# MEASURING HYDRODYNAMIC VEGETATION DENSITY IN A FLOODPLAIN FOREST USING TERRESTRIAL LASER SCANNING

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## ABSTRACT

In this paper a method is presented to extract the aggregated hydrodynamic vegetation density of a river floodplain forest using terrestrial laser scanning. Hydrodynamic vegetation density (*Dv*) is defined as the sum of the frontal areas of all vegetation elements divided by the ground surface occupied by the vegetation multiplied by the water depth. The laser-scan data and reference data were collected in a floodplain forest along the river Rhine. The laser scanning was carried out using a Leica HDS3000 laser scanner, a time of flight scanner. Field reference data consisted of (1) a stem map of 650 trees, describing the position and the diameter of these trees. Eleven plots were derived from the stem map. (2) 7 manually measured plots.

Data processing consisted of slicing the points around breast height. These points were selected to predict the vegetation density value. In a polar grid two models were used to predict the vegetation density: 1) the percentage value and 2) the vegetation area index. The percentage value was corrected for missing points which increased the $R^2$ value from 0.17 to 0.72. The vegetation area index ($R^2$ = 0.67) has to be corrected for missing points in future studies to increase the predictive quality. Furthermore a correction for distance is done by including the distance of the reference plots to the scan positions in the regression equation. This improved the predictive quality, but in later studies the correction for distance has to be improved. It has been concluded that both models are good predictors for the vegetation density values.

**Keywords:** Floodplain vegetation, hydrodynamic vegetation density, Terrestrial Laser Scanning

## 1 INTRODUCTION

Safety levels of rivers are computed using hydrodynamic models. Floodplain vegetation, which is inundated by water, causes a resistance to the water flow, thereby raising the water levels in the rivers. For forests, the vegetation density (*Dv*) is needed as an input variable, which is defined as the sum of the frontal areas of all vegetation elements divided by the ground surface occupied by the vegetation multiplied by the water depth when inundated (figure 1; equation 1; Petryk & Bosmajian, 1975).

$$Dv = \frac{\sum_{i=1}^{n} A_i}{V} \approx N \cdot d \qquad (1)$$

where $A_i$ is the sum of the frontal areas of the vegetation in the water flow, $V$ is the volume of water. Under the assumption of cylindrical vegetation, the vegetation density can be computed by the product of $N$, the number of stems per square meter and $d$ is the average diameter of the vegetation. Vegetation density is expressed as $m^2/m^3$.

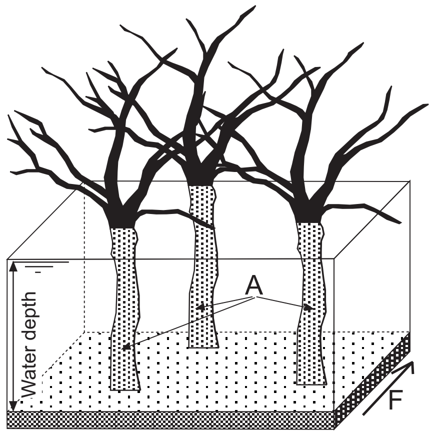


*Figure 1: Sketch of hydrodynamic vegetation density (Dv); the sum of the frontal areas of all vegetation elements divided by the ground surface occupied by the vegetation multiplied by the water depth when inundated*

To drive the hydrodynamic models, vegetation density needs to be mapped for all forested areas in the floodplain. Floodplain-wide mapping of vegetation characteristics is most appropriate using an remote sensing method, containing either spectral information from aerial photographs or satellites (Van der Sande et al., 2003), or height information from airborne laser scanning (Mason et al., 2003; Straatsma, 2005), or a combination thereof (Ehlers et al., 2003). Mertes (2002) gives an overview of remote sensing methods riverine landscapes. Independent of the remote sensing method however, accurate field reference data are needed for calibration or for a lookup table after classification of the vegetation types. The computation of the product of N times d does not generate reliable values in case the vegetation does not consist of cilindrical elements. Therefore, alternative methods have been proposed. Greame & Dunkerley (1993) determined the vegetation density using a photographic method. A white screen was used behind a vegetation plot and a photograph was made of the vegetation in front of the screen. The surface area of the frontal areas of the vegetation was determined by digitising the picture. The vegetation density was then acquired by dividing the percentage of coverage by the length of the plot. The number of stems per square meter ($N$) multiplied by the average diameter of the trees ($d$) at mid flow depth was used as reference data.

