Small hydrological basins in delta regions, past and future (climatic) changes, the Mark–Vliet basin

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Abstract The paper gives an overview of past and provisioned changes in climate, land use, and measures affecting the hydrology of the Dutch/Belgian basin of the Mark and the Vliet rivers. This is a small hydrological basin (~1400 km^2) situated in the delta of the rivers Rhine, Meuse and Scheldt. The basin is of recent origin. The period of study starts about the year 1820, when sluices were built at the outlets of the rivers draining the basin, and extends to the year 2050. The changes are analysed with respect to their effect on drainage and water supply. Key factors in hydrological change are identified: land use, drainage basis and layout and resistance of the open water system. Changes are analysed with respect to water levels and discharges during mean conditions as well as high flood and low flood conditions. The paper demonstrates: (a) the profound changes that took place in the hydrology of small basins like the Mark–Vliet basin, changes that in large river basins are flattened out; (b) the magnitude of future changes in the region's hydrology due to autonomous developments and due to the effects of climatic change; and (c) that the magnitude of future changes considerably exceeds that of changes in the past. The results for the Mark–Vliet basin are generalized to small hydrological basins in delta regions. It is argued that these basins are particularly vulnerable to climatic change.

Key words climatic change; delta regions; droughts; floods; hydrological change; water management

INTRODUCTION

This paper extends the analysis in Witter & Raats (2001). In that paper the effects on the regional hydrology of extensive reconstruction works of water systems in the small Dutch/Belgian river basin of the Mark and the Vliet during the 1960s were analysed. These reconstruction works were motivated by the rapid economic growth and the drive to modernize agriculture after World War II. It was demonstrated that they resulted in a growing imbalance of the hydrology of the regional water system.

In this paper the period of study is extended. It starts in 1820, when sluices were built at the outlets of the rivers draining the basin, the Mark and the Vliet, and extends to the year 2050. Past and provisioned changes in climate and land use, and measures affecting the hydrology of the basin, are analysed with respect to their effect on drainage conditions and water supply. Changes are analysed with respect to mean conditions as well as high flood and low flood conditions. The results for the Mark–Vliet basin are generalized to small hydrological basins in delta regions. It is argued that these basins are particularly vulnerable to climatic change.

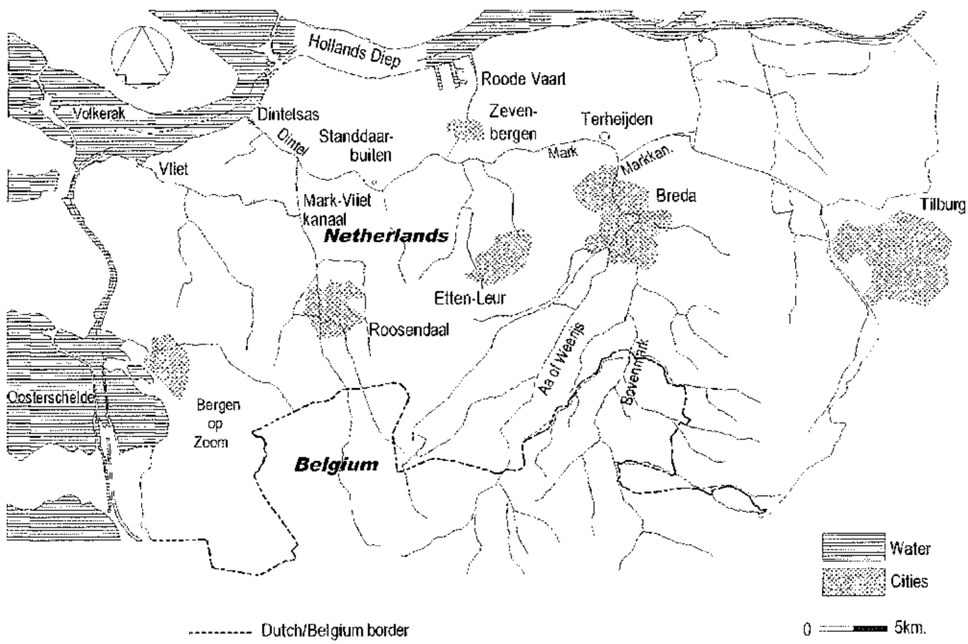

Fig. 1 Map of the Mark–Vliet basin.

The purpose of the paper is two-fold: (a) to compare past with future changes, and (b) to assess whether water management is making the right choices in facing the future.

