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Faculty of Civil Engineering
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Thesis Report

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Thesis subject:	Design of the bottom protection length of the closure dam of the Shiwa Tidal Basin

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Abstract

When designing the bottom protection of the closure dam of the Shiwa tidal basin, the hydraulic conditions at the site, the so called local hydraulic conditions must be known. These data can be obtained by making a model of the region in accordance with the geometry of the region, using the general hydraulic data such as appearing tide and upland flow as boundary condition. In this case, the model has been made with the help of the one dimensional computer package DUFLOW. The region has been schematized as a network of sections and nodes. With a tide, composed of the tidal constituents from the Admiralty Tide Tables given as a boundary condition, the tidal propagation has been studied. The resulting propagation of the tide appeared to be satisfactory. Therefore the model is used to simulate the different closure phases to obtain the local hydraulic data.

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1 Introduction

In the introduction of the main-report on the closure of the Shiwa Tidal Basin has been explained that my thesis study consists of designing the closure dam and its bottom protection according to Dutch design standards.
To design such a closure dam, it is necessary to know the local hydraulic conditions at the site during every phase of the closure. These local hydraulic conditions depend on the geometry of the region and the general hydraulic data such as the appearing tide, and the upland flow.
The required local data can be obtained by making a model in accordance with the geometry of the region, using the general hydraulic data as boundary conditions. This report discusses how a model of the region is made and what the results are.

In general, several options are available for making a model. At first there is the possibility of making a three-dimensional scale model. This is however very expensive and requires much labour and time. Three-dimensional numerical models can not be used in this case as the region is far too extensive. A more economic and easy option is to use an existing two- or one-dimensional computer model. Two-dimensional models give more accurate results than one-dimensional, but they also need much more data. As this detailed data is not available, it is questionable to use a two-dimensional model. Therefore, the one-dimensional computer package DUFLOW has been chosen. In chapter 2, some information about the use of this pc package is given.

The bounds of the model, i.e. the coastline of the basin, the tidal flats at the west and the two entrances near to the island Tokchok To are described in chapter 3. Within these bounds, a network of nodes and sections is designed in accordance with the geometry of the basin. At the place where the closure is planned, the sections are defined in such a way that weirs can be added. With these weirs the different closure phases can be simulated. To get a first impression about the tidal propagation, simulations have been carried-out with one single sine function as tidal boundary condition. The results are checked with manual calculations and with an adherent module of the DUFLOW package, EC DUFLOW. The results of this comparison are discussed in chapter 4. Subsequently simulations have been made with a double sine function as tidal boundary condition, as a good approximation of the appearing tide. These results are discussed in chapter 4 as well.

Chapter 5, finally describes the value of this model, the reliability of the results and recommendations for improvements.

2 Description and use of the DUFLOW package.

2.1 The unsteady flow equations

DUFLOW is a one-dimensional computer package for the computation of unsteady flow in networks of open channels.
The DUFLOW computer package has been developed with the support of three Dutch institutes:

The International Institute for Hydraulic and Environmental Engineering (IHE), Delft,
Rijkswaterstaat (Department of Public Works), Tidal Water Division, The Hague, and
The Delft University of Technology, Faculty of Civil Engineering.

The DUFLOW package is based on the following equations, describing the conservation of mass and momentum:

$$B \cdot \frac{\delta H}{\delta t} + \frac{\delta Q}{\delta x} = 0 \tag{1}$$

and

$$\frac{\delta Q}{\delta t} + \frac{\delta(\alpha Q v)}{\delta x} + gA\frac{\delta H}{\delta x} + \frac{g|Q|Q}{C^2 AR} = 0 \tag{2}$$

(neglecting the influence of wind friction)

with the relation:

$$Q = v.A \tag{3}$$

Where:

x	=	distance along the channel axis [m]
t	=	time [s]
H(x,t)	=	water level with respect to reference level [m]
B(x,H)	=	cross sectional storage width [m]
Q(x,t)	=	discharge at location x and time t [m^3/s]
α	=	correction factor for non-uniformity of the velocity distribution in the advective term
g	=	acceleration due to gravity [m/s^2]
v(x,t)	=	mean velocity [m/s]
A(x,H)	=	cross sectional flow area [m^2]

C = Chézy coefficient [$m^{1/2}/s$]
R(x,H) = hydraulic radius of a cross section [m].

The mass equation (1) states that if the water level changes at some location this will be the net result of local inflow minus outflow. The momentum equation (2) expresses that the net change of momentum is the result of interior and exterior forces like friction, wind and gravity.
For the derivation of these equations it is assumed that the fluid is well mixed and therefore the density may be considered as constant.

2.2 Discretization of unsteady flow equations

Equations (1) and (2) are discretized in space and time using the four-point implicit Preissman scheme.

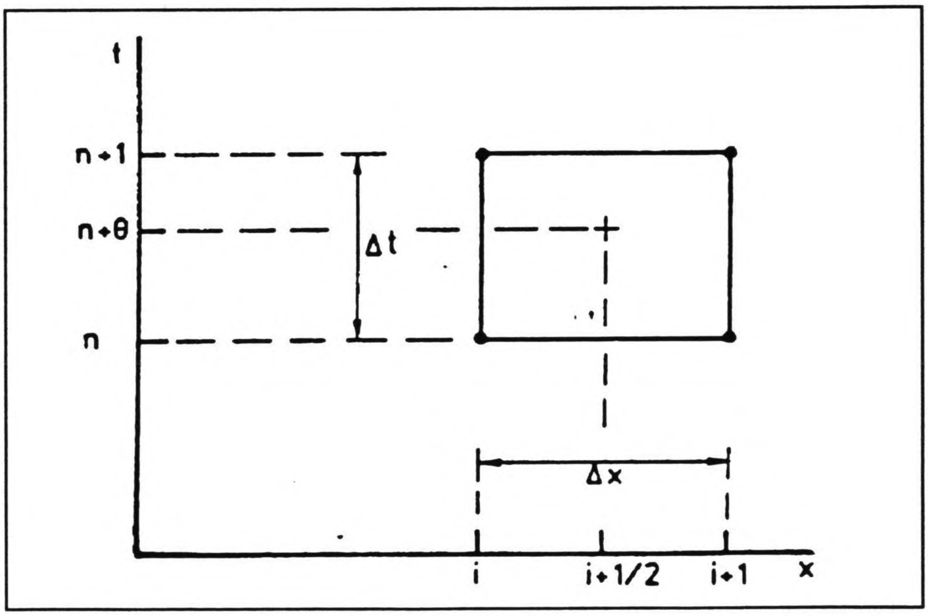

***Figure 2.1:** Preissman scheme*

Defining a section xi from node x_i to node x_{i+1} and a time interval Δt from time t = t^n to time t = t^{n+1}, the discretization of the water level H can be expressed as:

$$H_i^{n+\theta} = (1-\theta)\ H_i^n + \theta\ H_i^{n+1} \tag{4}$$

at node x_i and time t + $\theta.\Delta t$

and:

$$H^n_{i+\frac{1}{2}} = \frac{1}{2} (H^n_{i+1} + H^n_i) \tag{5}$$

in between node's x_i and x_{i+1} at time t.

The transformed partial differential equations can be written as a system of algebraic equations by replacing the derivatives by finite difference expressions. These expressions approximate the derivatives at the point of references ($x_{i+1/2}$, $t^{n+\theta}$) as shown in Figure 2.1

Equation (1) is transformed into:

$$B^*_{i+\frac{1}{2}} \frac{H^{n+1}_{i+\frac{1}{2}} - H^n_{i+\frac{1}{2}}}{\Delta t} + \frac{Q^{n+\theta}_{i+1} - Q^{n+\theta}_i}{\Delta x_i} = 0 \tag{6}$$

and equation (2) into:

$$\frac{Q^{n+1}_{i+\frac{1}{2}} - Q^n_{i+\frac{1}{2}}}{\Delta t} + g\, A^*_{i+\frac{1}{2}} \frac{(H^{n+\theta}_{i+1} - H^{n+\theta}_i)}{\Delta x_i} +$$

$$+ \frac{\alpha(\frac{Q^n_{i+1}}{A^*_{i+1}} Q^{n+1}_{i+1} - \frac{Q^n_i}{A^*_i} Q^{n+1}_i)}{\Delta x_i} + g \frac{Q^{n+1}_{i+\frac{1}{2}} |Q|}{(C^2 A R)^*_{i+\frac{1}{2}}} = 0 \tag{7}$$

The (*) expresses that these values are approximated at time $t^{n+\theta}$. This discretization is of second order in time and place when the value $\theta = 0.5$. It can be shown that in this case the discretized system is mass-conservative. In most applications, a somewhat larger θ value, such as 0.55 is used to obtain stability.

The values indicated with a (*) can be computed using an iterative process. For example, a first approximation of B is:

$$B^* = B^n$$

Which is adjusted in a subsequent iteration step:

$$B^* = ½(B^n + B^{n+1,*})$$

Where $B^{n+1,*}$ is the new computed value of B^{n+1}.

Finally, for all channel sections in the network two equations are formed which have Q and H as unknowns on the new time level t^{n+1}:

$$\begin{aligned} Q_i^{n+1} &= N_{11}\, H_i^{n+1} + N_{12}\, H_{i+1}^{n+1} + N_{13} \\ Q_{i+1}^{n+1} &= N_{12}\, H_i^{n+1} + N_{22}\, H_{i+1}^{n+1} + N_{23} \end{aligned} \qquad \textbf{(3)}$$

2.3 Solving the set of equations

A network as a whole is a system of sections and nodes, where each channel section or control structure is considered as a separate item. Each section or node of the network has a unique identification number, assigned by the user. The structure of the system is implicitly defined by the user specification of node numbers at both ends of the section. The number of unknowns is in principle equal to 2*J+I, where J is the number of sections and I the number of nodes; in each branch the unknowns are the discharges at both ends and at each node the water level. At structure sections the discharge at the beginning and end node is the same.

The number of equations is also 2*J+I; for each channel section j, two equations are derived, following from the mass and momentum equations (6) and (7). At structures only the momentum equation is applied as the mass equation can be neglected because of the no-storage condition. At each node there is a balance equation for the discharges (which says that at every node Q_{in} - Q_{out} = 0), since it is assumed according to the four-point method that the storage of water takes place inside the branches, and not at the nodes. At boundary defined nodes an additional boundary condition has to be specified so there is one equation for each node.

2.4 Structures

DUFLOW offers the option to define various types of structures such as weirs, culverts, siphons and pumping stations. At weirs and other structures discharges and levels can be controlled by manipulating the gates. A common characteristic of structures is that the storage of water inside the structure is negligible compared with the storage in the open channels.In this case of the closure of the Shiwa tidal basin, only weirs have been applied. The other structures will therefore not be discussed.

The discharge over a weir depends on the water level at both sides, the level of the sill, type of structures and the flow conditions (free surface or submerged flow). Figure 2.2 shows an example of the two types of overflow that occur in the case of the closure of the Shiwa tidal basin. All other possibilities will not be discussed as only a free surface is applied.
The general equation for the discharge over the weir reads:

$$Q^{n+1} = \mu B\ H \sqrt{2g\ \Delta H} \tag{4}$$

Where:
B = the width of the weir
μ = the discharge coefficient
H = the water depth above the sill
ΔH= water level difference over the sill

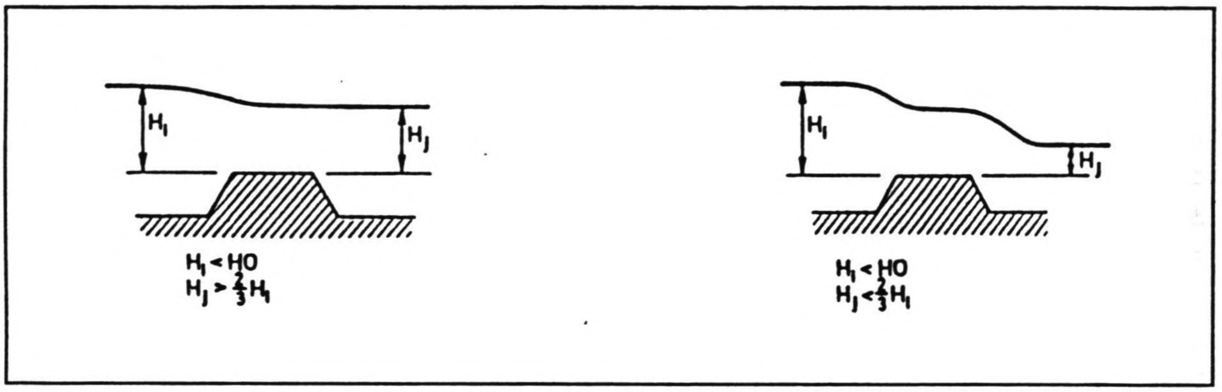

Figure 2.2: Two types of weirs, without and with a situation of free overflow

3 Schematization of the Shiwa Tidal Basin

3.1 Introduction

As the present three-dimensional situation will be schematized with a one-dimensional model, the real situation must be simplified. The direction of the flow is along the axis of a section. Therefore the sections must be set in the axis of the gullies in which the main-flow is expected to take place. No flow perpendicalar to the gully axis can take place and the influence of the Coriolis-force can not be taken into account. Finally the ebb-flow occurs in the same gullies as the flood-flow.
In this chapter, the schematization of the area will be discussed as follows: In paragraph 3.2, the bounds of the area (see Figure 3.6) will be determined. Within these bounds, the area is schematized as a network, consisting of sections and nodes. This is described in paragraph 3.3. Next, in paragraph 3.4 the cross sectional profile in every node is determined after which in paragraph 3.5 the boundary conditions are discussed. Then in paragraph 3.6 the network is adapted so weirs can be added to simulate all closure phases. Finally, in paragraph 3.7 the model is more or less calibrated with the tidal data given by the Admiralty Tide Tables so the model gives satisfactory results.

3.2 Bounds of the model

To keep the model as simple as possible, the area to be schematized must be as small as possible. At the other hand, the bounds of the model must be remote enough from the site for not being influenced by the closure. The area is limited in the east by the coast-line and in the north by the smallest part of the river. Between the islands Tokchok To and Taemuui Do, the shallow part over the shoals is taken as the north-western bound of the area. At the south-west, two main gullies enter the area near the island Tokchok To. As at Tokchok To tidal data is available, this point is taken as the south-western bound.

3.3 Schematization of the area

Within the determined bounds, with the help of a bathymetric chart the main gullies in which the flow is expected to take place are defined as channels. The length of these channels may not be too small to avoid unnecessary complexity of the model. However, they may not be too long as well because they have to give an approximation of the real situation. The two stations where tidal data is available, Taemuui Do and Inch'On, must be part of the model because this data can be used to check the model. At the location where the closure is planned, weirs have to be added to the sections that cross the dam

alignment. With these weirs, the flow width of the closure gap can be varied according to the closure strategy.
A weir must be located between two nodes so in section 27 and 43, this option has been implemented.
As can be seen in Figure 3.1 and Figure 3.2, the bottom level is not constant over the width. Therefore, more than one weir is added since only one sill level can be set per weir. These weirs are connected parallel between two nodes.

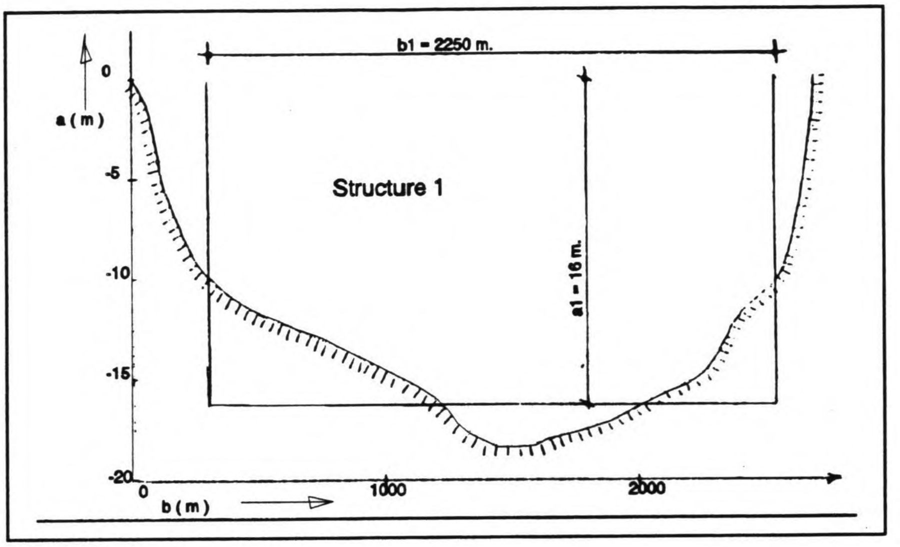

***Figure 3.1:** Bottom profile of the southern weir*

To determine the size of the weirs, first a more detailed schematization of the bottom has to be made, which is also demonstrated in Figure 3.1 and Figure 3.2.

