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**Remote Sensing and Field Mapping:**
**Requisite Bed Fellows for Assessing River Systems**

**Abstract:**

Mapping channel geomorphology, riparian vegetation and the extent of anthropogenic disturbance of river corridors has traditionally been conducted laboriously in the field. With the implementation of the EU Water Framework Directive (WFD), member states are mandated to complete river basin management plans requiring such fieldwork in order to achieve good ecological status by 2015. Thus, deriving wider land cover information from remotely sensed data will be an integral addition to fieldwork in order to meet the requirements of the WFD. The objective of this study was to use two types of remote sensing data, LiDAR and ortho-imagery, to delineate channel morphologies and to field check the analysis in the field to test the accuracy of the remote sensing techniques and assess their applicability for the WFD. Using Carneros Creek, in Napa, CA as a testing ground because of the publicly available LiDAR and ortho-imagery datasets, I achieved 80% accuracy in identifying large terrace features from the Digital Elevation Model (DEM), and a lower percentage at 66% accuracy in identifying steep or vertical banks. Field checking the data not only helped clarify existence of the morphological feature but it also allowed for more complex data gathering such vegetation patterns and species, bedrock outcroppings and land use evidence such as outlets of drainage systems and in-stream pumps, all of which I could not see from the DEM. Preliminary conclusions point towards effective usage of remote sensing data in the WFD. LiDAR scans portend to be specifically useful in Mediterranean climates that are dry most of the year, as opposed to wetter climates where water impedes accuracy of LiDAR mapping.

## Introduction

Mapping channel geomorphology, riparian vegetation and the extent of anthropogenic disturbances of river corridors have traditionally been conducted in the field using compasses, paper maps, and more recently, global positioning system units. Such field surveys are an essential part of understanding river systems. However, drawbacks of such methods include the laborious, time consuming, and expensive nature of the work which often renders them of limited geographic scope (Gilvear, 2004). Thus, deriving wider land cover information from remotely sensed data is an integral component of scientific research. Since the first Landsat satellite launched in 1972, remote sensing has made significant progress in terms of accuracy, spatial resolution and data availability (Hollaus, 2005). The field of remote sensing is an important addition to traditional fieldwork for improving accuracy of data and efficiency of data collection.

Remote sensing employs a series of instrument-based techniques to acquire and measure geographic data and information on a given surface, by measuring distances using reflected, or emitted radiation from Earth's surface (Campbell, 2006). There are two kinds of remote sensing, active and passive. Passive sensing that detects natural radiation emitted or reflected by the object or surrounding area being observed, such as reflected sunlight. Photography, high-resolution ortho-imagery, radiometers and infrared detection are other examples of passive remote sensors (Roughgarden, 1991; Campbell, 2006). Active remote sensing scans objects by emitting energy and measuring the distance between the sensor and the object using the time delay between emission of the energy and its return (Campbell, 2006).

Airborne laser scanning, often referred to as LiDAR or Light and Ranging technology, is an active remote sensing technique that measures the topography of the Earth's surface. A laser emits short infrared pulses toward the Earth's surface from an aircraft. The laser pulses to a target and records the time it takes for the pulse to return to the sensor receiver to determine surface elevations (NOAA Coastal Services). The travel path of the laser pulse creates 3-dimentional coordinates of features on the earth's surface (Hollaus, 2005). LiDAR mapping of terrain uses a technique called "bare earth filtering." The laser scans through most trees and buildings, leaving the bare-ground elevations (Campbell, 2006). This allows the generation of precise Digital Terrain Models (DTM), or Digital Elevation Models (DEM) for the areas covered by the LiDAR flight (Hollaus, 2005). The accuracy of the DEMs has improved rapidly over the last two decades, as the causes of inaccuracies in the LiDAR data have been identified and the technology improved. Pairing two or more remote sensing techniques has been shown to increase accuracy levels. For example using, LiDAR data sets coupled with orthographic imagery is a growing practice among scientific researchers and regional planners (Hollaus, 2005).

Similarly, remote sensing and fieldwork must be paired together to achieve higher levels of accuracy. In the field, vegetation, steep banks, or no-trespassing signs, often deter a field worker from seeing the entire channel system while on the ground. LiDAR can sight through much vegetation, often revealing areas of bank erosion, tributary confluences, outfalls, terraces or other features that would be missed in the field. Conversely, DEMs are often made using 1m by 1m grids (an XYZ coordinate system with points every 1 m in the X and Y direction) that can miss the fine scale details of soil and rock type, regeneration of plants, bedrock outcroppings and other in-channel features which would be missed if a field-check component were not part of the data collection process. Remote sensing provides a detailed look at a channel, but requires field verification to complete the picture.

