BUILDING A DECISION SUPPORT SYSTEM FOR THE TERNEUZEN LOCKS : COMBINING OPTIMAL MANAGEMENT FOR WATER AND SHIPPING

by

Chantal Martens[1], Gert-Jan Liek[2], Dré Maes[3], Herman Haas[2], Maarten Deschamps[1], Leen Dekker[2], Harry van ' t Westeinde[2], Mario Vermeirssen[2], Harm Verbeek[2], Kees Storm[2]

ABSTRACT

The Terneuzen lock Complex in the Dutch city of Terneuzen gives access to the Ghent-Terneuzen Canal and thus to the port of Ghent (Belgium) from the Western Scheldt. Currently, the construction of a new lock is being prepared, which is expected to be operational in 2022.
In the context of the licensing process for the new lock, how to deal with the available (fresh)water in the most optimal way was examined. The quality values for water (mostly focusing on salt intrusion) must be met, together with the shipping requests and taking into account the daily water management issues of the Canal. Following the conclusions of an expert group, set up to optimize the use of the lock complex, the decision has been made to prepare for a Decision Support System for the Ghent-Terneuzen Canal, in a joint Flemish-Dutch collaboration. This DSS will provide the planners and operators with streamlined and uniform information and support them in the economic and ecologic optimisation of the daily operations of the lock complex.
The paper gives an overview of the background and the preparation phase of the DSS.

1. INTRODUCTION

1.1 The Ghent-Terneuzen Canal and the Terneuzen Locks

The Ghent-Terneuzen Canal is situated on Belgian and Dutch territory and was constructed between 1823 and 1825. It links the Harbours of Ghent and Terneuzen (North Sea Port) to the Western Scheldt and thus to the sea.

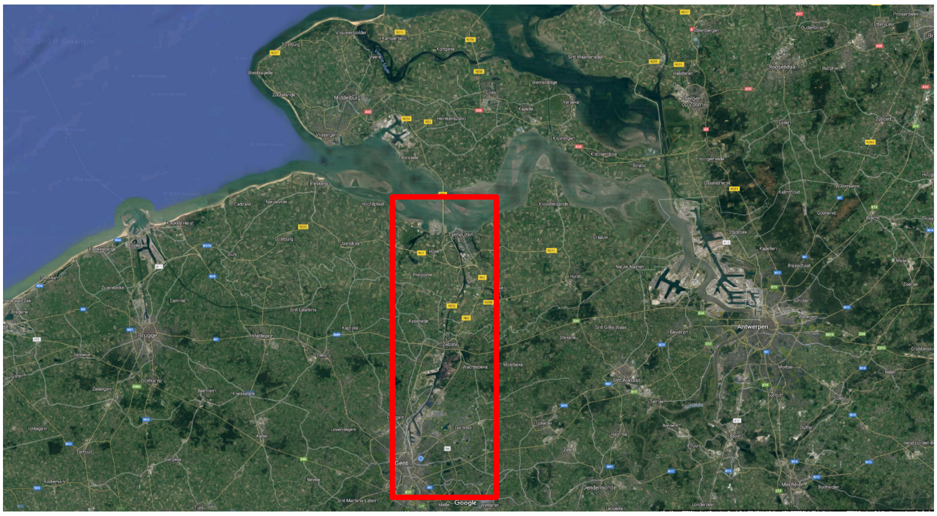

Figure 1 : The Ghent-Terneuzen Canal (in red), with the Western Scheldt and the North Sea (Google Maps)

The Canal ends, through the locks at Terneuzen, in the Western Scheldt as can be seen in Figure 1. The Western Scheldt is the mouth of the river Scheldt, and forms part of the Scheldt estuary. The Scheldt estuary has an average tidal range of 4 meters; and through its open connection with the North Sea it

[1] Flemish Government, Department of Mobility and Public Works, Chantal.martens@mow.vlaanderen.be
[2] Ministry of Infrastructure and Water Management, Rijkswaterstaat, The Netherlands
[3] Flemish Waterways NV, Belgium

has a gradual transition from seawater to freshwater. The salinity concentration near Terneuzen is on average between 10 and 15 g Cl-/L. The upstream border of the Canal, as mentioned, is the complex at Evergem. This consists of two segment weirs and two locks, to ensure the locking of inland vessels sailing between the Western Scheldt, the port of Ghent, the coastal harbours of Ostend/Bruges, and France via the rivers Lys en Upper-Scheldt. The first lock came into service in 1965. It is 16 m wide and 136 m long. The second lock, delivered in 2009, was constructed to accommodate inland barges up to 4400 tons, the adopted class for the new Seine-Scheldt link. Every year the locks are passed by about 30.000 vessels. The weirs deliver input of freshwater in the Ghent-Terneuzen Canal.