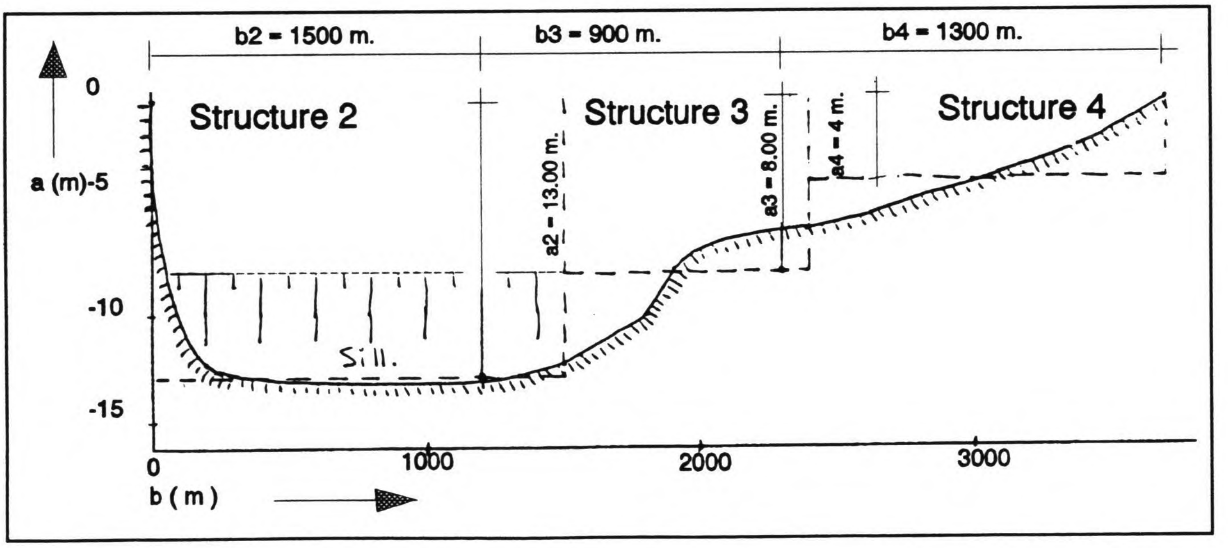

***Figure 3.2:** Bottom profile of the northern weir*

With the weirs added to the scheme, the flow velocities that occur during every phase of the closure can be calculated. As can be seen in Figure 3.3, a shunt is created between node 44 and 46. This is done to avoid that large water level differences occur between weir 1 and weir 2, 3 and 4. The schematization of the area resulted in a network consisting of 42 nodes, connecting 45 channels, see Figure 3.6. The coordinates of the nodes are related to a local coordinate system. The X-axis is pointed towards the east and the Y-axis points to the north.

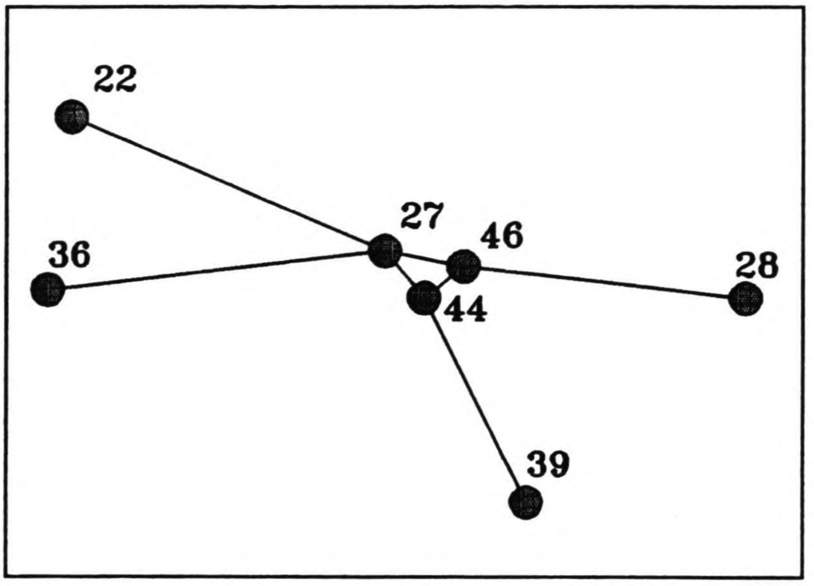

Figure 3.3: Detail of the scheme

3.4 Determination of the cross sectional area

The depth and width of each channel is determined in the nodes at the beginning and at the end of each channel. All levels are related to M.S.L. As all three tidal stations have a different reference-level, called Chart Datum, the region is divided into three parts where the respective Chart Datum is valid.
This Chart Datum, also mentioned in Annex A, is for Inch'On: MSL -4.64m., for Taemuui Do: MSL -4.53 m. and for Tokchok To: MSL -4.25 m.
An example of a cross section is demonstrated in Figure 3.4. Every cross section consists of a flow area and if present a storage area. The flow area is the area in which the flow takes place. Besides this flow area it is possible that a larger area of water is part of the cross section. This total area is called the storage area.

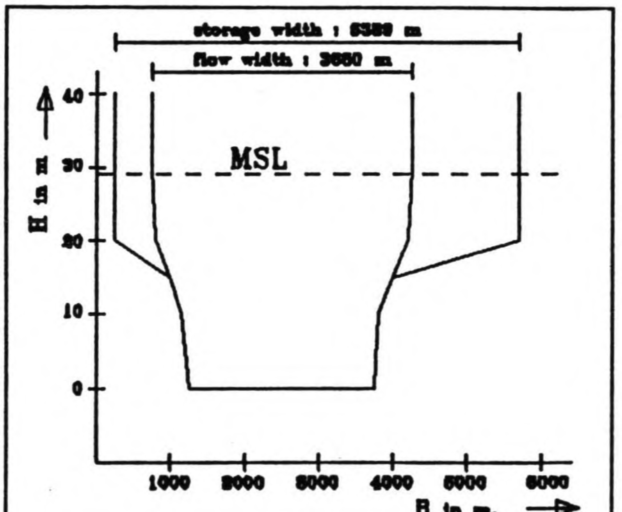

Figure 3.4: Cross section number 3

The storage width is determined by dividing the total surface of the modeled area among all channels in such a way that no channel has any overlap with another channel. The fact that the storage width and the flow width can change with the water level is taken into account by defining the widths at different levels in the nodes. In the shallow parts of the area, mainly in the area that will be closed, tidal flats have been observed. At low tide, parts of this area fall dry and the flow area is reduced considerably. Figure 3.5 shows a relation for the storage width of a section as a function of water level. In every section, the friction can be calculated with the formula of Chézy or with the formula of Manning. When applying the basic formula

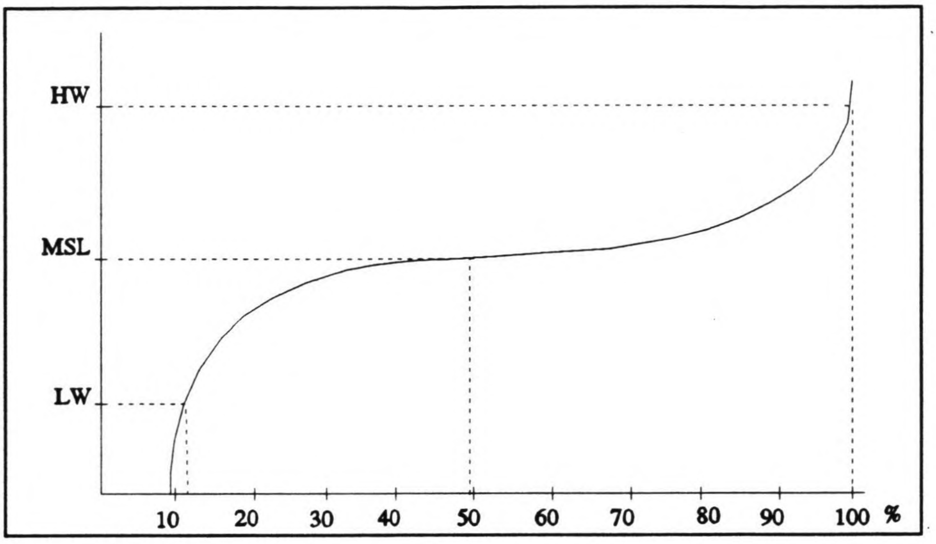

***Figure 3.5:** Storage characteristic*

$v = C\sqrt{RI}$, where C is the friction coefficient of De Chézy, this coefficient is constant over the height of the cross section. When applying the basic formula $v = \frac{1}{n}R^{\frac{2}{3}}I^{\frac{1}{2}}$,

where n is the Manning coefficient, the friction can be set as a function of the height. As there is not sufficient data available on the depth contours inside the tidal basin where the relation between depth and friction is of main importance, the Chézy coefficient is chosen.

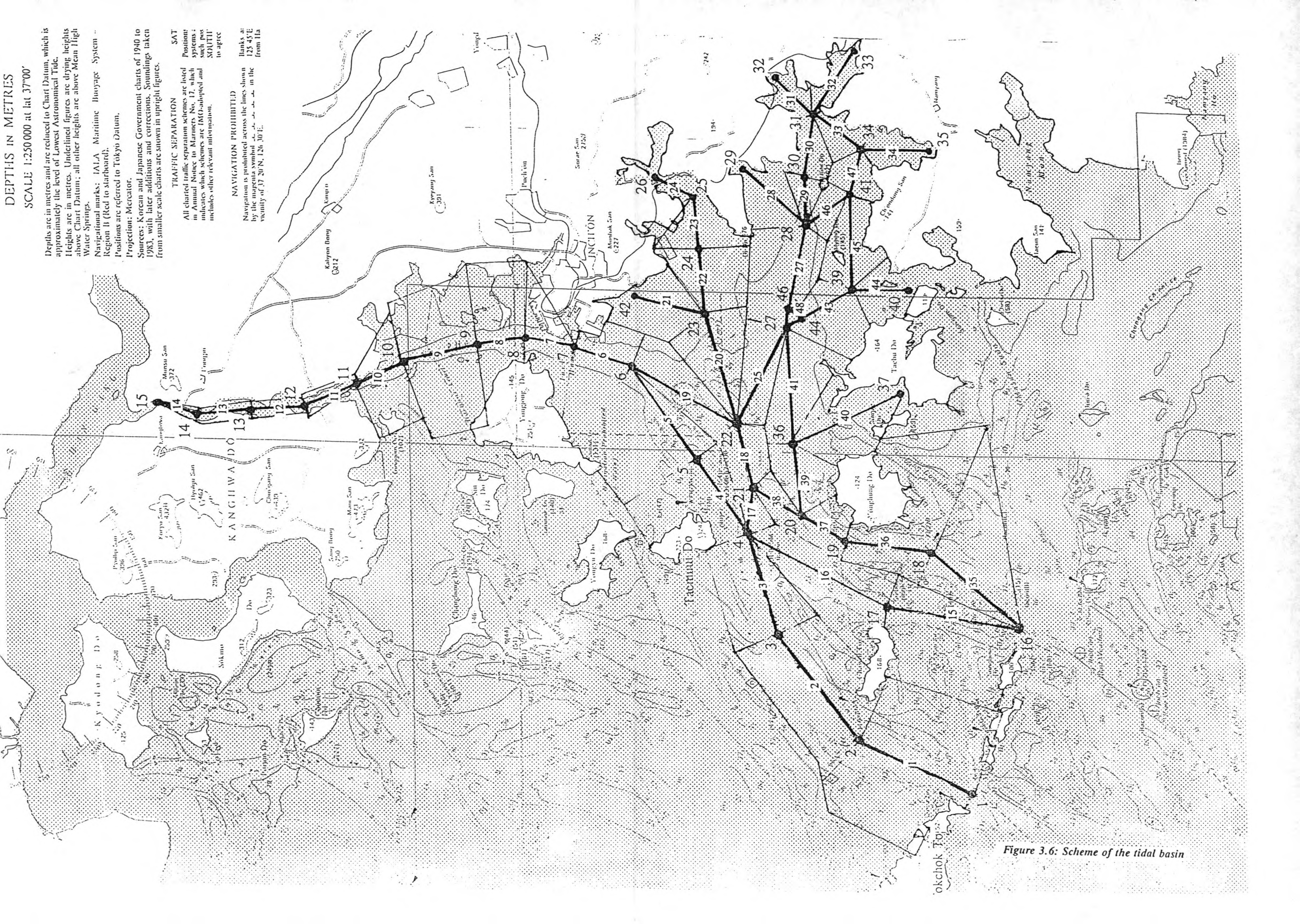

Figure 3.6: Scheme of the tidal basin

3.5 Boundary conditions

At the bounds of the network, boundary conditions have to be set. DUFLOW offers several possibilities to set a boundary condition like the water level H, the discharge Q or a relation between Q and H.
As we are dealing with a tidal basin, the water level inside the basin is influenced by the continuous rise and fall of the water level of the sea. The oscillations are caused by celestial bodies of which the sun and moon are predominant. They generate a tidal motion in the vast water- masses of the oceans that propagates over the continental shelves and penetrates into the coastal seas. There sub-systems can be observed as a result of reflection at the end of the basins. Also distortion of the tidal curve occurs because of an increasing resistance resulting from a decreasing depth.
In the South, there are two nodes at the sea side, number 1 and 16. In node number 1, the water level H as a function of time can be derived, using the tidal components given by the Admiralty Tide Tables [3]. Taking into account that the tide is intruding the tidal basin from the south-southwest, it is assumed that there will be no delay in time between the tidal curves in node 1 and 16. Therefore the boundary condition in node number 16 is chosen equal to the boundary condition at node number 1.
A node at the end of a channel is called an end node. At these end nodes a discharge Q = 0 is given as boundary condition. Node number 15 in the North is not really the end of a channel but as the river is very narrow at that point, the discharge is considered to be negligible compared to the discharge that enters the basin at node 1 and 16.
The boundary condition at node number 1 and 16 can be approximated in DUFLOW as a Fourier series as can be seen in the next expression:

$$h(t) = h_o + \sum_{n=1}^{N} A_n . \cos(n\omega t - \varphi_n) \tag{7}$$

Where:
A = amplitude in m.
ω = angular velocity in rad/s.
φ = phase in rad.

To make sure that the model is giving sound results, in the nodes number 1 and 16 first the boundary condition is prescribed as one sine function consisting of one component. Regarding the differential equations, it is possible to check the results of the calculation manually. The results of this T0 simulation, compared with the manual calculation are discussed in chapter 4. As these results are quit satisfactory, another simulation, T1 has been carried-out. For this simulation, a boundary condition that agrees more with the actual tide in node 1 and 16 is set. The Admiralty Tide Tables give a tide composed of the four main-components, M_2, S_2, O_1 and K_1 shown in table 1. DUFLOW offers the possibility to use a curve consisting of more components by executing a Fourier analysis, with a given period. The periods of all successive components differ a factor n, see equation (7), which can only be a whole number.

***Table 1:** Tidal data at the station Tokchok To*

Tokchok To	Z_0	M_2	S_2	K_1	O_1
	4.25				
g°		130	189	294	257
H in m.		2.48	0.96	0.43	0.32

To approximate the tide, given by the Admiralty Tide Tables, only two sine-shaped components are taken, a diurnal tide and a semi-diurnal tide:

$$h_t = Z_0 + A_1 \sin(1.405 \ . \ 10^{-4}\ t - \varphi_1) + A_2 \sin(2.81 \ . \ 10^{-4}\ t - \varphi_2) \qquad (10)$$

To fit these two components with the four components the Admiralty Tide Tables give, both are put into a spread-sheet program called QUATTRO.
By minimizing the sum of the square of the difference at all time steps one can approximate the best fit. This is done by changing constantly the amplitude and the phase of the two components until the minimum value of the total sum of the difference is reached.
The result of the comparison is shown in Figure 3.7. The boundary condition at nodes 1 and 16, consisting of one and two components are shown in Figure 3.8 and Figure 3.9.
In this case two Fourier components are sufficient to approximate the tide. This approximation however, is only valid for a limited period, say a few days. When considering a longer period, the higher harmonic terms become more important.

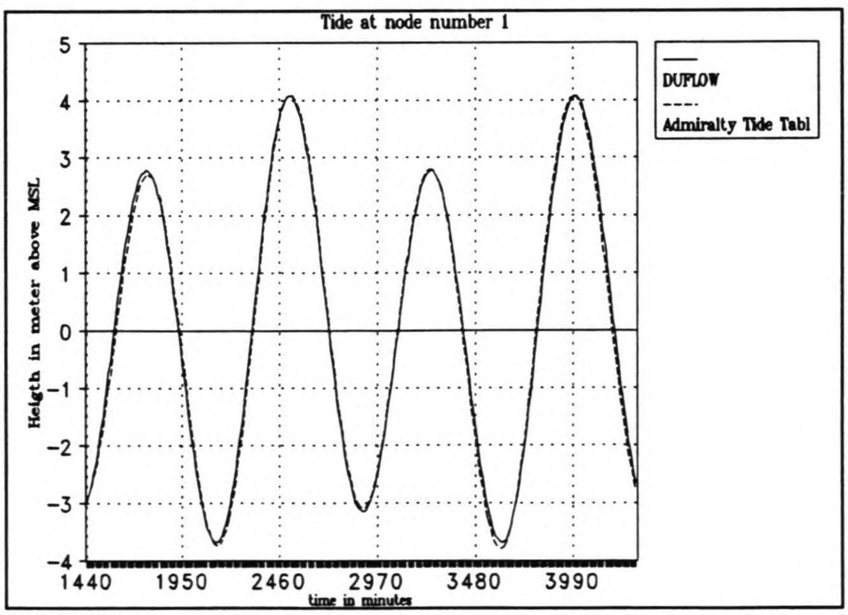

***Figure 3.7:** Comparison of a tidal curve with two (DUFLOW) and four components (A.T.T.)*

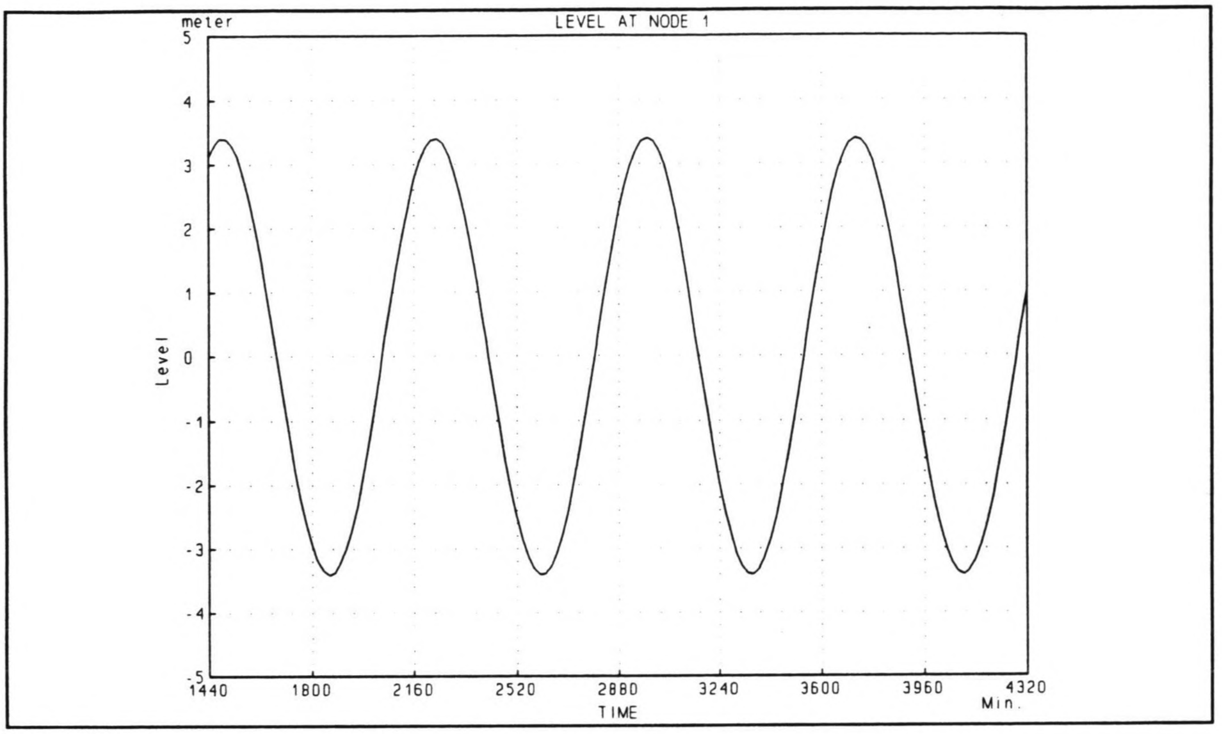

Figure 3.8: Boundary condition at node 1 and 16 consisting of one component.

