# USING HYPERSPECTRAL CAMERAS ON UAVS FOR SPATIAL MAPPING OF VEGETATED WATER-WAYS FOR INTEGRATED WATER MANAGEMENT STRATEGIES

W. ELLIS PENNING

*Inland Water Systems, Deltares, Boussinesqweg 1*

*Delft, 2629MH, The Netherlands*

RIK NOORLANDT-AUSTEN

*Soil and Groundwater Systems, Deltares, Boussinesqweg 1*

*Delft, 2629MH, The Netherland*

GÉ VAN DEN EERTWEGH

*KnowH2O, Watertorenweg 12*

*Berg en Dal, 6571 CB, The Netherlands*

KOEN BERENDS

*Inland Water Systems, Deltares, Boussinesqweg 1*

*Delft, 2629MH, The Netherland*

CHANJOO LEE

*HERI, Korean Institute of Civil Engineering and Building Technology, Goyangdaero 283*

*Goyang, 10223, The Republic of Korea*

ROB FRAAIJE

*Waterschap Aa en Maas, Pettelaarpark 70*

*'s-Hertogenbosch, 5216 PP, The Netherlands*

Spatially explicit information on the presence of vegetation in and along water ways was mapped using three different camera types: a standard RGB-SLR camera, a full spectrum camera (125 bands) and a multi-spectral camera (5 bands) operated on an Unmanned Aerial Vehicle (UAV/drone). When stitched, images from these cameras provide information on the amount and location of vegetation along the waterways. This information can be used to define when and where vegetation management through mowing might be necessary in order to provide sufficient conveyance capacity. At the same time the images can provide information about locations with ecologically valuable vegetation. This can help selecting an efficient and ecologically friendly mowing method. We compared the performance of three cameras for use in daily management. Tests were carried out on the performance capacity of the full spectrum camera in different water depths, and with various degrees of turbidity. The obtained images from these cameras were analyzed using various indices for vegetation and compared with ground measurements on vegetation biomass and types.

## 1    INTRODCUTION

Seasonal development of vegetation in streams and rivers can introduce enlarged flow obstruction, and increased flood risk upstream of dense vegetation patches. At the same time vegetation is a natural aspect of aquatic ecosystems and valued for its ecological services and provision of habitat for other organisms [1, 2]. Therefore, aquatic vegetation is an explicit part of the EU-Water Framework Directive (EU-WFD, [3]), aiming to meet the water quality targets by 2015, 2021, and 2027.

When vegetation obstructs flow it must be removed by mowing, cutting down trees, etc. To determine the threshold of acceptable levels of biomass in streams water managers make use of relationships between discharge and water levels. When water levels upstream increase beyond set thresholds the overall roughness in the channel has increased too much and mowing must be carried out. Ideally, field assessments are carried out to identify where and how much vegetation must be removed. However, in practice predefined plans combined with expert judgement are used, because objective quantitative vegetation mapping methods are currently lacking.

The use of multispectral images has taken a large flight with the coming of satellite images, providing information beyond the visible-light bandwidth [4]. Many advances in optical image analyses with multispectral bands have started and led to the development of indices to help quantify parameters as vegetation density,

classes, etc. Although satellite image availability and quality are improving, their resolution is often too coarse for narrow channels which are vulnerable to overgrowing with aquatic vegetation. Innovations in monitoring techniques, such as the availability of drones (UAVs – unmanned aerial vehicles) and optical cameras that sample a larger optical bandwidth in high resolution provide new opportunities to access high resolution information. A spatial coverage of waterways from airborne drones makes it possible to identify local obstructions that might be missed by visual observation from the shorelines.

The overall aim of our research is to provide water managers with spatially explicit information on the presence and extent of vegetation cover within a waterway, using new camera technologies to identify and quantify this vegetation. In this paper, we present results of performance test with RGB, multi- and full-spectrum cameras mounted on a UAV to identify and quantify vegetation cover.


## 2    METHODS

### 2.1    Study sites

Two study sites were used in the assessment of the camera performance:

1. The fully controlled outdoor flume facility of the Korean Institute of Civil Engineering and Building Technology - 'River Experiment Centre' (KICT-REC) located in Andong, Republic of Korea, where a controlled unscaled set-up of a straight stream with vegetation was available for testing the camera under specific flow and water quality settings (for details of the experimental set-up see [5]).

2. A field study site in the south-east of the Netherlands, where a channelized and weir-controlled stream 'Lage Raam' forms a 500 m long straight channel of 20 m width and average water depth of 1 m. This channel is dominated by submerged growth of *Callitriche platycarpa* over the full width of the channel, with patches of mixed emergent vegetation (dominated by *Glyceria maxima* and *Sparganium erectum*) along the sides. The discharge and water levels at the upstream and downstream weir are continuously monitored and mowing is carried out on a regular basis from a crane that can drive along one side of the bank.

