Environment Agency Geomatics is a leading provider of high quality LIDAR survey and remote sensing solutions. As a specialist unit within the Environment Agency’s National Operations department, we deliver integrated spatial data products to government and commercial clients. Combining cutting edge technology with expert personnel, we work to the highest scientific and ethical standards to provide accurate and high quality spatial data.

The Geomatics team supplies customized services to the Agency, other government agencies, non-governmental organisations (NGOs) and the commercial market.

We supply data to the rigorous quality requirements of the regulatory community. We are able to provide the integration of sensors required to address the complex environmental problems that are being addressed. The Geomatics team can work with customers to develop the required datasets as there is a shared understanding of the requirement.
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1 Introduction

Environment Agency Geomatics (part of National Operations) has the capability to capture, process and integrate data from airborne and satellite remote sensing systems with existing Environment Agency data. The integration of these diverse datasets within a GIS environment has wide ranging applications within the Water Framework Directive including habitat mapping, catchment visualisation and change detection.

Funding was identified to undertake a pilot study for a selected catchment to bring together these datasets and demonstrate their value to the wider WFD community. The project plan details the methodology and expected outcomes.

Geographical imagery, maps and GIS data analysis enable better decision making in environmental management and monitoring. Geomatics has a number of remote sensing tools and datasets that can help. We can also source 3rd party remotely sensed data such as from satellites and then integrate all these into map-ready outputs based on WFD management basins. These data can be used in Environment Agency GIS software, such as ArcMap.

Using the datasets and software already available, a demonstrator was developed to show the potential outputs that could be developed under this project. The aim is for this to be shared widely and for it to assist in communicating the aims of the project to the wider WFD community. This will also allow minimisation of overlap with work being commissioned externally.

Remote sensing can help target costly data collection on the ground. It is also useful in collecting data in dangerous or inaccessible areas. There are many forms of remote sensing, including airborne and satellite based platforms, and Geomatics is able to provide services to make use of these.

In small catchments, the scale of the monitoring suggests that airborne techniques can offer the most useful information. In larger catchments, satellite imagery may be more appropriate. Higher resolution aircraft data of key environments can also be integrated with lower resolution wide scale satellite data.

1.1 Pilot Study

This pilot study focuses on the River Leam Catchment, one of the ten WFD pilot catchments. Archive LIDAR (Light Detection and Ranging) data coverage of the Leam was approximately 50% and the remaining 200 km² of data was collected as part of the 2011-2012 National Programme between November 2011 and March 2012.

CASI and satellite data was captured during summer months when the lighting conditions were suitable for optical data capture and the vegetation species were fully developed and therefore more easily discriminated. CASI data were captured for three sub-catchments of the Leam.

To ensure that the full benefits of the data were realised, Geomatics proposed producing an initial suite of data products for consultation with the pilot catchment leads in Autumn 2012. We would then take forward the most favourable outputs to develop operational tools which could be applied to other catchments.
Potential outputs for a combination of LIDAR, CASI, satellite imagery and digital photography are:

- Potential overland flow routes for diffuse pollution studies
- Evidence of overland flow (gullies/erosion) where the river may be leaving its channel in higher flows and flowing over bare earth/crops etc.
- Evidence of channel structure/re-alignment/modification. For example this could include evidence of straightening, possibly channel depth and presence of pools/riffles
- Mapping bank-side vegetation (tree/shrub cover), mapping vegetation cover for whole catchments
- Extent of bare earth (identifying possible areas of cattle poaching, farm tracks etc crossing rivers/streams) showing where there may be issues with sediment run-off
- Relative shading, slope and aspect of river banks
- Improving flood modelling for whole catchment modelling
- Land cover mapping of certain crop types, (grazed grassland, deciduous woodland, coniferous woodland)

Further integration with existing datasets and display within an GIS environment will allow:

- catchment scale visualisation
- identification of access routes
- targeting of field visits.

The aim of this project is to demonstrate the value of outputs from Remote Sensing as integral operational tools in the day to day management of WFD catchments. One of the major misconceptions about remote sensing is that of the prohibitive cost of it. It is true that mobilising the aircraft for a single purpose data set would be relatively costly, however, from a data acquisition perspective, if there are two uses with value for these airborne data, then effectively the capture cost per product is halved, ten uses and the effective cost per product is one-tenth. That cost can then be borne across many different departments. In addition, these data can then be added to the Environment Agency's archive of remote sensing data which would add value to that for years to come. With this pilot we aim to demonstrate that, using data captured from just two or three instruments, many products can be made to substantially reduce the effective cost of data acquisition, using the principal that the more uses of genuine value that can be created, the more cost effective the technology becomes.
1.2 Remote Sensing

Remote sensing is a broad range of techniques that obtain information about the Earth's surface without coming into direct contact with it. In airborne remote sensing, specialised instruments are operated from aircraft to build up digital images of the Earth's surface based on a variety of physical parameters. These include reflected visible light, reflected invisible near infrared and emitted thermal radiation. Some instruments generate the source of energy which is to be detected, for instance LIDAR fires thousands of pulses of laser light and records the intensity of the reflected signal and the time taken to return, thus creating a 3-dimensional image of the terrain below the aircraft.

A range of techniques have been developed to convert data from these instruments into meaningful real-world mapping products. Many of these run using automated and semi-automated routines making them, when used appropriately, very cost effective survey techniques that complement traditional ground survey techniques. These data can also be used to build up continuous landscapes and maps without having to visit every square metre of land. This is particularly useful in hazardous and inaccessible terrain, such as bogs and military ranges. Even non-automated techniques that involve manual digitizing can present vast savings when compared to traditional ground methods. Remote sensing thus differs from \textit{in situ} techniques, as you can cover large areas of the earth's surface without having to visit it all. Although the initial cost of data acquisition is considerable, when used appropriately, there are huge cost savings that can be made by using these data in place of many tasks that are carried out using expensive ground survey methods.