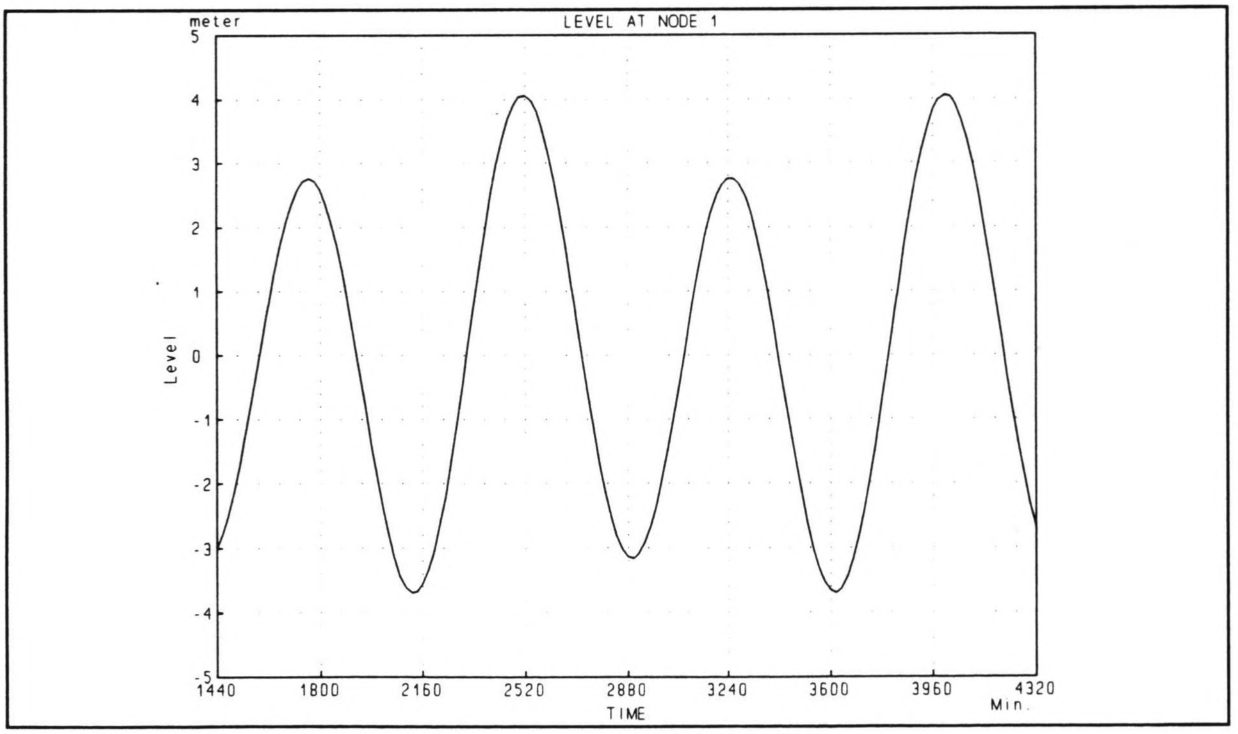

Figure 3.9: Boundary condition at node 1 and 16 consisting of two components

3.6 Interpretation of the tidal data

In node 4 and 7 the tide is known, given by the Admiralty tide tables. With these tidal constituents the results of the model can be checked. If the results do not agree sufficiently, the input, like the depth or the Chézy coefficient can be changed to achieve more realistic results.
Since the sea area is schematized as a one-dimensional network of gullies where, for example, the Coriolis-force can not be taken into account, it is likely that inaccuracies have occurred in defining the cross sections. These inaccuracies can partly be corrected by changing the cross sectional area and the Chézy coefficient until the tides in node 4 and 7 do agree with the curve consisting of the constituents given by the Admiralty Tide Tables. The Chézy coefficient can vary from 65 $\sqrt{m/s^2}$ in the deeper gullies to 35 $\sqrt{m/s^2}$ in the shallow parts of the tidal basin.
By changing the depth and the Chézy coefficient within acceptable margins, it appeared to be possible to achieve tidal curves in node number 4 and 7, which are almost equal to the Admiralty-curves, accept of a time lag of about 30 minutes in node 7. See Figure 3.10 and Figure 3.11.
In these figures it can be seen that the shape of the curves fit very well. Therefore no further adaptations have been made since a slight delay of the tide has no effect on the required data as velocities and water levels at the location of the closure.

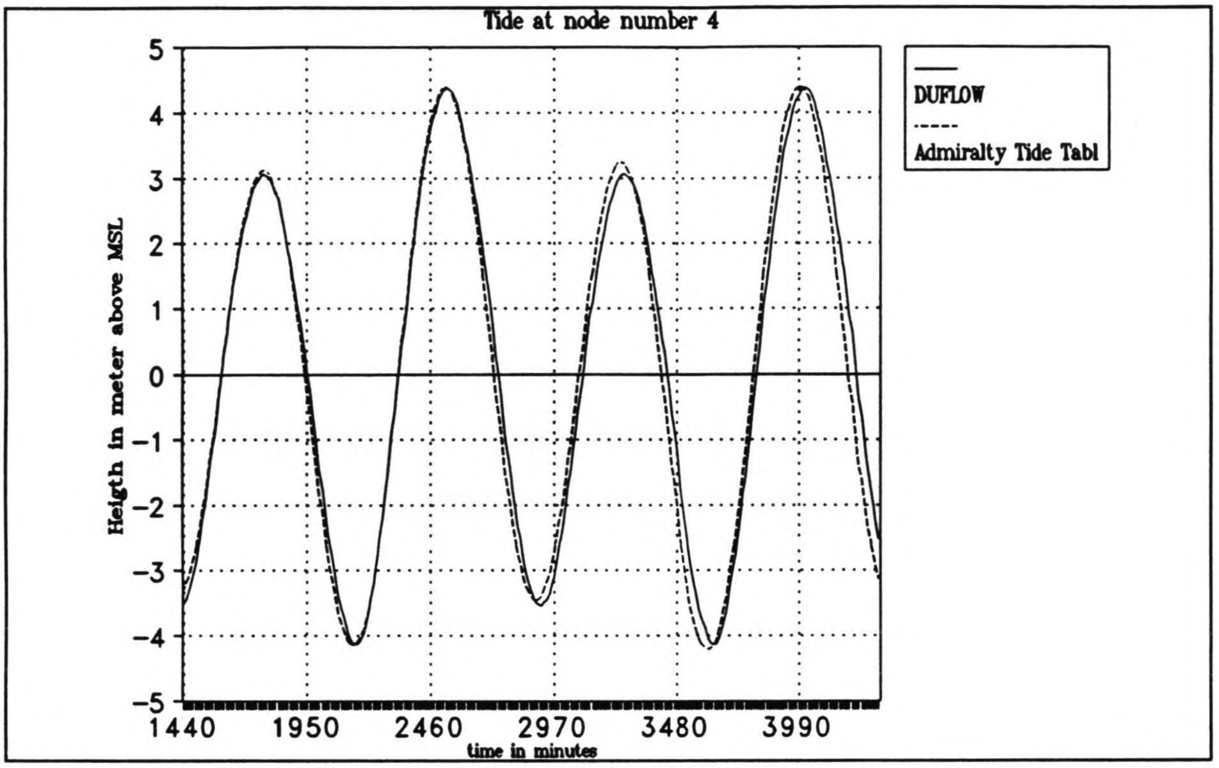

***Figure 3.10:** Appearing and calculated tidal curves at node 4.*

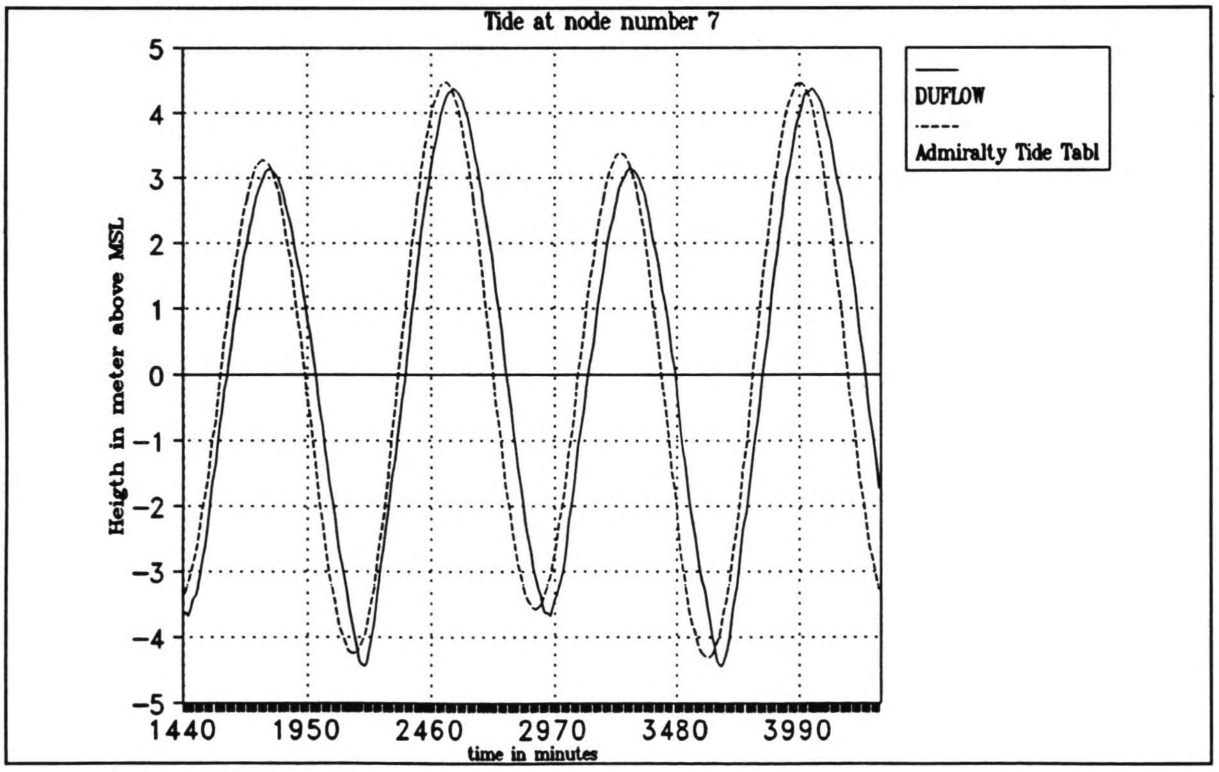

***Figure 3.11:** Appearing and calculated tidal curves at node 7.*

4 Evaluation and interpretation of DUFLOW results

4.1 Propagation of a single sine shaped tide

The tidal propagation inside the Shiwa tidal basin can be analyzed with the results of the DUFLOW calculations. Therefore, two paths are set. Path number 1, displayed in Figure 4.1 is set from node 1 up to 14 with a length of 79 km. and path 2, displayed in Figure 4.4 is set from node 1 to 33 with a total length of 68 km. To have a better insight in the water movement inside the basin, first a calculation (T0) has been carried out with a single sine shaped tide as input. The results of this calculation are displayed in Figure 4.2 and Figure 4.3.

Path 1:

Figure 4.2 shows a small shift in phase and an amplification of the amplitude from node 1 towards node 6. From node 6 towards node 14, the amplitude of the tidal wave decreases and a significant shift in phase occurs. The head during the ebb period appears to be higher than during the flood period. This results in a distortions of the h(t) curves. They become more zigzag shaped and the mean water level increases. In this case the increase of the mean water level amounts to 0.90 meter, see Figure 4.2. The discharges as a function of time are shown in Figure 4.3. It can be seen that the discharges decrease from node one to 14. This is a result of the decrease in the storage width of the section and the $\frac{\delta h}{\delta t}$ towards

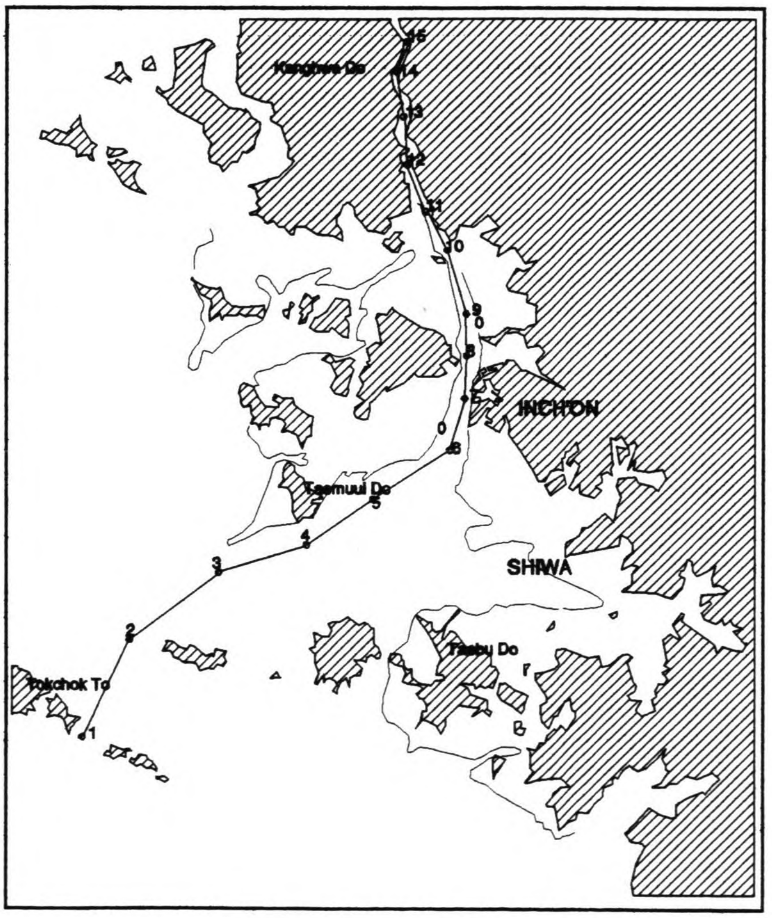

Figure 4.1: Path 1

node 15 where $Q = 0\ m^3/s$.

