Fig. A-2.1: *Field photograph of a floodplain with a side channel.*

After deposition, sediment-associated pollutants, such as metals, are incorporated in the ecological food-chain (Torres and Johnson, 2001). Floodplain characteristics and inundation frequency also influence ecological habitat ('ecotope') distributions, which in turn determine the potential biodiversity (De Nooij et al., 2004). Over the past centuries, the natural bio-geomorphology of many flood plain has been dramatically affected by humans, which has caused considerable degradation of their ecological status (Tockner and Stanford, 2002). In recent years, therefore, ecological restoration projects have been carried out in many countries (Buijse et al., 2002). At the same time, however, flood protection has remained a primary objective for river management.

The study was part of the LOICZ-project "Biogeomorphological interactions within floodplains and their role in sediment transport and ecological transformation processes in the lower Rhine delta". It consisted of three components. Firstly, a study was performed into the parameterization of floodplain vegetation for hydrodynamic models (Straatsma, 2007). Secondly, influences of multiple stressors on floodplain biota were studied (Schipper, forthcoming). The results of these two projects were integrated into a value-based scenario study of the biogeomorphological interactions under climate change (Straatsma et al., 2009).

2.1   Hydrodynamic roughness of floodplain vegetation: Airborne parameterization and field validation

Menno W. Straatsma, Hans Middelkoop, Steven de Jong

i. Problem

Hydrodynamic modeling is a central tool for flood risk management and lies at the base for the determination of deposition of sediment and heavy metals. In recent years, considerable effort has been made on the development of 2D and 3D hydrodynamic models that accurately simulate overbank flow patterns and predict extreme flood water levels in rivers and floodplains (e.g., Baptist et al., (2007) and Stoesser et al. (2003). In addition to surface topography (Marks and Bates, 2000), hydrodynamic roughness of the floodplain surface is the key input parameter of these models. Currently, no accurate, spatially distributed and quantitative method exists to

parameterize hydrodynamic roughness of the floodplains as input for models, leading to uncertainty in flood water levels as well as deposition patterns.

Vegetation roughness is dependent on vegetation structural characteristics like vegetation height and density, rigidity of the stems and the presence of leaves (Kouwen and Li, 1980) . To provide hydrodynamic modelers with reliable input, the spatial and temporal distribution of surface characteristics is needed. This requires accurate and fast monitoring methods that can cover large floodplain areas. Various remote sensing data may provide information on vegetation type, structure and dynamics, using vegetation classification. While the spatial resolution and the level of detail of the classification vary with the type of remote sensing data, in all cases vegetation classes are converted to vegetation structure, which leads to undesirable loss of within-class variation. In contrast, Airborne Laser Scanning (ALS) enables direct extraction of vegetation structural characteristics such as vegetation height, biomass, basal area, and leaf area index (Cobby et al., 2001; Lim et al., 2003). However, ALS was never tested for floodplain vegetation under leaf-off conditions representative for winter floods, which has specific problems of inundated ground surface and small herbaceous vegetation elements which cannot be detected.

Any mapping strategy requires accurate field reference data for validation of remote sensing information products. Vegetation density is a difficult parameter to measure in the field, due to the presence of side branches, complex stem shapes and leaves (Dudley et al., 1998; Zehm et al., 2003). In addition, none of the current field methods generates information on the three-dimensional distribution of vegetation density. Especially for herbaceous vegetation, no accurate method exists to determine density in the field. Therefore a large uncertainty remains in the input to hydrodynamic models. On the other hand, the output of roughness models is mostly calibrated in flume facilities, where high flow velocities are used, combined with steep water surface slopes and low water depths. These circumstances are not representative for flow conditions on lowland floodplains. Current in situ measurements of vegetation roughness using fixed current meters and water level meters are inadequate to measure the relevant hydrodynamic parameters such as water depth, water surface slope and the 3D flow field. This lack of calibration data further increases the uncertainty in the hydrodynamic modeling.

ii. Aims

Based on the problems described above, the research objectives were summarized as to:

Parameterize floodplain vegetation structure accurately, quantitatively and spatially distributed using ALS to derive vegetation roughness, and assess the effects on floodplain flow patterns

Develop a method that provides accurate estimates of hydrodynamic vegetation density using terrestrial laser scanning and field photographs.

Determine floodplain roughness from in situ measurements.

