Table of contents

1 Introduction

For centuries now, the transport of goods has been carried out in Europe by means of waterways. This was without doubt the first method of transport used in order to convey over long distances, goods and food, which were the basis of trade, at that time done through barter. According to the archives of the 6th century A.D., some feudal sovereigns in Belgium imposed taxes on boats travelling through their territory.

In the 10th century, the first adaptations of rivers were undertaken, and the first canals were built. Single locks were already built at that time. In fact, they were guarded gates and the passage of boats took place at flood tide. Locks appeared in the 13th and the 14th century. In the following centuries, locks and canals were perfected.

However, it was not until the last century that, thanks to the industrial development, the network of navigable waterways improved. This improvement was due, on the one hand, to the canalisation and regulating of the natural waterways; on the other hand, to the construction and the widening of the artificial canals. This effort was continued at the beginning of this century, especially after the Second World War. After that war, navigation underwent great changes both by motorization and the increased size of the boats and by the new techniques which sere used, as for instance push towing.

By way of information, and taking into consideration the total of each territory, Netherlands, Belgium, Germany and France have the following networks (Table 1):

	Surf km^2	Can km	Rivers and Lakes km	Total km	Density of network km/1000 km^2	Fraction of total transport capacity	
						Vol. %	Output %
Netherlands	33.491	3.538	852	4.390	131	48.3	63.1
Belgium	30.057	853	565	1.509	50,2	31.3	22.3
Germany	356.00	1992	4688	6608	38,96	14.5	29.5
France	551.50	3.84	2.759	6.603	11,97	10.7	8.0
Total	970.54	10.0	9.152	19.18			

Table 1: Utilization of inland waterways

One will notice that Belgium and chiefly the Netherlands have the densest network of navigable waterways. This is the outcome of their geographical situation, in or in the neighbourhood of the deltas of the Rhine, the Meuse and the Scheldt.

This part of Europe, which covers about 1/10 of its total surface (or of the surface of the United States) possesses a network whose length equals half of that of the United States' network.

2 Short description of the Belgian Waterways Network

The main frame of the Belgian inland waterways network is constituted by the three navigable rivers, Ijzer, Schelde and Meuse with the general direction West to East. Connecting these rivers transverse canals ensure the links with the other general direction North/South.

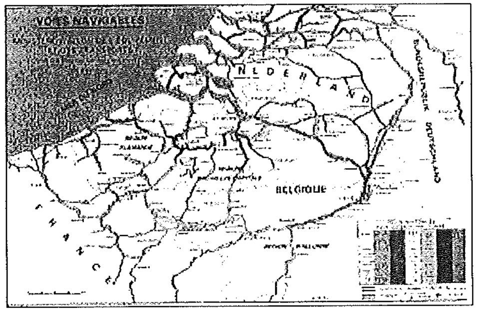

Figure 1: Belgian Waterways Network

Among those ones, the main canals are the Brussels/ Charleroi canal or Canal du Centre, and the Liege/ Antwerpen canal or Canal Albert.

The figure 1 gives the map of the inland waterways in Belgium, connected with the important networks of Netherlands, Germany and the less important one of France. The different categories and the corresponding boat-types are also indicated in that figure 1.

3 Design criteria

When the ECMT created the European (class IV), it determined the minimal dimensions for the civil engineering structures, and also fixed the minimal values of the different construction parameters of navigable waterways of this category. Consequently, the following minimal dimensions have been determined :

1. For single locks (one boat of 1,350 tons) :

   - useful length : 85 m
   - useful width : 12 m
   - depth at the pointing still : 3.5 m

2. For the current section : an average draught of 3.5 m for a width of 28 m; ratio between the immersed cross-section of the vessel and the wetted section of the waterway is equal to 5 at least; curvature radius : 800 m at least (= ten times the vessel's length) and an over width calculated in conformity with the formula $s = L^2/2R$.

   L= length of vessel; R= curvature radius.

3. Head room under the bridges : minimum 5.25 m, subsequently increased to 6.50 m.

The European States have considered these data as a basis for the modernisation of their navigable waterways. However, as the evolution of the navigation material progressed, one noticed (particularly because of the progress of push-towing) that these dimensions did not allow for any margin and that they needed to be adapted. More especially, because of the construction of European pushbarges of class V rather than of class IV, i.e. barges of 76.50 m length, 11.40 m width and from 2.5 m to 3.5 m draught, one had gradually to increase the length of the locks and to widen them to 12.50 m. Finally, the considerable increase of traffic on the waterways led to the construction of locks capable of accommodating several heavy tonnage boats.

Instead of push-towing 2 European barges in a row (+/- 4500 tons), nowadays convoys of 4 European barges (+/- 9000 tons) and even 6 barges are used on the Rhine.

The purpose of the Belgian Ministry of Equipment and Transport, in charge of the network of the waterways was to upgrade the main parts of this waterways in respect of the design criteria stated by the ECMT. In this paper we will give information about the latest rehabilitations or new implementations:

- the upper Meuse rehabilitation,
- the Ronquieres inclined plane,
- the Strepy-Thieu boat lift,
- the Houdeng Aimeries canal bridge implementation,
- the Brussels sea canal,
- the electromechanical equipment rehabilitation of Ivoz-Rawez movable weirs,
- the Confluent of the River Meuse and Ourthe rehabilitation.

4 Upper Meuse rehabilitation

The Belgian Meuse has been the object of a gradual river engineering work intended to control floods as well as to adjust the river to the developments of navigation.

Most of the improvement work has been carried out between Namur and Liège, the section with the densest traffic.

However, upstream of Namur and downstream of Liège, riverside residents could not be left exposed to disastrous floods any more than decayed weirs could be left for a dangerous operation. This is the reason for the already existing Lixhe weir, close the frontier between the Netherlands and Belgium, as well as for the replacement of the 9 weirs located between Givet and Namur, currently being carried out.

The Lixhe weir comprises six sluiceways with a 23.70 m clearance. The movable sluices include a caisson type valve with a curved skin-plate fitted on both ends to caissons as well as a gate also resting on both ends on these two caissons through two pivot pin hinges. The valves and gates are operated through cables.

The valve reduction gear is synchronised with the gate reduction gear through a negative control multi-plate clutch. The end mechanisms of a sluice are mechanically synchronised.

The electric control of the six sluiceways is carried out according to the piloted-pilot system through a programmable robot. One of the six sluiceways is selected as being the pilot. The foundations of the weir are quite substantial. The only possible site is located at the level of a large limestone dissolution pocket into which a soil mainly made of phtanites has fallen down.