One of the great advantages of using remote sensing is that the data can be revisited in the future once new feature extraction techniques are developed. The data can also be used in direct comparison studies with data that are collected in the future. The benefits of this are clear: the dynamics of the natural environment can be studied, both to monitor the progress of a restoration projects and to identify areas of degradation that require attention. In certain instances features on the landscape can be discovered that were previously unknown.

This report will describe how Geomatics has developed new techniques to extract information pertinent to Water Framework Directive applications using remote sensing data from instruments on board their aircraft and a satellite platform.
2 Study location

The River Leam is a tributary of the River Avon that flows through rural Warwickshire and the town of Leamington Spa. The Rains Brook, River Stowe, River Itchen and Radford Brook form its major tributaries, with the catchment including the town of Southam and Draycote Water reservoir. The landscape of the Leam catchment is characterised by a mixture of arable and livestock farming. The whole catchment covers an area of approximately 370Km².

![Figure 1 Showing the coverage of data from LIDAR, WorldView2 Satellite data (green and red) and CASI data (red only). The Rains Brook sub-catchment is the eastern-most one in red.](image)

There are 9 sub-catchments within the Leam catchment. Much of the focus of this study was within the Rains Brook sub-catchment.
Figure 2 Showing a coverage plot of the 1.5 metre resolution CASI data captured throughout three sub-catchments of the Leam. These data were captured on the 12th August 2012.

Figure 3 Showing a coverage plot of the WorldView2 satellite data captured on the 12th September, one month after the CASI data. These data are 2 metres in resolution show the reflectance in 8 different wavebands ranging from Blue to Near Infrared.
Figure 4 Showing a coverage plot of the LIDAR data acquired within the Leam catchment. These data are a mixture of data already held in the archive and data specifically commissioned for this project.
3 Comment on data used

Through a mixture of specifically commissioned data capture and archive imagery, the whole of the Leam catchment was covered with LIDAR data. These data are used to produce a very detailed height map of the Earth’s surface with an absolute vertical accuracy of better than 15 cm (6 cm in the last 5 years). This is relatively straightforward to capture as it is not nearly as weather dependent for capture as for instance aerial photography and it can be captured day or night. Optical satellite data were also acquired specifically for this project to cover the entire Leam catchment. CASI data were acquired over three of the sub-catchments of the Leam (Figure 1).

3.1 Compact Airborne Spectrographic Imager (CASI)

The CASI-1500 is a visible near Infrared (VNIR) hyperspectral sensor which has a swath of 1500 pixels across its field of view. This means that in a single pass, a 3 km swath of land can be scanned at 2 metre resolution and a 1.5 km swath at 1 metre resolution. Data can be captured at a resolution as fine as 50 cm, although the trade off with finer resolution is increased flying time and cost and generally reduced capture area. The instrument is capable of measuring reflected light in 288 separate wavebands. The Environment Agency usually operates CASI with our TerraCoast band set which comprises 19 wavebands in the visible and Near Infrared (NIR) regions of the electromagnetic spectrum (Figure 5).

![Figure 5 Showing the wavebands captured using the EA standard TerraCoast band-set (blue horizontal bars).](image)

CASI data were acquired on the morning of 12th August 2012 in blue sky conditions. It is important for these data to be acquired in these conditions as it ensures that lighting conditions across the scene are as uniform as possible. Cloud shadow can
disrupt the potential usefulness of the CASI data because a lot of work needs to be done to mitigate these effects before automated classifications can be performed.

These data were acquired at a flying height of approximately 3000 metres above ground level, meaning that each pixel in the imagery represents 1.5 x 1.5 metres on the ground, using the standard EA TerraCoast band set. It took approximately 1 hour to capture these data over 9 separate flight lines. These flight lines were stitched together to form a single image mosaic.

A plot of the CASI imagery captured for this project can be seen in Figure 2. These data will be valuable for targeted projects within a catchment context, for instance where individual sub-catchments require special attention with fine detail resolution and enhanced spectral information.

CASI data is generally more coarse in spatial resolution than aerial photography, however, it has greater spectral resolution. This means that automated interpretation based upon colour is much more likely than with aerial photography. Aerial photography is more ideal for visual interpretation tasks.

3.2 WorldView-2 Optical satellite data

WorldView-2 is a commercial Earth observation satellite owned by DigitalGlobe. It provides commercially available panchromatic imagery of 0.46 m resolution, and eight-band multispectral imagery with 1.84 m resolution.

In many respects, the data captured by WorldView-2 is the most like CASI of any of the satellites. Its spatial resolution is comparable and it collects eight wavebands in the visible and Near Infrared, in a comparable range to the CASI too.

It is capable of capturing data over an entire catchment in a single pass which is a distinct advantage in some respects because there are no problems to contend with.
in terms of lighting condition variations caused by length of time of data capture that may arise with CASI data capture.

The fundamental drawback of acquiring satellite data for a specific project is the lack of flexibility. The data providers are dealing with a worldwide market, meaning it is very difficult to prioritise your data capture. In addition, the WorldView-2 satellite only passes over at 10 o'clock in the morning. It has daily repeat cycle though.

The Environment Agency commissioned the acquisition of WorldView-2 data for the summer of 2012.

Once payment is made the data provider only promises to acquire your data within 60 days of payment, a two month window, dependent on weather conditions; so if there is a wash-off throughout the 60 day period, a refund will be given. This is relatively inflexible if there is a requirement to target specific seasonal cropping cycles.

