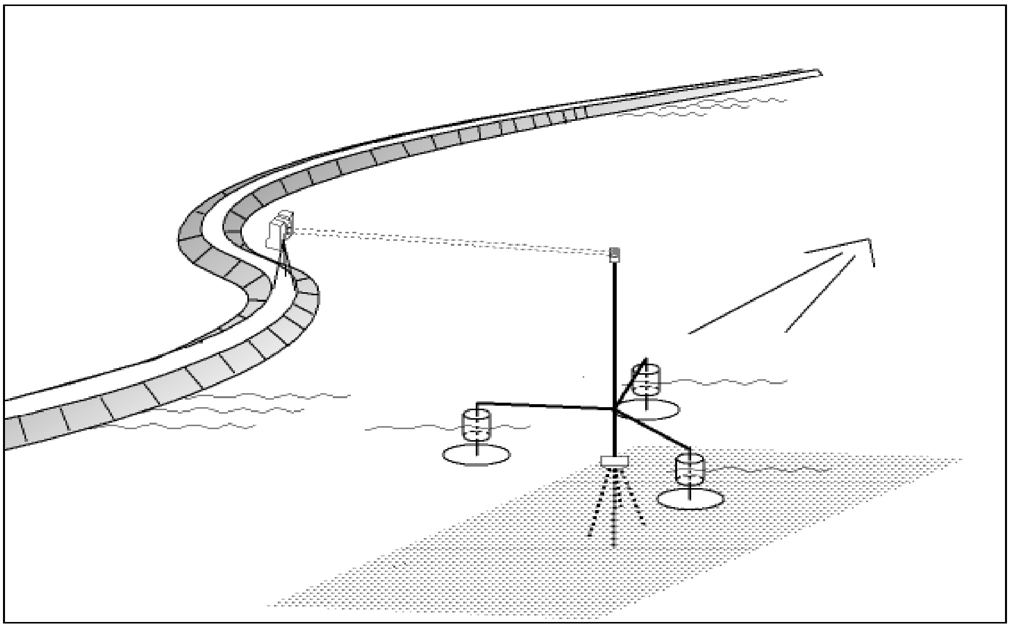
Measuring floodplain vegetation resistance in lowland rivers

Field campaign for flood stages of the river Rhine



Universiteit Utrecht

Menno Straatsma
Department of Physical Geography
Utrecht University
January 2003

1 Introduction

The underlying study is part of a PhD study carried out at the Department of Physical Geography of the Utrecht University. The study is aimed at the detailed mapping of the spatial distribution of vegetattion structural characteristics using remote sensing and the monitoring of the interaction of between vegetation and flow characteristics in the field. Floodplain vegetation resistance is one of the key parameters in hydraulic modeling of lowland rivers. Current and future nature rehabilitation projects are likely to increase the hydraulic resistance of floodplains, caused by more vegetation with a higher resistance than the current meadows. In addition, the vegetation characteristics will change faster in time due to succession. Resistance values are mostly derived from flume experiments using low water depths and high water surface slopes, which is not representative for lowland rivers such as the River Waal, IJssel or Meuse.

Research question: What is the effective hydraulic resistance of submerged vegetation types at the spatial scale of the floodplain.

In recent years, little progress has been achieved in measuring vegetation resistance under field circumstances. In this study it is proposed to measure the parameters needed for the calculation of resistance factor during high water levels of the River Rhine. The important hydraulic parameters are:

- water depth,
- water surface slope and
- flow velocity profiles.

Water depth and flow velocity will be measured using a Acoustic Doppler Current Profiler (ADCP), which is able to produce current velocity profiles every 10 seconds. Water surface slope will be defined by a tachymeter, which is able to track an active prism automatically. Both ADCP and active prism will be mounted on a floating tripod, see figure 2

Research goal: Defining the hydraulic vegetation resistance for various types of submerged floodplain vegetation in the Rhine-Meuse delta.