The compression tests have delivered limit pressure values and deformation modules that are relatively low and variable not only from one place to another but also over the depth of one single drill hole. However, an acceptable foundation level was found about 21 m under the lower level of the upstream floor.

The existence of locally very resistant layers made it impossible to use driven piles, while drilled piles entailed some risks of discontinuity. So, the technique that was finally adopted for the foundations was the cast wall segments technique.

However, as minor differential settlements could still be feared, the weir properly speaking was made isostatic through joints between the piers and the abutments on the one hand, and the floor on the other hand. The upstream side walls and abutments are connected to each other by thinner walls together with which they form a water tied diaphragm whose ends are themselves connected to the diaphragms of the bank walls.

The construction of the walls raised no problems. Substantial drainage plants collect the seepage water and avoid uplifts under the floors. The dissipation of the energy of the downstream current was studied in the Borgerhout Section of the Hydraulic Research Laboratory. One of the recommendations it produced was a substantial lengthening of the downstream floor.

The nine weirs on the Upper Meuse between Givet and Namur are to be replaced because of their decayed state. However, the reduced traffic on this waterway did not justify as comprehensive an improvement work as was carried out downstream Namur. Nine new weirs were designed according to a single type. They will be located on the same side as the former weirs and twinned with the existing locks.

A special care was taken of preserving the terrific attractiveness of this part of the Meuse valley. The small lifts of the order of 2 m were maintained. A new calibration of the wet section should allow the passage of 1,350 t ships with a draft of maximum 2.20 m. A more extensive improvement could be conducted later on by removing five weirs and building new locks at the level of the remaining four weirs. This would produce lifts of about four meters.

The floods discharge, the source of frequent floods, will be improved thanks to a new design of the weirs and of their management. Some study work has made it possible to select a single type of weir that will include four sluiceways with a clearance of 22.50 m. The single gate solution, in spite of its many advantages, was rejected because of the uncertainty around the damageable effects on the operation of the solid materials transported by the river.

The sluices are of an unusual shape, as they are composed of a tainter gate with a relatively limited height topped with a mushroom valve that is relatively large. This arrangement makes it possible to discharge a substantial quantity of water exclusively through overtopping. The joint flow, combining the overflowing sheet of water and the bottom flow will be limited to short periods of time, as the interim period between the overtopping flow alone and the complete opening of the weir is itself limited.

The movements of the segments and gates are controlled through oil-hydraulic rams without guide-rods nested in the piers over a downstream minimum water level.

The weir is managed on a mini-computer. Tests carried out in the Châtelet section of the Hydraulic Research Laboratory made it possible to dimension the main parts of the structures. The hydraulic gauging of the valves will make it possible to instantaneously compute the flow that is necessary for the management in case of flood.

For the time being, some floods are caused by maintaining a constant upstream water level. These floods will thus be avoided by regulating this level as a function of the flow so as to maintain over the whole of the reach minimum water levels that are compatible with a safe navigation. A preliminary study of the water lines has already resulted in determining for each reach the ratio between the flow (computer calculated) and the position of the valves (computer controlled).

5 The Ronquieres Inclined Plane

5.1 General

The Charleroi to Brussels canal is one of the oldest in the Belgian system of navigable artificial internal waterways. It originates on the left bank of the Sambre at Dampremy (Charleroi) and stretches for 68,202 m to the Sainctelette bridge in Brussels. The section located in the Walloon Region is 47,860 m long. Beyond that it runs through the Flemish and Brussels Regions for a distance of 20,342 m.

From top to bottom the structure includes: a section of the canal on a raised embankment, a canal bridge, the upper basin of the inclined plane, the inclined plane itself and the lower basin.

5.2 History of the canal

The need to link Charleroi with Brussels was felt as long ago as 1561. There were numerous studies for the building of a canal. They all failed over the problem of crossing the peak marking the division between the Sambre and the Senne basins. In 1825, under Dutch rule, the engineer Vifquain submitted a project. In 1832 the first canal, navigable for boats of up to 70 tons, connecting Charleroi with Brussels was opened.

Economic conditions soon made a canal for 300 tons boats necessary. Rebuilding on the Sambre side was completed in 1893. On the Senne side (Ronquières-Clabecq section) it took until 1920 as the work was interrupted by the 1914-1918 War. The capacity of the Clabecq-Brussels section was raised to 600 tons in 1933. It can also take vessels of up to 1,350 tons (80 m, 9.50 beam and 2.50 draft). In 1956, modernization work began to raise the capacity of the canal to 1.350 tons (the « European » standard capacity) and decrease navigating time between Charleroi and Brussels. The work was completed in 1968 when the Ronquières Inclined Plane, on which construction began on 15 March 1962, went into service.

The canal from Charleroi to Brussels now has:

- 3 locks on the Sambre side;
- the inclined plane at Ronquières;
- one lock in the Walloon Region on the Senne side;
- 6 locks in the Flemish and Brussels Regions on the Senne side.

5.3 The Ronquières inclined plane

The modernised 1,350 tons capacity canal from Charleroi to Brussels has to overcome a drop off of 67.73 m between Seneffe and Ronquières. A number of solutions were considered before, given local topographical and geological conditions, and an inclined plane was decided upon.

The inclined plane consists basically of two water-filled transporters that carry boats. They travel on roll ways (like the rails of a railway) with a 5% slope over a distance of 1,432 m. The transporters move at a speed of 1.20 m per second. The whole operation, including entering and leaving the transporter, takes about 40 minutes.

The inclined plane includes a whole complex of structures.

1. The high embankment.

The high embankment carries a 4.5 km section of the canal. It was built with material excavated from the terracing of the inclined plane and, at its highest point above the ground, is 27 m high.

2. The abutment between the high embankment and the canal bridge.

This is a concrete structure to retain the fill where the canal reaches the bridge carrying it.

3. The canal bridge.

The canal bridge serves as the upper holding basin for boats about to enter the inclined plane.

It is 290 m long and 59 m wide. It is carried on 70 reinforced concrete columns 20 m in height and 2 m in diameter.

4. The upper head and tower.

The upper head consists of a reinforced concrete frame and a tower.

The frame contains all the electromechanical equipment that controls the movement of the transporters and the maintenance and repair installations. The tower rises 150 m above the ground and contains a control and movements room. A network of cameras assists the operators so that they are constantly aware of the situation of the ships' and transporters' position and ensure the whole structure functions correctly. The tower is topped by a 17.20 m tall pylon for the various telecommunications installations.

The upper station and the tower rest on a foundation of 54 sunken columns averaging 13.50 m in length and 2 or 3 m in diameter.