![The 8 spectral bands of WorldView-2](image)

Figure 7 The wavebands captured by WorldView-2

The coverage plot of WorldView-2 data for this project can be seen in Figure 3. One of the striking features in these data which can be observed in this coverage plot is the brightening effect in the western half of the image. This is likely to be caused by either high level cirrus cloud or by sun-angle induced hotspot effects. Either way, these effects are extremely difficult to remove from the imagery. The data providers stipulate that imagery is acceptable when there is less than the maximum permissible cloud cover in the imagery. It is unclear at this stage whether cloud cover includes high level cirrus that you can see through yet still affects the quality of the imagery.

As with CASI, the benefit of using these data over aerial photography for certain types of mapping is the enhanced spectral resolution enabling automated mapping tasks.
3.3 Light Detection and Ranging (LIDAR)

LIDAR (Light Detection and Ranging) is an airborne mapping technique, which uses a laser to measure the distance between the aircraft and the ground. The aircraft is positioned and navigated using global positioning (GPS) corrected to known ground reference points. This technique results in the production of a cost-effective, continuous terrain map.

Figure 8 Principle of LIDAR data collection

The aircraft flies at a height of about 800 metres above ground level and a scanning mirror allows a swathe width of about 600 metres to be surveyed during a flight, with individual measurements made at 2 m, 1 m, 50 cm or 25 cm intervals. Highly accurate attitude data and post-processed differential GPS enable the direction of the laser pulse and the position of the laser head to be accurately determined, allowing a highly resolved Digital Surface Model (DSM) to be generated. The discrete LIDAR system records the first and last laser pulses to return to the aircraft. In a vegetated landscape, first returns will commonly be from the canopy top and the last returns can be ground hits, if the laser has penetrated through the vegetation canopy. These returns can be used to generate either first return or last return DSMs.

Figure 9 Principles of first and last return LIDAR capture

Although both datasets present information about surface objects, for vegetation analysis the first return DSM can provide a greater level of information than the last return DSM.
The first and last return DSMs are both true reflections of what is present on the landscape. On the other hand, a Digital Terrain Model (DTM) is a topography dataset which has had the surface objects removed. Geomatics has generated bespoke algorithms to remove surface features from the DSM, including vegetation and buildings.

LIDAR data were captured for the whole of the Leam catchment (Figure 4) and processed to a standard vertical accuracy of better than 6 cm Root Mean Square Error.

These data were filtered to remove surface objects such as trees, shrubs, buildings, vehicles and bridges.
4 Basic Products from LIDAR data

LIDAR data are very powerful for making very rapid assessments on the character and condition of the landscape. With very minimal manipulation, the following products can be gleaned:

- **Digital Surface Model (DSM)** - This is the height data of the landscape where the surface objects (trees, scrub, buildings, bridges etc) are included in the data.

- **Digital Terrain Model (DTM)** - This is the height data of the landscape where the surface objects (trees, scrub, buildings, bridges etc.) have been removed through variety of complex processes. This has included in the basic products here even though it is much more than a basic manipulation as it is a standard product that is delivered when LIDAR data capture is commissioned.

- **Shaded relief maps** - These maps are produced by casting an artificial illumination across the digital surface model. The data then comes to life to be displayed in a way that the brain can understand it because of the texture and context from light and shadows the illumination produces. Without this illumination, it is very difficult to visually interpret the LIDAR data. By adjusting the illumination appropriately it is possible to see surface expressions of less than 5 cm in height.

- **Surface object models** - These are produced by simply subtracting, pixel by pixel, the DTM from the DSM. What remains is the height of the surface objects. This is a very powerful tool for mapping the height and extent of vegetation in wood and scrublands. It can also be used for mapping the height, extent and condition of hedgerows (Figure 10).

- **Slope** - Each pixel in the imagery can be assigned a slope value in degrees or as a percentage, based on the relative height of the neighbouring pixels.

- **Aspect** - These maps show direction a pixel is facing based upon the relative heights of the neighbouring pixels. In conjunction with slope, these data can have many uses, for instance in determining suitability for planting particular crops.

- **Contours** - These are line features that connect locations of the same height.

- **Flow paths** - These are a powerful way of visualising the most likely overland flow routes of water based upon topography alone. They do not, in their raw form, account for soil type and saturation levels or climatic data (Figure 10).

- **3D visualisation** - Aerial photography or any other format of spatial data can be overlaid on top of a LiDAR DSM to render it into a virtual 3D world (Figure 10). This is extremely useful for putting the data into a real-world context. As an example, view-shed analysis can be quickly performed, calculating what you would be able to see if you were standing in a particular location.
Figure 10 Three images of the same location demonstrating some of the basic products of LIDAR. The top image shows aerial photography data draped over LIDAR DSM data. The centre image shows the surface objects isolated and classified (blue = hedgerows, green = trees, red = low scrub and orange = tall scrub. The lower image shows the LIDAR derived main overland flow pathways.
5 Study Topics

1. Overland flow modelling
2. Defining topographic catchments
3. Bare soil modelling
4. Riparian vegetation cover and shading
5. Channel realignment
6. Crop management mapping
7. Field boundary mapping

5.1 Overland flow modelling

Being able to predict the fate of a fertiliser or pesticide applied in a field is key to understanding the risks involved in that application. LIDAR data can be used to help predict overland flow paths of water. In reality, it is part of a complex chain of modelling which in isolation should be treated with some caution as some assumptions are made in this stage of the modelling. These are:

- There is no drainage into the soil (i.e. coming from a position of either hard surface or 100% saturation of soil)
- There is no account taken for potential variations in microclimate across the scene.

These are factors that can be built into more advanced modelling.

