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# LASER SCANNING AND NOISE REDUCTION APPLIED TO 3D ROAD SURFACE ANALYSIS

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**Abstract:** Terrestrial laser scanning was applied to acquire 3D-points of a road surface. These points are used as a basis of a mathematical topological model in order to derive the catchment area of a road with respect to a pilot plant. As laser scanning requires only a few minutes for surveying the environment, this method revealed as suitable because the traffic has to be stopped only for the short scanning interval. With regard to most laser scanning projects, in this application the gravity field plays an important role. The acquired 3D-points have to be referred to gravitation because water flows in respect of differences in gravitation potential. Another important aspect concerns the noise in laser scanning data. Considering influencing variables to accuracy, such as colour of objects, angle of incidence, roughness of the surface, filtering and reducing noise in laser scanning data becomes fundamentally. Before using the laser scanner data for further investigations, post-processing regarding registration, geo-referencing and noise reduction has to be carried out. Then, the calculation of catchment areas of the road with respect to a measurement facility for road runoff can be performed using the derived topological data. Based on the calculated catchment area, the percentage of road runoff collected in the pilot plant could be addressed as 36 % while 74 % of the total runoff is dispersed diffusively. As the pollutants load may be considered as proportional to the water distribution, about 36 % of the pollutants load in the runoff would infiltrate in the vegetated road shoulder directly beneath the road thus leading to high accumulation rates and concentrations of heavy metals and organic substances in the topsoil.

## 1. Introduction

Nowadays, there are ongoing discussions in Switzerland about how to treat polluted road runoff of roads with a high traffic density. One treatment possibility is the infiltration of road runoff in vegetated road shoulders. In order to determine their loading and removal effectiveness for heavy metals such as lead, zinc, cadmium and copper and organic substances, a pilot plant was installed in a road shoulder of a road with a traffic density of more than 17'000 vehicles per day. The purpose of the pilot plant was, among others, to collect the road runoff from a road section in order to calculate the percentage of runoff

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draining directly into the vegetated swale and not being dispersed diffusely with spray. Based on this information, mass balances can be calculated in order to access the accumulation rates of pollutants in the vegetated road shoulder and to calculate the removal efficiency of the vegetated swale.

The calculation of the part of runoff which drains directly can only be carried out if the size of the catchment area is known. Then, based on the rainfall height, the theoretical maximum runoff can be calculated and compared with the measured volume in the pilot plant. As the pollutants load is related in average to the runoff volume, the distribution of the pollutants between runoff infiltrating into the vegetated road shoulder and diffuse spray dispersion can be derived.

The classical approach to estimate the size of a catchment area is to conduct large scale experiments using coloured tracers sprayed over the whole road surface area near the pilot plant. For the present situation, this is hardly possible because due to the heavy traffic density, the road cannot be blocked for hours. As another possibility, a mathematical surface model based on topological data can be used in order to calculate the catchment area. Therefore, the topological data (3D coordinates) have to be acquired by surveying.

In general, 3D coordinates can be derived using different methods, such as tachymetry, levelling, GPS, and (terrestrial) laser scanning. These four methods have to be compared regarding accuracy, point density (sampling interval) and measurement time (sampling rate). Because the road can only be blocked for several minutes, the performance becomes a crucial parameter. In a preliminary trial, the different methods were evaluated. The conclusion is that laser scanning has a significant advantage because of the high sampling rate with several thousand points per second and high sampling interval with a point density from some centimetres up to several millimetres. Further, the desired accuracy for this project of one centimetre (single point) can be met with laser scanning. Based on the gained experiences and results of this preliminary trial as well as former investigations ([1] and [2]), the road area along the pilot plant was surveyed by laser scanning using the “Imager 5003” of Zoller+Fröhlich.

Overall, the workflow from surveying to deriving catchment areas includes

- surveying the road by using terrestrial laser scanning,
- preparing laser scanning data (for registration and geo-referencing),
- filtering laser scanning data (reducing noise),
- deriving catchment areas (3D-model) and
- calculation of mass balances for road runoff.

## **2. Surveying Road Surface**

### **2.1. Measurement Setup**

The road is located near the town Burgdorf (Switzerland). For this project, only a small section of the road of approx.  $15 \times 5 \text{ m}^2$  (catchment area) is investigated.

