Cranfield UNIVERSITY

National Soil Resources Institute

Monitoring urban sealing from space

The application of remote sensing to identify and measure changes in the area of soil prevented from carrying out functions by sealing

Technical report of GIFTSS project BNSC/ITT/54, Defra code SP0541

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BNSC BRITISH NATIONAL SPACE CENTRE

defra Department for Environment Food and Rural Affairs

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Executive summary

Overview

Urban development presents the greatest driver of soil loss due to sealing-over by buildings, pavement and transport infrastructure. To this end, soil sealing is recognised as one of the major threats to soil. The ability to monitor the rates, types and geo-spatial distribution of soil sealing is crucial to understanding the severity of pressure on soils and their impact on European and global socio-economic and environmental systems.

The overall objective of this work was to test the feasibility of using *space*-derived information to support the Defra Soils Team (ST) in monitoring the extent and pattern of soil sealing. The rate and nature of sealing should be routinely measured in order for it to be managed to best effect. Monitoring soil sealing is intended to be a part of a national soil monitoring scheme and to inform policy creation.

This report identifies appropriate Earth Observation (EO) technology and processing procedures to deliver a range of baseline and monitoring information, and assesses the practical scope for the routine use of EO information to support the delivery of the required tasks of the Defra ST[1].

The project was funded under the British National Space Centre's GIFTSS[2] programme with support from Defra.

The importance of soil

Increasingly, the importance of soil as a natural resource is recognised alongside that of air and water. Soil represents 'natural capital' that provides ecological capacity by delivering a range of functions including food and fibre production, biodiversity, environmental services, landscape and heritage, raw materials and physical platforms for the built environment (Wood *et al.*, 2005). Protection and efficient allocation of soil resources is critical to sustainable development goals because of the long renewal times for soil systems, which make soil effectively a non-renewable resource.

Defra ST has an across-Government responsibility for soil protection. There are a number of existing and anticipated policy developments which are related to soil protection, both directly (*e.g.* The First Soil Action Plan for England: 2004-2006; EC Communication on Soil Protection (2002); Soil Protection Framework Directive) and indirectly (*e.g.* CAP Reform Agreement: cross-compliance on Good Agricultural and Environmental Condition; Water Framework, Habitats, Birds, and Environmental Impact Directives). In view of these policy developments, and their likely monitoring requirements, Defra ST funded the National Soil Resources Institute (NSRI), Cranfield University to produce a summary review of the *"potential of aerial and*

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[1] http://www.defra.gov.uk/environment/land/soil/
[2] Government Information From The Space Sector - http://www.bnsc.gov.uk/

satellite remote sensing techniques for soil monitoring". This report was presented to Defra ST in April 2004. It was concluded that one of the opportunities for remote sensing was in monitoring soil sealing, which is a key threat to soil and its capacity to carry out essential functions.

The definition of soil sealing

Soil sealing describes the covering over of soil through urban development. Although areas of 'sealed' soils are characterised by urban expansion, it is not sufficient to equate the area of soil sealed to urban land-use area.

Soil that is sealed may be defined as being unable to perform the range of functions normally associated to it, other than support of urban infrastructure, *i.e.* a platform function. Perhaps a suitable qualification of whether a soil is sealed or not is to assess whether it is permeable, thus, impermeable surfaces would be, for example, gardens, embankments, and road-side verges, and impermeable (sealed) surfaces, roads, buildings, pavement or any other impermeable material (figure 1).

Figure 1. Example of unsealed soil, in the form of intermittent grass verges, within the built environment. Other areas are sealed by road, pavement and building infrastructure.

Monitoring requirements

Defra and BNSC commissioned Cranfield University[3] and Infoterra Limited[4] to evaluate the use of EO data as a cost-effective method of detecting and quantifying changes in sealed soils and land cover. Below is the list of requirements defined by Defra.

- Baseline data is required on sealed soils in urban areas
- Changes in area of sealed and unsealed soil in urban areas

[3] http://www.cranfield.ac.uk
[4] http://www.infoterra.co.uk/

- Patterns of change in sealed soil area
- Distinguish between green space and brownfield sites
- Soil quality measures
- Scale to identify gardens, parks, roundabouts greater than 2 metres
- User should be able to identify specific areas to direct data collection *e.g.* part of a planned/ongoing development such as the M11 corridor
- The value of the information is not quantified but Defra ST are anticipating that the soil sealing information will form part of a national soil monitoring scheme and underpin policy development.

The feasibility of acquiring this information has already been evaluated through a desk study[5], which concluded that it is likely to be possible to derive appropriate information from EO data (though the spatial resolution of current space-borne sensors would preclude a direct match to the required 2 m object detection). Hence it was concluded as being worthy of a focussed practical implementation test, supported by the Partner Departments, Defra and BNSC.

The routine measurement of sealed soil is not undertaken by Defra because there are no set requirements for doing so, in terms of policy delivery. In the absence of any specific requirements, but in wishing to understand the potential capability for monitoring, Defra requested that an initial specification for a monitoring system would be to investigate the ability to detect instances of sealing with a spatial precision of approximately 4 m^2, and with 90% certainty. Defra were more interested in the detection of larger features than this, but it was anticipated that the higher detail would be of interest across other government departments[6]. Consequently, this work reports on delivering the highest specification using satellite technology.

Estimating the degree of permeability of a surface material is considered beyond the scope of this report. As such, the degree of sealing caused by soil compaction in public green spaces or the use of permeable paving will not be considered. A ‘binary’ indicator, *i.e.* whether a surface is either sealed or unsealed, will define the specification for monitoring.

Earth Observation lends itself to monitoring vegetation. The discrimination between vegetated and non-vegetated urban surfaces provides a surrogate ‘indicator’ for making initial assessments of whether an surface is either sealed or unsealed. For the purposes of this study, therefore, vegetated surfaces will be equated to unsealed soil, and non-vegetated surfaces will be equated to sealed soils. Exceptions to this rule must be noted: bare soil is a non-vegetated surface, but is clearly unsealed. However, in the absence of available evidence, instances of bare soil will be assumed to occur infrequently within the built environment and be considered negligible. This was discussed with the Defra ST and was accepted as a basic assumption to proceed on.

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[5] The use of remote sensing to deliver soil monitoring: http://www.defra.gov.uk/environment/land/soil/indicators/remote-sensing.htm

[6] The 4 m^2 specification is not absolute, and the objective was to seek to achieve the highest detectable resolution possible.

The initial objective of a remote sensing based system would be to provide base-line data on the proportion of sealed soil for any given urban settlement. Over time, the ability to detect changes in the proportion of sealing will allow assessment across a range of socio-environmental applications, including the vulnerability to flooding and other aspects of reduced soil functionality. This, in turn, could improve the planning process for both urban and rural areas.

In so doing, it is expected that Defra ST would accrue the following benefits:

- Improved monitoring and prediction of a key environmental indicator
- Better informed policy decisions at the interface of Defra and the Department for Communities and Local Government (formerly ODPM).
- Informed knowledge to be able to influence and implement the anticipated Soils Framework Directive.

The recommended processing chain

Most reported procedures for utilising EO data for monitoring soil sealing, at best serve to match the spatial scales of already-existing topographic data available to Defra (*i.e.* OS MasterMap®), and there is clearly no advantage in replicating routinely collected data. At the scale requested by the Defra ST, this existing topographic data is adequate for mapping roads, pavement and buildings, but it does not contain specific information on the sealed vs. unsealed mix in remaining areas, *e.g.* gardens, or other private green spaces. Often these are simply identified is associated databases as ‘mixed’ surfaces.

Given the background to monitoring urban areas by remote sensing, the literature points towards an approach that uses 2-4 m resolution satellite data, with infrared capability (Herold *et al.,* 2003). However, in the absence of a clearly proven methodology for Defra’s specific requirements of monitoring sealing at the size of a typical UK garden, it was necessary to develop an approach that extended any work already reported.

The basis of our recommended configuration for a demonstration system also stemmed from work carried out in Dresden, Germany (figure 2). Dresden’s Office for Urban Drainage Systems sanctioned the mapping of sealed areas by aerial image mapping. Orthorectified 1:50,000 scale aerial photography was digitized stereoscopically (with 3D vision) and interpreted to include soil sealing values for the whole city of Dresden; over 300,000 polygons. This was carried out within their Authoritative Topographic Cartographic Information System (ATKIS[7]). The mapping was completed with a positional accuracy of less than 0.2 m. It was not the intention to duplicate the survey using the ATKIS approach (Meinel and Hernig, 2005), but to develop similar products to theirs (*e.g.* figure 2) but using semi-automated image classification of EO data.

Ordnance Survey MasterMap® topographic data would be used as the base map. In areas that cannot be identified as 100% sealed from the topographic data (e.g. areas other than roads, buildings, or pavement) high resolution satellite data

[7] http://www.atkis.de/metainfo/metainfo.meta_start_produkt?prod_id=54&inf_sprache=eng

(*e.g.* Quickbird) would be classified using a derived index of vegetation presence as a surrogate for unsealed soils.

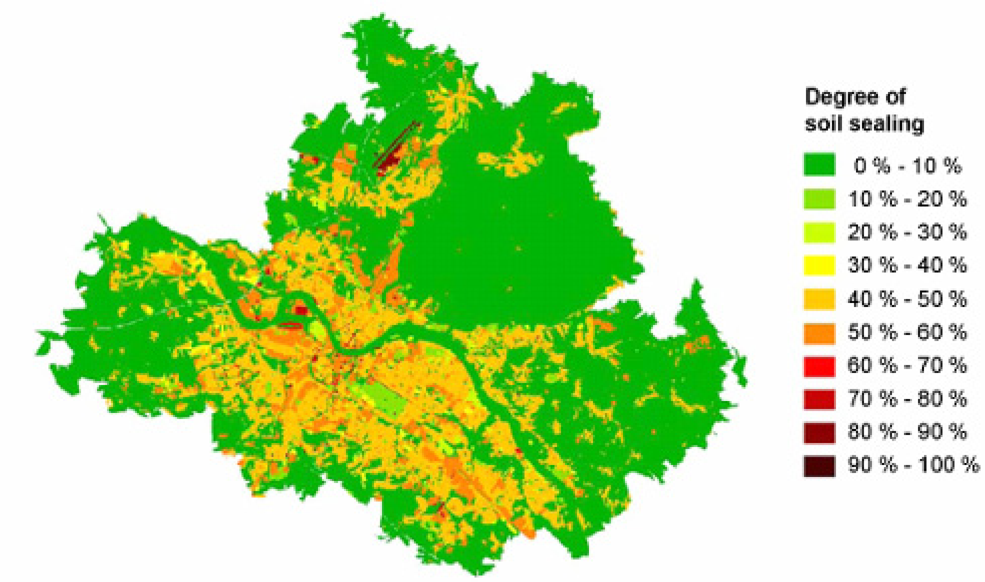

Figure 2 Soil sealing in Dresden, Germany (Meinel & Hernig, 2005)

An outline of the monitoring methodology is presented in figure 3, and utilises two principal data sources: i) OS MasterMap®, which is 1:1250 scale digital topographic map data, and ii) EO data, namely Quickbird (or Orbview-3, or IKONOS) imagery, which is 2.8 m pixel resolution, multi-spectral (including near-infrared) satellite image data.

Essentially, OS MasterMap® data provides a regularly updated, definitive map of what is known to be sealed surfaces, *e.g.* roads, buildings and pavement. In remaining areas, comprising gardens and other 'green' spaces, knowledge of the sealed or unsealed nature of a land parcel is either uncertain or unknown. Earth Observation images are used to investigate and classify these remaining areas. After matching the EO data to the Ordnance Survey mapping system (geocorrection) a Normalised Difference Vegetation Index (NDVI) image is calculated and extracted, which enhances the presence of vegetation in the image. A statistical, probability-based pixel classification of the NDVI serves to classify the image into unsealed and sealed surfaces (i.e. each pixel is tagged as being either vegetated and non-vegetated). The derived data sets from the two data sources are then reconstituted to produce a single combined map of sealed and unsealed land.

Metadata

As part of any operational service, it is important that data being captured on behalf of Defra is captured with metadata[8] and that this metadata complies with nationally recognised standards. Any operational data capture should conform to Defra's SPIRE standard as this is the most comprehensive standard, it is the *de facto* spatial standard for Defra, and it ensures full compliance with other national profiles like UK-Gemini.

[8] Metadata is associated database information about stored data sets (e.g. the soil sealing maps) which should include, for example, how, when, by whom it was acquired, created and quality-checked; how/if it is has been modified and when; how it is formatted; and how it should be used, including the original purpose of the data; and any associated accuracy assessment data.

Furthermore, the operational service will ensure that the GI Gateway, which acts as a central repository for metadata relating to spatial datasets within the UK, is populated with the metadata that is captured for the service. This ensures that users are aware that the data is available and conforms to best practice as laid out by e-government initiatives. Metadata will also be supplied to the SPIRE programme to ensure that a consistent record is held for Defra.

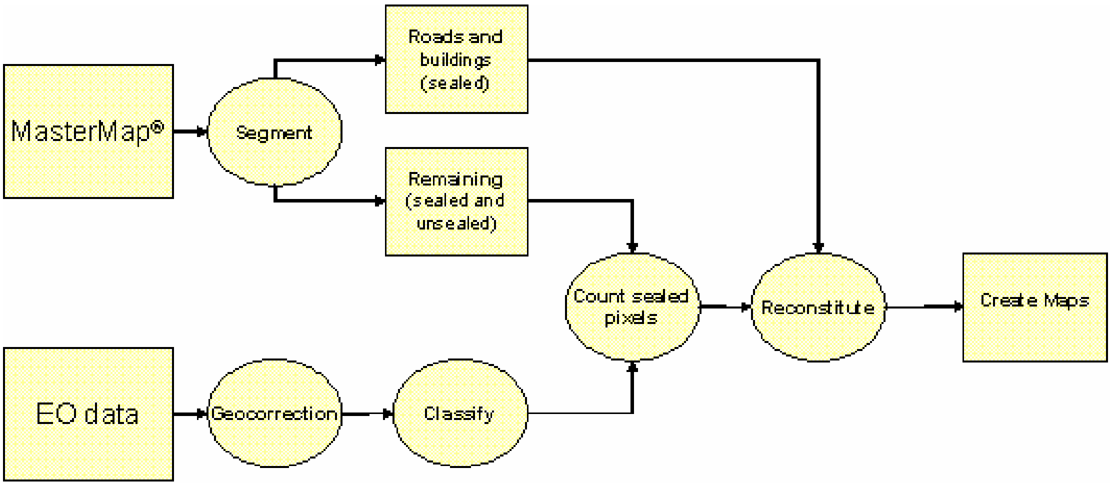

Figure 3. Outline methodological process for deriving sealing maps.

Operational feasibility

It was demonstrated that a user-directed operational system, directed at target cities every five years, is possible. It is noted that whilst the acquisition of high resolution satellite imagery for all[9] major cities in England and Wales (9,000 km^2) over a five year window is feasible, it does represent a significant tasking requirement. It is considered that there would be insufficient capability to acquire all 9,000 km^2 from a single satellite, *e.g.* Quickbird alone. Consequently, multiple satellites[10] working together could provide sufficient capacity.

In England and Wales the biggest influence on the operational collection of optical imagery is cloud cover. Whilst cloud-cover remains a significant issue with regards to large-scale optical imagery collection, in the UK, it is possible to acquire sufficient suitable imagery over targeted areas that are historically cloud-cover poor areas for image acquisition.

The total budgetary price for an operational sealing project would be around £250,000. The total costs for processing 9,000 km^2 of imagery would be about £137,000, and the total data costs would be about £113,000. It is noted that the costs that are included within the report are based on the use of Quickbird imagery,

[9] All urban areas with a population of greater than 50,000 people. This covers a total area of approximately 9000km2, and includes Sheffield, Reading, Northampton and Portsmouth; smaller towns such as Lancaster, Canterbury or Winchester do not have sufficient population and, therefore, were not considered
[10] Multiple satellites of approximately the same resolution, *e.g.* Quickbird, Orbview-3 or Ikonos

therefore, the £250,000 value is based on this imagery price – the prices of comparable sensors do vary but are similar; are based on May 2006 prices; and all prices are subject to change.

The assumption present in the report is that SPIRE, as a Defra programme, will provide storage and processing at no cost. However, this is a point that is under discussion within Defra, who has yet to decide how it wants to charge projects for access and storage costs. The storage costs are minor and if SPIRE were to cease to develop today then the soils team could store the data themselves, but at little additional cost. The principal costs would be in sourcing OS MasterMap® in a suitable format, as a centralised repository; a key goal of SPIRE is to remove the cost overhead of individual projects each processing MasterMap® and to provide projects with data in a format they can use. If SPIRE was unable to provide this service then the soils team or their contractor would need to undertake the necessary preparation work which would incur an additional pre-processing cost.

Mapping accuracy

The mapping accuracy at an individual land parcel level, *e.g.* a residential garden, is 44%, if the polygons that are classified using the MasterMap® *i.e.* the 100% sealed class are ignored. In other words, this represents the inherent EO-derived classification accuracy at the garden level. Individual class accuracy of the EO-derived classification is better (73%) for parcel sizes greater than 300 m^2.

The mapping accuracy is affected by the presence of a high number and density of urban trees. The air-photo interpretation combined with some ground checking revealed that in places where parts of gardens were sealed, land was sometimes obscured from above by tree canopies. The nature of using vegetation as an indicator of unsealed soil means that sealed land parcels will naturally be mis-classified by remote sensing if obscured by overlying vegetation (trees) – because this is what the sensor 'sees'. Most gardens in Cambridge are at least bordered by trees. This is possibly why the individual accuracy of parcels, for example, classified as 25% sealed, can be as low as 40-50%. When considering larger parcels of land (*e.g.* larger gardens and parks) this obscuring effect is reduced proportionally, although trees will still have an effect on accuracy.

It was demonstrated that it is better to re-present the maps using larger basic mapping units, than individual gardens, in order to achieve an overall mapping accuracy of over 90%. The recommended unit size is 50 x 50 m units (figure 4) using either regular pixels or real-world aggregations of individual land parcels, *e.g.* into associated groups of gardens. In the case of Cambridge City the accuracy of the data on a 50 m grid was 92%.

Assuming that maps are produced in a similar way for subsequent dates, and given that the observed Least Significant Difference (LSD) for Cambridge was *c.*16%[11], this would indicate that a real-world change in sealing levels greater than this amount would need to occur before any statistical confidence (at the 95% limit) could be placed on any mapped changes within the city. This is the estimate of change

[11] 2 x (100%-92%) = 16%

detection for the individual 50 x 50 m units. Consequently, maps of change in sealing within a city could be produced with robust statistical confidence, providing the measured change exceeds the LSD.

Extending to a whole town or city, if mapped variation within the city is not a requirement and only total amounts are required, estimates of sealing were shown to have an accuracy of over 95% using the regression estimator – this equates to an error of around 80 ha, out of 4070 ha for Cambridge. An LSD is estimated to be 10%, or 16 ha, representing the difference in the amount of sealing required before confidence can be put on any estimated changes over time.

Cost benefit of digital image classification

A cost-benefit analysis revealed clear benefits in favour of satellite remote sensing over-and-above undertaking the mapping of soil sealing by a detailed census[12] of a whole city. The digital classification of the satellite data cost approximately two orders of magnitude less than the detailed air photo interpretation. For Cambridge, the estimated costs were £1100 compared to £145,000.