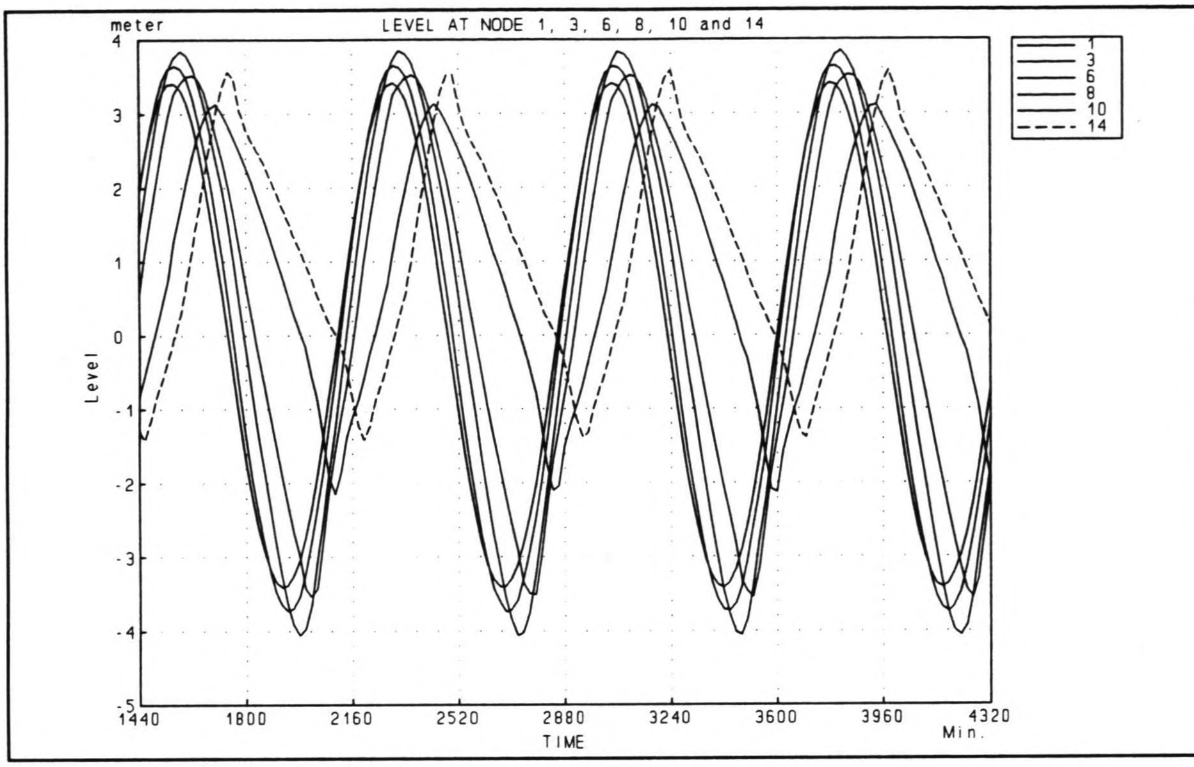

***Figure 4.2:* Water level along path 1**

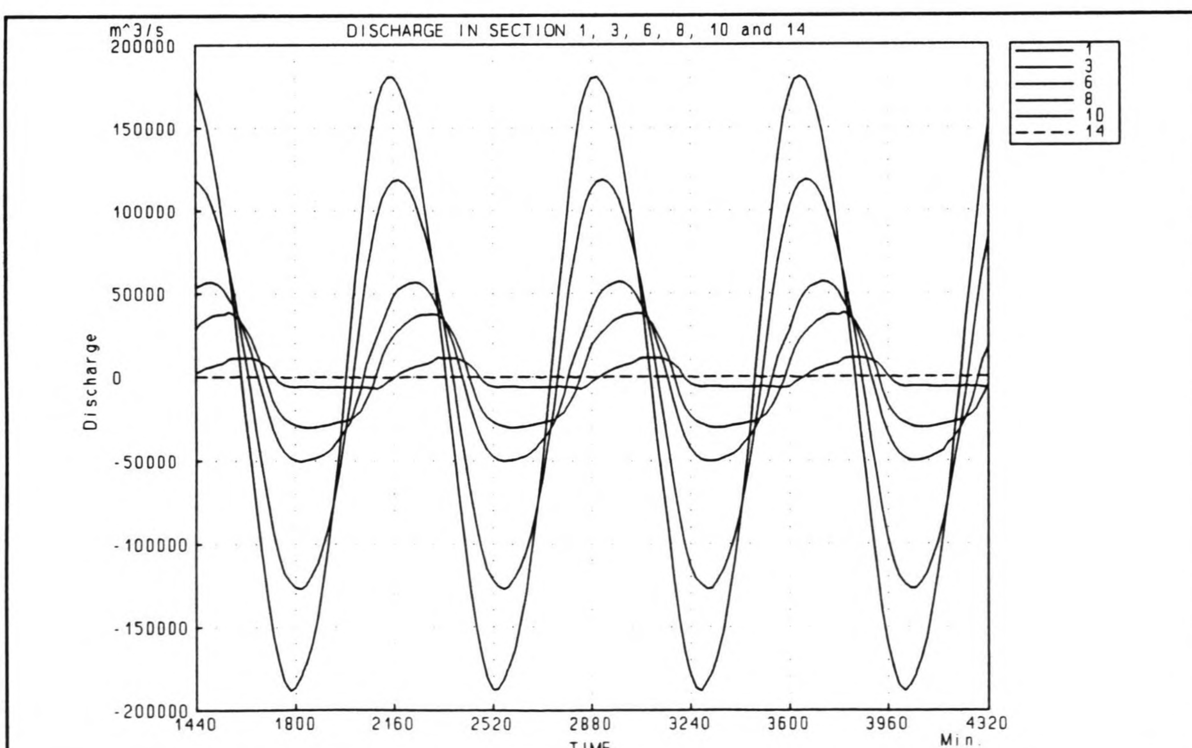

***Figure 4.3:* Discharge along path 1**

Path 2

Figure 4.5 shows an amplification of the amplitude and a small shift in phase from node 1 towards node 21 and a decrease in the amplitude with a larger shift in phase from node 21 towards node 33. Also in this path the head during ebb appears to be higher than during the flood period. Therefore again distortion of the tidal curve takes place. This results in a zigzag shape of the curve and a set up of the mean water level of 1.40 meter, see Figure 4.5. The discharges as a function of time are displayed in Figure 4.6. It can be seen that the discharges decrease from node 1 to 33. This is a result of the decrease in the storage width of the section and the $\frac{\delta h}{\delta t}$ towards node 33 where Q = 0 m^3/s.

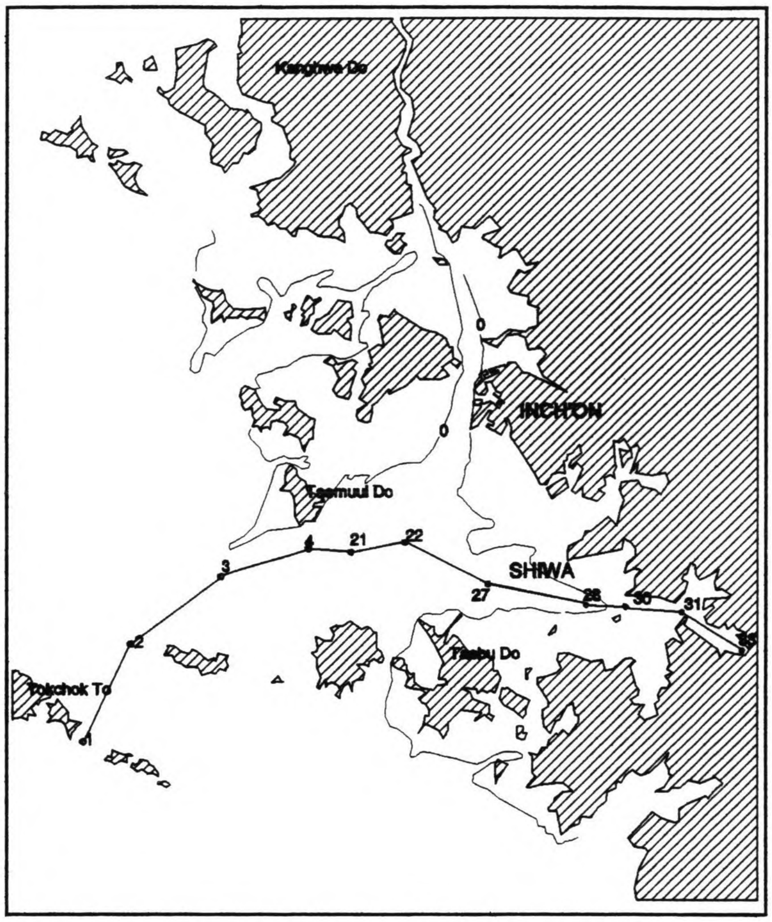

Figure 4.4: Path 2

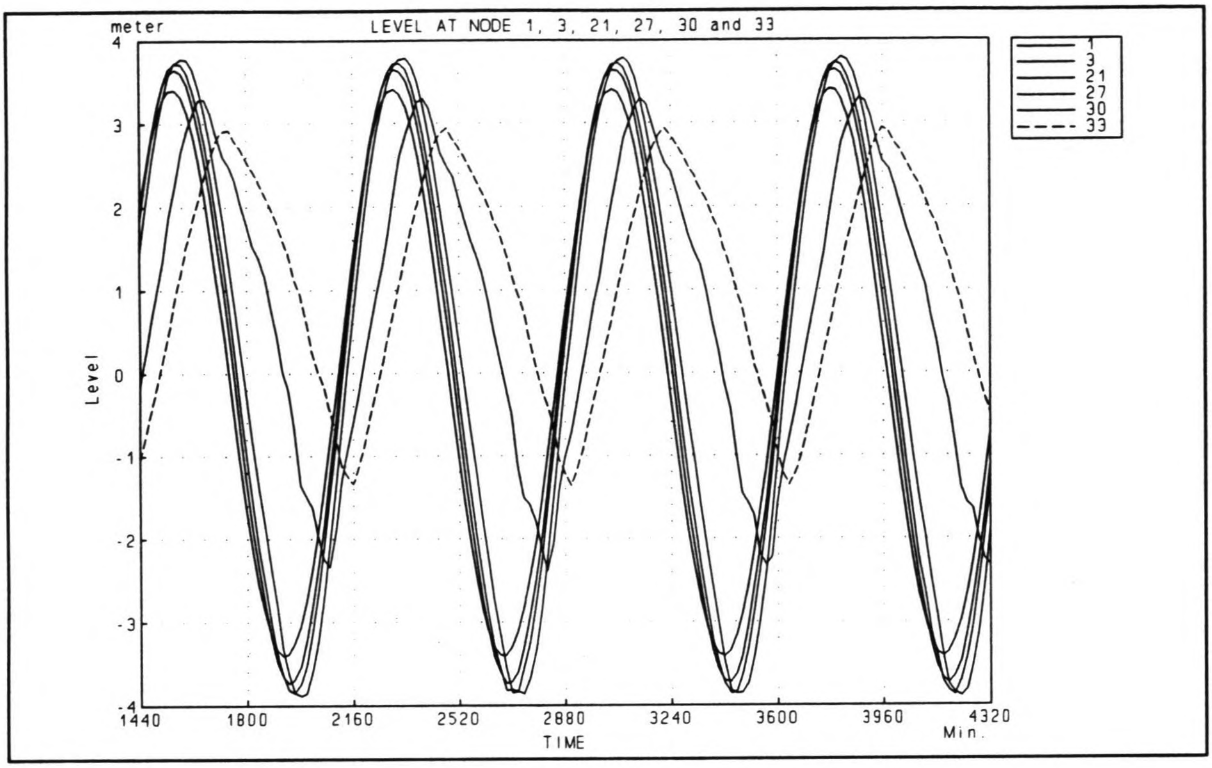

***Figure 4.5:* Water level along path 2**

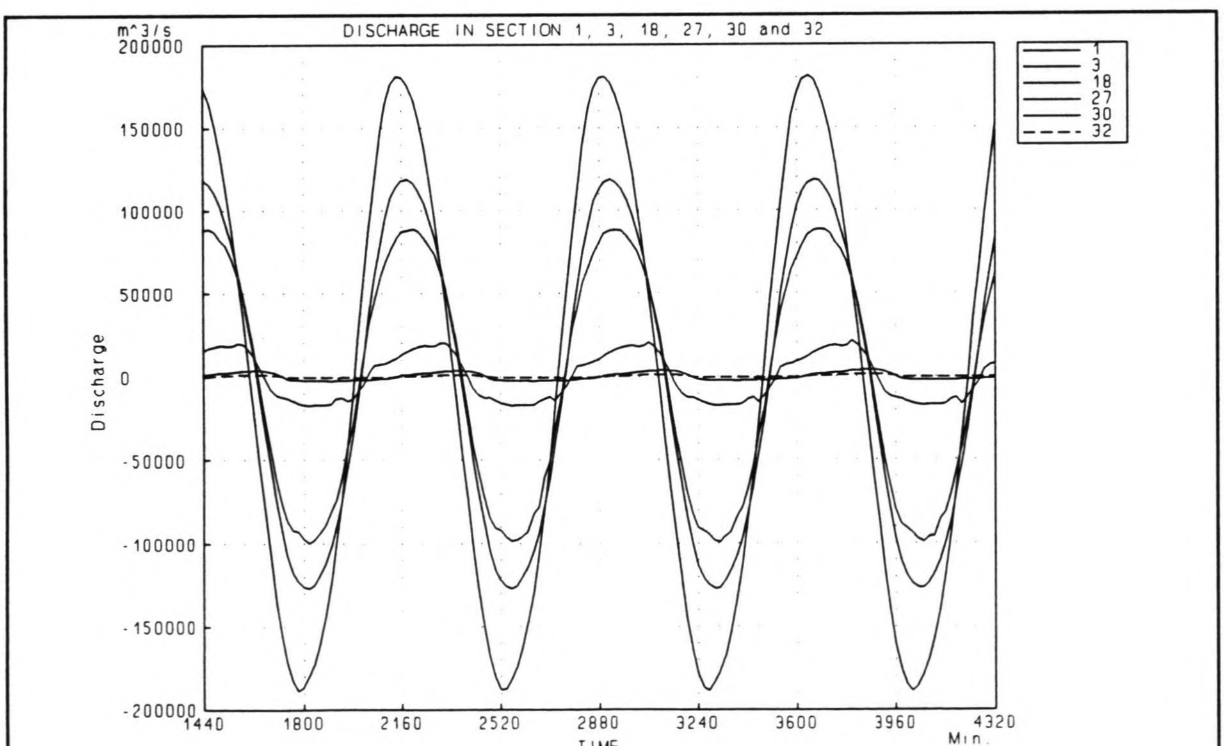

***Figure 4.6:* Discharge along path 2**

4.2 Manual calculation of T0

At a number of time-levels, calculations have been carried out in order to check the results of the computer-program DUFLOW. These calculations show the successive contributions of the friction-, the advective- and the local acceleration term related to the total water level difference between the beginning and the end of a channel. One can easily verify if one of these terms is extremely dominant for example.
For these calculations two sections are chosen, section 1 and 8. Looking at Figure 4.7 and Figure 4.8 it can be seen that section 8 shows the largest head and section 1 has the largest discharge. The results of these calculations will be compared with the results of the model. As input of the model a single sine, is put and the Chézy value is 65 $m^{½}/s^2$ is taken for section 1 and 35 $m^{½}/s^2$ for section 8. It must be noted that the DUFLOW calculations have been carried out with the advective term damped. This means that the advective term never exceeds the maximum value of the friction term. The reason for damping the advective term is that the calculations are instable without damping. Althoug damping the advective term is not a very elegant solution, it is the best way to overcome the numerical instability.

The first timelevel to be considered is t = 2140 min., measured from t = 0 which is the start of the calculation. At this moment, t = 2140, the flood discharge is maximum

and $\frac{\delta Q}{\delta t}$ in consequence equals zero which implies that the local acceleration term becomes zero.

Data:	H_1	= 0.83 m.	Q_1	= 201290 m^3/s
	H_2	= 0.81 m.	Q_2	= 160210 m^3/s
	H_m	= 0.82 m.	Q_m	= 180750 m^3/s
	H_2-H_1	= -0,02 m		

Calculated:	A_1	= 137786.4 m^2
	A_2	= 128115.4 m^2
	A_s	= 132950.9 m^2
	R	= 65.3 m
	L	= 9200 m
	C^2	= 4225 m/s^2

Friction term: $- \dfrac{|Q|.Q.L}{C^2.A_s^2.R} = - \dfrac{|180750|.180750.9200}{4225.(132950{,}9)^2.65{,}28} = -\ 0{,}06165\ m$

Advective term: $- \dfrac{(\dfrac{Q_2^2}{A_2})-(\dfrac{Q_1^2}{A_1})}{g.A_s} = - \dfrac{(200344.7\ -\ 294061{,}4)}{9{,}81\ .\ 132950{,}9} = 0{,}072\ m$

$\Delta H_{tot} = 0.01$ m

The 0.013 m. that is missing, can be found in the acceleration term that is not equal to zero at this timestep. The timestep where this might be the case is at t = 1450, but this timestep is not part of the DUFLOW output. This can be verified in Annex B where the ECDUFLOW output is demonstrated.

Now another moment is considered, t = 2440 min. At this moment the ebb-discharge is not maximum yet, so the acceleration term has also a contribution to the ΔH.

Data:	H_1	= 1,22 m.	Q_1	= -147040,0 m^3/s
	H_2	= 1,46 m.	Q_2	= -108860,0 m^3/s
	H_m	= 1,34 m.	Q_m	= -127950,0 m^3/s
	H_2-H_1	= 0,24 m.		

Calculated:	A_1	= 138597.6 m^2
	A_2	= 130368.8 m^2
	A_s	= 134483.2 m^2
	R	= 58.9 m
	B_s	= 1920 m
	L	= 9200 m
	C^2	= 4225 m/s^2

Friction term: $- \dfrac{|Q|.Q.L}{C^2.A_s^2.R} = - \dfrac{|-127950|.-127950.9200}{4225.(134483,2)^2.66} = 0,0299\ m$

Advective term: $- \dfrac{(\frac{Q_2^2}{A_2})-(\frac{Q_1^2}{A_1})}{g.A_s} = \dfrac{(90899,8-155996,65)}{9,81.134483.2} = 0,049\ m$

Acceleration term: $- \dfrac{1}{g.A_s}.\dfrac{\delta Q}{\delta t}.L = - \dfrac{1}{9,81.134483,2}.\dfrac{-50509}{2400}.9200 = 0,147\ m$

ΔH_{tot} = 0,226 m

This value agrees more or less with the water level difference of 0.24 m.

The same procedure as for section 1 has been carried-out for section 8.
At t = 2300 min., the flood-discharge is maximum and for this reason again the acceleration term can be neglected.

Data:

H_8	= 3.25 m.	Q_8	= 39912 m^3/s
H_9	= 2.64 m.	Q_9	= 35575 m^3/s
H_m	= 2,95 m.	Q_m	= 37743.5 m^3/s
H_9-H_8	= -0.61 m.		

