle ock	middle lock / lower lock	lower lock / ocean
4,01	**7,87**	**6,83**	**0,03**
4,65	**9,45**	**10,47**	**9,07**

ATLANTIC SIDE		**3 WSB**			
		Gatun / upper lock	upper lock / middle ock	middle lock / lower lock	lower lock / ocean
synthesis	**mini**	**3,31**	**6,61**	**6,56**	**3,09**
	maxi	**3,61**	**7,22**	**7,27**	**3,97**

2 WSB			
Gatun / upper lock	upper lock / middle ock	middle lock / lower lock	lower lock / ocean
4,13	**8,25**	**8,17**	**3,92**
4,52	**9,03**	**9,11**	**4,85**

Table 5.4.2.4-a

- WSB operations

		PACIFIC SIDE		ATLANTIC SIDE	
		3WSB	2 WSB	3WSB	2 WSB
filling lock from wsb	max	0.00	-0.02	-3.06	-3.89
	min	-8.38	-9.19	-3.98	-4.86
emptying lock into wsb	max	5.01	5.94	3.71	4.60
	min	0.06	2.56	3.20	4.00

Table 5.4.2.4-b

Consequently the options of 2 WSB has higher heads for lock to lock and WSB to lock operations than with 3 WSB, this would normally result in higher hawser forces. In fact, operating times have been increased in the 2 WSB configuration, leading to flows of the same magnitude. Consequently hawser forces will be of the same order of magnitude (see further section 10)

6 Water saving rate

6.1 SOFTWARE CALCULATIONS

The total head between the Gatun Lake level and the ocean varies in relation to the ocean tides. Specific calculations are made by the software to assess the water usage (volume of water taken from the Gatun Lake) and the water saving rate for each lockage.

- Water usage

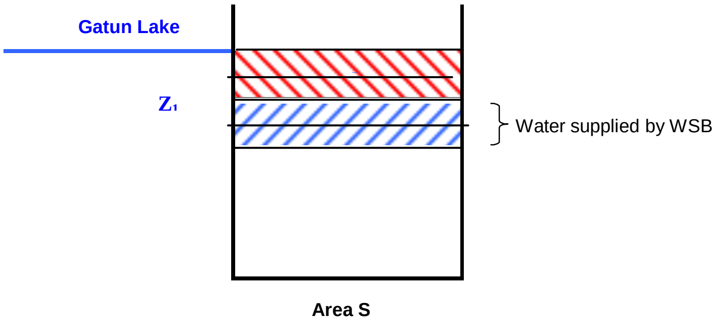


Figure 6.1-a

Let Z_1 be the water level in the upper lock at the end of the WSB-to-lock chamber operations. The software calculates the volume taken from the lake by:

$$V_{lake} = (Z_{lake} - Z_1) * S$$

This volume is calculated for each filling operation of the lock.

- Water saving rate

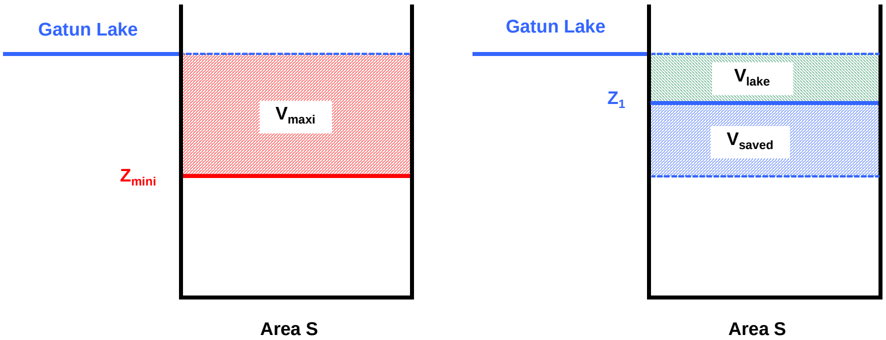


Figure 6.1-b

Let Z_{mini} be the water level in the upper lock at the beginning of the filling operation. Without any water saving basin, the volume of water required to fill the lock chamber would be equal to:

$$V_{\max i} = (Z_{lake} - Z_{\min i}) * S$$

The water saving basins allow tosave a volume equal to:

$$V_{saved} = (Z_1 - Z_{\min i}) * S$$

The water saving rate is then calculated by the relation:

$$e = \frac{V_{saved}}{V_{\max i}}$$

The water saving rate is calculated for each filling of the lock and at the end of the simulation. The final water saving rate is calculated by:

$$E = \frac{\sum V_{saved}}{\sum V_{\max i}}$$

The results achieved with the software are coherent with the theoretical ones: the triple lift lock system equipped with 6 water saving basins returns a good water saving rate (real value of 82.18 % at the Pacific side and 82.35 % at the Atlantic side, which is very near to the theoretical value of 83.33 %).
Note : the theoretical value of 83.33 % is obtained when sailing always in the same direction : Ocean to Lake or Lake to Ocean.

6.2 RECOMMENDATIONS

The initial chamber and water saving basin bottom levels and wall elevations, the number of possible transits, and the water usage calculations are established with the actual hypothesis and data introduced in the software developed by the consultant CPP. These results are still applicable and are not affected by the final filling and emptying times resulting from the Flowmaster^{TM} hydraulic analysis and the final design operating times.

7 Filling and emptying systems

General criteria

The hydraulic system is a triple lift lock with side wall culverts extending over the full lock length, side wall ports discharging directly in the lock chambers, and 2 water saving basins per lock chamber.

8 Hydraulic design of the filling / emptying system

8.1 SOFTWARE AND METHODS USED IN THE STUDY

The emptying/filling system has been studied using FLOWMASTER 2 software, a Trade Mark of Flowmaster Holding BV. A description of this tool has been given in the report of the first configuration of the conceptual design study.

8.2 SOFTWARE CALIBRATION

The calibration of the software was based on the physical model study of the Panama Canal locks performed in 1942. (see annex 3.4 of the first configuration report).

The Flowmaster model gave acceptable results, since the flow rate difference was found to be less than 10 %. All documents concerning this test and two other ones are given in annex 3.4 of the first configuration report.

8.3 HYDRAULIC DESIGN

The filling/emptying system is identical to the Pacific & Atlantic systems previously studied. The longitudinal culverts are used to fill and empty the locks. It has been demonstrated for the first configuration that this system was to be preferred because:

- Of its ability to provide a good distribution of the flow;
- Of its reliability (redundancy in the event of valve failure);
- Construction of an expensive concrete bottom floor can be avoided

8.3.1 SIZE OF CULVERTS, CONDUITS AND PORTS

For this alternative design of a triple lift lock system with 3x2 water saving basins it was found that the same culvert and conduit dimensions could be maintained as those which were identified for the 3x3 wsb system.

It is reminded that the main difference between the Pacific and Atlantic sides concerns the low variations in Atlantic Ocean levels. As a result, the former chapters have shown that this low tidal variation at the Atlantic side leads to relatively low level variations in each chamber or WSB. On the contrary, at the Pacific side the variations increased considerably between the upstream lock and the downstream one (including the corresponding WSBs). At the Atlantic side again, the heads between the different pools are similar in height, whichever pool is considered.

The hydraulic design leads to the following dimensions:

	Shape	Size (WxH)	Section	Quantity	Total section
Side-wall culverts	rectangular	9.00m x 6m	54m²	2	108m²
Valves	rectangular	4.5m x 6m	27m²	4(2 per culvert)	108m²
WSB-to-lock conduit	rectangular	Pacific side 4.5 x 6.0m Atlantic side 4.0 x 5.0m	Pacific side 27m² Atlantic side 20m²	4 per basin	Pacific side 108m² Atlantic side 80m²
WSB valves	rectangular	Pacific side 4.5 x 6.0m Atlantic side 4.0 x 5.0m	Pacific side 27 m2 Atlantic side 20 m2	4 per basin	Pacific side 108m² Atlantic side 80m²
Ports	rectangular	2m x 2m	4m²	40 (20 per lock side)	160 m²

Table 8.3.1-a

As far as the water saving basins are concerned, the number of conduits, the section and the total section of the conduits and ports is to be considered for each of the two water saving basins.

8.3.2 FLOWMASTER MODEL PARAMETERS

The same model parameters as in the Pacific side study have been retained for this solution. The main information concerning the most important components are given hereafter:

- **Culvert and conduit**: the culvert and conduit size are given above; the absolute roughness of the inner surface is 0.025 mm, which corresponds to the absolute roughness of a smooth concrete pipe (cf. Internal Flow System from D.S. Miller).

- **Valve**: the valves used in the model are gate valves with a section equal to that of the culverts.

- **Discrete loss**: to take into account the kinetic energy dispersal in every chamber (or component assimilated to a chamber), discrete losses have been introduced downstream the ports with a loss coefficient of 1. The reverse flow coefficient is taken equal to 0.5.

- **T-junctions**: T-junctions are used to model the ports. Loss coefficients in T-junctions are automatically set depending on the two branch flow and area ratios. The calibration of those components demonstrated that they are suitable to model the ports.

8.4 FILLING AND EMPTYING TIMES

8.4.1 ELEMENTARY OPERATIONS

About 30 simulations of the Pacific side and 20 of the Atlantic side have been run with Flowmaster™ in order to estimate the filling and emptying times, the flow rate and highest average velocities in the culverts. The simulations take into account the variations of Gatun Lake and Atlantic Ocean levels.

According to the terms of reference, the simulations have been performed for lock operation using water saving basins. Not using the wsb is a debase operation and will be examined in further studies.

The tables below give an overview of the filling and emptying times for a lockage using the water saving basins. These tables take into account the levels calculated by the CPP software: minimum and maximum head that can be reached between the Lake or Ocean and the lock chambers or between a water saving basin and a lock chamber, either during filling or emptying phases.

In the majority of cases, the filling and emptying times have been determined for a valve opening time of 2 min (either for Lake or Ocean-to-lock chamber or water saving basins-to-lock chamber operations). In all cases it was possible to fulfill the design criteria, excepted for the worst case at the Pacific side (lower lock emptying). Some additional runs were made to determine the extend of this phenomenon (see table 8.4.1-b and also Annex 3). As this case is relatively rare and above all represents one operation among many others in a full cycle of F/E operations, the daily performance of the system will not be affected.

The maximum global time has to be calculated by considering the worst case: highest head between the downstream lock and the Ocean. The heads between the WSB and the locks are then given by the CPP software.

Pacific side

Operation	Head (m)	Valve opening (s)	Time (s) (mn s)	Highest average velocity (m/s)	
				culverts	Port
Upper lock filling	4.70 max head	120 (2 mn)	310 (5 mn 10 s)	5.6	5.6
	4.00 min head	120 (2 mn)	290 (4 mn 50 s)	5.0	5.0
Lock to lock operation Middle to lower	10.50 max head	180 (3 mn)	325 (5 mn 25s)	5.9	7.0
	6.80 min head	120 (2 mn)	250 (4 mn 10 s)	4.9	5.9
Lower lock emptying	9.10 max head	480 (8 mn)	**575 (9 mn 35 s)**		6.9
	0.00 min head	/	/	/	/
Filling of lower bottom wsb	5.90 max head	120 (2 mn)	195 (3 mn 15 s)	5.7	4.1
	2.60 min head	120 (2 mn)	155 (2 mn 35 s)	3.2	2.3
Emptying of lower bottom wsb	9.20 max head	120 (2 mn)	255 (4 mn 15 s)	6.9	5.2
	0.00 min head	/	/	/	/

Table 8.4.1-a

Pacific side – additional runs

Operation	Head (m)	Occurrence (%)	Valve opening time (s) (mn)	operating time (s) (mn)	Highest mean velocity (m/s)	
					Culvert	Port
Lower chamber emptying	7.40	95%	360 (6 mn)	**485 (8 mn 5 s)**	5.7	6.8
	7.00	90%	360 (6 mn)	**470 (7 mn 50 s)**	5.5	6.5
	6.75	85%	300 (5 mn)	**440 (7 mn 20 s)**	5.7	6.8
	6.50	80%	300 (5 mn)	**430 (7 mn 10 s)**	5.6	6.6
	4.50	50%	180 (3 mn)	**320 (5 mn 20 s)**	5.0	6.0

Table 8.4.1-b

Atlantic side

Operation	Head (m)	Valve opening time (s) (mn)	Operating time (s) (mn)	Highest mean velocity (m/s)	
				Culvert	Port
Upper lock filling	4.50 max head	120 (2 mn)	310 (5 mn 10 s)	5.4	5.5
	4.10 min head	120 (2 mn)	295 (4 mn 55 s)	5.1	5.1
Lock to lock operation Middle to lower	9.10 max head	120 (2 mn)	285 (4 mn 45 s)	5.9	7.0
	8.20 min head	120 (2 mn)	270 (4 mn 30 s)	5.5	6.6
Lower lock emptying	4.90 max head	120 (2 mn)	305 (5 mn 5 s)	5.8	7.0
	3.90 min head	120 (2 mn)	280 (4 mn 40 s)	5.0	6.1
Filling of lower Bottom wsb	4.60 max head	120 (2 mn)	215 (3 mn 35 s)	5.5	3.0
	4.00 min head	120 (2 mn)	205 (3 mn 25 s)	5.0	2.7
Emptying of lower Bottom wsb	4.90 max head	120 (2 mn)	240 (4 mn)	5.2	3.0
	3.90 min head	120 (2 mn)	220 (3 mn 40 s)	4.5	2.5

Table 8.4.1-c

For all those simulations, both sides, the highest mean velocities in culverts and ports do not exceed 7 m/s, there is consequently no erosion risk to the culverts and ports. As Flowmaster only gives average velocities for each section, it will be necessary to verify on the scale model that this velocity isn't exceeded in some critical flowing sections.

When comparing Atlantic side to the Pacific side, all valves can be opened within 2 minutes without generating unacceptable velocities through the ports.

8.4.2 GLOBAL HYDRAULIC DURATION OF A COMPLETE LOCKAGE OPERATION BETWEEN GATUN LAKE AND THE OCEAN

During a complete lockage cycle, some elementary operations happen simultaneously : for instance, emptying the Upper lock into the Middle lock takes place at the same time as the emptying of the Lower lock into the Ocean. The purpose of table 8.4.2-a is to show the sequence of the longest simultaneous elementary operations, in order to calculate the full lockage time.

In the graph below, the heads are represented. The red line is a kind of critical path representing the longest time of the cycle, i.e. the real one. There are relationships between heads and times. The table 8.4.2-b is the result of the transformation of the heads into times (for example a head of 4.50 m in table 8.4.2-a leads to a 175 '' operating time in table 8.4.2-b)

time (mn)	Total time (mn)	Ocean level (m PLD)	Head Lake/Upper lock	Head Upper lock/Upper top WSB	Head Upper lock/Upper bottom WSB	Head Upper lock/Middle lock	Head Middle lock/Middle top WSB	Head Middle lock/Middle bottom WSB	Head Middle lock/Lower lock	Head Lower lock/Lower top WSB	Head Lower lock/Lower bottom WSB	Head Lower lock/Ocean
	46048	-0.903										
5	46053	-1.044										
20	46073	-1.584										
5	46078	-1.713										
5	46083	-1.838		4.50								
5	46088	-1.960			4.48							
6	46094	-2.101				9.04						
5	46099	-2.215										
12	46111	-2.471										
5	46116	-2.570										
5	46121	-2.664					4.29					
5	46121	-2.664			-4.52							
5	46126	-2.754						4.18				
5	46126	-2.754		-4.50								
6	46132	-2.855							9.30			
6	46132	-2.855	4.50									
5	46137	-2.934										
5	46137	-2.934										
12	46149	-3.100										
12	46149	-3.100										
5	46154	-3.160										
5	46154	-3.160										
5	46159	-3.214		4.50								
5	46159	-3.214						-4.65				
5	46159	-3.214								3.29		
5	46164	-3.263			4.50							
5	46164	-3.263					-4.41					
5	46164	-3.263									3.69	
6	46170	-3.313				8.86						
6	46170	-3.313										9.07
5	46175	-3.349										
5	46175	-3.349										
12	46187	-3.409										

Table 8.4.2-a

In the example given above, emptying the Lower lock into the Ocean takes longer than emptying the Upper lock into the Middle lock because, firstly the head of 9.07 m is greater than 8.86 m, secondly emptying the Lower lock into the Ocean takes longer than a lock to lock operation (the level of the Ocean does not vary during emptying)

On top of the requested times for each elementary operation, some additional time is needed to close the culvert valves, even though a part of it can be reduced during the filling or emptying phase.

In table 8.4.2-b below, an average time of 10” (calculated on some simulations with anticipated valve closures) has been added to the duration of the elementary wsb operations. As for the previous study, an additional time of 5’’has been taken into account due to the reduction in port size that allows to reduce the hawser forces.

Operation retained	Head (m)	estimated time (s)	Anticipated closure (s)	Ports (s)	Total cycle time (s)	Total cycle time (min)
Filling upper top wsb	4.50	175	+10 "	+ 5 "		
Filling upper bottom wsb	4.48	175	+10 "	+ 5 "		
upper lock / middle lock	9.04	300		+ 5 "		
Filling middle top wsb	4.29	170	+10 "	+ 5 "		
Filling middle bottom wsb	4.18	170	+10 "	+ 5 "		
Middle lock / lower lock	9.30	305		+ 5 "		

Filling upper top wsb	4.50	175	+10 "	+ 5 "		
Filling upper bottom wsb	4.50	175	+10 "	+ 5 "		
Lower lock / Ocean	9.07	560		+ 5 "		
		2205	60	45	2310	38 ' 30''

Table 8.4.2-b

The global cycle time (obtained for the worse case – maximum heads) is about 38'30''; compared to the target time of 51', which allows to increase the valve opening times and some elementary operations if required to reduce the hawser forces.

Note :

Anticipated closure of WSB valves leads to small additional time because of the reduction in flows when the valve is partly closed : the point where upper pool and lower pool meet is further on the time axis (see also explanation in section 5.2). For anticipated closure of culvert valves, see 5.2.1

8.4.3 DETAILED RESULTS

The graphs representing the flow rate and the water surface elevation in the lock chamber are given in annexes 4 to 7 for the Pacific side and 10 to 13 for the Atlantic side.

For both Pacific side and Atlantic side, the flow distributions through the ports are mainly of **3 types:**

Type 1: flows in the ports when filling or emptying the WSB. The graphs show the same magnitude of gap between the first and last ports, which is low and won't generate huge hawsers forces.

See annexes 6 and 7 for the Pacific side, 12 and 13 for the Atlantic side

Type 2: flows in the ports when emptying a lock. The head are of the same magnitude, Pacific side or Atlantic side (9.00 m to 10.50 m). The graphs show the same unbalanced distribution in the ports, due to the connection of the longitudinal culverts at their upstream extremity: the flow discharge through the 20th port starts earlier and is larger than in the 1st one.

See annexes 4 for the Pacific side and 10 for the Atlantic side.

Type 3: flows in the ports when filling a lock. The results are very similar, Pacific side or Atlantic side. In this case, the 1st port flow discharge starts earlier and more than the 20th one in the first stage, but the flow distribution reverses in the 2nd stage, resulting in a non balanced distribution.

See annexes 5 for the Pacific side and 11 for the Atlantic side.

9 Cavitation and air demand

Cavitational spreading is examined for the regular operation (i.e. with the water saving basins), in accordance with the TOR.

- *Lock to lock*

As the head between two chambers or between the Gatun Lake and the upper lock is always less than 10.50 m at the Pacific side and less than 9.20 m at the Atlantic side, and the minimum water height in the chamber is 18.3 m (Head < h), cavitation cannot occur.

Due to the great depth of the valves relatively to the water levels in the pools, the pressure on the valve remains much higher than the vapor pressure, which guarantees that cavitation will not occur, except maybe in the very first seconds (the Flowmaster™ calculation is not accurate enough in that period to confirm a total absence of cavitation, but the scale model will provide this information).

- *Water saving basins to lock*

As the head between the water saving basins and a chamber is always less than 9.20 m at the Pacific side and less than 4.90 m at the Atlantic side, and the minimum water height in the chamber is 18.3 m (Head < h), cavitation cannot occur.

- *Lock to Ocean*

As the head between the lower lock chamber and the Ocean is always less than 9.10 m at the Pacific side and less than 4.90 m at the Atlantic side, and the minimum water height in the chamber is 18.3 m (Head < h), cavitation cannot occur.

General remark :

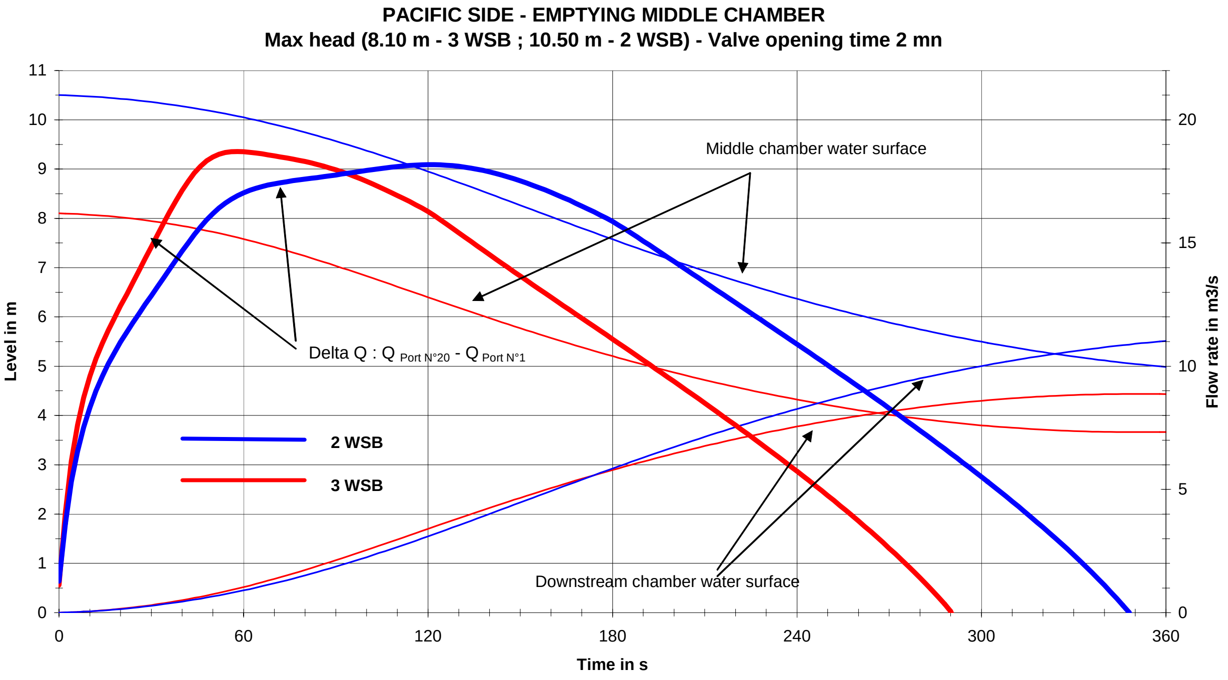
The increase of water depth in the lock chamber to 18.3m reduces the probability of cavitation occurrence (the deeper the valves and the higher the remaining water height in the lock, the more reduced is the risk of cavitation on the valves).