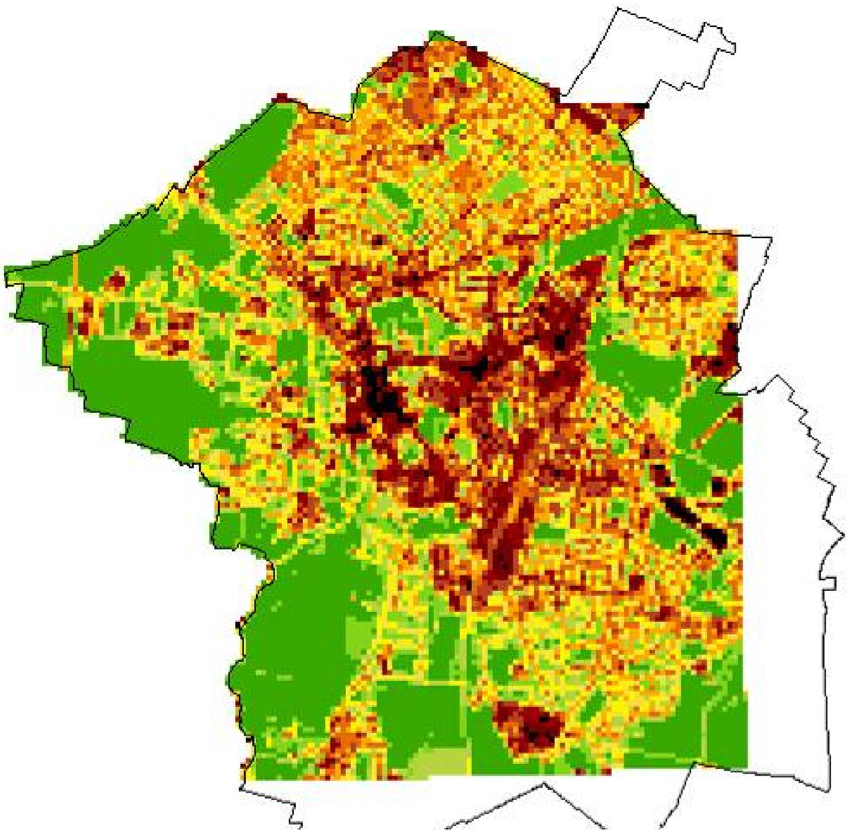

Figure 4. Classified map of sealing for Cambridge City district, 2003, resampled to a 50 m pixel indicating a 92% confidence (the blank areas represent areas outside of the Quickbird scene used in this study).

[12] By manual interpretation of 0.125 m aerial photography; ground survey is not logistically possible in private, residential gardens.

Demonstration of value-added information

The work has hitherto presented the potential to produce maps of sealed and unsealed land. In addition to this, a number of possibilities for adding value to maps of sealing were investigated, namely biodiversity value, drainage impacts and aesthetic impacts of sealing.

Biodiversity value

Remaining areas of unsealed land contribute to urban biodiversity. Measures of its fragmentation and interconnectivity offer the potential to value unsealed land and to estimate a cost of soil sealing. The work undertook exploratory analysis to determine the feasibility of assessing biodiversity value from the main work undertaken.

Indicators of biodiversity were determined, and pursued in two ways: modelling dispersal, using computer models to simulate animal movement from one unsealed area to another; and by measuring fragmentation and the size of the effective interior size of urban green spaces. This work indicates that it is realistic to envisage a toolkit based on a GIS system enabling planners to make robust decisions in the variety of contexts in which they operate. This will become particularly important if the concept of environmental constraints and limits is accepted as a principle. Further development is needed to realise this potential.

Drainage impact

Drainage impact was investigated at a coarse scale of 1 km^2 grids, by integrating national soil data. This indicated the potential contribution of the soil sealing data to large catchment scale modelling to aid catchment management plans for flooding and water quality. With better resolution soil data for the urban areas, the integration of soil sealing maps with Sustainable Urban Drainage Systems (SUDS) design offers considerable potential benefits to sustainable urban planning.

Aesthetic impacts

The assessment of aesthetic impacts of sealing was limited, but some useful findings were noted. Limitations existed because aesthetic value is based on a complex mix of attributes offered by the green space and not just on an impression of what is or is not sealed over. Trees, tree type, relief, tranquillity, etc., all contribute to the aesthetic.

Trees can be visually identified in aerial photography and, to a large extent, from high resolution satellite data as used in this project; and could be linked to the green space function to identify areas with greater depth and variety, which may be more preferable to monocultural vegetated areas (large expanses of grass).

A simple index model linking distance to green space and value is presented allowing summary statistics to be produced and to rank cities or urban sub-regions (districts) according to access to green space. One possible application of this would be, in areas with a low index, to impose planning restrictions to further increases in sealing on the basis of impacts on human health, well-being factors (re. rights of access). Conversely, green-space planning could be better informed to enhance social inclusion and cohesion in potentially sensitive urban areas. Further development is needed to realise this potential.

Recommendations

Based on the results for the Cambridge City pilot study, we recommend that an operational monitoring system is implemented, but that an extended feasibility study of the methods presented is carried out. This will provide a more robust indication of the levels of certainty that can be delivered nationally. It is not recommended to implement the proposed methods operationally until this verification work has been undertaken. Otherwise, we are confident that a cost-effective monitoring system is possible that satisfies the requirements set out by Defra's Soil Team: for a five-year rolling system for monitoring changes in sealing within the built environment.

One of the drivers behind the commissioning of this report was the apparent increase in the instances of sealing-over of front gardens – to provide off-street parking in densely populated residential areas. Defra ST wanted to see whether EO data could be used to monitor this level of detail. The contributory effect of sealing over of front gardens is included in the estimates of sealing in as much as it is included in the aggregated estimates, either over a block size of 50 x 50 m, or in the average estimate for a whole city. However, a specific estimate relating to individual front gardens *vis-à-vis* other types of sealed land use is not possible using the current satellite systems. This is principally due to the spatial resolution of current satellite data.

Some additional opportunities for monitoring soil sealing of front gardens and other smaller, unregulated areas where important sealing occurs, may be afforded by using airborne imagery (*e.g.* with 0.25-0.5 m ADS40 imagery). The space sector derived maps of sealing presented in this report could be used to target airborne surveys more cost effectively in areas where significant changes in sealing have been estimated. Similar methods to those reported here could be used to investigate this further. Other factors would need to be considered such as acquisition cost, processing and storage costs of larger amounts of (higher resolution) data.

1. Introduction

Overview

Urban development presents the greatest driver of soil loss due to sealing-over by buildings, pavement and transport infrastructure. To this end, soil sealing is recognised as one of the major threats to soil. The ability to monitor the rates, types and geo-spatial distribution of soil sealing is crucial to understanding the severity of pressure on soils and their impact on European and global socio-economic and environmental systems.

The overall objective of this work was to test the feasibility of using *space*-derived information to support the Defra Soils Team (ST) in monitoring the extent and pattern of soil sealing. The rate and nature of sealing should be routinely measured in order for it to be managed to best effect. Monitoring soil sealing is intended to be a part of a national soil monitoring scheme and to inform policy creation.

This report identifies appropriate Earth Observation (EO) technology and processing procedures to deliver a range of baseline and monitoring information, and assesses the practical scope for the routine use of EO information to support the delivery of the required tasks of the Defra ST[13].

The importance of soil

Increasingly, the importance of soil as a natural resource is recognised alongside that of air and water. Soil represents 'natural capital' that provides ecological capacity by delivering a range of functions including food and fibre production, biodiversity, environmental services, landscape and heritage, raw materials and physical platforms for the built environment (Wood *et al*., 2005). Protection and efficient allocation of soil resources is critical to sustainable development goals because of the long renewal times for soil systems, which make soil effectively a non-renewable resource.

Defra ST has an across-Government responsibility for soil protection. There are a number of existing and anticipated policy developments which are related both directly (*e.g.* The First Soil Action Plan for England: 2004-2006; EC Communication on Soil Protection (2002); Soil Protection Framework Directive) and indirectly (*e.g.* CAP Reform Agreement: cross-compliance on Good Agricultural and Environmental Condition; Water Framework, Habitats, Birds, and Environmental Impact Directives) to soil protection. In view of these policy developments, and their likely monitoring requirements, Defra ST funded the National Soil Resources Institute (NSRI), Cranfield University to produce a summary review of the *"potential of aerial and satellite remote sensing techniques for soil monitoring"*. This report was presented to Defra ST in April 2004. It was concluded that one of the opportunities for remote sensing was in monitoring a key threat to the capacity of soils to carry out their functions: soil sealing.

[13] http://www.defra.gov.uk/environment/land/soil/

The definition of soil sealing

Soil sealing describes the covering over of soil through urban development. Although areas of 'sealed' soils are characterised by urban expansion, it is not sufficient to equate the area of soil sealed to urban land-use area.

Soil that is sealed may be defined as being unable to perform the range of functions normally associated to it, other than support of urban infrastructure, *i.e.* a platform function. Perhaps a suitable qualification of whether a soil is sealed or not is to assess whether it is permeable, thus, impermeable surfaces would be, for example, gardens, embankments, and road-side verges, and impermeable (sealed) surfaces, roads, buildings, pavement or any other impermeable material (figure 1.1).

Figure 1.1. Example of unsealed soil, in the form of intermittent grass verges, within the built environment. Others areas are 'sealed' by road, pavement and building infrastructure.

Monitoring requirements

The routine measurement of sealed soil is currently not undertaken by Defra because there are no set requirements for doing so in terms of policy delivery. In the absence of any specific requirements, but in wishing to understand the potential capability for monitoring, Defra requested that an initial specification for a monitoring system would be to investigate the ability to detect areas with a spatial precision of $4m^2$, and with 90% certainty. Defra were more interested in the detection of larger features than $4m^2$, but it was anticipated that the higher detail would be of interest across other government departments. Consequently, this work reports on delivering the highest specification using satellite Earth Observation.

Estimating the degree of permeability of a surface material is considered beyond the scope of this report. As such, the degrees of sealing caused by soil compaction in public green spaces, or the use of permeable paving, will not be considered. A 'binary' indicator of whether a surface is either sealed or unsealed will define the specification for monitoring.

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The initial objective of a remote sensing based system would be to provide base-line data on the proportion of sealed soil for any given urban settlement. Over time, the ability to detect changes in the proportion of sealing will allow assessment across a range of socio-environmental applications, including the vulnerability to flooding and other aspects of reduced soil functionality. This, in turn, could improve the planning process for both urban and rural areas.

In so doing, it is expected that Defra ST would accrue the following benefits:

- Improved monitoring and prediction of a key environmental indicator
- Better informed policy decisions at the interface of Defra and the Department for Communities and Local Government (formerly ODPM).
- Informed knowledge to be able to influence and implement the anticipated Soils Framework Directive.

Defra and BNSC, under BNSC's GIFTSS[14] programme, commissioned Cranfield University[15] and Infoterra Limited[16] to evaluate the use of Earth Observation (EO) as a cost-effective method of detecting and quantifying changes in sealed soils and land cover. Below is the list of requirements defined by Defra at the outset.

- Baseline data is required on sealed soils in urban areas
- Changes in area of sealed and unsealed soil in urban areas
- Patterns of change in sealed soil area
- Distinguish between green space and brownfield sites
- Soil quality measures
- Scale to identify gardens, parks, roundabouts greater than 2 metres
- User should be able to identify specific areas to direct data collection *e.g.* part of a planned/ongoing development such as the M11 corridor
- The value of the information is not quantified but Defra ST are anticipating that the soil sealing information will form part of a national soil monitoring scheme and underpin policy development.

[14] Government Information From The Space Sector - http://www.bnsc.gov.uk/
[15] http://www.cranfield.ac.uk
[16] http://www.infoterra.co.uk/

The feasibility of acquiring this information had already been evaluated through a "desk study[17]", which concluded that it is likely to be feasible to derive appropriate information from EO data. Hence it was concluded as being worthy of a focussed practical implementation test, supported by the Partner Departments, Defra and BNSC.

This report identifies appropriate EO satellite technology, ancillary data and processing procedures to deliver a range of baseline and monitoring information, and assesses the practical scope for the routine use of EO information to support the delivery of their required tasks.

Work programme overview

The work was completed in two phases. Phase 1, reviewed the existing evidence relating to satellite systems and processing methods for monitoring soil sealing, and proposed a recommended configuration for a demonstration system. From phase 1 an outline was presented of the proposed sensors, systems, surface datasets and processes to be used to derive sealed soil statistics and a path to support the routine delivery of the output products to be derived from satellite data. An indication of the expected accuracy and timeliness of output was also reported based on a pilot demonstration of the recommended procedures. The aim of phase 1 was:

To review the technology available and the levels of accuracy associated with them. To identify gaps in technology, software, systems and their accuracy and to recommend implementation system to meet possibly evolving Defra ST requirements.

Task 1.1 Identify the appropriate satellite systems and best available algorithms and processing method to provide the required parameters.

Task 1.2 Report and recommend methodology and processing chain for a demonstration system.

Phase 2 extended the procedures tested in phase 1, refining the classification procedure where feasible. The main developmental aspects were to review and develop approaches to produce maps, derived from the soil sealing maps, that indicate biodiversity value, aesthetic value, drainage risk, and to derive associated statistics, where feasible, from them. Outline recommendations for developing these products, including a review of their likely accuracy and any limitations, is reported.

Finally, the project determined the issues relating to operational feasibility and the integration into Defra's existing and proposed soil monitoring procedures, and reports the opportunities and limitations for scaling up the trial study to a routine, national operational activity; this deals with technical issues, such as the continuity of current sensors and future technologies, as well as logistical, economic and human resource issues. The aim of phase 2 was:

[17] The use of remote sensing to deliver soil monitoring: http://www.defra.gov.uk/environment/land/soil/indicators/remote-sensing.htm

To implement an agreed test methodology and processing chain aimed at a practical test using satellite data obtained within the course of the project, from archived and current sources.

Task 2.1 – Specify a demonstration system .

Task 2.2 Demonstrate a range of outputs from the system including

- Maps of area sealed and unsealed soil, land cover, aesthetic quality of unsealed soil, value of soil for biodiversity.
- Statistics on area sealed to include pattern of sealing, permeability of the unsealed soil, drainage risk, proportion of sealed front gardens and biodiversity
- Provision of data and information for planning, response to Soil Action Plan and EU Thematic Strategy on Soil Protection
- Comparison of current and archived information
- Flexible user-directed service *e.g.* directed at target city each 5 years, directed at development areas
- Statistics to demonstrate the accuracy of the system

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Task 2.3 Include a benefit / cost comparison of the inclusion of satellite derived information within existing processes.

Task 2.4 Provide recommendations for the implementation of an operational system including; the continuity of data, the reliability and the expected costs of operation.

Report structure

Section 1 Introduction to the project aim and specifications

Section 2 reviews a range of satellite systems and available processing method for delivering monitoring of soil sealing in the built environment. It summarises work from an extensive range of existing literature, and concludes by proposing a system for the operational implementation of a cost-effective method for detecting and quantifying changes in sealed soils.

Section 3 reports in detail the recommended methodology and processing chain for a demonstration system such that a skilled remote sensing specialist can replicate the methodology. The non-technical reader can skip to Section 4.

Section 4 presents an example map produced using the proposed methodology, then sets out the method and results of assessing the accuracy of the sealed vs. unsealed maps.

Section 5 presents recommendations and implications for an operational system, covering a feasibility study for image acquisition and processing logistics, including metadata protocols. It also outlines data and processing costs in the context of the Defra Soil Team's current processes.

Section 6 covers the additional tasks laid out in Task 2.2, namely an evaluation of the opportunities for adding value to the soil sealing maps. It covers feasibility studies and examples for assessing the impact of sealing on three factors: biodiversity, drainage and aesthetic value.

Section 7 presents a cost-benefit analysis estimating the comparative value of Earth Observation (EO) techniques over and above full ground survey effort. This work uses a 'relative efficiency' indicator commonly used when assessing EO projects.

Section 8 summarises the main findings and makes appropriate observations and recommendations

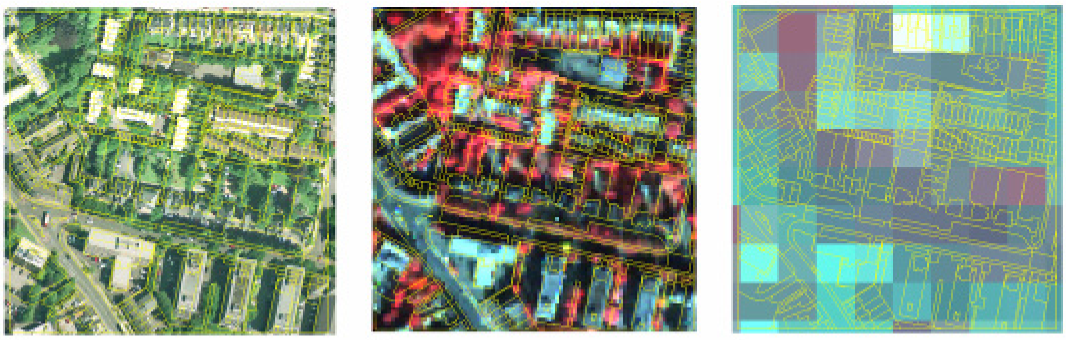
2. Processing technology

This section identifies the appropriate satellite systems and best available algorithms and processing method to provide the required parameters for the monitoring system.

Established approaches are reviewed for classifying soil sealing using EO imagery, as well as reviewing appropriate and available EO imagery. It derives understanding from an extensive range of existing literature, and concludes by proposing a system for the operational implementation of a cost-effective method for detecting and quantifying changes in sealed soils.

Review of processing technology

Methods for classifying images are numerous. However, there are three broad approaches available: i) object based classification, ii) pixel classification, and iii) sub-pixel classification (figure 2.1). For this work, pixel based classifiers were selected. In order to justify this choice, a summary description of each of the three approaches is presented below.



1. **2.** **3.**

1. Object based classification is based on segmenting an image into discrete 'objects' defined by groups of pixels, used in cases where the area of the features of interest are at least an order of magnitude greater than the equivalent ground pixel size.

2. Pixel based classifiers independently classify individual pixels. They are suitable for classifying images whose pixel sizes are at least equal to, or smaller than, the features of interest.

3. Sub-pixel classification is required where the features of interest are smaller than the ground pixel size of the image, and the problem to solve is to estimate the unknown proportions of each contributing land cover type within each 'mixed' pixel.

Figure 2.1 Comparison of pixel size vs. ground feature size, based on a 250 x 250 m area of Cambridge City. Image 1 is high resolution aerial imagery; Image 2 is 2.8 m Quickbird imagery; and Image 3 is simulated 30 m imagery (derived from 10 m SPOT data).

Object-based classifiers

Object based classification is where real-world surface objects are defined by groups of contiguous pixels. The 'eCognition' software package (Definiens Imaging GmbH) uses this approach. It is used in cases where the features of interest are at least an order of magnitude greater than the ground pixel size of the image data being classified. Object classifiers provide the advantage of being able to use measurable factors, such as shape, object texture and context to assist the classification – similar to the way humans visually interpret images.

Image 2 in figure 2.1 represents the highest resolution multi-spectral EO imagery from the space sector that is commercially available today, namely Quickbird XS imagery. Quickbird images have a 2.8 m ground pixel resolution. These individual pixels are marginally bigger than the minimum spatial resolution (4 m^2) required for detecting sealed soils set by the Defra ST, therefore, it was concluded that the use of object-based classifiers for identifying features of interest were not suitable for current space borne sensors.

Some attempts have been made to classify urban land cover with the use of object-based software. Examples include Herold, *et al*. (2003); Darwish, *et al*. (2003); Wang, *et al*. (2004); Guindon *et al*. (2004); Frauman & Wolf (2005); Greiwe & Ehlers (2005); Harayama & Jaquet (2005); Blaschke, *et al*. (2005). These either attempt to classify amalgamated blocks of the built environment to map urban growth (in which case the levels of sealing or unsealing within these blocks, *e.g.* gardens, is not estimated – gardens are subsumed into 'urban'), or they use airborne sensors with spatial resolutions better than that possible from space.

Object based classifiers could provide opportunities for classifying sealed surfaces using high resolution airborne data, however, the remit of this study is limited to using space-sector data. Whilst airborne sensors appear to have a better potential to get the best out of object classification techniques, other factors need to be considered such as acquisition cost, processing and storage costs of larger amounts of (higher resolution) data. It is our conclusion that with high resolution airborne imagery (*e.g.* with 0.25-0.5 m ADS40 imagery), opportunities for more detailed urban mapping of sealing and the nature of unsealed areas is a realistic proposition for further study.

