Cost estimation for a canalized river Rhine (Waal)

By: Ad van der Toorn (TUDelft / Civil Engineering / Hydraulic Structures)

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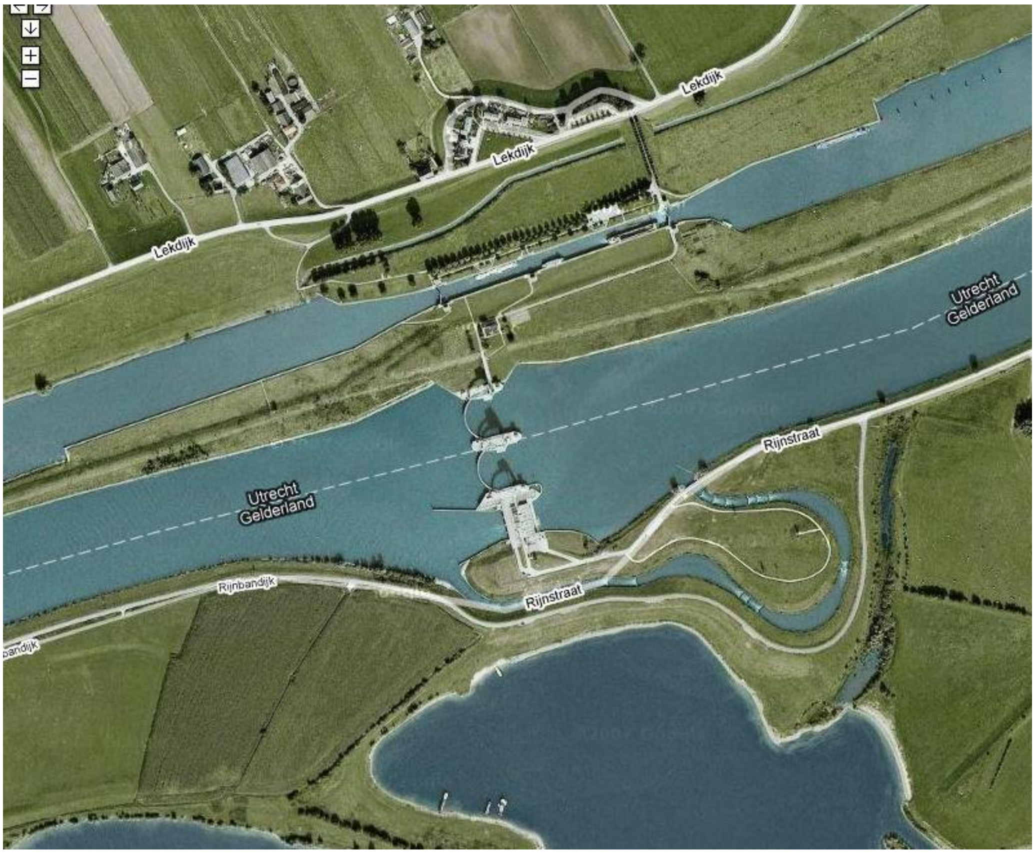
Ch.1: Introduction:

A possible solution for keeping the River Rhine (including its main Dutch branch the Waal) navigable up to the main industrial area in Germany, during periods of (very) low discharges and so very little water depth, is the construction of a few weirs in combination with navigation lock-complexes.

In times of normal or high discharge of the river Rhine, these weirs are in upward position, thus making nearly free flow possible for the river discharges (water and ice) and a nearly unrestricted passage for the inland navigation.
But in times of (very) low discharges and associated low water depth, the weirs were partly or nearly completely closed, in order to improve the navigability by means of a so called canalized river (see photo of present weir complexes in the river Lek).



In order to give passage to the navigation in these short periods (some weeks per year) of nearly closed weirs, these weirs are mostly combined with one or two navigation locks. Although with some delay in the order of 15 - 30 minutes per passage, these locks make it possible to overcome the created differences in heads, here estimated as about 5 meter.