10 Hawser Forces

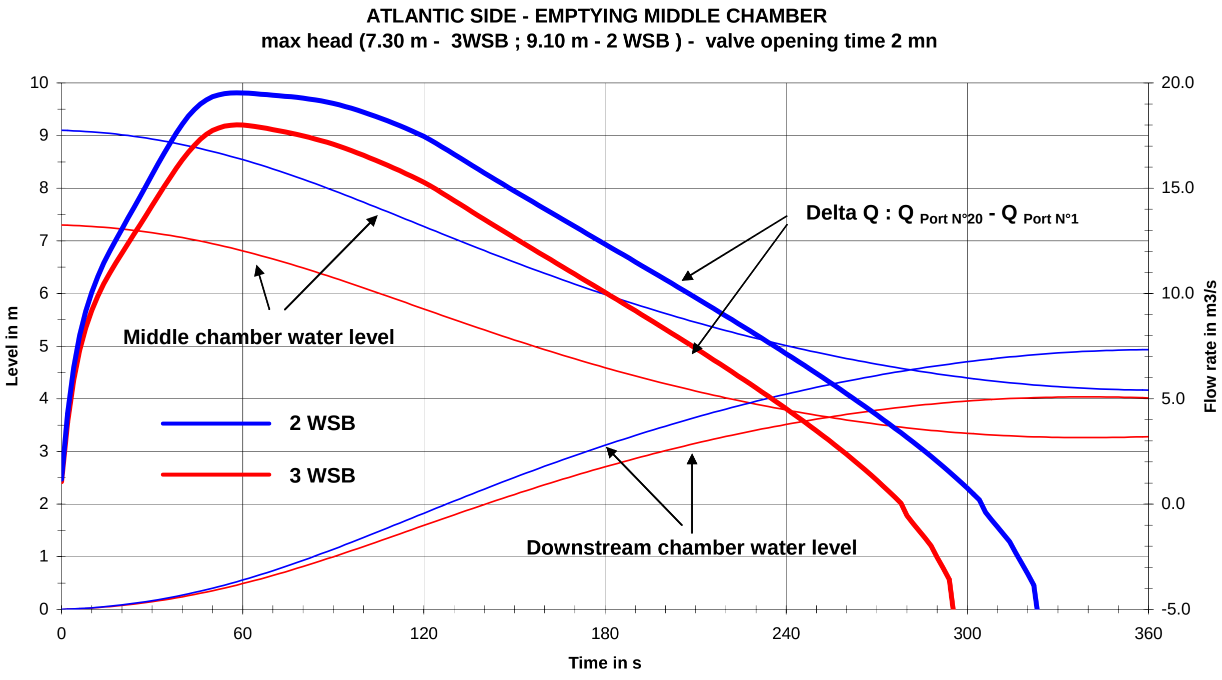
As shown in a previous report –Pacific side Actualization -, the three basic ways to reduce the hawser forces, mainly by reducing the differences of discharges rates through the ports, are:

- Unsteady stage: by modifying the opening diagram of the valve. Opening the valve more slowly means that each port starts discharging faster and the upstream ones reach their normal speed earlier.
- Quasi-steady stage: by reducing the efficient area of the ports that have the higher discharge, thus improving the balance of the discharge.
- Concentrating the ports closer to the “center of gravity” of the lock chamber: it has already been shown by means of physical model testing (CNR’s Avignon lock) that this leads to a reduction in hawser forces. This is particularly valid for the 3rd lane of Post Panamax locks, in the normal operation mode of the lockage of single large vessels..

The following graphs show the discharge differences between extreme ports, for both sides, and for the extreme head values, in the case of 3 WSB and 2 WSB configurations, and on the Pacific and Atlantic side respectively.



Graph 10 - a



Graph 10 - b

At the Pacific side, the discharge differences are nearly identical, 18 to 18.5 m3/s, consequently the hawser forces remain similar.

At the Atlantic side, the discharge difference between the extreme ports increases a little, from 18 m3/s to 19.5 m3/s, i.e. + 8 %. However, it can be considered that hawser forces will remain within the same order of magnitude.

A comparison of the 2 WSB configuration and the former 3 WSB configuration on Pacific and Atlantic sides shows that **the discharge differences between the extreme ports** accurately reflect hawser forces, as was demonstrated in the Pacific side actualization report and **are of the same order of magnitude.**

Consequently, if a two WSB configuration is retained, the same methods to reduce hawser forces as those proposed for the three WSB configuration can be applied during further studies.

11 Flows between the gates

Reference is made to the report of the actualization and harmonization study. Additional emptying/filling times would be very similar.

12 Conclusion and recommendations

With the alternative concept design of a **triple lift lock system with two water saving basins per lock chamber** it has been confirmed that the filling and emptying system, with some minor geometrical modifications, is perfectly suitable for both Pacific and Atlantic sides, and complies with all the design criteria and guidelines.

It has been confirmed that the Atlantic side lock system is less penalizing than the Pacific side lock system, due to the lower tidal amplitude. Consequently, the same optimizations explored for the Pacific side (Actualization study of a triple lift lock system with 3 water saving basins) should be taken into consideration during further design phases.

The most convenient way to proceed is to optimize completely the Pacific side lock (with 3 or 2 WSB), by means of more detailed numerical modeling (based upon a combination of Flowmaster™ software, 2D simulation of the water flow in the lock chamber and more refined numerical modeling of the forces and dynamics of vessel positioning system).
Eventually, the Atlantic side (with 3 or 2 WSB) should be optimized and validated by some final Flowmaster™ simulations.

From a hydraulic point of view, the main differences between 3 WSB and 2 WSB configurations are :

- The water usage : nearly 25 % more in the 2 WSB configuration
- The operating cycle time : 50 minutes in the 3 WSB configuration vs. 40 minutes in the 2 WSB configuration
- Heads are increased in the 2 WSB configuration, either in lock to lock operation or in WSB operations

The other parameters (highest mean velocities, flow discharges through the ports, hawser forces, …) remain rather similar.

ANNEXES

PACIFIC SIDE ACTUALIZATION & ATLANTIC SIDE HARMONIZATION CONFIGURATION WITH 2 WATER SAVING BASINS

List of annexes

ATLANTIC SIDE

Annex 8.1 : Atlantic tide levels – Data from the SHOM website

Annex 8.2 : Atlantic tide levels at Colo Colo station

Annex 8.3 : Real & calculated Atlantic tide levels

Annex 9.1 : Lock to lock operations – ordered levels

Annex 9.2 : Wsb to wsb operations – ordered levels

Annex 9.3 : Lock to wsb operations – ordered levels

Annex 10.1 : Emptying middle chamber - Flow distribution between the ports with max head (9.10 m) - Valve opening time 2 mn

Annex 10.2 : Emptying middle chamber - Velocity in the ports with max head (9.10 m) Valve opening time 2 mn

Annex 10.3 : Emptying middle chamber - Evolution of water surface with max fall (9.10 m) Valve opening time 2 mn

Annex 11.1 : Filling lower chamber - Flow distribution between ports with max head (9.10 m) - Valve opening time 2 mn

Annex 11.2 : Filling lower chamber - Velocity in the ports with max head (9.10 m) Valve opening time 2 mn

Annex 11.3 : Filling lower chamber - Evolution of water surface with max head (9.10 m) Valve opening time 2 mn

Annex 12.1 : Emptying WSB - Flow distribution between the ports with max head (4.90 m) Valve opening time 2 mn

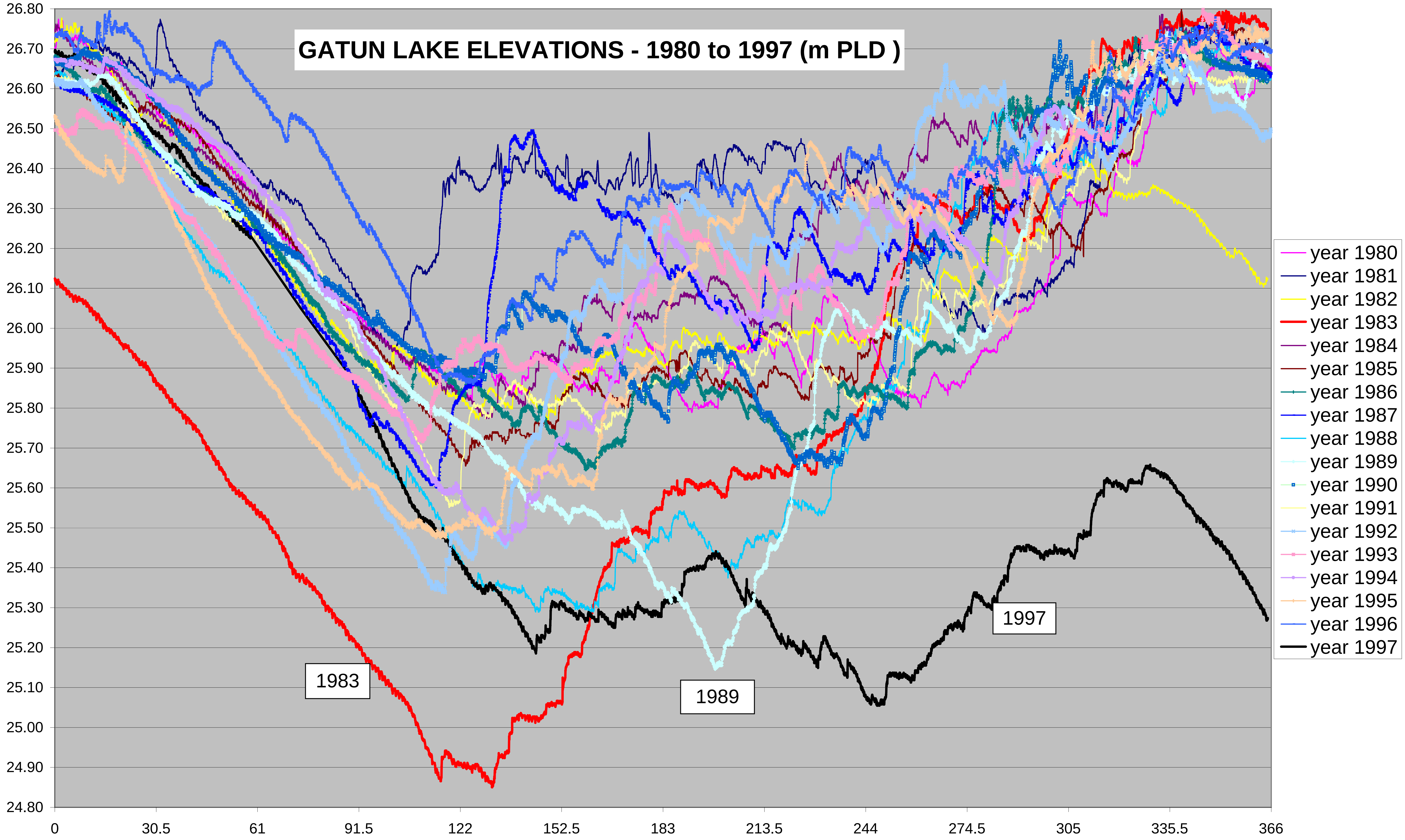
Annex 12.2 : Emptying WSB - Flow distribution between the ports with max head (4.90 m) Valve opening time 2 mn

Annex 12.3 : Emptying WSB - Evolution of water surface with max head (4.90 m) Valve opening time 2 mn

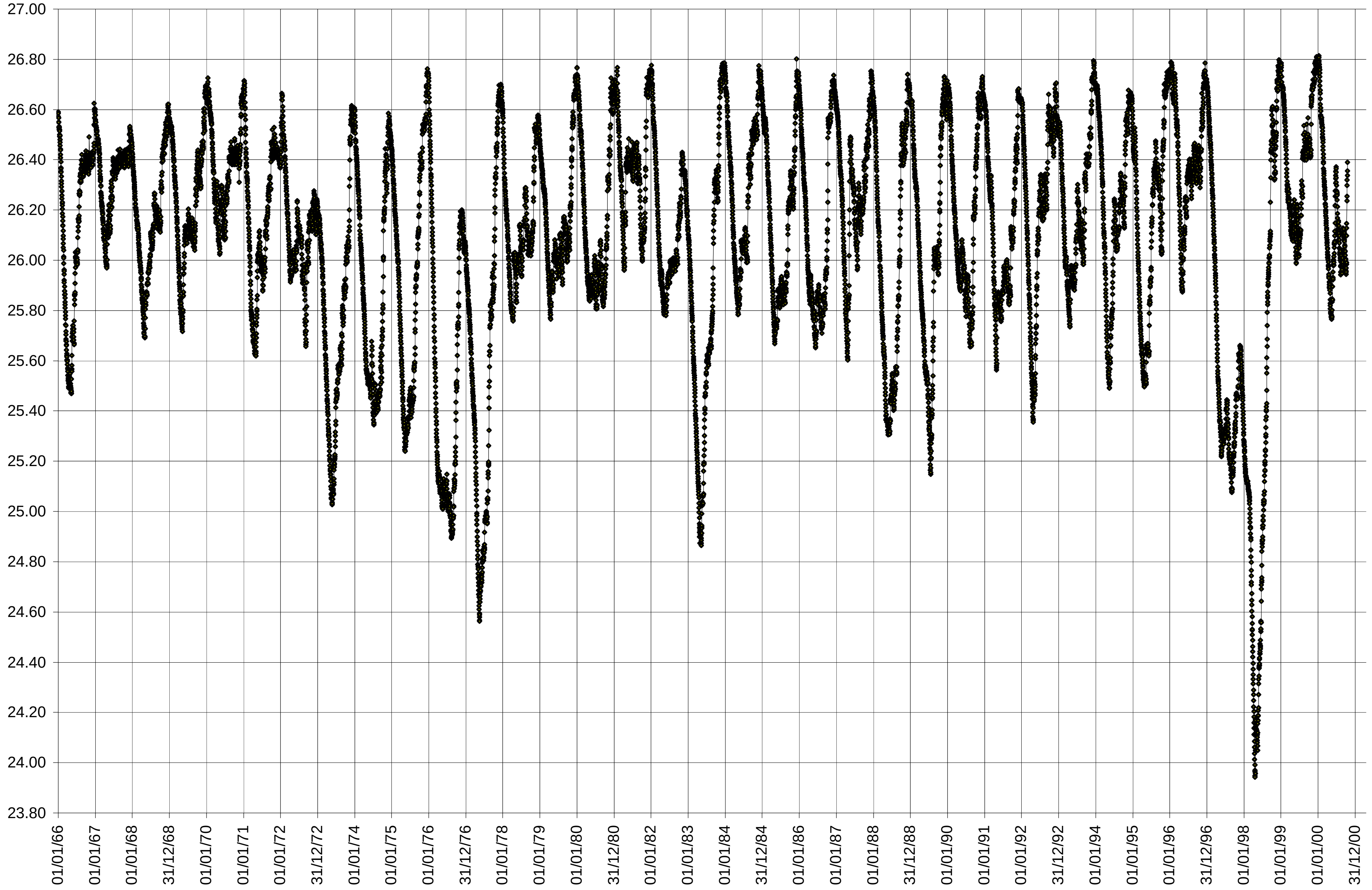
Annex 13.1 : Filling WSB - Flow distribution between the ports with max head (4.60 m) Valve opening time 2 mn

Annex 13.2 : Filling WSB - Flow distribution between the ports with max head (4.60 m) Valve opening time 2 mn

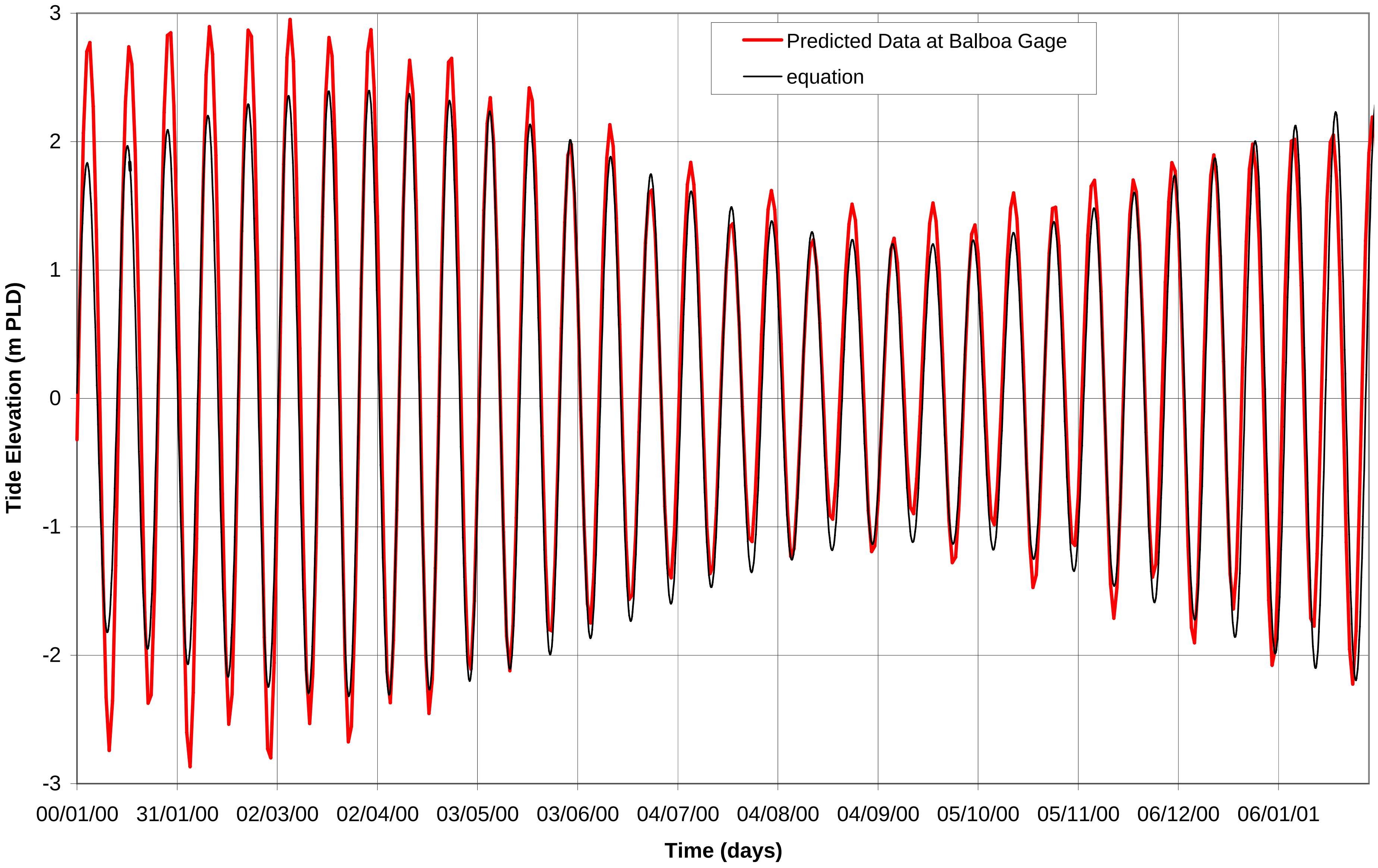
Annex 13.3 : Filling WSB - Evolution of water surface with max head (4.60 m) Valve opening time 2 mn


GATUN LAKE ELEVATIONS - 1980 to 1997 (m PLD)
26.80
26.70
26.60
26.50
26.40
26.30
26.20
26.10
26.00
25.90
25.80
25.70
25.60
25.50
25.40
25.30
25.20
25.10
25.00
24.90
24.80
0
30.5
61
91.5
122
152.5
183
213.5
244
274.5
305
335.5
366
1983
1989
1997
year 1980
year 1981
year 1982
year 1983
year 1984
year 1985
year 1986
year 1987
year 1988
year 1989
year 1990
year 1991
year 1992
year 1993
year 1994
year 1995
year 1996
year 1997