This can be subdivided into several secondary research goals:

1. What is the relation between flow velocity, water depth, water surface slope and vegetation structural characteristics for various vegetation types?
2. How reliable is the water surface slope measurement using a automatically tracking tachymeter?
3. How reliable is the bottom track and flow measurements of ADCP over vegetated river beds?
4. What is the quality of the water depth definition from ADCP over various vegetation types?

2 Theory

Vegetation resistance causes slowing down of the water. Two methods are proposed to derive resistance coefficients: (1) from hydraulic measurements during flood stage, (2) from measurements of vegetation structural parameters before and after flood stage. Both methods provide an estimate of the Chézy C coefficient, which will be compared subsequently.

(1) Chézy C coefficient is defined by flow velocity, water surface slope and water depth:

$$C = \frac{u}{\sqrt{hi}} \tag{1}$$

where C = Chézy coefficient ($m^{0.5}/s$), u = depth averaged flow velocity (m/s), h = mean water depth of the floodplain section (m) and i = downcurrent water surface slope (-). The Chézy equation (1) needs uniform flow conditions which is a boundary condition rarely met under natural conditions. Alternatively the one dimensional Euler equation for non uniform flow conditions will be used.

$$\frac{\partial u}{\partial t} + u\left(\frac{\partial u}{\partial x}\right) + \frac{g}{hC^2}\left(u\,|\,u\,|\right) - gi = 0 \tag{2}$$

where u = depth averaged flow velocity (m/s), x = longitudinal distance (m), h = mean water depth of the floodplain section (m), g = acceleration of gravity (m/s^2), i = down current water surface slope (-), t = time (s), C = Chézy coefficient ($m^{0.5}/s$).

Hydraulic parameters to be measured during flood stage:

- Flow velocity profiles using ADCP bottom tracking. In addition, water surface flow velocity is measured using a tachymeter
- Water surface slope using a self recording tachymeter.
- Water depth using ADCP. In addition water depth can be calculated from the difference of water surface level as recorded by the tachymeter and the national digital elevation model available at the Survey Department.
- Time is registered by both ADCP and tachymeter

(2) The Chézy coefficient can be defined using vegetation structural parameters as expressed by equation (3) (Van Velzen et al. 2002):

$$C_r = \frac{k_o\sqrt{\frac{2g}{C_d D_{vo}}} + \left(k - k_o\right)\sqrt{\frac{2g}{C_d D_v}} + \left(h - k\right)\left[\sqrt{\frac{2g}{C_d D_v}} + C_v\sqrt{h - k}\right]}{h\sqrt{h}} \tag{3}$$

where C_r = vegetation representative Chézy coefficient, k_o = height of vegetation undergrowth (m) (see figure 1), C_d = drag coefficient (-), D_{vo} = blockage area of undergrowth (m/m^2), k = vegetation height of upper layer (m), D_v = blockage area of upper layer (m/m^2)

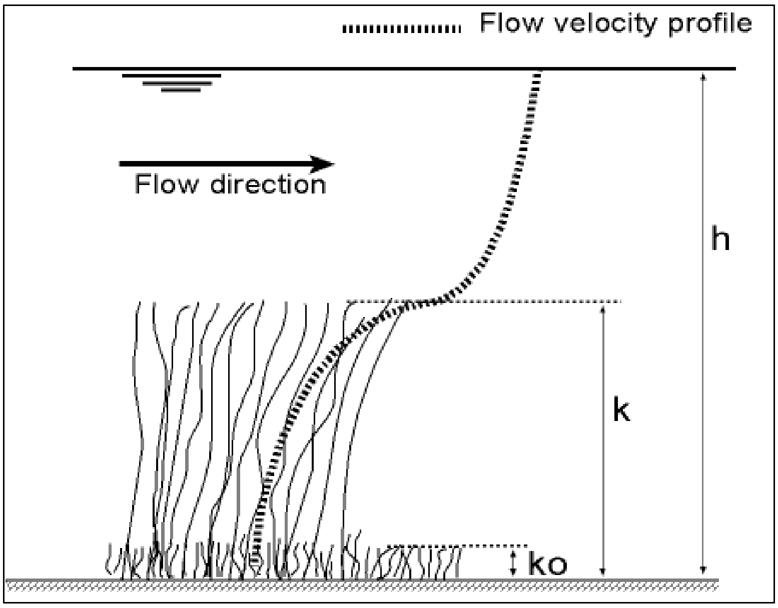


Figure 1. Symbols used for submerged vegetation

Vegetation parameters to be measured before and after flood stage:

- Vegetation height of lower and upper layer using tape measure.
- Blockage area of lower and upper layer as defined by number of stems per square meter and thickness of stems using measuring rod.
- Additional information is collected on species composition.

3 Field campaign

The field campaign is designed to collect data on all hydraulic and vegetation parameters listed in the previous section. Measurements will be done in the Rhine branches during the next flood stage. The required discharge for specific floodplains is listed in table 1. *Hydraulic parameters* will be collected on submerged floodplains: water surface slope, vertical velocity profiles and water depth. A floating tripod, see figure 2, is floating over the floodplains. Several runs will be made over the same lines. On this tripod an Acoustic Doppler Current Profiler (ADCP) and an active prism are mounted. The ADCP registers every 5 seconds the water dept and the current velocity profile above different vegetation types. The active prism is followed by an onshore self recording tachymeter also called a tracking total station. This generates XYZ data of the location of the active prism relative to the location of the total station. A second total station will simultaneously collect data on the location of the active prism to be able to define the measurement error. During measurements the location of 2 verification points is measured several times to estimate long-term changes. Post processing of the XYZ data generates the local Water Surface Slope (WSS). This will generate the data needed for equation (1) and (2).

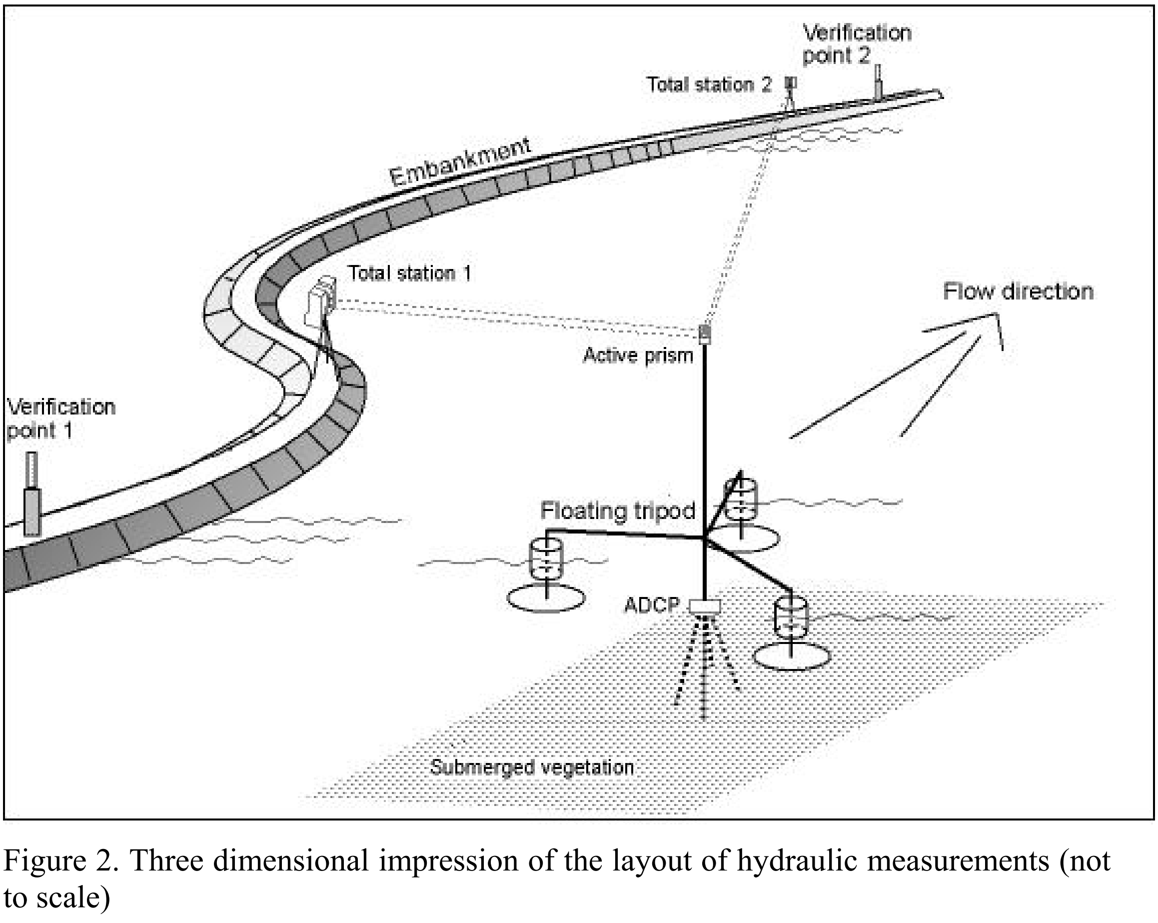


Figure 2. Three dimensional impression of the layout of hydraulic measurements (not to scale)

Vegetation structural characteristics are determined before and after the flood event. Characteristics include vegetation height and density from manual measurements and vegetation density from photographic sampling. Variation of vegetation height is defined by the standard deviation of thirty individual vegetation height measurements. Fieldwork before and after the flood is needed to study the effect of hydraulic forces on vegetation height and density. Vegetation can be down or even bend double by the current, resulting in decreasing vegetation height and increasing vegetation density. The amount of bending during flood can't be monitored under fielfd conditions. The above will generate the data needed for equation (3). Water depth will be taken from the measurements during flood stage.