These tools and methods may be useful to support assessments over large areas which have mandates, for example, the River Basin Management Plans required by the EU Water Framework Directive (WFD). Current legislation of the WFD requires assessments of the 'whole' river system, including floodplain and riparian habitats as a basis for improving their ecological 'status' or health (Heritage 2008). These data, if gathered through remote sensing technologies, can be used to support the preparation of the necessary information needed for integrated river basins to comply with the WFD.

Remote sensing, while requiring capital, significantly reduces person-hours in the field and directs the still integral field-work, towards a more efficient model of research (Gilvear, 2004). Many EU countries, such as Portugal, Greece, Italy and Spain are behind in their compliance with the WFD, and remote sensing may be a way for them to catch up with their fellow EU member states, by completing their River Basin Plans (Article 5) and fulfilling several other components of the WFD (Kallis, 2001, Moss, 2004). The EU commission can hand down heavy daily fines for instances of non-compliance (N. Handley, Personal Communication, May 2009). The fines are scaled by the severity of the issue and the GDP of the member state. For example, the EU commission threatened to fine France as much as 500,000 euros per day for failure to act on a WFD requirement. Finally, 30% of the river basin districts (66% by area) are classified as international river basin districts and jointly applied LiDAR scanning may allow countries work together more efficiently to meet the requirements of the WFD (Nilsson, 2004).

*Carneros Creek: Testing the Method*

Carneros Creek, a tributary of the Napa River, provides an ideal opportunity to apply these methods because there are several forms of publicly available remote sensing data, LiDAR and high-resolution ortho-imagery, which can be used in tandem to assess field conditions and identify morphologies in order to direct and make more efficient time spent in the field (Figure 1).

Carneros Creek watershed is heavily farmed for high value wine grapes, and the vines themselves often extend into the riparian corridor and up to the top of the banks themselves. The silt and loam soil profiles of Carneros Valley that consist of marsh sediment deposits produce highly valuable wine grapes (NRCS *Soil survey*). Thus, management of Carneros Creek has historically been focused on maintaining high levels of grape production. Carneros Creek poses a complicated challenge to land managers and habitat restoration professionals because of its incised, highly sinuous form and the tendency of banks to slough or fail completely. When incised banks fail, land managers tend to react by hardening the banks, which increases velocities and propagates bank failures up and downstream (Grossinger et al, 2003).

The incision and bank failures on Carneros Creek could have many sources. Some studies site the incision as a result of intense cattle grazing by the Spanish in the early 18$^{th}$ and 19$^{th}$ centuries (Grossinger et al, 2003), while others have traced the incision to the increased runoff from soil compaction due to the intense viticulture which has dominated the valley since the 1940s (M. Trso, Personal Communication, March 2009).

As a channel incises, it may leave terraces as a legacy of past active channel elevation (Knighton, 1998). Relative height of river terrace sequences has been often used to determine the relative position in time of morphological features (Figure 2). This height is taken relative to the current bed elevation, with the assumption that the highest terrace is the oldest (Knighton, 1998). These terraces are intermittent throughout the Carneros Creek channel, and often have single stem willow trees (*Salix lasiolepis*) growing on them, indicating that the age of the willow may correlate to the age of the terrace (Knighton, 1998). As willows usually establish on or near the channel bed or lower banks, where their roots can easily reach groundwater, their tree rings can provide a proxy for dating channel morphodynamics (Scott, 1996).

The objective for this study was to use two types of remote sensing data, LiDAR and ortho-imagery, to delineate two channel morphologies: terraces and steep banks, and to ground truth interpretations from remote sensing techniques. On terraces, I identified locations of single stemmed willow trees to core for dating information. Finally, based on my findings on Carneros Creek, I considered how LiDAR mapping might be useful to European member sates as they seek to comply with WFD requirements.

**Methods**

Pre-Field work:

I acquired 1-meter resolution LiDAR data and used spatial analyst in ArcView 9.2 to create .5m contours, and a slope gradient coverage. First, I created a polygon shapefile to outline the entire creek from top-of-bank to top-of-bank using the LiDAR slope data, and to outline the current active channel bed based on slopes and morphologies apparent in Digital Elevation Model (DEM), using contours and slope as guidance. Second, I downloaded orthographic imagery at a scale of 1:2400 (1 inch=200 feet), also publicly available, to use with the LiDAR. Using this high-resolution aerial photography, I outlined the riparian corridor based on tree canopy. These first two steps were important to determine a defined riparian area, and to differentiate between bed and banks to direct my search for terraces.