### 2.2    Equipment and measurement set-up

At the REC a full spectrum camera (UHD 185 - 'Firefly'; Figure 3.1) from the firm Cubert was tested in September 2016. This camera takes both a high resolution (1000*1000 pixels) black and white image and 138 low resolution (50*50) spectral images from 450 nm to 998 nm in steps of 4 nm bandwidth. These two types of data can be overlaid to obtain more detailed information.

This camera was tested for:
- The effect of varying water depth on resulting images. Water depth was stepwise adjusted from empty bed to bank full 0-0.6m depth with intervals of approx. 2 cm, with the camera positioned on a fixed point above the channel.
- The ability of the camera to deal with turbidity: images were obtained while changing the turbidity of the water by manually adding a sand-silt mixture to the flow. The camera was positioned on a fixed point. Suspended sediment samples were collected and PAR measurements using a LiCOR underwater light meter were recorded to link the images to related turbidity equivalents.
- The ability to distinguish between densities and types of vegetation for a longer stretch of channel with the camera fixed on a UAV: One vegetation type consisting of young willows, with two densities, covering a set of patches in the channel. At the same time, naturally growing vegetation along the banksides and on the bed of the channel was also photographed.

At the 'Lage Raam' field site, the full 500m stretch was covered to compare the performance of the full spectrum camera with the 5bands hyperspectral camera RedEdge-M of MicaSense and a standard RGB-SLR camera while mounted on a UAV, in October 2017. Additional measurements on flow patterns, water level change over the full stretch, vegetation biomass and bathymetry were concurrently carried out to link the images to discharge information and ecological interpretation of the data.

### 2.3    Data processing

The processing of the spectral images consisted of three main steps. First, the images taken were normalized for camera sensitivity and the incoming light spectrum. Second, because one image is typically not enough to cover the area of interest with enough resolution, multiple overlapping images were be stitched together to form one

high resolution image that covers the whole area of interest. The REC data was stitched using Autopano. The Lage Raam data was stitched using Pix4D. Third, the reflectance values were used to determine indices or clusters enabling the separation of the vegetation and other objects photographed.

After normalizing the raw spectrum data, NDVI and other clustering algorithms can be applied. Various types of indices can be used to assess the type and amount of vegetation present in the image. These indices result in a series of different images. Different types of vegetation indices listed in literature were reviewed. Among them, the indices that were best related to the measured biomass values were selected for our research based on the list provided in Mitchell et al [6].

## 3    RESULTS

### 3.1    Testing at the River Experiment Center - 2016

#### 3.1.1 *Full spectrum camera performance under varying water depths and turbidity changes from a fixed point*

Figure 1 visually shows the effects of water depth on a black and white image at dry bed compared with a water depth of 25 and 50 cm. With increasing water depth the reflectance decreases significantly (as can be seen by the (dark) blue colors in the graph) The steel plate is included as a reference. Larger wavelengths (above approximately 700 nm) get reduced quicker with increasing water depth than the lower wavelengths. A pixel selected from the area of the steel plate (Top of Figure 2) can be thought as a reference area to compare changes in a vegetation pixel at the side-slope of the channel (indicated in figure 1 as vegetation D - bottom of Figure 2). It shows that this reduction is similar for both pixels. This implies that the signal of submerged vegetation from deeper sections must be corrected for this depth depended effect.
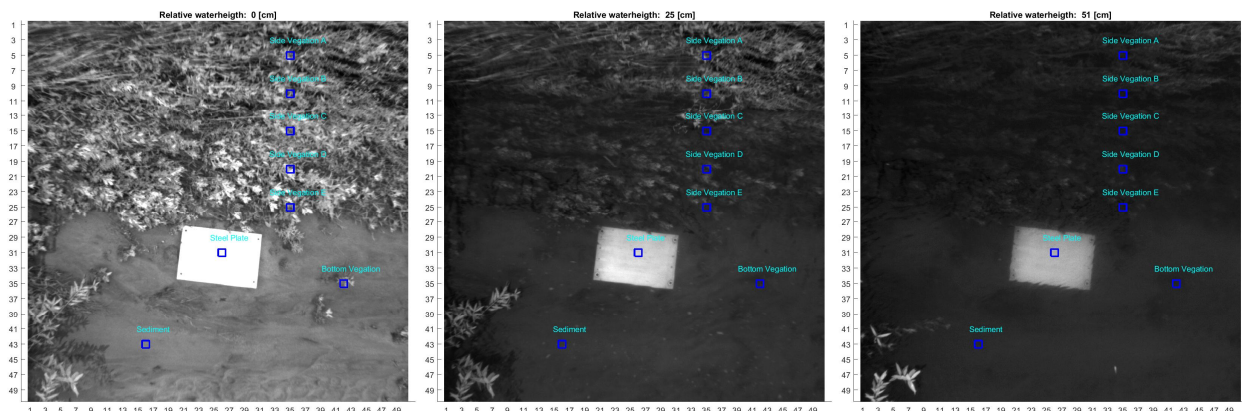