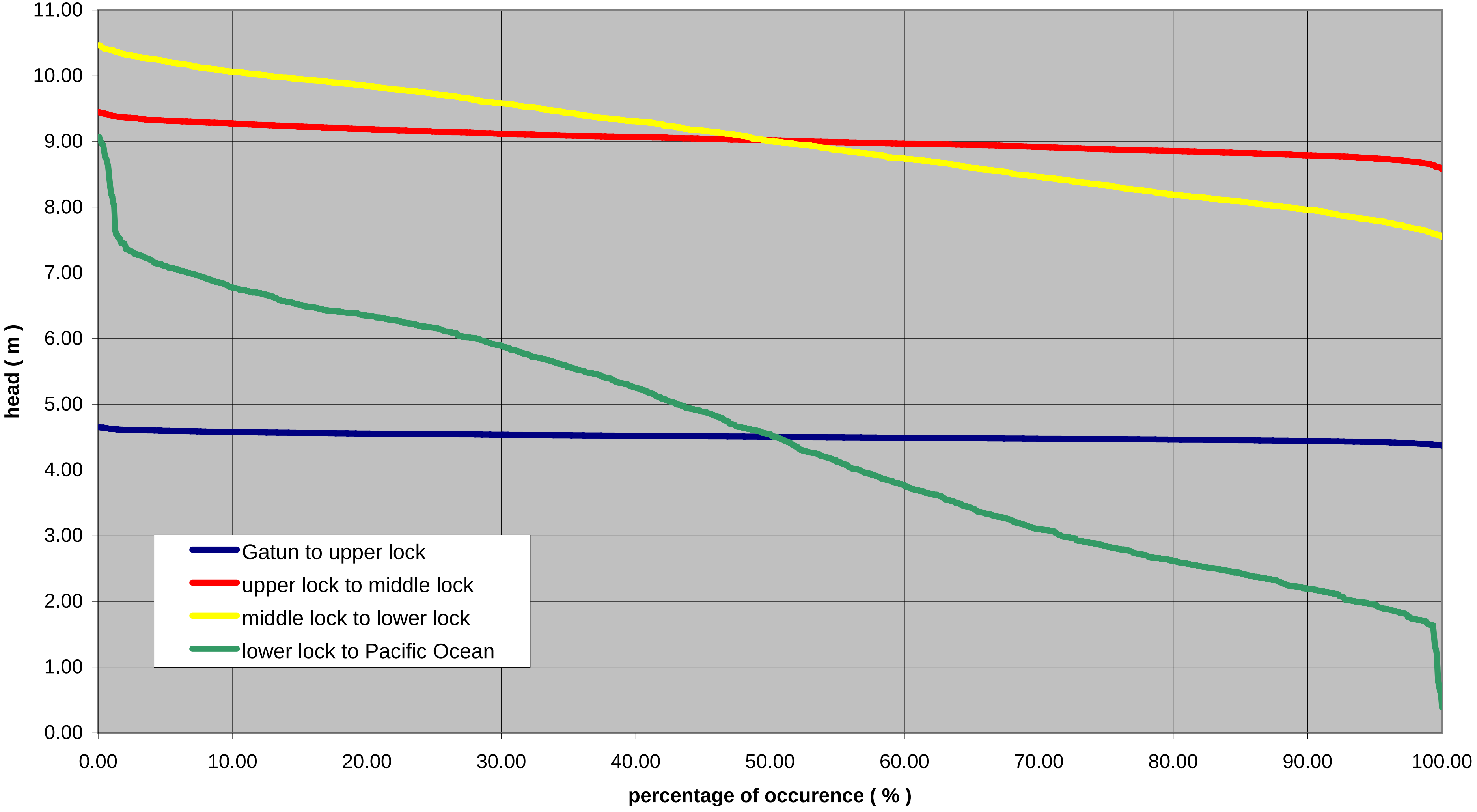
Gatun lake elevations (meters above PLD) - 1966 / 2000



Measured Vs. calculated Tide Data - Pacific Ocean Side
MLWS

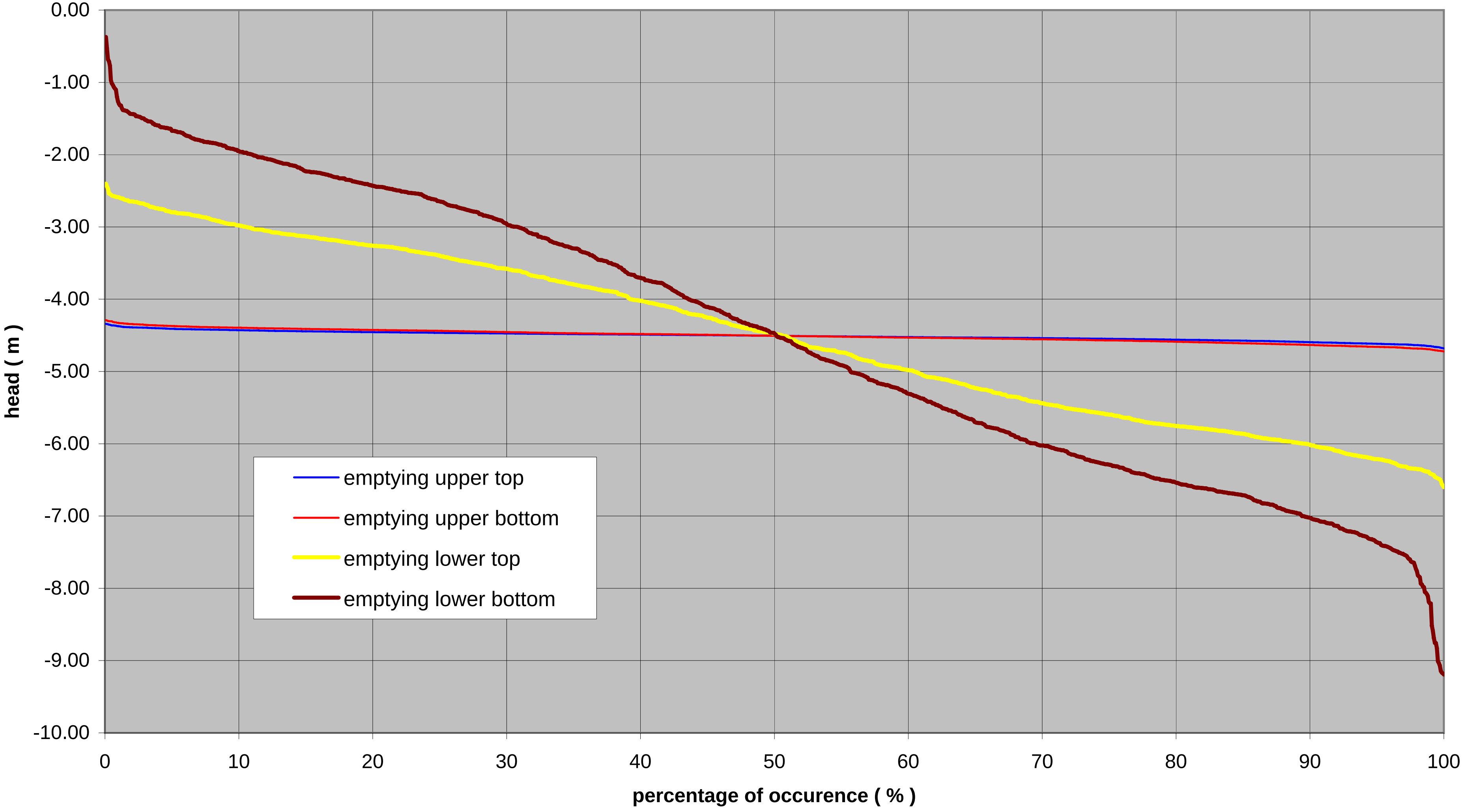


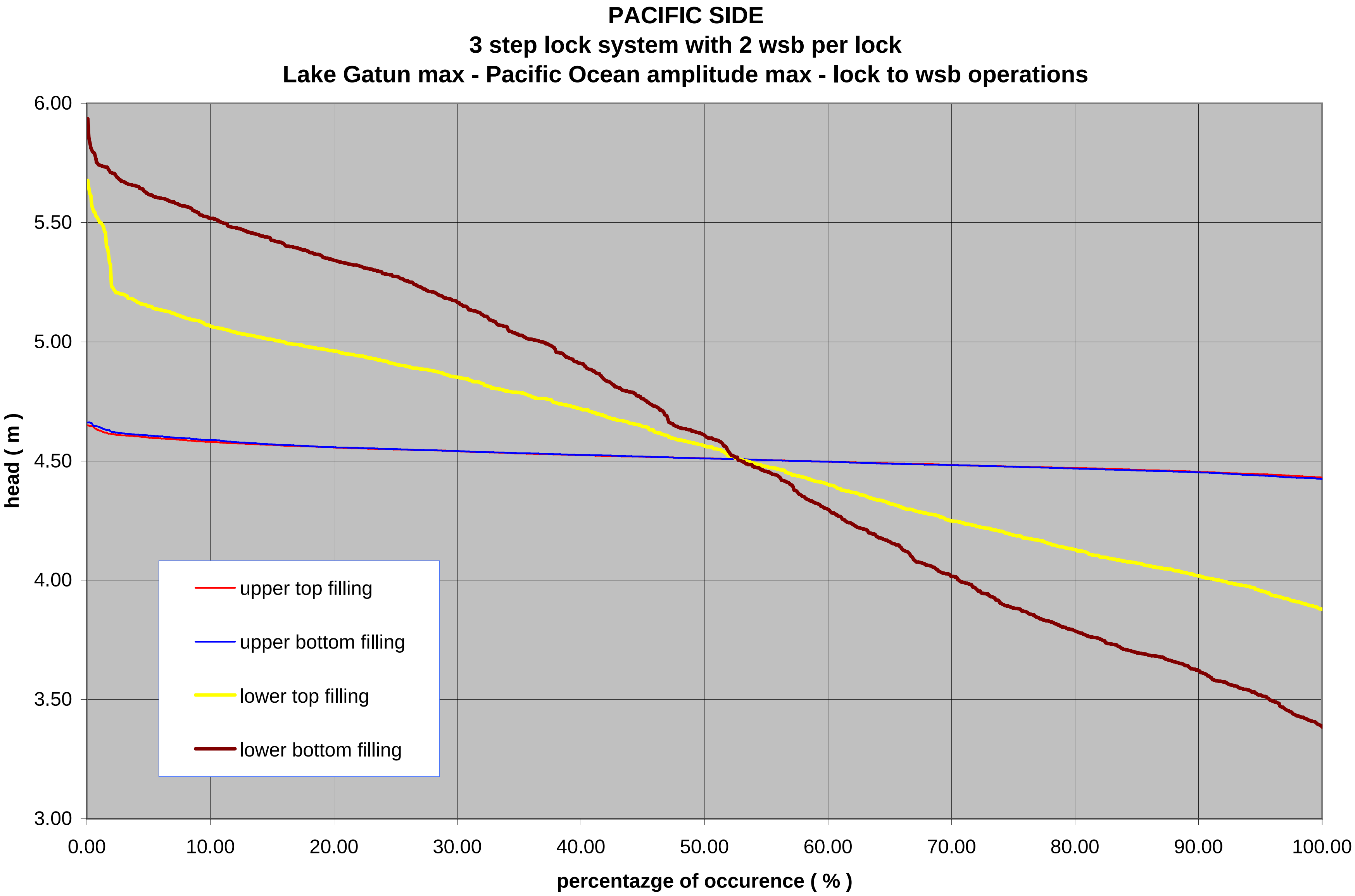
PACIFIC SIDE
3 lift lock system with 2 wsb per lock
Gatun max - Pacific ocean amplitude max - lock to lock operations



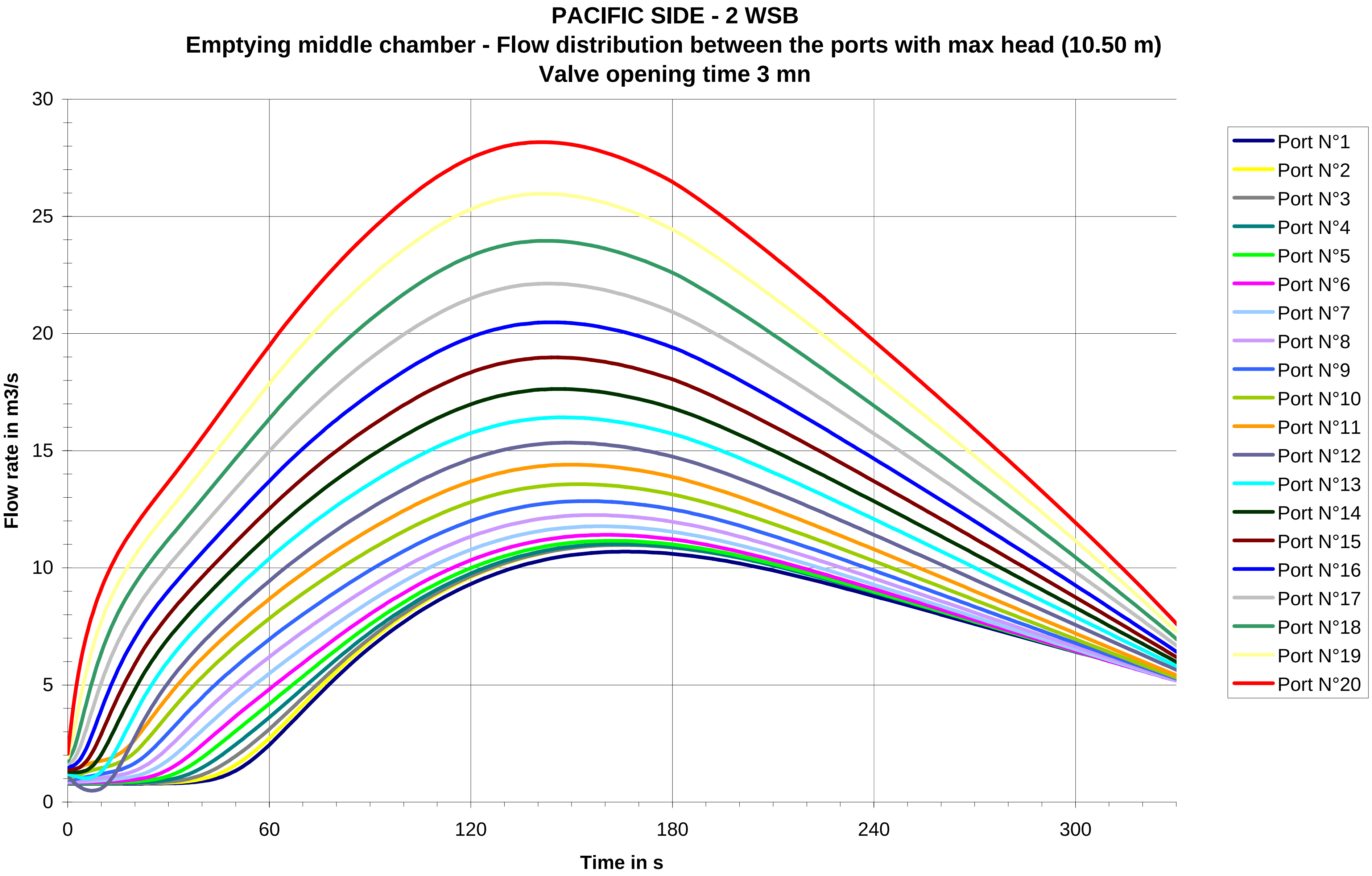
Annex 3.2

PACIFIC SIDE
3 step lock system with 2 wsb per lock
Lake Gatun max - Pacific Ocean amplitude max - wsb to lock operations

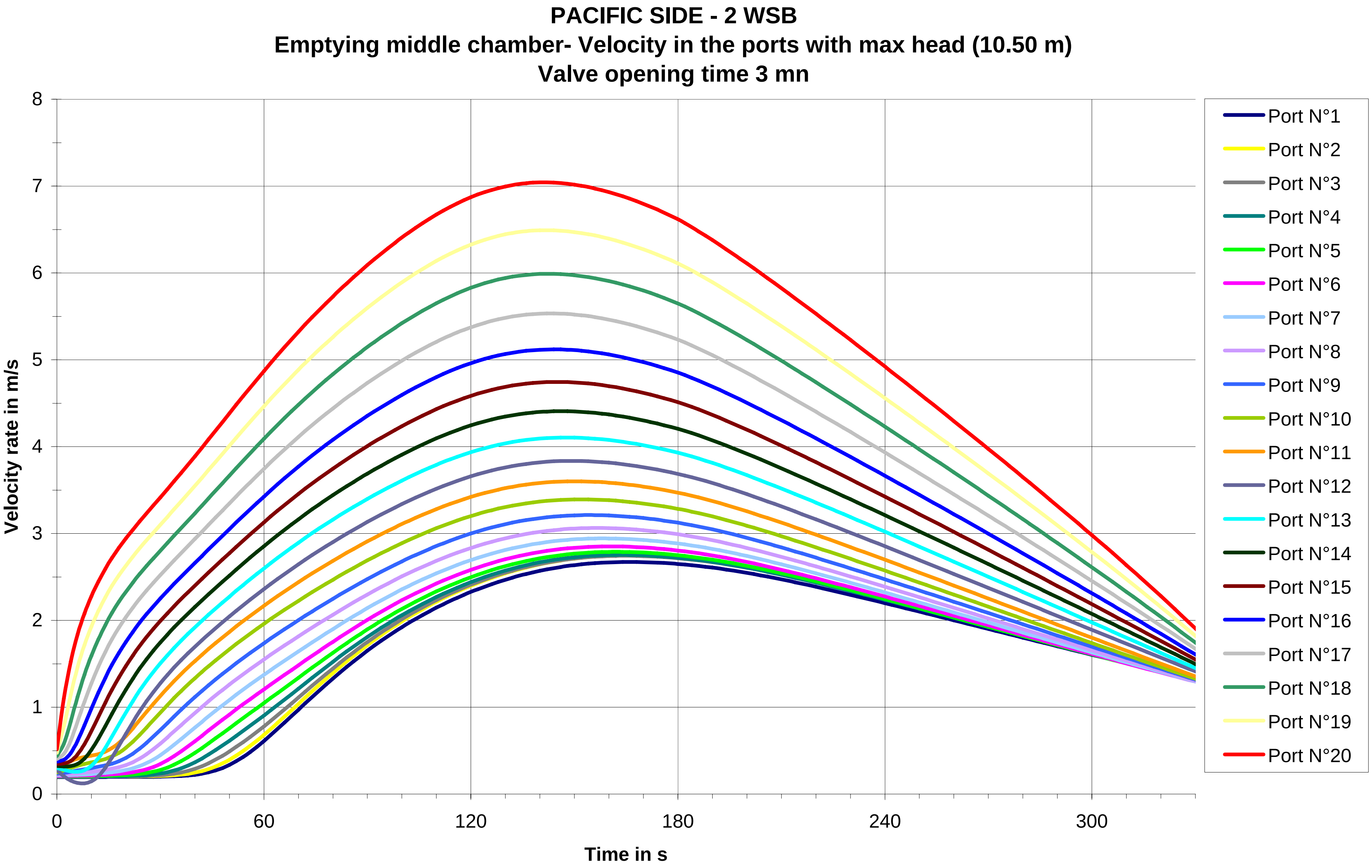



PACIFIC SIDE
3 step lock system with 2 wsb per lock
Lake Gatun max - Pacific Ocean amplitude max - lock to wsb operations
6.00
5.50
5.00
4.50
4.00
3.50
3.00
head (m)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
percentazge of occurence (%)
upper top filling
upper bottom filling
lower top filling
lower bottom filling

Annex 4.1

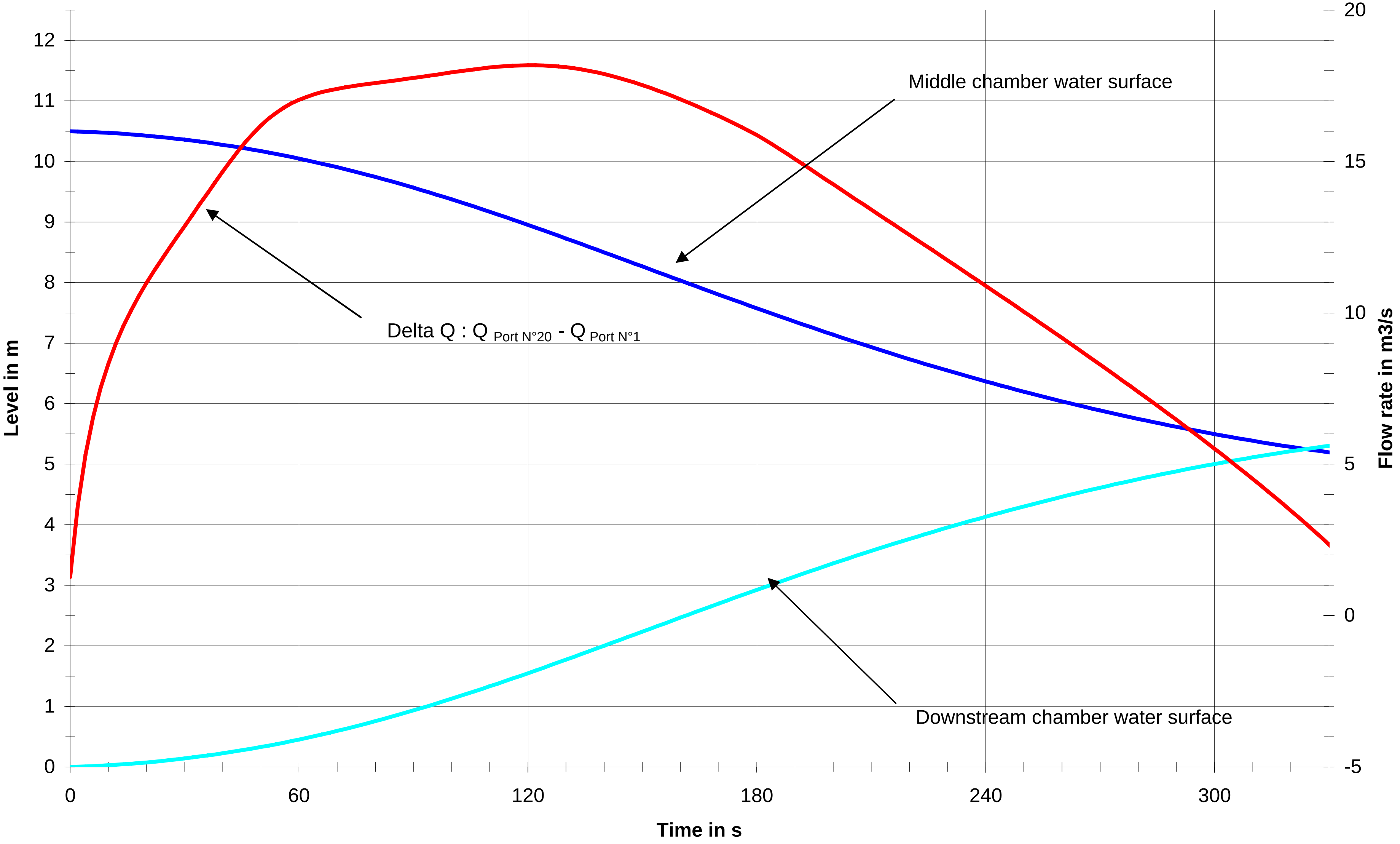

PACIFIC SIDE - 2 WSB
Emptying middle chamber - Flow distribution between the ports with max head (10.50 m)
Valve opening time 3 mn
Flow rate in m3/s
0
5
10
15
20
25
30
Time in s
0
60
120
180
240
300
Port N°1
Port N°2
Port N°3
Port N°4
Port N°5
Port N°6
Port N°7
Port N°8
Port N°9
Port N°10
Port N°11
Port N°12
Port N°13
Port N°14
Port N°15
Port N°16
Port N°17
Port N°18
Port N°19
Port N°20

