# SW – Project
# Task 4.3

# Use of LIDAR to characterise river morphology


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## Contents



## Figures



## Tables

## 1. Introduction

One of the primary drivers of riverine biological communities is the morphology and topography of the river channel as it controls the hydraulic conditions for a given discharge (eg depth and velocity distributions) ie the physical habitat available to aquatic organisms. A number of survey techniques can be used to assess the physical structure of a channel, eg River Habitat Survey (RHS), Rapid Habitat Mapping, which require significant resources (in particular in terms of field work). The objective of this study is to explore the potential of remote sensing data to derive some aspects of river physical structure, in particular bed topography, providing a cost-efficient alternative to field surveys.

In addition, the study aims at identifying significant difference between the study sites, located on the River Wolf, which could be attributed to the presence of the Roadford reservoir dam (see Edwards et al, 2014).

The original plan was to compare three different sources of remote-sensed data with increasing resolution for three River Habitat Survey (RHS) sites (ie 500-m stretches):

- Aerial photography (Next Perspectives; visible spectrum; lowest resolution)
- LIDAR data (British Antarctic Survey (BAS)/Environment Agency (EA); more detailed)
- Unmanned Airborne Vehicle (UAV) operated by CEH (visible spectrum, highest resolution)

Unfortunately, due to poor weather conditions during the project, the UAV data were not available in time to be included in the study. In addition, during the exploratory data analysis for the RHS report (Scarlett et al., 2014), it became quickly evident that standard aerial photography data would not provide useful information on river bed morphology, primarily due to the three stretches being hidden extensively by trees. As a consequence, this study focuses on LIDAR data only.

## 2. Methods

The study sites are the same three RHS stretches on the River Wolf described and analysed in Scarlett et al. (2014); see Figure 1 below.

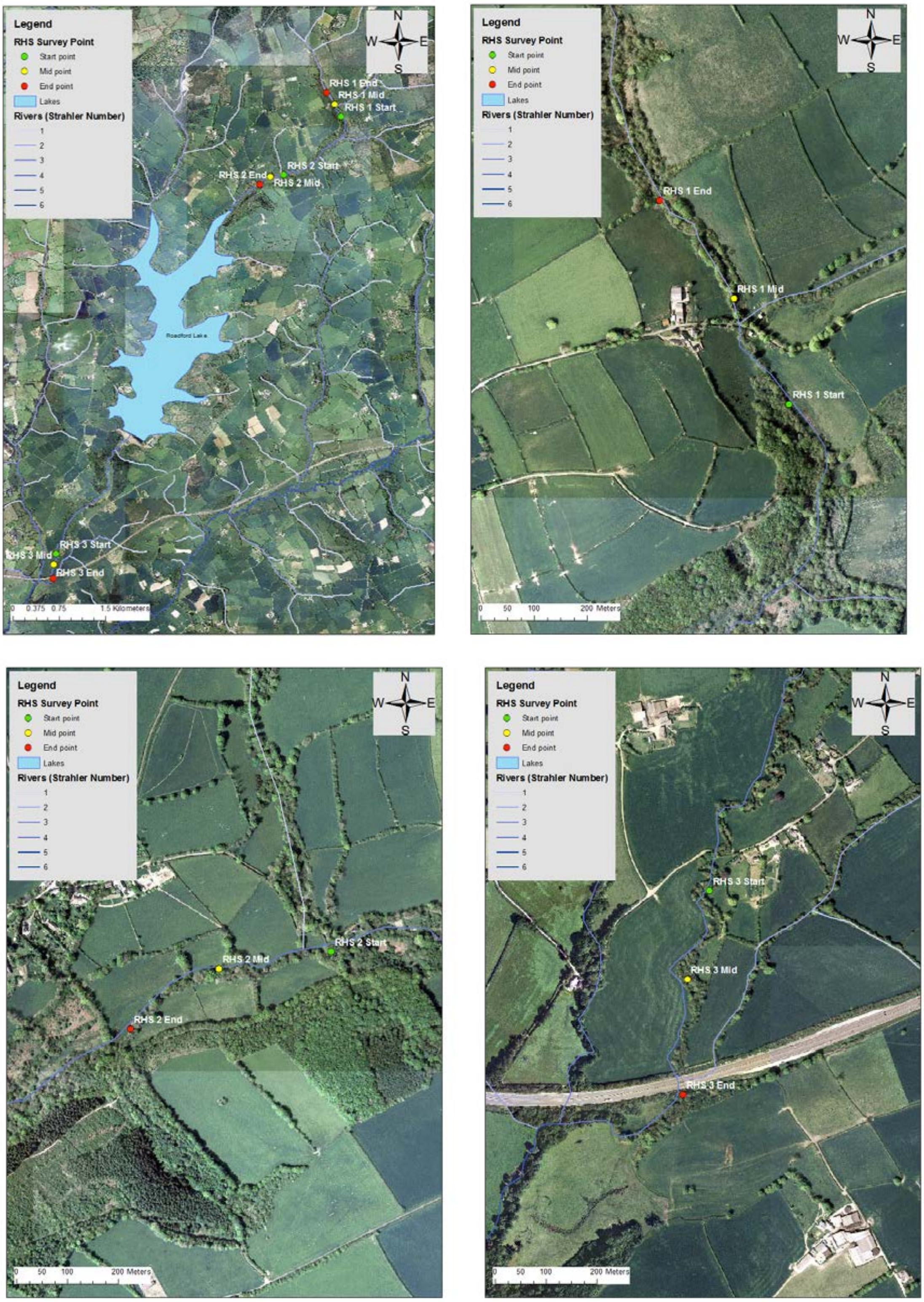


**Figure 1: a) top-left, location of the three River Wolf RHS sites used in the study; b) top-right, RHS 1 start, mid, end points; c) bottom-left, RHS 2 start, mid, end points; d) bottom-right, RHS 3 start, mid, end points (from Scarlett et al., 2014)**