*Figure 1. Effect of water depth on a black and white image at 0 cm, 25 cm and 51 cm of water depth, with indications of the pixels used for further analyses.*
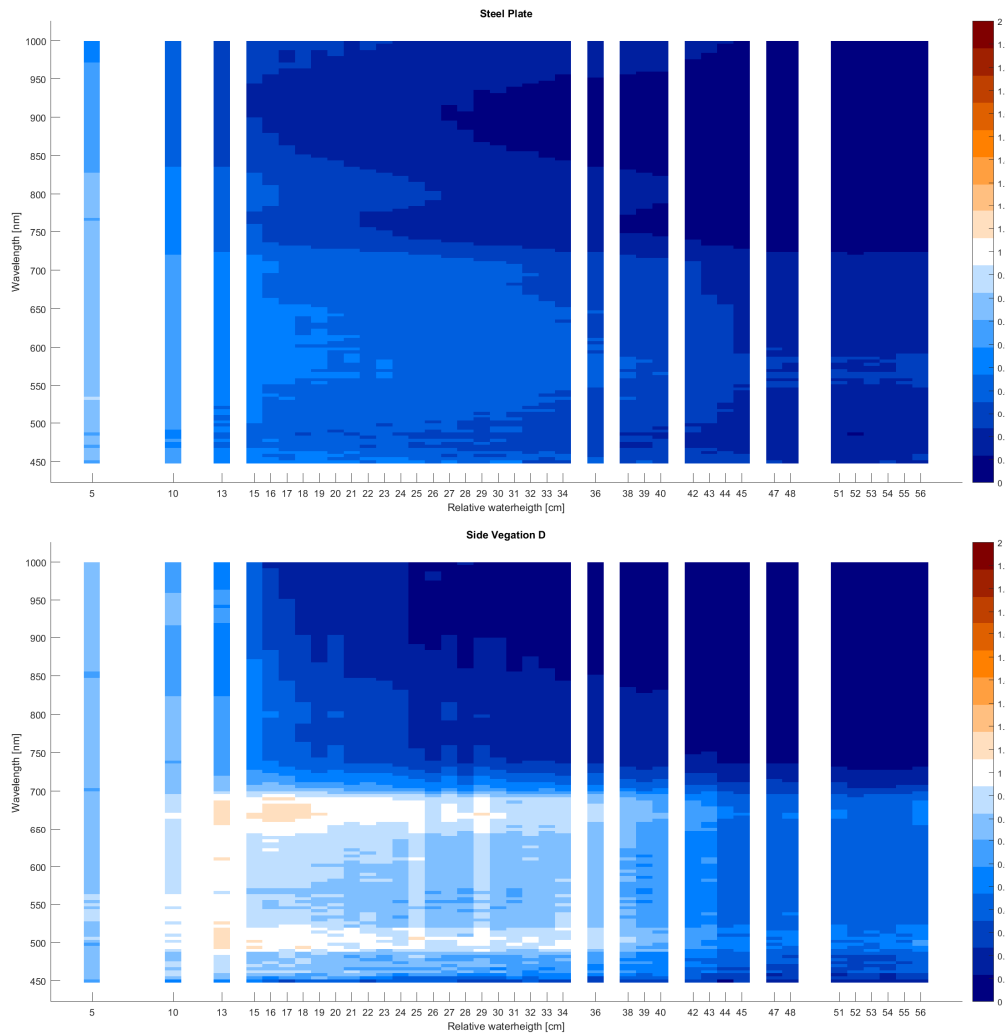
Figure 2. *Effect of water depth on an the observed spectrum of a steel plate (top) and vegetation d (bottom) pixels as indicated in Figure 1 above. Blue (red) colors indicate a decrease (increase) in reflectance compared to the case without water.*