Within this defined riparian area, I identified terraces, or flat surfaces within the boundary of the riparian zone that are at least 1 meter higher than the current bed elevation and 1 meter lower than the elevation of the top of the bank, or ground plane (Figure 3). I also used this overlay to identify the steepest banks based on where the slopes were above 80% and where the contours lines were very close together (Figure 4). I continued this process over the length of the creek.

Fieldwork

Because LiDAR scanning does not consistently cut through dense vegetation and water, "ground-truthing" is essential. Walking the channel 1510m from the Withers Rd Bridge upstream to the Highway 121 Bridge (Figure 5) I checked morphologies delineated using the DEM on a printed copy of the map. I checked each terrace or steep bank against how it was mapped on the DEM, noting bank material and stratigraphy exposed on steep banks, evidence of active erosion and vegetation established on steep bank tops. Banks of 80% grade or steeper may not be actively "failing," but provide a starting place for exploring issues of bank erosion and possible instabilities. For terraces, I noted if the LiDAR was accurate by judging if 1) the terrace was at least 1 meter below the elevation of the current ground plane 2) the terrace was at least 1 meter above the current bed elevation 3) the terrace had vegetation and was not regularly scoured indicating it was abandoned and not hydrologically connected to the current channel, except in very large events. I also noted what kind of tree species were present, and if single-stemmed willows occurred.

**Results**

Through the GIS analysis of the LiDAR data, for the channel as a whole, I found a total of 35 terraces and 170 occurrences of extremely steep banks (Figure 6). Results from the field checked terraces and failing banks are shown in Table 1, and results from the field-mapping component of the spot-checking are shown in Figure 7.

With regards to steep banks, I delineated 10 steep bank areas in the 1510 m reach from the DEM. All 10 polygons were confirmed to be steep or vertical banks, but in the field I noted that there were 5 other places that I had not picked out from the DEM that I also classified as a "steep bank," because they met the criteria of being vertical, bare, with little vegetation.  Of the 15 total "steep banks" noted in the field, 67% I had accurately identified in from the DEM, while 33% I had missed.

| Total 'steep banks' | LiDAR-based observation | % Accurate from field-checking | Field-based observation | % Missed |
|---|---|---|---|---|
| 15 | 10 | 66.67 | 5 | 33.33 |

With regards to the terrace morphology, I delineated nine occurrences using the DEM, and in the field found that one of these terraces was more than likely a point bar or, or a sharp meander bend, and did not display the elevation and morphological features of a terrace. Instead it was a flat place within the riparian zone that was raised from the bottom of the current channel but it was not below the elevation of the top of the bank or ground plane. Furthermore, I found one terrace in the field that I had not previously seen from the LiDAR (Table 1).

| Total Terraces (LiDAR and Field) | LiDAR-based observation | LiDAR-based Accurate with field check | % Accurate with field check | Not seen from LiDAR | % Missed |
|---|---|---|---|---|---|
| 9 | 10 | 8 | 80 | 1 | 11 |

**Discussion**

<u>Accuracy Limitations:</u>

Dense vegetation and shallow water has limited the achievement of high accuracy levels in this type of data collection (Gilvear, 2004). Thus, constraints for accurate hydraulic modeling and planning have been largely due to incomplete topographic data (Hollaus, 2005). However in recent years, technicians have achieved accuracies less than ±25 cm in the vertical direction and horizontal X, Y accuracies of 1-meter cells which is more accurate than simply using aerial or stereoscopic photography (Hollaus, 2005; NOAA Coastal Services Center). LiDAR scanning data often picks up bank failures or instabilities that are hidden behind vegetation, and may be missed in the field.

I achieved 80% accuracy in identifying large terrace features from the DEM, and a lower percentage at 66% accuracy in identifying steep or failing banks. Field checking the data not only helped clarify existence of the feature but it also allowed for more complex data gathering such vegetation patterns and species, bedrock outcroppings and land use evidence such as outlets of drainage systems and in-stream pumps, all of which I could not see from the DEM or orthographic photos. The DEM is useful however in that it allows for a field researcher to identify larger features which are not often readily apparent on the ground, or are covered with dense vegetation and rendered impassible. Thus, the two approaches are complementary

As with all methods, there are caveats. In certain conditions, there is "an unfavorable signal-to-noise ratio and insufficient calibration" which has restricted the use of the DEM data in the past (Hollaus, 2005). Most LiDAR lasers use near-infrared (NIR) radiation. Certain materials and surfaces, such as water, asphalt, tar, clouds, and fog absorb NIR wavelengths causing poor returns, or noise. Dense vegetation also inhibits clear results of topography of the earth's surface (NOAA Coastal Services Center).