The amount of weir- & lock-complexes depends on the total head over the shipping route and the head per weir. For the lower part of the River Rhine the head is about 1 meter per 10 kilometer. For a total sailing distance of about 200 kilometer from the Port of

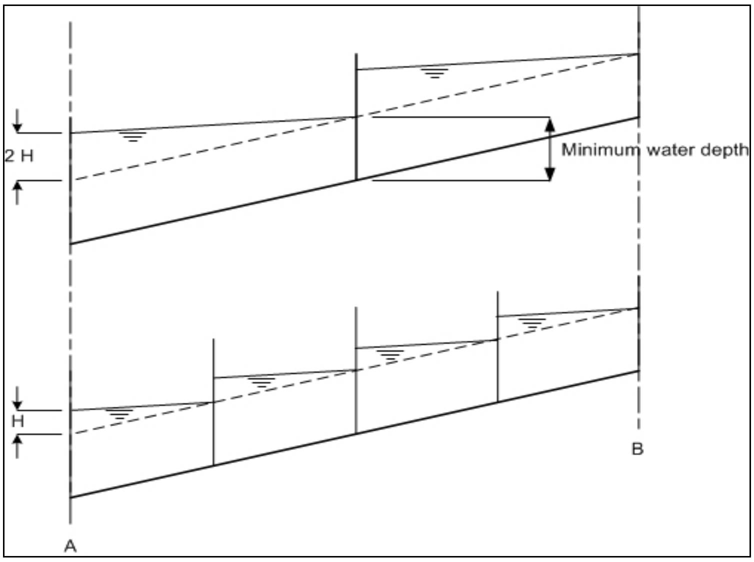
Rotterdam to the busy German Ruhr area, this gives a total head of about 20 meter. If for instance one chooses a mean head in the order 5 meter per weir-complex, than there will be 4 complexes needed

Because the water depth directly upstream of a (partly) closed weir will be higher than in the case that the weir is in an open position, one has to check if for this specific reason there is a necessity to make these local dikes higher. And if so, the next question will be to what extend and is it possible to higher them in an easy way against relative low costs. These costs depend highly on the area, if it is just a simple grass-dike or a much more complex hidden dike through an urban area (see Appendix C).

Because dikes along the river Rhine are designed for extreme high discharges with related extreme water depths (in the order of 10 - 12 meters) there is some reserve in dike height in times of low discharges. But in order to create enough water depth (e.g. 5 meter) directly downstream of an upstream weir, the water depth directly upstream of the correspondent downstream weir will be in the order of 5 + 5 = 10 meter (in the above given situation).

In fact the amount of weirs will be given by an optimization (see figure below), taking into account the cost of the total amount of weirs and navigation locks, the cost of raising some local dikes directly upstream of the weirs, the extra waiting hours for inland navigation, the visual damage to the landscape with these massive buildings and extra high dikes, etc.

But here the first estimate will start with an amount of 4 weir- and navigation-lock-complexes at regular distances of ~ 50 km, with a mean head of about 5 meter per weir and the assumption that in this case little or just a small amount of dikes has to be raised.



Ch.2: Cost estimation method:

The costs of a weir- and lock-complex can only be well estimated if there is a (pre)design of these four specific complexes and dike raising projects. But in this decision stage of the research project the costs will just be rough estimated on the basis of so called index-numbers, which are based on scaling and discounting cost figures of existing comparable complexes. However, because in the Netherlands no weir- and lock-complexes of this scale were realized in the last fifty years, the index-numbers will mainly be derived from separate cost figures for weirs and locks.
After all, as a rough check, the combined cost of the three weir- and lock-complexes in the river Lek, which have already been build in the fifties, were scaled and discounted.

Ch.3: An estimations of the expected costs:

Weir:
Based on a wet cross section in the order of 300 meters in width and 10 meters in depth, a head in the order of 5 meters per weir, and an index number of 30.000 Euro per cubic meter (see Appendix A) the **total price of that weir-complex will be 450 million Euro**.