The current lock complex at Terneuzen consists of three locks. The oldest, called Middensluis, was opened in 1910, has a length of 140 meters and a width of 18 meters. The lock was renovated in 1986. In 1968 two new locks were opened. The Oostsluis or inland lock, which has a length of 280 meters and a width of 23 meters. The Westsluis or sea lock, which has a length of 290 meters and a width of 40 meters. It is suitable for seagoing vessels with a draught of up to 12.5 meters and a load capacity of 83,000 tonnes. At this lock, provisions have been made to prevent salt water from entering the Canal. Every year the locks are passed by about 10,000 seagoing vessels, more than 50,000 inland barges, and 3,000 recreational vessels.

Figure 2 shows the geographical situation of the Canal, and the location of the upstream locks at Evergem (Belgium) and the downstream locks at Terneuzen (Netherlands).

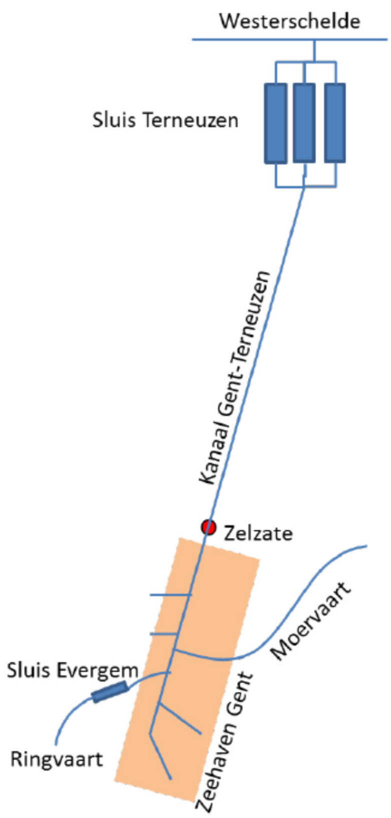

Figure 2 : schematic representation of the Ghent-Terneuzen Canal (Deltares, 2017)

The Canal has a total length of approximately 32 kilometres. Today, the water depth of the Canal is 13.50 m and the Canal is therefore accessible for ships up to 125,000 tons. The maximum dimensions of seagoing vessels are 265 * 34 * 12.50 meters. On Dutch territory the width at the bottom is 62 meters and at the water level 150 meters. In Flanders these dimensions are 67.7 meters and 200 meters, respectively.

A 1960 treaty between the two countries, with amendments in 1985, regulates the agreements on the water level, the supply of freshwater upstream and the available discharge capacity and minimization of the salt supply at the lock downstream.

The supply of freshwater to the Canal is controlled via the weir and locks at Evergem (Belgium), where water from Leie (Lys) and Schelde (Scheldt) is transported via the Ringvaart to the canal. Figure 3 gives the discharge distribution at the Evergem Weir. In addition to this, limited quantities of fresh water are also supplied via the Moervaart and the Avrijevaart (not on the map), which drain into the Canal. In addition to the shipping functionality, the canal is also important for the discharge of high waters and preventing flooding upstream. The average total yearly discharge is 24 m3/s, with maximum values reaching up to 150 m3/s in periods of high discharges from Lys and Scheldt (De Boeck et al, 2012) . During periods of high discharges, and depending on the intensity of the sluicing, the lock operations at Terneuzen can be suspended and shipping on the canal can be halted. During periods of low discharges and when the combined discharge of Lys and Scheldt are very low (order of magnitude 10-20 m3/s) the total discharge into the canal can be close to 0 m3/s.

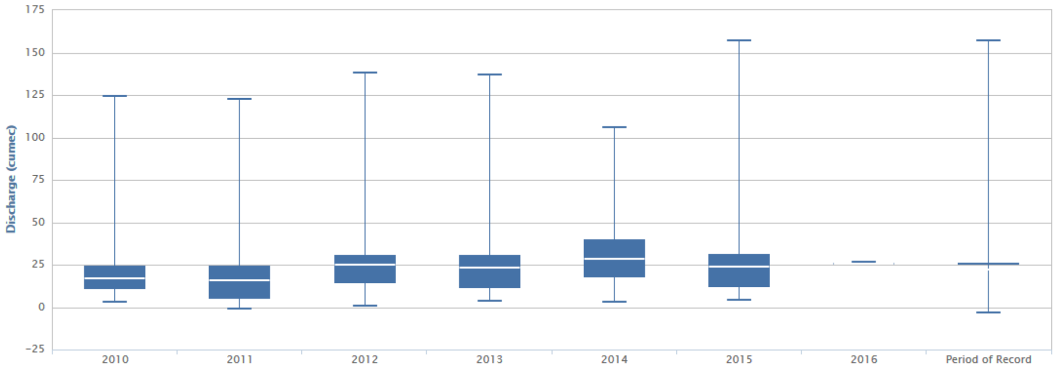

Figure 3 : discharge distribution at the Evergem weir (From waterinfo.be)

The water in the canal is brackish and is connected to the saline Western Scheldt through the locks in Terneuzen. The salinity in the Canal decreases in the upstream direction, and is highly dependent on the freshwater discharge as can be seen in Figure 4 and Figure 5 : during summer salinity increases and the salinity wedge moves in certain cases up to the beginning of the Canal in Ghent.