Figure 11 to 16 have been extracted from ArcGIS helpfiles to describe flow modelling in the Agency standard GIS software. The hydrologic modelling functions in ArcGIS Spatial Analyst provide methods for describing the physical components of a surface. The hydrologic tools allow you to identify sinks, determine flow direction, calculate flow accumulation, delineate watersheds, and create stream networks (Figure 11).

Figure 11 Stream network derived from an elevation model.
Using an elevation raster or digital elevation model (DEM) as input, it is possible to automatically delineate a drainage system and quantify the characteristics of the system. The following graphics illustrate the steps involved in calculating a watershed and stream network from a DEM.

Figure 12 The DEM on which the hydrologic analysis will be performed.

Figure 13 A schematic representation of Flow Direction

Using the DEM as input into the Flow Direction tool, the direction in which water would flow out of each cell is determined. (Figure 13)
With the Sink function, any sinks in the original DTM are identified. A sink is usually an incorrect value lower than the values of its surroundings. The depressions shown in the graphic above (the scattered coloured points) are problematic because any water that flows into them cannot flow out. To ensure proper drainage mapping, these depressions can be filled using the Fill tool in ArcGIS. (Figure 14)

Using the Watershed tool in ArcGIS, the watersheds are delineated for specified locations. However, if you only want to calculate the stream network, this step can be ignored. (Figure 15)
Figure 16 Flow accumulation output image

To create a stream network, the Flow Accumulation tool in ArcGIS is used to calculate the number of upslope cells flowing to a location (Figure 16). The output of the Flow Direction tool from Figure 13 is used as input for this tool.

Figure 17 showing a hypothetical stream order based upon flow accumulation

Thresholds can be specified on the raster derived from the Flow Accumulation tool; the initial stage is defining the stream network system. This task can be accomplished by using conditional Boolean statements within ArcGIS’s Map Algebra. An example of a conditional Boolean statement might be:

\[
\text{newraster} = \text{con}(\text{accum} > 100, 1).
\]
All cells with more than 100 cells flowing into them will be part of the stream network. Apply the Stream Order tool to represent the order of each of the segments in a network. For the purposes of the Leam Catchment, the stream order hierarchy chosen was 1km$^2$, 1Hectare, 1000m$^2$. (Figure 18)

To enforce the drainage so it adheres to known watercourses, it is possible to burn these known watercourses into the LIDAR imagery. So, for the Leam Catchment, the Detailed River Network (DRN) which is based upon OS MasterMap data was burnt into the LIDAR data to ensure that drainage derived during the processing is consistent with the DRN. This may seem slightly circular in logic, however what this does is ensure that culverts, bridges etc that may have been overlooked during the DTM filtering stage are ignored in the flow analysis.

![Drainage channels on LIDAR data](image)

**Figure 18** This image shows an example of drainage hierarchy based upon standard units of area measurement that could be considered to be field scale appropriate. Each of the cyan colour has a theoretical minimum of 1 hectare’s worth of pixels draining into it and each of the dark blue lines has a minimum of 1 square kilometres draining into its entire length. These drainage calculations have been carried out for the entire Leam Catchment using the 1000 m$^2$, 1 hectare and 1 km$^2$ hierarchy. These are thresholds which can be set in ArcGIS. The red circle highlights a patch of bare ground which coincides with a 1 Ha flow path.

ArcHydro is a powerful set of tools which can be used to manipulate LIDAR data to aid in modelling of overland flow. It is a free bolt on extension to ArcGIS. One example of a tool in ArcHydro is the Flow Path Tracing tool. The Flow Path defines the path of flow from a selected point following the steepest descent. This can be extremely useful for analysing pathway risk of applying a pesticide or fertiliser in a given location. It can give an indication of which watercourse it is likely to end up in (Figure 17 and Figure 20).
A series of images of outputs from the flow path tracing tool built into ArcHydro, which is a free plug-in to ArGIS. The technique assumes that water drains overland using the steepest descent rather than sinking into soil and that there is no surface spread. The yellow points indicate where the flow path is being measured from.
5.2 Bare Soil Mapping

CASI data were used to help in mapping areas of bare soil. It was not possible to really identify the causes of the existence of bare soil in each instance as there are too many. In many instances though, it would be caused by livestock poaching. A semi automated technique was used to map the bare soil throughout the Rains Brook sub catchment. The method is outlined below:

- **Step 1** - Identify locations of Bare Soil using visual interpretation in the true colour and false colour Near InfraRed (NIR) composite image (Figure 22).

- **Step 2** - Create vegetation index from NIR and red band of CASI data (Figure 23). This is a greyscale image layer created by dividing the Near Infrared channel of the CASI imagery by the Red channel. In areas of vigorous vegetation there is a large difference in the reflectance between these two wavebands, up to ten times greater reflectance in NIR than red with healthy grass and approximately equal reflectance in NIR and Red for bare soil (Figure 21).

- **Step 3** - Assign a vegetation index threshold to each of the regions identified with bare soil which reflects the outline of bare soil most appropriately (Figure 24).

- **Step 4** - Convert index layer to binary (classified) layer of Bare soil/Non bare soil using above mentioned thresholds.

- **Step 5** - Overlay overland flow routes and slope maps for more in depth risk analysis.
Figure 21 showing the difference in spectra as measured by 19 waveband CASI data between Healthy Grass and Bare Soil.

Figure 22 Step 1 - Approximate location of bare soil delineated.
Figure 23 Step 2 - Vegetation index created by dividing the NIR layer by the Red layer. The brighter the area, the more likely it is to be vegetation, the darker the area, the more likely it is to be non-vegetation.