The LIDAR data was collected by BAS during the summer 2013 and processed by the EA. LIDAR datasets include two different rasters (1-m grid, elevation in m): Digital Surface Model (DSM), which includes elevation of buildings, trees, etc; Digital Terrain Model (DTM), which gives the elevation of the terrain only (ie features like buildings or trees are removed). It is the former that is used to characterise the RHS river bed.

The LIDAR used in this study does not penetrate water (unlike bathymetric LIDAR); however it was deemed suitable to represent the river bed for the following reasons:

- RHS sites were surveyed at low flows
    - Records of the nearby gauging station are only available up to 1999 but they show typical patterns of really low flows for July-August (well after the dam was built, so most likely representative of current patterns).
    - The BAS survey report (British Antarctic Survey, 2013) states that the weather was generally good, ie no rain.
    - Pictures and field visits from that period and corroborate that flows were low.
    - Most of the DTM corresponds to the river bed, not to the water surface. Close inspection of the in-river parts of the DTM confirmed this (if the sites had been surveyed at high flows, the in-river DTM would appear as a generally flat ribbon).
- The aim was to identify where there is shallow (eg riffle, run, or glide) or deep habitat (pool). Generally, the water surface follows the bed topography more or less (in some cases, almost parallel to the bed); where there are pool-riffle sequences in the river (assuming there is enough water to cover the bed but it is not high flow conditions), the water surface mirrors the bed topography with a slightly offset and with less amplitude.

To summarise, it is likely that the actual bed elevation is off by a few cm (corresponding to the height of water flowing), but because most of the bed is emerged or submerged by a thin layer of flowing water, this would not affect much the characterisation of shallow/deep zones over 500m stretches.

The outlines of the surveyed stretches were digitised based on the RHS information (start, mid, and end points) and on Ordnance Survey maps. The resulting polygon shapefiles were used to extract the corresponding portion of the LIDAR DTM data, which was subsequently mapped.

Upon inspection, it appeared that LIDAR data picks up on local changes in elevation, which are typical of morphological features like pools (deeper) and riffles (shallower), but these local patterns are unsurprisingly largely dominated by the river slope (see example in Figure 2 below).