Calculated:

A_8	= 21622.5 m^2
A_9	= 21851.2 m^2
A_s	= 21736.9 m^2
R	= 16.1 m
B_s	= 1320 m
L	= 3651 m
C^2	= 1225 m/s^2

Friction term: $$-\frac{|Q|.Q.L}{C^2.A_s^2.R} = -\frac{|37743{,}5|.37743{,}5.3651}{1225.(21736{,}85)^2.16{,}1} = -0{,}558\ m$$

Advective term: $$-\frac{(\frac{Q_2^2}{A_2})-(\frac{Q_1^2}{A_1})}{g.A_s} = -\frac{(57918{,}2-73671{,}77)}{9{,}81.21736{,}85} = -0{,}074\ m$$

ΔH_{tot} = -0,484 m

The difference of almost 0.1 m. is mainly due to the difference in the calculated R so the friction term gives a lower ΔH than it should give.

At t = 2740 min., the ebb-discharge in section 8 is not at its maximum yet so the acceleration term has to be taken into account.

Data:

H_8	= -3.36 m.	Q_8	= -28094 m^3/s
H_9	= -1.93 m.	Q_9	= -23120 m^3/s
H_m	= -2.645 m.	Q_m	= -25607 m^3/s
H_9-H_8	= 1.43 m.		

Calculated:

A_8 = 12316 m^2
A_9 = 13950 m^2
A_s = 13133 m^2
R = 9,81 m^2
B_s = 2217 m
L = 5239 m
C^2 = 1225 m/s^2

Friction term: $$-\frac{|Q|.Q.L}{C^2.A_s^2.R} = -\frac{|-25607|.-25607.3651}{1225.(13133)^2.9{,}8} = 1{,}155\ m$$

Advective term: $$- \frac{(\frac{Q_2^2}{A_2})-(\frac{Q_1^2}{A_1})}{g.A_s} = - \frac{(38317,88-64085,16)}{9,81.13133} = 0,20\ m$$

Acceleration term: $$- \frac{1}{g.A_s}.\frac{\delta Q}{\delta t}.L = - \frac{1}{9,81.13133}.\frac{1485}{2400}.3651 = -\ 0,017\ m$$

$\Delta H_{tot} = 1.34$ m

DUFLOW has an adherecent module called EC DUFLOW. This module does the same as has just been shown in the previous manual calculation. The results of these control calculations are put in Annex B. One can see that there are some differences between the manual calculations and the EC DUFLOW output. The reason for these differences is the fact that the manual calculation is less accurate by calculating for example the cross sectional flow area or the hydraulic radius.

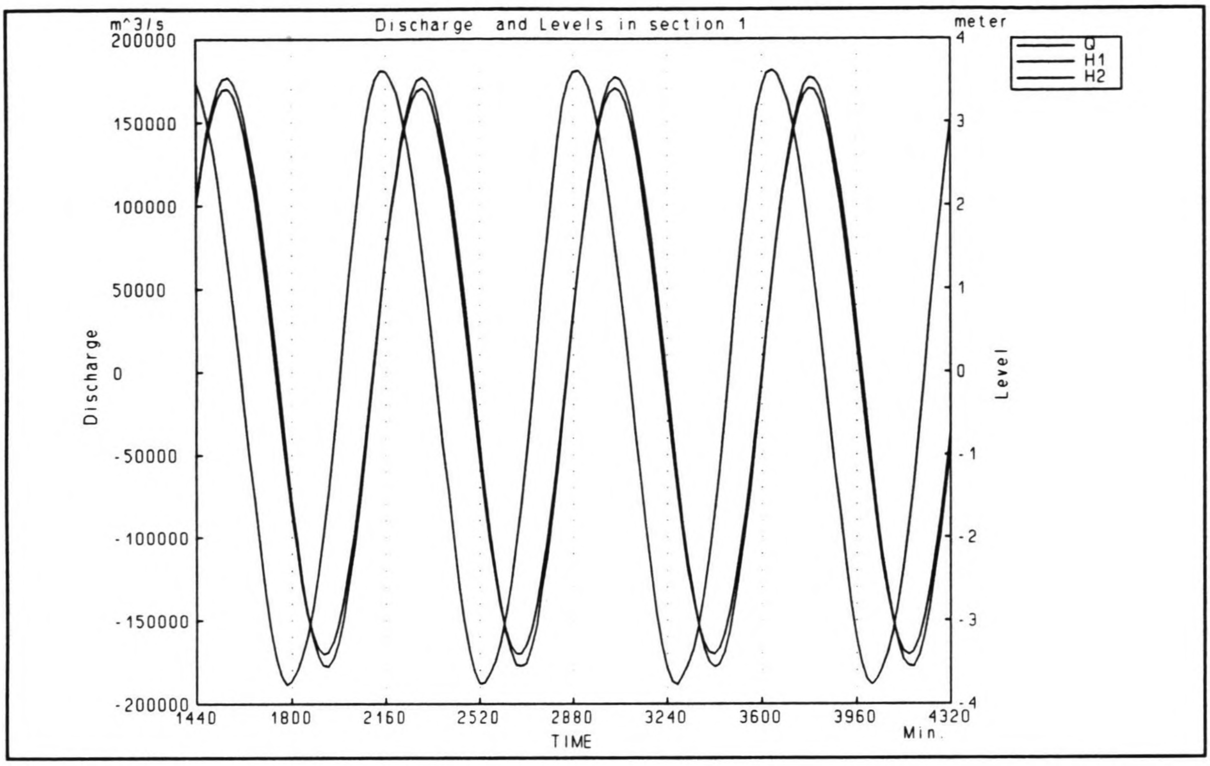

Figure 4.7: ***Water levels and discharge in section 1***

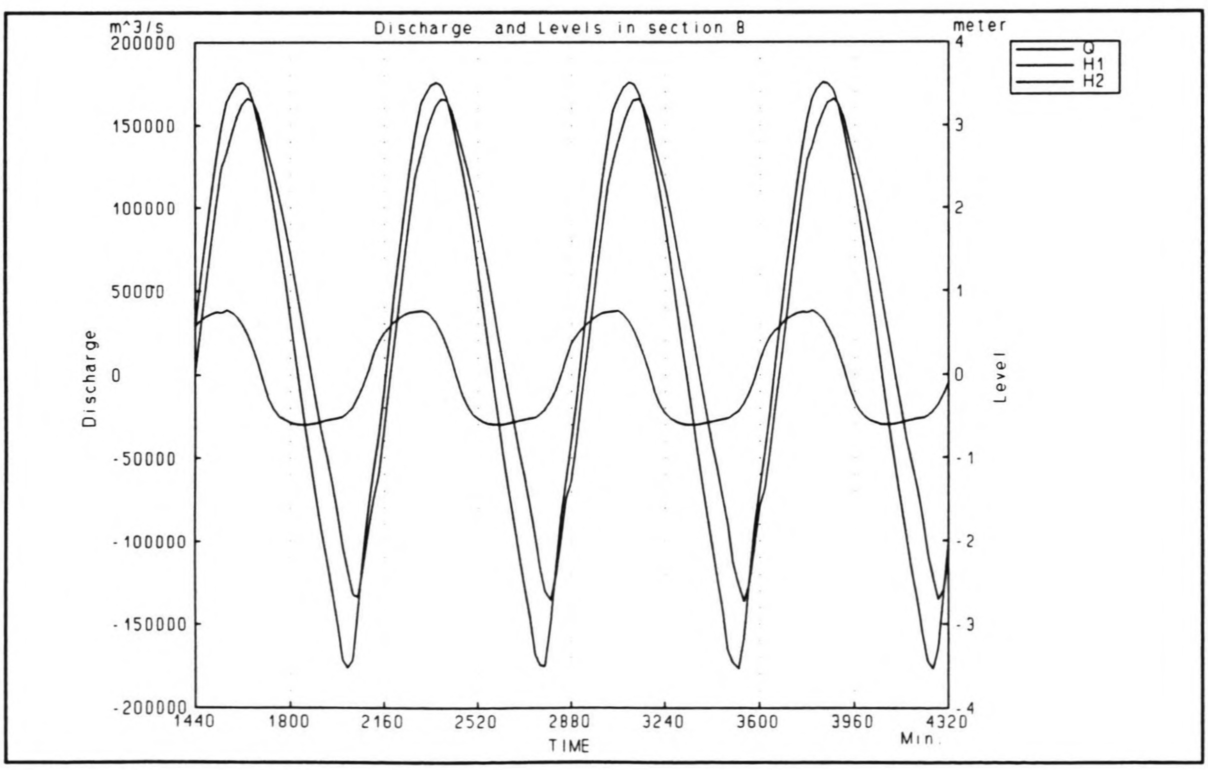

Figure 4.8: ***Water levels and discharge in section 8***

4.3 Propagation of a double sine shaped tide

Now the propagation of a single sine shaped tide gives satisfactory results, a double sine shaped tide is put as a boundary condition approximating of the appearing spring tide. Again path 1 and path 2 are considered. In Figure 4.9 to Figure 4.12, the same character of the tidal propagation can be observed as in the case of the propagation of a tide composed of one single sine. As for the simulation of the different closure phases the approximation of the appearing tide is preferred, this is used as boundary condition.

