Hydropolitan: An interactive tool for hydrology management in metropolitan deltas

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Introduction

A common issue of metropolitan deltas is the location in an estuary. Such a location has advantages: the soil is fertile, there is an abundance of fresh water, and it is near the sea, which offers a good trading location – reasons why densely populated metropolitan deltas exist all over the world. An estuary is a wet area, and in natural circumstances, the sea and rivers tend to flood regularly. If urban areas are developed in such an area, hydrological problems are bound to occur that must be solved, otherwise people get wet feet and wet houses. Therefore it is very important that physical planners involved in the development of delta regions understand the hydrological situation with its physical limitations. They should also be aware of the (technical) possibilities to make river deltas a saver place for inhabitants.

Why an interactive tool?

Planners need the help of experienced hydrologists to solve problems in metropolitan deltas. For an effective co-operation with hydrologists, planners and other actors in the planning process need to have a basic understanding of the hydrology, to search together for the best development plans and the best solutions for a delta region. The interactive tool "Hydropolitan", explains *hydro*logical problems and possible solutions of a metro*politan* delta, using simple pictures instead of complicated formulas, with Rotterdam and its surrounding area in the western part of the Netherlands as a sample area. The purpose of our tool is to offer an attractive means for non-hydrologists to develop the required basic understanding of the hydrological problems and solutions of metropolitan deltas. No models have been used to create the pictures: they are photomontages and drawings that are easy to grasp, based on sketches made by an experienced hydrologist. The scale of the pictures is indicative of the problems to be visualised, and is not necessarily accurate.

We hope that planners and other persons involved in the planning of metropolitan deltas will benefit from our tool. But we also hope to gain more insight in "hydropolitan" problems and solutions conceived in other countries by encouraging participants to put comments in the comment boxes of the tool. The tool is a website, so people from all over the world will be able to visit our tool and to add their comments through the Internet (http://cgi.girs.wageningen-ur.nl/Hydropolitan/index.htm).

Why this article?

In this article we would like to offer our readers an innovative way to discuss scientific issues between scientists and non-scientists, in this case between hydrologists and non-hydrologists, and discuss the usefulness of such a tool. At the same time we describe several problems and solutions given by the tool, to explain with what problems a metropolitan delta like the Rotterdam area is confronted, and what kind of solutions are already applied or

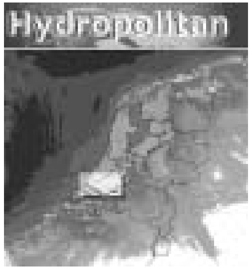

Figure 1: Location of Rotterdam in the delta of the rivers Rhine, Maas and Waal, as shown in the Hydropolitan website. *Source:* Netherlands Substratum as contained in the Vijfde Nota Ruimtelijke Ordening (Fifth Policy Document on Town and Country Planning), 2001, Ministry for Housing, Regional Development and the Environment

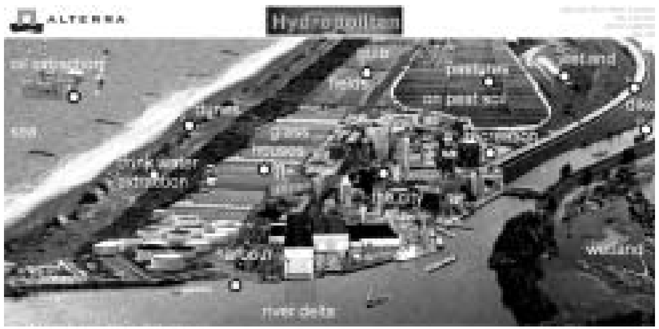

Figure 2: The home page of Hydropolitan: the buttons enable one to zoom in on problems and solutions in different areas around the Rotterdam metropolis

Figure 3: Possibility to add comments in Hydropolitan

are in discussion. This issue is becoming more urgent in view of the expected global rise in temperature, causing the sea level to rise with an increasing risk of flooding as a consequence.

How does the tool work?