THE STUDY AREA: MARK–VLIET BASIN

The Mark–Vliet basin (Fig. 1) is situated in the south of The Netherlands, near the Belgian border. It is a transboundary basin: 440 km^2 are situated in Belgium, whereas the remaining part, 970 km^2, is situated in The Netherlands. The basin consists of a gentle sloping and sandy, Pleistocene southern part of about 1000 km^2. At the Dutch/Belgian border the area is about 20–25 m above sea level. The cities of Breda, Roosendaal and Bergen op Zoom (Fig. 1) are situated more or less at sea level. The northern Holocene part of the region (~400 km^2) consists of clay polders situated at or slightly below (–1 m) sea level.

With an area of about 140 000 ha the Mark–Vliet basin is a small basin. Discharges can rise very fast and within 24 h water levels can rise from normal to critical levels, in particular in the city of Breda, which is located at the transition of the sloping Pleistocene part with the flat Holocene part. Particularly in recent years there have been frequent discharge peaks and yearly maxima of water levels show a distinct upward trend over the last 15 years. The basin drains in to Lake Volkerak (Fig. 1), which is part of the Meuse system.

The basin also depends on the Meuse for water supply to replenish part of the rainfall deficit in summer. Starting from April, mean potential transpiration exceeds mean rainfall and a rainfall deficit builds up. Mean cumulative potential rainfall deficit reaches its maximum value (89 mm) at the start of August (Buishand & Velds, 1980). About 220 km^2 of agricultural land receive freshwater during the growing season from the Amer (Fig. 1), ~25 km^2 directly from Lake Volkerak and ~325 km^2 from the Mark and the Vliet. These rivers, however, frequently have negative discharges during summer (because water withdrawal for agriculture exceeds discharge) and thus withdraw water from Lake Volkerak. Consequently, there is a strong dependency on the main river system of the Meuse for water supply.

THE PERIOD OF STUDY: 1820–2050

The study area is of recent origin. On the map of the territory of the present Netherlands around 800, shown in Van de Ven (1993), it is seen that at that time The Netherlands had a closed coastline. Around the year 1000 the sea started to penetrate what is now the Mark–Vliet basin, which at that time was part of the vast peat-covered delta of the Rhine, Meuse and Scheldt. Penetration by the sea was fostered by large floods and by massive peat-production to serve the expanding Flemish markets. However, gradually a counteracting force developed as dike construction grew more sophisticated and water authorities came into existence. Around 1500 the basin was more or less shaped into its present form. The genesis of the basin is presented in detail in Leenders (1996).

Around 1800 there were repeated complaints about inundations upstream of Breda. Also the navigability had deteriorated: the construction of dikes had considerably reduced the tidal volume of the Mark which caused rapid silting up of the river. Because of these problems, in 1804 the water authority “Hoogheemraadschap van de Mark en Dintel” was founded. The water authority took care of yearly dredging of the Mark and Dintel and started the construction of sluices at the outlets of these rivers. The period of study starts around the year 1820, when the sluices were completed. Three periods can be discerned since then: 1820–1900, 1900–1960 and 1960–2000. Around the year 1900 radical changes in land use took place in the southern part of the Mark–Vliet basin, because of large-scale colonization by farmers and afforestation of fallow land. Around the year 1960 extensive land reclamation schemes and reconstruction of drainage systems took place in the basin, with the objective of modernizing agriculture. The changes in rural land use and water management were accompanied by a rapid urbanization of the region. The period of study extends to the year 2050. In the future, changes of climate, sea level, the drainage basis of the Mark and Vliet and salinity of the Lake Volkerak (Fig. 1), are expected to take place, as well as changes in land use.

KEY FACTORS IN HYDROLOGICAL CHANGE

In Witter & Raats (2001) it was argued that for given soil and climatic conditions and in the absence of climatic change, hydrological systems generally are in a state of dynamic equilibrium. Under the conditions given, this is an equilibrium with respect to:

(a) vertical fluxes, governed by land use;
(b) morphology, governed by the drainage basis and the layout and resistance of the open water system;
(c) water quality, governed by land use.

Water quality is not the object of this paper; we concentrate on hydrological change. Consequently, land use, the drainage basis and the layout and resistance of the water system are the variables of interest in the study of changes in drainage conditions. Changes in water supply will be analysed separately.