Sub pixel classifiers

When the available image ground resolution is larger than the size of the features of interest it leads to 'mixed pixels', which presents a problem: how to estimate the unknown proportions of the mix of land cover classes within each pixel. A solution is to use sub-pixel classification procedures.

Sub-pixel classification (sometimes referred to as spectral 'unmixing') is based on the assumption that the merged spectral properties of mixed pixels can be reproduced using a combination of the individual, pure spectral signatures[18] of the land cover types present. By acquiring signatures of pixels with pure, uniform land cover, so called 'end-members', sub-pixel classifiers attempt to determine a unique linear combination of end-member signatures required to match the mixed pixel. In doing so, it estimates the proportions of land cover for each pixel.

[18] A spectral signature describes the reflectance pattern of surface cover types across a number of individual wavebands

Ridd (1995) developed a conceptual model for analysing urban land cover types. His vegetation-impervious-soil (V-I-S) model was initially presented as a possible aid for urban ecological investigations. The model is based around a V-I-S diagram, similar to the ternary of a sand-silt-clay diagram; values along each axis indicate the percentage of vegetation, impervious material, and soil. The V-I-S model was developed in Hung and Ridd (2001) to produce a sub pixel classifier using 30 m Landsat imagery. Instead of using only the three basic ground components (vegetation, impervious surfaces, soil) six ground components were selected to describe the end-members: two for vegetation (grass and trees), three for impervious surfaces (light, medium and dark surfaces) and one for soil. The accuracy assessment was compared with predicted component percentages from visual interpretation of aerial photographs. The results were not clearly presented, but indicated an accuracy of 73% for grass, 56% for trees, 30-48% for impervious (sealed) and 63% for soil. What is not clear is the spatial scale of these accuracy values, but they are likely to indicate the average accuracy across an entire image scene (analogous to the reporting of uncertainty in the UK LCM2000); the accuracy per pixel or basic mapping unit will, therefore, be less.

Similar studies are found elsewhere (Rashed *et al.* 2001; Phinn, *et al.*, 2002; Wu & Murray, 2003). All these approaches indicate that some success can be achieved for broad scale urban mapping of sealing when using medium resolution image data. The advantage of medium scale resolution data is that individual image scenes typically cover a greater area than higher resolution systems.

Sub-pixel classifiers were not selected because, at the scales for which the cited sub pixel classifiers were used in the examples presented in the literature, typically 1:25,000 or smaller for the UK, topographic data already exists (MasterMap®); *i.e.* MasterMap® provides analogous, perhaps more reliable, sources for mapping soil sealing. These methods were developed to overcome the spatial mis-match between urban land cover object sizes and the larger image resolutions available at the time (*c*.30 m). Sub-pixel classifiers could be applied to the 2.8 m pixels of Quickbird to investigate the potential of defining greater levels of detail than the pixel, but the quality of the results could not be guaranteed and this report is about delivering practical options and is not a blue-sky research project.

Pixel classifiers

Pixel classification is tried and tested, and typically approached by compiling a set of signatures for each land cover type of interest, by extracting the digital values from a sample of training pixels at locations of known land cover. The signatures are then used to automatically classify pixels at all other locations in the image based on their (spectral) similarity. Regression based techniques, to relate measured ground parameters to remote sensed values, can also be applied to each pixel as an alternative to statistical classification.

Much work has been reported related to monitoring urban growth on a regional scale using pixel classifiers. Deguchi and Sugio (1994) evaluated the use of medium resolution satellite data, 20 - 80 m, for estimating percentage of sealed areas in an urban environment. An automated classification was implemented to classify water, forest, open land, and 'urbanized' land. The estimation and evaluation of sealing was achieved by visual interpretation of buildings, roads and car parks from black and white aerial photography. The results showed that the estimation error of the average percentage of sealed surfaces derived was approximately 10%, the same error obtained by visual interpretation of the photography at the same scale. Whilst the focus was to map urban growth, largely ignoring intra-urban green spaces, their work indicated the opportunities for classification using the same approach with high resolution data. There are many examples of this type of approach for mapping general land cover (*e.g.* Ji & Jensen, 1999; Ward, *et al*., 2000; Smith, 2000; Grenzdorffer, 2005). Similar approaches lead to the existing EO land cover products such as the LCM2000 and CORINE. This scale of classification is also used within projects such as SoilSAGE (a GMES project; http://www.gmes-sage.info/ps/soil/index.php), where levels of sealing are summarised on a regional basis.

Herold, *et al*. (2003) simulate and compare Landsat data (30 m resolution) and IKONOS data (4 m resolution) using hyperspectral airborne data (AVIRIS). Their aim was to identify the optimum waveband positions for classifying the built environment. They conclude by indicating that the wavebands suitable for discriminating urban land cover are effectively either, outside the spectral range of, or much narrower than, typical satellite sensor configurations. The inclusion of specific short wave infrared (SWIR) wavelengths would improve classification accuracy according to their simulations.

In an unpublished manuscript by Herold, *et al*. (2003) their work points further to the use of near-infrared (NIR) waveband combinations for monitoring useful indicators of unsealed soil. Due to the distinct differences in vegetated *vs.* non-vegetated surfaces, maximised using vegetation indices (*e.g.* the NDVI), roads, buildings and vegetated surfaces are easily differentiated with high resolution data. They note the instances of mis-classification due to overhanging trees on roads, and in some cases complete coverage across roads – unavoidable problems from the remote sensing perspective (*i.e.* the bird's eye view). Unfortunately, during winter when opportunities might arise to see the otherwise obscured ground below, urban image scenes are typically of very poor quality. This is due to long shadows resulting from the early morning over-pass times of polar-orbiting satellites, and low solar angles.

The classification of thermal infrared imagery provides opportunities for improving the accuracy of pixel classifiers to estimate sealing beyond a binary classification of sealed and unsealed. Work by Elgy (2001) presents pre-dawn airborne thermal image data. Although quantitative evidence is not presented, he claims that the image is closely related to surface moisture content and, by inference, the permeability of the land cover.

Whilst we can envisage approaches to take advantage of thermal image characteristics and exploit a potential to quantify levels of permeability, it is clear that considerable fundamental research is required before any operational system can be proposed. It is beyond the scope of this work and must be the subject of a separate series of studies.

From the published work, and our own experience, it is our view that vegetation index images derived from high resolution satellite data (*e.g.* Quickbird, 2.8 m or IKONOS 4 m) provide the greatest opportunities for achieving Defra's aims within this project.

Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) sensors offers practical advantages across a wide range of remote sensing applications due to its ability to penetrate, almost unaffected, through cloud. However, it is limited in urban applications to measuring the presence or absence of physical surface features (*e.g.* 3-dimensional objects such as buildings). Three dimensional objects are detected either directly from the backscatter response that is characteristics of the *general* urban landscape, or indirectly, by processing the coherence between two perspective views of the same scene using a process called interferometry (Stabel and Fischer, 2001).

The signal recorded by SAR sensors is affected by surface roughness and so, theoretically, smooth tarmac roads, patios and other 'sealed' surfaces will respond differently in terms of its backscatter compared to rougher surface features such as grass and trees. The limitation of satellite-borne SAR data is that the spatial resolution is too coarse and lead to noisy images which are not suitable for discriminating intra-urban land cover types. It should be noted that future planned missions could deliver a 1 m resolution SAR image (*e.g.* TerraSAR-X). The best currently available resolutions are approximately 8-30 m (*e.g.* RADARSAT, 8.4 m; Seasat, 25 m; or ENVISAT, 30 m).

At these resolutions, the signal recorded by SAR sensors will be subject to large amounts of 'double-bounce' or 'specular reflectance' due to the interaction of the microwave signal and the hard geometric properties of roofs and buildings. This is potentially advantageous if the resolution was around 1-2 m; it might be possible, using X band data, to detect buildings through tree canopies and overcome some of the difficulty of optical sensors where these buildings are obscured (Weydahl, *et al*, 2005). Additionally, the surface properties beneath tree canopies, *i.e.* tarmac vs. grass, might also have a different type of backscatter. However, at currently available resolutions of 10-30 m, these strong backscatter signals tend to dominate a SAR scene, obliterating the spatial detail of interest to this project: the sealed:unsealed mix at the individual garden level.

There is great value in considering the potential of future SAR data (*e.g.* TerraSAR-X) for assessing its contribution for mapping urban area features. It is currently not a feasible option for this present work.

Recommended processing chain

Summary

Most procedures described in the literature at best serve to match the spatial scales of pre-existing topographic data on sealing (*i.e.* OS MasterMap®), and there is clearly no point in replicating routinely collected data. At the scale requested by the Defra ST, this existing topographic data is adequate for mapping roads, pavement and buildings, which is attributed as 'manmade', in MasterMap® (Figure 2.2), but does not contain specific information on the sealed vs. unsealed mix in remaining areas, *e.g.* gardens, which are attributed as 'multiple'.

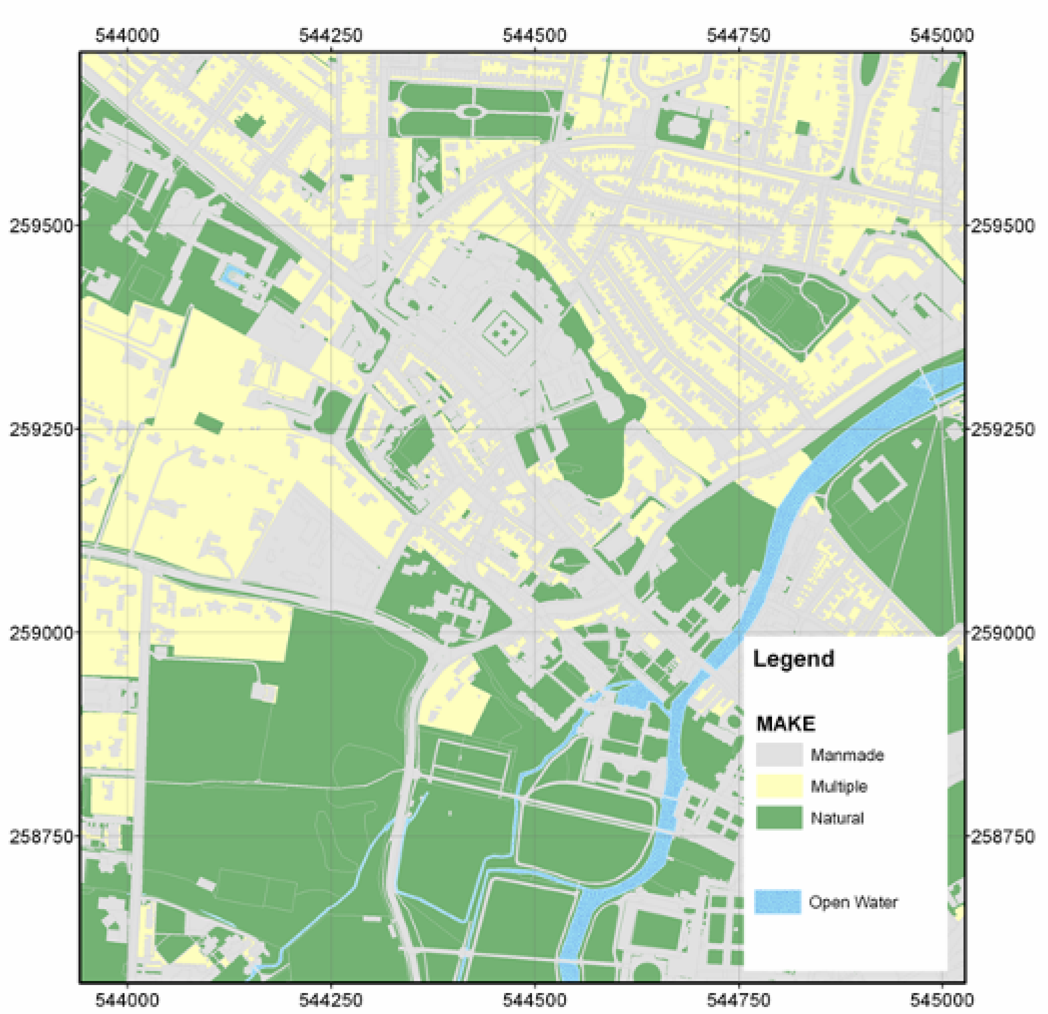


Figure 2.2. Section of MasterMap® indicating the level of existing detail in attribute information, where 'manmade' generally equates to sealed surfaces; 'natural' are areas of unsealed surfaces; and 'multiple' represents a mix of unrecorded sealed and unsealed surface cover types.

Given the background to monitoring urban areas by remote sensing, the literature points towards an approach that uses 2-4 m resolution satellite data, with infrared capability (Herold *op. cit.*). However, in the absence of a clearly proven methodology for Defra's specific requirements of monitoring sealing at the private garden level, it would appear necessary to develop an approach, extending the work reported hitherto.

The basis of our recommended configuration for a demonstration system also stems from work carried out in Dresden, Germany (figure 2.3). Dresden's Office for Urban Drainage Systems sanctioned the mapping of sealed areas by aerial image mapping. Orthorectified 1:50,000 scale aerial photography was digitized stereoscopically and interpreted to include soil sealing values for the whole city of Dresden; over 300,000 polygons within their Authoritative Topographic Cartographic Information System (ATKIS[19]). The mapping was carried out with a positional accuracy of <0.2 m.

It is not the intention to duplicate the survey using the ATKIS approach (Meinel and Hernig, 2005), but to aim to develop similar *products* to theirs (*e.g.* figure 2.3) using semi-automated image classification. It is proposed that OS Master Map topographic data is used as the base map. In areas that cannot be identified as permanently sealed from the topographic data, *i.e.* 'multiple' surfaces, high resolution satellite data (*e.g.* Quickbird) will be classified using vegetation abundance as a surrogate for unsealed soils. In urban areas with high proportions of sealed surfaces, MasterMap, which is typically updated twice a year, may be judged to be adequate for monitoring sealing.

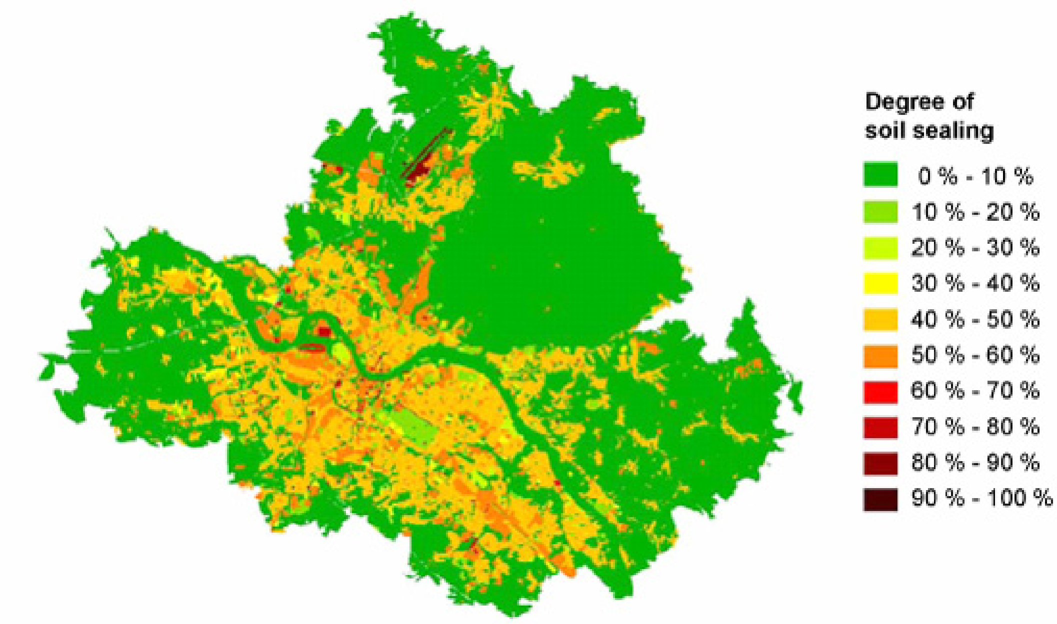


Figure 2.3 Soil sealing in Dresden, Germany (Meinel & Hernig, 2005)

The data that will be used in the subsequent demonstration, which is the recommended data to reproduce the methodology, is as follows:

Proposed sensor:	2.8 m Quickbird imagery (IKONOS or Orbview-3 imagery would be viable alternatives)
Surface datasets:	1:1250 topographic Ordnance Survey MasterMap®
Processes:	Maximum likelihood pixel classification of Quickbird-derived normalised difference vegetation index (NDVI) imagery. This method is described and tested in the following sections.
Supporting data:	Visual interpretation and digitisation of 0.125 m orthophotography for 'ground-truth' validation; including field visits.

[19] http://www.atkis.de/metainfo/metainfo.meta_start_produkt?prod_id=54&inf_sprache=eng

Processing flow

An outline of the monitoring methodology is presented in figure 2.4. The recommended process takes two data sources: i) OS MasterMap® to identify *a priori*, areas of known sealing – principally roads and buildings; and ii) Quickbird (or Orbview-3, or IKONOS) satellite imagery, which is classified and used in all remaining areas, *i.e.* not designated by OS MasterMap® as building or roads.

After geocorrection, the Normalised Difference Vegetation Index (NDVI) image is calculated and extracted. A maximum likelihood pixel classification of the NDVI serves to classify the image into unsealed and sealed surfaces (vegetated and non-vegetated).

The segmented layer of roads and buildings is classified as 100% sealed. All remaining OS MasterMap® polygons are used to automatically extract the average area of sealed pixels from the classified NDVI image, by counting the number of sealed pixels and dividing by the polygon area.

The two data sets are then reconstituted to produce a single combined map of sealed and unsealed land.

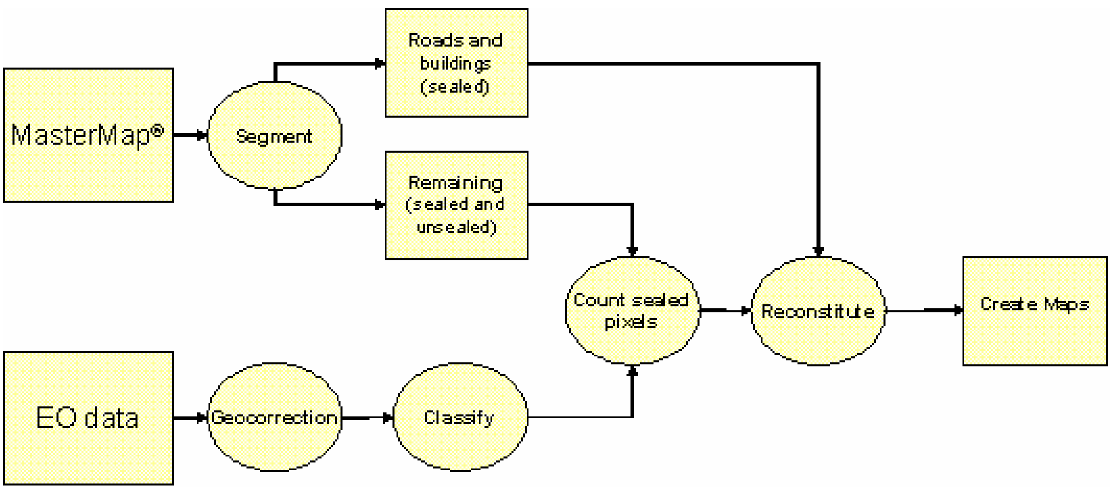


Figure 2.4 Methodological process for deriving sealing maps.

3. Mapping soil sealing - methodology

Overview

This section reports the recommended methodology and processing chain for a demonstration system in more detail. The non-technical reader can skip to Section 4.