After accessing the Hydropolitan website, an introduction on the purpose of the website is given as well as some instructions on how to operate the tool. Also a map is shown indicating the location of the Rotterdam area within the delta of the rivers Rhine, Maas (Meuse) and Waal (figure 1).

After clicking on the rectangle indicating the Rotterdam location, an overview picture is shown of the area of Rotterdam. It is a digital photomontage depicting a "condensed" visualisation of the area (figure 2).

This overview picture is the "home" page of the *Hydropolitan* website. By clicking on one of the buttons the tool zooms in on that area and explains the problem and its impact with animated pictures and a text box. Next, the visitor is invited to look at the solutions to the problem at hand. The picture gradually changes into a new situation that shows the new landscape when the proposed solution(s) is/are applied (e.g. the construction of a dam to avoid inundation). By clicking on "home" the visitor returns to the overview picture, where he/she can choose another problem to be visualised. The visitor is also invited to read or add comments to this solution. First a text is shown explaining the problems and solutions in more detail than in the pictures. Next the visitor is asked whether he or she wants to add any comments (figure 3). These comments are stored in documents that can be read by other visitors when looking at the relevant problem and solution.

Hydrological problems and solutions in the delta metropolis of Rotterdam

This paragraph describes several clusters of problems, impacts and solutions that are explained in the Hydropolitan tool, with some of the appropriate pictures. Note that the scale of the pictures is indicative of the problems, and is not necessarily accurate.

Problems and solutions related to drinking water

As the metropolis of Rotterdam grew, so did the demand for drinking water. Clean, fresh water was available in the dunes, so the city started to extract water from the dunes. As a result, the water table in the dunes fell, causing a decline of upward seepage in the inner dunes (figure 4) and a decline in nature conservation value of the inner dunes, as was reported e.g. by Bakker et al. (1981).

The first solution that was actually applied by the drinking water company in the Rotterdam area, was to infiltrate river water in the dunes, to keep the water table in the dunes from lowering rapidly. However, this caused the quality of the groundwater to decline, causing disturbance of the natural habitats in the inner dunes and the further decline of nature conservation quality. The drinking water company finally decided to stop the extraction of drinking water from the dunes, and use rain water (stored in reservoirs) and river water for drinking water instead. As a result, the water table in the dunes and upward seepage in the inner dunes has been restored (figure 5).

But now a new problem is arising for the use of river water as drinking water. The Intergovernmental Panel on Climate Change (2001) states that the average global temperature is expected to rise 2 to 4 degrees in the next 100 years. And according to Verbeek (2003) the temperature is rising in the Netherlands even more rapidly than was expected because the prevailing wind direction is shifting from west to south west, bringing warmer winds.

As a consequence, the sea water is expanding and the ice in the pole regions is gradually melting, especially in the South Pole, causing the sea level to rise. The rise in sea level is expected to be between 45 to 110 cm in the next 100 years, and this will cause further intrusion of salt water into the rivers, resulting in a higher salt content in drinking water that is extracted from rivers.

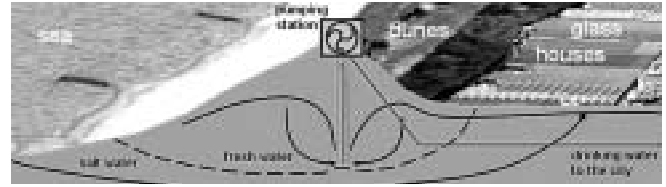

Figure 4: Fall of water table due to extraction of drinking water in the dunes

Figure 5: Restoration of water table and upward seepage in inner dune belt after stopping drinking water extraction in the dunes

Figure 6: Solutions to avoid salinization of drinking water due to rising sea level

We propose several solutions to this problem that can be combined (figure 6).

Firstly, air can be pumped through a perforated pipe on the river bed. This will generate an upward water flow which will push the salt water back towards the sea. This technique is actually in use near docking locks to prevent the intrusion of salt water upstream, but is not yet implemented in the Rotterdam area.