Other methods to measure the vegetation density in the field are compared by Dudley et al. (1998). The first method is the Cover Board method, where a person is walking backwards through the vegetation with a white board with a grid. An observer determines the distance where half of the board is covered and assuming a Poisson distribution the vegetation density can be calculated by the observed distance. A second method is the camera technique where the Leaf Area Index is measured by looking through a camera with a grid in the lens and measuring the distance for each grid point where the first vegetation element comes into focus. The digitisation process in the photographic method is done manually and introduces subjectivity. In the other methods the judgement of the observer is important on the measured values. Therefore the disadvantage of these methods is the high degree of subjectivity. Furthermore, the methods measure only a small plot and lack spatial variability.

In this pilot study, terrestrial laser scanning (TLS) is used for vegetation density measurements, which is a promising method for vegetation density mapping. TLS is currently used in vegetation research for recognition of individual trees. Gorte & Winterhalder (2004) used a voxel approach to reconstruct the branches of a single tree, which was scanned from multiple angles and Aschoff et al. (2004) used a tin triangulation for the digitisation of trees. Chasmer et al. (2004) characterized the three dimensional distribution of airborne and ground-based LiDAR data for conifer and mixed deciduous forest plots. For a plot containing large trees, object recognition techniques can be used for describing the vegetation, but when the vegetation consists of shrubs, with many small branches, object recognition is unlikely to give satisfactory results. The aim of this research is therefore to extract the aggregated hydrodynamic vegetation density of a river floodplain forest using terrestrial laser scanning. In this paper, we present two vegetation indices to extract vegetation density from TLS data: the Percentage and the Vegetation Area Index. This method was calibrated in a forest area with highly cylindrical stem shapes to enable the use of the Nd-method as a reference. The research was done in a test site along the lower river Rhine, where the TLS data and the reference data were collected.

# 2 METHODS

## 2.1 Study Area

The study was carried out in a forest patch in the “Gamerense Waard”, a floodplain area along the lower Rhine River in the Netherlands (figure 2). The forest is 60 meters wide and 120 meters long and consists of intermediate aged willow trees (Salix Alba). This forest was chosen, because little undergrowth was present and few side branches existed in the lower part which could limit the TLS measurements. These features made the vegetation close to cylindrical and therefore reference data could be collected using the Nd-method. The dense edges and the open middle part of the forest result in a wide range of *Dv* values in the forest. The dense parts have *Dv* values of 0.12 $m^{-1}$ and the open parts have *Dv* values of 0.01 $m^{-1}$. Furthermore the differences in surface elevation are small, with a maximum difference of 0.5 m.