5. The trench.

The trench is 1,432 m long at a 5% incline.

Part of the trench is overhead, carried on concrete arches, and part is in a cutting.

The concrete structure carries the rails that bear and guide the transporters.

6. The transporters.

They are 91.12 m long, 12 m wide and 4.70 m high. They are filled with water up to 3 – 3.70 m of their height. The structure of the transporters consists of a 12 mm-thick metal skin.

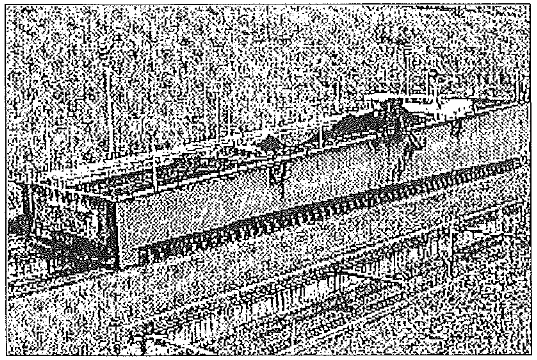

Figure 2 : View of the transporter

Each transporter is carried on 236.70 cm-diameter rollers grouped into two rows of 59 axles. The total weight ranges between 5,000 to 5,700 tons. To limit the power required for an operation, each transporter is balanced by a 5,200 tons counterweight that allows each one of them to move independently.

7. The lower head.

The lower head consists of a wall separating the bottom from the inclined plane properly speaking, the reach between two dislevels. On top of it there are frames for the lifting gates.

8. The hydroelectric power station.

The hydroelectric power station located at the lower head is equipped with two 1,200 kVA turbogenerators. A steel pipe admits water from the top of the incline under pressure.

5.4 Operating Principle

The inclined plane has two water-filled transporters for boats. They travel along the incline on rollers. Each transporter is equipped with two rows of rollers resting on rails and is carried along a 5% incline.

Each transporter is pulled by six 55 mm diameter cables driven by a winch and 5.5 m return pulleys. The machinery is powered by six 125 kW alternators. Boats pass from the holding basins into the rolling basins and vice-versa, through lifting gates that retain the ends of the basins and the transporters. The transporters can be opened for access to holding basins or isolated from them.

6 The Strepy-Thieu Boat Lift

6.1 General situation

The Strépy-Thieu boat lift, on the border between Le Roeulx and La Louvière territories, is part of the 27 km Canal du Centre which stretches from Mons to Seneffe.

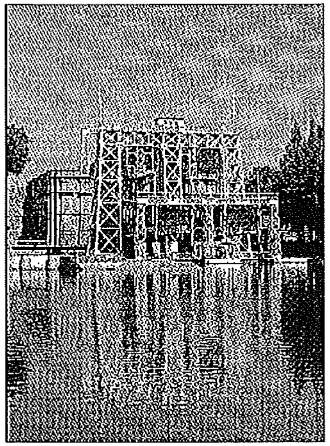

Figure 3 : Old Ship lift

The modernization of the Canal du Centre was planned pursuant to the so-called "1,350 t" law, programming to enlarge the capacity of the major waterways in the country. A new construction will replace the two locks and four hydraulic lifts of a capacity of 300 t.

Within the Belgian network, the Canal du Centre and its lift will make it possible to cross the crest of the ridge separating the Scheldt and Meuse basins; it is an important link in the Walloon waterway facilities.

The Canal du Centre integrates the inland waterways of European interest, as it is located on a transnational line running north-south in the industrial Scheldt-Meuse-Rhine delta (European project n°18). In the future, inland waterways will play an increasing role due to the guarantees offered by this means of transport : improved security, respect of the environment, lessening the burden on the roads, etc.

6.2 Presentation of the works

The works included in the framework contract include :

- the lift to overcome the change in altitude (76 meters);
- two canal bridges to the lift;
- the earthworks (4 million m^3)-removal and fill;
- rebuilding of the canal gutter upstream and downstream of the lift and the canal bridge;
- safety devices on the filled section to allow for immediate isolation should the dike give way.

This single construction includes two vertical cable lifts. The caisson is suspended by cables and balanced by counterweights. The vertical movement will be 20 cm/s, for total vertical displacement of 7 minutes. Crossing the entire construction will take 40 minutes.

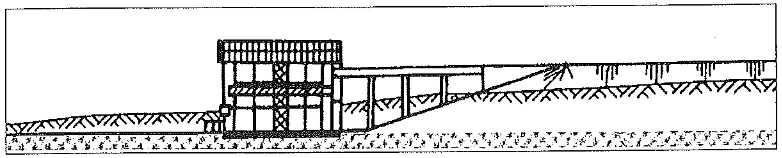

Figure 4 : Longitudinal cross section

6.3 Why a lift ?

The initial advantage of a lift is that it consumes little water at an altitude where the natural source of water for a lock is insufficient and water must be pumped in.

For the same reason, engineers, in the last century, designed and built four 300 t hydraulic lifts on the Canal du Centre.

A single construction, as is proposed today, is more economical at the site. It concentrates the total load (300,000 t) in a small space (1 ha) in a zone where the sub-soil is deformable and relatively varied; stress is constant at 3 kg/cm^2.

6.4 Studies of the terrain and foundations

Major geological, hydrogeological and geotechnical studies have been done as from the beginning of the project with the collaboration of the Geotechnical department and the Geological service of Belgium : drillings, penetration tests, pressure tests and installation of piezometric gauges.

The types of soils encountered are Albian, in which various fossils up to 65 million years old were found, and Wealden, on which the foundation is based. The groundwater was wrought down some 20 m.

6.5 The caisson-electromechanical equipment

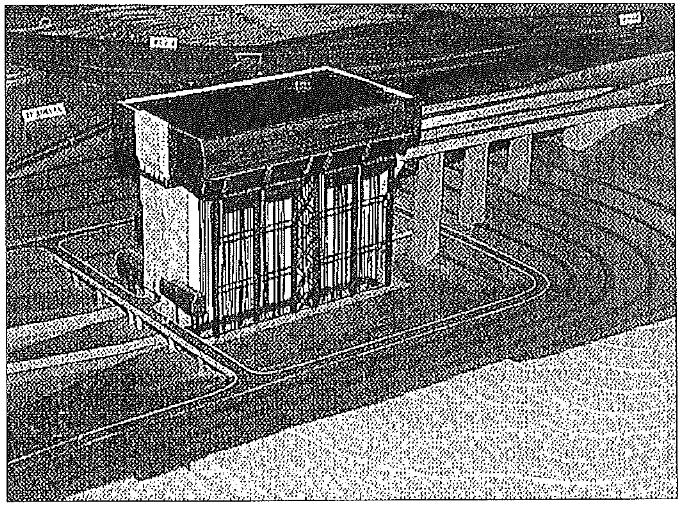

Figure 5 : View of structure

The characteristics of the caisson are :

- useful length : 112 m;
- useful width : 12 m;
- maximum depth of water : 4.15 m
- minimum depth of water : 3.35 m;
- mass of the caisson full of water : from 7,200 t to 8,400 t;
- mass of the metal frame : 2,200 t.