Figure 24 Step 3 - Assigning vegetation index to each region identified to have bare soil in. In this case, the redder the pixel, the more likely it is to contain bare soil.
Figure 25 Step 4 - Here the Bare Earth patches have been fine tuned using the vegetation index. They are outlined in red.

Figure 26 Here the Bare Soil patches (Red) have been overlaid onto a LIDAR DSM. The 1km² (Dark Blue) and 1Ha (Cyan) drainage lines have been included too. A Slope map has also been superimposed Showing where the steepest regions are (Dark Green = steep slope, Light Green = medium slope, Grey = insignificant slope).
5.3 Riparian vegetation cover

Using LIDAR data we are able to confidently map the extent and structure of vegetation using the surface object model technique described earlier which is performed by subtracting the DTM from the DSM. We can use MasterMap data to mask out any buildings from this map so we are left with vegetation only. There may be a limited amount of refinement work required by eye to account for any data that is not consistent with MasterMap.

For this study an index was developed which describes the density of vegetation along a river corridor.

- The index required a spatial framework. The river corridor was buffered by 20 metres (this can either be done using the Detailed River Network, which is centre line of the channels or by buffering MasterMap river polygons. The size of the river in question would determine the most appropriate layer to use. For larger rivers, it’s best to use MasterMap Polygons.

- Cross sections across the river were laid every 50 metres to split up the buffered layer into sectors of approximately 50 metres by 20 metres, on both sides of the river channel. The exact size is not too important because the index is based upon a proportion of vegetation cover. These sectors constitute the spatial framework (Figure 27)

- The area of vegetation greater than 50 cm in height in each sector was calculated, as was the area of the sector itself.

- The index = percentage vegetation area over 50 cm in height within each sector. So, for instance, the area covered by vegetation over 50 cm in height is 200 m² within a sector measuring 1000m². The index value would be 100*(200/1000) = 20% (Figure 28 and Figure 29)
Figure 28 Showing the riparian vegetation cover index for a small section of Rains Brook sub-catchment. The more red the colour becomes, the lower the vegetation cover index, meaning less vegetation protecting bank sides and potentially less mitigation against direct overland flow into the water courses, as well as less shading for the riparian fauna.

Figure 29 Showing the vegetation cover index for the whole of the Rains Brook sub-catchment.
5.4 Riparian Shade mapping

5.4.1 Purpose of riparian shade data set

The Environment Agency needs to understand where trees and landform contribute to water channel shading, potentially to reduce mean stream temperatures and create cooler refuges for fish on hot summer days. In particular, fisheries are keen to know where channels are exposed to heating and where new tree planting could help reduce this exposure. This is not a direct measure of water temperature but an indication of how effectively the local area provides shading compared to a neighbouring reach.

5.4.2 The shade maps

Shade maps have been created for a specific number of areas across England and Wales:

**WFD (Water Framework Directive) Management catchments in England and Wales (where coverage is available):** Hampshire Avon, Itchen, Test, Wye, Tyne, Ribble, Frome (Dorset), Adur & Ouse, Don, Wear, Welland, Tone, Ecclesbourne, Leam, Derwent (Derbyshire), Dove, Shropshire middle Severn, West Thames – Cherwell, Wey, Kennet & Pang, Thames – Lodden, Vale of White Horse, Cotswolds, Maidenhead to Surrey, Thames and S Chilterns, Anglian East – South Essex, combined Essex, East Suffolk, Broadland rivers, N Norfolk, Y&NE Region (all), Tamar.

Geomatics have produced rasters of insolation from both the LIDAR Digital Surface Model (DSM) and the Digital Terrain Model (DTM).

Insolation is a measure of solar radiation energy received on a given surface area in a given time.

The Insolation rasters have been produced using the ArcGIS function "Area Solar Radiation", with the date parameters set to May, June, July, August and September, with hourly intervals (every 14 days). The product from the function is a raster of incoming solar radiation in Watt Hours per square metre (WH/m²) for both the Digital Terrain Model (DTM) and the Digital Surface model (DSM).

The Relative Shade map is created from the Surface Objects and is a product of the difference between the DSM and DTM.

The Solar Insolation rasters, with units in WH/m², have then been clipped using Ordnance Survey MasterMap data.

MasterMap Water Feature polygons, that have themselves been clipped and dissolved using a 25mx25m or 100mx100m grid (depending upon the Area team request at the time). These clipped water polygons have been attributed with the Ordnance Survey reference code and overlaid on the hillshade of the DTM.

The resultant maps of relative shade are then produced as a series of PDF maps for each catchment (where there is LIDAR data). An example of one of these PDF maps from the Leam catchment is provided in Figure 30. Maps have been created covering the whole of the Leam catchment to demonstrate relative solar shading along its watercourses.
Figure 30 Showing relative shading of water features along a section of the upper Leam.
5.5 Historic channel realignment

Although there is probably little that can be done to automatically detect stretches that have been significantly realigned either due to natural processes or human intervention, LIDAR data can be manipulated and interpreted to look at where modifications in the landscape have taken place. This is similar to how most LIDAR work for archaeological prospecting is done.

Often we’re looking for fine scale anomalies in the landscape. Fine scale in both height expression and area expression. There are many different types of manipulation of LIDAR data that can be used to find details in the landscape that would otherwise be difficult to detect using other instrumentation, like aerial photography.

Digital Terrain Models (DTM) - These can be used to see through relatively large scale vegetation. LIDAR data in its raw form distinguishes between the first and last return of the laser pulse to the instrument's detector. The first return generally forms an approximate expression of the maximum canopy height; the last return generally provides an expression of the earth's surface, where gaps in the vegetation allow.