Because of the requirement of both high point density and high point accuracy, two view points for laser scanning were chosen on both sides of the road. Care and attention is focused on reflection aspects—especially the angle of incidence and the colour of the road. With an increasing distance to the road the angle of incidence is getting smaller. An aggravating factor is the dark surface of the road (colours go from grey up to black). For avoiding insufficient

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results regarding noise and accuracy, the range for surveying the road with laser scanning is reduced to several meters (less than 10 m). Therefore, two opposite view points along the road were realized.

For registration of the two scans, additional tie points (at least three) are required (see section 3.3). Because of their properties, e.g. visibility, deriving centre points and accuracy ([1]), spheres were used. The spheres have two different diameters (approx. 12 cm and approx. 15 cm) and were calibrated before. They can be placed in tribrachs on tripods and also they can be replaced by prisms. The advantage is that the tie points can be surveyed by using total station in high accuracy. Further, they can be included in a reference frame and also they can be aligned in respect to gravity (geo-referencing).

The tie points were well distributed around the road in a way that the area to be investigated is surrounded by them. This aspect is important because in the registration process the residuals at these tie points were minimized. An extrapolation can cause errors and has to be avoided by an appropriate setup. The measurement setup as well as the road area can be seen in Figure 1.



Figure 1: Measurement setup along the road area to be investigated

### **3. Preparing Laser Scanning Data**

#### **3.1. Total Station**

All tie points were surveyed by using a total station (TCA 1800 of Leica Geosystems). The prisms as well as the total station were levelled. For all tie points 3D coordinates were calculated in a local reference frame with respect to gravity field. The 3D accuracy for each point is less than 2 mm.

#### **3.2. Laser Scanner**

The laser scanner was set up at both sides close to the road. From each view point the road and the spheres were scanned. In order to avoid point shadows on the road surface because of passing cars, the traffic on the road was stopped during scanning time. Dividing the road into three scan sections, a scanning time of two minutes in maximum could be achieved. For registration, the centre points of the spheres were calculated by least square adjustment. Thereby, the diameter of the calibrated spheres can be fixed. The resulting 3D accuracy for each centre point is at about 3 mm.

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### 3.3. Registration and Geo-Referencing

Registration is the process of transforming (scaling, translating and rotating) different sets of data into one coordinate system. If one coordinate system refers to the gravity field and/or to east-north-direction, it is called a geo-referenced system.

The two different local coordinate systems resulting from laser scanning were transformed into the system defined by total station using the tie points. The residuals are between 1 mm and 6 mm by a mean error of 3 mm. A point cloud registration (e.g. Iterative Closest Points, Random Sample Consensus) is not recommendable in this application. Firstly, because significant points (e.g. edges or corners) can hardly be found on smooth surfaces like roads—the road is only aligned regarding more or less two directions (no significant height differences can be found). And secondly, because the accuracy was not as high as required (more than one centimetre)—gained by point cloud registration using the software Cyclone of HDS Leica Geosystems in the preliminary trial.

Based on this registration process, the point clouds are aligned regarding gravity and the gradients in height can be interpreted for water flow.

## 4. Reducing Noise in Laser Scanning Data

### 4.1. General

Several parameters influence the accuracy of laser scanning. They can be categorized in instrumental errors, e.g. distance measurement system, angle measurement system, instrumental errors, and natural constraints, e.g. surface properties, angle of incidence. Some errors are systematically and some are randomly distributed.

The largest influence to accuracy is related to the distance measurement system ([2]). Especially at this project, the parameters angle of incidence and (dark) surface colour of the road influence the accuracy. Thereby, the noise is aligned along the direction of measurement.

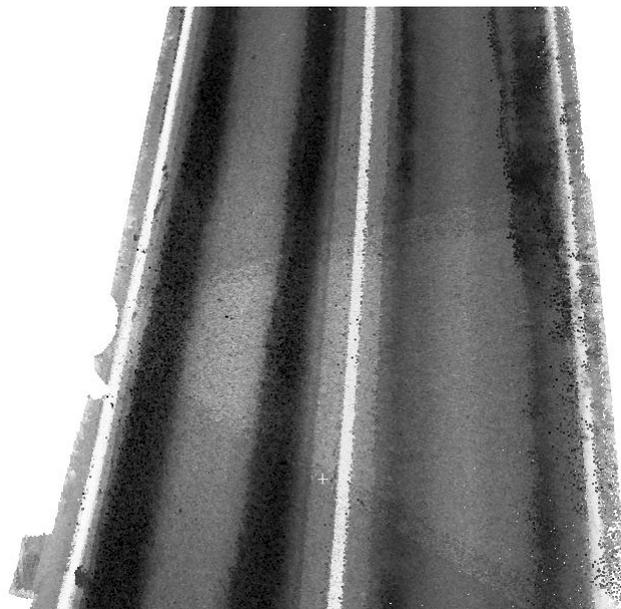


Figure 2: Intensity values of reflected laser beam caused by surface colour—the brighter the colour the higher the intensity values