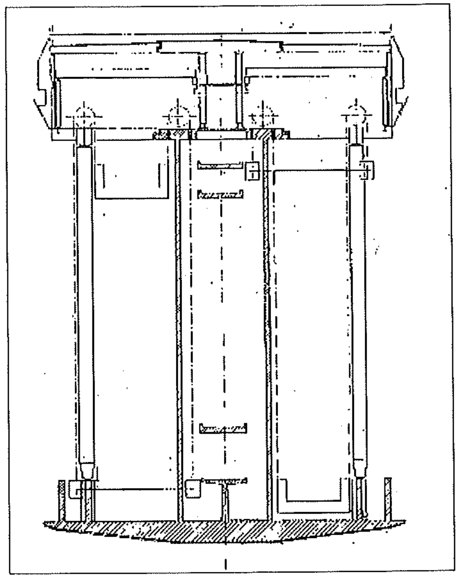

Figure 6 : Cross section of the structure

The caisson is balanced by counterweights; the caisson and the counterweights are connected by cables. The caisson is suspended by 144 cables of 85 mm in diameter : 112 suspension cables and 32 control cables. Eight identical winch and pulley groups move the caisson. These are located in a power house over the caisson.

Alongside the main suspension and lifting mechanisms, considerable equipment is needed to work the indispensable auxiliaries.

6.6 Frame of the lift

The frame carries the loads transmitted by the lift, the counterweights, the cables and the control mechanisms. Its complexity is due to the exceptional size of the construction. The lift has also been planned to resist earthquakes.

7 The canal bridge of Houdeng-Aimeries

The exceptional hydraulic structure is associated with the Strepy Thieu boat lift, will allow to pass over the valley at the crest between the two water sheets for the 2000 tons convoys.

7.1 Mains dimensions of the structures

Total length is 498 m - 13 bays of 36 m + 2 cantilevers of 15 m.

Width : - navigable : 34 m
- total including towing platforms : 46 m
- transverse span between supports : 33,40 m

7.2 Superstructure

The superstructure is constituted of a prestressed concrete container with an isostatic transverse working. (prefabricated cross girders + on site cast slab)

Longitudinally, the important height of the lateral walls ensures the working in continuous beam.

The inclined shape of the lateral wall allows to integrate with an elegant manner the towing platform and in the meantime it will increase efficaciously the hydraulic area of the cross.

7.3 Infrastructure

The structure is supported by two files of 14 pillars of 3 m diameter, in reinforced concert, lying on a slab of 10 m by 10 m, 3.0 m thick. The foundation of each pillar is constituted by 9 drilled sheeted piles of 1.5m diameter and a length from 10m to 20m.

7.4 Construction operation

The infrastructure is implemented on the classical manner. The bridge is built by part of 12 m length at the West abutment and pushed.

At the and of the pushing, the jacks with a whole capacity of 3,000 tons will move a total concrete mass of 64,000 tons, that will be a new world record for the bridges pushing.

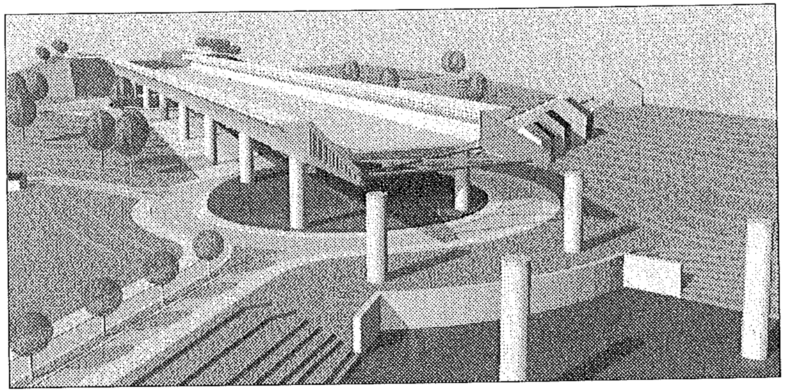

Figure 7 : View of the canal bridge

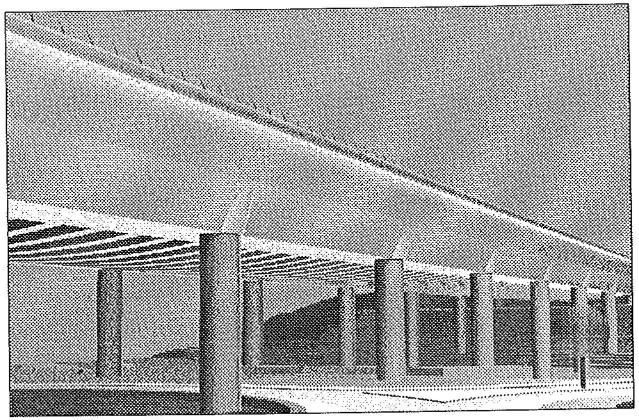

Figure 8 : View of the canal bridge

8 Major by-pass canal and sea lock at Hingene between the River Scheldt and the Brussels Sea Canal.

8.1 Structure

The almost 30-km-long Sea Canal to Brussels is one of the oldest artificial waterways in Belgium. The first plans were drawn in 1477, although work on the canal only started in 1550. Now, a traffic of some 10 million tons is recorded each year. At this moment, work on the lock in Hingene and on the bypass of the river Rupel between the river Scheldt and the Sea Canal is being completed. This will make the canal permanently accessible to pushbarge convoys of up to 9,000 tons (which corresponds to 4 Europe-II barges) and to sea-going vessels of up to 10,000 dwt (150 m long and 20 m wide), that do not have to sail up the sinuous Rupel river first and, subsequently, turn into the old Wintam lock. At present the majority of ships movements concerns inland navigation.

The new sea lock in Hingene is 25 m wide, 210 m long and has its floor bed at –7 m TAW, whereas the base of the upper bay is situated at –5.10 m TAW. The lock is located next to the mouth of the Rupel river. In the Sea Canal, the water level stands at +4.40 m TAW, which means that in the new connection to Willebroek a depth of 9.50 m will be available. Upwards, towards the Port of Brussels, the canal has a depth of 6.50 m.