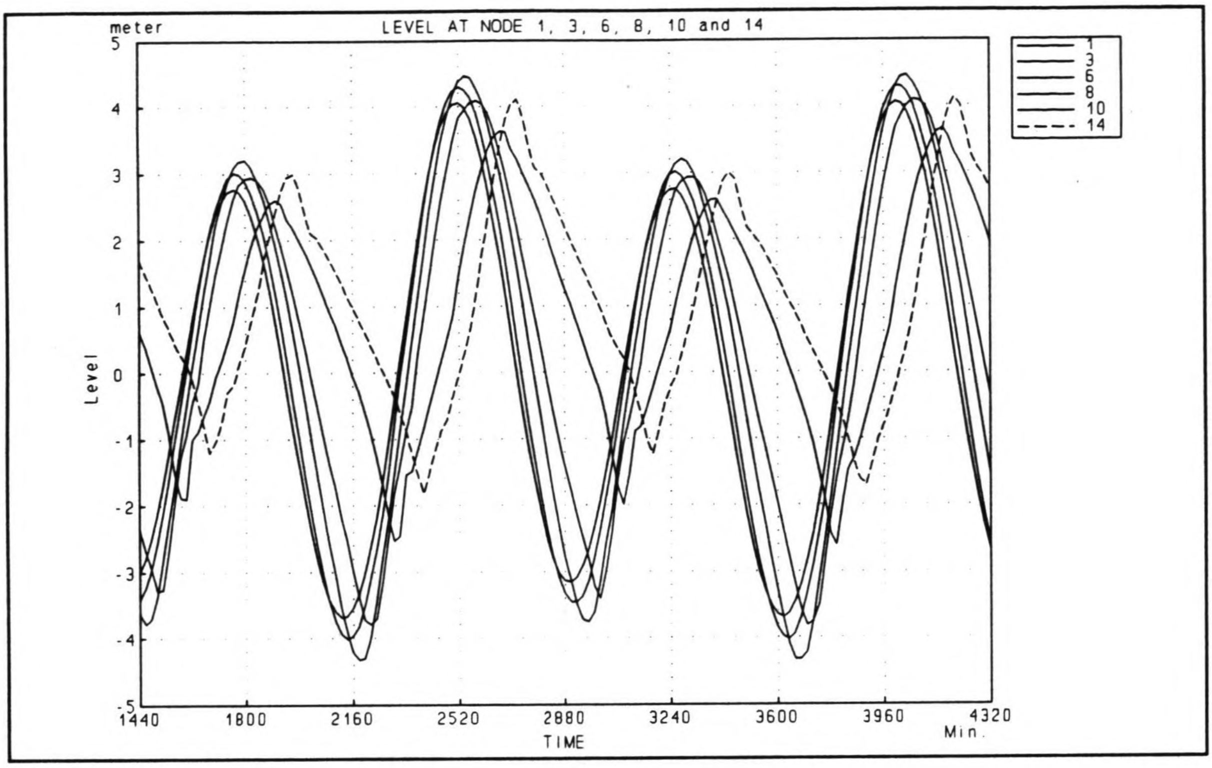

***Figure 4.9:* Water level along path 1**

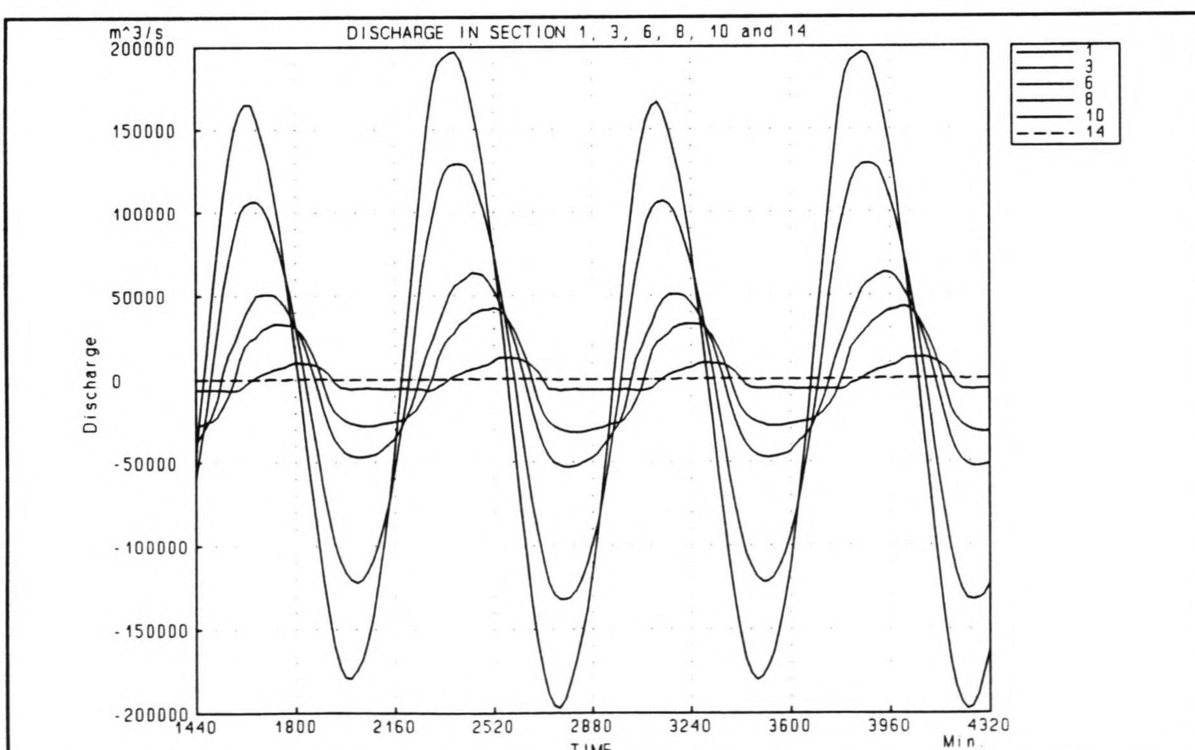

***Figure 4.10:* Discharge along path 1**

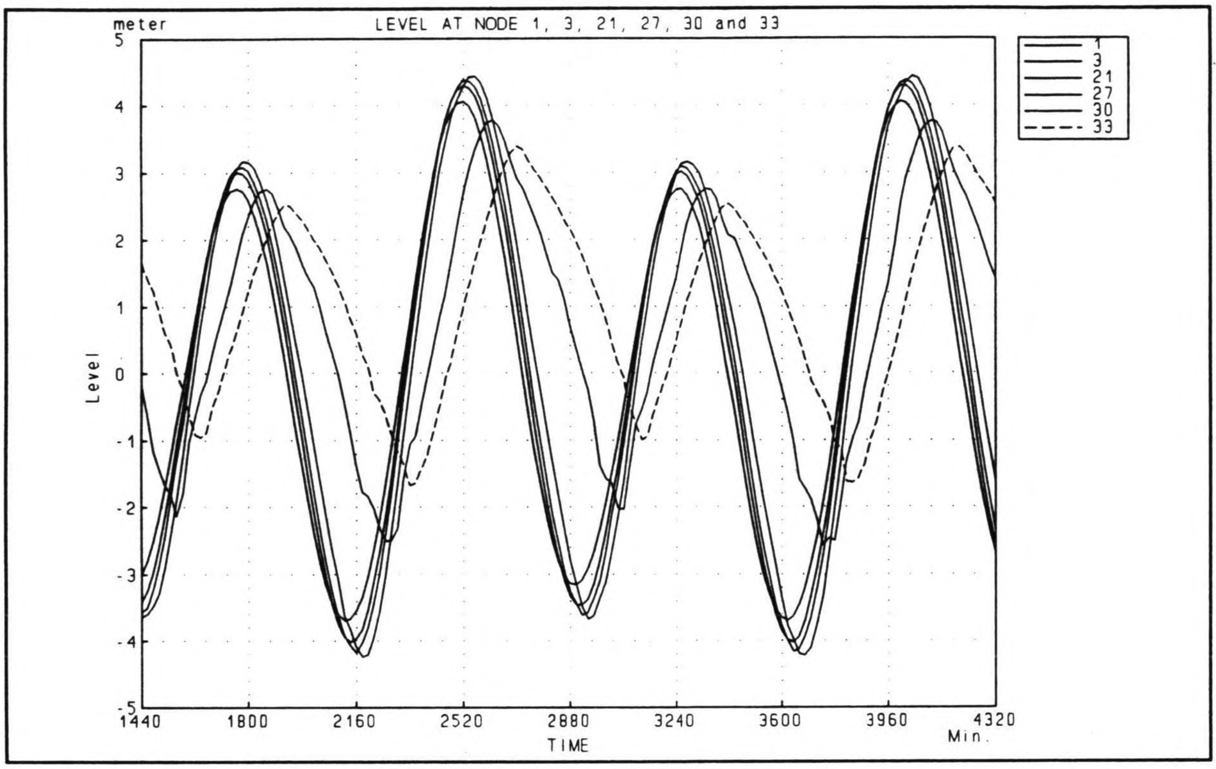

***Figure 4.11:* Water level along path 2**

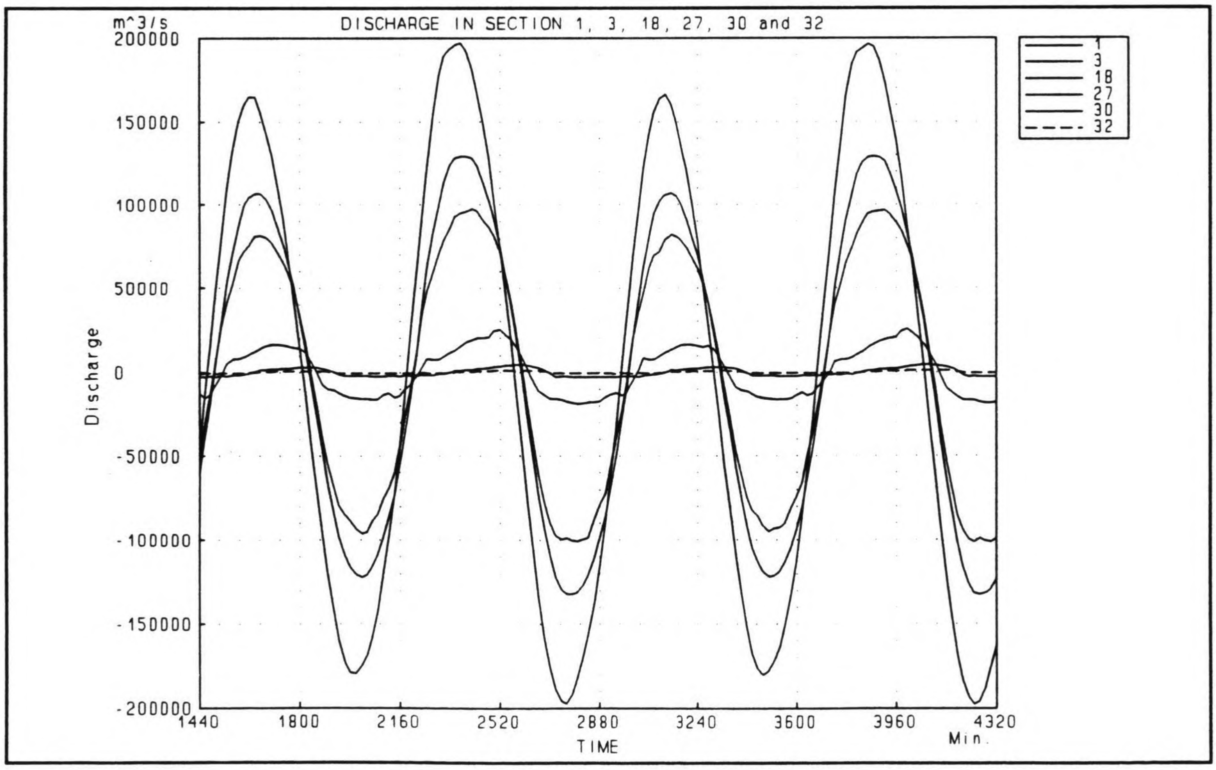

***Figure 4.12:* Discharge along path 2**

5 Conclusions and recommendations

Evaluating the results of the DUFLOW model, it can be seen that the tide is simulated satisfactory. The curve that results from the calculations with the DUFLOW model fits with the curves composed with the tidal constituents of the Admiralty Tide Tables, see Figure 3.7. Apart from a small time-lag however but considering the fact that a one dimensional model is used and no data of simultaneous water level measurements were available, this is sufficiently accurate. Therefore the model will be used to determine the flow velocities, water levels and discharges in the structures during all closure phases for the design of the bottom protection of the closure of the Shiwa tidal basin.

It is recommended to have measured data of at least six simultaneously measured water levels and a measurement of the velocity and discharge in a section when modeling a region in order to be able to validate the model.

Biblography

[1] Admiralty Tide Tables, Vol. 3. Hydrographer of the Navy, 1992

[2] Duflow Manual, Delft University of Technology, 1987

[3] Roode,F.C. van.Closure of tidal basins and waterways, (In Dutch), Lecture notes F11-C: Delft University of Technology, 1987

[4] Shiwa, the closure of the tidal basin, Dutch Ministry of Transport and Public Works, Delta Department, 1984

[5] Verspuy, C., Unsteady flow in network systems (In Dutch), lecture notes B73, Delft University of Technology, 1989

Annex A

General data

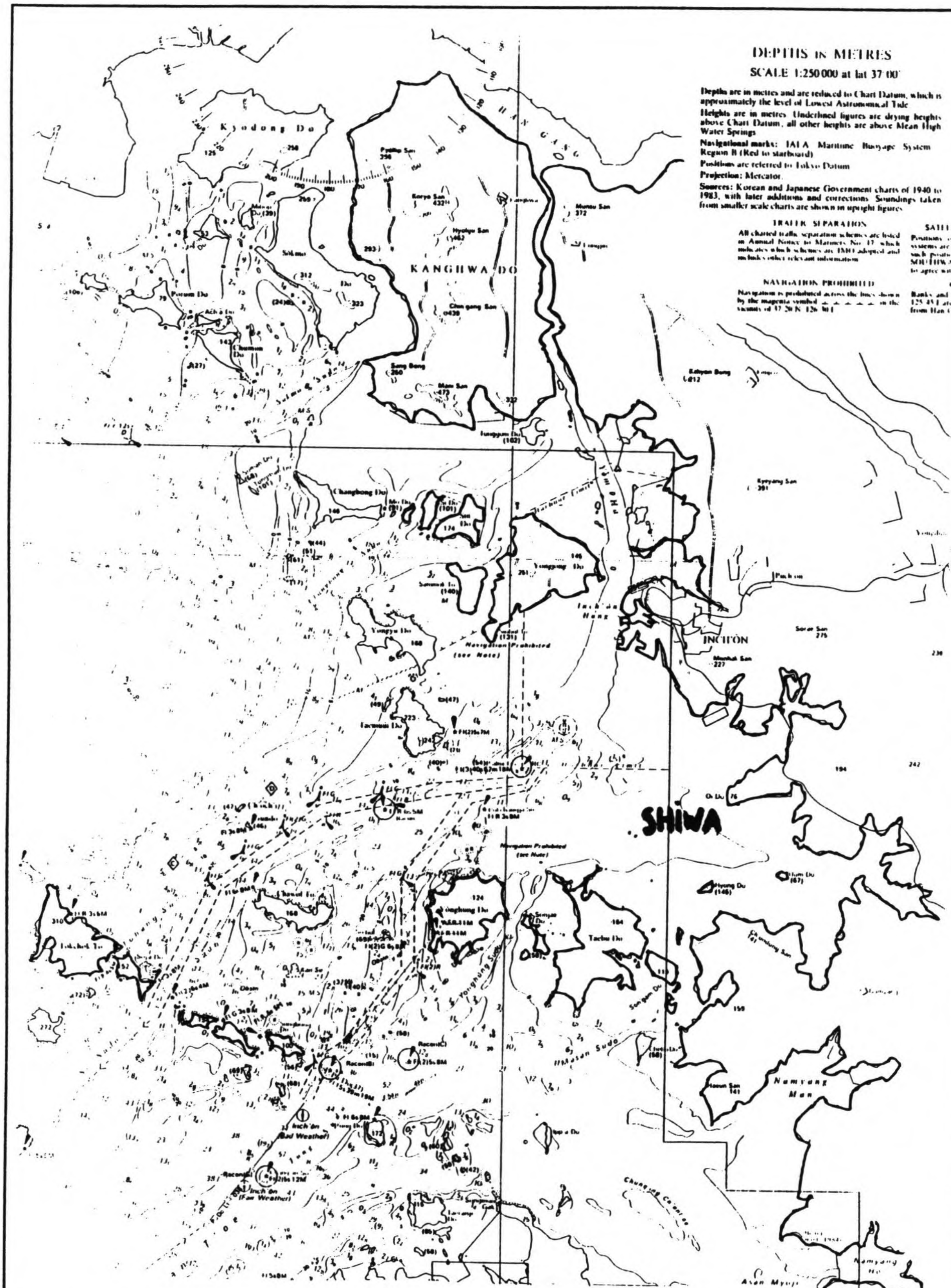

Figure 4.13: Map of the region

	Time differences	Z_0	M_2		S_2		K_1		O_1	
	hh.mm	m.	g°	H.m.	g°	H.m.	g°	H.m.	g°	H.m.
Inch'On	00.00	4.64	138	2.84	196	1.09	305	0.39	265	0.28
Taemuui Do	-00.06	4.53	136	2.78	197	1.05	303	0.40	263	0.30
Tokchok To	-00.18	4.25	130	2.48	189	0.96	294	0.43	257	0.32

Annex B

EC Duflow results

```
program DUFLOW                         analysis - Details
=====================================================================
CALCULATION TIME LEVEL  2140 minutes          SECTION   1

L   length           =      9200.00 m         Friction term:
H1  level begin      =     0.830380 m                 -Q*|Q|*L
H2  level end        =     0.807490 m                 --------     = -0.079021 m
Hav. prev timestep   =     0.233400 m                 C²*A²*R
Hav. next timestep   =     1.374050 m
Q1  discharge begin  = %201290.00000 m3/ss
Q2  discharge end    = %160210.00000 m3/ss    Acceleration term:
Q   average disch.   = %180750.00000 m3/ss            -L   dQ
Qav. prev timestep   = %175780.00000 m3/ss            -- * --      = -0.013751 m
Qav. next timestep   = %180460.00000 m3/ss            gA   dt
A1  area begin       = %137871.20313 m²
A2  area end         = %128103.23438 m²
A   average area     = %132987.21875 m²       Advective term:
R   hydr. radius     =    50.904263 m                 Q1²/A1-Q2²/A2
SW  Storage width    =   9332.77637 m                 -------------  =  0.071682 m
C   de Chezy coeff.  =      65.000 m½/s                    gA
dt  time interval    =        1200 sec

SW*L*dH/dt           =   40807.4883 m3/s      SUM of the 3 terms  = -0.021090 m
Q1 - Q2              =   41080.0000 m3/s      H2 - H1             = -0.022890 m
```

```
program DUFLOW                         Analysis - Table
=====================================================================
```

Analysis section 1 Page 5

Time min.	H1 (m) H2 (m)	Q1 (m) Q2 (m)	A1 (m²) A2 (m²)	R (m)	C (m½/s)	FRICTION (m)	ACCELERATION (m)	CONVECTION (m)
2100	-0.311	185390.0	135496.9	49.79	65.0	-0.0705	-0.0885	0.0678
	-0.394	144030.0	123938.1					
2120	0.263	197260.0	136691.8	50.35	65.0	-0.0775	-0.0477	0.0743
	0.203	154300.0	126009.1					
2140	0.830	201290.0	137871.2	50.90	65.0	-0.0790	-0.0138	0.0717
	0.807	160210.0	128103.2					
2160	1.374	200020.0	139001.5	51.43	65.0	-0.0762	0.0152	0.0673
	1.374	160900.0	130068.2					
2180	1.878	193020.0	140050.9	51.92	65.0	-0.0699	0.0386	0.0575
	1.902	158000.0	131896.2					
2200	2.329	182290.0	140989.2	52.35	65.0	-0.0616	0.0583	0.0469
	2.368	151750.0	133513.0					
2220	2.714	168140.0	141790.0	52.73	65.0	-0.0519	0.0807	0.0369
	2.777	141960.0	134932.3					
2240	3.022	148090.0	142430.6	53.03	65.0	-0.0406	0.1017	0.0235
	3.105	128770.0	136067.3					

program DUFLOW analysis - Details

CALCULATION TIME LEVEL 2440 minutes SECTION 1

L	length	=	9200.00 m
H1	level begin	=	1.218700 m
H2	level end	=	1.458000 m
Hav.	prev timestep	=	1.847250 m
Hav.	next timestep	=	0.785815 m
Q1	discharge begin	=	$-147040.00000 m3/s
Q2	discharge end	=	$-108860.00000 m3/s
Q	average disch.	=	$-127950.00000 m3/s
Qav.	prev timestep	=	$-100516.00000 m3/s
Qav.	next timestep	=	$-151025.00000 m3/s
A1	area begin	=	$138678.89063 m²
A2	area end	=	$130358.35938 m²
A	average area	=	$134518.62500 m²
R	hydr. radius	=	51.399952 m
SW	Storage width	=	9335.38867 m
C	de Chezy coeff.	=	65.000 m½/s
dt	time interval	=	1200 sec

SW*L*dH/dt = -37984.1484 m3/s
Q1 - Q2 = -38180.0000 m3/s

Friction term:

$$\frac{-Q*|Q|*L}{C^2*A^2*R} = 0.038328 \text{ m}$$

Acceleration term:

$$\frac{-L}{gA} * \frac{dQ}{dt} = 0.146722 \text{ m}$$

Advective term:

$$\frac{Q1^2/A1-Q2^2/A2}{gA} = 0.049255 \text{ m}$$

SUM of the 3 terms = 0.234304 m
H2 - H1 = 0.239300 m

program DUFLOW Analysis - Table

Analysis section 1 Page 7

Time min.	H1 (m) H2 (m)	Q1 (m) Q2 (m)	A1 (m²) A2 (m²)	R (m)	C (m½/s)	FRICTION (m)	ACCELERA-TION (m)	CONVEC-TION (m)
2420	1.736	-117740.	139754.9	51.88	65.0	0.0230	0.1609	0.0350
	1.959	-83292.0	132093.4					
2440	1.219	-147040.	138678.9	51.40	65.0	0.0383	0.1467	0.0493
	1.458	-108860.	130358.4					
2460	0.667	-171340.	137530.8	50.88	65.0	0.0552	0.1188	0.0617
	0.905	-130710.	128441.0					
2480	0.096	-189020.	136343.4	50.33	65.0	0.0710	0.0885	0.0694
	0.328	-147740.	126442.0					
2500	-0.478	-201400.	135150.3	49.78	65.0	0.0849	0.0589	0.0737
	-0.254	-160190.	124423.3					
2520	-1.038	-208320.	133985.4	49.24	65.0	0.0950	0.0205	0.0752
	-0.839	-167540.	122395.9					
2540	-1.568	-206680.	132881.7	48.71	65.0	0.0980	-0.0178	0.0692
	-1.420	-168380.	120381.2					
2560	-2.054	-198940.	131870.9	48.23	65.0	0.0955	-0.0411	0.0566
	-1.935	-165360.	118594.8					

program DUFLOW analysis - Details

CALCULATION TIME LEVEL 2300 minutes SECTION 8

L	length	=	3651.00 m
H1	level begin	=	3.253000 m
H2	level end	=	2.637700 m
Hav.	prev timestep	=	2.632350 m
Hav.	next timestep	=	3.119350 m
Q1	discharge begin	=	39912.00000 m3/s/s
Q2	discharge end	=	35575.00000 m3/s/s
Q	average disch.	=	37743.50000 m3/s/s
Qav.	prev timestep	=	37312.00000 m3/s/s
Qav.	next timestep	=	37394.00000 m3/s/s
A1	area begin	=	21642.00000 m^2
A2	area end	=	22097.19922 m^2
A	average area	=	21869.59961 m^2
R	hydr. radius	=	13.542227 m
SW	Storage width	=	8149.39551 m
C	de Chezy coeff.	=	35.000 $m^{½}$/s
dt	time interval	=	1200 sec

SW*L*dH/dt = 6037.4692 m3/s

Q1 - Q2 = 4337.0000 m3/s

Friction term:

$$\frac{-Q*|Q|*L}{C^2*A^2*R} = -0.655524 \text{ m}$$

Acceleration term:

$$\frac{-L}{gA} * \frac{dQ}{dt} = -0.000581 \text{ m}$$

Advective term:

$$\frac{Q1^2/A1-Q2^2/A2}{gA} = 0.076126 \text{ m}$$

SUM of the 3 terms = -0.579979 m

H2 - H1 = -0.615300 m

program DUFLOW Analysis - Table

Analysis section 8 Page 6

Time min.	H1 (m) H2 (m)	Q1 (m) Q2 (m)	A1 (m^2) A2 (m^2)	R (m)	C ($m^{½}$/s)	FRICTION (m)	ACCELERATION (m)	CONVECTION (m)
2260	2.480	42596.00	20496.73	13.02	35.0	-0.7404	-0.0099	0.1976
	1.925	31785.00	20862.27					
2280	2.886	42189.00	21095.27	13.33	35.0	-0.6816	-0.0040	0.1706
	2.378	32435.00	21646.85					
2300	3.253	39912.00	21642.00	13.54	35.0	-0.6555	-0.0006	0.0761
	2.638	35575.00	22097.20					
2320	3.368	39679.00	21814.98	13.68	35.0	-0.6206	0.0208	0.0800
	2.871	35109.00	22502.46					
2340	3.482	36408.00	21987.10	13.79	35.0	-0.5202	0.0473	0.0555
	3.066	33146.00	22844.01					
2360	3.514	31300.00	22034.72	13.87	35.0	-0.3938	0.0693	0.0270
	3.222	29822.00	23115.74					
2380	3.476	24487.00	21976.97	13.90	35.0	-0.2554	0.0911	0.0030
	3.310	24888.00	23269.41					
2400	3.333	15686.00	21762.62	13.86	35.0	-0.1266	0.1108	-0.0180
	3.302	18850.00	23256.12					

program DUFLOW   analysis - Details

CALCULATION TIME LEVEL 2740 minutes   SECTION 8

L	length	=	3651.00 m
H1	level begin	=	-3.359200 m
H2	level end	=	-1.930100 m
Hav.	prev timestep	=	-2.239800 m
Hav.	next timestep	=	-2.906950 m
Q1	discharge begin	=	%-28094.00000 m3/s
Q2	discharge end	=	%-23120.00000 m3/s
Q	average disch.	=	%-25607.00000 m3/s
Qav.	prev timestep	=	%-26243.50000 m3/s
Qav.	next timestep	=	%-23318.50000 m3/s
A1	area begin	=	12312.52051 m²
A2	area end	=	14317.43262 m²
A	average area	=	13314.97656 m²
R	hydr. radius	=	8.796208 m
SW	Storage width	=	3877.89624 m
C	de Chezy coeff.	=	35.000 m½/s
dt	time interval	=	1200 sec