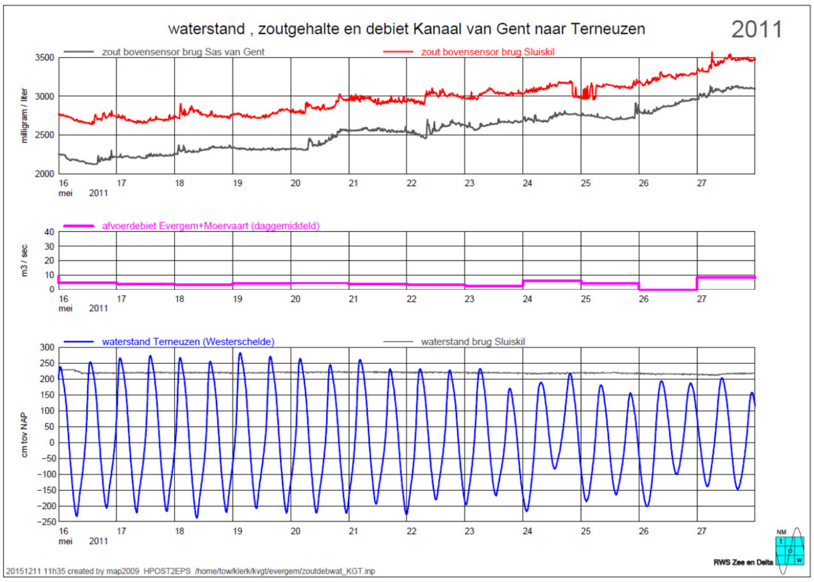

Figure 4 : Development of the chloride content at Sas van Gent and Sluiskil at a low freshwater supply (<10 m3 / s) to the canal. Water loss through lockage at the current complex is approximately the same or less than the supply to the canal. The result is a decreasing water level (Sluiskil) and rising chloride levels as a result of the salt load from the Western Scheldt. The ratio between the chloride content at Sas van Gent and Sluiskil is a fairly constant factor (around 0.8 to 0.9). (From Waterinfo.rws.nl)

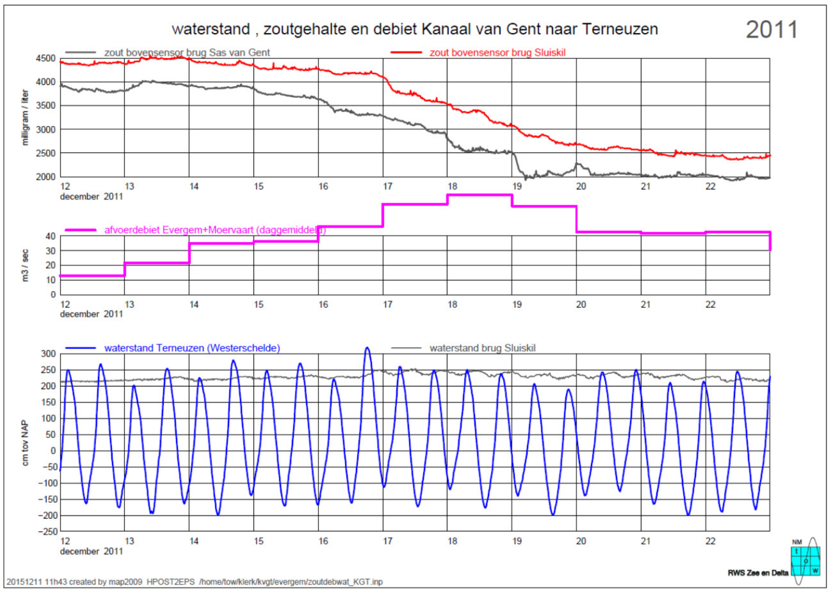

Figure 5 : Development of the chloride content at Sas van Gent and Sluiskil at a strongly increasing freshwater supply on the Canal. In this situation, there will high freshwater discharges. The result is an increasing water level and decreasing chloride content as a result of flushing the Canal (from waterinfo.rws.nl)

1.2 The New Lock at Terneuzen

In 2004, joint Dutch-Flemish research into the maritime accessibility of the Ghent-Terneuzen Canal was started. This research showed that the development potential of the Canal as a waterway was in the long run hampered by the dimensions, robustness and capacity of the current locks at Terneuzen. Further research in the subsequent years focused on the different possible solutions and in 2012 The Netherlands and Flanders agreed on building of new lock at Terneuzen. With the realization of the New Lock larger seagoing vessels can sail to the port of Ghent through the Ghent-Terneuzen Canal. The capacity of the lock complex also increases, which reduces the waiting time for inland vessels.

In 2017 the study phase and the permit process were completed and the construction of the New Lock was started. The lock is expected to be completed in 2022. The New Lock at Terneuzen is a Flemish-Dutch project, carried out by the Flemish-Dutch Scheldt Commission.

The lock will be 427 meters long, 55 meters wide and 16 meters deep and is shown in Figure 6. The dimensions correspond to those of the new locks of the Panama Canal.