Next, the intake points for water can be allocated further upstream, as has been done in the past. And lastly, drinking water reservoirs can be constructed (as was actually done near Rotterdam, when drinking water was no longer extracted from the dunes).

Problems and solutions related to pollution and rising sea level

Besides the extraction of drinking water from the dunes, there is another factor contributing to the decline of upward seepage in the inner dunes and the related decline in nature conservation value. *Bulb cultivation* is a major economic activity in the Netherlands. The sandy soil along the inner dunes is very suitable for bulb cultivation, so many bulb fields are situated there. However, the drainage of the bulb fields causes fresh water from the dunes to seep into the bulb fields, thus lowering the water table in the dunes and causing a decline of the upward seepage in the inner dunes. Moreover, the pesticides that are used in bulb cultivation pollute the surface water. Both problems cause a deterioration of the aquatic ecosystems and a decline in quality of the terrestrial ecosystems in the inner dunes (figure 7).

Van Bakel et al. (1999) propose to re-allocate bulb cultivation to less vulnerable sites. For the restoration of upward seepage in the inner dunes, one might consider the construction of a water basin along the coast. Such a water basin could be a *tidal lake*, offering at the same time an alternative "green" energy source instead of oil. More pollution caused by oil spills in the sea due to accidents during oil extraction from under the sea bed or by oil

Figure 7: Lowering of water table and pollution of surface water in the inner dunes, due to use of pesticides in bulb cultivation, causing deterioration of aquatic and terrestrial ecosystems.

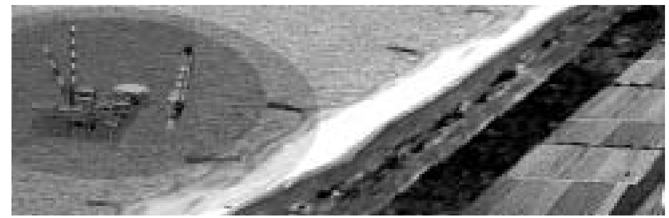

Figure 8: Oil pollution causing death of sea birds and marine organisms

transport causing the death of sea birds and marine organisms (figure 8), can then be avoided. On the Dutch coast, the tidal differences in sea level are not sufficient for tidal energy alone. Ina Klaasen (1981) reported that a Dutch researcher (Lievense) suggested using additional energy from *wind turbines* to fill lakes. By keeping the water level in a lake high, a buffer is created so that the water level can be lowered to create energy on demand (figure 9). The feasibility of tidal energy is currently under review. A drawback of a tidal lake is de fact that it contains salt water, which will cause a further increase in salt content of the groundwater in the surrounding area. Fresh water preservation will have to be sought elsewhere (e.g. by reservoir management upstream of the rivers, as is explained in the next section).

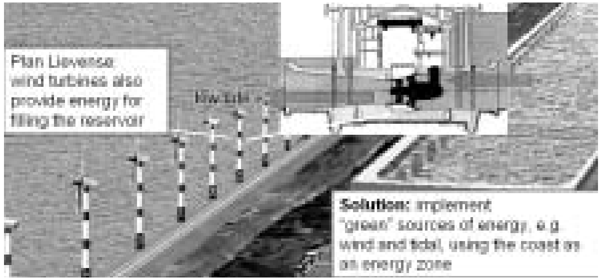

Figure 9: Construction of a tidal lake and wind turbines as green sources of energy, to avoid oil pollution. Since present bulb cultivation will have to make room for the tidal lake, lowering of the water table in the dunes and pesticide pollution will also stop. The dam will decrease the risk of flooding due to sea level rising.

Constructing a *dam along the coast* (figure 9) decreases the risk of flooding due to the rising sea level. Practically the whole western part of the Netherlands lies below sea level (1 to 7 m). Therefore, the greatest danger of the rise in sea level will be the erosion of the coastal zone, causing flooding of one of the most densely populated areas in Europe. One might consider improving the sustainability of the dunes, but the safest solution is to construct a retaining dam along the coast. By adding a road or train to the dam, travelling times in the coastal area will decrease significantly.

