Flow characteristics of the Rhine distributaries, The Netherlands, calculated from historic flow measurements

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Introduction

In the past decades Dutch water management adopted a new approach to enlarge the discharge capacity of the rivers if safety standards have to be maintained. A political decision was made not to build higher dikes, because of increasing chances for a catastrophic dike breach, but e.g. to remove obstacles in the embanked floodplains, to reopen abandoned (secondary) channels, and to excavate the top layer of the embanked floodplains. Efforts to establish sustainable flood protection, and simultaneously encourage nature rehabilitation and maintain shipping routes are most likely to be successful if they are linked as much as possible to natural processes. It is therefore important to study the morphodynamics of the rivers Rhine and Meuse during the period before they were completely harnessed, on a time scale of decades to centuries, using the wealth of historic data present in The Netherlands. Over the past centuries, series of measurements on channel dimensions and flow characteristics were carried out in the Rhine distributaries. These data was used to:

1 Identify channel pattern and flow characteristics of the Rhine distributaries;
2 Quantify these changes in characteristics on a timescale of decades to a few centuries.

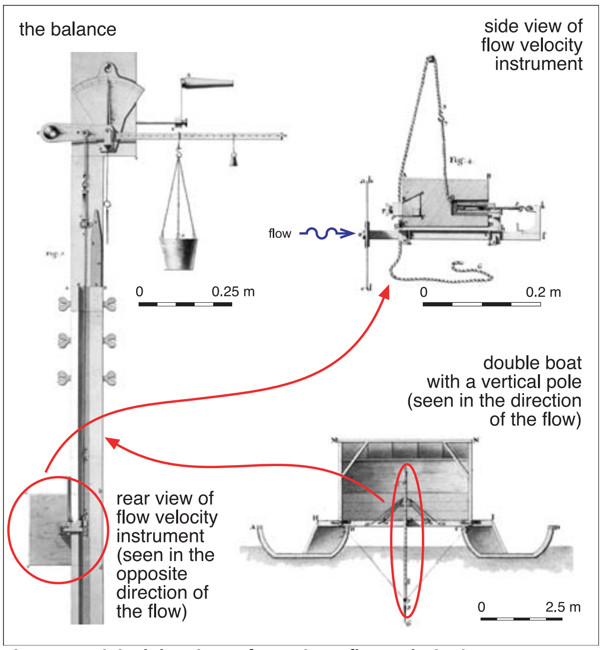

Figure 1. Original drawings of Brunings' flow velocity instrument (Conrads, 1798). The operation is based on a dynamic balance between the drag force (FD) exerted by the flow on a submerged vertical plate and the gravitational force (FG) on a weight above the water surface.

Brunings' historic flow velocity instrument

Two flow velocity measurements of the Rhine distributaries were carried out in 1790 and 1792 AD to determine the new discharge distribution over the Rhine distributaries after digging the Pannerdensch Canal in 1707 AD. For this purpose, Brunings developed a flow velocity instrument in 1786 AD (Figure 1), which he used to measure flow velocities at different height intervals (Figure 2). Brunings' thorough description of his flow velocity instrument, measurement techniques he used (Brunings, 1798), and flow velocities (Brunings *et al.*, 1790, 1792) enabled to assess the accuracy of the instrument and data to calculate flow velocities and discharge near the bifurcations of the river Rhine in 1790 and 1792 AD. Based on this assessment it was concluded that Brunings' flow velocity measurements are realistic, and have no significant systematic error (Hesselink, 2002).