Annex 4.2


PACIFIC SIDE - 2 WSB
Emptying middle chamber- Velocity in the ports with max head (10.50 m)
Valve opening time 3 mn
Velocity rate in m/s
0
1
2
3
4
5
6
7
8
Time in s
0
60
120
180
240
300
Port N°1
Port N°2
Port N°3
Port N°4
Port N°5
Port N°6
Port N°7
Port N°8
Port N°9
Port N°10
Port N°11
Port N°12
Port N°13
Port N°14
Port N°15
Port N°16
Port N°17
Port N°18
Port N°19
Port N°20

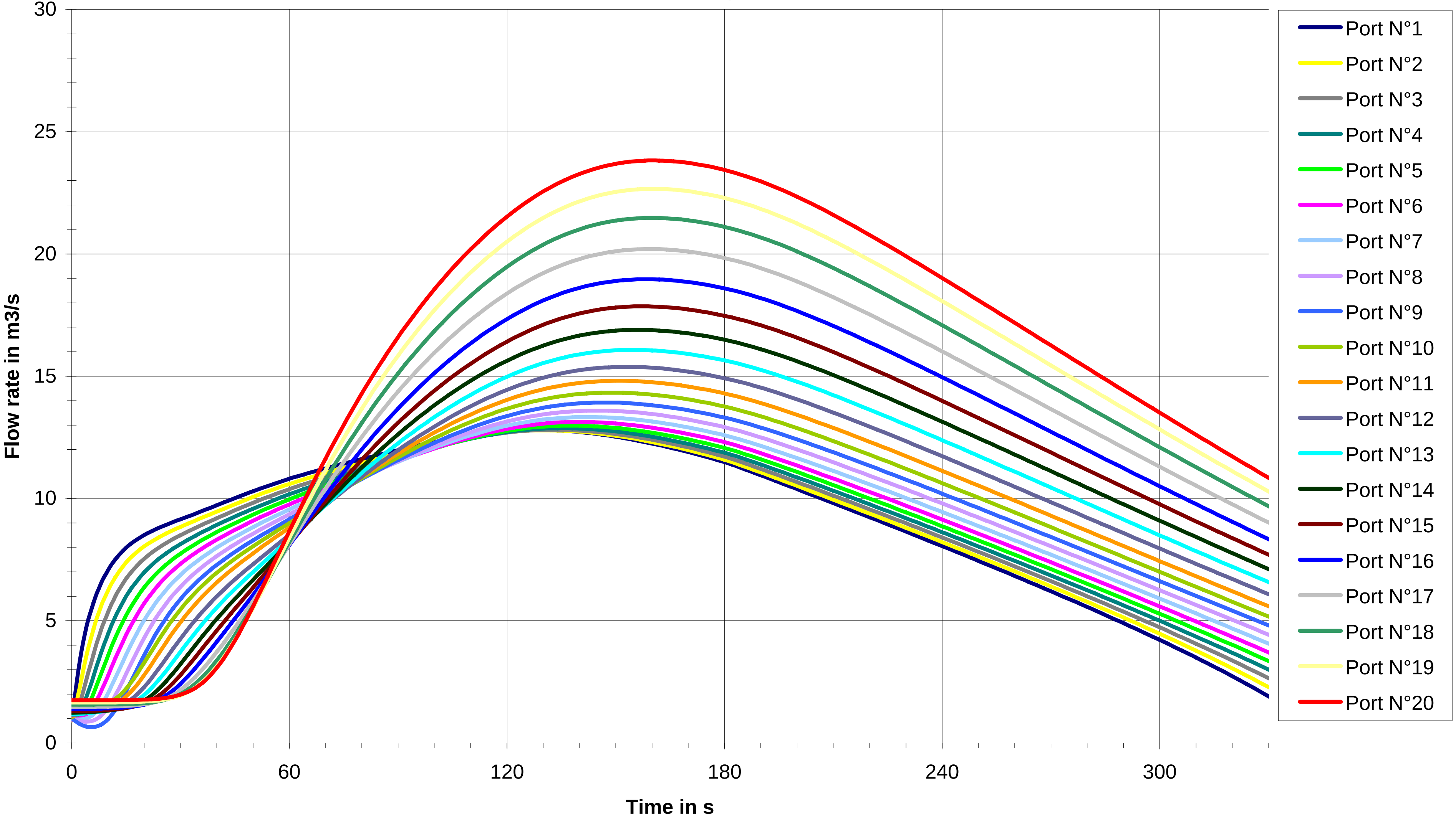
Annex 4.3

PACIFIC SIDE - 2 WSB
Emptying middle chamber - Evolution of water surface with max head (10.50 m)
Valve opening time 3 mn

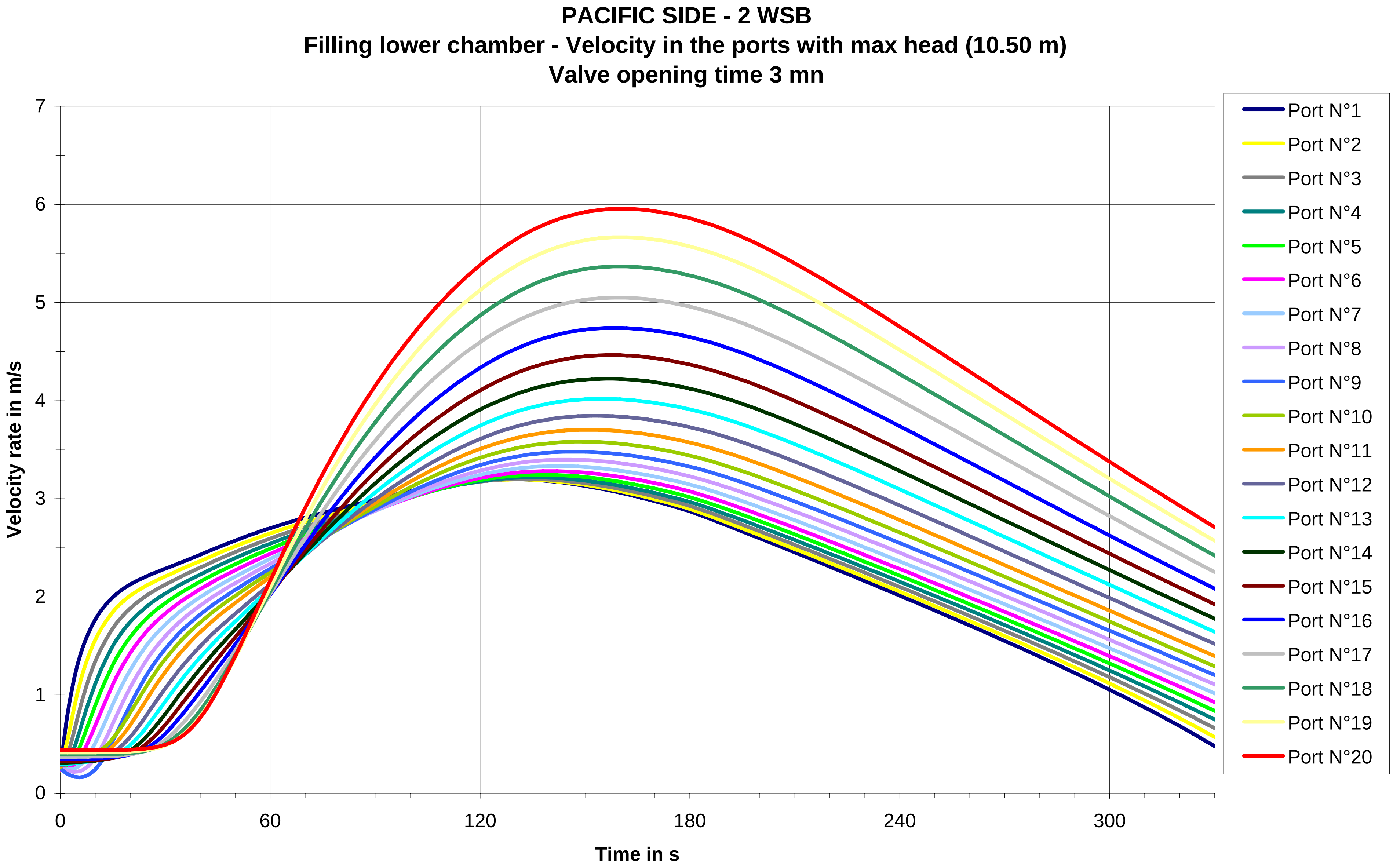


Annex 5.1

PACIFIC SIDE - 2 WSB
Filling lower chamber - Flow distribution between the ports with max head (10.50 m)
Valve opening time 3 mn

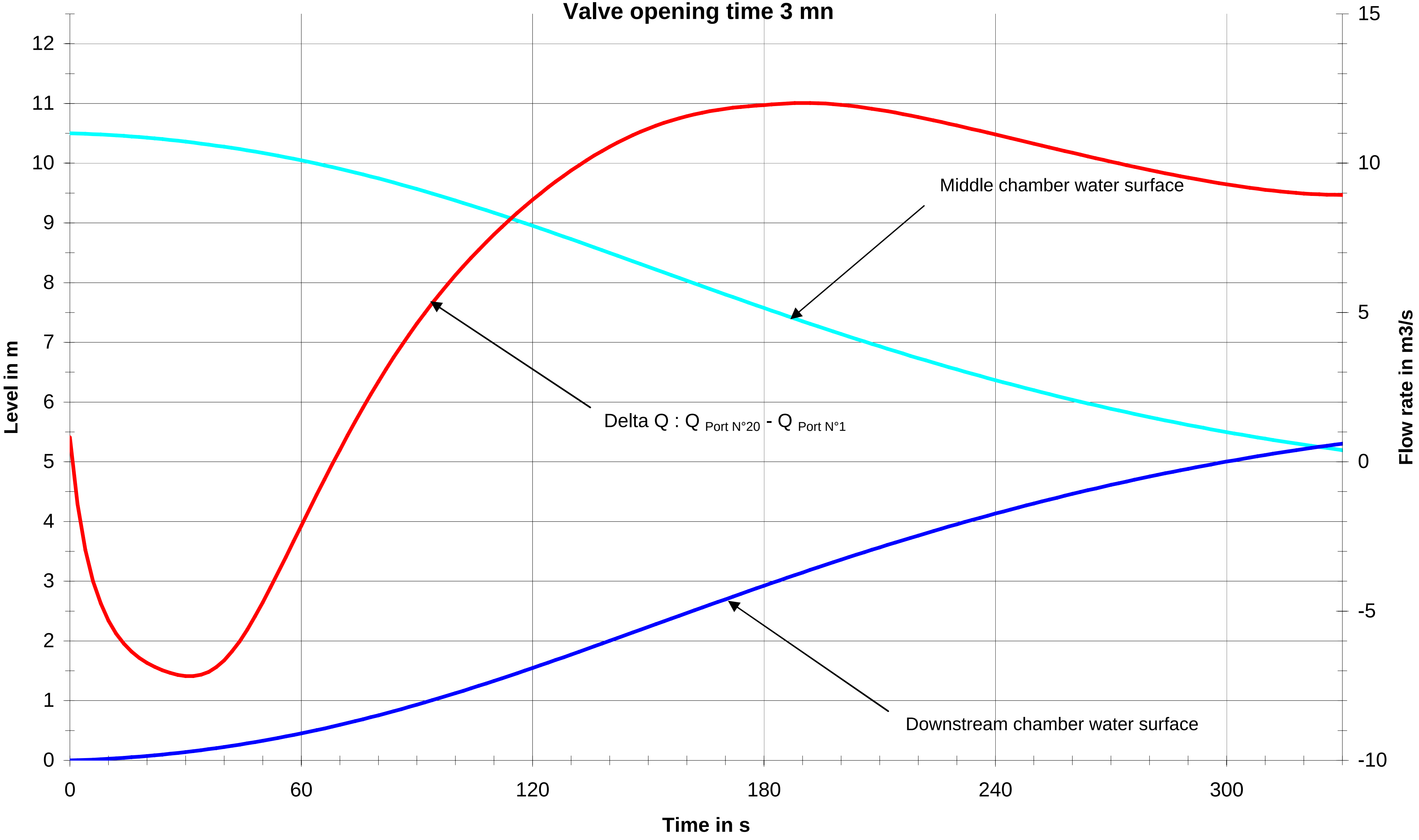


Annex 5.2


PACIFIC SIDE - 2 WSB
Filling lower chamber - Velocity in the ports with max head (10.50 m)
Valve opening time 3 mn
Velocity rate in m/s
7
6
5
4
3
2
1
0
0
60
120
180
240
300
Time in s
Port N°1
Port N°2
Port N°3
Port N°4
Port N°5
Port N°6
Port N°7
Port N°8
Port N°9
Port N°10
Port N°11
Port N°12
Port N°13
Port N°14
Port N°15
Port N°16
Port N°17
Port N°18
Port N°19
Port N°20

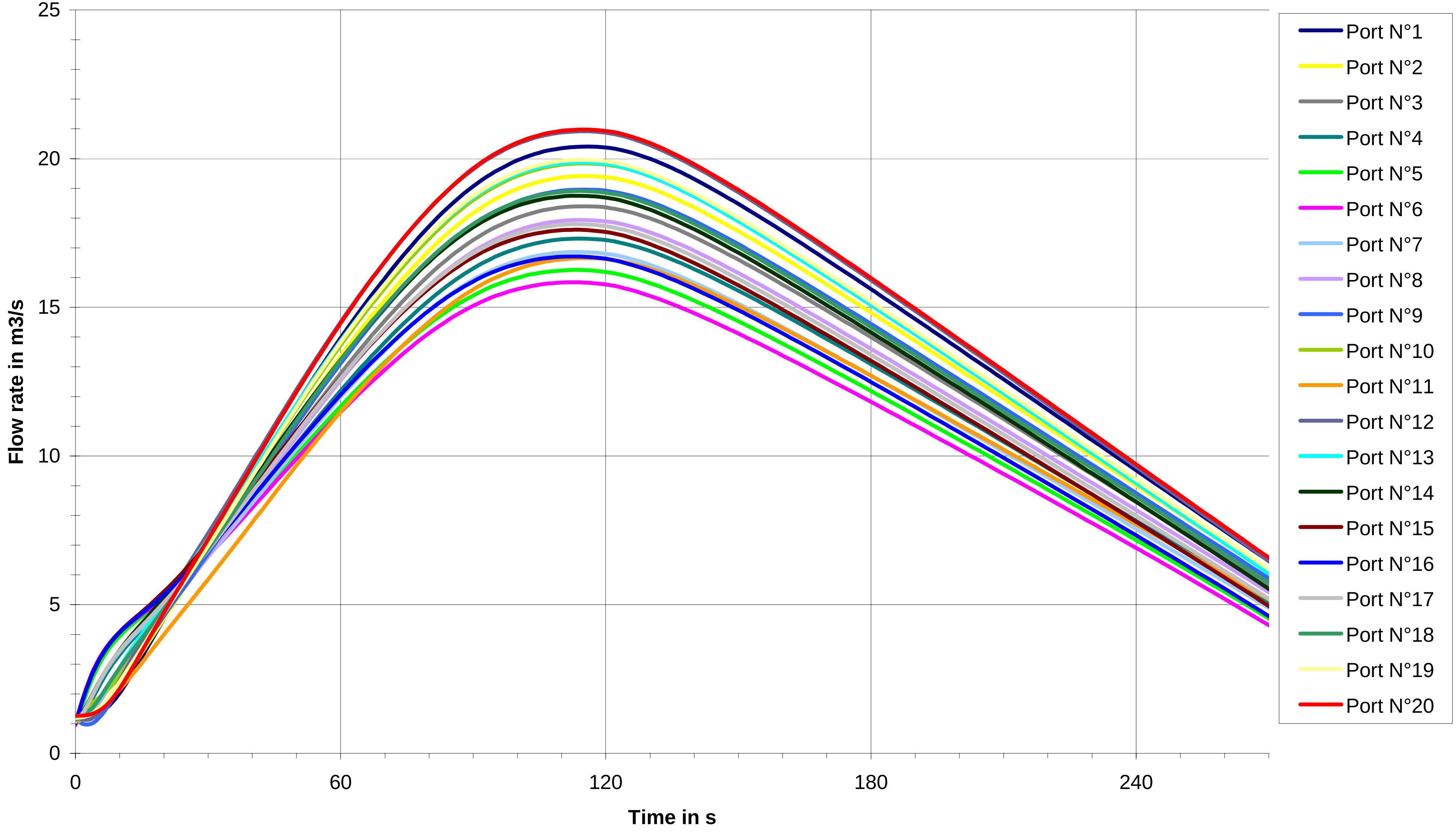
Annex 5.3

PACIFIC SIDE - 2 WSB
Filling lower chamber - Evolution of water surface with max head (10.50 m)
Valve opening time 3 mn



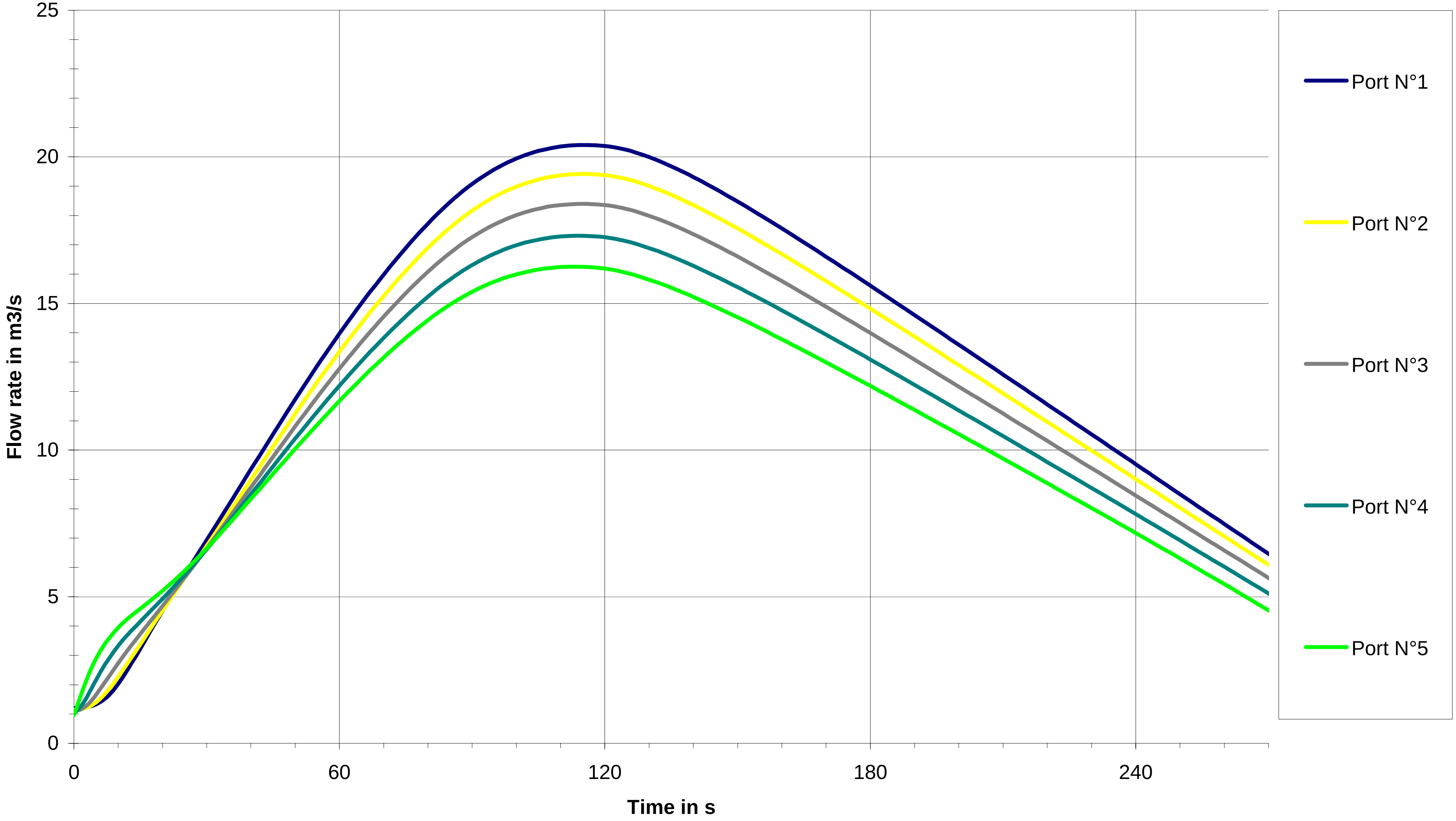
Annex 6.1

PACIFIC SIDE - 2 WSB
Emptying Lower bottom WSB - Flow distribution between the ports with max head (9.20 m)
Valve opening time 2 mn