One can see in Figure 2 the influence and correlation of the surface colour to the intensity values of the reflected laser beams. Along the lanes, wheel abrasion (skid mark) causes dark colour and an increasing noise (lower intensity of reflected laser beam), whereas white signposting in the middle and to the borders causes white colour and a decreasing noise (higher intensity values of reflected laser beam). The brighter the colour in Figure 2 the higher the intensity values are.

#### 4.2. Principle of Reducing Noise

As mentioned before, the noise is aligned along the measurement direction. In Figure 3, one can see the vertical section along one lane. The skid mark causes much more noise than expected.

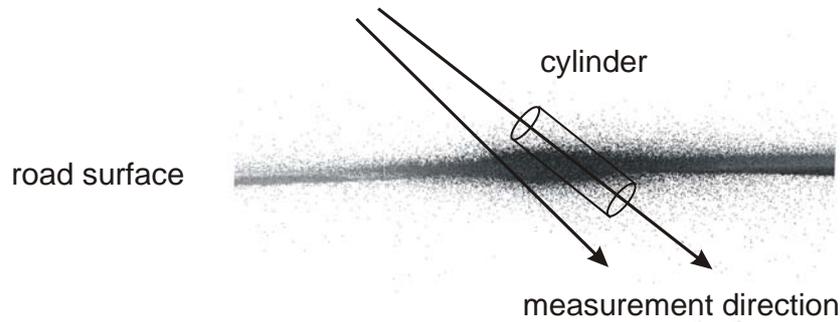


Figure 3: Measurement noise aligned along measurement direction

The noise reduction has to be made regarding a cylinder, whereas the principal axis represents the measurement direction from the centre of laser scanner to object points. The diameter of this cylinder has to be determined depending on the acquired point density and desired sampling interval in an iterative process.

The appropriate diameter is described by a horizontal and a vertical angle increment. The length of the cylinder is also limited for eliminating blunders. One point is selected and the angle differences as well as the distances between the selected point and all other points are computed:

$$\text{Horizontal direction (} h \text{): } |h_i - h| < \Delta h \quad (1a)$$

$$\text{Vertical direction (} v \text{): } |v_i - v| < \Delta v \quad (1b)$$

$$\text{Distance direction (} s \text{): } |s_i - s| < \Delta s \quad (1c)$$

$\Delta h$  and  $\Delta v$  are maximum angle intervals (e.g. 1 mgon) and  $\Delta s$  is the maximum length (e.g. 5 cm). Then, all detected points are averaged by using their polar coordinates:

$$h = \frac{1}{n} \sum h_j, \quad v = \frac{1}{n} \sum v_j, \quad s = \frac{1}{n} \sum s_j. \quad (2a), (2b), (2c)$$

$n$  is the number of points to be averaged and index  $j$  describes the points meeting the criteria (1a), (1b) and (1c). Besides polar coordinates, also the intensity values were averaged corresponding to formulae (2a), (2b) and (2c). The polar coordinates for noise reduction have to be used because of the alignment of noise along the measurement direction (laser beam

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direction). Cartesian coordinates are not appropriate in this present case because the orientation of noise and the change in orientation of the noise would not be considered.

The quality of the results depends on the criteria (1a) and (1b). The smaller the angle differences  $dh$  and  $dv$  the smaller is the diameter of the cylinder. But the diameter must not fall below the sampling interval used for scanning. In the present application, an appropriate interval is 5 mgon for  $dh$  and  $dv$ . Thereby, the interval correlates to the measured sampling interval (point density). The primary affect of reducing noise follows a secondary affect in reducing the point number and point density.

### 4.3. Results

The result of noise reduction is a reduced and smoothed point cloud. An example is shown in Figure 4 as cross section of the road surface. It represents the vertical section of one lane including skid marks. One can see the smoothed road surface (b) in comparison to the original point cloud (a). The noise caused by wheel abrasion and the corresponding results are clearly visible.