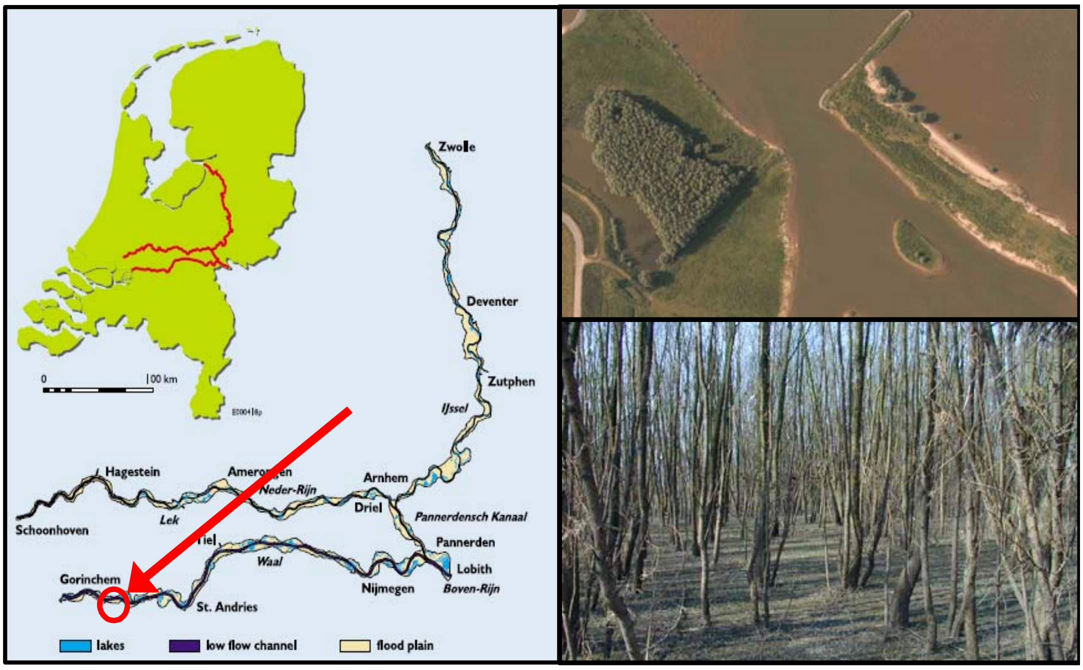


*Figure 2: a) Location of the ‘Gamerense Waard’ floodplain along the river Rhine (RIZA, 2001), b) aerial photograph of the studied forest and c) a side view of the forest*

## 2.2 Data Collection

### 2.2.1 Reference data

Firstly, to enable geo-referencing, 27 wooden poles were installed, distributed around the forest. The centres of these poles were marked and geo-referenced using differential GPS. Both TLS data as well as reference data were tied to these points. Secondly, two different types of field reference data were collected in the forest, simultaneously with the TLS data: (1) a stem map, and (2) plot level vegetation density measurements. The stem map contained 650 trees covering a quarter of the surface area of the forest (figure 3). A tacheometer was used to measure the coordinates of the centres of the trees, which was reconstructed by placing a reflector in front of the tree for the direction and beside the tree for the distance. The diameter was measured separately at breast height using a measuring tape. The accuracy of the stem map is 5 cm of which 2 cm of the uncertainty is caused by the inaccuracy of the tacheometer. Based on the stem map 11 plots were created of which the *Dv* value was computed using the Nd-method for comparison. Furthermore 7 plots were outlined in the field, and were measured manually for larger spatial variability and to obtain a larger range of *Dv* values. The corners of these plots were measured using a surveyor's level for geo-referencing. In total, 18 vegetation density values were available for comparison with the TLS data.