Unfortunately, this dam and the proposed "coastal energy zone" will affect the scenic beauty and cause a decline of the nature conservation value of the dunes, although mitigating measures might be applied (e.g. avoid visibility of the dam by hiding it behind higher dunes). The wind turbines will likely cause the death of many birds. That is one of the reasons why many environmentalists as well as politicians oppose against the construction of vast amounts of wind turbines, especially along the coast. The construction of a retaining dam along the coast is not yet considered as a serious option, but in the coming decades it will certainly be a subject for discussion.

Problems related to wetlands and river management

Natural deltas are characterised by wetlands with a rich nature. In the Rotterdam area only a few fragments of wetlands remain. The nature conservation quality of these fragments declines gradually, due to downward seepage caused by the drainage of (lower) neighbouring pastures. Most pastures in the western part of the Netherlands are situated on peat soil, where drainage causes soil subsidence and land level decline, mainly through mineralization of the soil. This process has been going on for a long time, and will not stop until firmer soil is reached underneath the peat layer. The subsidence of the soil causes damage to the foundations of buildings in the area, and pumping costs for drainage are high. These costs are expected to increase even more due to the ongoing global climate change, which will result in a rise of precipitation and higher peak levels of rivers, and thus the need for more pumping capacity (figure 10).

In the past, the pumping capacity in the Dutch peat areas has frequently been increased, and might be considered again. However, the only really sustainable solution will be to cease using peat soil for agriculture and instead choose other forms of land use which allow seasonal variation in water level and salt content, e.g. wetlands. By expanding the wetland areas, soil subsidence will cease and seepage from the existing fragments of wetlands to lower pastures will stop, resulting in an increase of nature conservation quality. To avoid damage to buildings it might be considered to modify building techniques on peat soil: e.g., place buildings on pillars or on floating islands. This "living on water" will also make the implementation affordable (figure 11).

One of the ways to create new wetlands is the expansion of *river flood plains.* Over the past centuries, many areas that were originally part of the flood plains have been embanked, not only in the Netherlands, but also in neighbouring countries, causing high-peak river water levels after heavy precipitation upstream. The ongoing climate change will result in an increase of

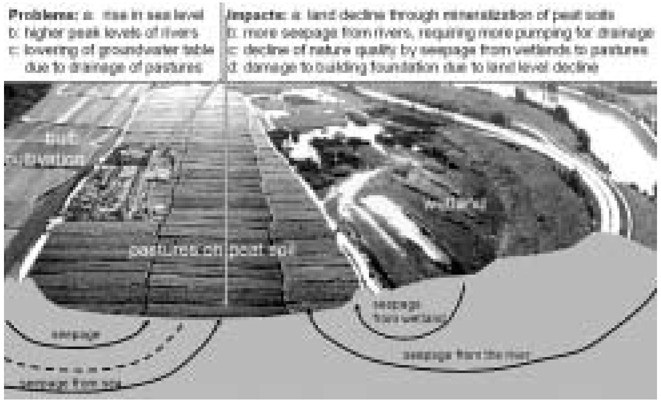

Figure 10: Soil subsidence causing land level decline due to drainage of pastures on peat soil, resulting in high pumping costs, the decline of wetland quality and damage to buildings

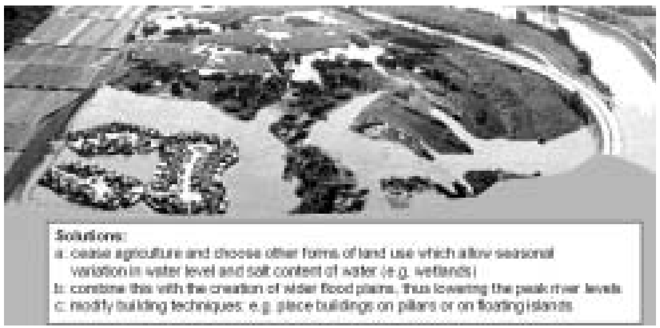

Figure 11: Expansion of wetlands/flood plains as a sustainable solution to stop further land subsidence and to avoid flooding of the rivers in view of climatic changes

precipitation (6 % to 12 % expected in the next 100 years), and higher extremes in precipitation (expected rise of 20 % to 40% in the next 100 years according to the Intergovernmental Panel on Climate Change, 2001). This means we can expect higher risks of overflowing river banks and flooding of the enclosed areas in the future.