The secondary research goals can now be answered:

1. All data is collected to make a comparison between the resistance coefficients based on the Euler equation and the equation of Van Velzen (2002). A calibration will be done to fit the vegetation derived resistance to the hydraulics derived resistance.
2. Water surface slope measurements will be measured using two total stations. This provides the means to define the measurement error from reflection on the water as the trajectory of the signal of the two total stations will not cover the same water surface. Long term changes in the horizontal plane, as defined by the total station, are monitored by measuring three verification points before, during and after the measurements.
3. The flow velocity will be determined by the bottom tracking of the ADCP and from the displacement of the active prism in time. The dual measurement of the flow velocity provides an excellent method to define the quality of the bottom tracking of ADCP over submerged vegetation..
4. The water depth can also be derived from the difference between external surface elevation data and the water surface elevation from the tripod. In spring 2003 a detailed digital elevation model (DEM) of the fluvial area, including the floodplains, will be ready. The DEM will have a 5 meter resolution. The total station generates a XYZ data point every 0.4 or 0.7 seconds depending on instrument type. Depending on flow velocity this will generate a water surface elevation point every 0.15 to 0.5 meters. The ADCP water depth will have a support of 3 to 10 m.

4 Field locations

High demands are placed on the lay-out of the floodplains suitable for this field experiments.

The field sites have to satisfy the following conditions:

- Natural submerged vegetation: > 0.5 m of free flowing water
- Large areas of homogeneous vegetation: > 200 m in downstream direction
- Vegetation changes should be at least at 20 times water depth distance from measuring location to avoid edge effects
- Flow velocity between 0,3 and 1.0 m/s
- Slope measurement: < 500 m from dry and accessible ground
- "One dimensional" flow field: no contracting or expanding flow
- Safety for field crew

For the Netherlands a list of field sites has been derived from the output of the 1995 flood modeling. For water levels ranging from 6000 to 12.000 m^3/s sites have been selected that satisfy the conditions, see table 1.