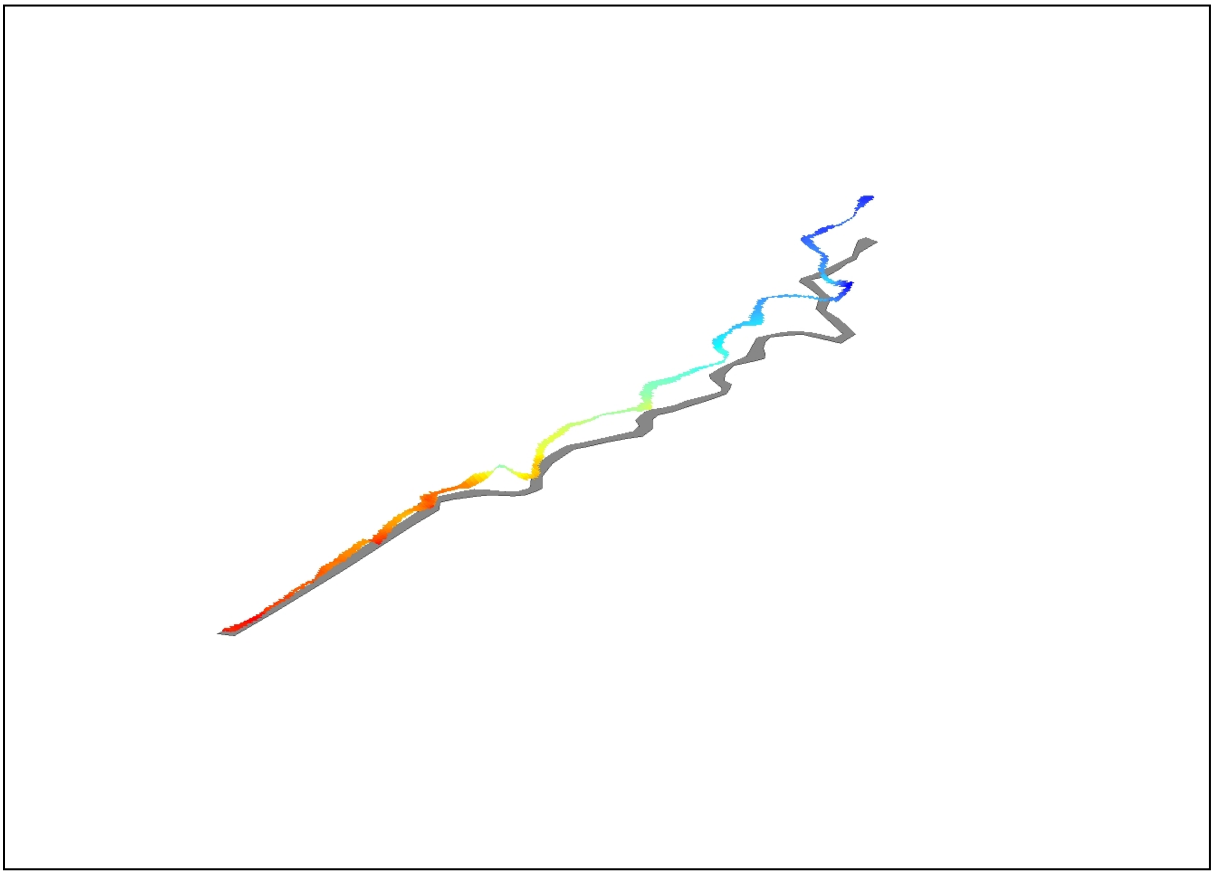

**Figure 2: LIDAR DTM extracted for river corridor of RHS 1 displayed in pseudo-3D; grey shadow indicates zero elevation; colours from dark blue to bright red indicate decreasing bed elevation (river flows from top-right to bottom-left of figure)**

A second stage was therefore added. First, using focal statistics (ArcGIS ArcToolbox/Spatial Analyst Tools/Neighborhood/Focal Statistics), the minimum elevation within a circle of 10 grid cells (ie 10 m) was extracted for each grid cell. This gives a good approximation of the overall river topography. This was then subtracted (using ArcToolbox/Spatial Analyst Tools/Map Algebra/Raster Calculator) from the LIDAR DTM. The resulting raster thus features the differential bed elevation between actual bed elevation and a theoretical zero elevation flat surface (ie it is analogous to rotate the DTM extract so that it is roughly horizontal and with its lowest points set at zero elevation); see Figure 3.

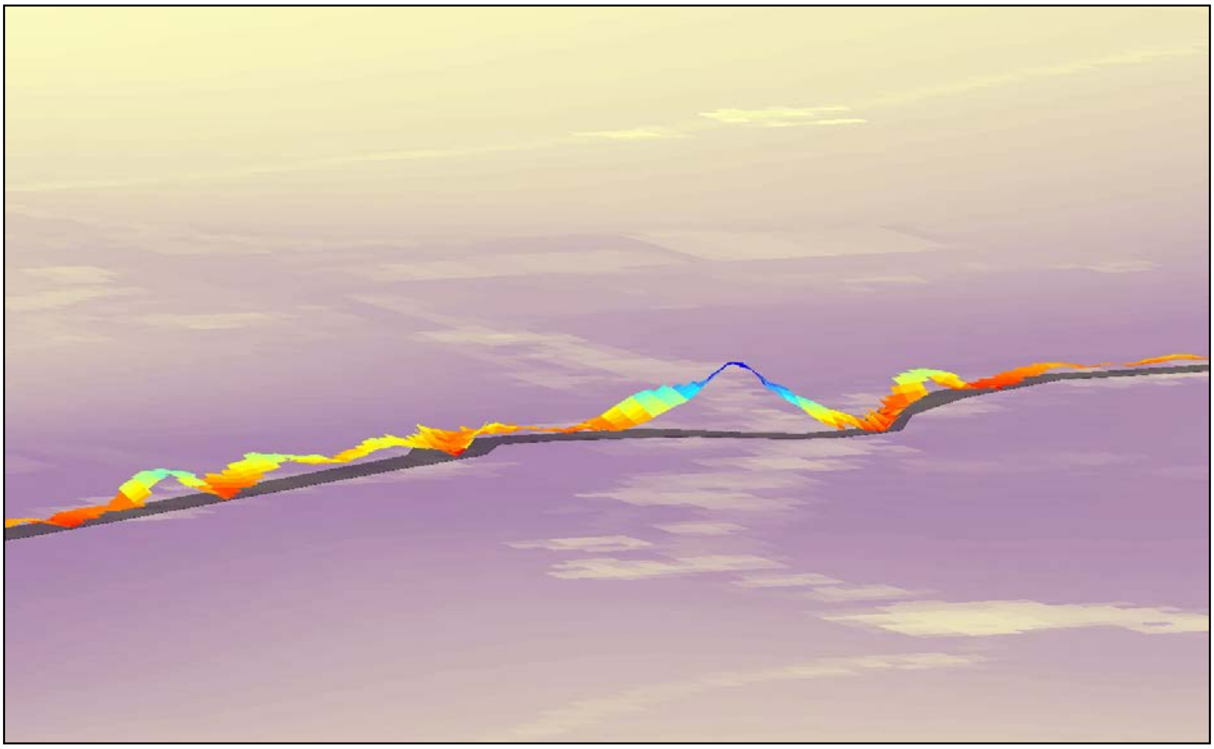

**Figure 3: Example of differential bed elevation of RHS 1 (detail); the grey shadow indicates the "zero" elevation; LIDAR DSM displayed underneath; blue cells correspond to the shallower section of the RHS stretch, red cells to the deeper sections**

## 3. Results

The three RHS sites are mapped in pairs (actual bed elevation first, differential bed elevation second): RHS 1, Figures 4 and 5; RHS 2, Figures 6 and 7; RHS 3, Figure 8 and Figure 9. This approach allows the identification of sections that are deeper (red in Figures 5, 6, and 7) or shallower (blue). However for RHS 1 and 3, the shallowest sections identified correspond to differential elevation of more than 2 m. On cross-checking the LIDAR DTM with the LIDAR DSM or the OS base map, it appeared that these sections corresponded to roadways crossing the river: a small road (RHS 1, secod half downstream; see Figure Figure 5) and a dual-carriage way (RHS 3, downstream end; see Figure Figure 9). At those locations, the LIDAR DSM does not provide information on the river bed itself because it is in effect hidden from view.