Vegetated vs. non-vegetated

It was agreed at the project kick-off meeting that land cover would be classified as either vegetated or non-vegetated, and that these would be considered as acceptable surrogates for unsealed and sealed soils, respectively. To this end, the use of image band combinations of red and near infrared wavelengths would provide the greatest opportunity for discriminating vegetation (Jensen, 2000). Such band combinations are typically referred to as vegetation indices, the most popular being the normalised difference vegetation index, or NDVI, and calculated as:

$$NDVI = \frac{\rho_{IR} - \rho_R}{\rho_{IR} + \rho_R}$$

where ρ is the pixel reflectance value in the near infrared (IR) and the red (R) wavebands.

Image classification

Image classification comprises five stages, i) definition of a land cover typology, ii) 'training' – the production of signatures by extraction of sample satellite image pixels from locations of known land-cover, iii) signature evaluation, by assessing their spectral separability; iv) image classification, and v) accuracy assessment, using independent ground data, or an equivalent (*e.g.* air photo interpretation).

Our approach to classification uses a maximum likelihood classifier (Richards and Jia, 2005) of an NDVI image derived from 2.8 m Quickbird imagery. The image is of Cambridge City District, dated October 2003.

Land cover typology

A land cover typology was designed to provide a simple two-class grouping of sealed vs. unsealed land. Table 3.1 provides a list of land cover/feature types observed in high resolution aerial photography, and their membership to either the sealed or unsealed classes. For the purposes of an operational system, and accepting the use of vegetation as a proxy for unsealed surfaces, the simple sealed-unsealed (non-vegetated:vegetated) typology should be used.

The reason for breaking down the sealed:unsealed typology onto sub-classes was two-fold:

1) to assist in extracting all surface types present to avoid, for example, simply choosing gardens and houses, and not representing the true variation in surface characteristics present in an urban area, and;
2) to provide a means of identifying any problem surface types, e.g. worn grass was expected to be spectrally similar in the worst case to sealed surfaces.

Class no	Land cover	API classes	Sealed/Unsealed
1	White roof	Sealed	Sealed
2	Red roof	"	"
3	Grey roof	"	"
4	Artificial sports	"	"
5	Yard/drive	"	"
6	Road (light)	"	"
7	Road (dark)	"	"
8	Car park/playground	"	"
9	Path	"	"
10	Roadside pavement	"	"
11	Patio	"	"
12	Sealed (other)	"	"
13	Green roof/roof-garden	"	"
14	Arable fields	Vegetation	Unsealed
15	Lawn	"	"
16	Mixed garden	"	"
17	Playing field	"	"
18	Allotment	"	"
19	Worn/scrub grass	"	"
20	Deciduous trees (green)	Trees	"
21	Deciduous trees (red)	"	"
22	Coniferous trees	"	"
23	Bare soil	Soil	"
24	Construction ground	"	"
25	Unsealed (other)	Unsealed	"
26	Loose chippings	Sealed	Semi-sealed
27	Railway track/base	Soil/mix	"
28	Unclassified	Unclassified	Unclassified
29	Water	Water	Sealed

Table 3.1 Land cover typology and its relation to soil sealing.

Training the classifier

To classify a whole city, it is necessary to identify a sample of pixels of known land cover in order to 'train' the classification software and record the associated pixel reflectance variation for each class. A number of factors affect the reflectance value recorded within satellite image data, of which atmospheric variation is one of the greatest. To avoid the associated uncertainties and complications of classifying images of different places or times, the work presented here assumes that individual image frames will be classified independently. This means that a limited amount of repeated 'training' will be required for each subsequent acquisition over the same site or for additional sites.

The survey area, Cambridge City District, was sub-divided into a number of 250 m x 250 m segments (figure 3.1). The sample segments provide the survey units within which 'ground truth' mapping can take place, and for which satellite image classification results can be compared. From a total of 650 possible segments, 15 (*c*.2.5%) were randomly selected.

Orthorectified aerial photography was used to select training pixels in contemporaneous Quickbird imagery (figure 3.2). Care was taken to avoid errors in co-location from apparent 'leaning' of buildings or trees that occurs due to relief displacement. Individual seed points, which are groups of pixels used to 'train' classification rules, were kept small to avoid autocorrelation of training pixels (figure 3.3; table 3.2). From the training pixels a set of signatures were computed. Since only the NDVI image was to be used, the classification would be univariate and, consequently, each class signature is defined only by its mean and variance.

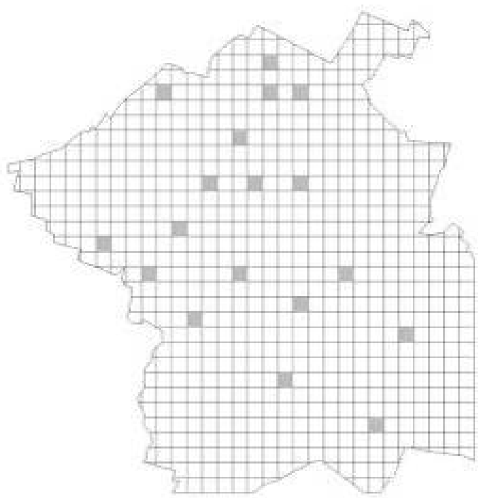


Figure 3.1 A 250 x 250 m area-frame overlaid over Cambridge City District. Filled squares represent a random sample

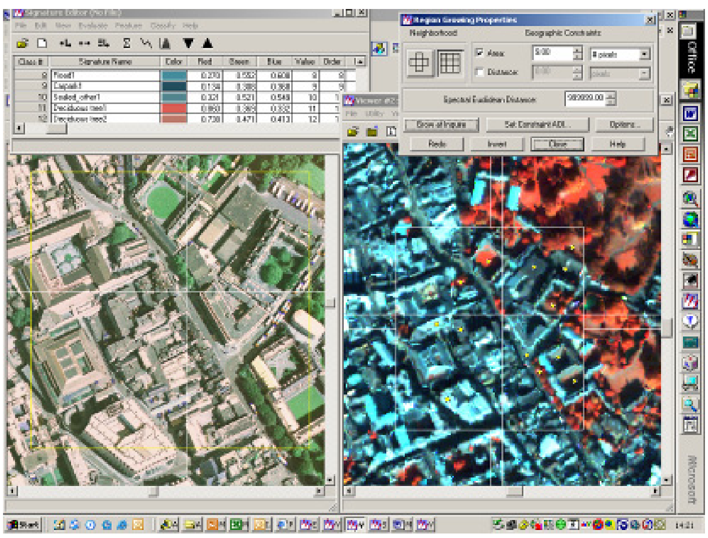


Figure 3.2 Selecting training pixels. Contemporaneous aerial photography (left) was used to locate training pixels in the Quickbird imagery (right).

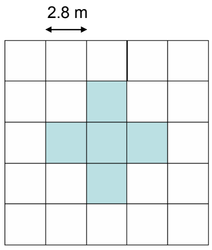


Figure 3.3 Training pixels configuration.

Classes observed	*Seed points*	*Pixels*
White roof	18	90
Red roof	20	100
Grey roof	60	300
Yard/drive	3	15
Road (light)	32	160
Road (dark)	14	70
Car park	18	90
Lawn	28	140
Mixed garden	13	65
Playing field	16	80
Allotment	4	20
Worn grass	3	15
Deciduous trees (green)	34	170
Deciduous trees (red)	3	15
Construction	8	40
Arable (green)	2	10
Arable (soil)	7	35
Artificial sport surfaces	4	20
Total	*287*	*1435*

Table 3.2 Land cover classes observed, number of individual 'seed point' training locations and equivalent pixels counts in the random sample

Class separability

Figure 3.4 presents the mean and standard deviations of the individual class signatures. Not all land cover types were observed, due to a combination of their low frequency of occurrence and the random selection procedure. In general, there is separability between the broad sealed class and unsealed class. There is no seperability between the sub-classes within either the sealed class (*i.e.* between roofs, roads, car parks, driveways, etc.) or the unsealed classes (*i.e.* between lawn/grass, mixed garden, trees, arable fields, allotments and playing fields/parks). This was expected and, as described earlier, the sub-classes served to identify where potential spectral confusion between classes occurs (*e.g.* arable, which was later omitted from the classification)

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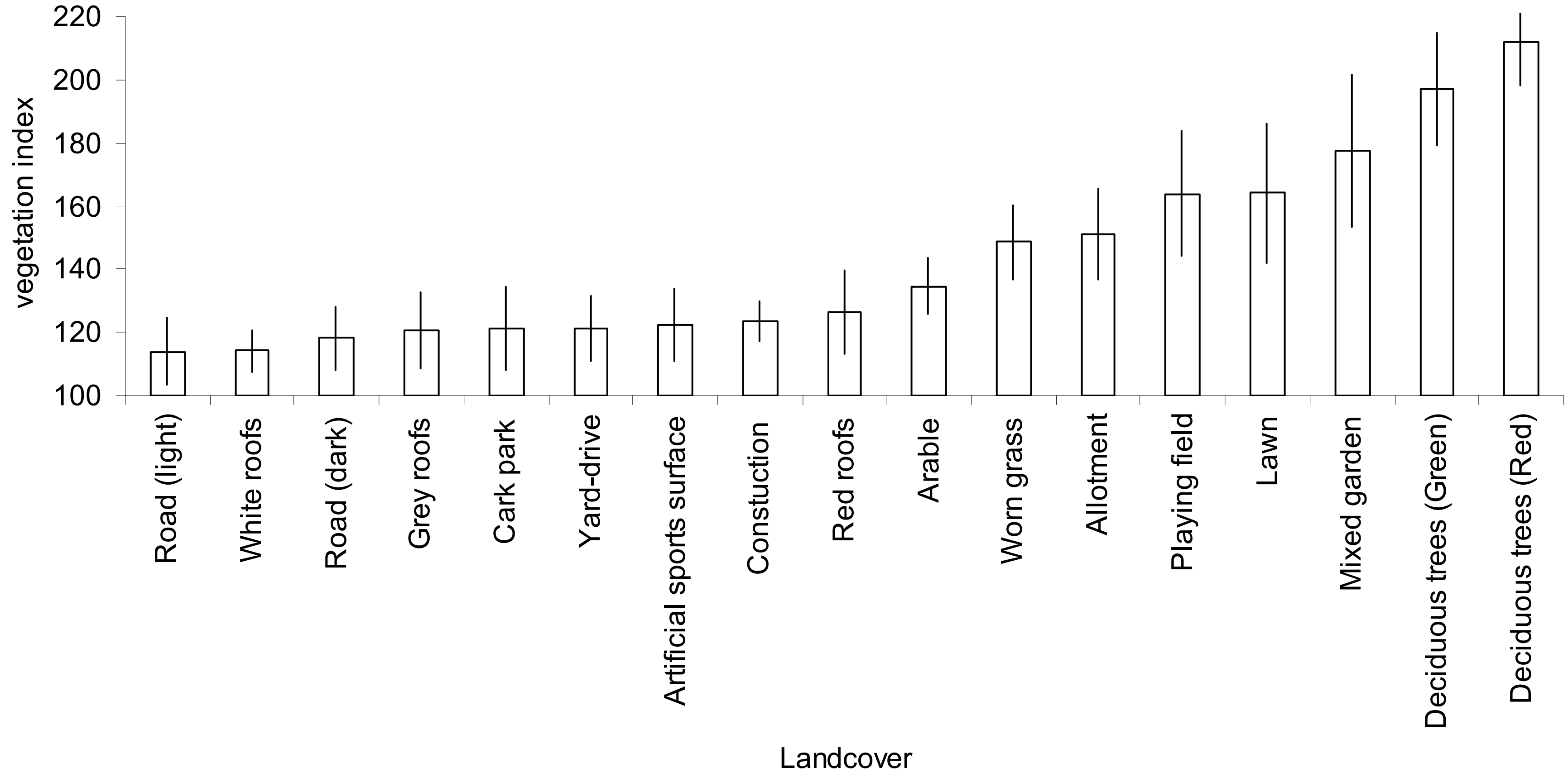

Figure 3.4 Mean and standard deviation of raw NDVI values for each observed land cover class.

Image classification

Using the collated sealed-unsealed class signatures the October 2003 Quickbird image was classified using univariate maximum likelihood classification (Richards and Jia, 2005). A 3x3 km subset of the classified image is presented in figure 3.5.

When considering the classified map at the detailed level of individual gardens and other land parcels, aided visually by overlaying Ordnance Survey 1:1250 topographic data (figure 3.6), a small amount of misclassification begins to become apparent. This is evident for buildings and roads, which ought to be sealed (non-vegetated), but a small number of pixels are misclassified as unsealed. Misclassification of a proportion of pixels will always occur using remote sensing techniques.

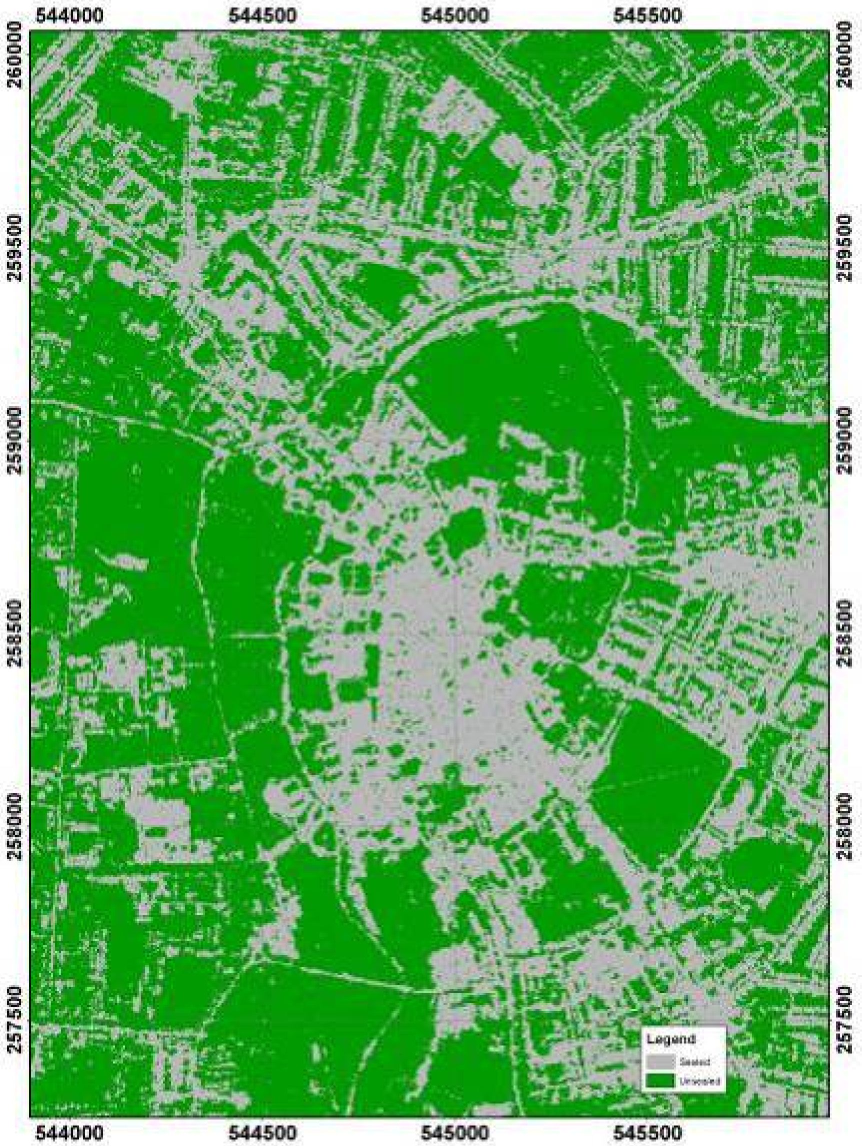

Figure 3.5 Classified October 2003,image of Cambridge City centre and surroundings derived from 2.8 m Quickbird imagery. Green pixels indicate vegetation (unsealed) and light grey indicates no vegetation (sealed).

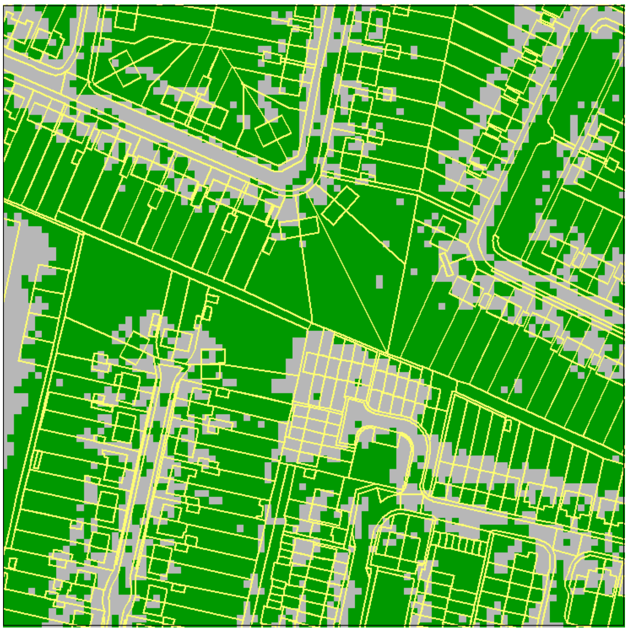

Figure 3.6 Satellite classification of non-vegetated (grey) and vegetated (green) surfaces (inferred as sealed and unsealed, respectively). The yellow polygon boundaries represent the basic units on which the API was implemented (Ordnance Survey MasterMap® data).

For any country, such as England or Wales, with available and regularly updated topographic data that contains information about urban infrastructure, the classification of sealed and unsealed can be improved by dividing urban areas into two categories:

1. The first category defines areas that are known *a priori* to be sealed-over, using attributes held in digital versions of Ordnance Survey data. MasterMap® has national coverage and includes attributes that describe the 'type' of the surface material, *e.g.* it will state 'manmade', to represent surfaces that have been constructed. If a land parcel feature has the attribute, 'manmade' and is either a 'building' or 'road' then it is automatically classified as 100% sealed. This overrides any misclassification errors (of omission) from the satellite classification.
2. The second category defines all remaining areas, parks, gardens, allotments railway sidings, road-side verges and a range of open public spaces, including arable and Greenfield land at the urban fringe. The majority of these areas are classified in the OS MasterMap® data as having a catch-all surface type category coded as 'multiple'. Such areas can be either completely sealed over or unsealed, or any mix in-between. Particularly for private spaces, such as gardens, there is no regulatory control or monitoring of levels of sealing (hence the purpose of this reports' objectives). These remaining areas are classified by extracting the information produced by image classification.

Figure 3.7 presents the same segment shown in figure 3.6, which has been processed by setting all building and road polygons in OS MasterMap® to 100% sealed whilst extracting the total proportion of pixels classified as sealed from the satellite classification for all remaining polygons.

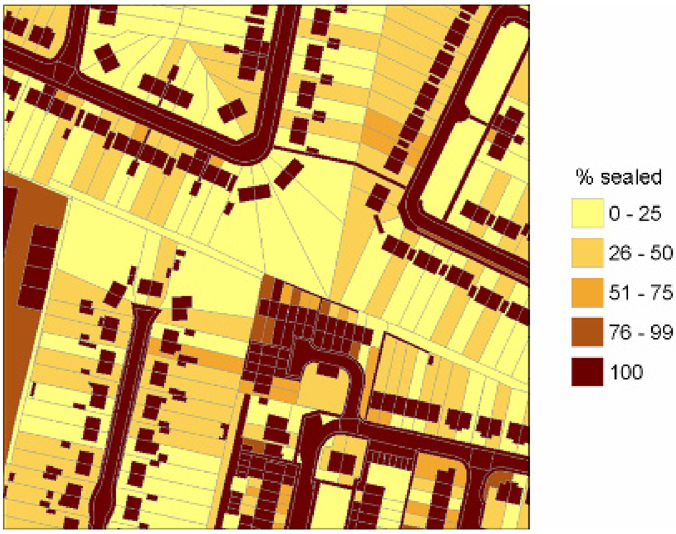

Figure 3.7 Levels of sealing for individual land parcels extracted from supervised classification of 2.8 m Quickbird satellite imagery, with buildings and roads from Ordnance Survey MasterMap® data 'stamped' on top.