Table 1 Field locations for hydraulic measurements during floods in the Netherlands:

Location	**Vegetation type**	**Flow conditions (m/s)**	**Required discharge at Lobith (m^3/s)**
Arnhem	meadow	0.3	6500
Gendse plaat	meadow	0.3	5600
Dreumelse overlaat	pasture	0.4	6000
Wamel	arable land	0.4	8600
Deventer	all sorts	0.3	7800
Deventer	all sorts	0.7	8600
Zutphen	meadow	0.4	8600
Heerde	reeds	0.4	8600

5 First experimental results

First results from WSS determination using a total station and a floating buoy have generated fairly good results. These datasets were collected in summer 2002 in the summer bed of the River IJssel and in November 2002 in the floodplains of Arnhem and Dreumel. In stead of the tripod a floating buoy was used limiting the distance from the water surface to the active prism to 20 cm. Depending on weather conditions the results were of variable quality. The main problem was the reflections of the optical signal on the water, lowering the recorded water levels according to the absence of small waves. Small waves make the water surface behave like a Lambertian reflector, effectively diffusing the path of water-reflected signal. Too often large scatter was present in the data. Therefore the design was changed into a floating tripod, effectively enlarging the distance between water surface and active prism, while preserving the mobility of the method.
The results of the November 2002 field measurements are presented below for the Dreumel floodplain. Figure 3 shows the results of the six runs close to the embankment and the three runs close to the main river. The color indicates the height of the water level relative to ordnance datum (NAP). Figure 4 shows the hydraulic parameters for the downstream section of the runs closest to the embankment.

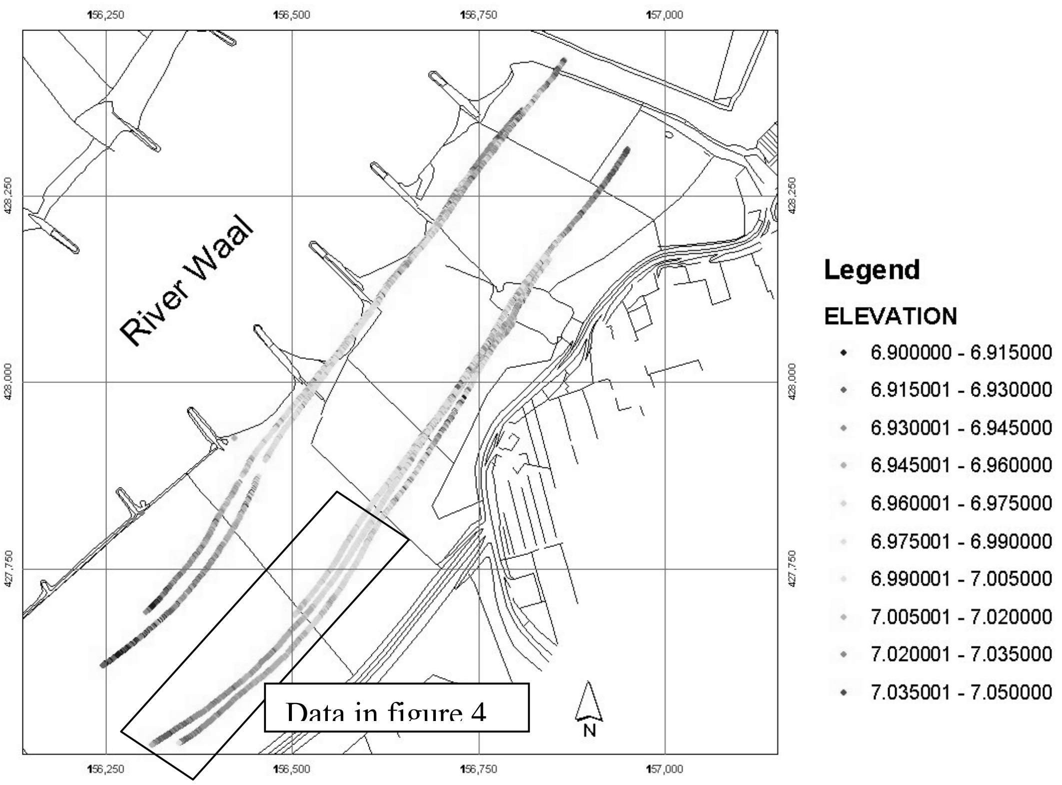


Figure 3 Dreumel floodplain and the water surface levels as measured from the float tracking. Basemap is provided by the Survey Department