The effects of turbidity are also to be taken into account when measuring with the full spectrum camera. Figure 3 shows the impact of a turbidity cloud passing over the test area in time. Inorganic turbidity especially reflects in the higher wave length bands above 700nm. Through the two conditions were applied in this test, the results suggest environmental conditions such as those of light and water depth have an influence of performance and analysis of a full spectrum camera.
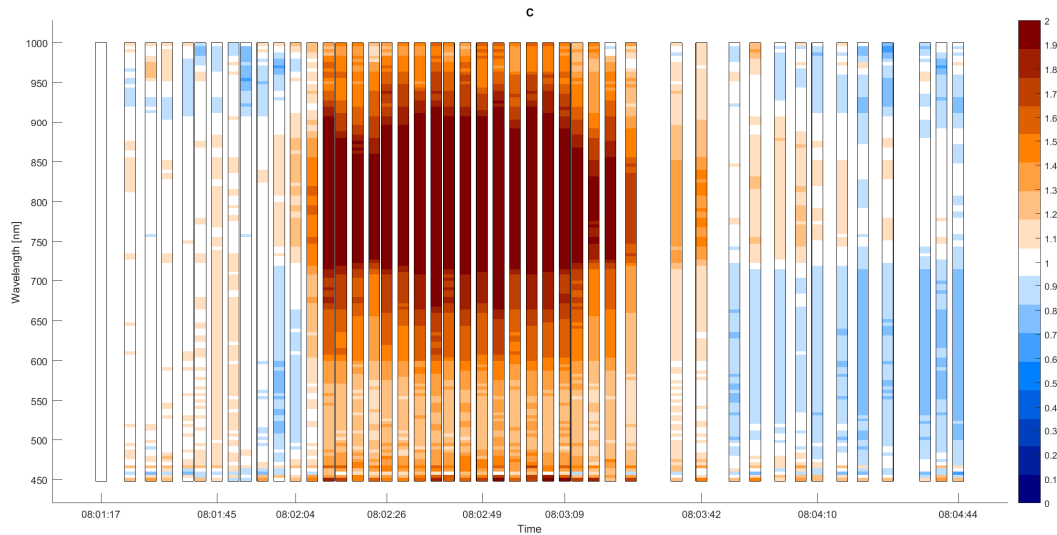
Figure 3. Changes in reflectance spectrum with a passing cloud of suspended material over time. The reflectance changes especially in the red and infrared spectrum.

### 3.1.2 Full spectrum camera performance from a UAV

Drone based images taken at the REC were easily and quickly stitched (within a few hours) using an automated stitching procedure using panorama software (Figure 4). Because this program is not georeferencing the images, the channel is not straight after stitching. The pronounced differences/contrast of the drone images helped for easy stitching. The NDVI index calculation of these images clearly shows the green vegetation in the channel. However, there are still issues with this index. For example, the wooden bridge (red painted, left side of the image) also shows up having a medium NDVI value, while it is not vegetated. Therefore we also compared additional indices based on Mitchell *et al.* [6] in figure 5, which shows that more information can be derived from the full spectrum images depending on the chosen index. For example the PSRI index does pick up the bridge and the bare sand patches in a more accurate way. Combining these indices to a full classification will be the next step to get towards a good interpretation of the data.
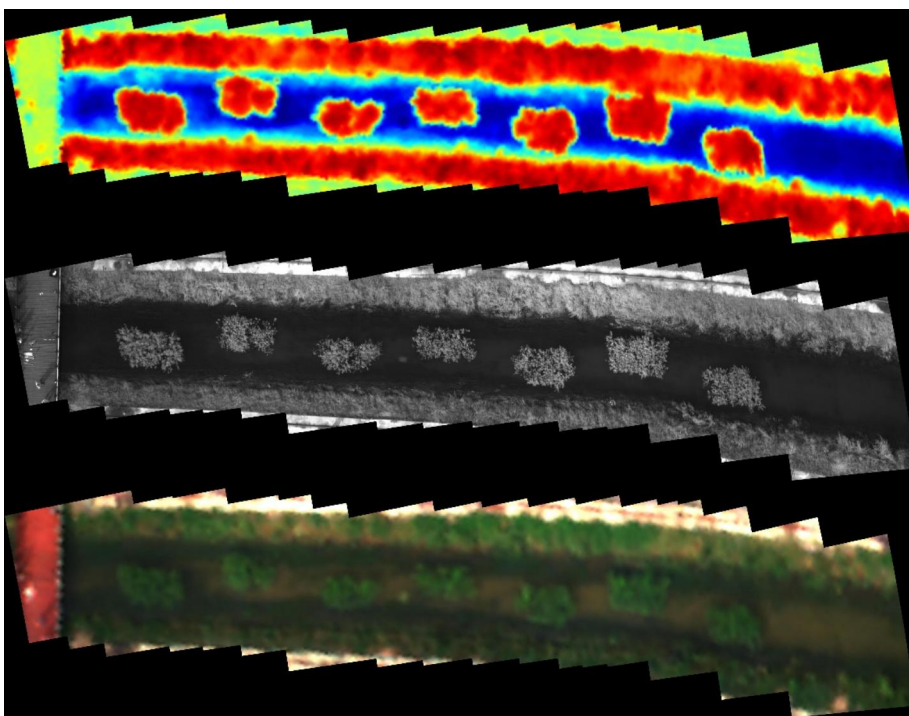