Accuracy assessment

Image classification is not recommended without undertaking some degree of accuracy assessment. For the purpose of this study, a very detailed assessment was made, which will be described here. However, as part of an operational system, accuracy assessment could be limited to a periodic evaluation of sample cities. This would provide only an indication of whether the accuracy is stable over time; stability in the sample would indicate a good chance of stability across all cities classified. This approach is incorporated later when discussing operational feasibility. In this report, the accuracy of the classification was assessed by comparison with baseline maps that were produced by visual interpretation of the 0.125 m orthorectified air photos, for 18 (250 x 250 m) segments (Appendix 1). These segments were <u>not</u> used in the training of the classifier.

Aerial photo interpretation (API) is a widely accepted technique since the human brain can identify and recognise features that automated methods cannot distinguish reliably. The downside of API, whilst very precise and reliable, is the time it takes to do the interpretation. API is very well suited as an accurate surrogate for ground survey; it also allows for private spaces to be evaluated that would otherwise be inaccessible by ground survey. The API was implemented on-screen by overlaying 1:1250 scale Ordnance Survey MasterMap® data onto the orthophotos of Cambridge. For each of the 18 segments, each land parcel in the topographic data was allocated a proportion of the following broad land cover types:

i) sealed surfaces
ii) trees
iii) other vegetated surfaces (*e.g.* lawns, parks)
iv) bare soil
v) water
vi) unclassified

To see how these relate to the typology, refer back to table 3.1.

The proportions were estimated visually and limited to proportioning the area of sealed land into quarters, *i.e.* a parcel was classed as being 0%, 25%, 50%, 75% or 100% sealed. All information was recorded directly in a GIS database and stored as appended attributes to the MasterMap® data. In instances where a land cover type was present, but was estimated to be less than 25% of the total land parcel area, a note of this was made. In this way there was no confusion that 0% indicates a true absence of that land cover type. Additional notes related to any difficulties in interpretation, if they occurred, were also included in the attribute table. This is important, since those uncertainties will affect the accuracy assessment.

Figure 3.8 shows an example of the API-updated Ordnance Survey MasterMap® data for one of the 250 x 250 m segments. The map is displayed using the API information on the degree of sealing. This procedure was carried out on all 18 ground segments.

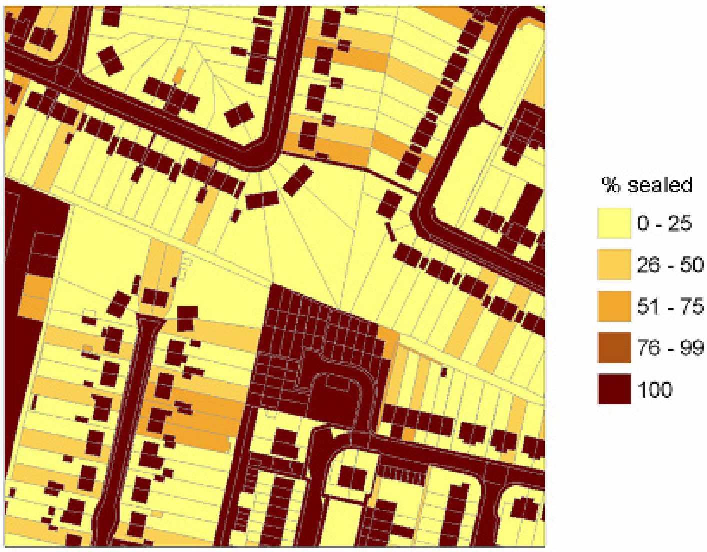

Figure 3.8. API-augmented Ordnance Survey MasterMap® data for one of the 250 x 250 m segments (area 11), indicating the degree of sealing.

4. Mapping of soil sealing - results

A map, using the example area of Cambridge, was produced using the following data:

Sensor	Quickbird
Spatial Resolution	2.8 m MS; 0.7 m PAN
Spectral Properties	0.45-0.52; 0.52- 0.6; 0.63-0.69; 0.76-0.9 µm
Processing	Nearest Neighbour, no enhancement, 16 bit
Area	8 x 8 km
Acquisition date	16th October, 2003

Image type	Aerial photography, Cities Revealed
Spatial Resolution	0.125 m
Processing	Ortho-correction by rubber sheet transformation
Area	Cambridge District
Acquisition date	June-July, 2003

Data	Ordnance Survey MasterMap®
Scale	1:1250
Description	The OS MasterMap® Topography Layer is a large-scale digital database of the detailed surface features on the landscape. This accurate, flexible resource covers some 400 million man-made and natural features, from fields to pillar boxes, each with its own unique identifier or TOID® for easy reference. It is broken down into nine themes to make it easier to access the data
Main themes	• roads, tracks and paths; • land; • buildings; • water; • rail; • elevation; • heritage; • structures; and • administrative boundaries
Area	Cambridge District

Additional data were made available, courtesy of Cambridge County Council, which listed the 'Housing Completions' for 2003 (the date of the imagery).

Data	Cambridge County Council Housing Completions
Scale	1:1250 (based on OS MasterMap®)
Description	Polygons of planned and completed developments submitted to and held by the Cambridge Planning Office. The data are annual collations of monitoring periods which end 31st March The data will be used to help to verify land cover discrepancies between image dates, and also between image acquisition and the ground survey visit.
Main themes (of interest)	Dev type, COU = change of use, NEW indicates new building, REB - rebuild CON - conversion of existing building
Area	Cambridge District

Following the method for processing described in Section 3, a 2003 map of sealing for Cambridge was created. A subset of the map is presented in figure 4.1 to illustrate the detail of the output – a subset of the digital classification of sealing is favoured for presentation in this report, because the whole of Cambridge would need to be printed at an A2 size to present the full detail.

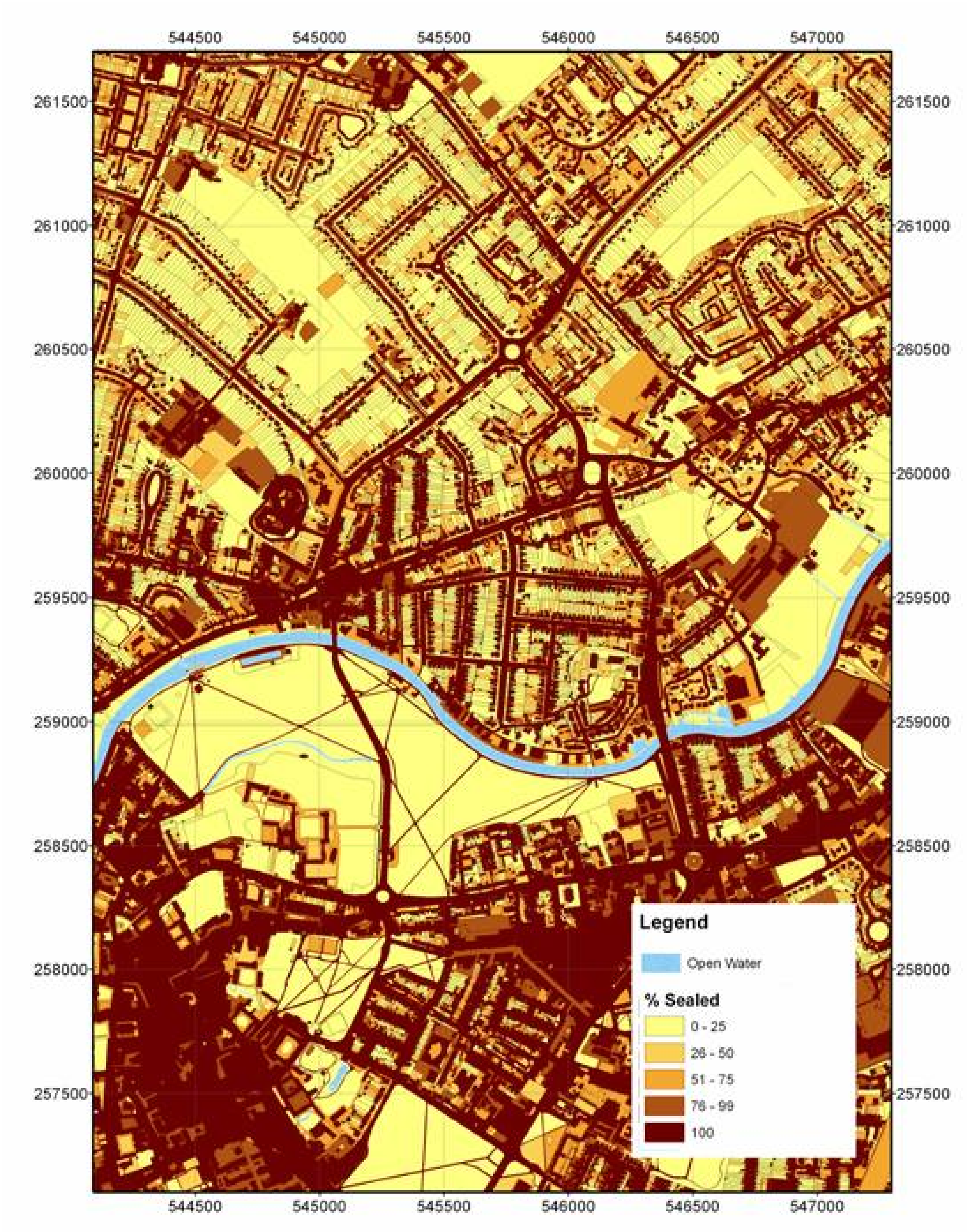

Figure 4.1 Percentage of sealed soil – an example extract from the Cambridge City district (coordinates are in meters).

Assessing classification accuracy

This section sets out the method and results of assessing the accuracy of the sealed vs. unsealed maps.

Eighteen segments, 250 x 250 m, have been classified using air photo interpretation (API) of 0.125 m resolution orthorectified aerial photography, and represent a detailed data source ('ground truth') against which the digital classification can be compared. An example of one of the classified map segments is presented in figure 4.2. This particular segment has 561 individual polygons. Given all 18 segments, 8102 polygons are available to test the correspondence between the classification and the API.

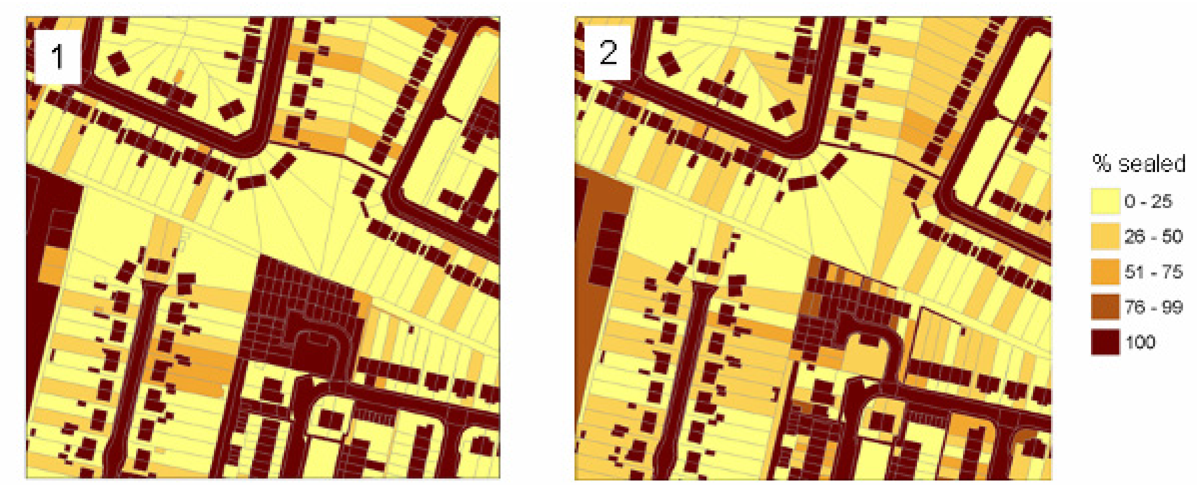

Figure 4.2 Comparison of aerial photograph-derived classification (Example 1) and supervised image classification (Example 2)

Digital classification vs. the sample survey

A quantitative assessment of the agreement between the digital classification results and the API 'ground truth' is presented in a confusion matrix (table 4.1). A confusion matrix cross-tabulates the classes in the digital classification, *i.e.* 0%, 25%, 50%, 75% and 100% sealed classes, with the same areas in the API classification. If the maps matched exactly, then only the diagonal axis of the matrix will have values. However, in some cases the classes will be 'confused' with others – *e.g.* the digital classification may class a parcel as 50%, but the API determined it as 75%, etc.. The total proportion of values in the diagonal axis represents agreement between the two maps, and off-diagonal values represent mis-classification errors.

In table 4.1, the overall accuracy is 69% (the sum of the diagonal divided by the total number of elements). The user accuracy is the percentage of pixels classified correctly for each class in the map, *e.g.* 91% of parcels that were identified as 100% sealed in the API were correctly classified in the digital classification.

It should be noted here that the so-called 'ground truth' has inherent uncertainty because the correct allocation within each class boundary is subject to some level of human interpretation error; and the coarse 25% intervals introduce a low level of precision (necessary in this work due to the short time available limiting the opportunity to digitise the API more precisely). For example, if a garden was 37% sealed, a visual interpretation would place this to nearest the 25% interval. In this case, 37% is close to half-way between 25% and 50%; visual interpretation cannot be precise enough to judge whether it is nearer to 50% than 25%, and so could go either way in allocating the class. The digital classification, however, is absolute, though subject to classification error. Assuming that it correctly estimated 37% sealing, it would allocate the class to 50%. In the absence of a detailed study to quantify the exact nature of this problem, it is assumed here that 50% of the values in those classes falling adjacent to the diagonal in the confusion matrix are incorrectly labelled leading to a possible underestimate of the mapping accuracy.

To accommodate this, 'fuzzy' boundaries were applied to the confusion matrix interpretation. With more time the API could be supported by the use of object-based segmentation software to provide greater precision and the interpretation of sealing on a more continuous scale, *e.g.* 1% intervals and not in 25% intervals. The numbers in brackets (within table 4.1-4.4) represent the values used in a weighted accuracy estimate. A 50% weight was given to the values either side of the diagonal, and 100% to the diagonal.

		CLASSIFICATION (Satellite + topographic)						
		0	**25**	**50**	**75**	**100**	*Total*	*Producer*
API	**0**	475	134	50	36	140	835	**57%**
	25	288	267	94	53	66	768	**35%**
	50	149	124	88	53	107	521	**17%**
	75	111	47	28	50	150	386	**13%**
	100	523	143	120	123	4683	5592	**84%**
	Total	1546	715	380	315	5146	8102	
	User	**31%**(40%)	**37%**(55%)	**23%**(39%)	**16%**(44%)	**91%**(92%)		**69%**(75%)

Table 4.1. Confusion matrix indicating the correspondence between the digital classification of sealing and the API reference maps. Figures in brackets indicate adjusted accuracies, to allow for a degree of uncertainty in the API.

The effect of parcel size on user accuracy

The use of 25% intervals in the API limits a true understanding of the accuracy but provides an indication of accuracy. The accuracy of the satellite classification is better for larger land parcel sizes (Figure 4.3). This is most likely due to there being a smaller proportion of edge (or mixed) pixels in larger land parcels. Within larger parcels it is more likely that individual image pixels are made up of pure cover types, *i.e.* either all vegetated or all sealed-over. Within smaller parcels, however, especially gardens, there may well be a mix of lawn, patio, trees, etc., that fall within all or most individual pixels, thus making the correct classification of a pixel to one or other class (sealed or unsealed) less likely. Furthermore, for land parcel blocks with less than four (2.8 m) Quickbird pixels, *i.e.* $<32m^2$, the subdivision into 0%, 25%, 50%, 75% or 100% proportions is not possible and will contain erroneous artefacts, adding further to the problems of classification.

For Cambridge, it was determined that 44% of the land parcels (not land area) are smaller than 32 m^2. By excluding those smaller polygons, and repeating the accuracy assessment using only areas greater than 32 m^2, and then for those greater than 100 m^2, and then 300 m^2, in turn, the accuracy estimate improves. It is also noted that excluding smaller polygons has no effect on overall (average) accuracy which remains approximately 75% (76%, 73% and 76% for polygons with areas greater than 32 m^2, 100 m^2 and 300 m^2, respectively). The low impact on overall accuracy is largely due to the high proportion of the parcels classified as

100% sealed (over 80% of parcels). With any classification, the 'extreme end' classes are easier to classify correctly than the 'grey areas' in-between. In this approach, the accuracy of the 100% sealed class is improved by using the OS MasterMap® to override the satellite classification. To this end, the positive effect on accuracy of using the MasterMap® has been excluded from the summary of results in Figure 4.3, by excluding the 100% sealed class from the calculation of the mean. This provides a clearer indication of the contribution that the satellite data are adding to the sealing estimates.

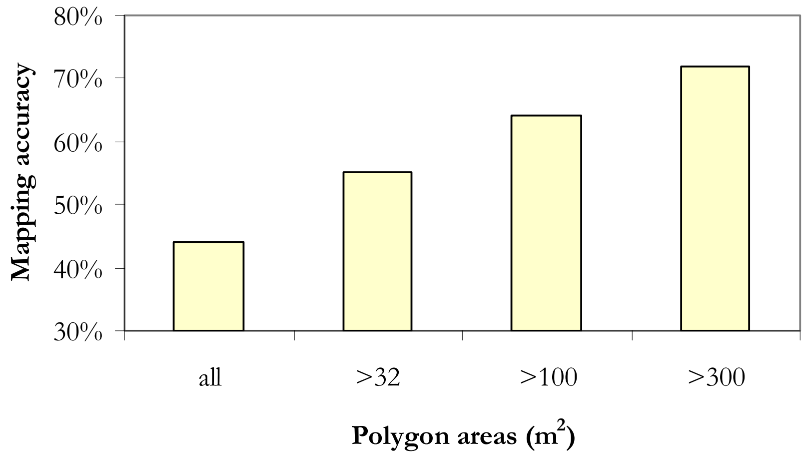

Figure 4.3. The average user accuracy for sealing classes 0%, 25%, 50% and 75%, as a function of parcel size.

	CLASSIFICATION (Satellite + topographic)						
	0	25	50	75	100	*Total*	*Producer*
0	346	123	37	25	30	561	**62%**
25	261	267	92	48	50	718	**37%**
50	130	115	82	49	78	454	**18%**
75	88	41	24	49	127	329	**15%**
100	83	58	31	40	2298	2510	**92%**
Total	908	604	266	211	2583	4572	
User	**38%**(52%)	**44%**(64%)	**31%**(53%)	**23%**(44%)	**89%**(91%)		**66%**(76%)

Table 4.2 Digital classification vs. API for areas **>32 m².** Figures in brackets indicate adjusted accuracies, to allow for a degree of uncertainty in the API.

	CLASSIFICATION (Satellite + topographic)						
	0	25	50	75	100	*Total*	*Producer*
0	220	55	11	6	3	295	**74%**
25	146	194	67	24	12	443	**43%**
50	47	70	53	23	35	228	**23%**
75	22	17	10	22	59	130	**17%**
100	26	18	11	18	535	608	**88%**
Total	461	354	152	93	644	1704	
User	**47%** (64%)	**54%**(72%)	**34%**(60%)	**24%**(46%)	**83%**(88%)		**60%**(73%)

Table 4.3. Digital classification vs. API for areas **>100 m².** Figures in brackets indicate adjusted accuracies, to allow for a degree of uncertainty in the API.

	CLASSIFICATION (Satellite + topographic)						
	0	**25**	**50**	**75**	**100**	*Total*	*Producer*
0	124	14	1	0	2	141	**88%**
25	68	91	24	8	6	197	**46%**
50	12	16	19	13	14	74	**26%**
75	8	1	4	7	32	52	**13%**
100	11	7	3	5	195	221	**88%**
Total	223	129	51	33	249	685	
User	**56%**(70%)	**70%**(82%)	**37%**(65%)	**21%**(48%)	**78%**(85%)		**64%**(76%)

Table 4.4 Digital classification vs. API for areas **$\geq$300 m^2.** Figures in brackets indicate adjusted accuracies, to allow for a degree of uncertainty in the API.