Hillshades - These can be manipulated to suit the topography of the area being investigated. One of the strengths of LIDAR data is that it is not a static data source dependent on lighting conditions at the time of survey, as is the case with aerial photography. The artificial light source used to illuminate a DSM or DTM can be set from any angle, even physically improbable ones (e.g. from the North). The lower the altitude of the light source angle, the greater the likelihood of seeing finer scale features.

De-trending the DTM - One of the other techniques we use is de-trending the LIDAR data. This technique is used to essentially flatten the landscape out to remove the macro-topography, while preserving the finer scale detail as far as possible. This is sometimes necessary when the presence of hills or valleys obscures the fine detail being investigated. This is often the case with features at the bottom of a river valley. For the Leam investigation the DTM was de-trended and scanned by eye to see if there were any features that suggested historic channel realignment.

It is important to note that generally the LIDAR data cannot tell you why something has happened, for instance, whether re-alignment has occurred through a natural or anthropogenic process. It does enable you to focus attention in a better targeted way, for instance, informing decisions on where to take a closer look on the ground.

In Figure 31 the image shows some CASI data in true colour, showing a stretch of Rains Brook. Without the Ordnance Survey 10k data overlaid, one might overlook the presence of a brook at all.

The LIDAR DSM hill shade (Figure 32) makes the presence of the river channel more clear than photography and CASI data.

The de-trended LIDAR DTM (Figure 33) makes the presence of the river channel very clear, and also allows the viewer to see the an impression of the historic course of this section of the river.
Figure 31 True colour CASI on a section of Rains Brook with OS 1:10,000 mapping data overlaid. © Crown copyright and database rights, 2012, Ordnance Survey 100024198

Figure 32 This LIDAR DSM hillshade shows the vegetation objects. The river channel is visible in this image diagonally bisecting the image from North East to South West.
Figure 33 The de-trended LIDAR DTM data. The current river channel is clearly visible in these data as a relatively straight line going from North East to South West, as are the impressions meanderings of the old river course. These are highlighted in red on image b).
5.6 Generic crop mapping

One of the potential uses for satellite data and CASI data is generic crop mapping. This is very difficult with just one image as a single snapshot in time to work with, but using two images, the CASI image and the Satellite image which were acquired a month apart from each other, we can start to use some of the differences in the imagery to aid in generic crop discrimination. These data sets can be stacked together to produce a false colour composite that can aid in crop identification (Figure 34).

Crop identification is a difficult area of work using remote sensing data because often the differences in colour between different crops can be very small. You also have to contend with the fact that a similar crop in different fields, or even within a field can be at a very different stage of development. The more generic you can make the class list that you are able to work with, generally, the more accurate it will be.

Figure 35 shows CASI data in true colour. There are some clues in this image that help with certain aspects of identification. For instance, the contrast between the brown fields and the green fields gives us a clue about which fields are in senescence and which have vegetative growth. However, looks can be deceiving. It is only when you view the later satellite data (Figure 36) that, some of the apparently senesced crops are suddenly bright green again. This suggests that the fields may have recently been cut for hay in the CASI image and then the grass recovered during the following month when the Satellite data were captured. When you zoom in you can also see tramlines in many of the fields which may help in identifying those fields that have cereals and those fields which may have been ploughed.

The output of this interpretation can be seen in Figure 37. The spatial framework of the interpretation for Rains Brook is based upon MasterMap field boundaries, which were modified manually to account for any inconsistencies between the image data and MasterMap data. In this sense, it is a kind of object based classification. Rule sets were developed to interpret the image data in a consistent manor, using a combination of automated and visual techniques. Here are some examples of these:

1. Does field contain livestock and its colour largely green - probably pasture
2. Is field very pale in colour in the August imagery and verdant green in September imagery - probably cut grass in August
3. Is field pale brown with tramlines visible in both August and September imagery - probably cereals not yet harvested
4. Is field green with clear tramlines - probably Arable Other e.g. potatoes
5. Is field verdant green with evidence of livestock poaching around gateways and feeding centres - probably pasture
6. Is field brown with tramlines in August but very pale green in September, no tramlines clearly visible? - possibly under-sown cereals
7. Is field medium to dark green in August imagery but very dark, almost purple in colour in September image? - probably Arable Other
8. Is field medium green in August image and September image? - probably pasture
9. Does field contain evidence of archaeological Ridge and Furrow features in LIDAR data and is field medium green in CASI data? - probably pasture.
There are more rules that could be developed given some expert guidance. We have found that having multiple sets of imagery to work with, captured at different times, is crucial for crop identification. Ideally, imagery from as many as 4 key points during the year would give the best possible chance of producing the most accurate generic crop map for that year. Appropriate ground data should ideally be acquired to a) train the interpretation and b) validate the classification.

There may be some crop types that are quite straightforward to detect from a single image, appropriately targeted at the right time of year, for instance Oil Seed Rape.

By integrating a crop map with LIDAR data, overland flow routes and slope, we could potentially build up models of risk in relation to agricultural applications and watercourses.

The orientation of crop lineaments can be determined using CASI or satellite data. When lined up with LIDAR contour lines, it becomes quickly apparent which fields might be at greatest risk of sediment/pesticide/fertiliser runoff due to inappropriate cropping orientation (Figure 38).

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**Figure 34** A false colour composite showing CASI data and WorldView 2 data stacked on together. Generally, in this particular image, the blue-purple-magenta colours represent pasture or grass that has been cut and the green-brown-yellow-orange colours represent arable areas.
Figure 35 True colour CASI data captured over the Rains Brook catchment 12th August 2012

Figure 36 True colour WorldView 2 data captured over the Rains Brook sub-catchment 12th September 2012
Figure 37 Generic crop interpretation map, based upon clues found within CASI data captured on 12th August and WorldView 2 Satellite data captured on 12th September 2012.