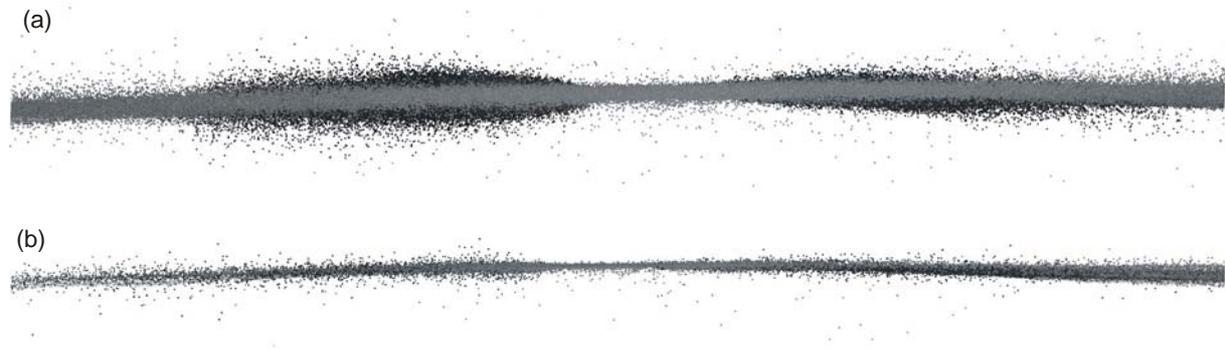


Figure 4: Noise caused by wheel abrasion (a) and results of noise reduction (b) of one lane–cross section of the road.

## 5. Deriving Catchment Areas and Mass Balances

### 5.1. Overview

Generally, in order to calculate mass balances for heavy metals in the vegetated road shoulder as a function of the road distance, one has to know the part of the heavy metal load which is in the road runoff to be drained directly and infiltrated into the vegetated road shoulder and the part of runoff which is distributed diffusively with spray. The total heavy metal load in road runoff can be calculated by multiplication of average heavy metal concentration times the total runoff volume. The total runoff volume is calculated by multiplication of rainfall height with the catchment area, minus 20% of losses caused by wetting effects and evaporation ([3]). In summary, the catchment area, the runoff volume and the rainfall height must be measured or calculated.

In the pilot plant, the road runoff was collected in a storage tank using a 0.5 m long gutter located directly beneath the road and the volume was measured periodically (Figure 5, left). The rainfall height was measured at a distance to the road of 6 m. First calculations yielding a catchment area of 1.5 m<sup>2</sup>, (0.5 m times 3 m road width) revealed not to be meaningful because there was too much water collected in the sampling tank relative to the road surface of 1.5 m<sup>2</sup>. Obviously, the catchment area must be much larger than assumed.

This would be the case if (a) the road would have a slight slope in longitudinal direction or (b) other effects, such as preferential flow would occur. In order to assess the latter, simple tracer experiments were conducted. They revealed that a significant water flow exists from beside the road into inlet gutter of the water storage tank. The total length of this section is 2.5 to 3.5 m in total and the watershed can be located within a range of 1 m (Figure 5, right side). Although this tracer experiment could answer the question that there is indeed some preferential flow, the question of the size of the catchment area is still unsolved.