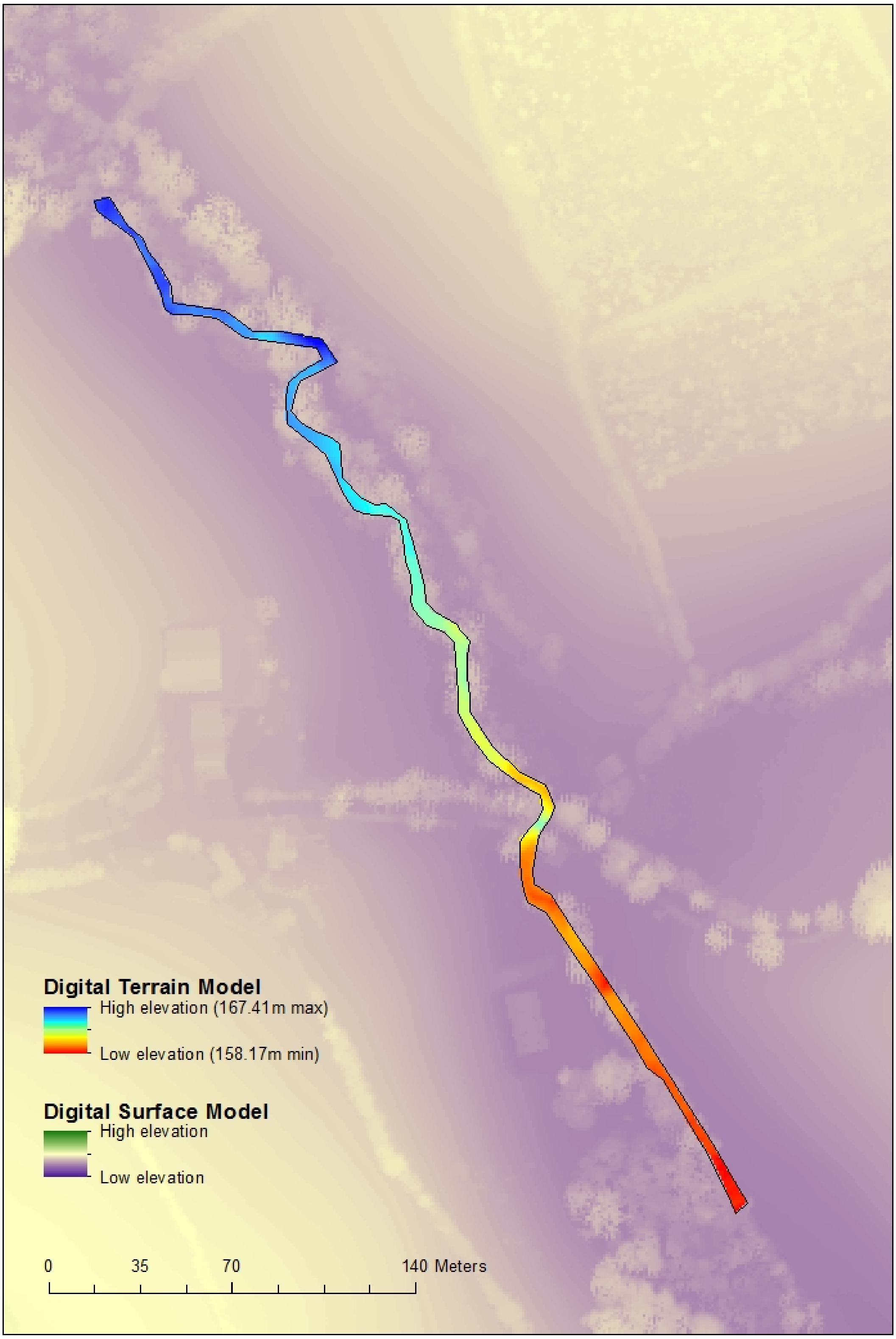


**Figure 4: RHS 1; LIDAR DTM extracted for river corridor; LIDAR DSM displayed underneath**

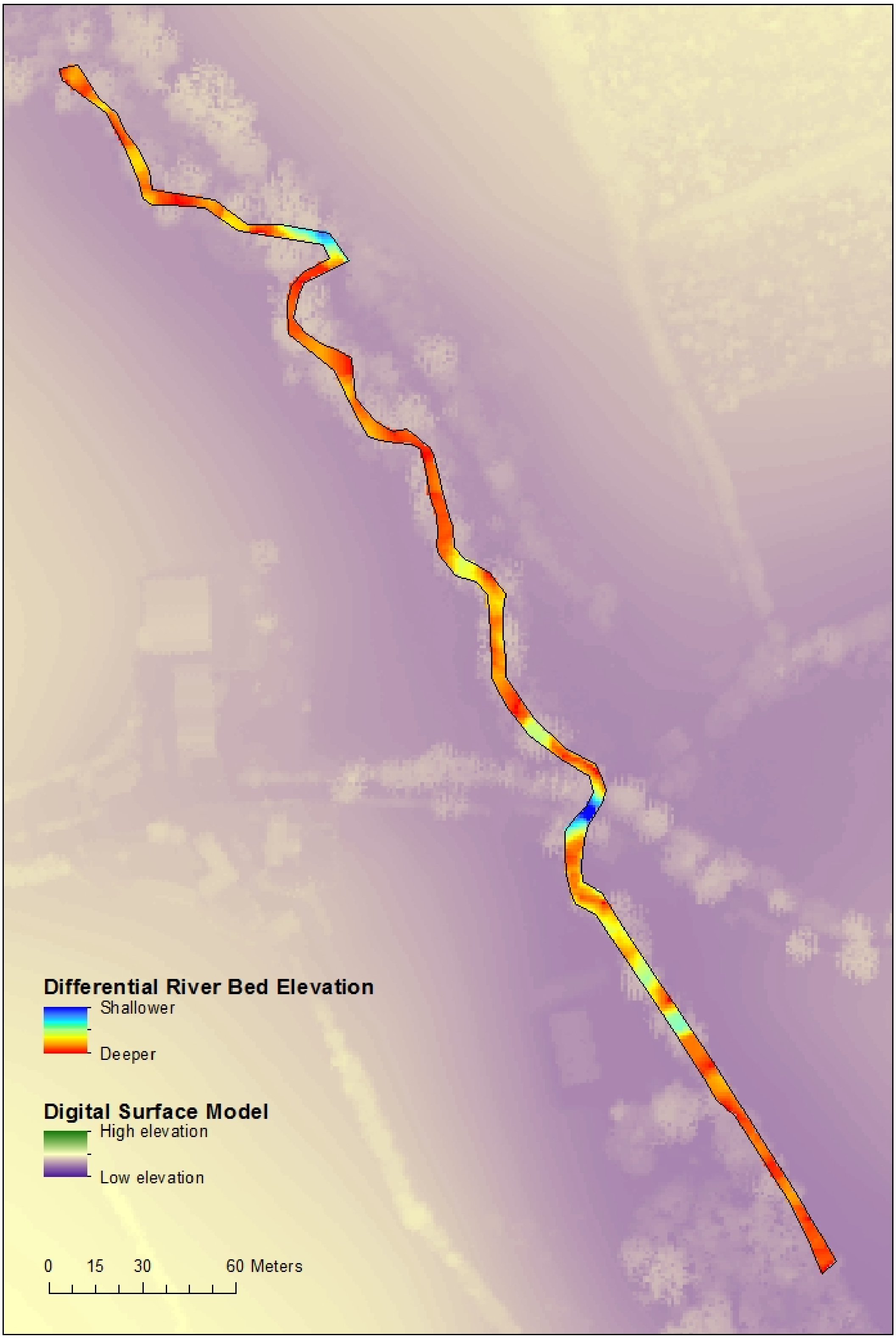