The study was carried out in different floodplain sections along the lower Rhine distributaries, including the Gameren and Afferden floodplains along the Waal, and the Duursche Waarden along the IJssel branch.

iii. Results

Floodplain vegetation characterization

In this research we developed a novel method for automated roughness parameterization. It delivers a spatially distributed roughness parameterization for an entire floodplain by fusion of airborne multispectral data with laser scanning data (Straatsma and Baptist, 2008). The method consists of three stages: (1) pre-processing of the raw data, (2) image segmentation of the fused dataset and classification into the dominant land cover classes, (3) determination of hydrodynamic roughness characteristics for each land cover class separately. In stage three, we assigned roughness values to the classes' water, sand, paved surfaces (e.g., roads, parking lots), meadows and built-up area. For forest and herbaceous vegetation, ALS data were used for spatially detailed analysis of vegetation height and density. The vegetation density of forest and height and density of non-woody herbaceous vegetation were mapped using calibrated regression models (Straatsma and Middelkoop, 2007). Herbaceous vegetation cover was further subdivided in single trees and non-woody vegetation. Single trees were delineated using a novel iterative cluster merging method, and their height is predicted. The vegetation density of single trees was determined in an identical way as for forest (Straatsma, 2008). Fig. A-2.2 shows the different input maps for the hydrodynamic model. A 2D hydrodynamic model was applied with the results of this method, and compared with a traditional roughness parameterization approach. The modeling results showed that the new method is well able to provide accurate output data, it provides an easier and quantitative way of obtaining floodplain roughness and it yields a high spatial detail.
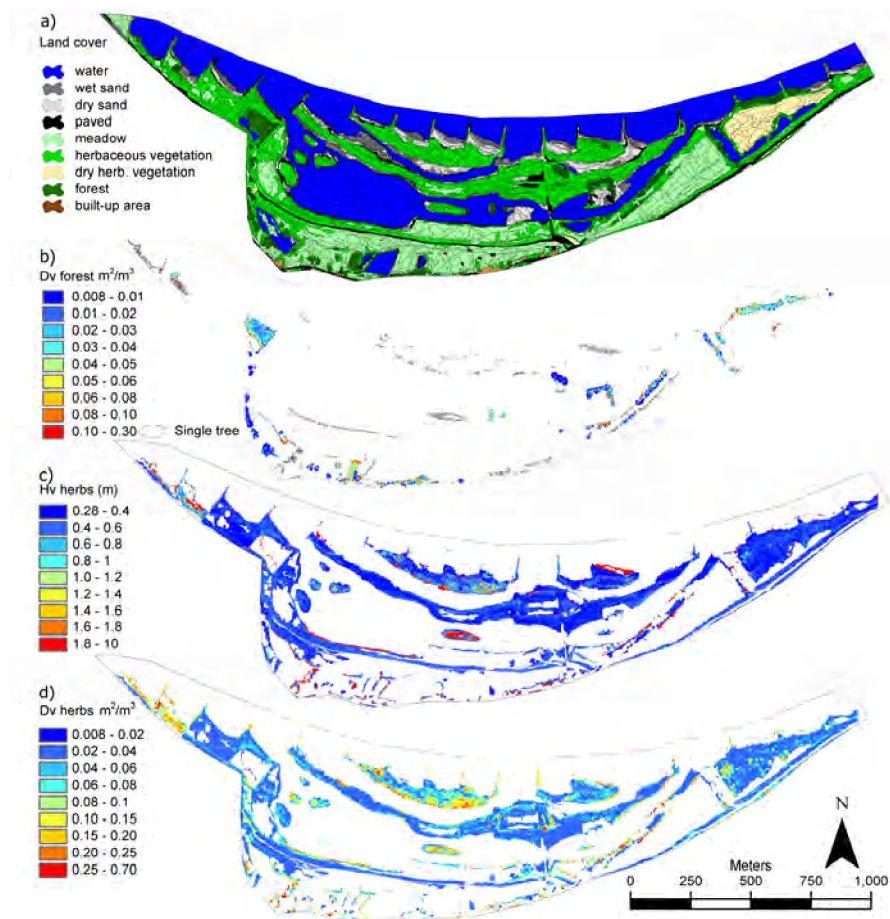
Fig. A-2.2: Map stack describing the surface properties of the Gameren floodplain (Waal river). a) classified land cover map, b) vegetation density of forest (m^2/m^3), c) vegetation height of herbaceous vegetation (m), d) vegetation density of herbaceous vegetation (m^2/m^3).