Naviagation lock:
Based on a lock chamber of 280 * 40 square meter, a head in the order of 5 meter and an index number of about 5.000 Euro per cubic meter (see Appendix B), **the total price of that navigation lock-complex will be 280 million Euro**.

Dikes:
Based on a restricted amount (~10%) of dike raising in the order of 2 * 5 km = 10 km, and an index number of about 6 million Euro per meter per kilometer grass dike (see Appendix C), **the total price of that dike raising will be 60 million Euro.**

Complexes:
So all together, for about 200 km canalization, only based on the realization cost of 4 weir- & lock complexes, the total prize will be: 4 * (450 + 280 + 60) = 3.160 million €, so **the total price will be in the order of 3 milliard Euro**.

NB 1: Scaling and discounting the three weir- and lock-complexes in the river Lek (1958!) gives a total amount of: 2,5 * 2 * $(1,04)^{50}$ * 120 M fl / 2,2 ~ 2 milliard €. So for four complexes a comparable amount of 2,7 milliard Euro. This is still exclusive some raise of the dikes, which gives an extra 240 million Euro, so together ~ 3 milliard Euro.

NB 2: Beside the direct cost of construction there will be cost of inspection and maintenance. If well designed and constructed, there will be just periodic inspection needed in the first 10 to 15 years and some preventive maintenance for the mechanical parts. But after this period and often earlier because of “children diseases” more

maintenance may be expected, not only for replacement and revision of electrical and mechanical parts, but also to the civil engineering works.
Though hard to predict for a specific work under specific conditions, it has been proven from experience, that inspection and maintenance in the long run will take a rough 1% of the realization costs per year. Presenting this as a net-present-value makes a total amount in the order of $(1+r)/r * C_c \sim 20\%$ of the construction costs (if the rate is about 5%). This gives a summed amount of 20% * 3 milliard Euro, thus in the order of <u>**600 M Euro**</u>!

<u>**NB 3:**</u> Besides these structure related costs, there will be operational cost for operation, administration and control of the weir gates and navigation locks. When the complex is in operation, the service for these complexes will be needed 7 * 24 hour. So there will be **operational costs** in the order of 6 * 5 * 0.1 M Euro /year ~ 3 M Euro/yr, which represents a net present value of about <u>**60 M Euro**</u>.

<u>**NB 4.**</u> Such a civil engineering work also gives energy costs, because of the operation activities, like opening and closing of gates and doors, the lighting, heating, etc.

<u>**NB 5**</u>. The tempered discharge of the river in times the weirs are (partly) closed, will cause extra sediment to settle down and that will need extra dredging activities (costs!) to keep the river navigable. And opposite, during opening of the weirs, there could be some scour despite of the local bottom protection around the weirs.

<u>**NB 6**</u>. Though the closing period is expected to be just a few weeks per year, of course there will be some consequences for the environment, because the natural flow of the river is suddenly artificially disrupted. Though migrating fish could partly pass the complex by means of a fish passage, river banks will change, flood plains and beaches may be drowned, etc.

<u>**NB 7.**</u> There is an ecological and (thus) social opposition against large scale interventions in the natural environment (see the experience in Germany, weir 11 in the upper Rhine).

<u>**NB 8.:**</u> A temporary canalization of the river Waal will heave effect on the discharge of the other branches like the IJssel. So something has to be done around the bifurcation point.

<u>Ch.4: A rough estimate of the expected benefits</u>

To have any feeling about the cost given above to canalize the lower part of the River Rhine, which are in the order of 3 to 4 milliard Euro, in this chapter a first estimate is done for the expected “benefits” in case of that canalized river Rhine compared to the situation without any measures (but with the negative influence of climate change).