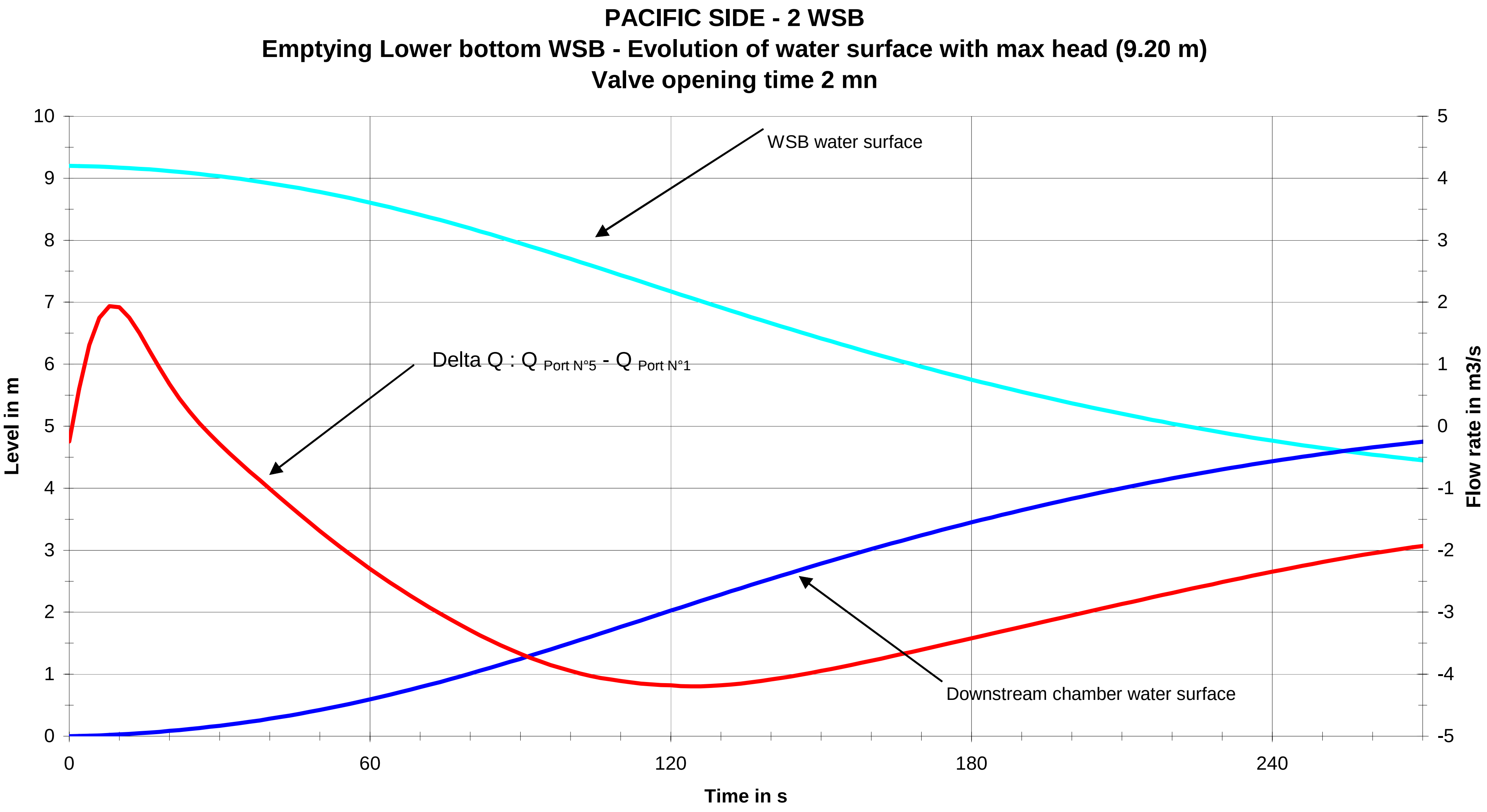


Annex 6.2

PACIFIC SIDE - 2 WSB
Emptying Lower bottom WSB - Flow distribution between the ports with max fall (9.20 m)
Valve opening time 2 mn

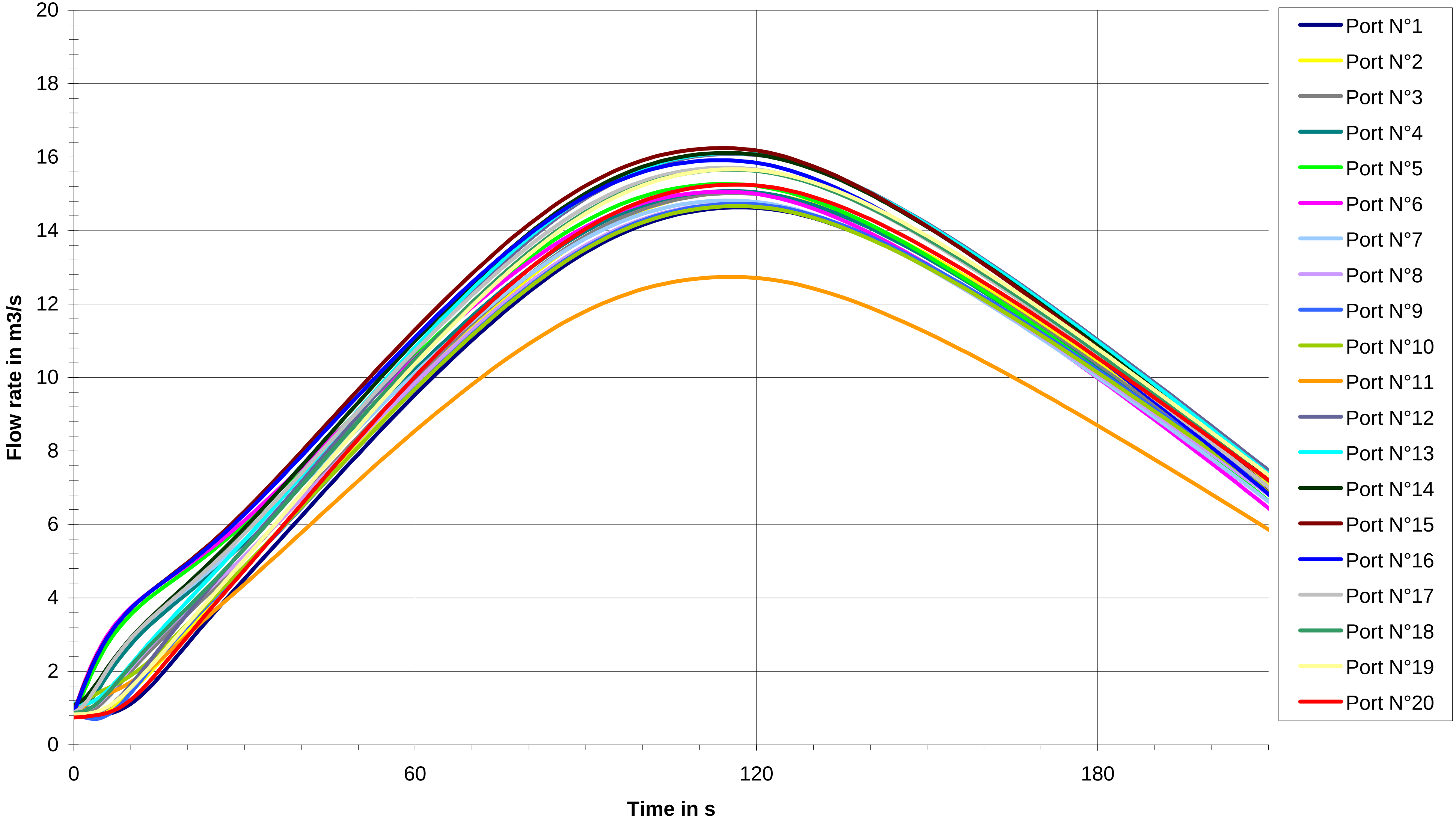


Annex 6.3


PACIFIC SIDE - 2 WSB
Emptying Lower bottom WSB - Evolution of water surface with max head (9.20 m)
Valve opening time 2 mn
WSB water surface
Delta Q : Q Port N°5 - Q Port N°1
Downstream chamber water surface
Level in m
Flow rate in m3/s
Time in s
0
1
2
3
4
5
6
7
8
9
10
-5
-4
-3
-2
-1
0
1
2
3
4
5
0
60
120
180
240

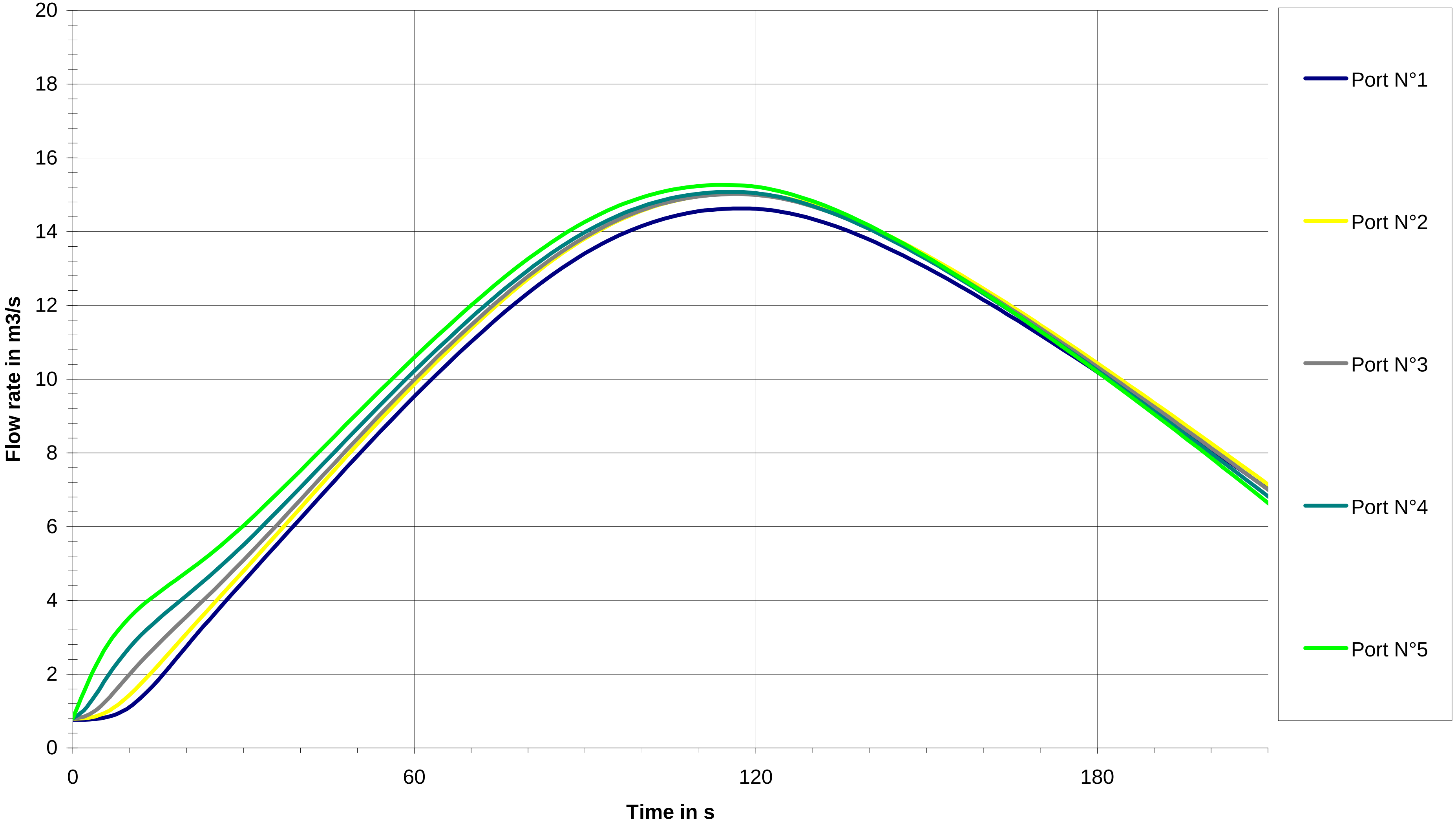
Annex 7.1

PACIFIC SIDE - 2 WSB
Filling Lower bottom WSB - Flow distribution between the ports with max head (5.90 m)
Valve opening time 2 mn



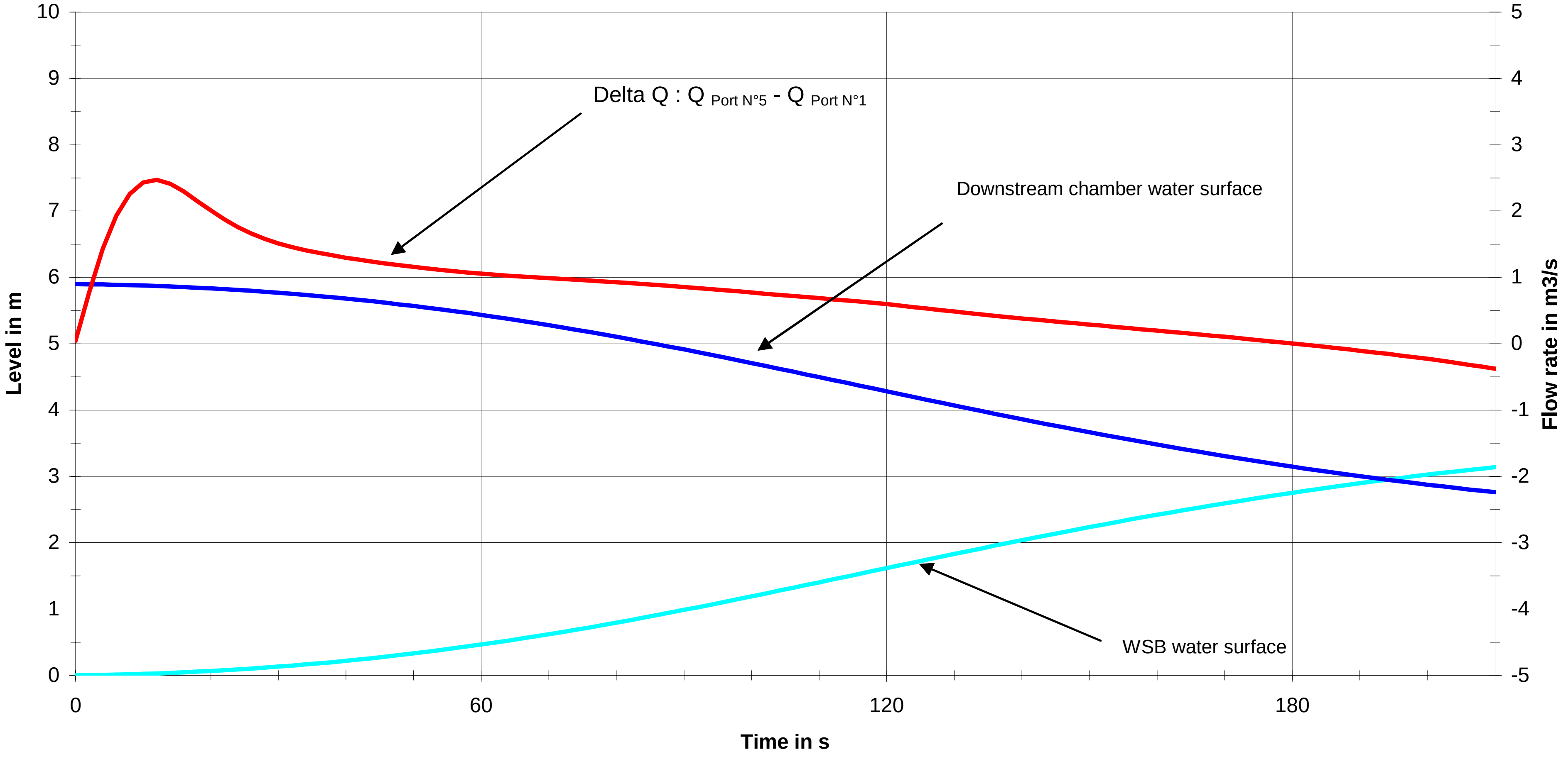
Annex 7.2

PACIFIC SIDE - 2 WSB
Filling Lower bottom WSB - Flow distribution between the ports with max head (5.90 m)
Valve opening time 2 mn

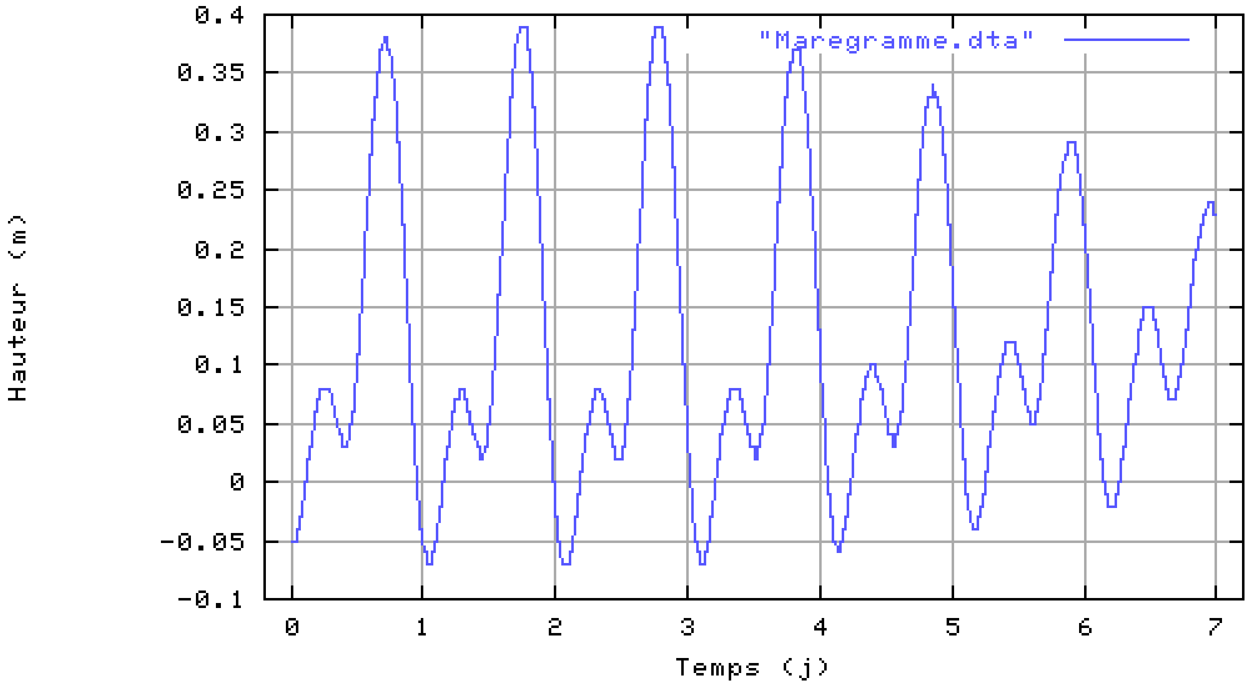


Annex 7.3

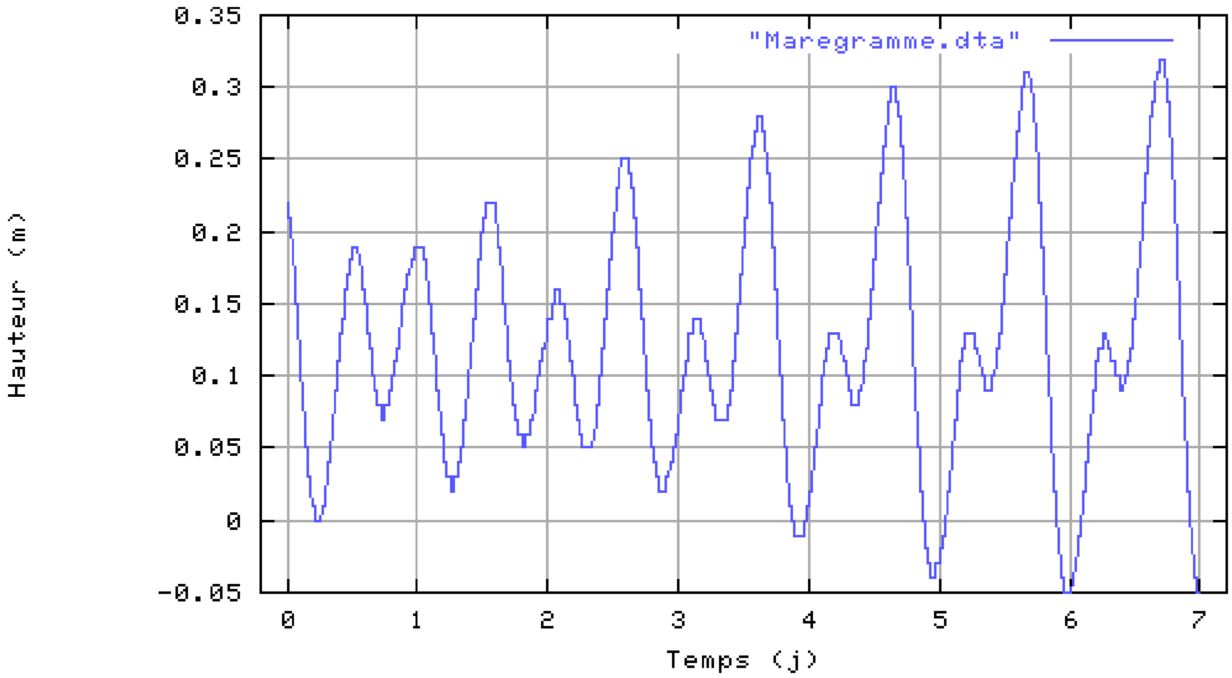
PACIFIC SIDE - 2 WSB
Filling Lower bottom WSB - Evolution of water surface with max head (5.90 m)
Valve opening time 2 mn



Annexe 8.1



20/09/04



27/09/04

atención
Cheryl George

PANAMA CANAL COMMISSION
ENGINEERING AND CONSTRUCTION BUREAU
Meteorological and Hydrographic Branch