Field validation of hydrodynamic vegetation density

To measure vegetation density in the field, two new methods were developed (Straatsma et al., 2008). In Parallel Photography (PP) we used a large number of parallel photographs that were taken in a horizontal direction through the vegetation against a contrasting background (Fig. A-2.3).
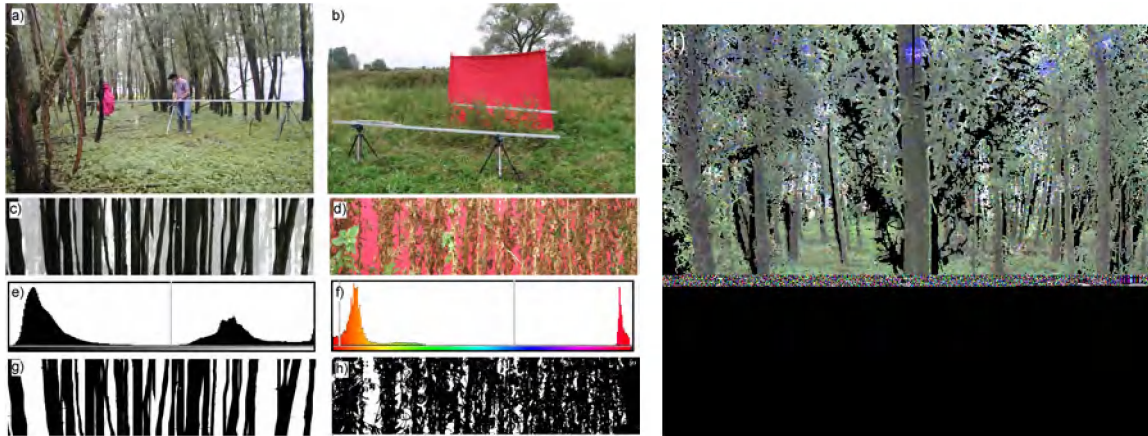
Fig. A-2.3: Parallel Photography (PP) methods: a,b) setup of the guide rail for the camera and background for forest and herbaceous vegetation, c,d) derived parallel photo-mosaics, e) histogram of intensity values (0 to) with threshold, f) histogram of hue values (0 to 360) with thresholds, g,h) thresholded images, i) TLS point cloud, with the points colored using the built-in camera.

From these we created a photo-mosaic of the central vertical slices of these adjacent images. This solves the problem of overestimating the size of vegetation elements that are close to the camera). Using the inverse gap fraction method (Jonckheere et al., 2004) the density was computed. PP proved extremely accurate in predicting the hydrodynamic vegetation density at plot level. The regression model was linear and did not deviate from the line of identity, which indicates that this method does not have to be calibrated and generally applicable. In addition, the support of this method is variable as the distance between the digital camera and the background screen is easily varied. The second method that was tested was based on Terrestrial Laser Scanning (TLS), which generates a 3D point cloud based on distance measurements (Fig. A-2.3i). TLS provided a 2D distribution of the forest vegetation density with a high accuracy. This method is easily extended to 3D. PP and TLS are complementary techniques as they combine high plot level accuracy and spatially distributed estimates of vegetation density. More detailed analyses of the composite image and laser data might enable the distinction between stems, twigs, and leaves. Such a method should include the classification of different vegetation elements and an estimate of their size. In this way, average stem spacing or flexural rigidity might be derived from the same methods.

Floodplain roughness determination

For in-situ quantification of hydrodynamic roughness of submerged floodplain vegetation, a novel method called ´3D float tracking´ was developed and tested (Straatsma, 2009). A platform floating over an inundated floodplain (Fig. A-2.4) was tracked using a shore–based laser positioning instrument (total station), while a current meter measured the flow profile.
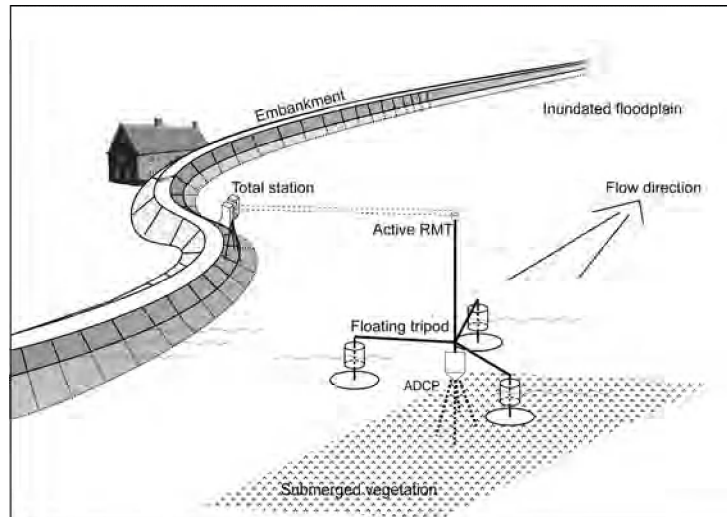
Fig. A-2.4: Sketch of 3D float tracking, in situ roughness parameterization.