Figure 4. The general results for the full spectrum camera shown for NDVI, Black and White and RGB colouring.
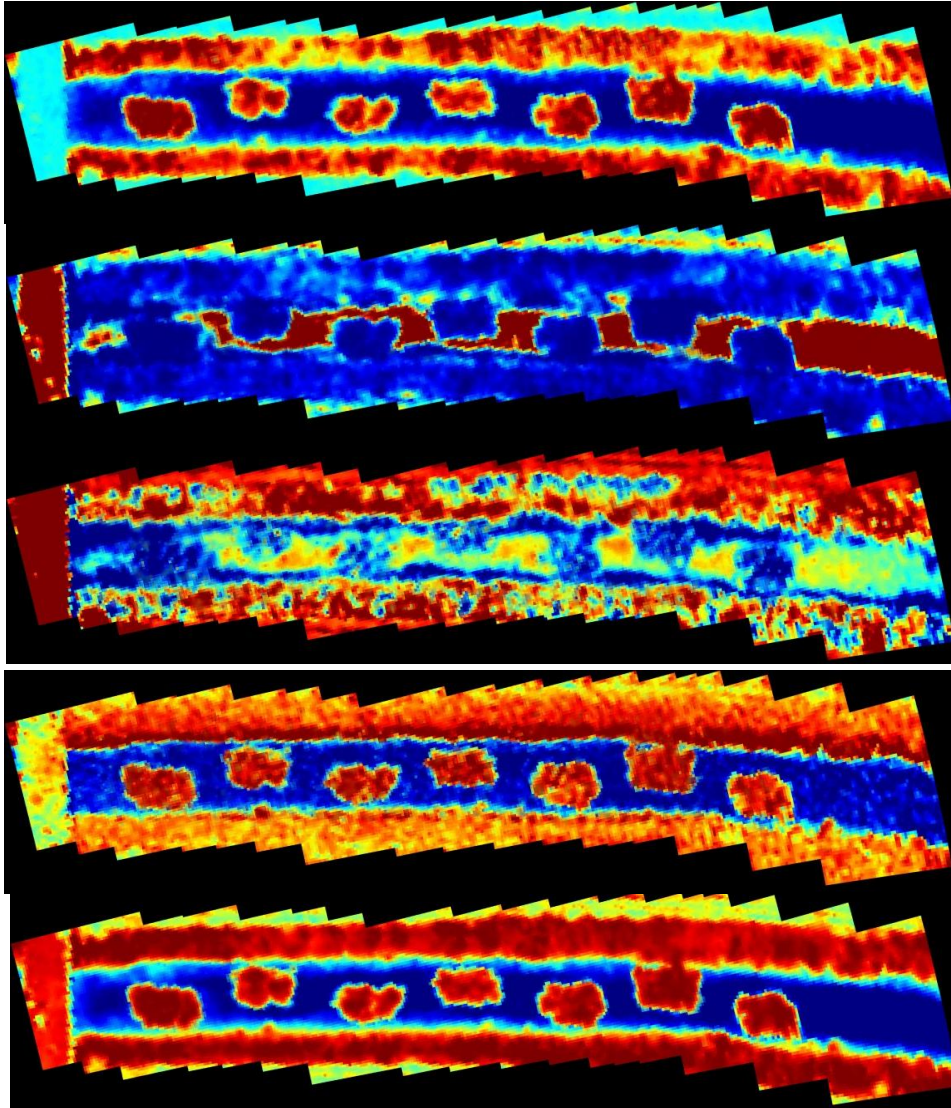
Figure 5. Indices tested for the stitched images of the full spectrum camera from top to bottom: VOG1, PSRI, ARI1, WBI, GNDVI (based on [6]).

## 3.2 Testing in the field site 'Lage Raam'

### 3.2.1 Full spectrum camera from a UAV

During the testing of the Full Spectrum camera under the UAV at the Lage Raam test location, picture taking settings were set too slow with respect to the flight speed of the UAV. As a result there was no overlap between photos to enable processing the data into a stitched image. In order to obtain sufficient images for stitching the UAV would have to fly substantially slower than its default setting. Resolution of individual images was sufficiently good for processing in a similar way as was done with the images from the REC in 2016, but the technique is proving unsuitable for standard 'quick' processing in a more standardized way.