The effect of land parcel aggregation on accuracy

The previous discussion concluded that the relative accuracy of classification is greater for larger land parcel sizes. In a similar way, this next section presents the effect of grouping smaller, adjacent polygons into larger blocks, to determine the effect on classification accuracy; in other words, simulating larger parcels by spatial aggregation.

A sensible aggregation 'unit' of polygons is considered to be groupings of houses and gardens that share a common 'block' of land, *e.g.* delineated by a road network for instance. For this exercise, 20 examples like that in figure 4.4 were selected from the already-interpreted survey data. The average area of sealing for each of the 20 examples from the digital classification was compared by statistical regression against the API survey. Figure 4.5 shows a good correspondence between the results. Its associated statistics indicate that the average mapping accuracy of aggregated blocks is over 92%.

These results indicate that, if the maps were presented as summarised blocks, the maps should be more reliable. What has not been possible to investigate during this project is to aggregate the polygons for the *whole* of Cambridge into spatial units that represent the real-world shapes of the garden-house blocks. This would require considerable editing of OS MasterMap® vector data. An alternative solution was to use regular shaped polygons, or 'pixels' (*e.g.* figure 4.6). The pixels should be of equal area to the average residential block, which was approximately 4000m^2, equivalent to a 64 x 64 m pixel. 64 m is not a conveniently divisible block size for integration into existing environmental data (such as 1 km datasets), and, as such, a 50 x 50 m pixel has been chosen to present the data for input into a GIS and for quantitative purposes.

Figure 4.4 An example block of associated gardens and houses used to assess the improvement in accuracy using parcel aggregation.

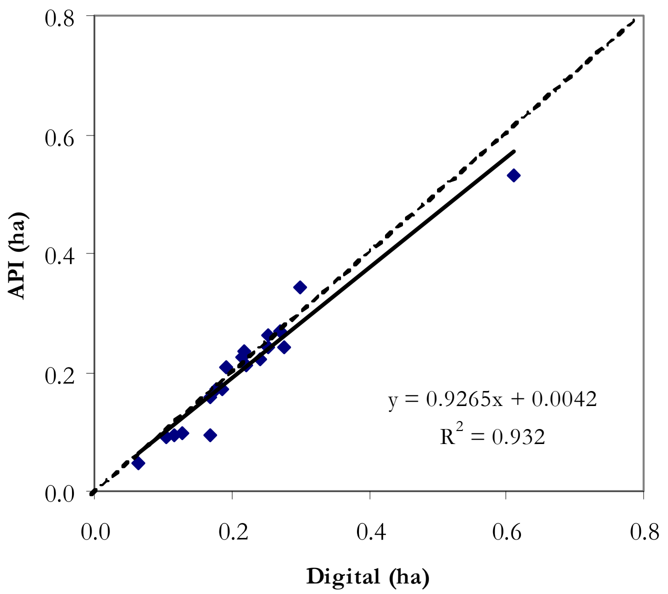

Figure 4.5 Correlation between estimates of sealing from digital classification and observations from air photo interpretation for amalgamated blocks of gardens and houses, with an average area of 4000 m^2.

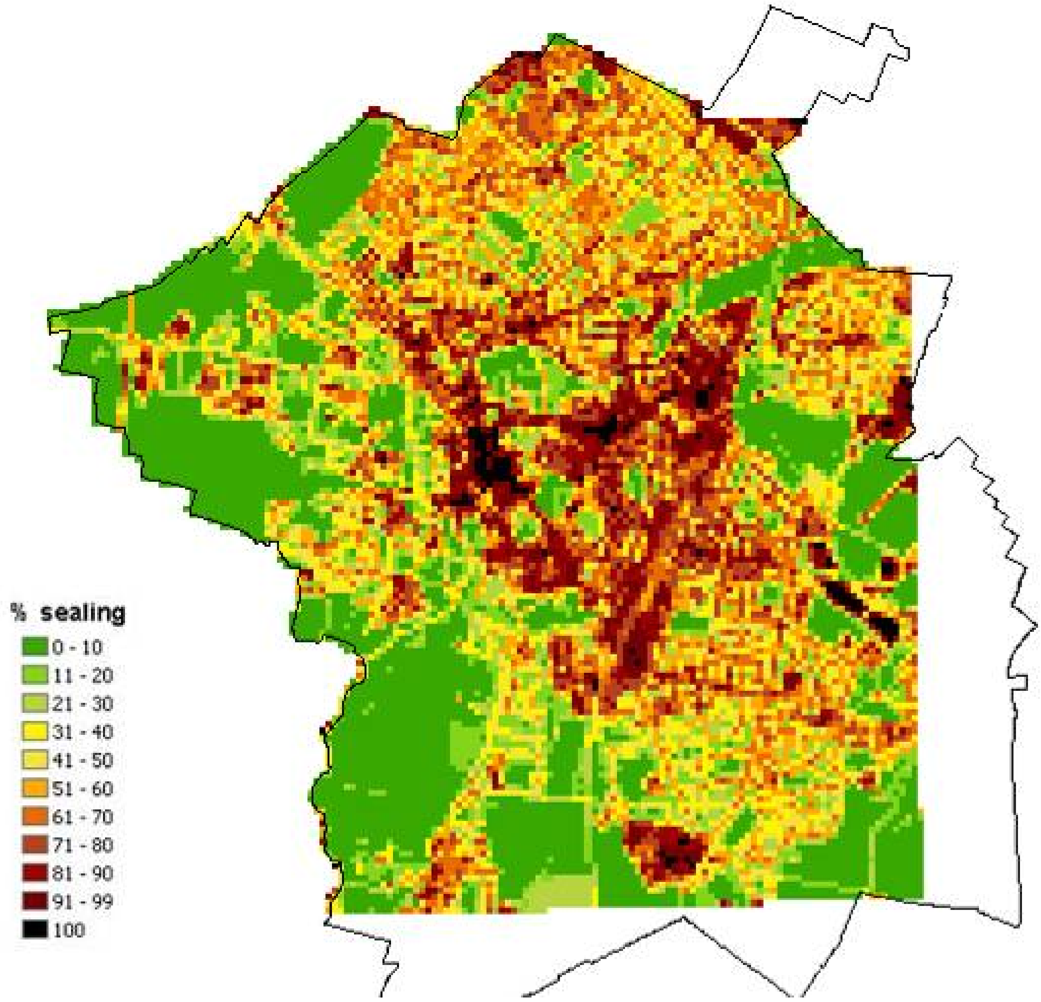

Figure 4.6 Classified map of sealing for Cambridge City district, 2003, resampled to a 50 m pixel indicating a 92% confidence (the blank areas represent areas outside of the Quickbird scene used in this study).

The accuracy of whole-city estimates of sealing

The previous section indicates that maps of sealing[20], with overall mapping accuracies of 90%, and prediction accuracies of *c.*80% for any 50 x 50 m area, can be produced. As spatial aggregation increases, the reliability of the estimates increases albeit at the expense of spatial precision. This section summarises a method for estimating a mean sealing value for a *whole* town or city, and its likely error, for instances maps of internal sealing variability are not required. When using satellite derived classifications of land cover of any kind, estimations of percentage cover can be biased, due to misclassification errors. Simply summing up the values from the classified pixels in a GIS would lead to biased estimates. To test this, and to correct any bias, statistical methods can be applied that integrate image classification data with associated ground sample data. For an excellent overview of these statistical approaches see Taylor *et al*. (1997); we have provided end-notes to this section to provide more details of the statistical methods adopted specifically for this report (p49).

[20] N.b. an indirect measure using *non-vegetated* surfaces as a proxy for sealing.

In overview, three city-average estimates of sealing area can be made given the data we have presented hitherto:

i) The first is by using the air photo-interpreted (API) observations (samples) of the average area of sealing within the 250 x 250 m sample squares drawn randomly across the city district. The total area of sealing in the whole of the city district is estimated by classical statistical estimation of the sample mean and variance from those sample squares and then by extrapolation to whole survey area. These estimates suffer from sampling error.
ii) The second estimate uses the digital classification approach. From the digital classification, which is a synthesis of image classification and *a priori* sealing data from Ordnance Survey MasterMap®, the whole of the city district is classified. The total area of sealing is calculated by summing up all the areas sealed across the whole city. The digital classification has no sampling errors, but suffers from classification error from the satellite image classification component, which can introduce a bias.
iii) Finally, a third estimate uses the two sources of information together. The relationship between the API sample information and the digital classification is determined by statistical regression. This yields a 'regression estimate' (Cochran, 1977) whose results are more accurate than either the API sample or the digital classification.

The statistics detailed in the end-notes indicate that it is possible to estimate the degree of sealing for a whole city to within ±5% of the mean. This is compared with ±20% of the mean if a classical sample was adopted. In other words, given that the area of Cambridge district is 4070 ha, by taking a traditional sample the total area sealed is estimated to be 1869 ± 397 ha. By integrating remotely sensed data, to improve the estimate, the area of sealing is determined to be 1642 ± 83 ha.

But how does this compare with the mapped data already produced? The regression results (figure 4.7) indicate that there is no significant bias in the image classification. This means that, for the example of the 2003 Cambridge data, an unbiased estimate of the overall sealing statistics can be derived from the classified map (Figure 4.6) without the need for using the regression estimator, n.b. this may not always be the case for other cities or for Cambridge at other dates. It does indicate that a high degree of reliability could be assumed and that estimates from the maps alone could be used to compare and rank cities within England and Wales, and when monitoring over time.

Summary

The example map of Dresden (figure 2.2), which was used as 'template' product, was derived by laborious air photo interpretation and is, therefore, a reliable map with high detail. The map of sealing for Cambridge City has been produced using a semi-automated approach and will always, therefore, have a higher degree of uncertainty associated to it.

The mapping accuracy at the individual parcel (MasterMap® TOID) level means that the maps produced by the more automated methods produced in this report, must not be interpreted at the garden level other than with caution and with an understanding of the inherent uncertainty of the sealing estimates. The individual class accuracy was 44% (if the 100% sealed class is ignored, *i.e.* representing the satellite classification accuracy at the TOID level). Individual class accuracy was higher (73%) for parcels greater than 300 m^2. The 100% sealed class is a special case: it corresponds to a class accuracy of over 90%. This is because this class had less subjective error in the API and. predominantly, because the majority were classified directly using the OS MasterMap® data.

The mapping accuracy is affected by the presence of a high number and density of urban trees. The air-photo interpretation combined with some ground checking revealed that in places where parts of gardens were sealed, land was sometimes obscured from above by tree canopies. The nature of using vegetation as an indicator of unsealed soil means that sealed land parcels will naturally be mis-classified by remote sensing if obscured by overlying vegetation (trees) – because this is what the sensor 'sees'. Most gardens in Cambridge are at least bordered by trees. This is possibly why the individual accuracy of parcels, for example, classified as 25% sealed, can be as low as 40-50%. When considering larger parcels of land (*e.g.* larger gardens and parks) this obscuring effect is reduced proportionally, although trees will still have an effect on accuracy.

It was demonstrated that it is better to re-present the maps using larger basic mapping units, than individual gardens, in order to achieve an overall mapping accuracy of over 90%. The recommended unit size is 50 x 50 m units (figure 4) using either regular pixels or real-world aggregations of individual land parcels, *e.g.* into associated groups of gardens. In the case of Cambridge City the accuracy of the data on a 50 m grid was 92%.

Assuming that maps are produced in a similar way for subsequent dates, and given that the observed Least Significant Difference (LSD) for Cambridge was *c.*16%[21], this would indicate that a real-world change in sealing levels greater than this amount would need to occur before any statistical confidence (at the 95% limit) could be placed on any mapped changes within the city. This is the estimate of change detection for the individual 50 x 50 m units. Consequently, maps of change in sealing within a city could be produced with robust statistical confidence, providing the measured change exceeds the LSD.

Extending to a whole town or city, if mapped variation within the city is not a requirement and only total amounts are required, estimates of sealing were shown to have an accuracy of over 95% using the regression estimator – this equates to an error of around 80 ha, out of 4070 ha for Cambridge. An LSD is estimated to be 10%, or 16 ha, representing the difference in the amount of sealing required before confidence can be put on any estimated changes over time.

Extending this to the whole city, estimates of sealing were shown to have an accuracy of over 95% using the regression estimator, around 80 ha (out of 4070 ha). An LSD is estimated to be 10%, or 160 ha, representing the difference in the amount of sealing required before confidence can be put on any estimated changes over time.

In the example of Cambridge for 2003, the estimate of sealing was 1642 ha (±83 ha) within a total city district area of 4070 ha. In percentage terms this equates to approximately 40% (±5%).

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[21] 2 x (100%-92%) = 16%

End-notes: statistical reporting on the area sealed

Classical statistics – direct expansion

The classical 'direct expansion' formulae give an unbiased estimate for the area of sealed land. The estimate of sealed land (s) would be given by:

$$\overline{y}_s = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad (1)$$

with variance

$$Var\left(y_s\right) = \left(1 - \frac{n}{N}\right)\frac{1}{n(n-1)}\sum_{i=1}^{n}(y_i - y_s)^2 \qquad (2)$$

where: y_i is the proportion of a square segment i covered by sealed land use s, N is the total number of segments in the survey area, n is the number of square segments in the sample. The sample fraction is n/N; when this is less than 5%, the correction factor (1 - n/N) can be omitted from the formula (Cochran, 1977).

The estimate of the total area sealed for the entire survey region is then:

$$\hat{Z}_s = D\,\overline{y}_s \qquad (3)$$

with variance

$$Var(\hat{Z}_s) = D^2\,Var(\overline{y}_s) \qquad (4)$$

where D is the area of the region.

The regression estimator

Integration of the two approaches (image classification and ground survey) provides an opportunity to improve the area estimates of sealed land by using the regression estimator.

The relationship between the observation of sealed area from the API sample survey and estimates from the digital classification (table 4.5) is determined by linear regression of y on p, given by:

$$y = \overline{y} + (p - \overline{p}) \qquad (5)$$

where $\overline{y}$ and $\overline{p}$ are the sample mean values and b is the slope of the regression line.

In the case of the mapping approach, $\overline{p}$ can also be estimated from the digital classification, and is calculated by summing all the areas sealed from the whole of the city district. This value is used in the regression equation to produce a correction factor for the sample estimate of the mean sealed proportion per unit area, $\overline{y}$; this is the regression estimator, $\overline{y}_{reg}$, shown in figure 4.7 and given by:

$$\overline{y}_{reg} = \overline{y} + b(\overline{p}_{pop} - \overline{p}) \qquad (5)$$

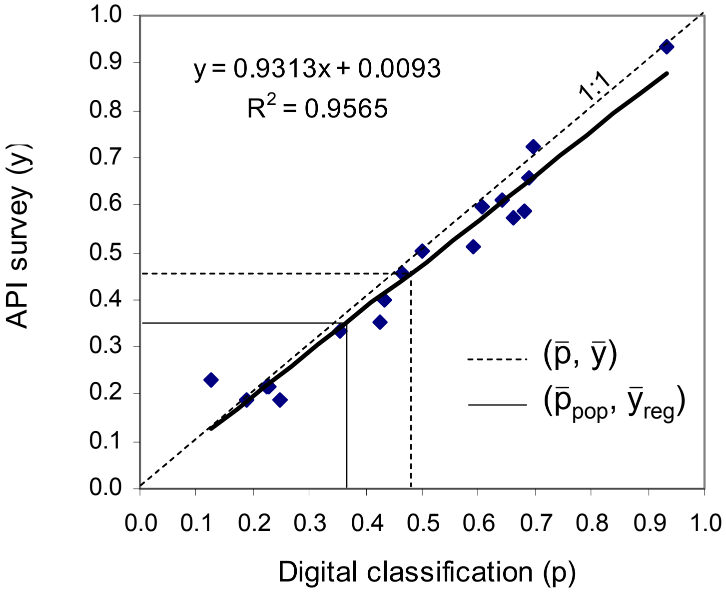

Figure 4.7 Relationship between the digital classification and API survey for sealing in Cambridge district

The variance is:

$$Var(\bar{y}_{reg}) = \tfrac{1}{n} Var(y)(1 - r_{py}^2) \tag{6}$$

where r_{py}^2 *is the coefficient of determination.*

The estimate of the total area sealed is then:

$$\hat{Z}_{reg} = D\,\bar{y}_{reg} \tag{7}$$

with variance

$$Var(\hat{Z}_{reg}) = D^2\, Var(\bar{y}_{reg}) \tag{8}$$

<u>Estimates of sealing for Cambridge district</u>

Table 4.5 lists the API-derived area measures of sealing that were extracted from the 18 sample segments; the 18 sample segments represent a randomised sample selected from a systematically aligned 250 x 250 m area frame (refer back to figure 3.2). Table 4.6 summarises the key statistics for both estimation methods: Direct Expansion and the Regression Estimator.

Segment	Proportion sealed (API)	Proportion sealed (Digital Classification)
Area1	0.595	0.605
Area2	0.229	0.126
Area5	0.573	0.660
Area6	0.656	0.689
Area10	0.188	0.249
Area11	0.504	0.498
Area12	0.512	0.591
Area13	0.399	0.434
Area16	0.188	0.191
Area17	0.217	0.226
Area19	0.350	0.423
Area20	0.932	0.935
Area21	0.215	0.230
Area22	0.333	0.353
Area24	0.723	0.696
Area25	0.609	0.643
Area26	0.454	0.467
Area28	0.589	0.680

Table 4.5 *the average area proportions of soil sealing for all 18 ground segments (250 x 250 m), measured from the API and estimated from the Digital Classification.*

	Direct Expansion	Regression Estimator
Sealing estimate (%)	45.9	40.4
Total area sealed (ha)	1869	1642
95% C.I. (ha)	397 (21.2%)	83 (5.1%)
Range (ha)	1472 - 2266	1559 - 1725

Table 4.6 *Summary sealing statistics using direct expansion and the regression estimator*

The average proportion of sealing estimated from the sample is 0.459 (46%). The area of Cambridge district is 4070 ha, so by direct expansion the total area sealed is 1869 ± 397 ha (table 4.6). Using the regression estimator to improve the estimate, the area of sealing is determined to be 1642 ± 83 ha.

The variance-reduction is usually the main benefit of the regression estimator, but in this case the survey sample appeared to be biased towards more urbanised segments. If ground survey alone were to be used to derive sealing statistics, more samples would be needed, not only to improve the statistical precision of any estimates, but also to ensure that the estimate of the average value is more accurate. The statistical precision (defined using the 95% confidence limits) indicates that the regression estimator provides an estimate of the mean to within ±5%; this is compared to over 20% error using a survey sample of the city. Not only, therefore, is the confidence of the estimate using the regression estimator much better – ±5% of the mean, as opposed to ±20% of the mean – but the accuracy of the estimate is significantly different.

5. **Operational feasibility: logistics and finance**

Technology matching

From the review of processing technology, a number of key criteria were identified, principally spectral range and spatial resolution, but also timing and image acquisition frequency. For spectral range, the following three criteria were stated in order of preference:

- Visible/NIR: the principal configuration requirement was to review sensors with visible and near infrared wavelengths. The review identified that approximate wavebands were acceptable and, as a result, no *exact* band spectral ranges/parameters were specified.
- Thermal Infrared (TIR), in a spectral range that covered 8500-9000 nm
- Short Wave Infrared (SWIR) at approximately 2000 nm

Within each of these key criteria, the Coverage Scenario requires analysis at specific spatial resolutions of:

- <2m (this matches airborne capability)
- 2m – 10m (a range centred on Defra's specified requirements)
- 10m -50m (this provides a match to work that adopted sub pixel classification)
- >50m (to complete the range, for information only)

The technology matching process involved matching the key criteria identified during the literature review to satellites and instruments. This process utilised historical sensors, current operational sensors and future sensors. The technology matching for current and historical sensors was conducted first on TIR, then SWIR, followed by VIS + NIR. This is presented in Appendix 2.