This method is easily applied at various locations with different submerged vegetation types. The main achievement of this method is its high accuracy of the local water surface height determination (residual standard deviation of 0.7 mm) in the absence of waves. Combined with the depth averaged flow velocities and the water depth this enables solving the 1D equation for free surface flow locally, leading to the hydrodynamic roughness. 3D float tracking proved very suitable for inundated floodplains with high water depth and modest flow velocities. A clear spatial pattern in roughness could be detected using this method. In addition, 3D float tracking generates the detailed hydrodynamic data that are needed to verify the output of high-resolution hydrodynamic models, which will provide a substantial improvement of the calibration of these models. The effective roughness estimates, obtained using this device, are well within the range of suggested values from previous studies. The real achievement of this study is that it shows the spatial patterns in roughness, which points at the underlying processes.

iv. Conclusions and recommendations

Flood risk reduction and ecological restoration will remain important objectives of integral river management in the future. Within this project we developed methods to create building blocks for accurate parameterization of the input of hydrodynamic models and to validate the output of these models. We conclude that:

Vegetation height and density of herbaceous vegetation can be determined using airborne Lidar with high accuracy. However, the conversion of laser measurements to vegetation density still requires calibration for new flight campaigns. In the future, full waveform laser data analyses could improve the characterization the roughness of low vegetation.

Airborne laser scanning is able to provide maps of vegetation density of floodplain forest at high spatial resolution.

Field reference data of vegetation density can be acquired using parallel photography for plot level estimates and terrestrial laser scanning for 2D and 3D mapping. Detailed analysis of the PP

photo-mosaics and TLS point clouds are required to estimate leaf coverage and flexural rigidity of the vegetation.

3D float tracking can be used to estimate the vegetation roughness under field conditions. At the same time it provides additional calibration data for hydrodynamic models to constrain parameter setting to realistic values. 3D float tracking could be further expanded using horizontal ADCP and small-footprint echo sounders to map the horizontal flow field and the vegetation structure of inundated floodplains.

The fusion of airborne spectral imagery with ALS data provides an effective source for mapping vegetation structural characteristics required to determine floodplain roughness. The method that was developed in this project provides more accurate determination of 3D floodplain vegetation structure than the current method of manual delineation and classification of floodplain ecotopes and, hence, of hydraulic roughness. Multi-temporal data analyses seems a promising way to optimize discriminate between herbaceous vegetation and meadows.

2.2   Influences of land use, flooding and metal contamination on biota in lowland Rhine River floodplains

Aafke M. Schipper, Rob S.E.W. Leuven, Ad M.J. Ragas, A. Jan Hendriks

i. Problem

Floodplains of large rivers are among the most dynamic and diverse natural systems on earth. The large spatial diversity of site conditions, combined with the flooding-induced dynamics, yields a constantly changing habitat mosaic, which favors a high diversity of both aquatic and terrestrial plants and animals (Sparks, 1995; Tockner and Stanford, 2002; Ward et al., 2002). Apart from their biological richness, floodplains provide important resources to mankind, for example through the supply of fresh water, food and fertile soils (Costanza et al., 1997). Particularly in densely populated regions, large areas of natural floodplain have been reclaimed for agricultural, industrial and urban activities, thus modifying or simply eradicating natural floodplain habitats (Nienhuis and Leuven, 2001; Tockner and Stanford, 2002). Due to the profound human influences, floodplains are ranked among the most altered ecosystems worldwide (Millennium Ecosystem Assessment, 2005; Tockner and Stanford , 2002). The lowland floodplains of the Rhine River represent a clear example of such man-dominated and deteriorated systems (Nienhuis et al., 2002). These floodplains have a long history of reclamation and land use and received large loads of persistent contaminants, notably metals, during the past century (Lenders, 2003; Middelkoop, 2000; Nienhuis et al., 2002; Thonon, 2006).

Triggered by the extreme floods of 1993 and 1995, major reconstruction measures are to be performed in many floodplain sections along the Rhine River in The Netherlands, in order to enlarge the discharge capacity of the river corridor (Nienhuis et al., 2002; Van Stokkom et al., 2005). Possible measures include the creation of side channels, removal of minor embankments and lowering of the floodplain surface (Straatsma et al., 2009). These reconstruction measures