Discharge and levelling is done through the lock gates. No infrastructural measures for salinity intrusion are built into the lock, but no-regret measures are taken during construction to be able to implement those later on, when necessary.

Figure 6 : sketch of the lock complex at Terneuzen. The New Lock will be constructed centrally in the complex and will replace the original Middensluis (VNSC, 2015)

1.3 Legal Framework and EIA process for the New Lock at Terneuzen

The project must comply with the applicable regulations, legal and administrative frameworks. For water management relevant frameworks are the Water Framework Directive, which for the Dutch part of the Canal stipulates that the three years averaged salinity should be between 300 and 3000 mg/l. It should be noted that the WFD salinity requirements only apply to the Dutch part of the Canal; the Flemish part does not impose any requirements on salinity. The 1960 treaty (Belgium and the Netherlands, 1960), defines the minimum and maximum water levels in the Canal and sets these at 2,13 NP +/- 25 cm. The treaty also contained agreements on the minimal amount of freshwater discharge, the measures against salinity intrusion and the available discharge capacity downstream.

The construction of the New Lock follows the Dutch procedures and an Environmental Impact Assessment was carried out.

For salinity, the EIA (VNSC, 2015) concluded that until 2050, the averaged salinity is expected to be within the WFD standard, also when the average discharge on the canal would decrease in summer, due to climate change. Permanent measurements and follow up are however essential to monitor the results of the EIA. It was noted that differences between individual years can be significant and that in individual years the salinity could be higher than 3000 mg/l. Exceeding the (3 year averaged) WFD salinity standard could lead to a (temporal) shutting of the lock procedures in order to minimize salt intrusion through the lock. Because of this, a number of trajectories have already been started in order to be optimally prepared for the future. No-regret measures are already being taken during the construction of the New Lock, to facilitate and simplify the implementation of salt separation measures in the future.

For water management, the EIA concluded that both high and low discharges will also lead to a limitation of lock operations in the future. The impact of the high water discharges on the operation of the New Lock will be limited (as discharge will take place mainly through the other 2 locks in the complex). But for low water discharges, the EIA calculated that locking operations in the New Lock would be halted for 4,3% of the time in order protect the water level in the canal from water loss through lockage.

In the longer term, the challenge to meet the prerequisites for water quantity and quality will increase. The EIA indicates that this will be after 2050, but this could also occur earlier, with an increase in shipping traffic and the frequent occurrence of long periods with low river discharge from Scheldt and Lys. The most critical are the situations where, as a result of prolonged low upstream supply from Evergem, there is both a low water level and a threat of exceeding the WFD standard. At those times shipping to and from the canal will be seriously hindered by the fact that on the one hand the operational minimal water level cannot be guaranteed, and on the other hand because the number of locking operations must be limited in order to counter the increasing salt load on the canal.

2. THE DECISION SUPPORT SYSTEM : TWO-PHASED APPROACH

Following the conclusions of the EIA study, a Flemish-Dutch group of experts was asked for guidelines to optimize the lock operations in function of minimum waiting times, optimal discharge planning and controlled salt intrusion. In the first instance the expert group focused on salinity, but given the issues concerning high discharges and low freshwater availability, and the necessary coordination needed for this between Flanders and the Netherlands, it was decided to take a broader approach in order to arrive at a number of guidelines for the operational management of the entire lock complex.

The final guidelines aim to:

- Respect the minimal and maximal canal level, as stipulated in the 1960 treaty
- Respect the norm for salinity, with respect to the WFD
- Ensure that ships pass through the complex as quickly as possible, with minimal waiting time

The expert group also came to the conclusion that, in order to be able to apply these agreed guidelines properly, a decision support system (DSS) would be a welcome aide. This DSS checks the boundary conditions for water management with the requests for shipping and delivers all information to the operator so that an objective choice for the optimal use of the lock complex can be made. In addition to this, the DSS also gives feedback to the operator on the consequences of the chosen lock operations on water quality (salinity) and water levels in the Canal.

The following paragraphs first zoom in on the work of the expert group, where the guidelines were drawn up; then look in more detail at technical preparation for the decision support system.

2.1 Expert group (2015-2016): guidelines

The expert group included representatives from both countries, from the water management, the lock management as well as the port authorities. The expert group focused on three scenarios, in addition to the standard use of the locks: (i) periods of high upstream discharge, (ii) periods of low upstream discharge and (iii) periods of high chloride content, as well as the possible combinations thereof. The working group has agreed on limit values for each of the possible scenarios to which actions are linked to ensure that the applicable boundary conditions for shipping and environment can be respected. For each of the three scenarios (high discharge, low water levels in the Canal and high salinity) management options were given and longer-term gradual measures were defined, with minimal disruption to shipping; in order to avoid that lock operations should experience an acute shut down because e.g. the salinity levels in the Canal were too high or the water level in the Canal too low. The expert group looked for a good balance between sufficient and timely intervention on the one hand and minimizing nuisance as much as possible on the other. Early intervention can lead to unnecessary delays for the vessels. To intervene too late, for example with regard to the underestimation of the minimum level, can lead to very long periods where only limited lockage is possible. The aim therefore was to provide guidance for pro-active water and navigational management, based on the relevant variables.