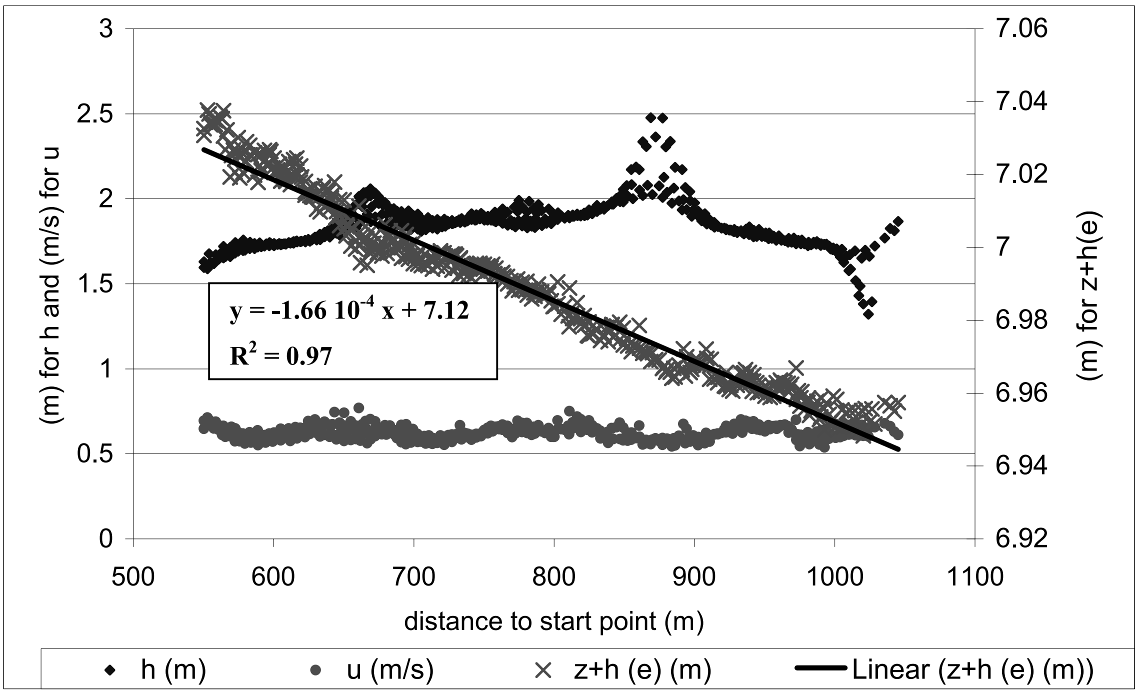


Figure 4 Water surface slope, flow velocity and water depth as measured from the downstream part of the runs closest to the embankment.

The downstream part is selected as this part of the runs was not influenced by the presence of a floodplain lake. Water surface slope is 16 cm per kilometer for this stretch. The overall WSS is lower. The flow velocity is 0.626 m/s on average, water depth is 1.85 m. Water depth is based on ground surface elevation from the national digital fluvial database (DTB-nat). The related Chézy is 35.7 $m^{0.5}/s$. The same procedure was followed for the runs closest to the River Waal. This resulted in a resistance coefficient of 38.4 $m^{0.5}/s$. Vegetation height is 0.07 m, based on two field measurements just after the flood. The related nikuradse resistance coefficient is 25 cm using the expression (5) (Van Velzen 2002). This relation describes the representative Nikuradse roughness (k_r in m) based on the height of the vegetation (k in m).

$$k_r = 1.6 * k^{0.7} \qquad (5)$$

The related Chézy resistance is 35.0 $m^{0.5}/s$ based on the White-Colebrook equation. Results from hydraulics and vegetation-derived friction coefficients are close together, showing the potential of the method..