Current and historical sensors

A number of instruments that could provide data to meet the key spectral bands identified from the literature review have been identified. None of the instruments identified would be able to meet the <2m spatial resolution range identified. For both SWIR and, much more relevant to TIR the spatial resolutions available would not be able to provide any imagery better than 18 m.

Given the importance of pixel resolution as a key criterion along with NIR capability, three sensor systems featured highly:

- Quickbird (2.8 m)
- IKONOS (4 m)
- Orbview-3 (4m)

Future Missions and data continuity

The continuity of service from current and future systems is estimated to extend well beyond 2019. This section summarises a review that identifies the range of future missions available, which is presented in more detail in Infoterra's main report (Appendix 3; section 3)

Data users need to have data sources stable over long periods of time, because the development of applications can be lengthy and costly. Customers with an operational requirement will not allow themselves to become dependent on a measurement system that does not have a clear commitment to provide the required information for the foreseeable future. In order to identify what further satellites could be available over the next ten years a review of named programmes that are planning to develop and launch satellites within this period was undertaken. Table 5.1 shows planned satellites with resolutions better than 2m and table 5.2 shows those planned satellites with resolutions of between 2m and 10 metres.

Instrument	Satellite	Resolution (m)
Orbview 5	Orbview 5	1.64
WorldView II	WorldView II	1.8

Table 5.1 VIS/NIR Instruments with a resolution of less than 2m

Instrument	Satellite	Resolution (m)
EROS-C1	EROS-C1	2.8
EROS-B1	EROS-B1	3.68
LAPAN-Tubsat	LAPAN-Tubsat	5
CBERS-3	CBERS-3	5
CBERS-4	CBERS-4	5
RazakSat	RazakSat	5
Resourcesat-2	Resourcesat-2	5.8
RapidEye	RapidEye	6.5
X-Sat	X-Sat	10

Table 5.2 VIS/NIR Instruments with a resolution of 2-10m

Two instruments that match the VIS/NIR up to 2m resolution criterion were identified. These will offer an improvement on the "best" instruments currently available (2.4m resolution data). Both of these instruments offer a continuity of services from existing sensors (Quickbird to WorldView II and Orbview-3 to Orbview-5). Both also have funding in place and are scheduled to be launched within the next two years. The design life of existing and future instruments allows for a continuity of service until at least 2019. As the vest majority of instruments operate beyond their design life, the continuity of service can therefore be considered to extend well beyond 2019 (figure 5.1).

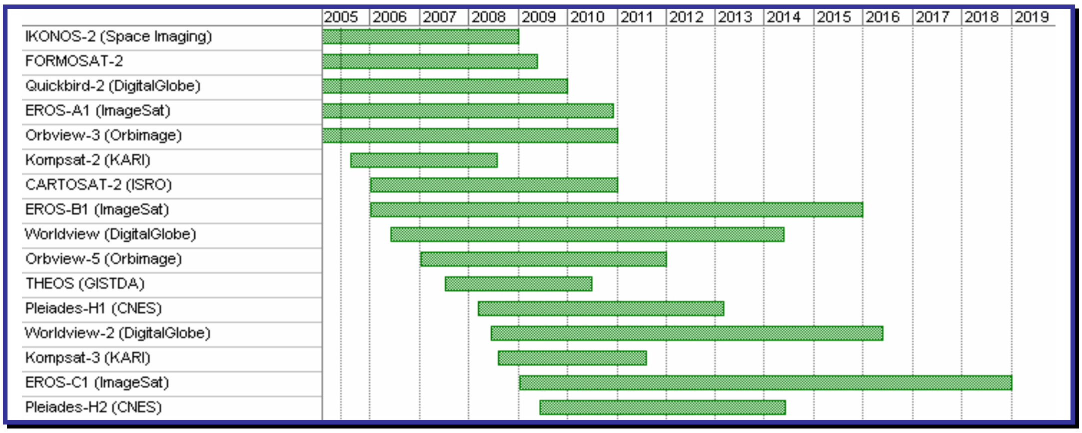

Figure 5.1 Future high resolution optical satellites

Data continuity allows users to spread their system costs over time and reduce expenditure by avoiding having to "chase" replacement data sources or changing data formats. Continuity of measurement capability and data availability are crucial to motivate investments in operational data utilisation. This requires a commitment from the satellite operators for the replacement satellites, an operational budget, and backward compatibility of observations with inter-calibration when new systems are implemented. When planning the launch schedule for new satellites, continuity of operational and backup service must be preserved.

To allow for the sometimes lengthy commissioning phases, a new backup satellite must be launched well before the satellite's lifetime fuel limit has been reached. But continuity cannot be guaranteed until a community of users has expressed a sustainable demand and a mechanism to support the provision of information.

As has been shown in the list of high-resolution future optical satellites the issue of data continuity has been acknowledged and satellites such as EROS-B1/C1, Orbview-5, Resourcesat-2 and Worldview II have already been confirmed and will launch in the next few years to enable continuity of measurements.

It is believed that these identified long-term plans for future satellites will go a long way towards satisfying these requirements. These are, therefore, appropriate for development of an operational service.

Operational feasibility

Feasibility of operational scale image acquisition

A feasibility study of Cranfield's work was subcontracted to Infoterra UK Ltd. It was demonstrated that the acquisition of high resolution satellite imagery for all[22] major cities in England and Wales (9,000 km^2) over a five year window is feasible. This is not a straightforward operation and so a brief explanation of the recommended steps and assumptions are now presented.

[22] All urban areas with a population of greater than 50,000 people. This covers a total area of approximately 9000km2, and includes Sheffield, Reading, Northampton and Portsmouth; smaller towns such as Lancaster, Canterbury or Winchester do not have sufficient population and, therefore, were not considered

In England and Wales the biggest influence on the operational collection of optical imagery is cloud cover. However, issues with cloud-cover can be overcome. During the year 2005, Quickbird acquired a total of 1048 scenes over the United Kingdom. Of these 1048 scenes, 275 scenes have a cloud-cover rating of less than 20% and a subsequent 110 scenes are rated cloud-free. The 110 scenes cover a nominal area of 28,160 km^2, while the total urban area under investigation is likely to be less than 9,000 km^2. This shows that while cloud-cover remains a significant issue with regards to large-scale optical imagery collection, it can be possible to acquire sufficient suitable imagery over targeted areas that are historically cloud-cover poor areas for image acquisition.

The requirement to collect all 9,000 km^2 of imagery within a single year would be a significant tasking requirement. European Space Imaging has estimated that a tasked area of interest (AOI) of 6,000 km^2 would be the best feasible option that could be achieved within a May to October collection window – the window to minimise the problems of cloud cover. As such it is considered that there would be insufficient capability to acquire all 9,000 km^2 from a single satellite. Multiple satellites[23] working together could provide sufficient capacity.

Discussions on the format of any such collection sharing between operators have indicated that there is tentative agreement between satellite operators. It is considered that an even split of the AOI's between operators would be the most likely scenario for how this could be achieved.

Dividing the collection of imagery over the five year reporting period reduces the area to be collected to 1,800 km^2 per year. European Space Imaging has indicated that they would see "no major problems" in acquiring an annual AOI of this size.

To date no preference has been indicated on how to split the AOI's evenly across the five year reporting period. If priority ranking was required, it is likely that London would be ranked for collection in year-one. However, through discussions with various satellite operators, it is recommended that the AOI's should not be ranked into a preferred collection order so that the effect of cloud-cover difference across the five year reporting period is minimised.

The ideal approach would be to consider a fully flexible mission. By submitting all the AOI's into an operator's tasking system at the beginning of the project, it would enable the operator to select AOI's for tasking based on the most favourable cloud-cover conditions available. The annual tasking could be capped at 20% of the total AOI, but it maybe preferable to allow collection to continue beyond the 20% limit in a good year – any additional tasked imagery would be retained for deferred analysis, *i.e.,* in the following year. This could allow balancing between years with low cloud-cover and years when imaging conditions are consistently poor. It would be preferable to group AOI's based on regions and not to have a fragmented array of AOI's across the whole of England and Wales.

[23] Multiple satellites of approximately the same resolution, *e.g.* Quickbird, Orbview-3 or Ikonos

Feasibility of operational scale map production

Using estimates of processing time[24] and resources required for each stage of the outlined methodology, and simplifying it for a project that was split evenly across five years, it is possible to calculate the timescale for running an operational monitoring project – this is based on using only one member of staff.

Since the segmenting of the MasterMap data is not necessarily dependent upon external factors it is considered that this could be started first. The selection of tiles however is dependent upon which AOI's are tasked and acquired, therefore it is possible that this could alter the start date for this process. Also the start date for beginning this process is dependent upon the lead time that Defra would need to supply the required MasterMap tiles.

Two timescales have been provided based on:

- acquiring all imagery in one window
- acquiring an even split of imagery across 5 years

<u>One collection window</u>

The start date for the main processing has been moved to begin at the end of the collection window for the satellite data. The collection window is stated to run from May to October, and the main processing has been set to begin on the 01-November. The timescales are based on a single operation using a single calculation.

- Geocorrection (figure 2.3) :
  - The Ortho-correction process is due to last for a total of 110 days
    - Start Date : 01-November
    - End Date : 09-April
- Classification of satellite data:
  - The Classification process is due to last for a total of 105 days
    - Start Date : 10-April
    - End Date : 08-October (Year2)
- Count sealed pixels :
  - The Count process is due to last for a total of 75 days
    - Start Date : 09-October (Year2)
    - End Date : 21-January (Year2)
- Reconstitute:
  - The Reconstitute process is due to last for a total of 50 days
    - Start Date : 21-January (Year2)
    - End Date : 31-March (Year2)
- Map Creation:
  - The Map Creation process is due to last for a total of 25 days
    - Start Date : 01-April (Year2)
    - End Date : 30-April (Year2)

[24] For a detailed breakdown of estimated processing time refer see section 5 of Appendix 3

- Accuracy Assessment:
  - The Accuracy Assessment process is due to last for a total of 25 days
    - Start Date : 04-March (Year2)
    - End Date : 30-April (Year2)

Split across five years

The Start date for the main processing has been moved to begin at the end of the collection window for the Satellite Data. The collection window is stated to run from May to October, and the main processing has been set to begin on the 01-November.

- Geocorrection (figure 2.3) :
  - The Ortho-correction process is due to last for a total of 22 days
    - Start Date : 01-November
    - End Date : 30-November
- Classification of satellite data:
  - The Classification process is due to last for a total of 21 days
    - Start Date : 03-December
    - End Date : 17-January
- Count sealed pixels :
  - The Count process is due to last for a total of 15 days
    - Start Date : 18-January
    - End Date : 08-February
- Reconstitute:
  - The Reconstitute process is due to last for a total of 10 days
    - Start Date : 11-February
    - End Date : 22-February
- Map Creation:
  - The Map Creation process is due to last for a total of 5 days
    - Start Date : 25-February
    - End Date : 03-March
- Accuracy Assessment:
  - The Accuracy Assessment process is due to last for a total of 5 days
    - Start Date : 04-March
    - End Date : 06-March

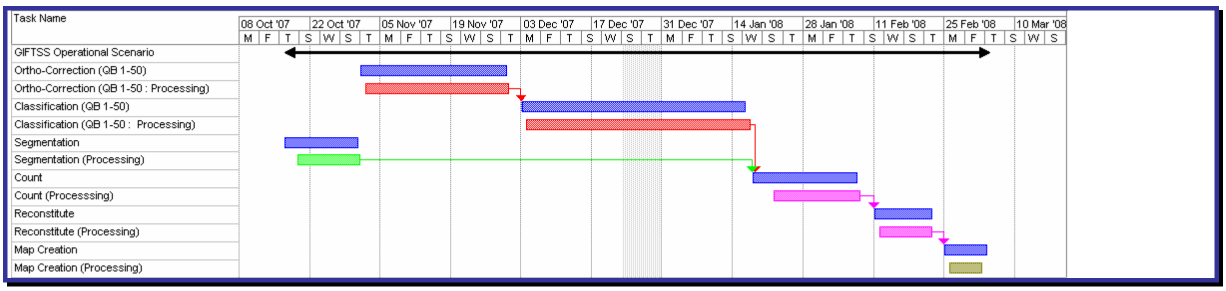

Figure 5.2 project timeline for a five year split collection

Implications on timescale

During the estimation of the timescale it has been appropriate to assume a worst case scenario in which the image acquisition conditions are at their least favourable.

Additional worst case assumptions have been made on data acquisition. The largest time component on the project is the orthocorrection and classification of the data. During these processes it has been assumed that only individual scenes would be available.

During the Quickbird analysis for the operational scenario it was estimated that a total of 198 individual Quickbird imagettes would be required to cover all of the AOI's. However this could be reduced to some 80 segments of imagery if scenes are acquired from a continuous swath.

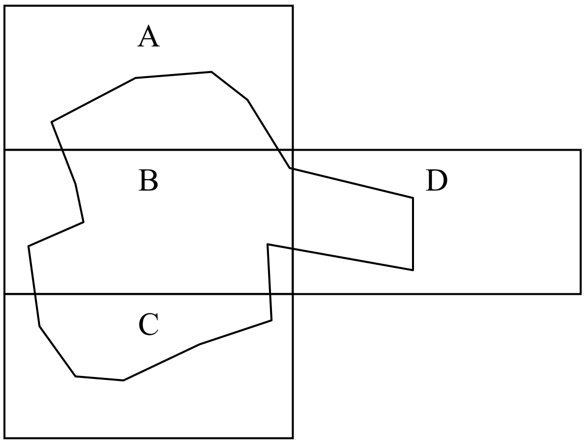

Figure 5.3. Schematic diagram representing four image scenes to cover a complete city. Scenes A, B and C are derived from one swath strip; scene D is from an adjacent strip.

If the urban area under observation (*i.e.* the AOI) is covered by four Quickbird scenes (figure 5.3) then in a worst case it would require four separate scenes each acquired on four separate dates. However if scene D could be acquired as a single scene on day 1 and then on day 2 scenes A, B and C could all be acquired together as a single swath this would mean there would be just two segments of imagery. Spectrally scene D and scenes A to C would be acquired under different conditions so they would need to be treated separately. However scenes A-C can be treated as one continuous image as they would share common spectral characteristics, which would improve the processing timescales through reducing processing from four individual scenes to just two blocks of imagery.

Operational costs

The estimated final cost for the project has been broken down into Data costs and Production costs. The Data costs have been estimated using current DigitalGlobe Quickbird pricing and a long-term dollar currency rate.

Data Costs

Product prices for high-resolution data are calculated by selecting the product type and product options, and multiplying that price by the area (in scenes or square kilometres).

The Final Total Price is calculated by adding the Product Price and multiplying by any applicable Licence Uplifts.

The total area of data required for England and Wales is 9,000 km^2.

The current DigitalGlobe Quickbird Ortho-Ready Standard tasking price is $22.00 per sq km for a multispectral image.

- The total data costs would be : $198,000
- The long-term exchange rate used was $1.75 to £1.
- The total data costs would be : £ 113,000

At the time of ordering discounted prices may be available.

Processing Costs

The following budgetary price has been estimated using Infoterra's standard costs and conditions. The final figure reflects a standard value for a single person undertaking all the required processing stages, contingency, appropriate hardware and software costs, applicable data storage costs, as well as project management and interaction with the customer. The estimate is correct as of May 2006; the stated price is not a formal Infoterra price offer. No annual inflation of fee rates is included in this estimate.

- The total costs for processing 9,000 km^2 of imagery would be around £137,000.

The price breakdown for the processing costs, which would be the same for both five years or one year, includes fixed costs such as hardware and software required to analyse the data. Workstations are assumed to be standard image processing workstations. These costs do not include any costs of aerial photography used for accuracy assessment; this could, for example, be provided through Defra's existing UK Perspectives licence at no additional cost to the soil sealing project. Assuming that aerial photography is available, the costs for accuracy assessment are included in the total processing costs, using the methodology described in Section 5.2.1.8 of Appendix 3 – the report on operational feasibility.

Defra would need to consider the costs of purchasing the necessary data processing tools if they wanted to do the image processing, analysis and accuracy assessment work in-house, including the purchase of the relevant hardware and image processing software applications.

The assumption present in the report is that SPIRE, as a Defra programme, would provide data storage and processing at no cost. This is a point that is under discussion within Defra, who has yet to decide how it wants to charge projects for access and storage costs. However, the storage costs for this particular data set would not be great and if SPIRE development were to cease, then the soils team could store the data themselves at little additional cost, given the current low costs of electronic data storage.

A more significant potential cost would be in sourcing OS MasterMap® in a suitable format. A key goal of SPIRE is to remove the cost overhead of each individual project processing MasterMap® and to provide projects with data in a format they can use. If SPIRE was unable to provide this service then the soils team, or their contractor, would need to undertake the necessary preparation work which would incur an additional pre-processing cost for converting OS MasterMap® data. Depending on the configuration required and the software used, this could add a cost of £2k to £5K for pre-processing time.

Total Costs

The total budgetary price for an operational sealing project would be £250,000, including satellite data purchase and data processing and analysis and excluding any additional data storage, air-photo purchase and MasterMap® pre-processing, as outlined above. It is noted that the costs that are included within the report are based on the use of Quickbird imagery, therefore, the £250k value is based on this imagery price. Changing the type of imagery used will change the data costs and the overall price. However, Quickbird provides an indicative cost – the prices of comparable sensors are similar; all are subject to change.

Metadata protocols

The formats of any data produced using the methods presented must be integrated into current information systems used by the Defra ST. An important component of providing and storing such data relates to its associated 'meta-data'.

There are currently a number of Metadata standards that are available to data providers. However in the UK the principal current standards are:

- ISO 19115
- UK Gemini
- Defra SPIRE Standard

The ISO 19115/19139 Geographic Information: Metadata standard is currently still under development but is becoming the international standard for geoinformation metadata. The content of the standard is defined by ISO 19115 which has already been released and the XML schema implementation is defined by ISO 19139 which is due to be released in 2006. There is also an extension, ISO 19115-2 Imagery Extension, under development covering imagery metadata. The ISO standard will supersede the current GI-Gateway / NGDF specification via the UK national profile UK Gemini.

The UK Gemini (Geo-spatial Metadata Interoperability Initiative) was launched in October 2004 after a year-long consultation process. As a profile of ISO 19115 it is a subset of these standards, adopting elements, structures and rules relevant to the UK geoinformation community. The UK Gemini profile will replace NGDF as the national geospatial metadata profile, allowing metadata creation that is compliant to both ISO 19115 and the national e-Government Metadata Standard. The UK Gemini profile is also being supported through the redevelopment of the MetaGenie tool that has been made publicly available by the GI-

Gateway thorough Central Government funding via the National Interest Mapping Services Agreement (NIMSA).

Defra is currently developing its own spatial information repository under the SPIRE programme (Spatial Information Repository). As part of the programme it was necessary to develop the existing UK Gemini standard to incorporate additional elements, following a Defra Data Standards workshop in October 2004, to make the metadata more appropriate for SPIRE and hence spatial data management use. The SPIRE standard is a development of the UK Gemini standard and in complying to the standard, compliance with UK-Gemini and ISO 19115 is achieved. The modifications are additions to the UK Gemini standard and not a replacement of any elements. Therefore, conformity to the SPIRE standard will mean conformity to the UK Gemini standard (figure 5.3).