These “benefits” will mainly consist of <u>lower cost of transport</u>, because of a much higher loading percentages of the vessels and so the same amount of goods will be transported against lower prices and by less vessels. Besides these direct benefits there are more indirect benefits, like the <u>higher reliability</u> to deliver the goods at the right time, and so consequently <u>less risk of break downs</u> at the site of the receiver, the industry. This may also result in a <u>better imago</u> and prevent a switch to other transport modalities or even loss of transshipment for the Port of Rotterdam to German ports, with more rail capacity.

At the same time this canalized Rhine will cause extra indirect costs, like waiting time for inland navigation in times of closed weirs (about half an hour per passage), extra dredging and bottom protection, environmental damage during the construction period as well as in times of operation.

The benefits can firstly be estimated with the help of earlier projects.

1. <u>Investeringsruimte voor toekomstige droogte (RWS/RIZA, 2007):</u>

The expected maximum shipping benefits in the G+ and W+-scenario are estimated as 175 to 280 M Euro per year. For an eternal time horizon and a rate of 5%, this will result in a summed amount in the order of 20 times this yearly value. So the NPV will be in the order of 3.5 to 5.6 milliard Euro.

2. <u>Report of the Delta commission (2008):</u>

In this report the same amount of money is given for the G+ and W+-scenario's, consisting of avoided cost for the inland shipping in the order of 175 respective 280M Euro as NPV(!?). It looks as if the same source was quoted, but incomplete.

3. <u>Verkenning kosteneffectiviteit van grootschalige maatregelen tegen droogteschade als gevolg van de G+ en W+ scenario's (Deltares, 2008)</u>

Again the same source seems to be quoted here, so for G+ of W+ benefits are foreseen of about 175 resp. 280 M Euro/yr. But in this study, because of the expected delays, c.q. waiting time plus passage time of the four navigation locks in the order of 2 - 2,5 hours, at a normal undisturbed sailing time in the order of 10 - 12 hours. Though this is a twenty percent delay in time, a reduction on the benefits side is suggested of 0.45(!?)
Here the investments were roughly estimated as 4 * (300 + 350) = 2.600 M Euro.

4. <u>Investeringsruimte droogte KNMI'06</u>

The common source of all above mentioned articles seems to be Appendix 15 of this report, where Royal Haskoning makes a navigation damage estimation of 90 M Euro per year by means of a 100-years damage series. In Appendix 16 this value is extrapolated for the G+ and W+-scenarios to 175 resp. 280 M Euro per year.
These are the well known and often quoted numbers. They are in fact "just" <u>extra</u> costs for inland navigation, so for sailing, transshipment and waiting hours near locks. But the "real" costs, i.e. risk, which is probability of low water depth, and related low transport capacity, times consequences for the industry (shortage of energy, loss of production, loss of market share) are not taken into account!

<u>**For a more actual and detailed research, see the work of Olaf Jonkeren (VU).**</u>

Appendix A: Cost estimation for weirs / barriers by index numbers

The costs of a new weir, barrier or other structure can be estimated by a few steps:

1. Defining a so called index number (= unity price), based on relevant parameters;
2. Discounting the costs of a number of representative structures to present values;
3. Calculation of this index number for that representative existing structures;
4. Extracting a representative mean value out of these index numbers;

In the past these steps are undertaken for the State Public Works for series of tunnels, locks, etc and more recently for the Port of Rotterdam for series of quay walls.
The simplest index numbers are linear relations, but of course rather rough. The more parameters are taken into account, the better the fit, but opposite the more data is needed!

Here a group of well known weirs / barriers inside and outside the Netherlands are used to come up with enough data. The index number is based on the consideration that the strength and so the cost of a weir or barrier are strongly related with the **width**, the retaining **height** and the **head** over the weir or barrier.
So in this case the index number has the dimension [€/m^3] and is more or less the mean value of the separate calculated index numbers for the different weirs / barriers. Extreme values may be excluded if there is a known special reason (e.g. the storm surge barrier of st.-Petersburg has an opening for normal navigation and a special one for the navy!).