For a single image of this camera (Figure 6) the the reflectance spectra of selected pixels was plotted and overlaid with the bands of the MicaSense 5band camera. These show the strong reflectance in NIR of shoreline vegetation (blue), the intermediate reflectance in NIR of aquatic vegetation at different depths (green, purple and red) and the open water (yellow) and also indicates the areas where information of the vegetation is missed by the MicaSense camera. For instance the submersed vegetation indicated in the red pixel has a pronounced increase and decrease in reflectance around 750nm, which the MicaSense would not pickup, potentially making classification of this submersed vegetation less accurate.
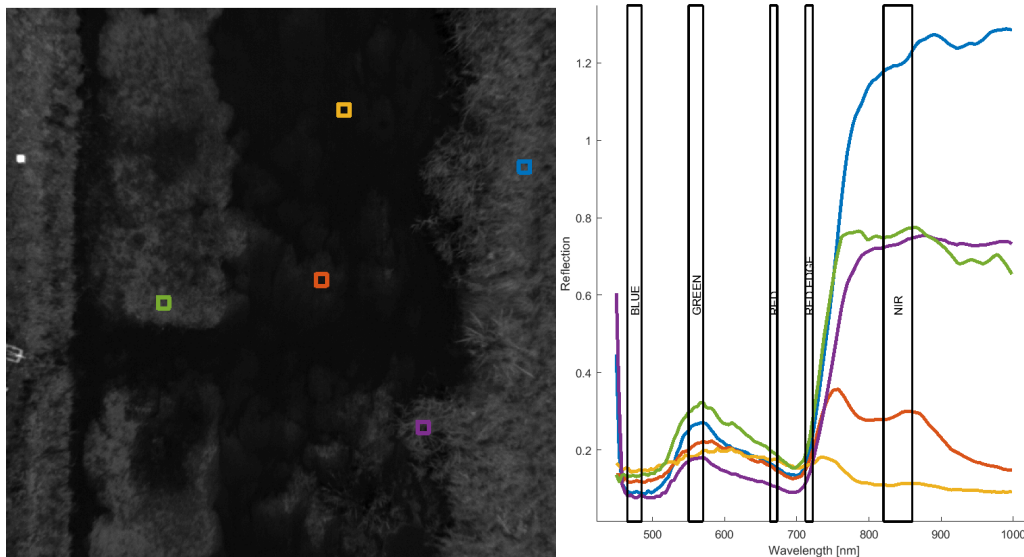
Figure 6. Full spectrum image of a small stretch of the stream in black and white (left hand pane) and the reflectance spectra of selected pixels (right hand pane).

### 3.2.2 Multispectral camera performance from a UAV

The MicaSense images are georeferenced and therefore easily stitched and processed. The limited amount of bands make the available indices less detailed, clustering based on the 5 bands available is possible.

This gives sufficient indication of the proportion of the waterway covered with vegetation along the reach (figure 7). The classification clearly shows the difference of shoreline vegetation from instream vegetation covering the full water column, submerged vegetation and water. The round 'dots' at the bottom of each image are tree canopies along the stream.
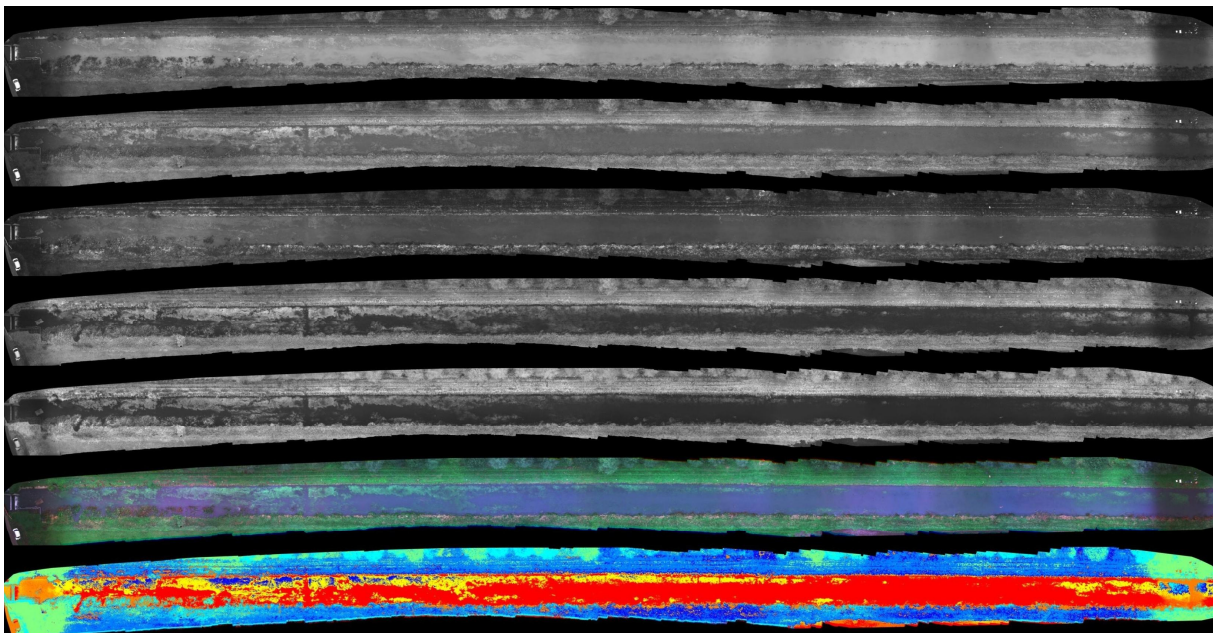