Figure 38 The blue arrows indicate the orientation of crop tramline lineaments. In these three fields, as with the one to the far East, these lineaments travel largely in the same direction.
direction of the aspect of the slope, meaning that there may be an elevated risk of runoff from these fields

5.7 Field boundary mapping

This is a technique that was developed for the Dartmoor condition assessment pilot project. There are no modifications required for rolling this out to anywhere we have appropriate data for.

Datasets used

- First return LIDAR data (1 m resolution N.B. Ideally 50 cm data would be used)
- LIDAR DTM data (1 m resolution)
- CASI data
- OS MasterMap road and river layer

Methodology

- Subtract the first return LIDAR data from the DTM layer to produce an object layer.
- This object layer is cleaned to remove scrub and woodland and stone walls using CASI infrared data to assist the process.
- This layer can be converted into a shapefile to describe the outline of the hedgerows.
- The objects raster layer is run through a thinning algorithm to estimate the centre line of the hedgerow.
- Points are positioned every 2 metres along the length of the centre line. This could be made more frequent than 2 m.
- Transects are placed across the centreline at every 2 m point.
- Transects are clipped by the vector outline of the hedgerows.
- The length of the clipped hedgerows is the width of the hedgerow at that point.
- Maximum heights along each of the clipped transects can be extracted from the objects raster layer.

Some screen shots of the methodology and examples of the results follow in Figure 39 to Figure 43.
Figure 39 LIDAR first return hill shade data clearly showing hedgerows

Figure 40 Hedgerow areas are automatically extracted using a DSM minus DTM object extraction technique.
Figure 41 Showing automatic delineation of the hedgerow centre lines. This is a key parameter for determining width of hedgerows.

Figure 42 Showing how widths can be extracted at two metre intervals along the hedgerow.
5.8 Sediment risk modelling with SCIMAP

SCIMAP (scimap.org.uk) is a spatially distributed hydrological model coupled with a landscape erodobility module used to assess the risk of fine sediment delivery to river channels. The key concept in SCIMAP is connectivity to the watercourse. Connectivity is assessed by creating a network index for each cell in the model. The network index is proportional to the probability of connection to the watercourse. This is combined with erosion likelihood to create a landscape risk classification. The model then transports landscape risk to the watercourse and calculates risk loadings.
and risk concentration. A full model description is given in Lane et al. (2005)¹ and Brookes et al. (2003)².

Two SCIMAP – fine sediment models were constructed for the Rains Brook WFD waterbody. Both used LCM2000 land cover data and 1km LTA (61-90) rainfall. The first model was constructed using the composite 10m DTM and the second using a 2m LIDAR DTM. A visual comparison was made between the two models to assess the potential for accurate LIDAR DTMs to improve the efficacy of SCIMAP in predicting fine sediment critical source areas. A higher resolution DTM should allow SCIMAP to more accurately identify flow paths (as small scale flow structures such as tramlines are visible) and therefore calculate better connectivity and landscape risk classifications.

The risk loadings and concentrations generated by the two models cannot be directly compared as SCIMAP scales these relative to the risk generated in each individual model run. However the spatial patterns were similar with the tributary flowing north-westerly from Barby Hill and the smaller tributary flowing south-easterly from Dunchurch having the highest risk concentrations in both models.

The benefit of the LIDAR DTM can clearly be seen in Figure 44 & 45. Figure 44 shows the network index for a small area south of the main channel of Rains Brook. The 2m model clearly shows a series of deep ploughed fields, with the furrows being more connected than the ridges, towards the east of the scene. The same fields in the 10m model show the higher connectivity scores spread across the parcels. The triangular parcel in the south east of the scene shows a broad area of highly connected land branching south in the 10m model, however in the 2m model the highly connected land propagates west and then south (note how this correlates with the ArcHydro calculated flow paths). In both examples SCIMAP with a 2m DTM was better able to represent flow pathways.

A similar pattern is observed in the landscape erosion risk (Figure 45). In the deep ploughed fields the risk generation is confined to the furrows. The large highly risky area to the south of the scene becomes more spatially constrained. Both of these effects should make effective management intervention more practical as the areas to be investigated are more strictly defined.


2 Lane, S N, Heathwaite, A L and Brookes, C J 2005: Where does diffuse pollution come from? A multi-scale risk-based approach grounded in hydrological conductivity; European Geosciences Society General Assembly, Vienna, April 2005
Figure 44 SCIMAP – fine sediment network index. Blue: more connected, Red: less connected. a) Generated from 10m DTM, (b) Generated from 2m DTM. Scale 1cm = 75m
Figure 45 SCIMAP – fine sediment landscape risk. Purple: more connected, Green: less connected. a) Generated from 10m DTM, (b) Generated from 2m DTM. Scale 1cm = 75m
6 Conclusions and Recommendations

This study has delivered the following key outputs:

- Satellite and LIDAR data across the whole Leam catchment
- CASI data across 3 sub-catchments, including Rains brook
- Key products generated across whole catchment
  - hierarchical flow paths
  - shade maps
  - Slope maps
  - Shaded relief maps
  - High resolution catchment boundaries.
- Specific products generated across single sub-catchment for testing. These can be ultimately applied across whole catchments.
  - Bare Earth mapping in conjunction with slope and overland flow maps
  - Raparian vegetation cover mapping
  - Channel realignment scanning
  - Crop management mapping
  - Field boundary mapping.

In order to ensure that further work is well targeted, we now need feedback on which products may be useful in delivering the Agency’s Water Framework Directive obligations and how these might be delivered to the people that need them. We also need to ascertain whether training could be provided to Regional/Area teams so that they can produce these mapping products themselves or whether the Geomatics team would need to produce them. In addition we welcome any feedback on ideas that other teams may have for how these data might be used. The output from this pilot is in no way exhaustive, but it does require some input from stakeholders to provide ideas for potential uses.