That this index number may be seen as a reasonable representative value may appear from the fact that the spread is limited and if not, that there are good reasons for the separate differences to the mean index number. For instance the index number will be relative low if there are a lot of nearly the same, repeating gates in one big barrier (see for instance the Easternscheldt), and opposite the index number will be relative high if there are three types of gates in one small barrier (for instance Ems or Theems).

From this analyses of eight well known weirs / barriers (see spreadsheet) the index number based on Total Price / (Width * Height * Head) turns out to be **30.000 €/m^3.**

	Name barrier	Type of gate	Year	Width [m]	Height [m]	Head [m]	Constr. Cost [Euro]	nt Constr. Cost [Euro]	Cost / cubic meter [Euro / m.m.m]		Remarks
1	Maeslant barrie	Floating sector	1991	360	22	5	450.000.000	945.000.000		23864	strong competition
2	Hartel barrier	Vertical lifting g	1991	170	9,3	5,5	140.000.000	294.000.000		33811	one big span (~100m)
3	Easternscheldt	Vertical lifting g	1986	2400	14	5	1.136.000.000	2.910.000.000		17321	strong repetition
4	Rampspol	Bellow barrier (	1996	240	9	3,2	100.000.000	173.000.000		25029	innovation
5	Ems-barrier	Sector gate + 2	1998	360	8,5	3,8	290.000.000	464.000.000		39904	3 types of gates
6	Thames-barrier	Sector gates +	1980	530	17	7,2	800.000.000	2.600.000.000		40079	2 types of gates
7	Nakdong-river	Vertical lifting g	2010	200	10	2	125.000.000	125.000.000		31250	
8	New Orleans	?	2015?								
9	Venice Mose-pr	Flap gates 78 *	2014?	1560	15 ?	2 ?	3.000.000.000	5E9 ?	~100.000?		very big flap gates!
							Cost-index (mean of 1 to 7):			**30.180**	[Euro / m.m.m]

Some remarks should be made on this index number:

- A difference between weirs and (high water) barriers is the fact that the first ones have only high water at the upstream side of the river, while storm surge barriers may also have a negative head and are more affected by waves, which can be seen as an extra head. Here half of the barriers is situated near the sea, so these cost may be at the high side compared to the others.
- Often cost of existing structures are unclear (often for political reasons!) in the sense that cost of additional works, like demolishing earlier structures, access roads, dredging, bottom protection, connections to nearby infrastructure, etc. are included in the price or not. This gives an extra spread in the index numbers.

Appendix B: Cost estimation for navigation locks by index numbers

Here some navigation locks are analyzed: First individual costs are discounted, then normalized in square-meter-prizes, then the mean value is determined and at the end a cubic-meter-prize is derived.

	name	year	build.cost M. Fl	build.cost M. Euro	pres.cost M. Euro	area m * m	unit costs K.Euro/m.m	remark
1	Lith	1992	100	45	91	3600	25	second lock
2	Helmond	1992	26	12	24	1375	17	
3	Oranje	1990	130	59	129	4800	27	
4	Oester	1990	64	29	63	3173	20	
5	Vlaardingen	1986	20	9	23	650	36	also storm barrier
6	Schiedam	1978	25	11	43	720	60	also storm barrier
7	Terneuzen	1962	98	45	296	21160	14	2 chambers
				Total	**669**	**35478**	**19**	
8	Terneuzen	2015?		200 - 300	200 - 300	6 - 27000	11 tot 13	Not build yet! excl. dredging

In the case of a mean head of 4 meter, the unit costs are ~ 5000 Euro / cubic meter

NB1. There are a lot of additional works in the construction stage of a navigation lock, such as demolition of the old lock, dredging, bottom protection, guiding works, etc. Often it is not clear if all these works and related costs are included in the "total" price or not.