One might argue that in Mediterranean climates where streams and rivers run dry, such as Portugal, Southern France and Napa County, aerial LiDAR is more effective than in a temperate climate because it does not encounter impenetrable water. In assessments in Scotland, where water often flows year round, Gilvear et al. (2004) classified morphological features based on the DEM, as I have done on Carneros Creek, and found a 68% rate of accuracy of the LiDAR as compared to a field survey (Gilvear, 2004). The researchers found that the waterline formed the boundary between what the LiDAR scans could accurately depict and concluded that the lower accuracy percentage may be due to the perennial presence of water in the river which limited the resolution (Gilvear, 2004).

With several European member states struggling to keep pace with the demands of the WFD, remote sensing technology might be a partial solution to speeding up the river basin planning process (Heritage, 2008). The speed and accuracy of LiDAR makes it feasible to map large areas with the kind of detail that before had only been possible with time-consuming and expensive ground survey crews (NOAA Coastal Services Center). The question then arises, how well can you "know" the river system from LiDAR data and field checking, and is it a worthwhile venture for European countries to invest in to comply with the WFD in creating river basin plans. It may be that drier Mediterranean climates will achieve higher accuracy rates and thus more reliable data sources and find it worthwhile to invest in LiDAR flights.

Cost is often cited as a barrier to employing LiDAR technology in the public realm. The average cost range for LiDAR data is approximately $1,000 to $2,000 per square mile for 2 to 3-meter resolution according to a NOAA Coastal Services report (NOAA Coastal Services Center). This cost includes flight, LiDAR collection, post processing, and delivery. Costs vary depending on the size of the project (NOAA Coastal Services Center). A single flight can cover as much ground as 250$mi^2$ in one day. LiDAR is also less expensive the larger the project becomes (NOAA Coastal Services Center). The cost and time of ground surveying 250 $mi^2$, or the fines associated with non-compliance, may well surpass the price of LiDAR flights and should be considered in the river basin management plans of the WFD.

**Conclusion**

In sum, given favorable conditions, remotely sensed digital imagery provides a potential means to observe, monitor change and gain synoptic coverage of river systems, and to provide a database for quantitative analysis that is potentially less costly on a long-term basis (Gilvear, 2004). Based on the results of this study, accuracy in delineating channel morphologies seems acceptably useful, at very least for providing a first pass at defining morphologies and existing conditions. Ground-truthing and finer scaled fieldwork is also important, but the two methods can work symbiotically.

The WFD requires member states to produce a characterization report for each river basin district. This includes documenting 'hydromorphological' elements, including hydraulic habitat, channel morphology, the presence of man-made features and management activities such as channelization, as well as with corresponding geomorphic consequences (Gilvear, 2004). Terraces and steep banks are not necessarily the morphologies in question for every river. For example, Gilvear's study on the River Tummel in Scotland used high-resolution digital photography to 'remote-sense' for features such as riprap, bare soil, and different types of vegetation. The ground-truthing component was similar to this study. Thus, there are several ways to remotely sense the physical status of a nation's rivers. The type of remote sensing used, and the features mapped, will vary by basin and even by reach. However, in the context of new legislation, which requires environmental protection agencies to have robust tools for monitoring the physical status of rivers across an entire member state, remote sensing, including both digital photography and LiDAR mapping, may prove useful (Gilvear, 2004).

In order to support implementation of the WFD, Chena et al (2007) identified five major areas in which remote sensing technology could be applied to monitor surface water status:

(1) The provision of systematic observations of relevant surface water areas (Article 8);
(2) Support for the establishment of river basin management plans (Article 3, Article 5)
(3) The detection and spatial distribution of changes in surface water areas (Article 4, Article 16);
(4) The quantification of chlorophyll concentrations and associated changes therein (Article 4, Article16);
(5) The mapping and monitoring of certain sources of, e.g. pollution by nitrates, total nitrogen and total phosphorus (Article 10) (Chena, 2007)

LiDAR, as described in this paper, would specifically be useful for the first three of these suggestions addressing spatial distribution of morphologies, and observing change over time.

The need for looking at rivers and water bodies using multiple tools continues to be important in wide scale planning such as the WFD as well as in the US. A major limitation to attaining high accuracy LiDAR mapping results continues to be the presence of water in streams year round, so water bodies in the Mediterranean climates such as Portugal, and France, which go dry, will benefit most from this technology. However, the high accuracy results of several types of remote sensing tools point to the possibility of using a diverse set of these tools appropriately for diverse climates and conditions in the European Union and elsewhere.

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