Raising the river banks or dikes is one option, but a more sustainable solution is restoring or creating new flood plains. If necessary, roads along the rivers should be constructed on pillars to allow wider flood plains (figure 11). Additionally, it should be considered to retain more water upstream by modifying the land use, e.g. extensive grazing, that allows regular high water tables and flooding in extreme circumstances. An additional option is the construction of reservoirs that can be filled during high-peak water levels of rivers. This water can later be used in summer to increase the water discharge of rivers, ensuring transport on water and sufficient availability of water for agriculture during dry periods.

At the moment serious plans are being made to increase flood planes and several plans are actually being implemented, as has been reported by the "Commissie Noodoverloopgebieden" (2002). There are also plans for the construction of water reservoirs and the allocation of areas that are allowed to flood in extreme circumstances.

Discussion

This section discusses the usefulness of the Hydropolitan tool and presents ideas for future research.

Visualisation technique

When we presented the tool during the conference of the International Association of Landscape Ecology (IALE) in Darwin (July 2003), the reactions of potential visitors were positive. They liked the visualisation technique, using simple pictures to explain complex problems and solutions. They thought the tool to be unique and innovative, bridging the gap between science and society.

Linkages between different solutions

One of the participants of the IALE conference, a hydrologist, missed a clear insight into the interactions between the different solutions. He wondered what the influences would be of one particular solution on the other problems and solutions. We admit that these inter-linkages are not obvious while using the tool only briefly, as each problem and its solutions is viewed separately. In the text that explains the problems in more detail (which can be viewed through the "comment button"), the linkages between the different problems and solutions is expressed by referring to other problems and solutions. For example, in the text explaining the solution to the problem of declining quality of wetlands due to seepage to drained neighbouring pastures, it says: "The most sustainable solution is therefore to cease agriculture and expand the wet nature areas... This solution might seem drastic, but in the next problem you will see that many lower pasture areas in the western part of the Netherlands are not very suitable for agriculture anyway, due to soil conditions."

How the different solutions fit together is also presented after clicking the problem button in the middle of the city of Rotterdam. First the risk of inundation of the city of Rotterdam is visualised (figure 12a). Then the picture zooms out to illustrate the additional risk of oil pollution (figure 12b). After clicking the solution button the image gradually changes into a (quite technocratic) landscape of the future of the whole area, in which all the solutions are incorporated (figure 12c).