In general, this meant that for each of the three scenarios the expert group considered over which period certain processes can be allowed to comply with the prerequisites. This was done taking into account the boundary conditions and the relevant time period (for high water, this is obviously shorter than for a too high chloride content which reacts much more slowly). For example, in the event of low water levels in the Canal, it will be calculated how many of which type of lockage, with a certain amount of lockage water, can still be admitted over a certain period in order to avoid total blockage of the entire complex. The different lockage operations can be compared to building blocks; and these building blocks can in turn be used in different combinations to build an operational concept.

<u>High discharge scenario</u>

When high discharges occur, coming from upstream Lys and Scheldt, one or more locks need to be used for discharging and no ships can pass the lock. Modelling studie were carried out in the framework of the EIA to estimate the percentage of time that locks are blocked. Results showed that the total complex is blocked at 0 % of the time (i.e. there will always be a lock that is accessible to shipping), but individual locks can be blocked, so a careful planning is needed to minimize the impact of the high discharges on shipping.

The following measures can be taken

- Regulate the upstream discharge at the complex in Evergem (within the boundaries of flood safety)
- Preventive discharge through the locks in Terneuzen until a minimal water level of 2;05 mNAP in the Canal;
- Discharge through the complex in Terneuzen
    - Westsluis : via 2 circulation sewers
    - Oostsluis : via the lock gates
    - New Lock Terneuzen : via the lock gates

Year	Middensluis	Oostsluis	Westsluis	New Lock
current	2,1 %	0,0 %	0,5 %	-
2030	-	0,4%	3,2%	0,0%

Table 1 : percentage of time the lock complex is not accessible for ships due to high water discharges (VNSC, 2015b)

The decision whether there is high discharge scenario is taken based on the predicted discharges for the upcoming 48 hours. These discharges for the upcoming 48 hours are indicative, based on the expected discharge from Lys and Scheldt. It is possible to lower the water level in the canal, in the prospect of high discharges. This can be done 24 hours before an announced high discharge, taking into account the minimum defined water level and taking into account the seagoing traffic that is expected during that period. These discharges should take place when no hindrance for shipping is expected.

If the predictions indicate that the level will be above 2.38 mNAP within 48 hours if no action would be taken, then the high water scenario is activated.

Based on the predicted discharges and water levels on the canal, it is then calculated how many m3 is to be discharged over the next 48 hours. Taking into account the expected shipping traffic and the predicted water levels on the Western Scheldt (including tidal cycles), the provisional discharge targets for the next 24 and 12 hours are calculated. Based on these preliminary targets, the operator will check how the required discharge quantity for the next 24 and 12 hour period can be achieved with minimal hindrance for shipping. The assignment of seagoing vessels to a lock passage is done 6 hours in advance; the allocation of inland vessels to a lock passage is made 3 hours in advance. Within this period of six hours, the operator has only limited flexibility to adjust the discharge regime in view of the agreements with shipping.

The combination of the available information results in a preliminary distribution of the discharge over the different locks in the complex. The targets are updated regularly and tested against the expected shipping traffic.

In consultation with the sluice operation upstream in Evergem, the discharge target is further refined and a definitive discharge targets for a 3 and 6 hours periods are set.These targets are binding, which means that at that moment shipping is subordinate to the necessary discharge.

<u>Low water level scenario</u>

The water level in the Canal is regulated by the upstream freshwater discharge in Evergem and the downstream discharge in the Western Scheldt through the Terneuzen Lock complex. When the discharge through lockage water is higher than the upstream discharge, there is a nett loss and water level in the Canal will fall. The minimal water level in the Canal is agreed at 1,88 mNAP. However the larger sea-going vessels that access the harbour of Ghent need a minimal water level of 2 mNAP. Per nett 1 m3 / s loss per day, the water level on the Canal decreases by 1 cm per day. It is assumed that the water loss from lockage in the Terneuzen complex, including the New Lock, is on average 12 m3 /s with regular use of 3 locks and an average shipping intensity; during summertime the freshwater discharge can be as low as 5 m3/s. Research carried out in the framework of the EIA study showed that in 2030, the New Lock will be not accessible during 4,7 % of the time because of low water levels in the Canal.

Climate	Middensluis	Oostsluis	Westsluis	New Lock
current	0,0 %	0,0%	0,0%	-
2030	-	2,6%	0,8%	4,7%

Table 2 : percentage of time the lock complex is not accessible for ships due to low water levels (VNSC, 2015b)

The freshwater discharges are known up to 48 hours in advance. If the predictions show that the nett daily average loss of the next 48 hours will be more than 4m3/s for the same amount of lockage, then this scenario becomes active.