PANAMA CANAL TIDAL DATA

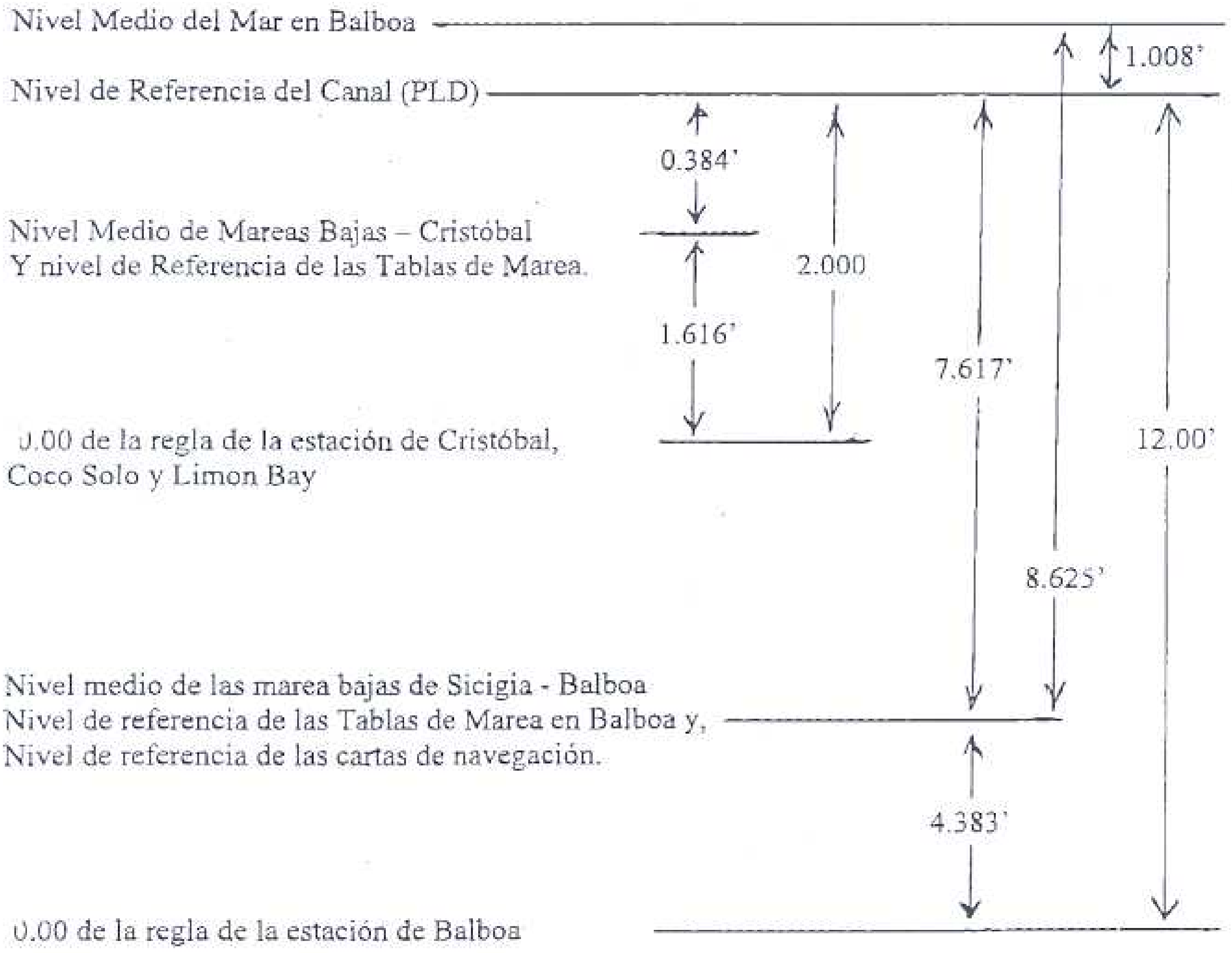
DIABLO (Pacific Coast)	Datum for Pamama Canal Tide Records Feet	Datum for Navigational Charts and Tide Tables Feet	Panama Canal Precise Level Datum Feet
	(Zero of Diablo Tide Gage)	(Mean Low Water Springs)	
Data for Diablo tidal values *			
(1) Zero of Balboa Tide Gage	0.000	- 4.383	-12.000
(2) Mean Low Water Springs	+ 4.383	0.000	- 7.617
(3) Precise Level Datum	+12.000	+ 7.617	0.000
19 year means, 1973-1991			
Mean monthly highest high water	+21.920	+17.537	+ 9.920
Mean high water	+19.022	+14.639	+ 7.022
Mean sea level	+13.008	+ 8.625	+ 1.008
Mean low water	+ 6.438	+ 2.005	- 5.562
Mean monthly lowest low water	+ 2.856	- 1.527	- 9.144
83 year extremes, 1909 - 1991			
Higest high water	+23.800	+19.417	+11.800
Lowest high water	+14.220	+ 9.837	+ 2.220
Higest low water	+10.930	+ 6.547	- 1.070
Lowest low water	+ 0.700	- 3.683	-11.300

COCO SOLO (Atlantic Coast)	(Zero of Coco Solo Tide Gage)	(Mean Low Water)	
Data for Coco Solo tidal values *			
(1) Zero for Coco Solo tide gage	0.000	- 1.616	- 2.000
(2) Mean low water	+ 1.616	0.000	- 0.384
(3) Precise Level Datum	+ 2.000	+ 0.384	0.000
19 year means, 1973 - 1991			
Mean monthly highest high water	+ 3.341	+ 1.725	+ 1.341
Mean high water	+ 2.973	+ 1.357	+ 0.973
Mean sea level	+ 2.355	+ 0.739	+ 0.355
Mean low water	+ 1.829	+ 0.213	- 0.171
Mean monthly lowest low water	+ 1.520	- 0.096	- 0.480
83 year extremes, 1909-1991			
Highest high water	+ 3.860	+ 2.244	+ 1.860
Lowest low water	+ 0.710	- 0.906	- 1.290

* Note: Data for Dialo tidal values refers to the data at Balboa and Diablo. Data for Coco Solo tidal values refers to the data at Cristobal and Coco Solo.

AUTORIDAD DEL CANAL DE PANAMA

NIVELES DE REFERENCIA PARA ALTURAS DE MAREA



En el Pacífico:

Elevación en PLD = Tabla de Mareas – 7.617'
Elevación en PLD = Estación Diablo Heights – 12.00'
Tabla de Mareas = Estación Diablo Heights – 4.383'

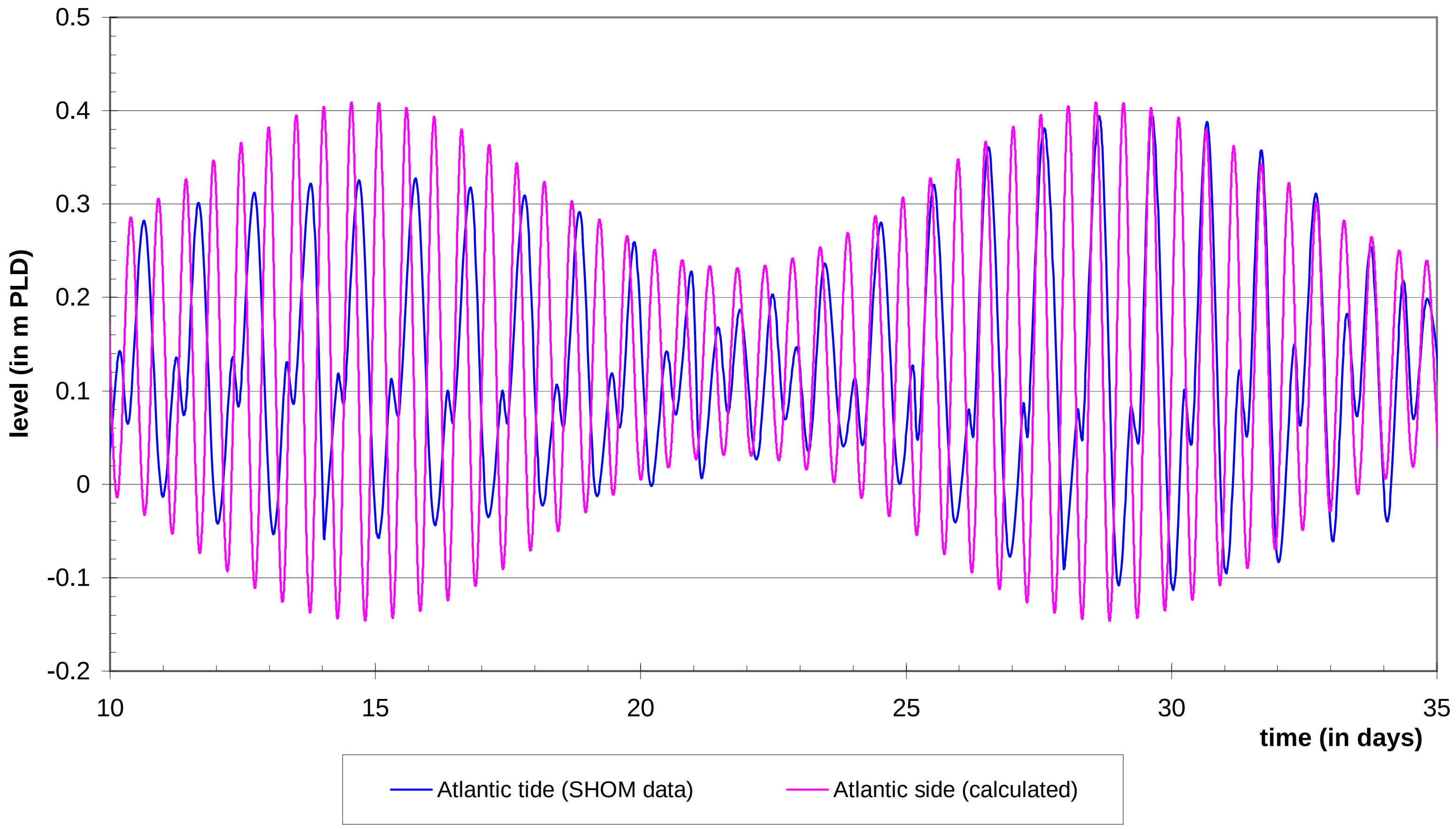
En el Atlántico:

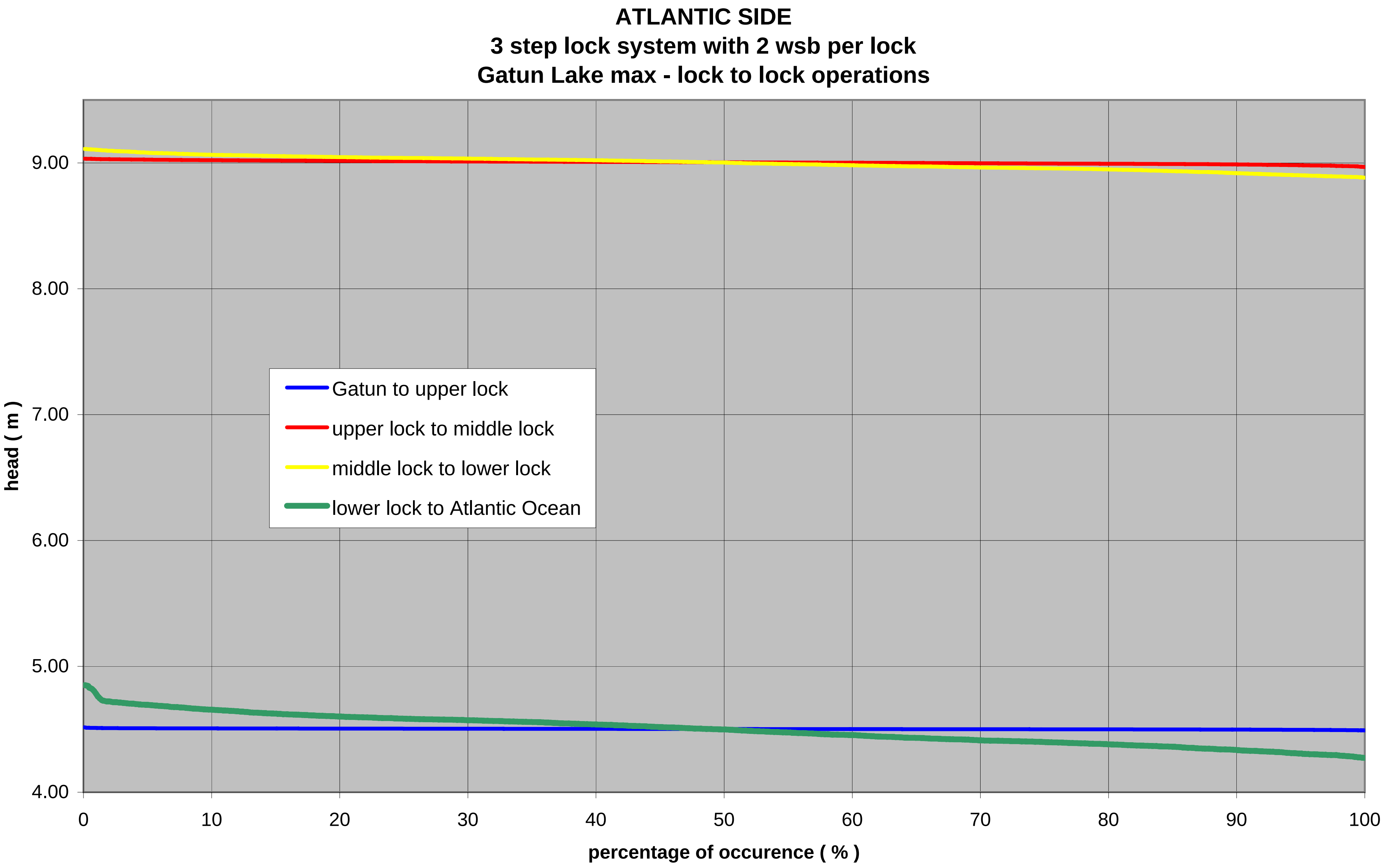
Elevación en PLD = Tabla de Mareas – 0.384'
Elevación el PLD = Estación Limon Bay – 2.00'
Tabla de Mareas = Estación Limon Bay – 1.616'

Modesto Echevers
Sección de Meteorología e Hidrología
4 de Enero de 2001

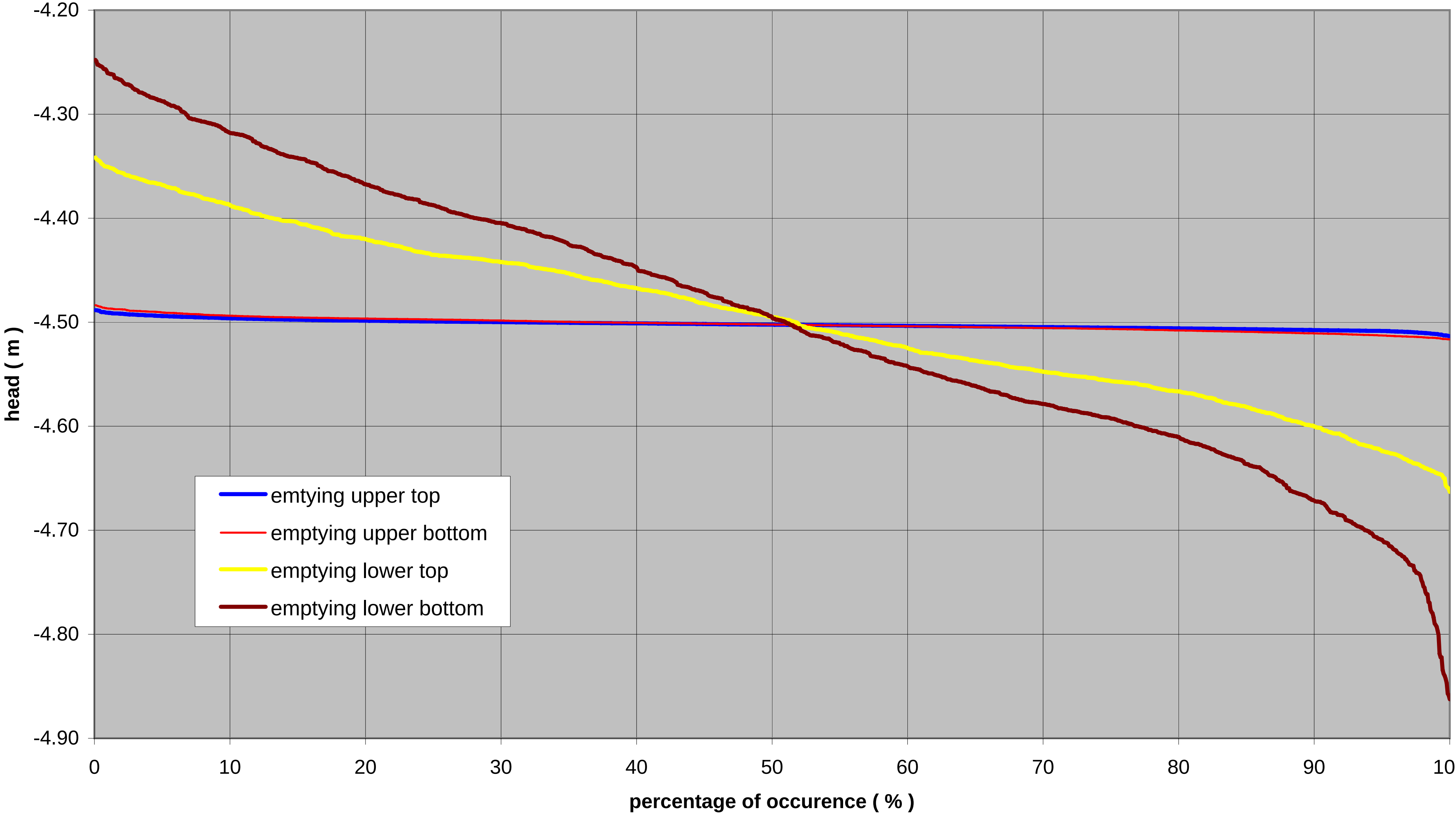
Annex 8.3

Comparaison between real and calculated Atlantic tide level

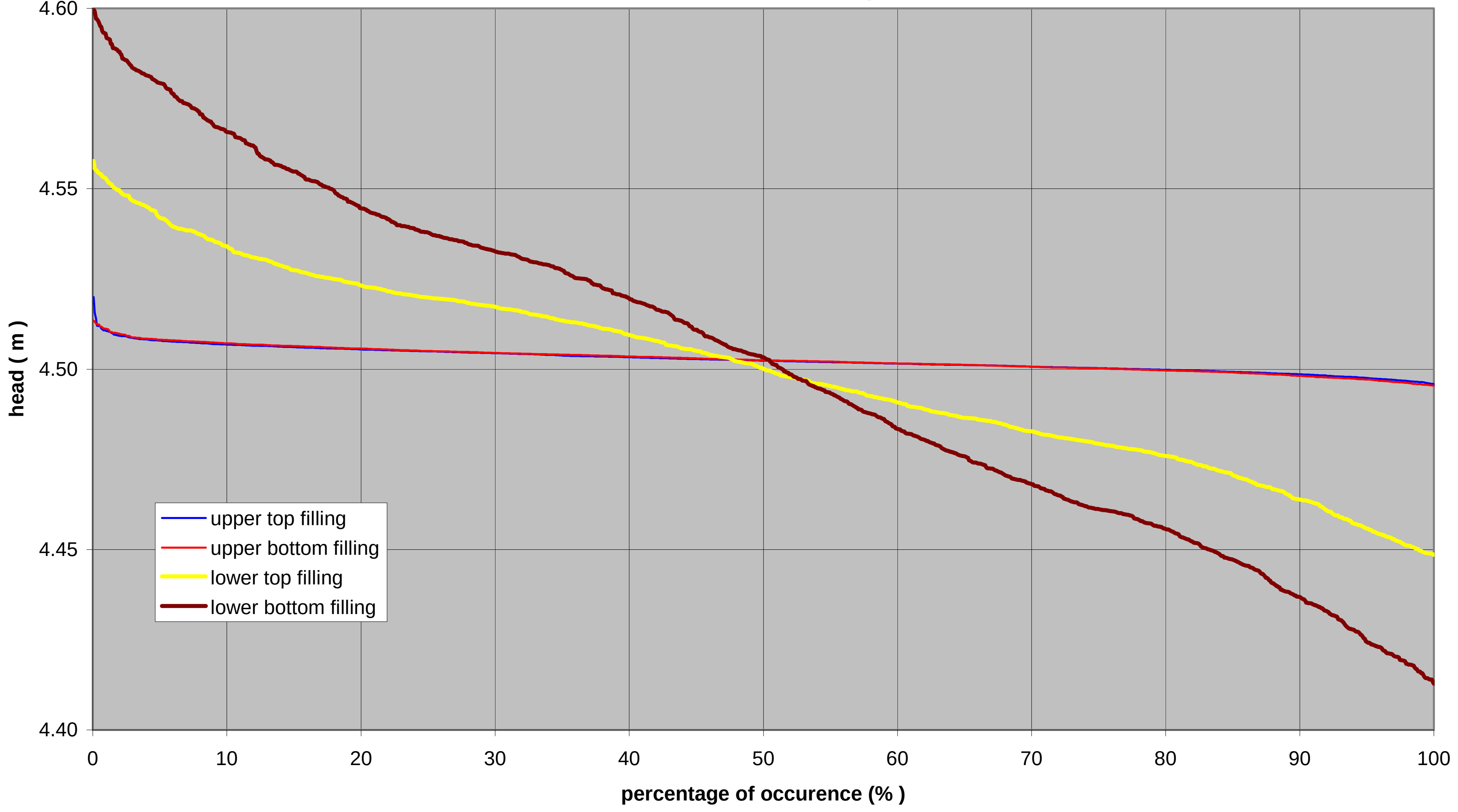



ATLANTIC SIDE
3 step lock system with 2 wsb per lock
Gatun Lake max - lock to lock operations
head (m)
9.00
8.00
7.00
6.00
5.00
4.00
0
10
20
30
40
50
60
70
80
90
100
percentage of occurence (%)
Gatun to upper lock
upper lock to middle lock
middle lock to lower lock
lower lock to Atlantic Ocean