HISTORICAL AND FUTURE CHANGES IN DRAINAGE CONDITIONS: 1820–2050

During the period 1820 to present, a long series of measures were taken that affected the region's drainage conditions. Table 1 gives a summary.

Most of the information presented in Table 1 has been taken from Anonymous (1936). In Table 1 a distinction is made between measures in the upstream part of the basin and in the Mark and Vliet themselves. We can conclude that in a period of about two centuries:
(a) the Mark has been deepened about 65 cm, assuming an initial water depth of 2 m;
(b) the river has been shortened from about 40 to 37 km;
(c) the river has been widened but no quantitative data are available to what extent;
(d) a number of sharp bends have been removed, resulting in a decrease of the river's resistance;
(e) riverbank storage has decreased dramatically, as about 20 km^2 of former flood-lands have been converted into polders;
(f) the drainage basis has remained more or less constant at MSL (mean sea level), but the important tidal influence has been removed.

The future

In the future we will probably see a stand-still with respect to the layout and resistance of the water system, possibly even a modest return in the direction of former conditions. The drainage basin, however, will change drastically. Climatic change will result in both sea level rise and increased discharges of the large rivers: for the Rhine, e.g. an increase from 15 000 $m^3 s^{-1}$ in 2000 to 18 000 $m^3 s^{-1}$ in 2050. The higher sea level will affect the drainage of the Rhine and Meuse.

In order to cope with this situation, plans are being developed to use the delta to store excess water of the rivers Rhine and Meuse. This will result occasionally in very high water levels at the Volkerak (about 2.00 m + MSL as opposed to MSL at present). This may completely obstruct drainage of the Mark and Vliet into Lake Volkerak over a couple of days. Also, in order to improve water quality and aquatic ecological conditions in Lake Volkerak, a return of water dynamics is proposed, including an influx of brackish water from the Oosterschelde into the Volkerak (Fig. 1). This will lead to a return of tidal dynamics, though possibly with a minimum water level of only about 0.30 m – MSL as opposed to 1.10 m – MSL before 1987.

Table 1 Measures that affected drainage conditions of the Mark–Vliet basin (1820 to present).

Year or period	Description
Mark and Vliet:	
1823	Realization of sluice at Benedensas; salt intrusion on Vliet ends
1827	Realization of sluice at Dintelsas; salt intrusion on the Mark ends
1828–1830	Deepening of the Mark over its full length to 2.25 m – MSL in Breda, 2.55 m – MSL near Zevenbergen and 2.75 m – MSL near Dintelsas (Fig. 1)
1870–1880	The fortress of Breda with its moats is demolished; construction of new water courses around the city of Breda to drain the part of the basin upstream of Breda
1884	Realization of a new drainage sluice in Benedensas (Fig. 1)
1893–1897	Deepening of the Mark over its full length to, respectively, 2.65 m – MSL near Breda and 2.95 m – MSL near Dintelsas (Fig. 1)
End nineteenth century	Embankment of about 0.7 km^2 of river forelands downstream of Standdaarbuiten (Fig. 1)
1906	Two sharps river bends downstream of Breda (Terheijden) are removed; river is widened between Breda and Terheijden (Fig. 1)
1913–1915	Construction of the Markkanaal (completed in 1915), deepening of the Mark between Breda and Terheijden from 2.65 m – MSL to 3.00 m – MSL with a bottom width of minimal 15 m
1917–1926	Widening of the Vliet, deepening by about 40 cm
1935–1965	Embankment of about 9 km^2 of river forelands downstream of Breda
1960–1965	Works (deepening, widening) to adapt the Mark to improvements upstream
1965	About 4 km^2 of river forelands are converted into flood retention areas
1966	Realization of a new sluice (for shipping) in Dintelsas
1980	Realization of a new drainage sluice in Dintelsas
1983	Realization of the Mark–Vliet Canal, connecting Mark and Vliet (Fig. 1)
1987	Damming of the Volkerak (Fig. 1) which becomes a lake; end of tidal influence for the Mark and Vliet
2000	Embankment of about 7 km^2 north of Etten-Leur (Fig. 1)
Upstream part of basin:	
1880–1890	Construction of pumping stations to drain the polders in the basin and replacing windmills and drainage sluices
1962–1975	Extensive land consolidation and normalization of streams

MSL: mean sea level.