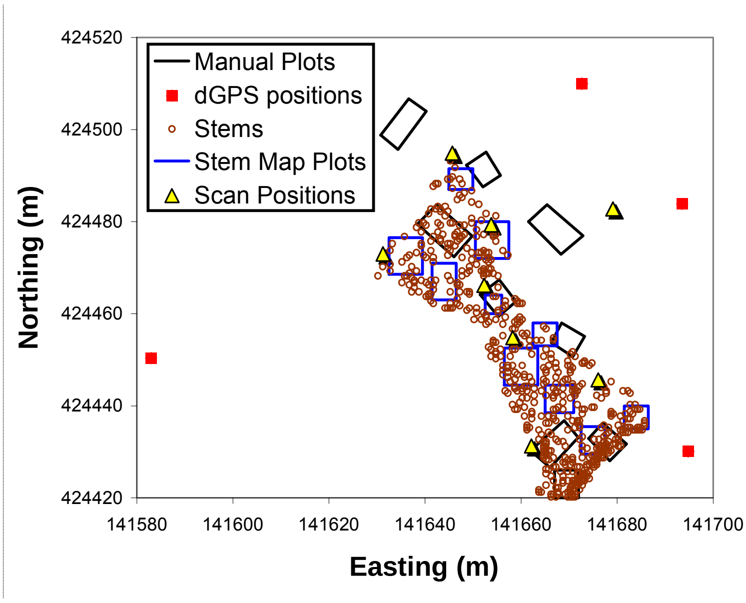


*Figure 3: Reference data collected in the study area.*

### 2.2.2 TLS data

The laser-scan data was collected in August 2005 using a Leica HDS3000 laser scanner. This scanner is a time-of-flight scanner, which was chosen because it has a large effective range (100 m). The disadvantage of this type of scanner is that it is slow compared to a phase based scanner. A scan with a horizontal angle of 360˚ takes approximately 1.5 hour per scan with the resolution set at 2 cm at 20 m distance. The specifications of the scanner are presented in table 1. The laser scanning was carried out by and geo-referenced by Delfttech and external company specialized in laser scanning projects.

*Table 1: Specifications of Leica HDS3000 (Leica Geosystems)*

| | |
|---|---|
| Field of View | 360˚ x 270˚ |
| Spot size | < 6mm @ 50m distance |
| Positional accuracy | 6mm @ 50m distance |
| Angle (horizontal & vertical) | 60 micro-radians |
| Optimal effective range | 1 - 100m |

In the forest, 8 different laser scans were made, with different resolutions set per scan (table 2). Because the resolution was kept constant per scan, the number of emitted points is known for each angle. After the first scan the decision was made for the next scan location and after 8 scans about half the forest was covered. The range of the scanner proved about 25 m effectively. For the scans the field of view was set at 360˚ horizontally and from 45˚ below horizontal to 35˚ above horizontal vertically. The scanner was positioned about 2 m above the forest floor. Detailed scans of the geo-referenced poles were made for initial geo-referencing, and subsequently the laser scans were tied together using the Iterative Closest Point algorithm.

*Table 2: Scan resolutions per scan position in cm @ 20m distance to the scanner*

| Scan | Horizontal Res. | Vertical Res. | Scan. | Horizontal Res. | Vertical Res. |
|---|---|---|---|---|---|
| 1 | 3.6 | 2.7 | 5 | 8.3 | 1.5 |
| 2 | 4.6 | 1.8 | 6 | 3.1 | 2.7 |
| 3 | 8.3 | 1.8 | 7 | 3.8 | 2.7 |
| 4 | 3.5 | 2.0 | 8 | 5.0 | 4.7 |

## 2.3 Data Analysis

The first step in the processing of the laser data was the selection of the points in a horizontal slice of 1m thick around breast height, thereby eliminating the ground points. The slice was corrected for ground level for each scan position. Subsequently a polar grid was created with cell sizes of 4 degrees and 0.5m length. At 25 m distance to the scanner a threshold was applied, because few points have penetrated the forest at larger distances. The points behind the threshold value are included in the calculation. For each cell in the polar grid, the number of hits in each cell is determined and the vegetation density was predicted using two models. The first model computes the percentage (P) of laser hits in each cell using the following equation:

$$P_{d1-d2} = \frac{1}{d2-d1} * \frac{N_{d1-d2}}{N_{tot}} \qquad (2)$$

in which $N_{d1-d2}$ is the number of points between distance *d1* and *d2* to the scanner (*d*2 > *d1*) and $N_{tot}$ is the total number of emitted points in each horizontal angle increment. The first term of the equation is added to make the index independent of the cell length.