Friction term:

$$\frac{-Q*|Q|*L}{C^2*A^2*R} = 1.253190 \text{ m}$$

Acceleration term:

$$\frac{-L}{gA} * \frac{dQ}{dt} = -0.034066 \text{ m}$$

Advective term:

$$\frac{Q1^2/A1-Q2^2/A2}{gA} = 0.204936 \text{ m}$$

SW*L*dH/dt = -3935.6846 m3/s

Q1 - Q2 = -4974.0000 m3/s

SUM of the 3 terms = 1.424060 m

H2 - H1 = 1.429100 m

program DUFLOW   Analysis - Table

Analysis section 8   Page 8

Time min.	H1 (m) H2 (m)	Q1 (m) Q2 (m)	A1 (m²) A2 (m²)	R (m)	C (m½/s)	FRICTION (m)	ACCELERATION (m)	CONVECTION (m)
2580	-0.106	-34150.0	16802.79	11.50	35.0	0.7317	0.0043	0.1933
	0.819	-25946.0	18963.14					
2600	-0.534	-33679.0	16202.83	11.15	35.0	0.8052	-0.0020	0.1911
	0.452	-26267.0	18336.07					
2620	-0.978	-33549.0	15583.27	10.80	35.0	0.8840	-0.0066	0.2070
	0.103	-26098.0	17742.04					
2640	-1.377	-32572.0	15028.77	10.47	35.0	0.9415	-0.0120	0.1985
	-0.247	-25950.0	17149.93					
2660	-1.785	-32016.0	14464.49	10.14	35.0	0.9969	-0.0141	0.2151
	-0.589	-25135.0	16571.85					
2680	-2.166	-30573.0	13940.22	9.82	35.0	1.0502	-0.0177	0.1881
	-0.926	-25119.0	16003.84					
2700	-2.547	-29383.0	13418.13	9.50	35.0	1.0829	-0.0172	0.1840
	-1.228	-24347.0	15496.79					
2720	-2.902	-28583.0	12933.49	9.17	35.0	1.1545	-0.0140	0.1819
	-1.578	-23904.0	14909.46					

program DUFLOW Analysis - Table

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Time min.	H1 (m) H2 (m)	Q1 (m) Q2 (m)	A1 (m^2) A2 (m^2)	R (m)	C ($m^{1/2}$/s)	FRICTION (m)	ACCELERATION (m)	CONVECTION (m)
2740	-3.359	-28094.0	12312.52	8.80	35.0	1.2532	-0.0341	0.2049
	-1.930	-23120.0	14317.43					
2760	-3.496	-24218.0	12127.14	8.54	35.0	1.1405	-0.0592	0.0916
	-2.318	-22419.0	13666.26					
2780	-3.505	-20898.0	12114.83	8.40	35.0	0.9481	-0.0938	0.0347
	-2.602	-20462.0	13188.64					
2800	-2.996	-13571.0	12805.85	8.57	35.0	0.5124	-0.1403	-0.0780
	-2.714	-17756.0	13001.32					
2820	-2.330	-5802.30	13714.79	9.01	35.0	0.1450	-0.1763	-0.0644
	-2.418	-12212.0	13497.09					
2840	-1.706	3249.90	14573.10	9.50	35.0	0.0001	-0.2004	-0.0015
	-1.974	-3641.30	14243.51					
2860	-1.266	12865.00	15182.43	9.94	35.0	-0.1213	-0.1902	0.0553
	-1.488	6369.20	15059.49					
2880	-0.812	21605.00	15814.55	10.23	35.0	-0.4028	-0.1335	0.0961
	-1.290	15093.00	15392.80					

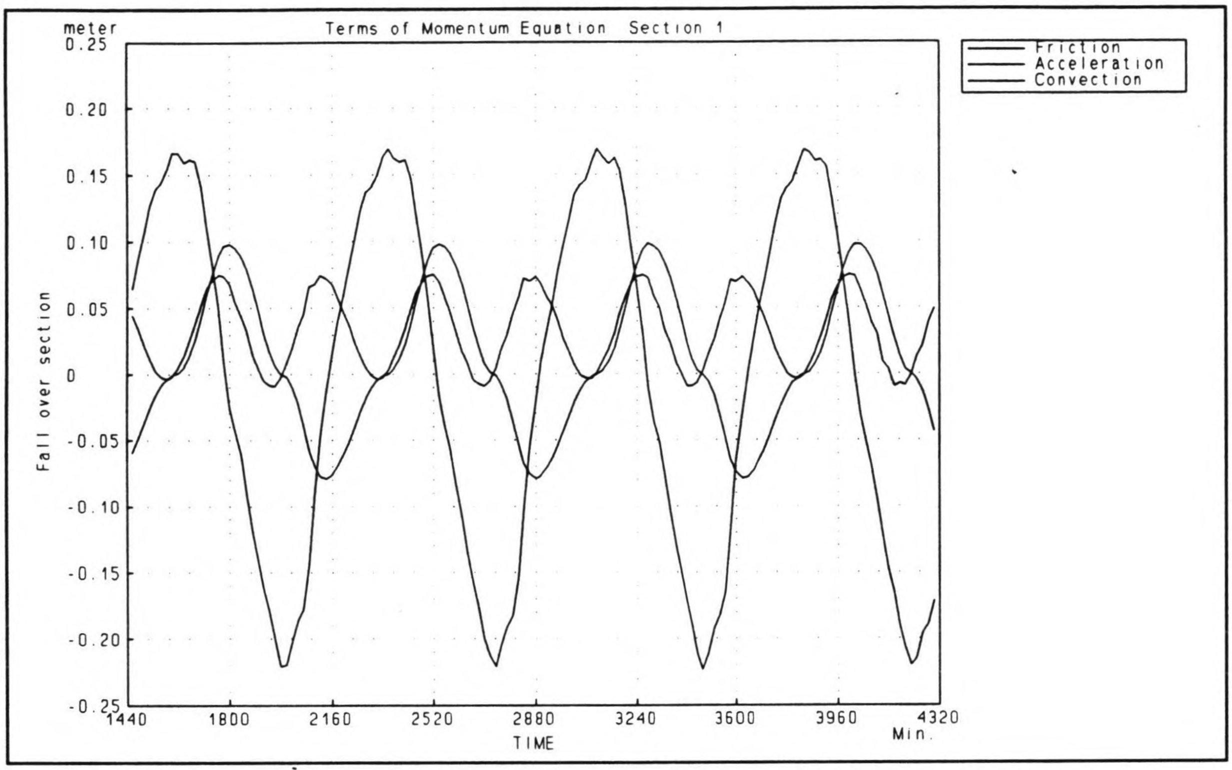

***Figure 4.13:** Friction-, advection- and acceleration term as a function of time for section 1*

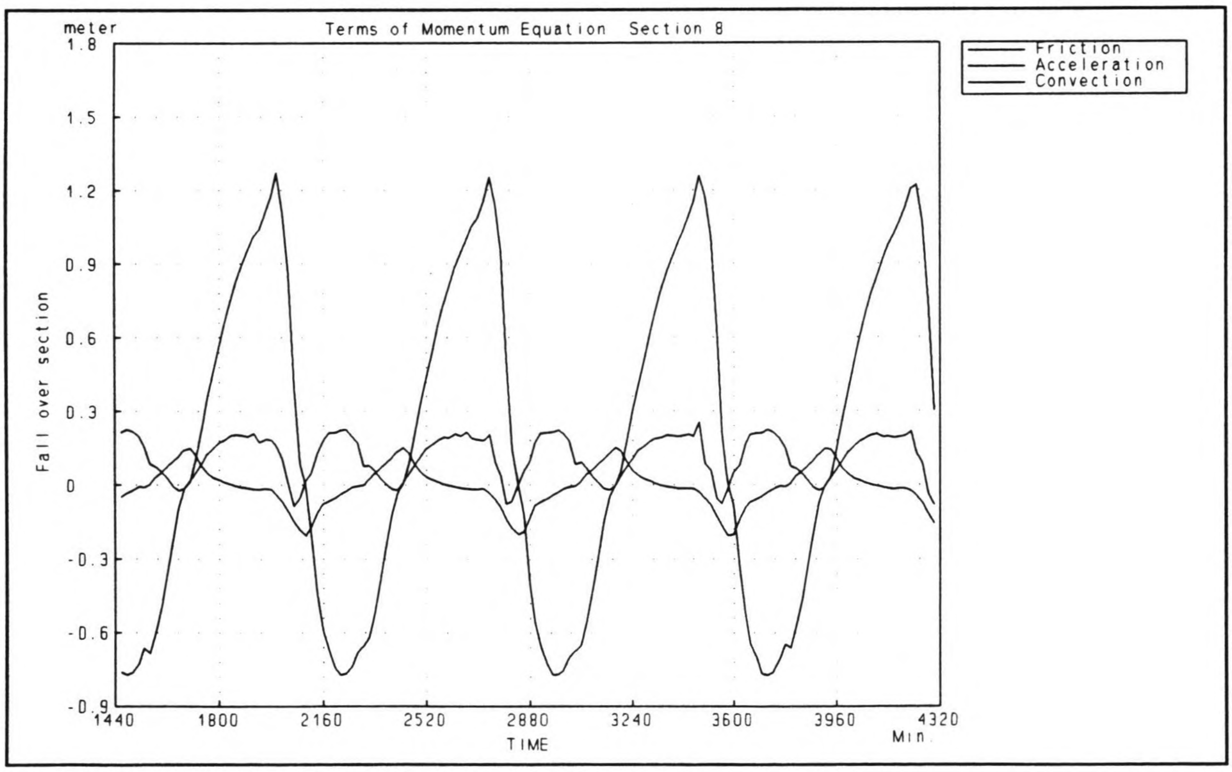

***Figure 4.14:** Friction-, advection- and acceleration term as a function of time for section 8*

Annex C

Input

NODE	X-COORDINATE (m)	Y-COORDINATE (m)
1	250	7750
2	4500	16500
3	12500	22500
4	22000	24800
5	26300	28800
6	33400	33400
7	34800	38000
8	34700	41800
9	34800	45450
10	33000	51200
11	31200	55000
12	29300	59000
13	29000	63200
14	28400	67400
15	29300	70200
16	13400	3600
17	15000	14300
18	19300	10700
19	19900	17600
20	21700	20700
21	24100	24200
22	29200	25400
23	37700	27300
24	43000	27800
25	47300	28200
26	48900	31400
27	36900	21200
28	45400	19700
29	49600	24500

NODE	X-COORDINATE (m)	Y-COORDINATE (m)
30	49200	19600
31	54200	18850
32	57300	22000
33	59800	15700
34	51600	15200
35	51500	9600
36	27500	21000
37	31900	12200
38	35600	20100
39	39900	16300
40	39900	11700
41	47600	16200
42	39100	33000
43	35591	20101
44	37050	20725
45	39090	23002

SECTION	BEGIN NODE	END NODE	LENGTH (m)	BOTTOM begin (m)	LEVEL end (m)	CHEZY pos. dir.	CHEZY neg. dir.
1	1	2	9200	-74.30	-42.30	65	65
2	2	3	10200	-42.30	-28.55	65	65
3	3	4	8200	-28.55	-27.55	65	65
4	4	5	7300	-27.55	-20.00	65	65
5	5	6	8400	-20.00	-16.50	55	55
6	6	7	4900	-16.50	-14.00	50	50
7	7	8	3900	-14.00	-13.00	40	40
8	8	9	3651	-13.00	-11.00	35	35
9	9	10	6025	-11.00	- 9.10	35	35
10	10	11	4205	- 9.10	- 8.15	35	35
11	11	12	4428	- 8.15	- 7.14	35	35
12	12	13	4300	- 7.14	- 6.15	35	35
13	13	14	4243	- 6.15	- 5.18	35	35
14	14	15	2941	- 5.18	- 4.50	35	35
15	16	17	10819	-40.00	-34.30	65	65
16	17	4	11900	-34.30	-27.55	65	65
17	4	21	2184	-27.55	-33.55	65	65
18	21	22	5239	-33.55	-31.55	55	55
19	22	6	9035	-31.55	-14.50	50	50
20	22	23	8710	-24.55	- 4.50	40	40
21	23	42	5869	- 4.50	- 4.50	35	35
22	23	24	5324	- 4.50	- 4.50	35	35
23	24	25	4319	- 4.50	- 4.50	35	35
24	25	26	3578	- 4.50	- 4.50	35	35
25	22	27	10187	-24.55	-13.00	40	40
27	46	28	7105	-13.00	- 7.50	35	35
28	28	29	6378	- 7.50	- 4.50	35	35

SECTION	BEGIN NODE	END NODE	LENGTH (m)	BOTTOM begin (m)	LEVEL end (m)	CHEZY pos. dir.	CHEZY pos. dir.
29	28	30	3801	- 7.50	- 4.50	35	35
30	30	31	5056	- 4.50	- 4.50	35	35
31	31	32	4420	- 4.50	- 4.50	35	35
32	31	33	6425	- 4.50	- 4.50	35	35
33	31	34	4481	- 4.50	- 4.50	35	35
34	34	35	5601	- 4.50	- 4.50	35	35
35	16	18	10900	-34.30	-27.30	35	35
36	18	19	6926	-27.30	-27.05	35	35
37	19	20	3585	-27.05	-28.55	35	35
38	20	21	4244	-28.55	-33.55	35	35
39	20	36	5808	-28.55	-17.15	35	35
40	36	37	9839	-17.15	- 4.50	35	35
41	36	27	9402	-17.55	-16.00	35	35
43	44	39	5649	-16.00	- 4.50	35	35
44	39	40	4600	- 4.50	- 4.50	35	35
45	39	41	7701	- 4.50	- 4.50	35	35
46	28	41	4134	- 4.50	- 4.50	35	35
47	41	34	4123	- 4.50	- 4.50	35	35
48	44	46	426	-16.00	- 7.50	35	35

CROSS-SECTION Profile SECTION 1

Depth to bott.(m)	Flow width (m) at n. 1	Flow width (m) at n. 2	Storage Width (m)
0.00	1440.00	2400.00	1920.00
10.00	1600.00	2666.70	2133.40
20.00	1680.00	2933.00	2306.50
30.00	1760.00	3200.00	2480.00
40.00	1840.00	3466.70	6826.60
50.00	2000.00	3466.70	6906.90
55.00	2040.00	3466.70	11814.00
60.00	2080.00	3466.70	11814.00
70.00	2080.00	3466.70	11814.00
80.00	2080.00	3466.70	11814.00

CROSS-SECTION Profile SECTION 2

Depth to bott.(m)	Flow width (m) at n. 2	Flow width (m) at n. 3	Storage Width (m)
0.00	2400.00	2400.00	2400.00
10.00	2666.70	2666.70	2666.70
15.00	2800.00	2933.00	2866.50
20.00	2933.00	3200.00	5566.50
30.00	3200.00	3680.00	6486.50
40.00	3466.70	3680.00	6973.00
50.00	3466.70	3680.00	6973.00

CROSS-SECTION Profile SECTION 3

Depth to bott.(m)	Flow width (m) at n. 3	Flow width (m) at n. 4	Storage Width (m)
0.00	2400.00	3040.00	2720.00
10.00	2666.70	3120.00	2893.40
15.00	2933.30	3200.00	3066.60
20.00	3200.00	3360.00	5389.00
30.00	3680.00	3520.00	5389.00
40.00	3680.00	3520.00	5389.00

CROSS-SECTION Profile SECTION 4

Depth to bott.(m)	Flow width (m) at n. 4	Flow width (m) at n. 5	Storage Width (m)
0.00	3040.00	1600.00	2320.00
5.00	3060.00	1680.00	2370.00
10.00	3120.00	1760.00	2880.00
15.00	3200.00	1840.00	6173.00
20.00	3360.00	1920.00	6173.00
30.00	3440.00	1920.00	6173.00
40.00	3440.00	1920.00	6173.00

CROSS-SECTION Profile SECTION 5

Depth to bott.(m)	Flow width (m) at n. 5	Flow width (m) at n. 6	Storage Width (m)
0.00	1600.00	960.00	1280.00
5.00	1680.00	960.00	1440.00
10.00	1760.00	960.00	1800.00
15.00	1840.00	1200.00	8534.20
20.00	1920.00	1440.00	8534.20
30.00	1920.00	1440.00	8534.20
40.00	1920.00	1440.00	8534.20

CROSS-SECTION Profile SECTION 6

Depth to bott.(m)	Flow width (m) at n. 6	Flow width (m) at n. 7	Storage Width (m)
0.00	2000.00	1600.00	1800.00
10.00	3200.00	2000.00	2600.00
11.00	3200.00	2160.00	8055.00
15.00	3200.00	2240.00	8055.00
20.00	3200.00	2240.00	8055.00
30.00	3200.00	2240.00	8055.00

CROSS-SECTION Profile SECTION 7

Depth to bott.(m)	Flow width (m) at n. 7	Flow width (m) at n. 8	Storage Width (m)
0.00	1600.00	1200.00	1400.00
10.00	2000.00	1360.00	1680.00
11.00	2160.00	1376.00	4514.00
15.00	2240.00	1440.00	4546.00
20.00	2240.00	1600.00	7652.00
30.00	2240.00	1600.00	7652.00
40.00	2240.00	1600.00	7652.00