Also, with respect to land use, the big change has yet to come. In Table 2 developments in land use are presented based on the soil statistics for 1832 and 1960 and statistics on land use for 1996 by the Central Bureau of Statistics (CBS) of The Netherlands. Data for 2050 are obtained from Anonymous (1999) for the whole province (5050 km^2) and are corrected for the relative area of the Mark–Vliet basin (20% of the province).

Table 2 shows a steady increase of built-up area. Agricultural land use first increased (due to land reclamation) followed by a decrease. The development of nature is exactly the opposite. Also in the future an increase of nature is expected: from 200 km^2 in 2000 to 300 km^2 in 2050.

Discussion of the effects on drainage

When we look at the key factors affecting hydrological change which were pointed out above, we can conclude the following:

Table 2 Developments in land use in West-Brabant: 1820–2050.

Year	Land use (km^2): Agriculture	Built-up	Other	Total	Population
1832	585	7	447	1040	71 410
1960	779	43	180	1001	No data
1996	696	95	217	1009	441 000 (year 2000)
2050	425	237	340	1010	No data

(a) Land use, governing vertical fluxes, has changed drastically, but the big change has yet to come (Table 2). Consequently, it will be of utmost importance to safeguard that the effects of these changes are not rolled off to the water system.
(b) The external drainage basis has not changed much. It is still at about MSL although the tidal influence has disappeared. Also here, the big change has yet to come: restoration of the tidal influence, possibly with an unfavourable tidal amplitude. Occasionally water levels at the Volkerak will be a high as 2.00 m + MSL resulting in obstruction of drainage.
(c) The layout and resistance of the water system have been changed drastically in the past, particularly in the years after World War II. Here at least a stand-still and probably a modest return to former conditions can be expected to take place.

In Witter & Raats (2001) the effects of the measures taken in the period 1960–1970 (Table 1) have been quantified:
(a) an increase of peak discharges by about 40% and of maximum water levels by about 15%;
(b) a shift in the water balance resulting in less storage;
(c) a decrease of mean surface water and groundwater levels in the upstream part of the basin by about 20 cm.

What does the information presented in Table 1 on measures taken prior to 1960 to add to this? As the drainage basis has remained more or less the same during the whole period 1820 to 1960, we may safely conclude that prior to 1960 there has not been any further drop in mean (ground)water levels. Consequently, over the complete period, there has been a drop in mean surface water and groundwater levels of about 20 cm, occurring specifically in the period after the 1960s. As improvements in the drainage of the upstream areas prior to 1960 have been few (Table 1), we can also deduce that prior to 1960 there had not been a substantial increase in peak discharges. On the other hand, Table 1 shows that prior to the 1960s there have been lots of improvements in the discharge capacity of the Mark and Dintel themselves, which may lead to the conclusion that in the downstream part of the basin maximum water levels decreased at least prior to the 1960s. Figure 2 shows a Peaks Over Threshold series (water levels equal to or in excess of 1.44 m + MSL) for Trambrug (Breda 4 in Fig. 1) for the period 1876–2002 (prior to 1876 no data available). The distinct downward overall trend in water levels (0.05% significant for one-tailed test) seems to validate this conclusion.

The upward trend of the preceding 10-day rainfall (10% significant, one-tailed test) is also in agreement with the previous conclusion. Recent research has shown that this is mainly caused by an increase in the number of days with a large amount of rainfall (Bruin, 2002). It must be added, though, that the upward trend in rainfall will be partly due to improvements in the measurement of precipitation (Buishand & Velds, 1980).

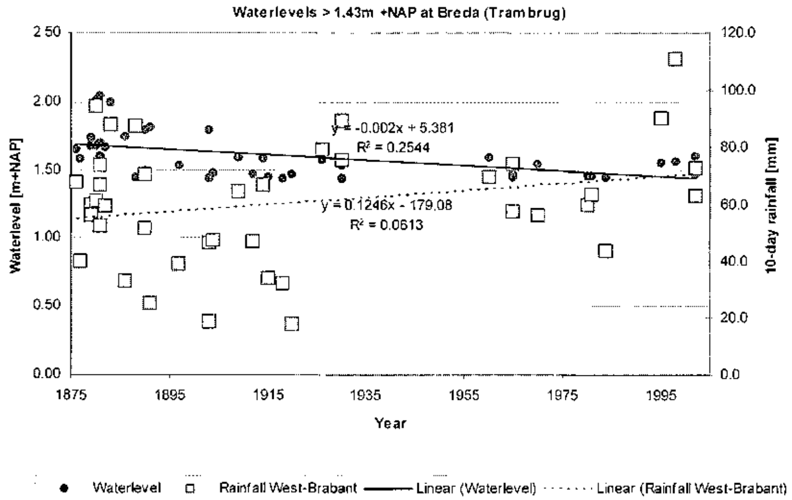

Fig. 2 Water levels at Trambrug (Breda) equal to or in excess of 1.44 m + MSL Note: no data available prior to 1876 and for the years 1931–1946 and 1973–1979.