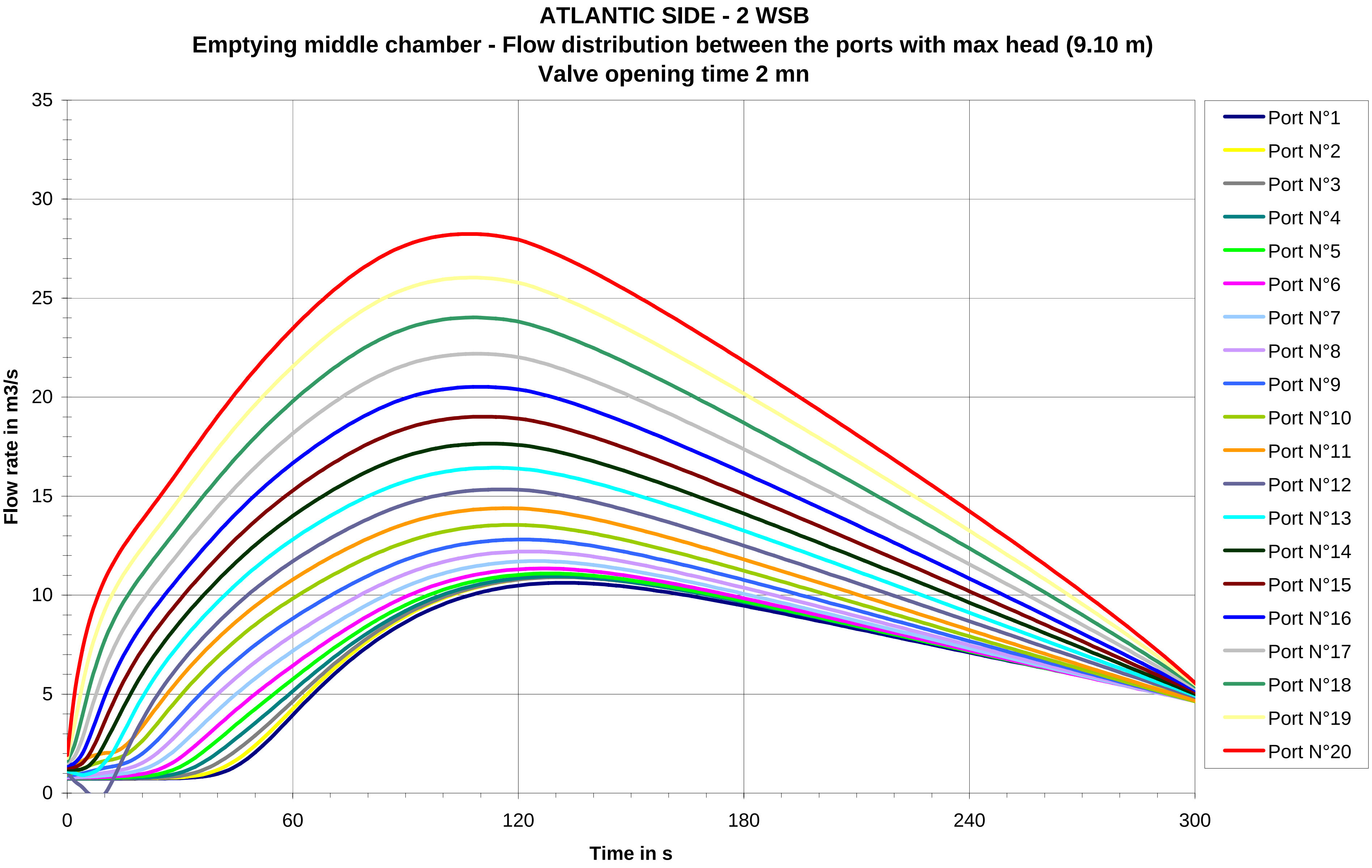
ATLANTIC SIDE
3 step lock system with 2 wsb per lock
Gatun Lake max - wsb to lock operations



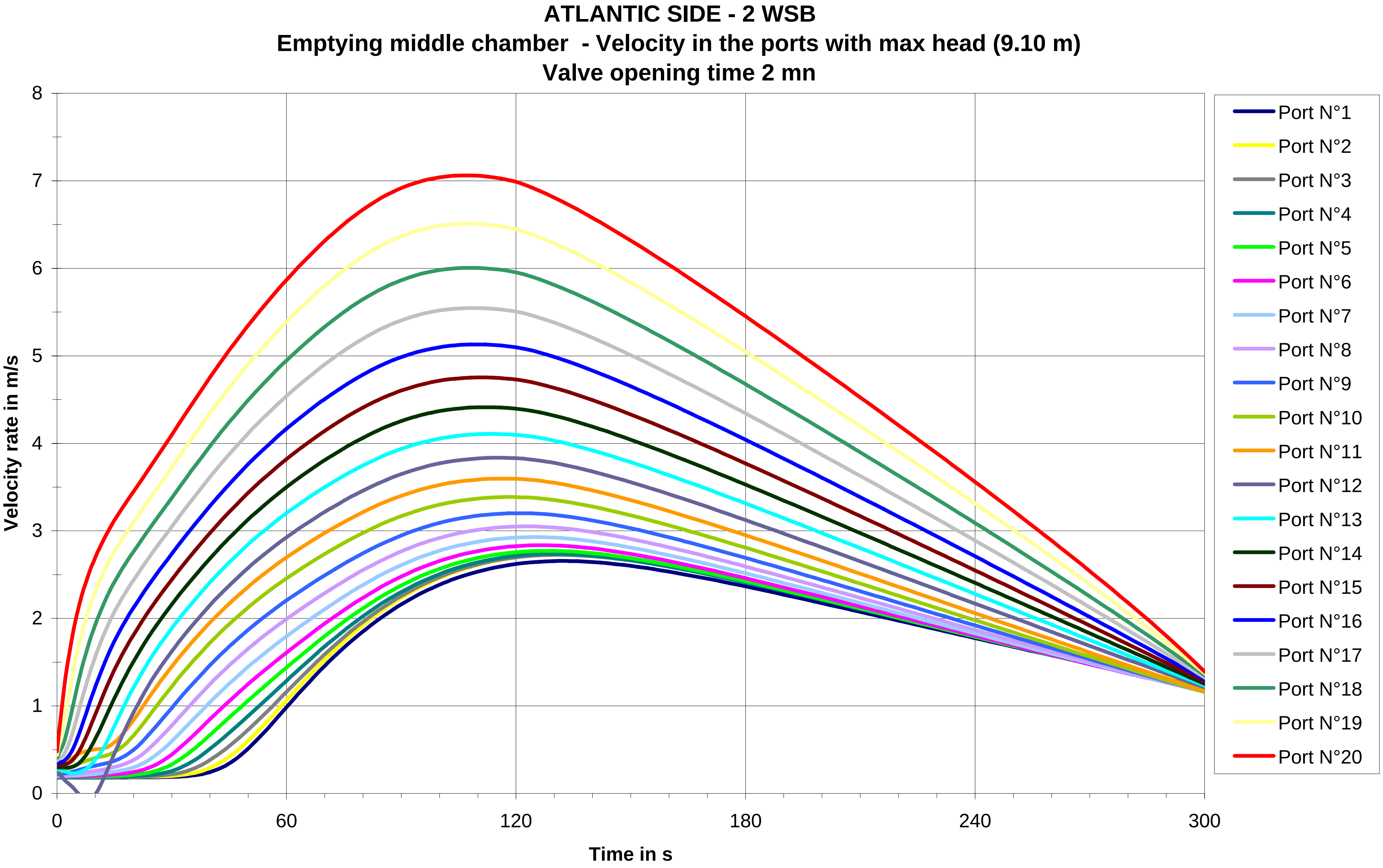
ATLANTIC SIDE
3 step lock system with 2 wsb per lock
Gatun Lake max - lock to wsb operations



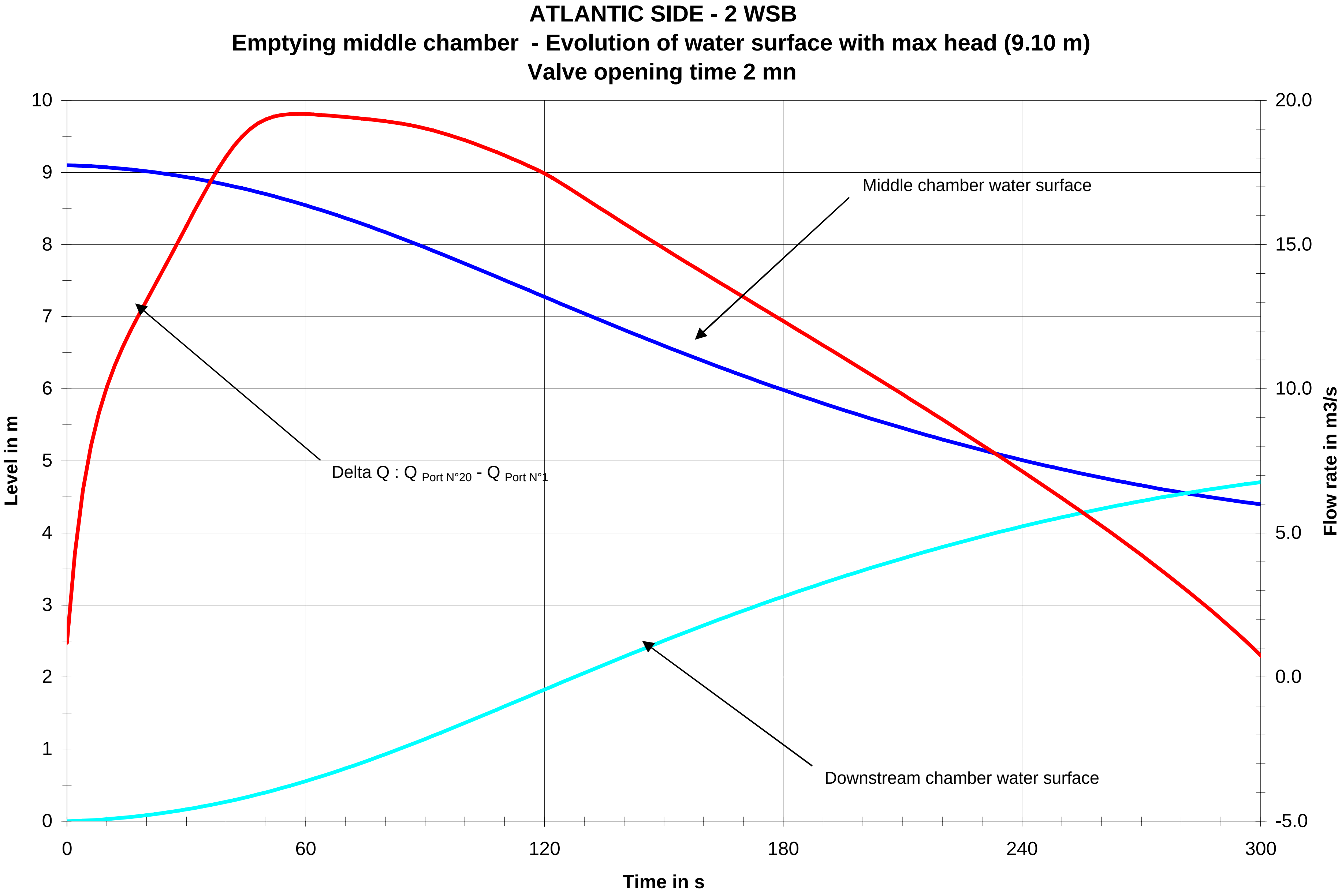
Annex 10.1


ATLANTIC SIDE - 2 WSB
Emptying middle chamber - Flow distribution between the ports with max head (9.10 m)
Valve opening time 2 mn
Flow rate in m3/s
35
30
25
20
15
10
5
0
0
60
120
180
240
300
Time in s
Port N°1
Port N°2
Port N°3
Port N°4
Port N°5
Port N°6
Port N°7
Port N°8
Port N°9
Port N°10
Port N°11
Port N°12
Port N°13
Port N°14
Port N°15
Port N°16
Port N°17
Port N°18
Port N°19
Port N°20

Annex 10.2

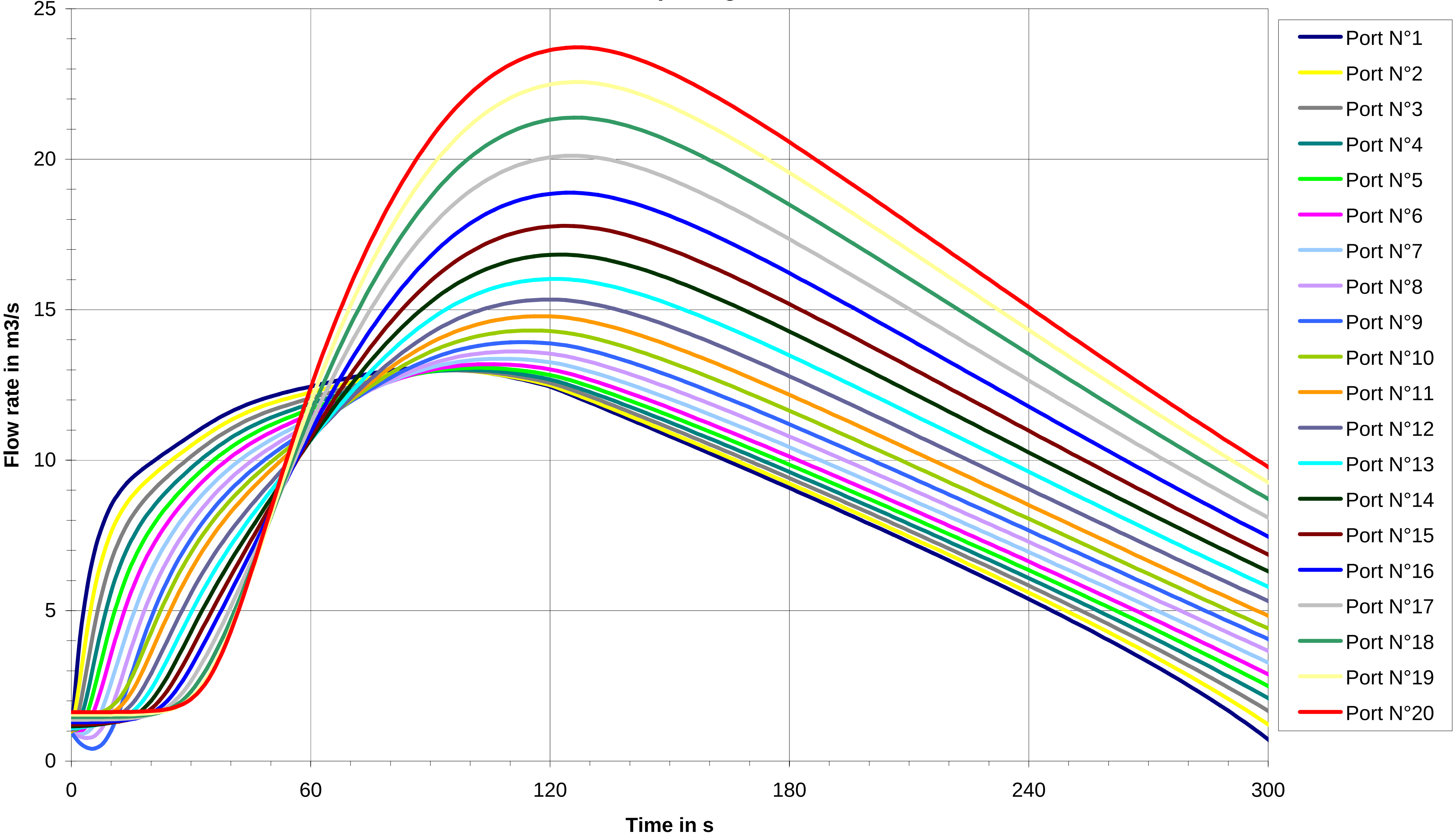

ATLANTIC SIDE - 2 WSB
Emptying middle chamber - Velocity in the ports with max head (9.10 m)
Valve opening time 2 mn
Velocity rate in m/s
0
1
2
3
4
5
6
7
8
0
60
120
180
240
300
Time in s
Port N°1
Port N°2
Port N°3
Port N°4
Port N°5
Port N°6
Port N°7
Port N°8
Port N°9
Port N°10
Port N°11
Port N°12
Port N°13
Port N°14
Port N°15
Port N°16
Port N°17
Port N°18
Port N°19
Port N°20

Annex 10.3

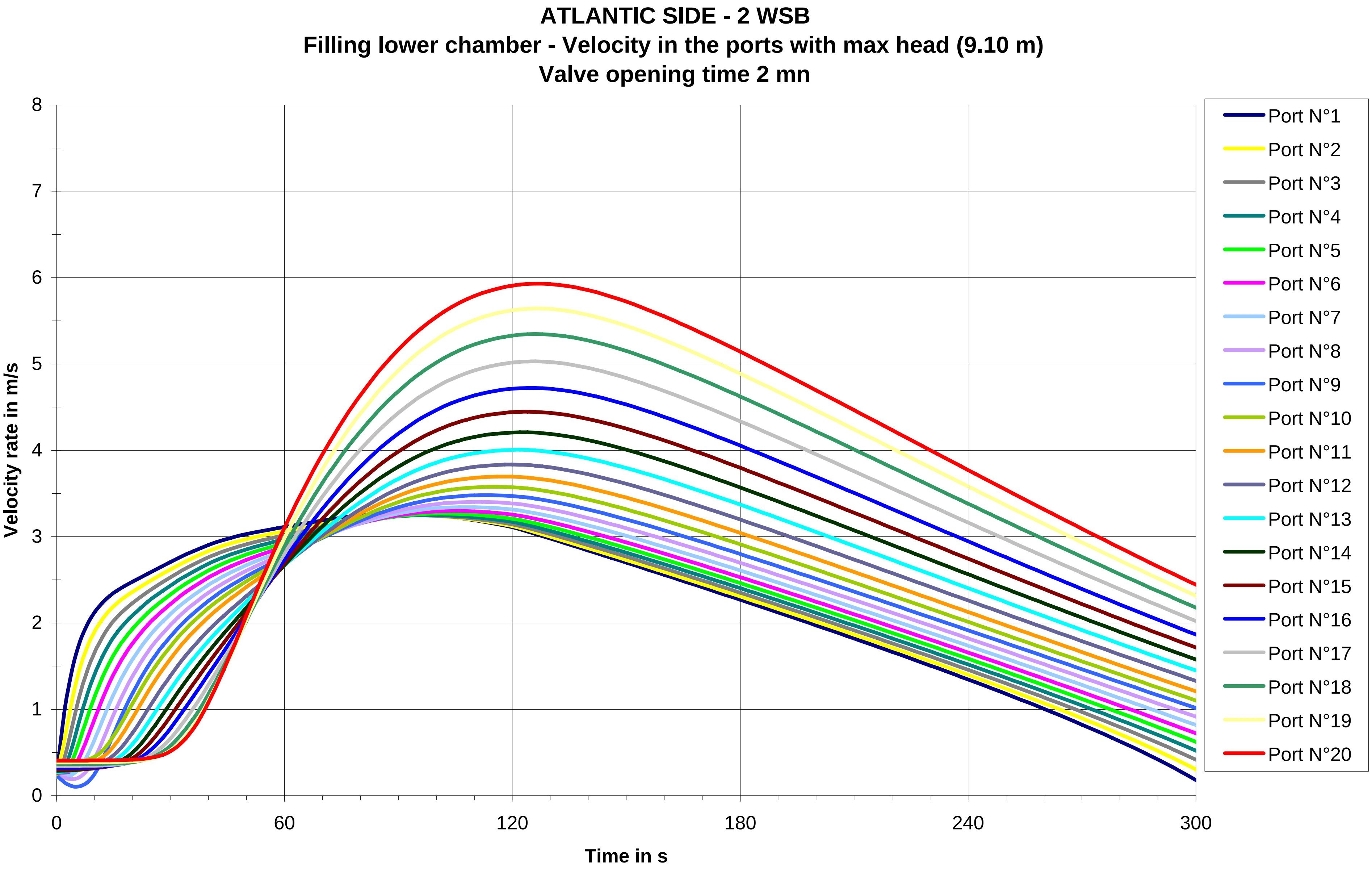

ATLANTIC SIDE - 2 WSB
Emptying middle chamber - Evolution of water surface with max head (9.10 m)
Valve opening time 2 mn
Level in m
10
9
8
7
6
5
4
3
2
1
0
Flow rate in m3/s
20.0
15.0
10.0
5.0
0.0
-5.0
Time in s
0
60
120
180
240
300
Middle chamber water surface
Delta Q : Q Port N°20 - Q Port N°1
Downstream chamber water surface

Annex 11.1

ATLANTIC SIDE - 2 WSB
Filling lower chamber - Flow distribution between the ports with max head (9.10 m)
Valve opening time 2 mn