The following management measures are proposed (the order in which the measures are proposed is indicative, and can be adjusted by the operator according to the range of ships to be locked):

- Maximizing the freshwater discharge at Evergem (when available)
- Optimizing the lockage process (only passages with completely filled lock chambers);
- Only locking in the New Lock if the water level in Western Scheldt is the same or higher than in the Canal, causing no nett loss
- •Only locking in the Oostsluis if the water level in Western Scheldt is the same or higher than in the Canal, causing no nett loss
- Only locking in the Westsluis if the water level in Western Scheldt is the same or higher than in the Canal, causing no nett loss
- Depth restriction for the (sea) shipping in the Canal;
- Aim for a level of 2.30 mNAP in the period from 1 April to 31 October in so far as the impact to navigation (taking into account the height restrictions for bridges further upstream); and connected watercourses remains limited.

In addition to this, restrictions on the maximum allowed nett freshwater loss were defined.

Two options are possible: when prioritizing seagoing vessels (requiring a minimum depth of 2.00 NAP), the nett loss of water will be limited to 0 m3 / s from 1.95 mNAP. In prioritizing the levels from the treaty (1.88 mNAP), some loss will be allowed at that time.

Water level in the canal	**Management measures to reduce water loss and maintain water level in the Canal**
Higher than 2,30 mNAP	No limitations on lockage water
Between 2,20 mNAP and 2,30 mNAP	Maximum nett loss through lockage (next 24 h) **3.5 m^3/s**
between 2,13 mNAP and 2,20 mNAP	Maximum nett loss through lockage (next 24 h) **3 m^3/s**
between 1,95 mNAP and 2,13 mNAP	Maximum nett loss through lockage (next 24 h) **2 m^3/s**
between 1,88 mNAP and1,95 mNAP	*In accordance with the 1960 treaty* : **1 m^3/s**

	Taking into account seagoing ships : **0 m³/s**
Water level Canal below 1,88 mNAP	No loss through lockage allowed

Table 3 : overview of maximum allowed nett loss of freshwater, related to the water level in the canal

Comparable to the salt load, the available space (defined by this maximum permissible lockage loss per day) is built up from a combination of a number of "building blocks". These building blocks consist of lockage with a certain lock, at high water, low water and average water levels on the Western Scheldt, each with an associated nett loss of fresh water. Which of these building blocks are used is free for the operator to choose and decide on the basis of the types and intensity of shipping.

High summer-average chloride levels

The WFD standard stipulates that the three year summer average (from 1 April to 30 September) must be between 300-3000 mg / l at the measurement point at Sas van Gent. This means that controlling the chloride content in the Canal requires an especially long-term planning.

If the forecasts of the triennial average, calculated at the end of the summer and based on the projection based on the current chloride content, show that the three-yearly average chloride content is higher than the permitted chlorides standard, this scenario becomes active.

The following management measures are implemented:

- Maximizing the freshwater discharge at Evergem (when available)
- Optimizing the lockage process (only passages with completely filled lock chambers);
  - Use the New Lock for the larger ships, taking into account the available salt balance. A possibility to limit the salt load is to restrict use around high water.
  - Use Oostsluis for shipping, taking into account the available salt balance. A possibility to limit the salt load is to restrict use around high water.
  - Use Westsluis for shipping, taking into account the available salt balance. A possibility to limit the salt load is to restrict use around high water.
  - Blocking lockage

Based on the actual salinity in the Western Scheldt and the Canal and on the projected salinity at the end of the summer of the current year, the projected triennial average salinity can be calculated. From this, the available salt balance for the current summer can be calculated. This available salt balance for the current summer can then be translated, on a weekly basis, to an admissible number of kg of salt / day (salt load). This permitted amount of salt per day can be adjusted weekly on the basis of the available data for the salinity and the increasingly accurate predictions for the available freshwater discharges. If significant changes occur in the boundary conditions (e.g. sudden dry period, or sudden wet period), the permitted salt load may be revised after 48 hours.

The salt load per day can in turn be filled in with a certain number of lockages whereby for each of the locks in the Terneuzen complex a salt load is determined. The absolute salt load per lockage per lock will be determined as a fixed value, based on modelling. These values will be further refined after a certain period on the basis of monitoring and advancing insight.

2.2 Technical preparation group (2016-2018): practical implementation

Following the suggestion of the expert group, that a DSS could be a valuable tool, further steps were taken towards the realization of such an advisory tool, which will support the choice of the operators on the use of the locks in Terneuzen under a given range of ships and hydrological boundary conditions (upstream discharge and water height in the Western Scheldt and the Canal).

As with the expert group, the technical group consisted of specialists in shipping and water management for both countries, and representatives for the management of the lock complexes. The technical preparation group looked further into the technical requirements to implement the guidelines formulated by the expert group in a decision support system.

2.2.1 Data streams

As a first step, the necessary data streams and their respective frequency updates were identified. The DSS needs information on the hydrodynamic boundary conditions (water levels, predicted and expected discharges), water quality information (mainly for salinity) and shipping information. This information is provided by operational models and forecasts, in-situ measurements and existing tools for planning of the lockages.