The second model was developed by MacArthur & Horn (1969) and verified by Aber (1979). This method is based on an extinction model in which a correction is included for the decreased probability of hitting a tree at larger distance to the scanner, caused by the occlusion effect. The occlusion or 'hiding' effect can be visualized by the decrease of the intensity of light with distance travelling through a forest. If we assume that the trees are randomly distributed a simple relation exists for this decrease of light intensity. Straatsma (2005) assumed that leafless trees show the same way of occlusion as trees in leaf on conditions and used the Vegetation Area Index as a predictor for vegetation density of airborne laser scanning data. This method was applied for predicting the *Dv* using terrestrial laser scanning, but has to be used horizontally resulting in the horizontal Vegetation Area Index:

$$VAI_{d1-d2} = \frac{1}{d2-d1} * \ln\left(\frac{N_{d1}}{N_{d2}}\right) \qquad (3)$$

in which $N_{d1}$ and $N_{d2}$ are the number of points behind distances *d1* and *d2*. Three assumptions underlie this method: 1) the laser pulses travel parallel through the forest, 2) the trees are randomly distributed and 3) all emitted laser pulses have returned. Strictly speaking none of these assumptions hold.

For all plots, the P and VAI values were calculated by taking the average of all polar grid cells, which centres fall within the plot area. Because most plots are covered by more than one scan the P and VAI value resulting from the scan closest to the plot is taken as the representative value for the plot. For each plot, the P- and VAI-values are compared with the vegetation density values measured in the field. To assess the predictive quality of the models linear regression was used with the P- and VAI-values as independent variable and the observed values of vegetation density in the field as the dependent variable.

## 3 RESULTS & DISCUSSION

Figure 4 shows the results of the P and VAI calculation in the polar grid for a single scan position. The size of the circles represents the positive value of the P and VAI values. In this figure it can be seen that the values decrease with distance to the scanner. This is caused by the decreased probability of hitting a tree due to the radial emission of laser pulses. For the P value the occlusion effect enhances this. In the polar grid occlusion results in wedges where the values become zero, because all laser pulses were captured by trees close to the scanner. A smaller decrease of the VAI with distance can be seen compared to the P value. The correction for occlusion included in the VAI model can explain this effect.

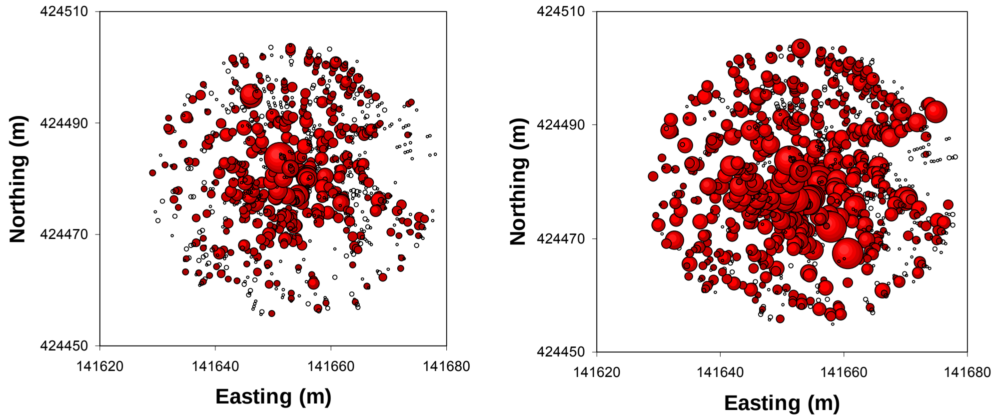


*Figure 4: The P (left) and VAI (right) values for the model values of a single scan in the polar grid. The size of the bubble is scaled to the P or VAI value in the cell*

The comparison between the reference data and the model values are presented in figure 5. Regression analysis shows that the P- values explains little variance ($R^2 = 0.13$). The VAI model explains more variance ($R^2 = 0.67$) because this model accounts for the occlusion effect. The regression equations are presented in table 2. Two complications however are not included in the calculation. Firstly, the assumption that all emitted pulses have returned does not hold in this case. About 5% of the emitted points have not returned and these points should be reconstructed. This can be done because the number of emitted points is known for each angle increment. The reconstruction is done for the P value to study the effect of this correction. The plot of the corrected P value ($R^2 = 0.72$) is presented in figure 5. The correction for missing points had a large effect on the predictive quality of the P-value. In future studies the VAI has to be corrected for missing points, which may improve the predictive quality.