CHANGES IN WATER SUPPLY: 1820–PRESENT

Water supply had not been much of an issue in the basin prior to 1900, simply because in those times agriculture was not as intensive and water-consuming as it is now. Because prior to 1828 brackish water could enter the basin with each tide and brackish groundwater was still present in most of the polders, agriculture was adapted to these circumstances. Also, in the absence of heavy agricultural machinery there was no motivation for excessive drainage. Extensive heathland reclamation in the sandy soils upstream of Breda around 1900 created the need for water supply. Not so much because agricultural production needed the water but it needed the nutrients that came with the water. This eventually resulted in the Law on Irrigation (1908). Soon, however, the introduction of fertilizer out-priced irrigation for fertilization purposes.

Intensification of agriculture in the polders downstream of Breda created the need for water supply. To this end, in 1923 a culvert was constructed for the supply of fresh water to the Markkanaal (Fig. 1) and from there, to the Mark and Dintel. The Markkanaal itself had been completed in 1915. Prior to 1923, occasionally freshwater had been withdrawn from the Hollands Diep by the Roode Vaart (Fig. 1).

It was only after the Second World War that water supply at a large scale started. Due to the scarcity of food during and right after the war, and the need to increase agricultural production at reduced costs, the drainage conditions of agricultural lands were improved greatly, accompanied by water supply during the growing season. After the 1960s surface water quality improves, due to the effects of the building of sewage water treatment plants as a consequence of the Water Pollution Act (1970). Prior to that, water quality often impeded use of surface water for agricultural purposes. At present the need for agricultural water supply in West-Brabant is about 7 $m^3 s^{-1}$ during the growing season, and of the same magnitude as the mean discharge of Mark and Vliet during that period.

The future

Agricultural water supply will presumably remain more or less constant as the increased rainfall deficit during the growing season due to the effects of climatic change will be more or less counterbalanced by a slight decrease of agricultural land use. A threat to agricultural use of surface water is the possibility that Lake Volkerak could turn brackish as a result of plans to flush the lake with salt water. This should improve the water quality and ecology of the now stagnant lake. It is doubtful whether there will be alternative freshwater sources in the future.

Discussion of the effects on water supply

Past changes in the water system have had two main effects. The greatly improved drainage conditions created a demand for agricultural water supply, because of the often excessive drainage. On the other hand, the possibility of water supply was also created. At present there are no problems with respect to agricultural water supply. In future, with a brackish Lake Volkerak, it is likely that problems will arise.

GENERALIZATION TO SMALL BASINS IN DELTA REGIONS

From a theoretical point of view it can be argued that small basins in delta regions are particularly vulnerable to the effects of climatic change, due to the following: In the first place, the effects of rising sea levels and increased river discharges are most prominent in delta regions. Secondly, small basins in delta regions often use the main river system to export their excess water. Climatic change, however, may pose such problems to the main river systems, that this relationship is reversed. That is, small basins in delta regions are used to store excess water from the main river system. Finally it can be noted that, as land use is particularly intensive in delta regions, it will be more difficult to cope with the effects of climatic changes.

CONCLUSIONS AND RECOMMENDATIONS

The present paper is not more than a first and general reconnaissance of the problem. For the basin of the Mark and Vliet, much is left to be investigated. It will be particularly interesting to quantify the effects of past and future changes in the water system by using models. This will be investigated in a forthcoming paper (Witter, 2003). There is also a need to broaden the scope by investigating other small basins, in The Netherlands as well as in other countries. Yet the following conclusions can already be drawn. In the first place that, at least in The Netherlands, small basins have been subject to many and profound changes. In the second place, that the real changes have yet to come, due to climatic change and changes in land use. The challenge posed by future changes in land use may be even bigger than that posed by climatic change. To cope with both changes, a radical change in water management is needed: water systems are to become more natural, giving more space to water. And future built-up areas must be realized in such a way that they do not result in increased discharges. Finally, the international context becomes increasingly more important as delta regions generally collect the water from several countries.

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