**Figure 5: RHS 1; LIDAR DTM extracted for river corridor; LIDAR DSM displayed underneath**

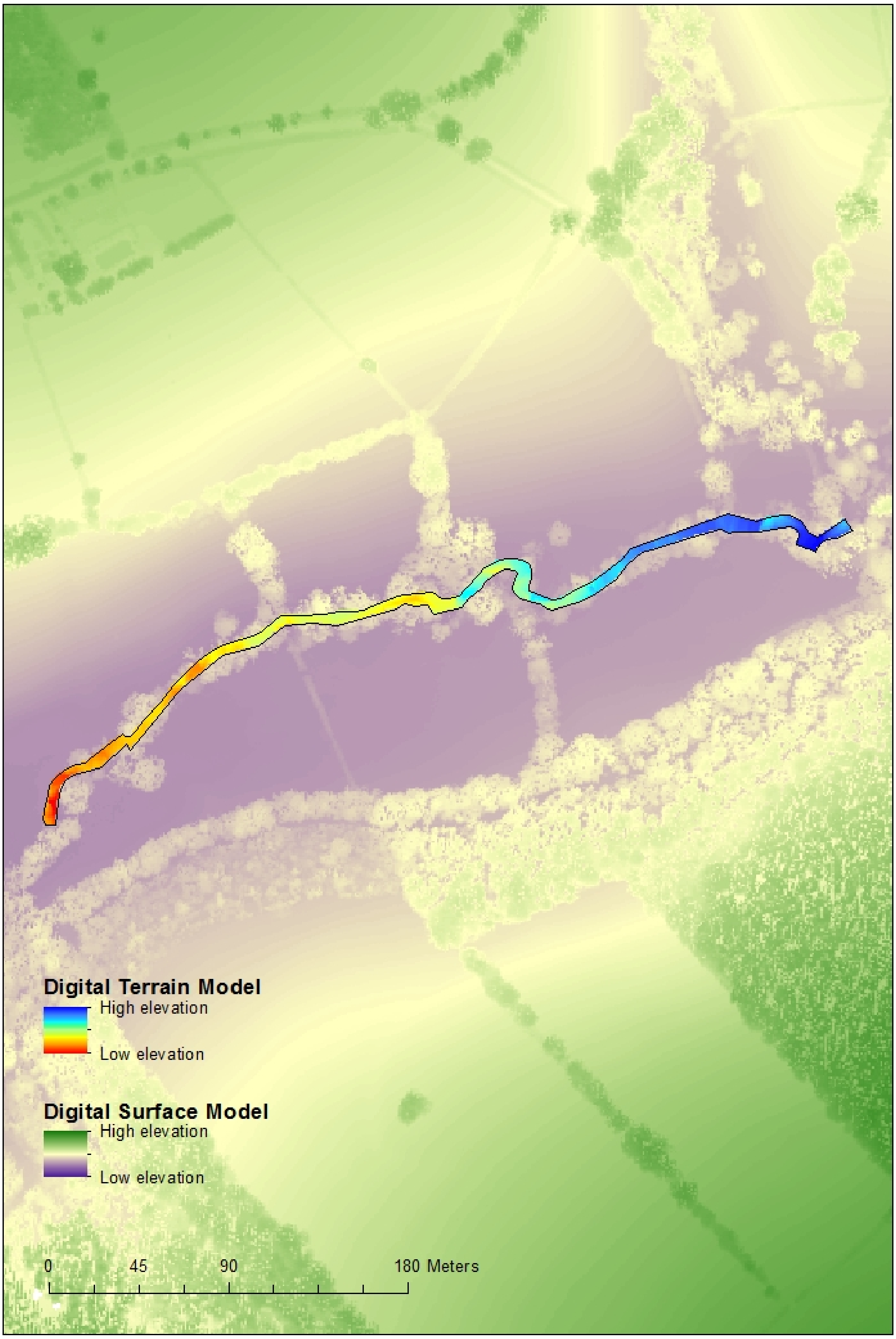


Figure 6 RHS 2; LIDAR DTM extracted for river corridor; LIDAR DSM displayed underneath