CROSS-SECTION Profile SECTION 8

Depth to bott.(m)	Flow width (m) at n. 8	Flow width (m) at n. 9	Storage Width (m)
0.00	1200.00	1440.00	1320.00
5.00	1280.00	1600.00	1440.00
8.00	1328.00	1680.00	1504.00
10.00	1360.00	1680.00	5007.00
15.00	1440.00	1760.00	8645.00
20.00	1680.00	1840.00	8645.00
30.00	1680.00	1840.00	8645.00

CROSS-SECTION Profile SECTION 9

Depth to bott.(m)	Flow width (m) at n. 9	Flow width (m) at n. 10	Storage Width (m)
0.00	1440.00	550.00	995.00
4.60	1587.20	550.00	1068.60
5.00	1600.00	550.00	6375.50
8.00	1680.00	550.00	6415.50
10.00	1680.00	550.00	11151.00
20.00	1840.00	550.00	11151.00
30.00	1840.00	550.00	11151.00

CROSS-SECTION Profile SECTION 10

Depth to bott.(m)	Flow width (m) at n. 10	Flow width (m) at n. 11	Storage Width (m)
0.00	550.00	500.00	525.00
6.50	550.00	500.00	525.00
7.00	550.00	500.00	4689.50
10.00	550.00	500.00	8829.00
13.50	550.00	500.00	8829.00
20.00	550.00	500.00	8829.00

CROSS-SECTION Profile SECTION 11

Depth to bott.(m)	Flow width (m) at n. 11	Flow width (m) at n. 12	Storage Width (m)
0.00	500.00	500.00	500.00
5.00	500.00	500.00	500.00
5.50	500.00	500.00	857.00
8.00	500.00	500.00	1214.00
20.00	500.00	500.00	1214.00

CROSS-SECTION Profile SECTION 12

Depth to bott.(m)	Flow width (m) at n. 12	Flow width (m) at n. 13	Storage Width (m)
0.00	500.00	700.00	600.00
3.00	500.00	700.00	600.00
3.50	500.00	700.00	867.50
6.50	500.00	700.00	1235.50
20.00	500.00	700.00	1235.50

CROSS-SECTION Profile SECTION 13

Depth to bott.(m)	Flow width (m) at n. 13	Flow width (m) at n. 14	Storage Width (m)
0.00	700.00	500.00	600.00
2.70	700.00	500.00	600.00
3.00	700.00	500.00	788.20
5.70	700.00	500.00	876.00
20.00	700.00	500.00	876.00

CROSS-SECTION Profile SECTION 14

Depth to bott.(m)	Flow width (m) at n. 14	Flow width (m) at n. 15	Storage Width (m)
0.00	500.00	250.00	375.00
2.00	500.00	250.00	375.00
5.00	500.00	250.00	446.00
10.00	500.00	250.00	446.00
20.00	500.00	250.00	446.00

CROSS-SECTION Profile SECTION 15

Depth to bott.(m)	Flow width (m) at n. 16	Flow width (m) at n. 17	Storage Width (m)
0.00	1480.00	1800.00	2640.00
10.00	1480.00	2040.00	2760.00
20.00	1480.00	2360.00	2920.00
21.00	1480.00	2388.00	4932.00
25.00	1480.00	2600.00	6476.00
30.00	1480.00	2600.00	6476.00
40.00	1480.00	2600.00	6476.00
50.00	1480.00	2600.00	6476.00

CROSS-SECTION Profile SECTION 16

Depth to bott.(m)	Flow width (m) at n. 17	Flow width (m) at n. 4	Storage Width (m)
0.00	1800.00	2000.00	2400.00
10.00	2040.00	2000.00	2520.00
20.00	2360.00	2000.00	3180.00
25.00	2600.00	2000.00	3300.00
26.00	2600.00	2000.00	3300.00
30.00	2600.00	2000.00	3225.50
35.00	2600.00	2000.00	4451.00
40.00	2600.00	2000.00	4451.00
50.00	2600.00	2000.00	4451.00

CROSS-SECTION Profile SECTION 17

Depth to bott.(m)	Flow width (m) at n. 4	Flow width (m) at n. 21	Storage Width (m)
0.00	2800.00	2000.00	2400.00
10.00	3040.00	2000.00	2520.00
20.00	3360.00	2000.00	3180.00
25.00	3600.00	2000.00	3300.00
26.00	3600.00	2000.00	3300.00
30.00	3600.00	2000.00	3225.00
35.00	3600.00	2000.00	4251.00
40.00	3600.00	2000.00	4251.00
503.00	3600.00	2000.00	4251.00

CROSS-SECTION Profile SECTION 18

Depth to bott.(m)	Flow width (m) at n. 21	Flow width (m) at n. 22	Storage Width (m)
0.00	2540.00	2480.00	2137.00
10.00	2540.00	2540.00	2217.00
15.00	2540.00	2540.00	2257.00
16.00	2540.00	2540.00	2540.00
25.00	2540.00	2540.00	2540.00
40.00	2540.00	2540.00	2540.00

CROSS-SECTION Profile SECTION 19

Depth to bott.(m)	Flow width (m) at n. 22	Flow width (m) at n. 6	Storage Width (m)
0.00	680.00	960.00	1120.00
10.00	840.00	960.00	1350.00
15.00	920.00	960.00	1600.00
20.00	1000.00	960.00	1776.00
25.00	1000.00	960.00	1776.00
40.00	1000.00	960.00	1776.00

CROSS-SECTION Profile SECTION 20

Depth to bott.(m)	Flow width (m) at n. 22	Flow width (m) at n. 23	Storage Width (m)
0.00	880.00	1200.00	1040.00
5.00	920.00	1200.00	1060.00
6.00	935.00	1440.00	1722.30
10.00	960.00	1440.00	1734.30
18.00	1040.00	1440.00	2409.00
25.00	1040.00	1440.00	2409.00

CROSS-SECTION Profile SECTION 21

Depth to bott.(m)	Flow width (m) at n. 23	Flow width (m) at n. 42	Storage Width (m)
0.00	420.00	420.00	420.00
1.50	420.00	420.00	420.00
2.00	420.00	420.00	840.00
3.00	420.00	420.00	2400.00
4.00	420.00	420.00	3000.00
4.50	420.00	420.00	3397.10
10.00	420.00	420.00	3397.10
20.00	420.00	420.00	3397.10

CROSS-SECTION Profile SECTION 22

Depth to bott.(m)	Flow width (m) at n. 23	Flow width (m) at n. 24	Storage Width (m)
0.00	1020.00	1020.00	1020.00
1.50	1020.00	1020.00	1020.00
2.00	1020.00	1020.00	2040.00
3.00	1020.00	1020.00	2200.00
4.00	1020.00	1020.00	3500.00
4.50	1020.00	1020.00	3882.80
10.00	1020.00	1020.00	3882.80
20.00	1020.00	1020.00	3882.80

CROSS-SECTION Profile SECTION 23

Depth to bott.(m)	Flow width (m) at n. 24	Flow width (m) at n. 25	Storage Width (m)
0.00	1020.00	1020.00	1020.00
2.50	1020.00	1020.00	1020.00
3.00	1020.00	1020.00	2000.00
4.00	1020.00	1020.00	2500.00
4.50	1020.00	1020.00	3000.00
6.00	1020.00	1020.00	3407.00
10.00	1020.00	1020.00	3407.00
20.00	1020.00	1020.00	3407.00

CROSS-SECTION Profile SECTION 24

Depth to bott.(m)	Flow width (m) at n. 25	Flow width (m) at n. 26	Storage Width (m)
0.00	1020.00	1020.00	1020.00
1.50	1020.00	1020.00	1020.00
2.00	1020.00	1020.00	1020.00
3.00	1020.00	1020.00	2500.00
4.00	1020.00	1020.00	3000.00
4.50	1020.00	1020.00	3301.40
10.00	1020.00	1020.00	3301.40
20.00	1020.00	1020.00	3301.40

CROSS-SECTION Profile SECTION 25

Depth to bott.(m)	Flow width (m) at n. 22	Flow width (m) at n. 27	Storage Width (m)
0.00	1040.00	1040.00	1680.00
10.00	1040.00	1040.00	1946.00
11.00	1040.00	1040.00	2750.00
20.00	1040.00	1040.00	2750.00
30.00	1040.00	1040.00	2750.00

CROSS-SECTION Profile SECTION 27

Depth to bott.(m)	Flow width (m) at n. 46	Flow width (m) at n. 28	Storage Width (m)
0.00	1250.00	850.00	1040.00
6.00	1250.00	850.00	2000.00
7.00	1250.00	850.00	4000.00
10.00	1250.00	850.00	5106.00
20.00	1250.00	850.00	5106.00
30.00	1250.00	850.00	5106.00

CROSS-SECTION Profile SECTION 28

Depth to bott.(m)	Flow width (m) at n. 28	Flow width (m) at n. 29	Storage Width (m)
0.00	550.00	340.00	340.00
3.50	550.00	340.00	340.00
4.00	550.00	340.00	340.00
4.50	550.00	340.00	800.00
5.00	550.00	340.00	800.00
6.00	550.00	340.00	1000.00
10.00	550.00	340.00	3430.00
20.00	550.00	340.00	3430.00

CROSS-SECTION Profile SECTION 29

Depth to bott.(m)	Flow width (m) at n. 28	Flow width (m) at n. 30	Storage Width (m)
0.00	600.00	350.00	350.00
1.50	600.00	350.00	350.00
2.50	600.00	350.00	350.00
4.50	600.00	350.00	500.00
5.50	600.00	350.00	800.00
6.00	600.00	350.00	1000.00
10.00	600.00	350.00	1750.00
20.00	600.00	350.00	1750.00

CROSS-SECTION Profile SECTION 30

Depth to bott.(m)	Flow width (m) at n. 30	Flow width (m) at n. 31	Storage Width (m)
0.00	350.00	350.00	350.00
1.50	350.00	350.00	350.00
2.00	350.00	350.00	350.00
3.00	350.00	350.00	500.00
5.50	350.00	350.00	600.00
8.24	350.00	350.00	2101.60
10.00	350.00	350.00	2101.60
20.00	350.00	350.00	2101.60

CROSS-SECTION Profile SECTION 31

Depth to bott.(m)	Flow width (m) at n. 31	Flow width (m) at n. 32	Storage Width (m)
0.00	350.00	350.00	350.00
1.50	350.00	350.00	350.00
2.00	350.00	350.00	350.00
4.00	350.00	350.00	500.00
5.50	350.00	350.00	1000.00
7.00	350.00	350.00	2036.20
10.00	350.00	350.00	2036.20
20.00	350.00	350.00	2036.20

CROSS-SECTION Profile SECTION 32

Depth to bott.(m)	Flow width (m) at n. 31	Flow width (m) at n. 33	Storage Width (m)
0.00	810.00	810.00	500.00
1.50	810.00	810.00	500.00
2.00	810.00	810.00	500.00
4.00	810.00	810.00	500.00
5.50	810.00	810.00	900.00
7.00	810.00	810.00	1459.10
10.00	810.00	810.00	1459.10
20.00	810.00	810.00	1459.10

CROSS-SECTION Profile SECTION 33

Depth to bott.(m)	Flow width (m) at n. 31	at n. 34	Storage Width (m)
0.00	350.00	350.00	350.00
1.50	350.00	350.00	350.00
2.00	350.00	350.00	350.00
4.00	350.00	350.00	400.00
5.50	350.00	350.00	1000.00
7.00	350.00	350.00	2008.50
10.00	350.00	350.00	2008.50
20.00	350.00	350.00	2008.50

CROSS-SECTION Profile SECTION 34

Depth to bott.(m)	Flow width (m) at n. 34	at n. 35	Storage Width (m)
0.00	200.00	200.00	200.00
1.50	200.00	200.00	200.00
4.00	200.00	200.00	400.00
5.50	200.00	200.00	800.00
7.00	200.00	200.00	2181.50
10.00	200.00	200.00	2181.50
20.00	200.00	200.00	2181.50

CROSS-SECTION Profile SECTION 35

Depth to bott.(m)	Flow width (m) at n. 16	at n. 18	Storage Width (m)
0.00	3200.00	2760.00	2480.00
10.00	3440.00	3000.00	2720.00
15.00	3480.00	3080.00	2780.00
20.00	3520.00	3120.00	4492.20
22.00	3520.00	3200.00	5464.40
25.00	3620.00	3240.00	5464.40
30.00	3620.00	3240.00	5464.40
40.00	3620.00	3240.00	5464.40

CROSS-SECTION Profile SECTION 36

Depth to bott.(m)	Flow width (m) at n. 18	at n. 19	Storage Width (m)
0.00	2760.00	2320.00	2040.00
10.00	3000.00	2400.00	2200.00
15.00	3080.00	2440.00	2260.00
20.00	3120.00	2480.00	6740.20
25.00	3240.00	2480.00	10120.00
30.00	3240.00	2480.00	10120.00
40.00	3240.00	2480.00	10120.00

CROSS-SECTION Profile SECTION 37

Depth to bott.(m)	Flow width (m) at n. 19	at n. 20	Storage Width (m)
0.00	2320.00	2000.00	2160.00
10.00	2400.00	2160.00	2280.00
20.00	2480.00	2320.00	3510.50
25.00	2480.00	2400.00	3661.00
30.00	2480.00	2400.00	3661.00
40.00	2480.00	2400.00	3661.00

CROSS-SECTION Profile SECTION 38

Depth to bott.(m)	Flow width (m) at n. 20	at n. 21	Storage Width (m)
0.00	1280.00	1200.00	1200.00
10.00	1440.00	1400.00	1788.00
25.00	1600.00	1400.00	1788.00
26.00	1600.00	1400.00	1788.00
40.00	1600.00	1400.00	1788.00

CROSS-SECTION Profile SECTION 39

Depth to bott.(m)	Flow width (m) at n. 20	at n. 36	Storage Width (m)
0.00	1600.00	1920.00	1760.00
5.00	1600.00	2160.00	1880.00
10.00	1600.00	2480.00	2240.00
11.00	1600.00	2480.00	2427.60
20.00	1600.00	2480.00	2427.60
21.00	1600.00	2480.00	3255.20
30.00	1600.00	2480.00	3255.20
40.00	1600.00	2480.00	3255.20

CROSS-SECTION Profile SECTION 40

Depth to bott.(m)	Flow width (m) at n. 36	at n. 37	Storage Width (m)
0.00	640.00	400.00	540.00
1.50	800.00	400.00	540.00
6.00	880.00	400.00	1000.00
7.00	880.00	400.00	1500.00
8.00	880.00	400.00	2000.00
9.00	880.00	400.00	2700.00
10.00	880.00	880.00	3430.00
20.00	880.00	880.00	3430.00
40.00	880.00	880.00	3430.00

CROSS-SECTION Profile SECTION 41

Depth to bott.(m)	Flow width (m) at n. 36	at n. 27	Storage Width (m)
0.00	2280.00	2250.00	1800.00
10.00	2440.00	2250.00	2000.00
11.00	2600.00	2250.00	3346.00
15.00	2600.00	2250.00	3346.00
20.00	2600.00	2250.00	3346.00
40.00	2600.00	2250.00	3346.00

CROSS-SECTION Profile SECTION 43

Depth to bott.(m)	Flow width (m) at n. 44	at n. 39	Storage Width (m)
0.00	1000.00	500.00	600.00
1.00	1000.00	750.00	600.00
4.00	1000.00	1000.00	600.00
5.00	1000.00	1000.00	600.00
6.00	1000.00	1000.00	750.00
10.00	1000.00	1000.00	1500.00
14.00	1000.00	1000.00	4647.00
20.00	1000.00	1000.00	4647.00
40.00	1000.00	1000.00	4647.00

CROSS-SECTION Profile SECTION 44

Depth to bott.(m)	Flow width (m) at n. 39	at n. 40	Storage Width (m)
0.00	200.00	200.00	600.00
1.50	200.00	200.00	600.00
2.00	200.00	200.00	600.00
3.00	200.00	200.00	800.00
4.00	200.00	200.00	900.00
4.50	200.00	200.00	1000.00
8.50	200.00	200.00	3192.90
20.00	200.00	200.00	3192.90

CROSS-SECTION Profile SECTION 45

Depth to bott.(m)	Flow width (m) at n. 39	at n. 41	Storage Width (m)
0.00	300.00	300.00	400.00
1.50	300.00	300.00	400.00
2.00	300.00	300.00	500.00
3.00	300.00	300.00	700.00
4.00	300.00	300.00	750.00
4.50	300.00	300.00	800.00
8.50	300.00	300.00	2086.00
20.00	300.00	300.00	2086.00

CROSS-SECTION Profile SECTION 46

Depth to bott.(m)	Flow width (m) at n. 28	at n. 41	Storage Width (m)
0.00	600.00	250.00	300.00
1.50	600.00	250.00	300.00
2.00	600.00	250.00	400.00
3.00	600.00	250.00	600.00
4.00	600.00	250.00	750.00
4.50	600.00	350.00	800.00
8.50	600.00	350.00	1700.00
10.00	600.00	350.00	1700.00
20.00	600.00	350.00	1700.00

CROSS-SECTION Profile SECTION 47

Depth to bott.(m)	Flow width (m) at n. 41	at n. 34	Storage Width (m)
0.00	550.00	550.00	300.00
1.00	550.00	550.00	550.00
2.00	550.00	550.00	550.00
3.30	550.00	550.00	550.00
5.50	550.00	550.00	1000.00
7.70	550.00	550.00	2812.00
10.00	550.00	550.00	2812.00
20.00	550.00	550.00	2812.00

CROSS-SECTION Profile SECTION 48

Depth to bott.(m)	Flow width (m) at n. 44	at n. 46	Storage Width (m)
0.00	500.00	500.00	500.00
5.00	600.00	600.00	600.00
8.00	700.00	700.00	700.00
12.00	1250.00	1250.00	1250.00
16.00	1250.00	1250.00	1250.00
50.00	1250.00	1250.00	1250.00

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