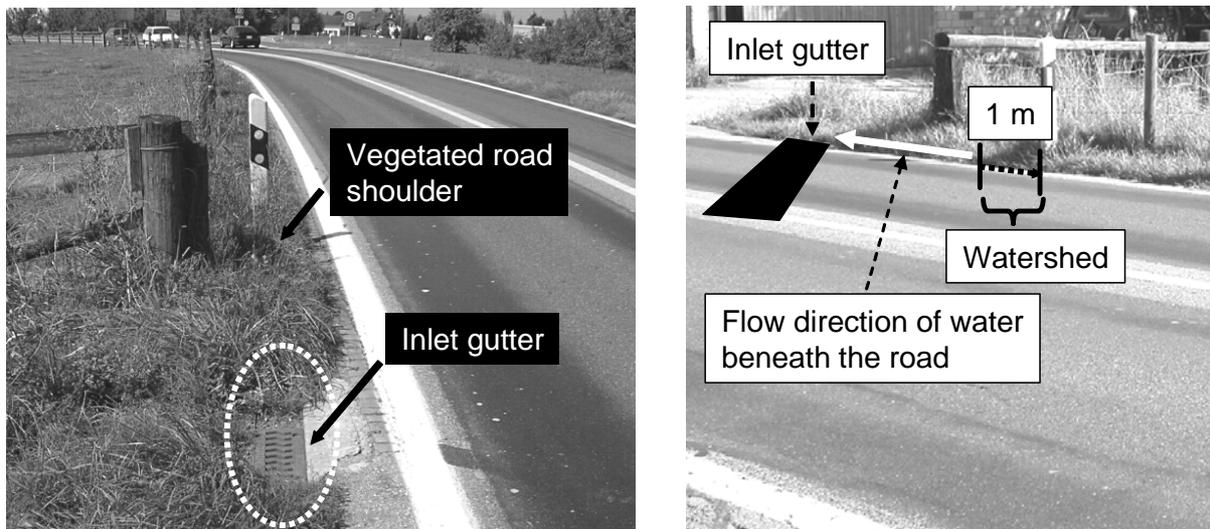


Figure 5: Inlet gutter and the vegetated road shoulder (left), watershed and initially assumed catchment area (right). Flow direction due to preferential flow beneath the road is indicated.

## 5.2. Calculation of the catchment area

The catchment area was calculated using ArcView 3.3 by ESRI, upgraded with the Spatial Analyst and the CRWR-PrePro-Modul. As input for the calculation, noise-reduced data as described in section 4 were imported. Based on the laser scanning data a grid is derived with a sampling interval of 8 cm. After creating this surface model, the CRWR-PrePro-Modul was used both to calculate the streams leaving the road (Figure 6) and to derive the different catchment areas for the inlet gutter (Figure 7). These calculations show that water flow is almost perpendicular to the road direction, as it can be derived from Figure 4b. In addition, sensitivity analysis results showed that the point density for deriving the grid is sufficient and that an increased resolution does not affect the size of the different catchment areas significantly.

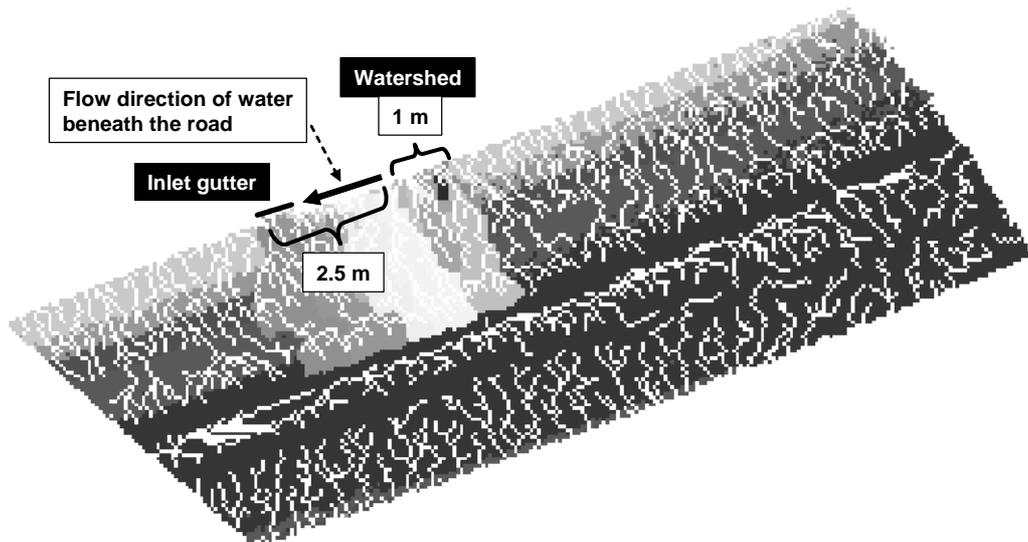


Figure 6: Calculated streams based on the topological model. Flow direction due to preferential flow beneath the road is indicated.