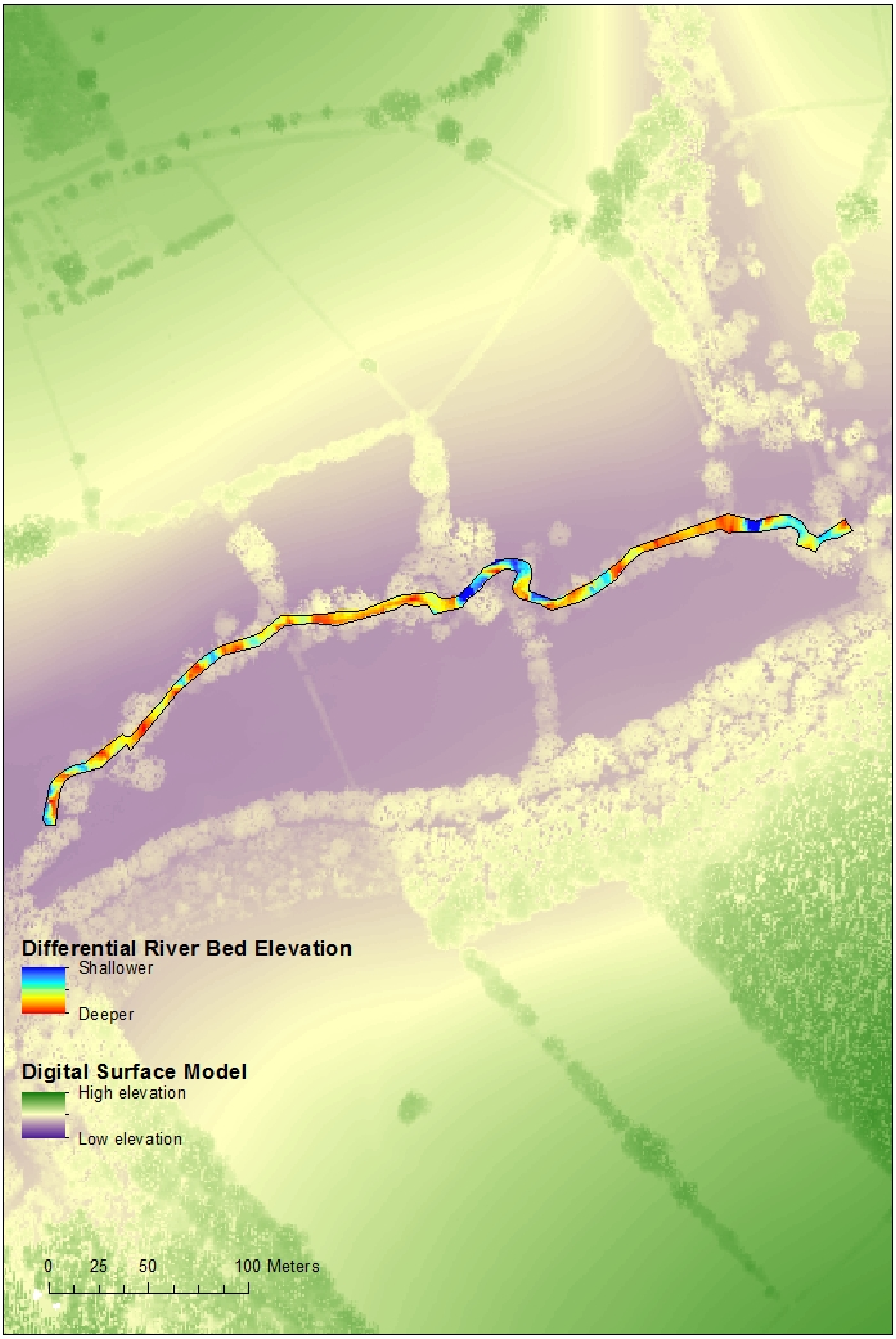


**Figure 7: RHS 2; LIDAR DTM extracted for river corridor; LIDAR DSM displayed underneath**

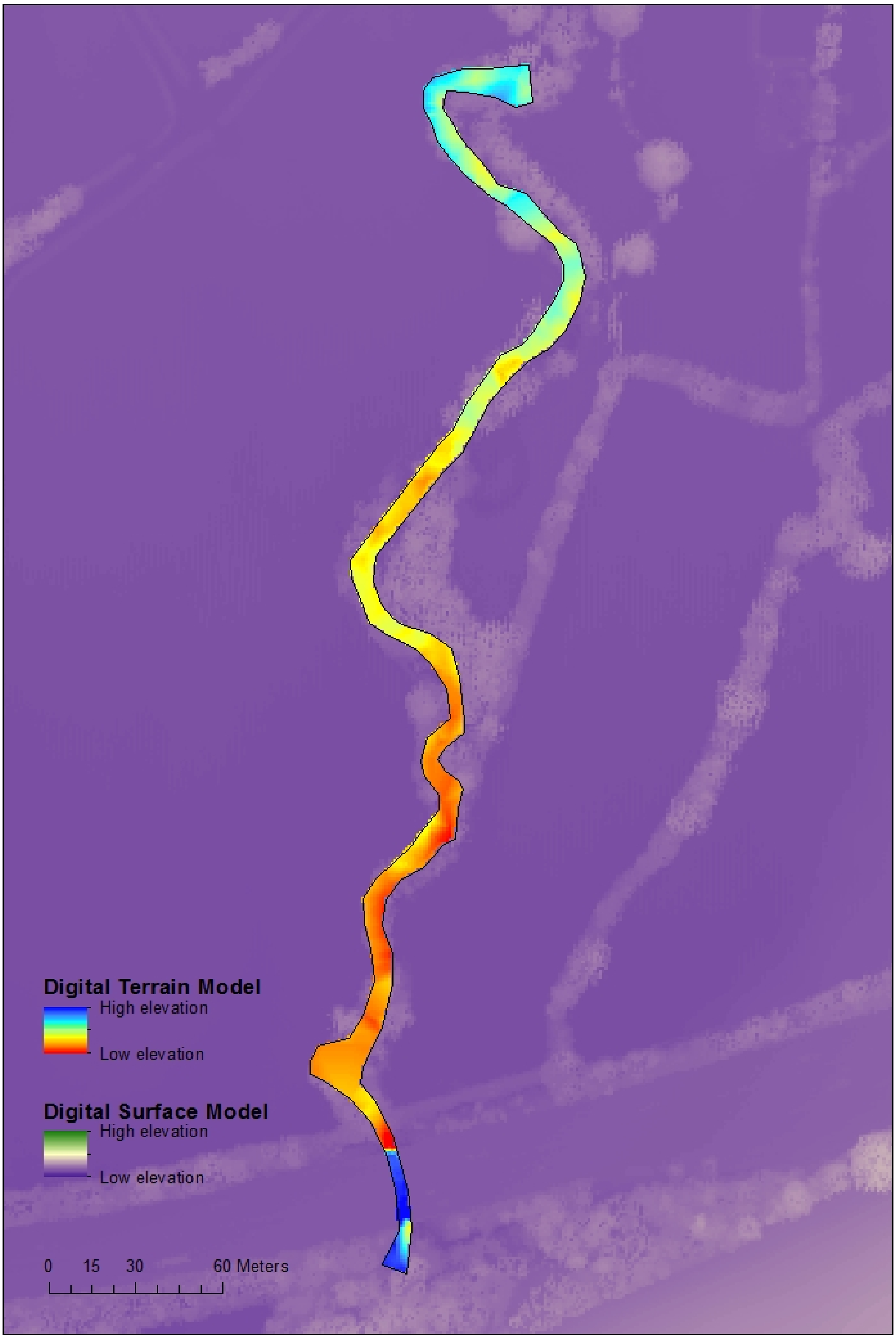


**Figure 8: RHS 3; LIDAR DTM extracted for river corridor; LIDAR DSM displayed underneath**


**Figure 9: RHS 3; LIDAR DTM extracted for river corridor; LIDAR DSM displayed underneath**

## 4. Discussion

### *River corridor outline*

As seen in the figures above, the width of the three stretches does not generally vary. Extracting the area of each polygon, and approximating the stretches as rectangle with the long side equal to 500 m, the average width can be estimated as about 4.5, 5.0, 7.5 m for RHS 1, 2, 3 respectively. RHS 3 is larger than RHS 1 and 2, which is consistent with its location downstream of a tributary with a catchment of similar size to the area containing RHS 1 and 2.

### *Slope*

Based on the minimum and maximum elevation measured from LIDAR, the overall slopes (ie for the full 500 m) of the RHS stretches were estimated to 1.8%, 1.1%, and 1.0 for RHS 1, 2, and 3, respectively. The three RHS sites have similar slopes. The slightly steeper slope for the most upstream stretch is consistent with what is usually observed in the majority of catchments (Leopold, 1953).