Operational models and input from the lock operators upstream

The prediction values for freshwater discharges and water levels in the Canal for the Flemish section of the Canal are provided through a link with the HIC system. Upstream regulations of weirs will be assessed by the Flemish inland navigation authority to deliver a more definitive short term prediction for the freshwater discharge. This (with expert judgment) enriched information will be transmitted to the DSS by the River Information Service operators in Evergem.

The Hydrological Information Centre (HIC) is an operational service of the Flanders Hydraulics Laboratory which is part of the department of Mobility and Public Works of the Flemish administration. The HIC is responsible for measuring and predicting water levels and discharges on the navigable waterways in Flanders. It has an extensive monitoring network for this. These measurements are recorded via a telemetry system in the HIC databases. For all navigable waterways with a water management problem (with a focus on flooding) the HIC has also developed prediction models (computer models based on Mike11) with which water levels and discharges are predicted. This information (both measurements and predictions) is used to inform and warn the Flemish waterway authorities in the event of imminent flooding. This system is currently a combination of two types of models (Mike11 and Waqua) that operate within different operating shells (Floodwatch, Nautboom / Simona). The Floodwatch system is replaced by a FEWS system. It is from this system that predictions (via FTP or web services) will be made available to the DSS.

Information is exchanged every six hours with the HIC system; information on the discharges is exchanged every three hours with the operators of the upstream lock.

The communication with HIC is a two way communication. The DSS also returns data to the HIC system: the use of the locks is fed back into the operational models of the HIC system so that the predictions can be updated.

In-situ measurements and predictions

The measurement data and forecasts for the Dutch section of the Ghent-Terneuzen Canal will be provided through a link with the LMW (Landelijke Meetnet Water). The National Water Monitoring Network (LMW) is a facility of the Dutch central government that is responsible for the collection, storage and distribution of water management data. These are hydrological data such as water height, flow rate, water temperature and conductivity, and meteorological data such as wind speed and wind direction.For the DSS, the most important data from LMW are the water levels in Western Scheldt.

The communication is one-way: there is no feedback from the DSS to LMW.

Shipping information

The GTi-Tool was developed in 2012 in cooperation and coordination between the port and waterway managers, pilots, towage services and the business community. The tool is currently used for the lock planning of seagoing vessels in the locks of Terneuzen, but an extension of the tool for inland navigation is being developed at the moment. This extension will initially be used during the construction of the New Lock, to minimize hindrance to shipping. After completion of this development, the tool will be called Gti+. The GTi-Tool works on a time resolution of minutes. A lockage takes usually less than an hour and depends on the lock and the properties of the ships.

Seagoing vessels receive a confirmed time for lockage at least six hours in advance, for inland ships this is 3 hours. This means that, for inland shipping, the lock operations will be fixed from the current time to 3 hours in the future and for shipping up to 6 hours. Over a time horizon greater than the next 3 (inland shipping) resp. 6 (seagoing) hours the lock planning is still flexible.

The communication with GTI is two–way: GTI provides the DSS, in 15 minute intervals, with the information on the planned seagoing and inland ships. The DSS provides GTI with information on the time windows where locks are not available, so that the ships can be planned around these time windows.

2.2.1 Development options

For the implementation of the DSS the following options were worked out, from relatively simple (1) to very complete (3) (Deltares, 2017):

- (1) A hydraulic model, where the choices the operators make for lockage are checked against the operational preconditions. This should be considered a feedback module, rather than a decision support module
- (2) An advisory module that performs optimization on hydraulics and water quality (advice discharge, lockage) under a certain distribution of ships in the lock complex.
- (3) An advisory module that maximally optimizes both hydraulics and shipping (advice discharge, lockage and distribution of ships over the locks).

For further development, option 2 was chosen. Not only because the cost for option 3 was considerably higher, but also because the expertise of the operators have with regard to the optimal distribution of the ships should be used maximally and that this expertise is very difficult to capture in an algorithm.

Option 2 consists of a combination of an optimization tool and a hydraulic model. The combination of optimization algorithm and a matching hydraulic model is suitable to give advice on the use of the lock chambers. The planning for lockages is taken from the GTi tool and is therefore not part of the optimization.

The hydraulic boundary conditions are upstream freshwater flow and the water level in the Western Scheldt. Boundary conditions for the optimization are the operational objectives and limit values for the hydraulics and shipping planning from the GTiTool. The result of the advisory module is a proposal for lock use that meets the operational objectives and hydraulic limit values, if this is physically possible. The user can indicate a prioritization for the different operational purposes and limit values.

The hydraulic model is executed several times in succession (approx. 30 to 100 times), for this reason a simplified model is proposed; to further increase the calculation speed of the advisory module, a commercial solver will be used.

3. THE DECISION SUPPORT SYSTEM : FEATURES AND APPLICATIONS

The first goal of the DSS is to provide the lock operator with an awareness of the current scenario, whether that be high water, low water, high salinity or regular, and then to provide him with a standardized, uniform overview of all relevant parameters for that scenario : discharge quantities, water levels, forecasted discharges, shipping traffic,…etc.