Construction of the new sea lock, designed to replace the Wintam lock, started in the second half of the Seventies. This included digging a new section which would form a direct link between the Sea Canal and the river Scheldt. This diversion was built in three stages : the first stage comprised the preparation of the site, including deforestation and soil consolidation. Then the core of the embankments and the quay-walls were built.

Laying the final bank revetment, building the embankments along the fairway (with a length of 3 km), dredging the canal and landscaping the site using indigenous plants will finish the implementation.

8.2 Environmental opportunities

Apart from the optimisation of the canal section (widening the canal bed, consolidating the banks and protecting the bed against erosion), it was also examined which was the best way to give nature in this area new opportunities.

In that respect, it was of course a prerequisite to work ecologically, even during the construction of the lock and the canal. Amongst other things, the choice fell on an ecologically sound drilling technique for the positioning of underwater pipes.

To bring the material, set free during dredging, to its final destination, it was necessary to make two underwater crossings in the river and the canal. After evaluation of all financial and environmental aspects and of the construction time, the method of directional drilling was chosen to build those underwater crossings : one under the Sea Canal, with a length of 280 m, another one, 420 m long, under the river Rupel.

Alternatives for directional drilling were either a classic sinking operation or transport of the spoil by road. Sinking implied quite a lot of hindrance for shipping, problems of storage of the dredged silt and would create risks for the stability of the quay-walls. Road transport would severely damage the road infrastructure and cause a lot of nuisance for people living in the vicinity. That is why preference was given to directional drilling.

8.3 Proposals

The landscaping proposals range from planting indigenous trees (black and grey poplars, willows) and seeding the verges and embankments, thus creating a spontaneous overgrowth, to create an area which is in many ways attractive for leisure activities (footpaths and bicycle routes, recreation areas, steps and slopes between the existing streets and the embankment...).

The most notable proposals concerned the land development on the Northern Island, between the Rupel River and the new canal section. There it was of prime importance to make sure that the banks of the canal and the Rupel would accommodate as flowery a vegetation as possible and that the arable land used (including the exploitation strips) would be attracted from intensive cultivation.

On the Northern Island, 1.1 million m^3 of soil is to be reclaimed, but only up to a height of 6.5 m TAW, which offers the best guarantees for the creation of a nature reserve. The low lie would indeed make the area quite watery. When reclaiming hydraulically, an energetic environment is created at the outlet of the pipe, in which only the coarse particles from the dredged soil settles down. The finer parts sink further down, peat the furthest. This creates a soft slope, sandy and dry on the highest part, moister and clayish at the bottom.

Furthermore, it is proposed that the industrial complex of Schelle would be hidden from view by planting a visual screen of trees in the north-eastern corner of the "island", next to the bank of the Rupel river. Also, one or two observation huts could be installed for bird-fanciers and day trippers alike. The optimal development of the area would be achieved by having cows grazing on it. One could in that respect think of a sturdy, hardy breed that easily calves.

8.4 Ecologically sound embankments

The method used by Bitumar (bank protection with bituminous materials) makes it possible to obtain embankments that are solid and ecologically sound at the same time. Studies show, indeed, that bituminous embankments are environmentally friendly (the asphalt products used do not contain any quantities of Polycyclic Aromatic Hydrocarbons that could possibly leach away into the surface water) and can serve usefully as the basis for an environmentally sound embankment protection. The rubble, doused with asphalt, offers sufficient hold for an indigenous and spontaneous overgrowth. The vegetation on the embankment and the water plants are in turn complemented by little artificial islets. In the end, the asphalt won't be visible at all.

8.5 Spawning grounds

Bitumar's bank conservation techniques even make it possible to create spawning grounds for fish. It goes without saying that fish have little chance of survival when the banks of the canal consist entirely of concrete walls, open to the currents and the wash created by the ships. It is therefore important for an ecologically sound embankment to be relatively free of wash and currents. In this context, it was proposed to create an artificial berm, placed on the underwater embankment, which would offer adequate protection but still would be sufficiently permeable to guarantee the continuity of the water and the life forms therein. In this way a broad, wet embankment area is created between that berm and the body of the embankment, partly laid out as a spawning and feeding ground, partly as a gently sloping vegetation area. The berm is built of rubble (5-25 kg), penetrated with asphalt, with a reinforced toe made of fibrous open-stone asphalt mats. Every 50 m, a dip will be provided for water exchange and as an exit for the animal life.

9 Electromechanical equipment rehabilitation of Ivoz-Ramet movable weirs

9.1 Structure

The Ivoz-Ramet weir built in 1936, bombed and rehabilitated 1941, comprises 5 sluiceways with a 25 m clearance. The movable sluices include a caisson type valve with a curved skin-plate fitted on both ends to caissons as well as a gate also resting on both ends on these two caissons through two pivot pin hinges. The valves and gates are operated through chains from an upper gallery.

The valve reduction gear is synchronised with the gate reduction gear through a negative control multi-plate clutch. The end mechanisms of a sluice are mechanically synchronised.

The electric control of the 5 sluiceways is carried out according to the piloted-pilot system through a programmable robot. One of the six sluiceways is selected as being the pilot.

During the 1993 and 1995 floods, it appeared that the safe conditions of operation movements were no more guarantied. Stop logs had to be installed in view to regulate the discharge in one sluiceway. So it was decided to replace all the gates and the moving mechanisms.

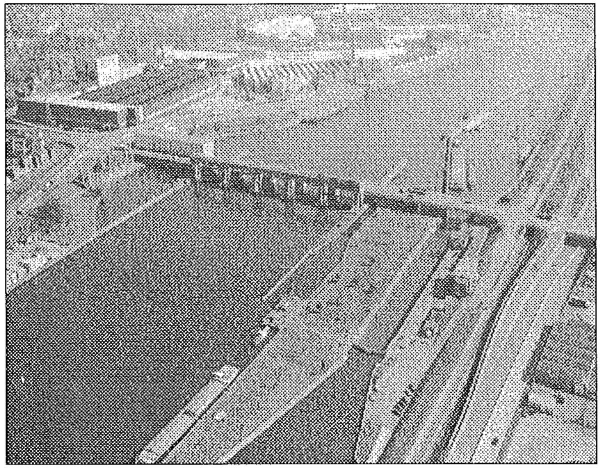

Figure 9: General view of the Ivoz-Ramet movable weirs and locks

9.2 New electromechanical equipment

The new movable sluices will include like the old ones, a caisson type valve with a curved skin-plate fitted on both ends to caissons as well as a gate also resting on both ends on these two caissons through two pivot pin hinges. Each valve and gate will be operated by 2 lateral jacks resting on the side pillars.