Figure 7. Images of different bands of the MicaSense camera. From top to bottom: Blue, Green, Red, Red Edge, NIR, the combined RGB channel information and a classification of the data in 7 clusters with similar spectra,

### 3.2.3 RGB camera results from a UAV

Although RGB cameras were useful to provide a high resolution overview of the test site, the information in terms of green-indices is obviously of little analytical values, due to the lack of NIR and Red Edge Bands. As a result we were not able to classify these images in a similar way as we did with the MicaSense.

# 4 DISCUSSION AND CONCLUSION

## 4.1 Comparing the performance and usability of the tested camera's under UAV set-up

The three cameras tested here were all able to be mounted on a UAV and operated to take images. While the full spectrum camera was able to take images in the UAV setup, the speed at which these images are taken is slow (less than 1 per second) and together with its lower resolution it is impairing the flight speed of the UAV. Also, the lack of automated georeferencing of the images means that the applicability of this camera for daily operation is still relatively difficult. However, the information obtained with the full spectrum imaging camera allows for more and deeper analysis, making the technique promising for vegetation classification studies that give e.g. a cover of dominant vegetation types.

The MicaSense multispectral camera is a more developed product for use with UAV applications and the images it creates are more easily processed into georeferenced photos, making the applicability of this instrument for daily practice more suitable. The stitching and analysis is relatively easy, but information is only limited to the 5 bands available, with less possibilities to classify these images for vegetation types, which limits the use of the camera for ecological interpretation.

The RGB camera gives images of high spatial resolution, but further analysis of the images is very limited. It can be concluded that this camera would only serve as visual check of the current state of a channel. It is therefore limited if quantified information on the vegetation density, cover or types is a required output of the image analysis. As RGB camera images have a high resolution, that the full spectrum and multispectral cameras cannot provide, the RGB images can be used for edging and image combination to delineate more accurately the boundary of vegetation from the surrounding water body.

## 4.2 Data analysis

Data analysis consists of two parts, first the individual images of small parts of the waterways need to be stitched together to form an image of the whole waterway, second the pixels containing vegetation in the image need to be determined. Stitching of vegetated waterways proved more difficult than expected because the images do not contain many clear and fixed reference points. Moving vegetation and flowing water cannot be fully accounted for. Furthermore, because the camera is moving along the waterway at relative low altitudes to get the best resolution significant parallax effects occur.

The detection of vegetation was done in a number two different ways. Different indices were determined using the spectra available (Figure 4 and 5). The indices mainly differ in the choice of bandwidths they compare. As is clear from Figure 5 the different indices highlight different parts of the image. The other approach is to use all bandwidths at once and cluster similar bandwidths together, as result of this approach is shown in Figure 7. The advantage of indices is that they are more comparable to information available from satellite observation, while the advantage of clustering is that all information available is used to quantify patches of similar origin.

## 4.3 Future use in vegetation management

The use of full spectrum and multispectral images can be an objective source of spatial information on instream vegetation. Water managers that maintain their waterways by means of physical removal of vegetation may benefit from knowing the location of flow obstructing vegetation, in order to enhance flood flow conveyance but also reduce the impact of this mowing on the ecosystem functions these macrophytes provide [7]. A first step is to quantify the amount of blockage by vegetation. In the absence of detailed information on vegetation, blockage can be used as a proxy to estimate hydraulic resistance [8].