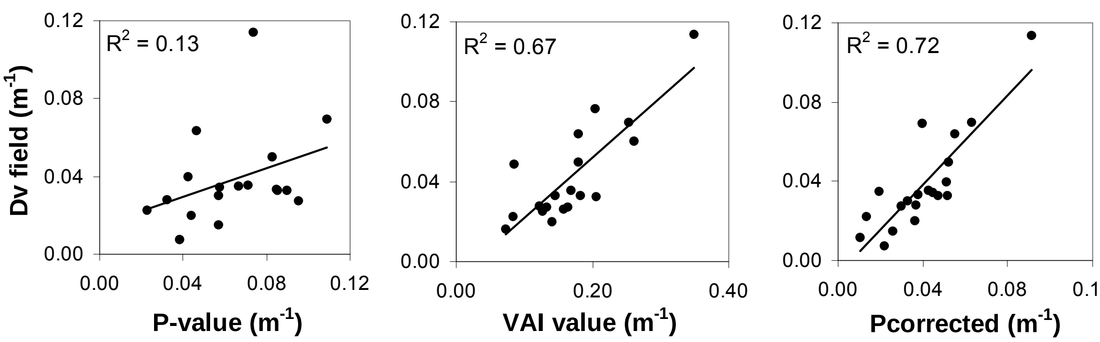


*Figure 5: Values of the vegetation density measured in the field of the plots versus 1) P-value not corrected 2) VAI-value and 3) Corrected P-value, with regression lines and explained variance.*

The second assumption that the laser pulses enter parallel into the forest is not valid. This results in an increasing deviance of the values of the predictors with larger distances to the scanner, because the pulses are emitted radially. This effect was corrected by including the distance in the regression equation. The regression results are presented in table 2. It can be seen that both predictors improve slightly when distance is included. The improvement is limited because the P and VAI values for the plots are calculated by the laser data of the scanner closest to the plot. This results in little variation of the distance for the different plots. This method for correcting for the radial emittence is not sufficient. It is expected that better correlation can be achieved when assigning a weight factor to the prediction values in the polar grid.

*Table 3: Regression analysis of different models*

| Method | Regression equation | R square | Standard Error |
|---|---|---|---|
| **P** value not corrected | Dv = 0.40*P + 0.014 | 0.17 | 0.023 |
| **VAI** not corrected | Dv = 0.31*VAI - 0.01 | 0.67 | 0.014 |
| **P** corrected | Dv = 1.13*Pcor -0.007 | 0.72 | 0.013 |
| **P** corrected distance included | Dv = 1.11*Pcor + 0.001*dist - 0.02 | 0.75 | 0.013 |
| **VAI** not corrected distance included | Dv = 0.27*VAI + 0.002*dist – 0.02 | 0.75 | 0.013 |

The presented single slice method can be further expanded to the creation of a 3-dimensional voxel space of the forest using multiple slices.

## 4 CONCLUSIONS

In this paper a method is presented to extract aggregated vegetation density parameters from terrestrial laser scanning data for application in hydraulic models. Two different models were tested to predict the vegetation density: (1) the percentage model and (2) the vegetation area index based on the extinction model of MacArthur & Horn (1969). It has been show that:

- Both models increase linearly with the vegetation density;
- Correction for missing point increases the predictive quality of the P-value
- Distance included in the regression equation improves the predictive quality of both models
- The presented method has a high degree of objectivity

For future studies a phase based scanner is more appropriate for forest scanning. It must be noted that it is essential to know the number of emitted points and the distribution of the laser points must be constant. The method will be improved by correcting the vegetation area index for missing points and applying a weight factor to correct for the distance to the scanner. Furthermore the presented method can be extended to a voxel space to create a 3 dimensional density map of a forest.

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