The upper is already demolished and the works are in progress.

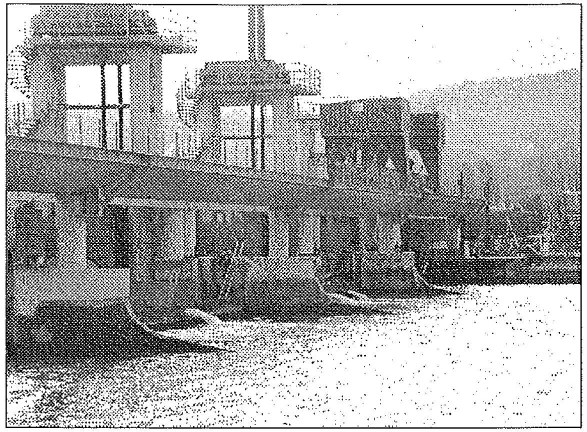

Figure 10: General view of the Ivoz-Ramet new implementation

Due to the ships traffic jam in that part of the River Meuse, (Liège reach the second position between inland harbours of Europe) very soon a new 200 m long by 25 m wide lock has to be implemented.

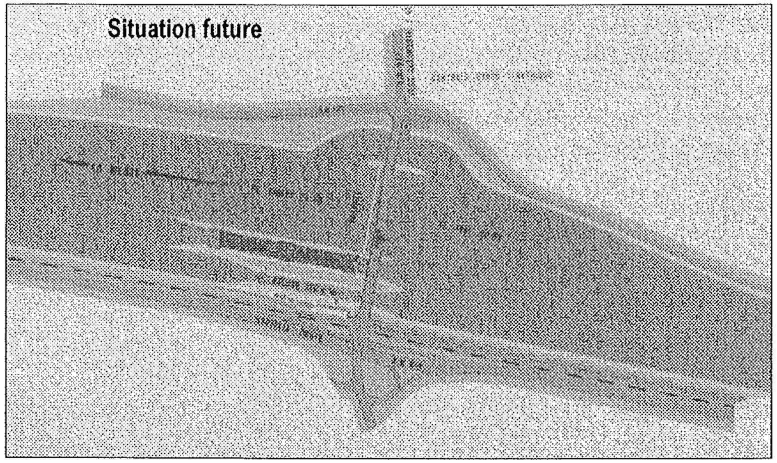

Figure 11: View of the Ivoz-Ramez new lock project

10 Numerical tools for water management and structural design

10.1 Introduction

It is obvious that protection against floodings remains or becomes more than ever a fundamental concern, especially when the industrial activity leads to modify the flow conditions and to worsen hydraulic features. Besides, it is understood that rivers, as a part of nature, cannot be mastered by force but to a certain extend by understanding.

Moreover, the increasing water supply, the potential climate changes with rainfall event evolutions and the manmade flow conditions prompt the manager to search a fit management of the available resources, land practices and alteration of catchment features.

In order to gain results for an optimized hydraulic management of catchments and waterways networks considered as a whole, we are developing original packages including several codes that accurately describe the different stages that arise in the open-air course of water. They deal with physically based models to reproduce the whole sequence of the rain drop history, to finally deduce the flows that it induces in river networks. Unsteady considerations result to instantaneous informations at any locations along the river path.

Concerning the origin of the floods, the Laboratory of Hydraulic Constructions is specialized in the overall assessment of distributed hydrological codes (finite element and finite volume schemes) arisen from the recent improvement of computer hardware capabilities. Physically based distributed models easily handle every topographic characteristics and soil types, as well as with spatial and temporal distribution of rainfalls. Different landuse allocations can be simulated that affect roughness factors as well as the rates of evapotranspiration and infiltration.

With the physical interpretation of the parameters, the impact of any change of catchment features can be predicted with confidence by modifying their value. Furthermore, sensitivity tests can be performed with data variation in realistic limits to quantify the corresponding error scope of the output hydrographs, leading to easier and faster fitting stages than for any black box models.

Since rainfall events dealing with large watersheds are computed, such models should be used in a final stage in order to detail hydrological exchanges on numerical terrain models. However, focusing in a first stage on the downstream stages of the flows, an overall distribution of lateral hydrographs is provided that are poured along each river element to be propagated.

Quasi 2D hydrodynamic codes deal with the spreading of hydrographs in river nets of variable arms with evolutive cross-section shapes. In order to manage floods in a complete network of Belgian rivers, a original complete quasi-bidimensional scheme was developed that handle flows in compound channels The coexistence of several flow rates with shocks and bores in ramified nets of variable cross section arms, the explicit modelization of transverse flow exchanges between the main path and lateral flooding areas require dealing with suitable new mathematical formulations as well as capturing methods to solve the conservative quasi-bidimensional Navier-Stokes equations. Those advanced schemes secure reliable solutions of unsteady appearances, movement and disappearances of discontinuities in the most various conditions of hydraulics. This assurance is required to deal with endangered areas.

Since we have to deal with large natural networks and large scales, the quasi-bidimensional approach has to be preferred for sake of computing time economy, along with a detailed computation of transverse discharges between channels (main channel and floodplains) to face the poor results obtained by classical methods based on conveyance. Large-scale studies seem very important to quantify the influence of any modification on the basin (to avoid effects locally favorable, inefficient or dangerous from a global point of view) and to optimize water management.

However quasi-tridimensional schemes are required for small-scale studies in order to provide speed and depth distribution anywhere to optimize the hydraulic structure design, their location, in the framework of ecological impact minimization and economic point of view (entrances and exits of locks for ships, aquatic life, stability of banks and bottom profile,...). Its why quasi-tridimensional codes were developed, resolving Navier-Stokes equations either on structured or on unstructured grids and dealing with any topography or bed friction.

The codes are computed in a new programming environment. WOLF is a hydraulic surface flow software where coexist the resolutions of quasi two- or tridimensional Navier-Stokes equations, as well as powerful graphical pre- and post-processings.

The two following examples highligts the potentail of both method in the scope of water management and structure design.

10.2 Wolf 1D : a quasi two dimensional surface flow software

Wolf 1D uses an original approach to deal with unsteady compound flows in natural river and waterways netrworks. The cross-section is divided into relatively large homogeneous and easier to analyze sub-areas. The complete set of equations is resolved for each component, with suitable transverse exchange relationships based on the unsteady states of each channel. Furthermore, interactions are introduced in the equations between the flows of each subdivided areas, based on simplified turbulence laws. Even if the first tests are successful, a large field of prospect remains to assess the mathematical laws and to fix the range of values for the parameters by comparison with complete numerical codes or with experimental models.