In figure 8 two images show the before- and after mowing of the test channel in the Lage Raam and the resulting calculated vegetation cover along the stretch. It is shown that the cover at the start of the transect is large and that mowing at that part of the stretch would be most beneficial. More downstream the cover is less pronounced from which we can conclude that mowing at that section would not be needed or could carried out at a later time in the year. Furthermore, by linking this information to hydraulic models a quantified (empirical) relationship of vegetation cover can be integrated to stage-discharge relationships, which is the next step within this research.
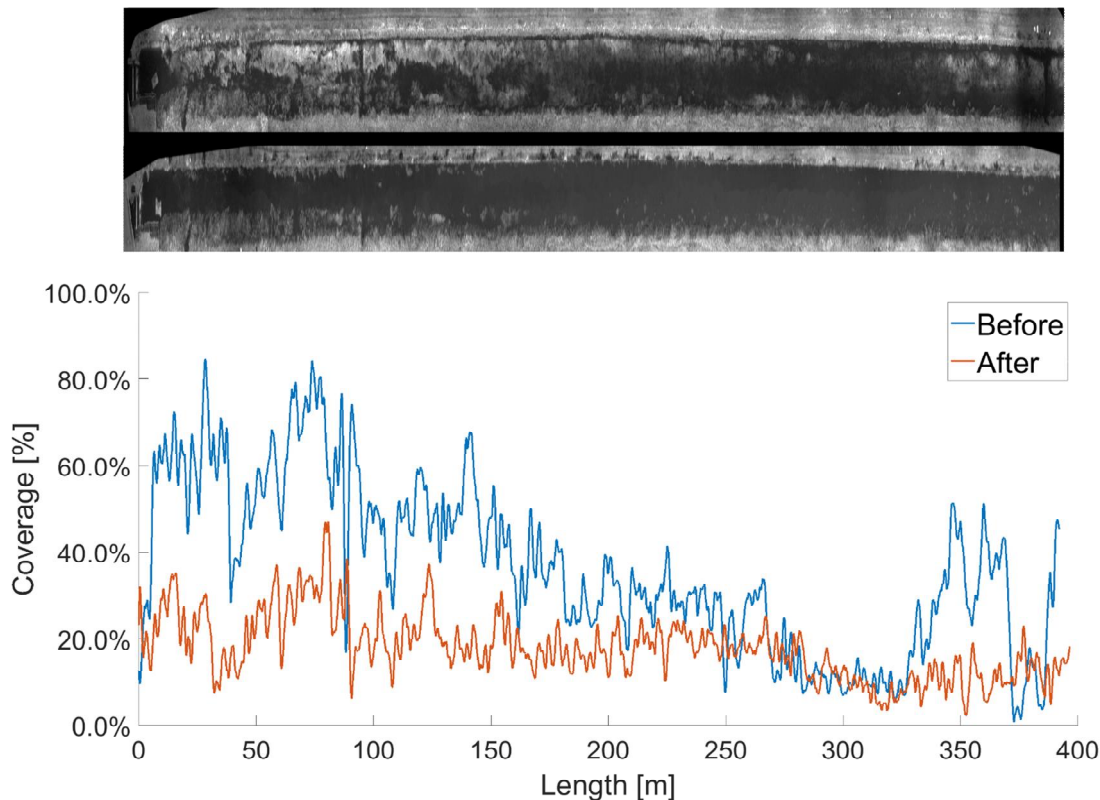
Figure 8. UAV-based NIR images from the Mica Sense stitched for the 400m stretch of the Lage Raam before (top) and after (bottom) mowing and the % cover with vegetation derived from these images over the stretch before and after mowing.

## 5    ACKNOWLEDGEMENTS

## REFERENCES

[1]  Scheffer, M., "*Ecology of shallow lakes*", Kluwer Academic Publishers, Dordrecht (2001).

[2]  Moss, B., "*Ecology of Fresh Waters. Man and Medium, Past to Future*", Third Edition, Blackwell Science. (1998).

[3]  European Union, "*Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Communities in the field of water policy*", Official Journal of the European Communities, L 327/1, 22.12.2000. (2000).

[4]  Adam, E., Mutanga, O. and Rugege, D., "Multispectral and hyperspectral remote sensing: for identification and mapping of wetland vegetation: a review", *Wetlands Ecol Manage,* Vol. 18, (2010), pp 281-296.

[5]  Ji U, Kang, J., Ryu, Y., Jung, S. H., Penning, W.E., Harezlak, V., Berends  K.D., and Jang, C. "Stream-scale Experiments on Vegetated Flows: Flow Measurement and Analysis". *E-proceedings of the IAHR River Flow Conference*, July 2016 St. Louis USA.

[6]  Mitchell, J.J., Shrestha, R., Spaete L. P. and Glenn, N.F. "Combining airborne spectral and LiDAR data across local sites for upscaling shrubland structural information: Lessons for HyspIRI." *Remote Sensing of Environment*, Vol. 167 (2015), pp.98-110.

[7]  Old, G. H., Naden, P. S., Rameshwaran, P., Acreman, M. C., Baker, S., Edwards,… F. K.,Neal, M., "Instream and riparian implications of weed cutting in a chalk river", *Ecological Engineering*, Vol. 71, (2014),  pp 290–300.

[8]  Green, J.C., "Modelling flow resistance in vegetated streams: review and development of new theory". *Hydrological Processes*, Vol. 19, (2005), pp 1245-1259.