### *Physical habitat*

The differential bed elevation can be understood in terms of physical habitat types commonly used in ecological studies. If the river were at bankfull discharge, the elevation would correspond directly to the depth of water in the channel. Deeper sections are typically identified as 'pools', where water is deeper and slower flowing, while shallower sections relate to 'riffles' (faster turbulent flow) or 'glides' (smoother flow). In order to characterise each RHS site simply, the differential bed elevations were reclassified as a simple 5-class typology and class breakdowns calculated; see Table 1. The anomalies identified for RHS 1 and 3 (bridge and dual-carriage way) are agalmated in class '>2 m'. Breakdowns were re-calculated excluding those anomalies to allow a more accurate comparison of the three RHS sites. The three sites are not very different. The main pattern is that the channel gets progressively deeper as one goes downstream from RHS 1 to RHS 3 (lower % for '<=0.5 m' class, higher % for '0.5-1 m' class). This is expected as generally the average depth and width increase downstream, reflecting gradual flow accretion along the length of the river.

**Table 1 Breakdowns of reclassified differential bed elevation**

| | Reclassified RHS 1 | | Reclassified RHS 2 | | Reclassified RHS 3 | |
|---|---|---|---|---|---|---|
| Differential bed elevation | % | % excluding >2 m | % | % excluding >2 m | % | % excluding >2 m |
| <= 0.5 m | 57.6 | 58.9 | 54.7 | 54.7 | 50.1 | 51.6 |
| 0.5-1 m | 27.4 | 28.0 | 34.2 | 34.2 | 37.7 | 38.9 |
| 1-1.5 m | 9.2 | 9.4 | 10.3 | 10.3 | 7.6 | 7.8 |
| 1.5-2 m | 3.7 | 3.8 | 0.8 | 0.8 | 1.6 | 1.7 |
| >2 m | 2.1 | - | 0.0 | - | 2.9 | - |

## 5. Conclusions

LIDAR offers a way to circumvent the problem of tree cover hiding the river channel in remote observation surveys. However, where the river is covered by a bridge or a road, then LIDAR data capture that feature. Some basic checking is therefore needed. The three case studies presented here showed that: (i) identifying such issues is relatively straightforward, as there were obvious anomalies in differential bed elevation (around 3 m is unrealistic for these stretches); (ii) explaining the issues is also relatively easy by cross-checking with other information (OS maps, aerial or satellite pictures, RHS). In the present study, this was done manually, but with the prospect of automating river bed mapping for wider monitoring networks (e.g. the EA's drought monitoring network), it should be possible to build automated checks to investigate outlier river bed portions, therefore keeping manual checking to a manageable level.

Combined with appropriate hydraulic and hydrological data (eg current metering at a key flow percentiles, stage), and information on bed roughness (this could be obtained from RHS, or the current metering) at selected transects, the LIDAR data has the potential for building hydraulic models of any surveyed river. In turn, this would allow modelling the stage along the river, therefore mapping where pools, glides, and riffles would occur for a given flow, or plugging in other physical habitat models (eg RAPHSA).

However, these two conclusions are subject to verifying the assumption used in this study (surveys done at low flows, ie the DTM is representative of the bed topography). The assumption held for these three RHS sites but there is a need for ground-truthing at more sites within the South-West study area, and ideally outside it as well, to confirm the extent to which LIDAR can be used to characterise river morphology and for hydraulics.

Although this was not explored in this study, LIDAR could also gives a handle on the actual tree cover in the riparian area (see Figure 10). The EA has recently produced maps of tree shading for several catchments across the UK, based on LIDAR data. Although its exact specifications are not known at the time of writing, it is understood to be based on relatively simple assumptions linking the presence of trees and actual shading. It is in theory possible to develop a more sophisticated tree shading model, which would take into account the actual duration of daylight, sun trajectory, cloud cover, status of the tree crown (for deciduous) for a given time or season.

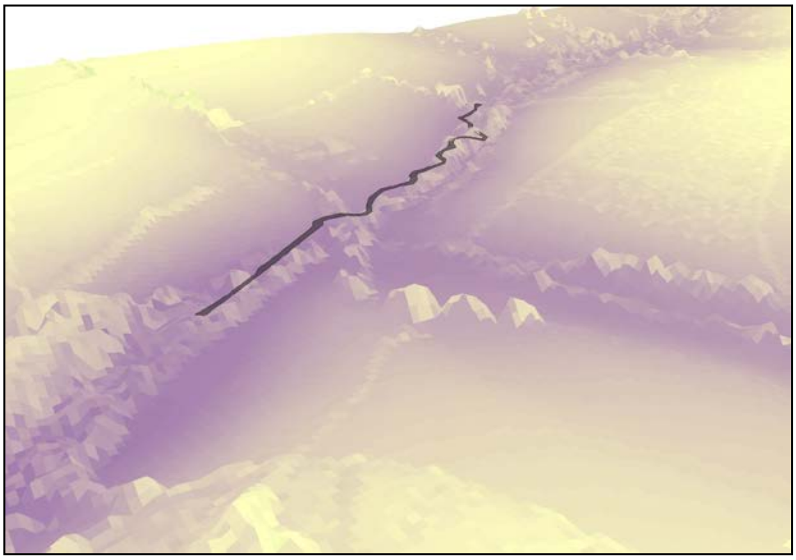

**Figure 10: LIDAR Digital Surface Model for RHS 1; the raised features correspond to trees**

The three RHS sites are generally similar, and if not, their differences are consistent with what would be expected from such a river network under generally accepted knowledge on river morphology. There was no evidence of major differences between sites above and below the Roadford Dam reservoir.

## 6. References


British Antarctic Survey. 2013. TELLUS SW project- Cornwall / Devon LiDAR Survey Report

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