The spatial discretisation of the 1D conservative shallow-water equations is performed by a widely used finite volume method. The partial differential equations are integrated on control volumes covering the whole computational domain. This ensures the mass and momentum properties to be conserved, especially across discontinuities such as hydraulic jumps.

Flux treatment is here based on two different upwind schemes. The first one uses an original flux-vector splitting technique developed for Wolf. Fluxes are splitted according to the sign of the flow path, requiring a suitable downstream or upstream reconstruction for both part according to the stability analysis. Efficiency, simplicity and low computational cost are the main advantages of this scheme.

On the other side, the well-known approximate Riemann solver of Roe brings its robustness to the code, and was introduced as reference in the scope of numerical comparisons. Both method showed their ability to simulate sharp transitions without excessive smearing on several meshes or excessive growing of dissipative processes.

Variable reconstruction can be selected to gain a first or second order accuracy on regular grids. However, it is well known that such second order finite volume scheme, although very accurate in smooth regions, causes unphysical oscillations near the discontinuities. The flux reconstructions were therefore limited to prevent such undesired effects. The limiter bounds the reconstructed variables between the minimum and maximum of neighboring cell values. In spite if its effectiveness, this limiter suffers from parasite activation in near-constant regions. The limiter modification introduced by Venkatakrishnan was adopted to avoid this drawback.

Besides, an explicit second-order accurate Runge-Kutta algorithm is applied to solve the ordinary differential equation operator.

The following figure shows the kind of network we are presently dealing with to assess the approach in comparison with gauged flooding results.

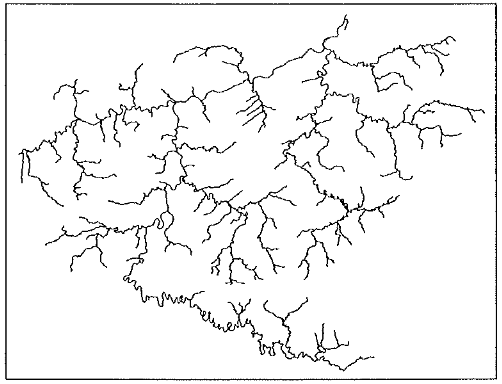

Figure 12: River network of the Meuse catchment handled by the software WOLF1D

The tests recently carried out to validate the 1D approach on sub-catchments (see figure 14) indicates that more details and accuracy are gained by comparison with classical approaches, based on conveyance, for example. The formulation of the equations, while general for unsteady flows in any natural river networks, allows straightforward interpretation of maximum depths and discharge distribution with fairly robust predictions, without the introduction of any additional parameters. Regarding overall accuracy in simulations of natural Belgian flooding situations, reasonable results lead to conclude to a global performance superior to the general 1D flood routing models usually proposed. This overall conclusion is especially true for the case of local floodplains, uneven topography or irregular cross-sections with widening.

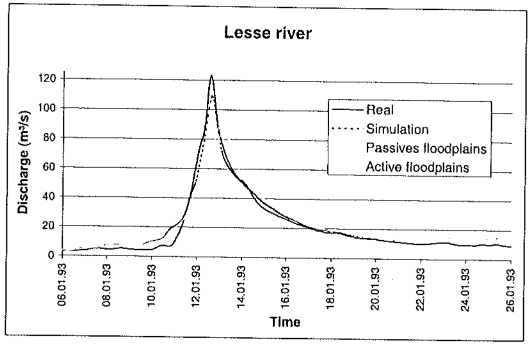

Figure 13: Comparison between the Lesse catchment gauged and computed dischargefor a flood event on

With the assurance of reliable simulations gained by comparison with gauged measurements, computations will be shortly devoted to forecast floodings in large Belgian catchments. They will reflect the lowering of water profiles after topographical or morphological modifications and will provide useful information in the scope of an economical localization and design of hydraulic structures.

10.3 Wolf 2D : a quasi tridimensional surface flow software

10.3.1 Introduction

The scheme used in Wolf2D resorts to an extension of the 1D approach. The 2D shallow-water equations are solved either on structured or on unstructured grids dealing with any topography and soil properties.

The code deals with the crucial problem of movable boundaries in order to handle the wetting and the drying for floodplains and wetland studies. It benefits from the whole experience gained in the treatment of transient shocks implied in the still prospected context of dam-break-flood wave propagations.

Studies to extend modelizations to a quasi-tridimensional context seem all the more obvious for confined and detailed flow descriptions, when the propagation locally and temporarily runs into inundation plains or in topographic singularities as widenings or confluences. The codes have to reproduce the flow features at these locations.

The approach we usually concretize, for the following example, consists to compute floods in the overall network in a first stage with WOLF1D to provide boundary conditions for a spatially distributed model (2or 3D) for local impact studies and design.

10.3.2 Confluence of the River Meuse and Ourthe rehabilitation

Until the begin of the 19th century, a complete anarchy reigned into the liegeois rivers. The Meuse and the Ourthe were splitted into multiple arms allowing a lot of low islands, which prevented from any effective navigation. Different canalisation works began then on both liegeois rivers to increase the navigation safety and the carriage of higher capacity ships. In this way, the number of river arms was drastically reduced. Downstream the Meuse – Ourthe confluence, the Meuse was canalised in two arms, the main one and the 'Dérivation'. A needle dam coupled with a mole were constructed between the Meuse and the 'Dérivation' (see figure 15), ensuring a sufficient water level in the Meuse for the navigation, and forcing the Ourthe to flow directly in the 'Dérivation'.

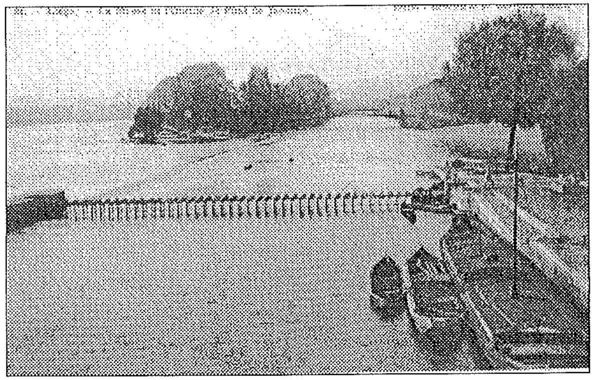

Figure 14: View of the Meuse – Ourthe confluence and the needle dam in 1910

Later, this dam was removed but the mole was conserved in order to reduce the transversal flows induced by the Ourthe and dangerous for the navigation in the Meuse. However, the 15th of september 1998, an important flood concerning only the Ourthe basin caused big damages to this mole. The high water level difference induced by the transversal flows of the Ourthe led to the rupture of a 32m long breach (see figure 16).