NB2. If navigation locks are situated near the sea or estuaries, the high head door has often a double function, because beside normal water conditions it has to withstand extreme high water conditions. Such a "flood door" will cost extra money and thus raise the total price.

Appendix C: Cost estimation for dike raising by index numbers

Even in the case of estimating the cost of dike raising one may use index numbers, if derived from a rather homogeneous group of realized dike raising projects.
In its simplest form the cost of dike raising can be expressed in cost per kilometer in length and per meter dike raising. To make the group more homogeneous one has to distinguish the category pure up stream river dikes and dikes under influence of tides and/or more significant wave attack along estuaries and in coastal zones.

For cost of dike raising there is a data collection by Eigenraam [..], and he already distinguishes dike raising projects in the downstream area (with wide waters, so more wave attack and some tidal influence) and dikes more upstream. In this data there are three dike raising classes, namely per 0.5 – 0.75 – 1.0 meter.

What surprises in the down stream subset of data, which now contains only 6 reference projects, is the rather wide spread of 4,3 to 13,3 million € per km, per meter of dike raising. A comparable spread, but now at a lower cost level, is present in the much bigger (sub)set of 16 upstream dike raising projects.

The big spread of a factor 3 in both categories gives rise to the feeling that in this simple cost index number, there is still an important parameter missing. This could be the difference between simple dike raising projects and dike reinforcement projects. In the first case only ground work is needed, while in the last case the reinforcement in the zone of water and wave attack on the outside of a dike is strengthened as well. Beside this extra cost generating factor, there may be an influence of higher cost at the inner side if some local buildings change simple groundwork into more complex locally specified solutions, like sheet piling walls or even cofferdams. But this point stays unclear, because more detailed information about these projects is not available.

Elaborating this point it is essential to distinguish categories dike raising in rural areas from the ones in urban areas, which can be much more complex, so much more costly.
Therefore six categories are distinguished, increasing from a simple grass-dike to a very complicated hidden road-dike with (historical) buildings at two sides. A good example of this last category is the Voorstraat in Dordrecht (see photo) which retaining level is just 3.25 meter + NAP.

In the case of dike raising in urban areas with buildings on one side, often sheet piling walls or similar are used and with buildings at two sides, an even more expensive so called cofferdam (a kind of coupled double sheet piling wall) is used.

Deriving index numbers for these categories is a problem, because these are all rather special, i.e. not frequent constructed and rather unique projects, often mixed up with "normal" dikes. In order to find index numbers for these categories, one needs another approach. There are rather reliable index numbers for ground and water retaining structures like quay walls [.] and a cofferdam can be seen as a nearly double quay wall.

In the case of ground retaining structures, like quay walls, index numbers are used in the order of 1200 – 1500 €/m^2. But one has to realize that for a dike elevation of 1 meter in an urban area, there is more retaining height needed than one meter quay wall, because the sheet piling wall will have a higher (sloping) active pressure and a reduced lower (sloping) resistant. For simplicity a factor 4 is used, so 1 meter of raising dikes needs a quay wall with a retaining height of about 4 meters.
Besides these direct costs, it is assumed that every building with a width of about 10 m, needed extra reinforcement of about € 100.000, so an extra 10 million Euro per kilometer.

Thus the index number for road dikes with one-sided buildings and some indexation (factor ~ 1,5), comes to K(1-sided) = 4*1,5*1,35E6+10.000.000 ~ 18 million €/km.m.
For road dike raising with (historical) buildings at both sides of the road the double price is estimated, so K(2-sided) ~ 36 million €/km.md.
Without further analysis the heightening of a simple "green" grass-dike or park-dike the index number is given by ~ 6 million €/km.m, based on the data of Eigenraam.
In the case of a firm road dike or another reinforcement on top, the cost are estimated to double and so their index number will be ~ 12 million €/km.m

After these simplifications the index numbers for different dike categories are presented in the next table:

Cost index numbers of dike raising