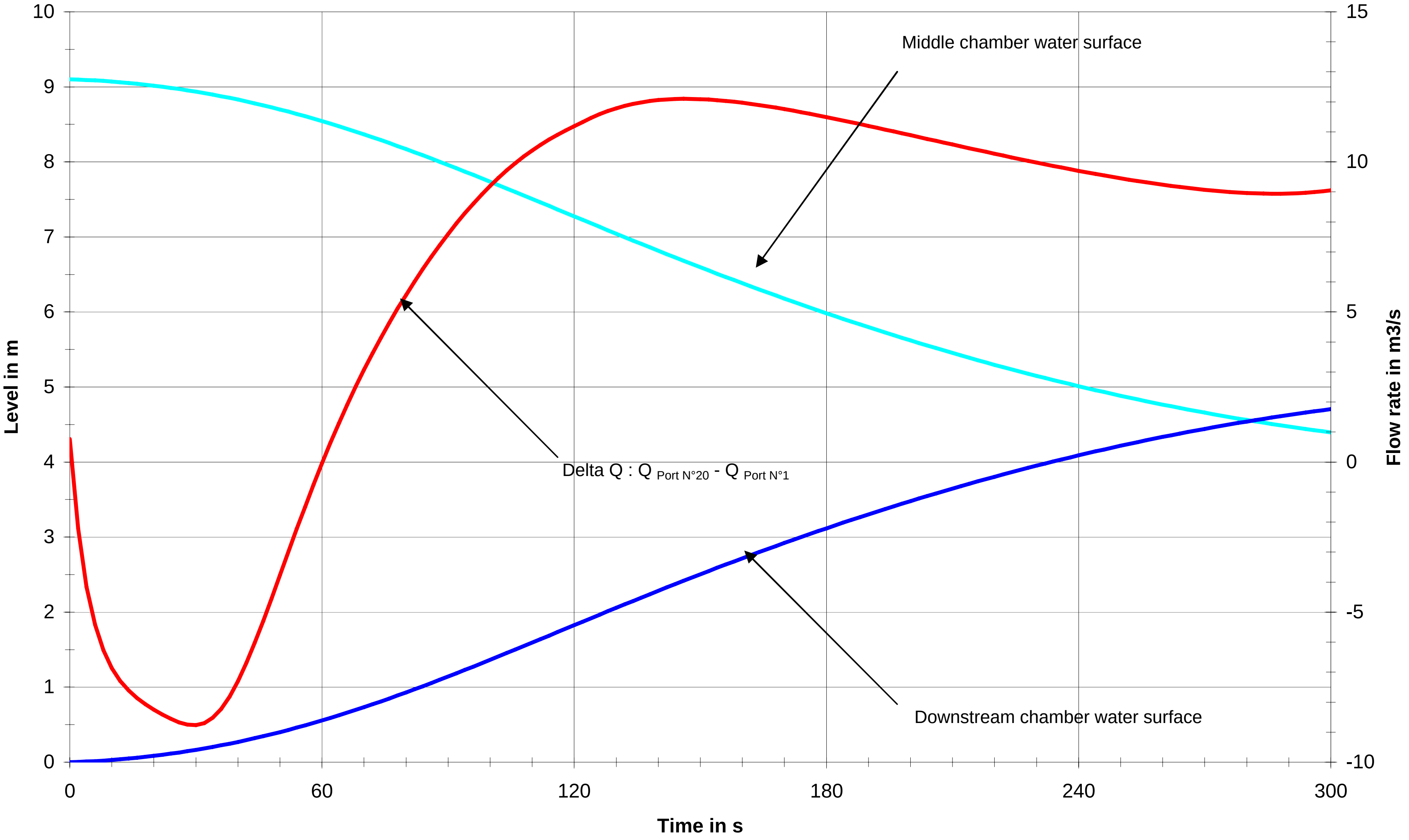


Annex 11.2

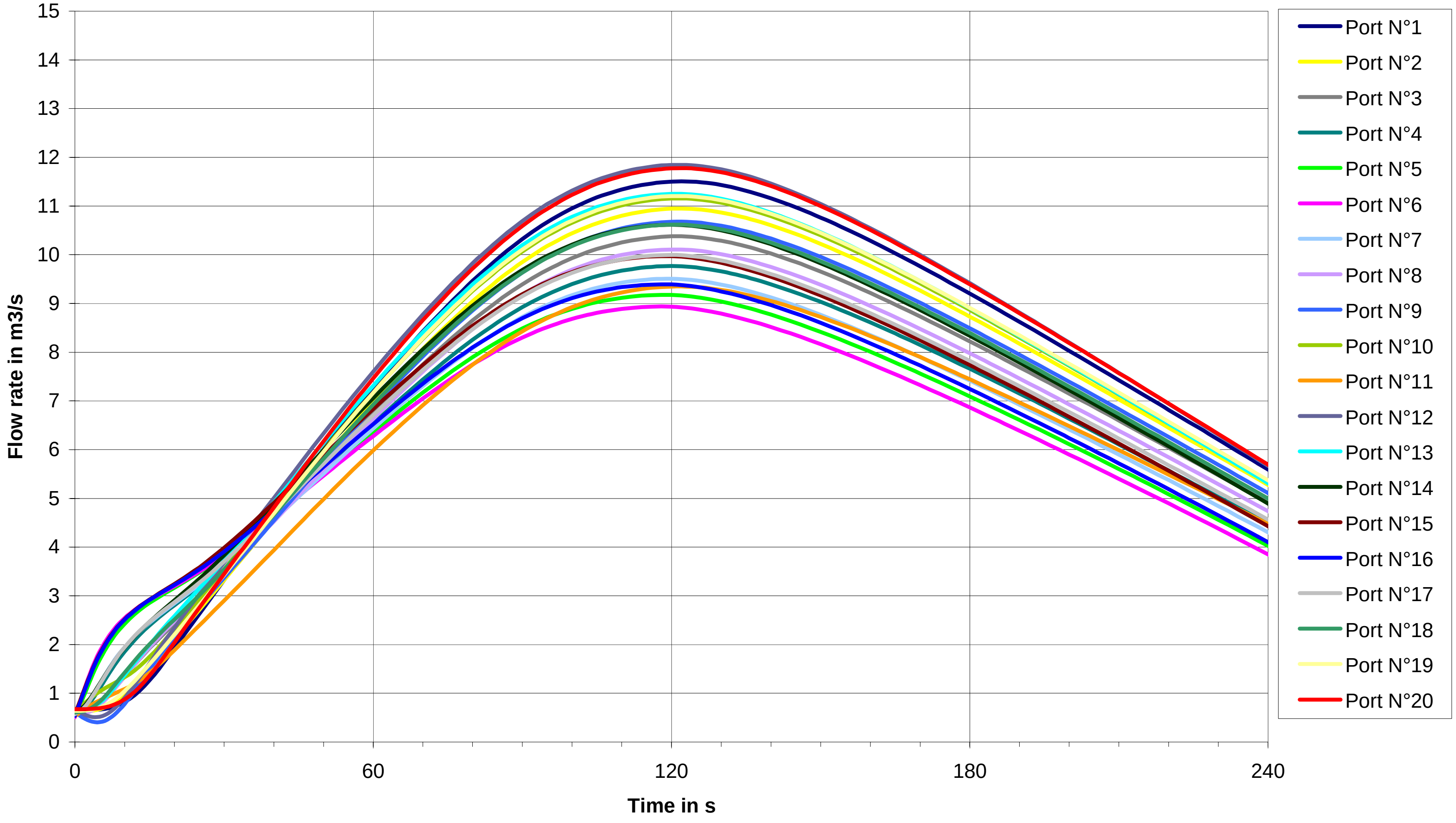

ATLANTIC SIDE - 2 WSB
Filling lower chamber - Velocity in the ports with max head (9.10 m)
Valve opening time 2 mn
Velocity rate in m/s
8
7
6
5
4
3
2
1
0
0
60
120
180
240
300
Time in s
Port N°1
Port N°2
Port N°3
Port N°4
Port N°5
Port N°6
Port N°7
Port N°8
Port N°9
Port N°10
Port N°11
Port N°12
Port N°13
Port N°14
Port N°15
Port N°16
Port N°17
Port N°18
Port N°19
Port N°20

Annex 11.3

ATLANTIC SIDE - 2 WSB
Filling lower chamber - Evolution of water surface with max head (9.10 m)
Valve opening time 2 mn



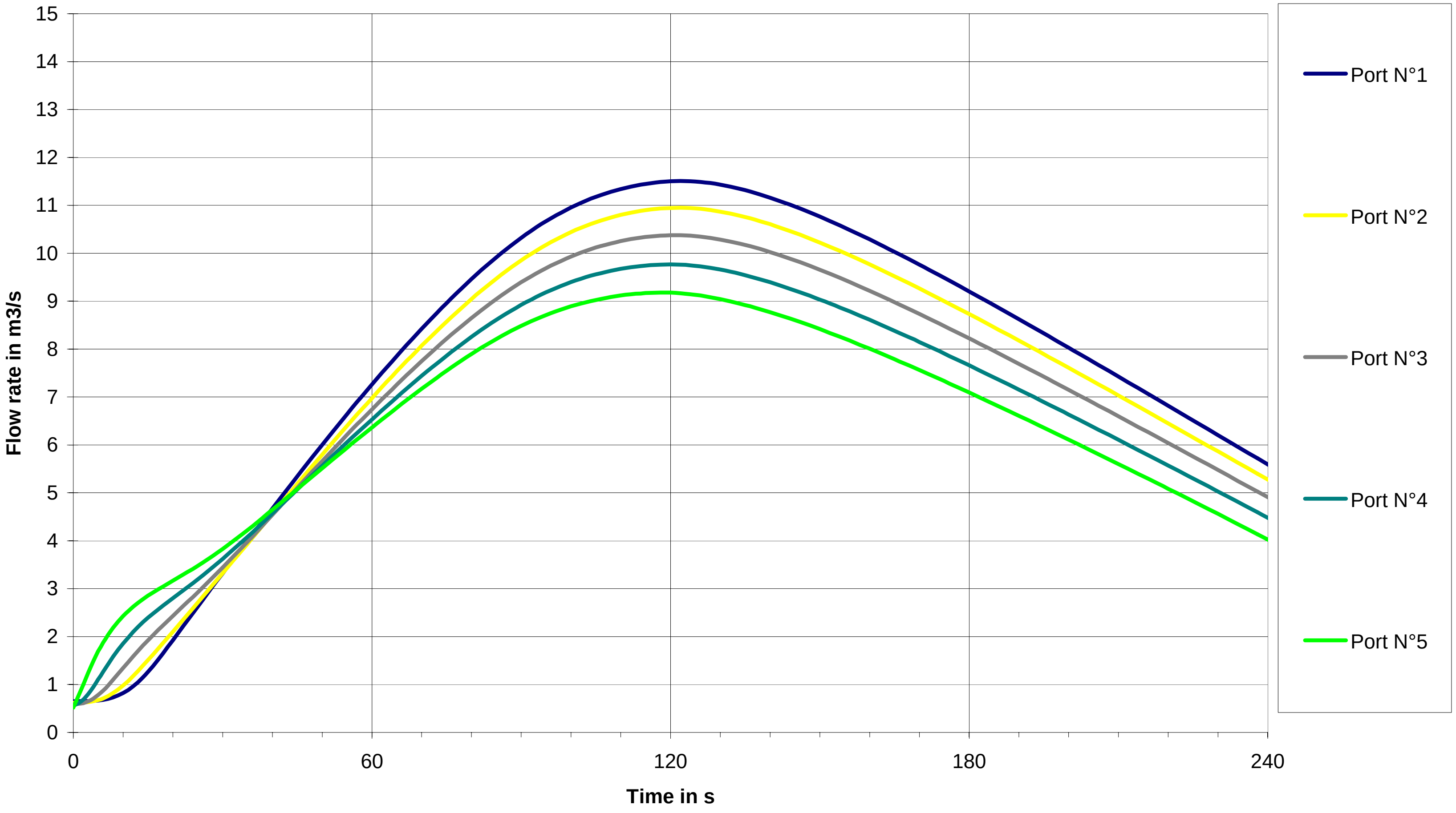
Annex 12.1



ATLANTIC SIDE - 2 WSB
Emptying Lower bottom WSB - Flow distribution between the ports with max head (4.90 m)
Valve opening time 2 mn

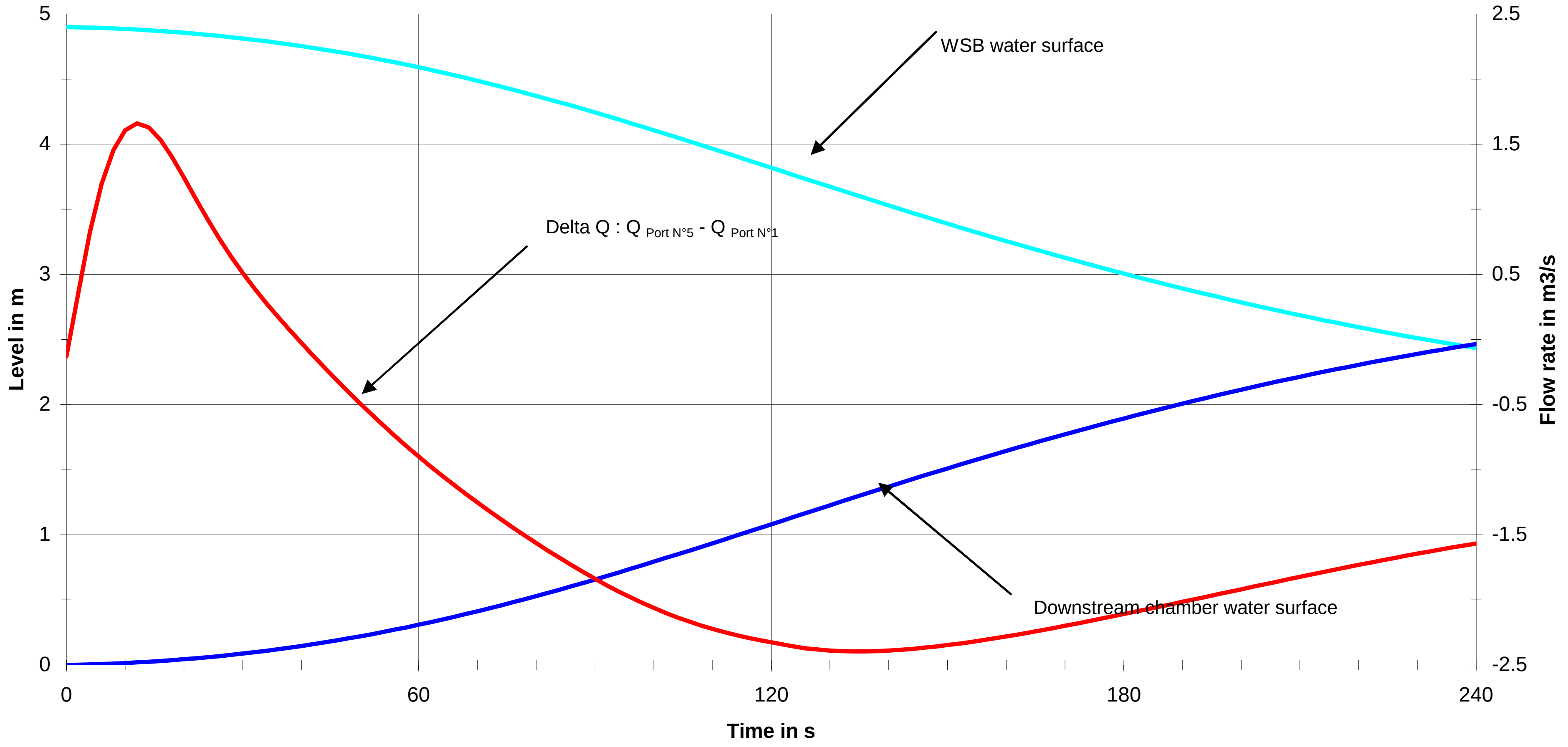
Annex 12.2

ATLANTIC SIDE - 2 WSB
Emptying Lower bottom WSB - Flow distribution between the ports with max head (4.90 m)
Valve opening time 2 mn



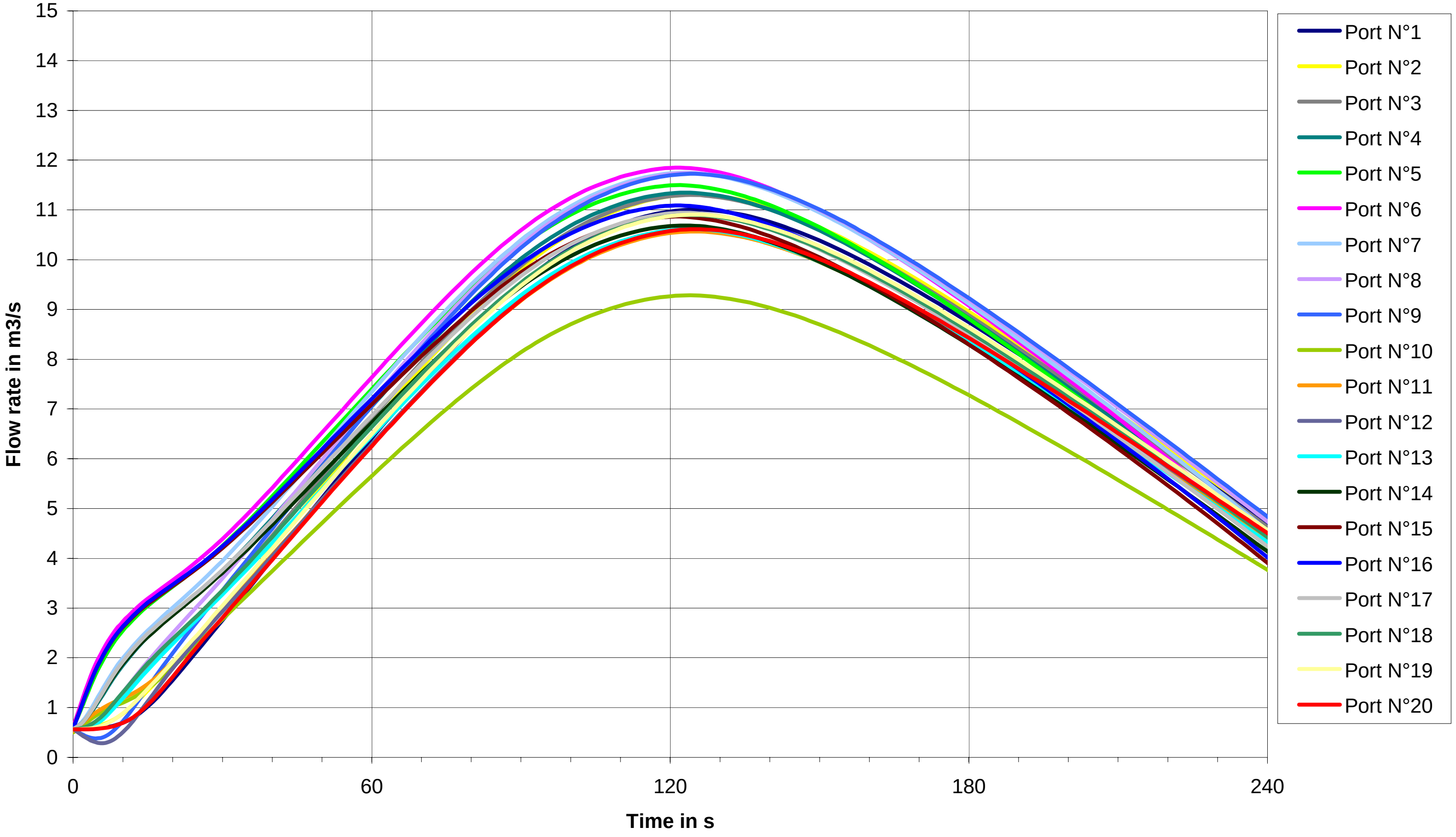
Annex 12.3

ATLANTIC SIDE - 2 WSB
Emptying Lower bottom WSB - Evolution of water surface with max head (4.90 m)
Valve opening time 2 mn



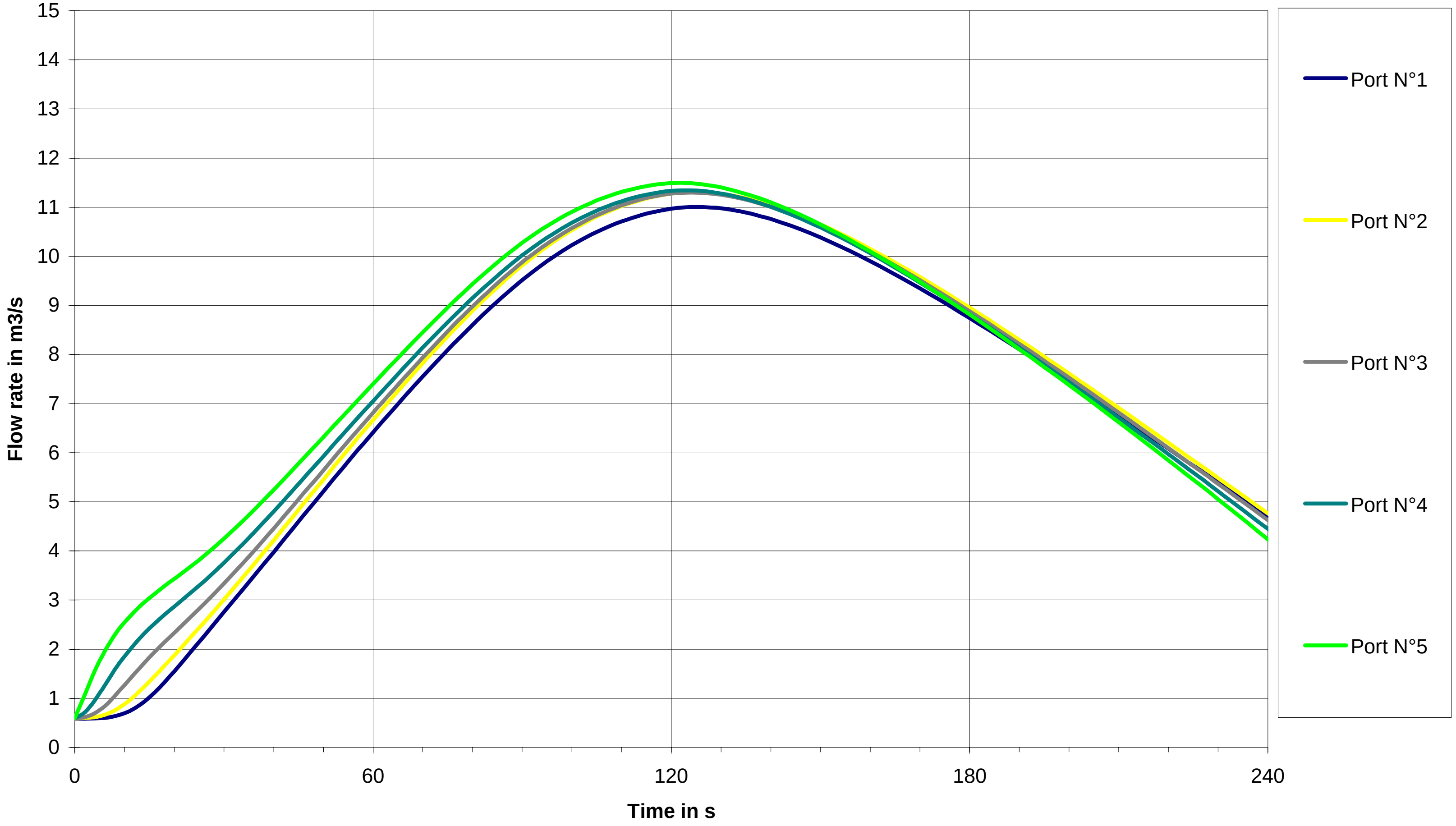
Annex 13.1

ATLANTIC SIDE - 2 WSB
Filling Lower bottom WSB - Flow distribution between the ports with max head (4.60 m)
Valve opening time 2 mn



Annex 13.2

ATLANTIC SIDE - 2 WSB
Filling Lower bottom WSB - Flow distribution between the ports with max head (4.60 m)
Valve opening time 2 mn



Annex 13.3

ATLANTIC SIDE - 2 WSB
Filling Lower bottom WSB - Evolution of water surface with max head (4.60 m)
Valve opening time 2 mn