During this pilot study we have shown that there would be multi-departmental/agency demand for these data sets for different purposes. It is again important that the requirements of these various stakeholders are well understood to ensure that the data products are targeted to deliver the highest impact outcomes.

This report will be widely circulated and feedback on the specific products actively sought to allow prioritisation. Recommendations for future activities will then be made.
7 List of abbreviations

CASI - Compact Airborne Spectrographic Imager
LIDAR - Light Detection and Ranging
TABI - Thermal Airborne Broadband Imager
DEM – Digital Elevation Model
DSM - Digital Surface Model
DTM - Digital Terrain Model
NIR - Near InfraRed
### 8 Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Boolean analysis</td>
<td>Analysis relating to a combinatorial system devised by George Boole that combines propositions with the logical operators AND and OR and IF THEN and EXCEPT and NOT.</td>
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<tr>
<td>CASI</td>
<td>A multispectral imaging sensor that detects visible and near infrared electromagnetic energy reflected from the earth’s surface.</td>
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<tr>
<td>Digital Surface Model</td>
<td>A digital surface model (DSM) on the other hand includes buildings, vegetation, and roads, as well as natural terrain features.</td>
</tr>
<tr>
<td>Digital Terrain Model</td>
<td>Generally refers to a representation of the Earth's surface (or subset of this), excluding features such as vegetation, buildings, bridges, etc.</td>
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<tr>
<td>Electro-magnetic spectrum</td>
<td>The total range of wavelengths or frequencies of electromagnetic radiation, extending from the longest radio waves to the shortest known cosmic rays.</td>
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<tr>
<td>Error of commission</td>
<td>A measure of the overestimation of class assignment in image classification.</td>
</tr>
<tr>
<td>Error of omission</td>
<td>A measure of the underestimation of class assignment in image classification.</td>
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<tr>
<td>Feature extraction</td>
<td>The process by which an initial measurement pattern or some subsequence of measurement patterns is transformed to a new pattern feature.</td>
</tr>
<tr>
<td>Geomatics</td>
<td>Field of scientific and technical activities which integrates all means used to acquire and manage spatially referenced data.</td>
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<tr>
<td>LIDAR</td>
<td>An airborne mapping technique, which uses a laser to measure the distance between the aircraft and the ground. From this, highly accurate 3D elevation models can be created.</td>
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<tr>
<td>Maximum Likelihood Classifier</td>
<td>A method of image classification that is based on probability.</td>
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<tr>
<td>Multispectral imaging</td>
<td>Two or more images taken simultaneously, but each image taken in a different part of the electromagnetic spectrum.</td>
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<tr>
<td>Near infrared</td>
<td>Infrared radiation extending approximately from 0.7 to 1.3 micrometers and being part of the radiative infrared. Particularly useful in remote sensing of vegetation as vegetation is generally a strong reflector of NIR.</td>
</tr>
<tr>
<td>Normalised Difference Vegetation Index</td>
<td>A measure of the amount and vigour of vegetation on the land surface based on the difference between reflected NIR and red light.</td>
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<tr>
<td>Object based classification</td>
<td>Object-based image analysis is based on information from a set of similar pixels called objects or image objects.</td>
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<tr>
<td>Panchromatic</td>
<td>Imagery taken of all wavelengths within the visible spectrum, though not uniformly.</td>
</tr>
<tr>
<td>Pan-sharpening</td>
<td>Fusing high-resolution gray scale and low-resolution colour images into high-resolution colour images.</td>
</tr>
<tr>
<td>Pixel based classification</td>
<td>Classification based on the information in each pixel.</td>
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<tr>
<td>Term</td>
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<tr>
<td>Raster</td>
<td>A raster is a rectangular grid of picture elements representing graphical data for display.</td>
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<tr>
<td>Red edge</td>
<td>Spectral region at the limit of the red and near-infrared wavelengths characterized by a sharp rise in the plant reflectance.</td>
</tr>
<tr>
<td>Remote Sensing</td>
<td>The science, technology and art of obtaining information about objects or phenomena from a distance (i.e. without being in physical contact with them).</td>
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<tr>
<td>Resolution</td>
<td>Spatial resolution is a measure of the smallest object that can be resolved by the sensor, or the linear dimension on the ground represented by each pixel or grid cell in the image.</td>
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<tr>
<td>RMSE</td>
<td>The root mean square error (RMSE) is a frequently-used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modelled or estimated.</td>
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<td>Shapefile</td>
<td>A set of files that contain a set of points, arcs, or polygons (or features) that hold tabular data and a spatial location.</td>
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<tr>
<td>Spectral radiance units</td>
<td>Radiance and spectral radiance are radiometric measures that describe the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle in a specified direction. They are used to characterize both emission from diffuse sources and reflection from diffuse surfaces. The SI unit of radiance is watts per steradian per square metre ($W \cdot sr^{-1} \cdot m^{-2}$).</td>
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<td>TERRACOAST band set</td>
<td>Geomatics Group's CASI band set. This incorporates visible, red-edge and NIR wavebands.</td>
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<tr>
<td>Triangulated Irregular Network</td>
<td>A digital data vector based structure used in a geographic information system (GIS) for the representation of a surface.</td>
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<tr>
<td>True colour</td>
<td>A colour imaging process whereby the colour of the image is the same as the colour of the object imaged, as perceived by the human eye.</td>
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<tr>
<td>Vector</td>
<td>A straight line segment whose length is magnitude and whose orientation in space is direction. This is the basis for construction of shapefiles.</td>
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