Scientific validity of the tool

While creating the tool, we had some discussions with the hydrologist of

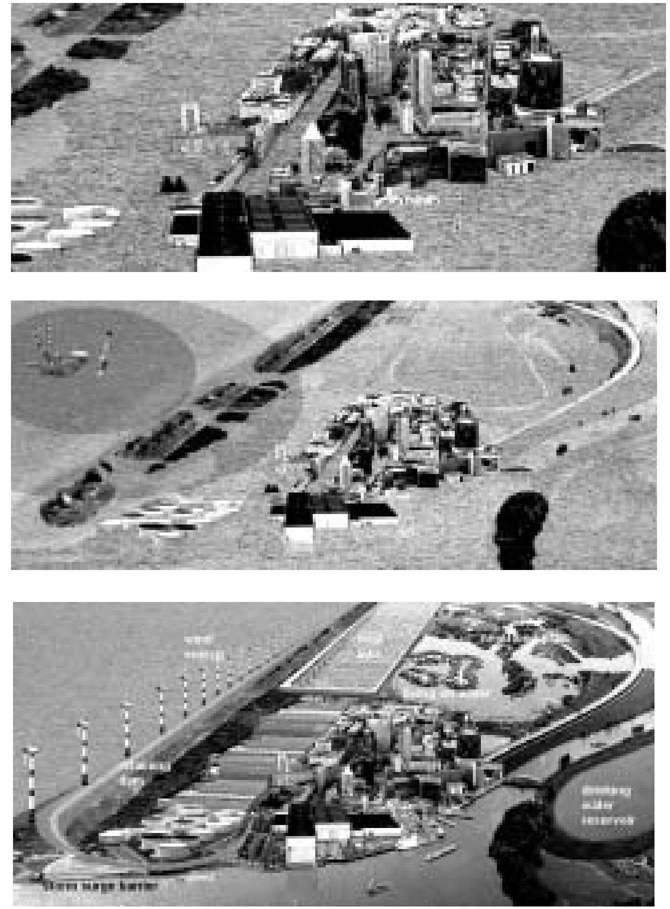

Figure 12: Presentation of the problem of increasing risk of inundation (a), zoomed out to the whole area adding the problem of oil pollution (b), and presentation of all solutions incorporated into one future landscape (c)

our team on the accuracy of the pictures. He would have liked more detail in the pictures, staying more in line with the hydrological reality and the way hydrologists usually visualise hydrological situations (e.g pictures generated by software offered by the hydrological internet site http://www.waterloohydrogeologic.com/software/visual_modflow_pro/index.htm). However, that meant that a lot of details needed to be added to the pictures that were not directly relevant to the problems to be visualised. We were afraid that these details would only confuse non-hydrologists, and would distract the viewer. So we decided to focus on the relevant hydrological lines and arrows, and leave out the rest. For the same purpose parts of the pictures are oversized and many presentations are exaggerated (e.g. figure 12). Although the hydrologist in our team accepted this (reluctantly), others might argue that our pictures are not scientifically correct.

As mentioned earlier, another point of discussion is the fact that no models have been used to support the creation of the pictures; they are merely based on sketches made by an experienced hydrologist. Scientists might therefore argue that our pictures are not scientifically valid, and that the presented solutions are not proven to be realistic or even effective. We must admit that this is true.

However, the purpose of our tool is not to give an accurate, hydrologically correct answer to the presented problems. For that purpose hydrological models have been (and are being) developed with which hydrologists try to predict impacts of technical solutions in relation to climatic change. But the results of these models are only comprehensible to highly specialized scientists or engineers. Our tool on the other hand is meant to be used by non-specialists, people who are involved in the planning process. It would therefore be a major challenge to combine both and link these scientific models to visualisation tools that would convert the model outputs automatically into comprehensible pictures. Current three dimensional visualisation tools offer the technical possibilities to make accurate, detailed pictures of model outputs; these kinds of tools are offered on the Internet (e.g: the earlier mentioned website on waterloohydrogoelogic software). The major challenge will be to make these pictures less technical, emphasising relevant issues and leaving out less relevant details.

Benefits of our tool

We hope that tools like *Hydropolitan* will stimulate discussions between hydrologists and non-hydrologists, in order to find good planning solutions. We do not pretend that our tool presents the only, or the best solutions for the problems of metropolitan deltas. For example, we are aware of the fact that, if the temperature and the sea level will consistently rise in the next few hundred years, the only sustainable solution might be to move all inhabitants of the lower western part to the higher eastern part of the Netherlands, giving the western part back to the sea.

So, the solutions presented in the tool apply only to this century, not beyond. But we do not particularly like the technocratic landscape that we propose as a solution for this century in the area of Rotterdam. Of course measures might be considered to improve the scenic value, but we hope others, hydrologists or non-hydrologists alike, will help us to find better solutions for our area. That is one of the reasons why we have installed the tool on the Internet (http://cgi.girs.wageningen-ur.nl/Hydropolitan/index.htm). Visitors can help us finding better solutions by filling in their comments in the tool. But we also hope that our tool will stimulate people all over the world to find creative solutions for their own metropolitan deltas.

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