In addition to raising awareness the DSS will provide the operator with a proposal for the use of the lock complex over different time scales; and the DSS will, when requested, provide the operator with all the underlying relevant information. The final decision on how to operate the lock complex lies with the operator; the DSS provides support in applying the management rules and ensures that the necessary information is provided uniformly and objectively.

Operation of the DSS will be done according to the following step, see also the schematic representation in Figure 7.

1. Calculation of the advice of DSS under the given boundary conditions and the demands for lockage. If no conflicts emerge and all requests can be met, the locks can be used for shipping and water management as planned.
2. If adjustments to the use of the locks are necessary, the advisory module initially provides advice on the use of the locks in a fixed sequence, the so-called standard solution. The standard sequence for the deployment of locks for high discharges, for example, Westsluis, Oostsluis, New Lock. Other orders apply to other situations.
3. If the standard solution is not satisfactory, the fixed sequence is released and the operator can decide which lock is to be used for which purpose (shipping, discharges, etc).For this, the DDS will provide the necessary information (for example discharge targets, (actual) discharge capacities per lock, salt loads per lockage, planned ships).
4. The DSS calculates the operator's proposal based on the current hydraulic data available in the DSS and shows the results to the operator.

5. The operator finalizes his choice and passes on the necessary lock management commands via the existing paths. The other relevant data (lock use, discharge volume) are transferred to other systems (HIC system, GTI tool).

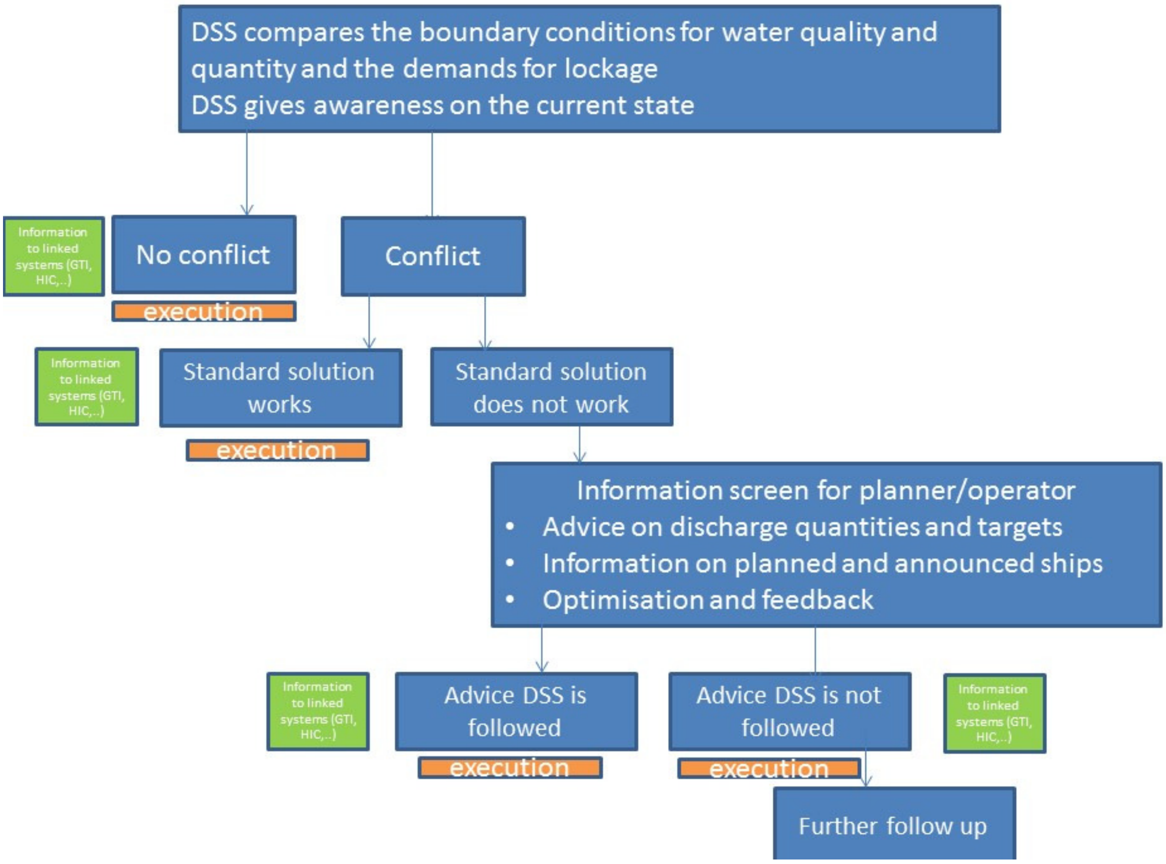

Figure 7 : schematic representation of DDS flow chart

The DSS gives also options for reporting and evaluation, which gives possibilities for optimisation of lock and weir-management up- and downstream the canal.

4. **NEXT STEPS**

The development of the DSS is expected to start 2nd half of 2018 in order to possess an operational system when the New Lock is taken into use in 2022. Testing of the DSS is expected to take place during the construction of the New Lock

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