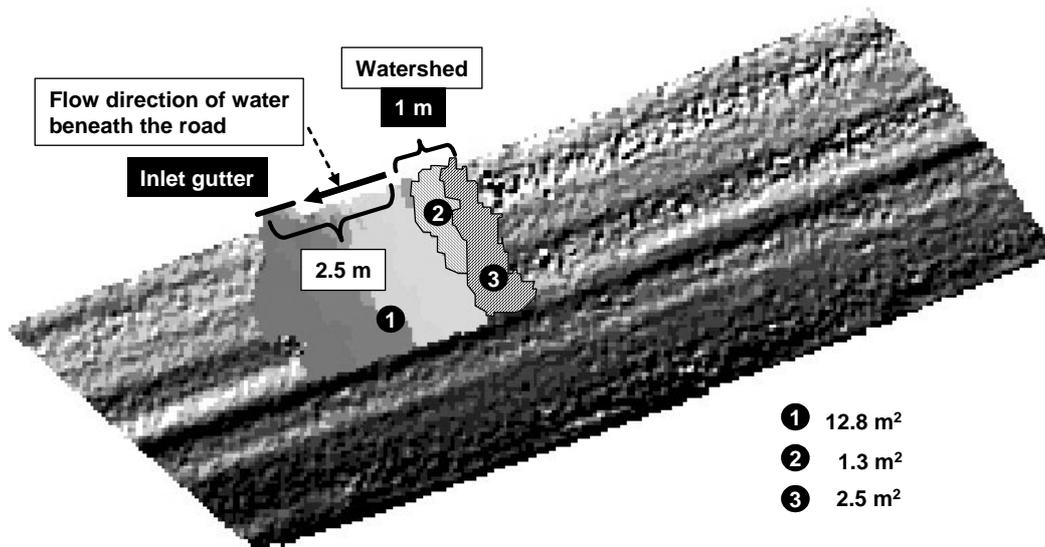


Figure 7: Calculated catchment area for the inlet gutter. Flow direction due to preferential flow beneath the road is indicated.

### 5.3. Results

As measured by the tracer experiments, the assumed location of the watershed lies within a range of about 1 m. Based on the coloured tracer experiment it was not possible to estimate the watershed more accurate. For this reason, it was assumed that the watershed is located in the middle of the range at 0.5 m. Consequently, the two different catchment areas, number 1 and 2, can be summarised leading to a size of the catchment area of 14.1 m<sup>2</sup>, as shown in Figure 5 on the right hand side.

Based on the catchment area of 14.1 m<sup>2</sup>, the maximal runoff could be calculated and be compared with the collected road runoff. As result, 36 % of the maximal runoff drains directly into the storage tank and therefore would infiltrate into the vegetated road shoulder. The other 74 % of the road runoff are dispersed mostly diffuse within a distance of the road of

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25 m ([4]). As the heavy metal load can be assumed to be nearly proportional to the water flow, about 36 % of the pollutants load in road runoff infiltrate in the vegetated road shoulder directly beneath the road. During infiltration, many pollutants such as heavy metals and organic substances are accumulated. Thus, accumulation results in high concentration of pollutants in the topsoil of the vegetated road shoulder.

Considering other treatment possibilities such as centralised on-site options, 36 % of pollutants load in road runoff could be collected with a gutter beneath the road. However, further calculations showed that if an additional impermeable surface such as a sidewalk or an emergency lane would exist beside the road, the percentage of collectable road runoff could be increased significantly ([4]).

## **6. Conclusions**

Terrestrial laser scanning revealed as best method for acquiring 3D coordinates for small surface areas of max. 50 m<sup>2</sup>. Compared to tachymetry and levelling the sampling rate, the accuracy and the sampling density are superior. The accuracy of the data is strongly dependent on the angle of incidence, the structure and colour of the surface. Noisy data result in extensive post-processing including special filtering and noise reduction techniques.

In this project, a surface model of a road segment was derived (ArcView combined with the Spatial Analyst) using 3D data acquired by terrestrial laser scanning. The surface model was applied subsequently to derive the catchment area of a pilot plant collecting road runoff. For this purpose, the CRWR-PrePro Module was used in ArcView. Based on the calculated catchment area, the rainfall data and the measured road runoff volume, the percentage of road runoff which drains directly into the vegetated road shoulder could be calculated as 36 %, while 74 % of road runoff is dispersed diffusively. As the pollutants load may be considered to be proportional to the water distribution, about 36 % of the pollutants load in the runoff would infiltrate in the vegetated road shoulder immediate beneath the road. Thus, infiltration leads to high accumulation rates and high concentrations of heavy metals and organic substances in the topsoil.

This new method for the calculation of small scale catchment areas can be assessed as successful. However, it is recommended to control the results at critical parts of the surface drain e.g. inlet with small scale tracer experiments which only require a few minutes.

## **References:**

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