Discharge distribution in 1790 and 1792

The measurements of 1790 and 1792 showed that the discharge distribution of the Rhine discharge

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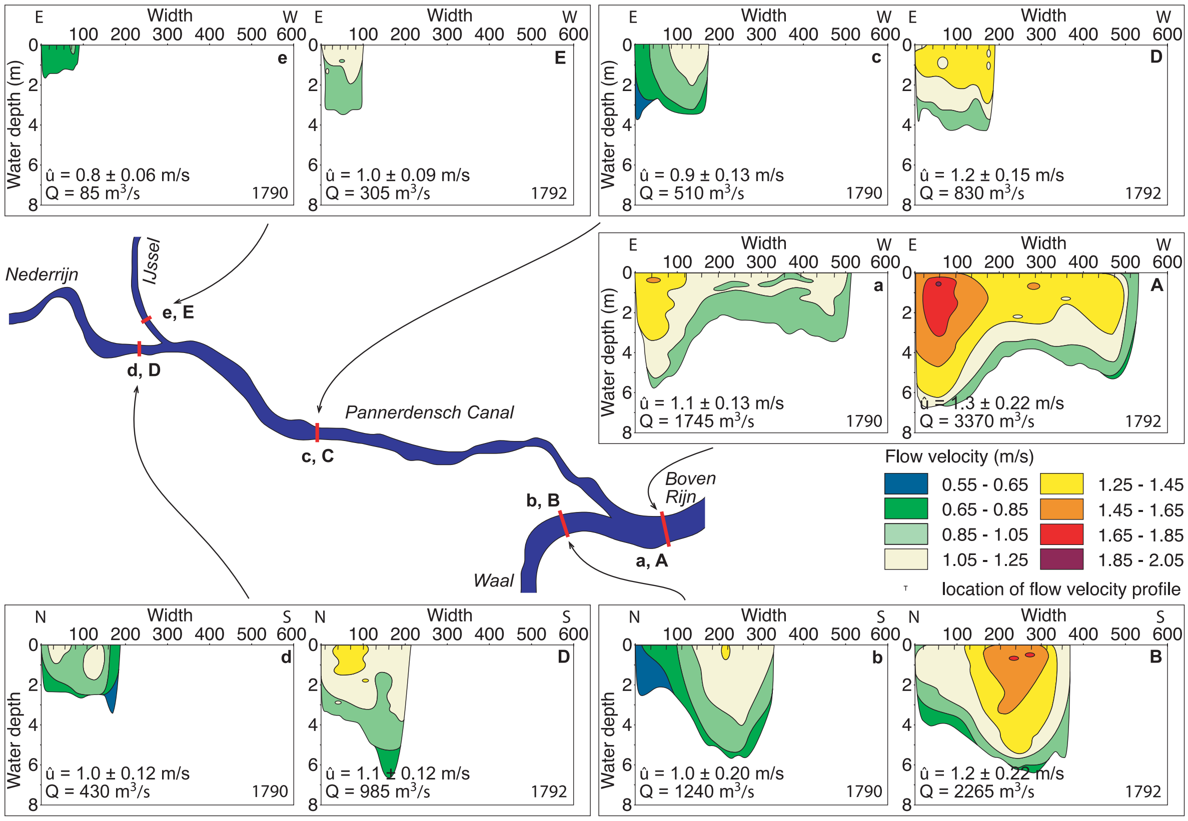

Figure 2. Flow velocities in the the Rhine distributaries in 1790 and 1792, based on the flow velocity measures by Brunings *et al.* (1790, 1792).

over the Rhine distributaries had improved after digging the Pannerdensch Canal (Table 1). The discharge at the end of the 18th century was even almost the same as the desired discharge distribution determined in the 18th century.

Discussion

Changes in channel width and depth, discharge, and valley gradient were quantified using old maps, depth measurements and the flow velocity measurements of Brunings for three periods with specific channel and flow characteristics of the Rhine distributaries (Figure 3):

1. 1350-1707 AD. The period between embankment and modification of the Rhine bifurcations is characterized by wide and shallow channel. The specific stream power of the rivers Boven Rijn and Waal is three to four times as high as the stream power of the smaller branches Nederrijn and IJssel.
2. 1707-1850 AD. The period from the modification of the bifurcations of the Rhine distributaries to the river normalization is characterized by an increase of discharge of the rivers Nederrijn, and IJssel. Sediment-mobility in the Pannerdensch Canal and the river IJssel was lower than that in the river Waal. This probably caused a tendency of silting of the rivers Nederrijn and IJssel in the long term.