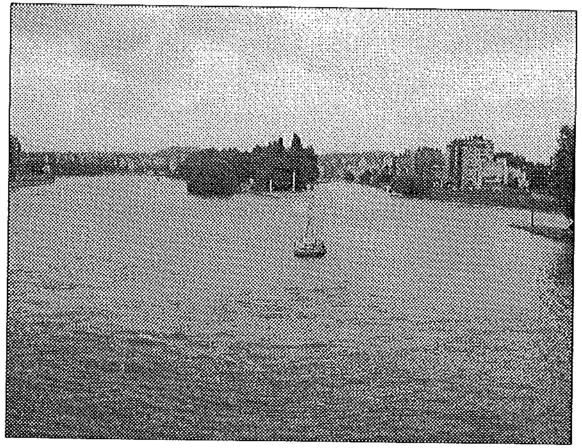

Figure 15: View of the breach in the mole caused by the flood

Several flood simulations were realised in the Laboratory of Hydraulic Constructions, in order to propose acceptable hydraulic solutions for the reconstruction of the mole. A first simulation reproduced the confluence with a discharge of 600 m^3/s in the Ourthe and 188 m^3/s in the Meuse, as observed during the flood peak. The high water level difference, represented at figure 17, is responsible for the mole break. This last was in fact initially designed to support a water level higher in the Meuse than in the Ourthe, but not the opposite.

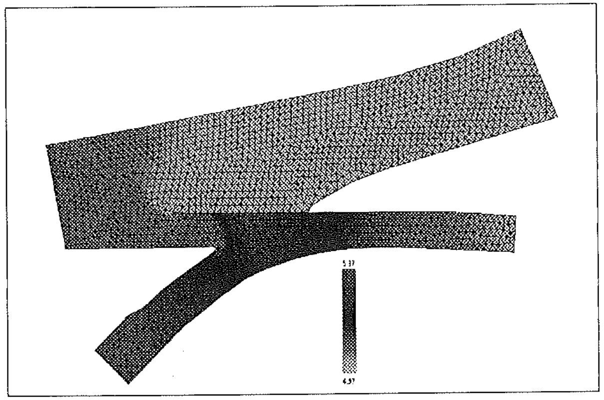

Figure 16: Water depths (m) at the confluence during the flood peak

In order to avoid similar structural problems in the future, it was decided to build a new mole, adapted to the hydraulic and hydrologic situations. Several geometries were tested, with one or more holes in the mole to reduce the efforts applied on the construction in the case of a flood of the Ourthe (see figure 18).

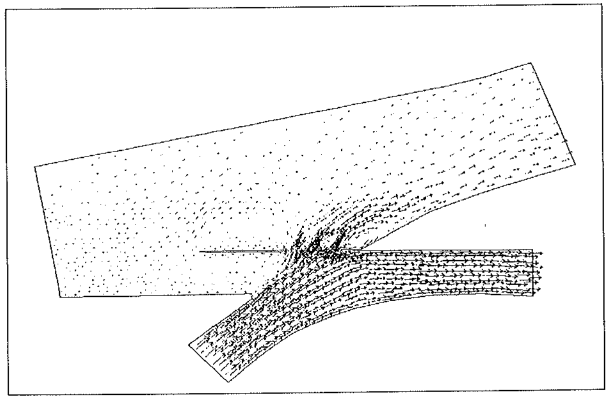

Figure 17: Speed vectors during a flood around the mole designed with 3 holes.

10.3.3 Conclusions

The computing of the actual situation was demonstrated to correlate perfectly with behaviors measured on site.

Gaining experience from those refined models, the overall results led to a fitted positioning and design of the holes in order to minimize the interaction effects of both flows, adjusting transverse effects and water depths gradients in the vicinity of the confluence.

11 Bibliography

1. CLINCKERS L., GRARE W., LAFORCE E., SAS M., ELSKENS F., PAUWELS S., LUYCKX J. and DRAELANTS R. (1998) : The realisation of a major bypass canal and sea lock at Hingene between the River Scheldt and the Brussels Sea Canal ; 29th PIANC International Navigation Congress.

2. ROENEN F. (1999) : Conférence lors de la visite du 22 octobre 1999 de Monsieur le Ministre VAN CAUWENBERGHE ; Ministère wallon de l'Equipement et des Transports (MET).

3. GELISSEN E., LOHEST P., PETERS J.J., ROTHILDE C., SCHIEPERS N. (1985) : Innovations dans la conception des nouveaux barrages de la Meuse ; 26th International Navigation Congress ; Permanent International Association of Navigation Congresses.

4. MARECHAL R.J. (1990) : Strépy-Thieu ; Press and Information Department, Walloon Ministry of Equipment and Transport (MET).

5. HILDE J.-L., WELTER Ph. (1993) : L'ascenseur à bateaux de Strépy-Thieu ; Ministère wallon de l'Equipement et des Transports (MET).

6. HAMBYE Walloon Ministry of Equipment and Transport (MET) (1994) : The Strépy-Thieu Boat Lift .

7. LAURENT J., de FAYS R., DAMBRAIN M. (1990) : Le Canal du Centre ; Ministère wallon de l'Equipement et des Transports (MET).

8. NORAC C., GAILLIEZ J.-P. (1994) : Le Canal du Centre ; Editions Casterman.

9. R. DE PAEPE (1982-1983) : Développement, fonctionnement et financement de la navigation intérieure en Europe , bulletin n°43 ; Permanent International Association of Navigation Congresses.

10. Association des Amis de l'Unesco (1994) : Les nouvelles du Patrimoine, Au fil des canaux, périodique n°57.

11. M. PIROTTON: Modélisation des discontinuités en écoulement instationnaire à surface libre. Du ruissellement hydrologique en fine lame à la propagation d'ondes consécutives aux ruptures de barrages. Editions L.H.C.N., 1994.

12. M. PIROTTON: Modèle Hydrologique Conceptuel Distribué d'Écoulement Quasi-Tridimensionnel en Fine Lame sur Bassin Versant. "Research and Development in the Field of Dams", pp. 689-700, Symposium 1995 of the Swiss National Commitee on Large Dams, Switzerland, 1995.

13. M. PIROTTON and A.G.H. LEJEUNE: An example of river channel design in Belgium. Meeting européen de Santander "River channel design and environmental protection in Europe", 22 - 25 october 1997.