Table 1. Discharge distribution of the Rhine distributaries in 1790 and 1792.

Distribution	Boven Rijn (%)	Waal (%)	Pannerdensch Canal (%)	Nederrijn (%)	IJssel (%)
Desired	100	67	33	22	11
1790	100	69	28	23	5
1792	100	70	31	26	8

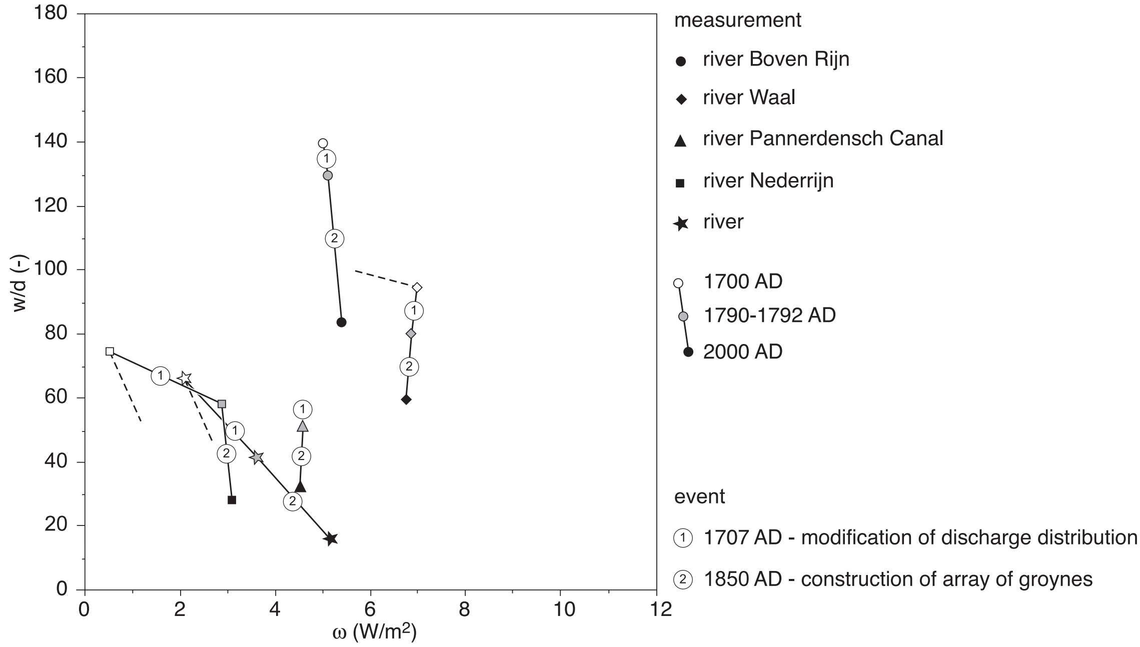

Figure 3. Changes in width/depth-ratio and specific stream power of the Rhine distributaries.

3 1850 AD- present. The period after the river normalisation works to the present is characterized by vertical erosion of the channel, and sediment deposition between the groynes. This had little effect on the specific stream power.

Conclusions

Reliable historical sources are a valuable source of information for the reconstruction of fluvial morpho- and hydrodynamics over the past changes. From these past changes, a few inferences can be made with regard to changes induced by future river management. If the river would be allowed to return to a (semi-) natural condition without groynes and other structures, this would in the long run result in wider and shallower channels with higher width/depth-ratios and smaller specific stream power. Removal of the structures at the bifurcations that ensure sufficient discharge through the Pannerdensch Canal would potentially lead to a renewed tendency of silting-up of the Pannerdensch Canal and the river IJssel, and eventually abandonment of the rivers IJssel and Nederrijn.

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