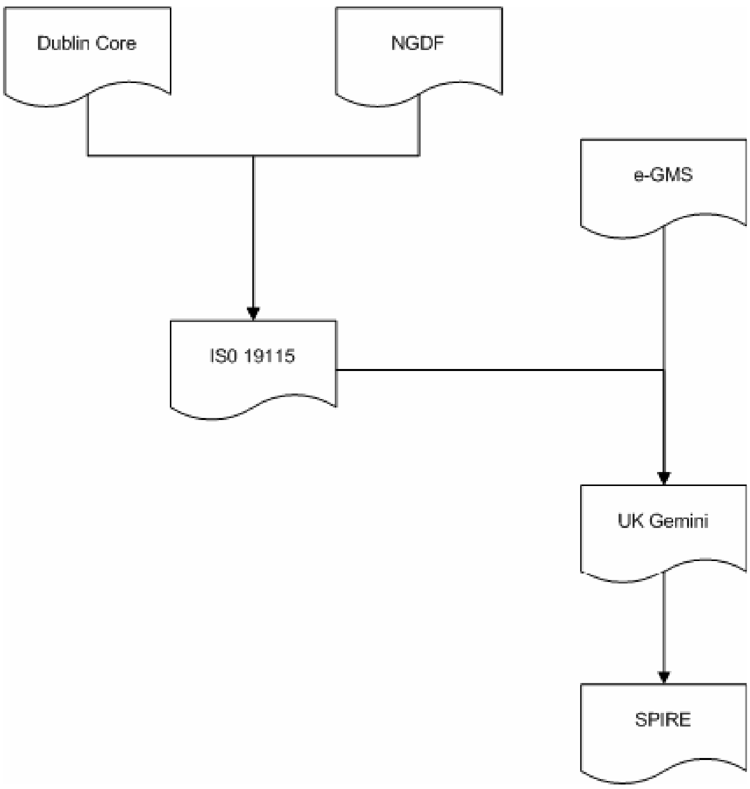

Figure 5.3 Derivation of SPIRE metadata from existing standards.

As part of any operational service that would be provided it is important that data being captured on behalf of Defra is captured with metadata and that this metadata complies with nationally recognised standards. Any operational data capture should conform to Defra's SPIRE standard as this is the most comprehensive standard, it is the *de facto* spatial standard for Defra, and it ensures full compliance with other national profiles like UK-Gemini.

Furthermore, the operational service will ensure that the GI Gateway, which acts as a central repository for metadata relating to spatial datasets within the UK, is populated with the metadata that is captured for the service. This ensures that users are aware that the data is available and conforms to best practice as laid out by e-government initiatives. Metadata will also be supplied to the SPIRE programme to ensure that a consistent record is held for Defra.

6. Adding value to soil sealing maps

This section of the report evaluates the opportunities for adding value to the soil sealing maps. It will cover feasibility studies for assessing the impact of sealing on three factors: biodiversity, drainage and aesthetic value.

Assessing biodiversity potential in urban areas

Overview

In this section we:

- identify and review the approaches and models designed to identify biodiversity potential in urban ecosystems
- illustrate how these might be applied using the Cambridge data
- identify some limitations and recommendations for further work.

It is important to note that this is not intended as a comprehensive review of the literature, but significant papers have been used to derive and illustrate important concepts and principles.

Introduction

Urbanization has been identified as a major cause of biotic homogenisation, favouring "urban adaptable" species (McKinney, 2006). The importance of biodiversity in urban areas is linked not only to ecosystem function, but also to human well-being *i.e.* the experience of nature enriches people's lives, and increases beneficial social interaction (Boland and Hunhammar, 1999; Thompson, 2002; Yli-Pelkonen, 2005). There is also growing realisation and pressures to incorporate "natural capital" and ecosystem goods and services provision into the planning framework (Hindmarch *et al*, 2006). It is therefore essential that urban planning institutional arrangements include biodiversity at the core of their procedures and statutory requirements, by building on existing ecological planning methods, incorporating the latest conceptual models with the best empirical evidence (Pickett *et al*, 1997; Leitao and Ahern, 2002). In order for this to deliver required protection or enhancement of biodiversity it is important that tools to assess changes in urban areas due to development are cost-effective and, more critically, predictable - allowing effective planning decisions to be made.

A further potential gain from this approach will be to utilise biodiversity assessment and decision making for delivering beneficial outcomes with respect to urban biogeochemistry (Decker *et al*, 2000) and its consequences for other ecosystem parameters, particularly those subject to specific statutory instruments, such as water quality and quantity issues in respect of the Water Framework Directive and pressures such as flood risk. This may be equally applicable to other Directives.

In combination with existing planning procedures and tools, it is possible to envisage a planning framework capable of "satisficing" multiple objectives and outcomes prevalent in the urban arena.
Two principal approaches used in determining the potential for biodiversity have been:

- Assessment of fragmentation
- Modelling meta-population dispersal and establishment, *e.g.* the interaction between several small populations in one area may be critical for survival.

These approaches have often been combined to produce some clear indications of the impacts of differing development strategies in urban areas.

Fragmentation

One process clearly affecting biodiversity in urban areas which is also predominant in the rural landscape is that of fragmentation (Collinge, 1996). This impacts upon both dispersal and establishment/regeneration phases. Critically, a range of substrate types, stress and disturbance regimes are required to maintain biodiversity. Large green areas are as likely to have only slightly higher biodiversity than sealed surfaces (Gilbert, 1989). An ongoing debate in this arena concerns the difficulties in agreeing a typology of fragmentation type, although several schemas have been suggested (*e.g.* Watson, 2002).

A principal concern in fragmentation studies is the relationships between the ratio of edge to interior spaces. Interior spaces are essential for many species to complete their life-cycles, minimal disturbance being important when raising young, or setting seed. This may be combined with some requirement for edge habitat for foraging and finding a mate. Also, some predatory species will require a certain amount of open space for hunting. The precise dimensions of “edge” will vary from species to species; the larger they, or their ranges, are the larger the edge effects (Collinge, 1996).

Relationship between sealing and biodiversity potential

With respect to the present study it is clear that links need to be made with regards to the relationship between surface sealing and biodiversity function. Very little work has been carried out on this and none on how assessment of sealing using remotely sensed data may relate to ecological function in general, other than measures of vegetation cover, let alone biodiversity in particular.

It is possible to make some working assumptions (which in themselves lead to suggestions for further work) as to the link between sealing and function such as:

- Hard, open, impermeable areas will have little or no function as to providing habitat for complex organisms with respect to nesting, food or other resources. They may offer some opportunities for movement but this depends on the type of organism and its mode of locomotion *e.g.* birds generally may cross roads, but would find large buildings an obstacle; because of thermal properties some insects find a large area of dark tarmac impossible to cross during hot sunny periods due to fast rising air currents.
- Undisturbed vegetated areas provide food and establishment opportunities, modified by vegetation type and soil type *e.g.* bare areas of sandy soil make ideal nesting conditions for many invertebrates *e.g.* burrowing bees.
- The size and arrangement of these areas are critical in determining the overall biodiversity outcome.

Approaches to quantifying biodiversity potential: Ground based surveys

It is currently not possible to quantify biodiversity comprehensively using remote sensing techniques which is not surprising as it is still impossible to do this easily using ground based techniques. Rather ground based surveys tend to aim for particular groups or organisms indicative of other parameters. The Biodiversity of Urban Gardens in Sheffield (BUGS) project represents a major effort to identify the importance of a key resource (urban gardens) in providing habitat and dispersal opportunities in urban areas (Thompson *et al*, 2003; Thompson *et* al, 2004; Gaston *et al*, 2005a and b; Smith *et al*, 2005). This programme has identified the key role that gardens play in providing habitat in urban areas. It is difficult, however, to easily extrapolate these findings to provide parameterisation for other types of urban green space.

Approaches to quantifying biodiversity potential: Dispersal and establishment models

Computer based models simulating the movement, establishment and regeneration of species within urban areas show great promise. They are based on generating movement models on maps where the polygons are ascribed "movement", "resource" (*e.g.* food) and "establishment" suitability. These are, to some degree, analogous to the extent of sealing of surfaces (see above), and the quality of the mapped areas delineated are often presented in movement models as "friction" or "permeability" surfaces (*e.g.* Vuilleumier and Prelaz-Droux, 2002).

The principal outputs of these models are:

- Movement based on:
  - Corridors and barriers
  - Residence times
  - Observation probabilities
- Foraging strategies
- Home ranges
- Migration

By varying the properties of the mapped polygons it is possible to alter the outputs in the above terms. This, then, readily lends itself to using these models in a planning context, as by "sealing" (*i.e.* built development) or "unsealing" (*e.g.* installation of a green roof) the consequences for biodiversity can be predicted. This then indicates the potential of areas to support wildlife and plant movement and dispersal, and regeneration phases.

The two principal modelling approaches are:

- Grid based with cell to cell jumps where landscapes are represented in raster (or pixel) format (*e.g.* GridWalk)
- Vector based with movement simulated as random walk vectors (*e.g.* SmallSteps)

Usually, species "types" rather than actual species are modelled. These are termed "eco-types" and are based on dispersal characteristics, such as lifespan, food requirements, mode of locomotion (walking/flying) (Snep *et al*, 2006).

Model characteristics include length of movement steps, turning angle, and response to boundaries *i.e.*:

- Bouncing
- Returning
- Return angle
- Edge tracking
- Chance of crossing from one polygon to another.

Model outputs

Outputs of these types of model tend to be patch-based and take three general forms:

- Arrivals probability matrix
    - These summarise the potential for maintaining a stable meta-population, and indicates landscape connectivity
- Population based
    - Which represent the range and density of population spread and establishment
- Landscape based
    - Landscape connectivity
    - Resource exploitation
    - Probabilities of "experiencing nature"

There have been several projects where spatial classification data have been used to assess the potential for the movement and establishment of organisms in urban areas (*e.g.* Vos *et al*, 2005; Snep *et al* 2006), based on either grid walks or vector based programmes. Figure 6.1 illustrates one model applied to Limburg, Netherlands, using a model based on a vector approach to simulate the dispersal and establishment of tree frogs. The output is a map of low suitability (pink/white) to high suitability areas (dark green). This gives a readily understandable visual output, and further metrics such as connectivity/area/edge:interior can be easily derived from it.

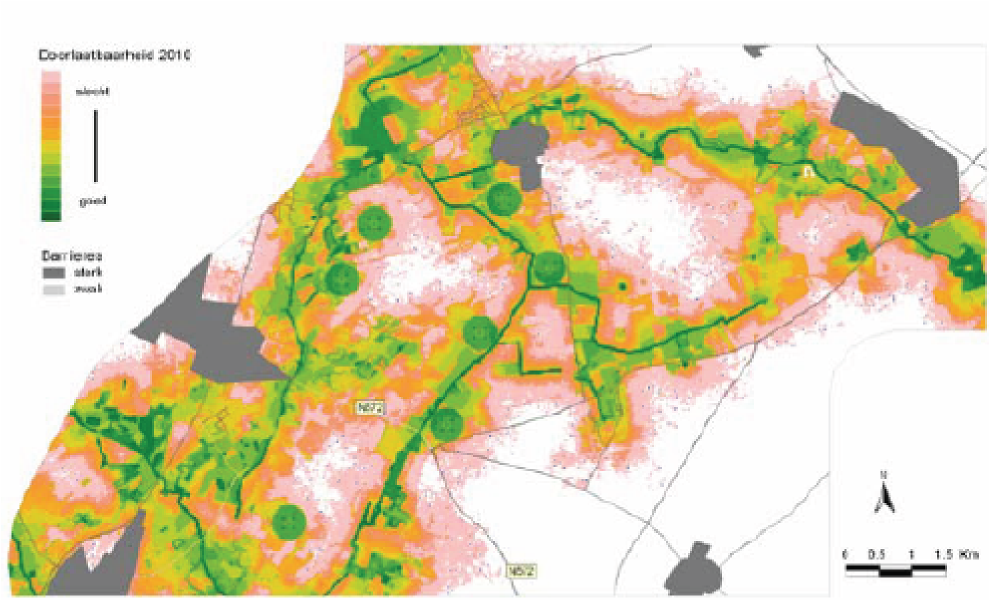

Figure 6.1 Landscape suitability and connectivity for the treefrog in Limburg (from Vos *et al* 2005)

Illustrations using the Cambridge data-set

<u>Edge:interior</u>

Three sub-set areas of the Cambridge dataset were identified as roughly corresponding to urban, sub-urban and peri-urban (figure 6.2). The edge-to-interior ratios were applied to these data.

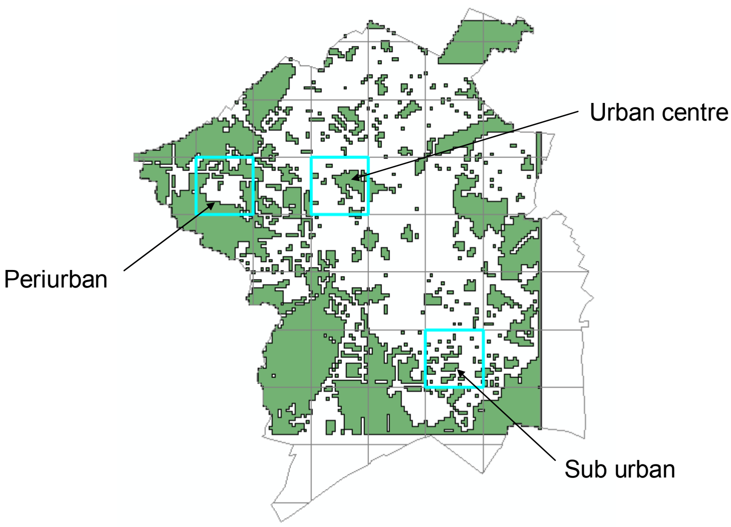

Figure 6.2 Selected sub-sets from the Cambridge data set. The green areas have been extracted from the soil sealing map (50 m pixel version) for areas with less than 25% sealing.

Two “edge” or margin sizes were selected: 50 m and 100 m; these are commonly used in fragmentation studies, and represent areas where organisms behave differently than in interior spaces. The output is shown in figure 6.3. In the case of the 50 m edge setting, the peri-urban area had much lower edge compared to interior than the other two areas. At the 100 m setting, the peri-urban area was the only area to have any interior at all. This is what we might have expected, where peri-urban areas have developed with larger green spaces. This approach may be useful in setting targets for total interior requirements in urban planning schemes but needs more work to determine what the quality of that interior should be (*e.g.* open maintained grass vs. scrub/woodland).

	Periurban	**Suburban**	**Urban**
Green area (ha)	52	18.0	25
Total 50 m edge (ha)	33	17.5	20
Total 100 m edge (ha)	46	*18.0*	*25*
Total '50 m' interior (ha)	19	1	4
Total '100 m' interior (ha)	6	0	0
edge:interior (50m)	2	35	5
edge:interior (100m)	8	n/a	n/a

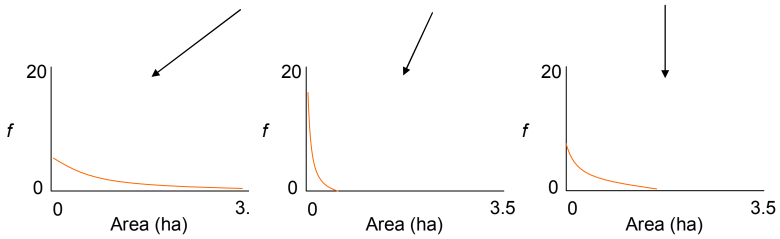

Figure 6.3 Edge:interior statistics for the three selected areas

Dispersal model

In collaboration with colleagues at Alterra in Wageningen (Hans Baveca and Robert Snep) the SmallSteps vector based model was applied to a section of the Cambridge dataset, where suitability or “resistance” to movement was related to the sealing characteristics of the area. The outcome of this is an animation of a time-series representing the increasing dispersal of a butterfly “EcoType” over time. Figure 6.4 represents a ‘snap-shot’ for one point in time showing the dispersal, with red indicating a high probability of “experiencing” a butterfly, and light green zero possibility. The pattern indicates an irregular, fragmented but approximately radial dispersion emanating from the source area (A).

From this modelled data a number of metrics could be used to represent and compare either i) different locations within or between cities or ii) the effect of changing the pattern of sealing – through urban development. It is possible to illustrate two potential approaches to derive metrics which may be applied to these models. Figure 6.4 shows how “sampling stations” could be located on the map, at which the frequency of encounters at these stations could be determined; the more frequent the occurrence, the higher the dispersal and establishment. Figure 6.5 illustrates an alternative approach, time to saturation. Here the number of iterations (time) until all polygons within the selected area have “experienced” a butterfly could be logged. Shorter times would indicate better dispersal and, thus, represent more favoured conditions (preferred planning/design).

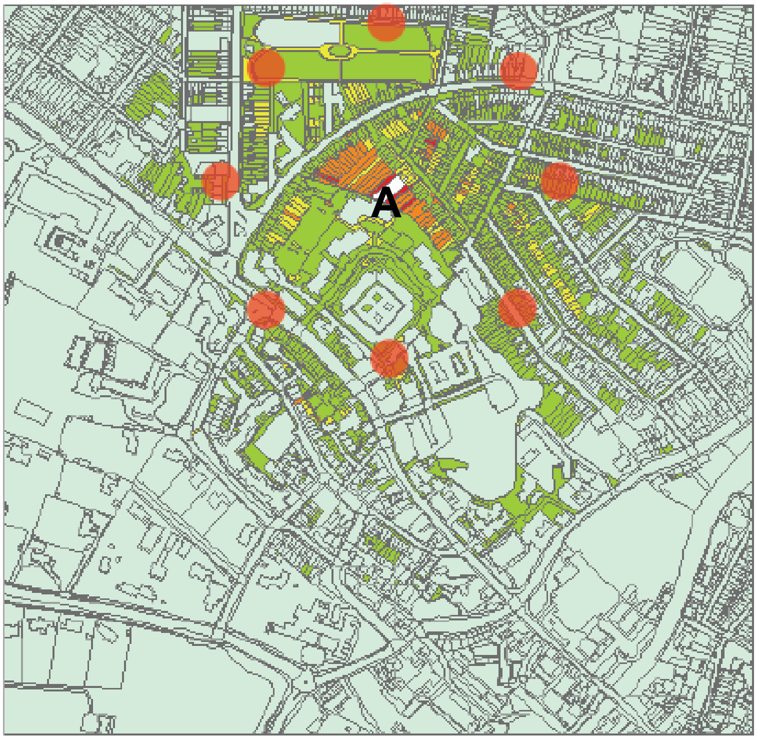

Figure 6.4 SmallSteps applied to Cambridge - sampling station approach

Figure 6.5 SmallSteps applied to Cambridge - time to saturation approach

Potential application to planning regimes

Implementing policies which favour wildlife in urban areas is often problematical (Harrison and Davies, 2002). There have been attempts to incorporate "rules of thumb" into the planning regime, notably English Nature's "Accessible Natural Greenspace Standards" model (ANGSt). This sets out a number of "minimum standards" such as "no person should live more than 300 m from their nearest area of natural green space of at least 2 ha in size" and "there shall be one accessible 100 ha site within 5 km" (Harrison *et al*, 1995). Further work on assessing this specific approach has been carried out by Handley *et al* 2003, and revealed the low take up of the strategy in the Local Authorities studied. Some of the key aspects of the low take up rate were reported to be:

- the lack of GIS systems in many local authorities, and
- the perception that this one model was not suitable for all urban areas. This view stems from the perception that it is already "too late" for some urban areas *i.e.* they are already below this standard, for example, Manchester city centre

This latter point should not be an obstacle to the development of a toolkit or GIS-based decision support system which could be deployed for future planning decisions to be made consistent with targets for minimum area size, type and connectivity for biodiversity and green space aspirations. The GIS based approaches outlined in this present study are readily amenable to implementing and testing the type of rule based approach outlined in the ANGSt model.

It is apparent from the many studies which have been carried out that the dispersal models based on GIS mapping of polygons are sufficiently advanced to be applied at pilot scale in contrasting areas. These may be tested under a variety of development scenarios.

Limitations and opportunities

The concept of modelling biodiversity potential in urban areas and consequences of development is well advanced and has been successfully applied in the Netherlands and Germany.

The limitations to implementation with respect to this present study are:

- Uncertainties as to the relationship between degree of surface sealing and suitability for biodiversity
- Precise relationship of biodiversity potential to other ecosystem functions
- Extent of ground truth available with respect to the above

Our recommendations are as follows:

- A pilot trial of the dispersal/establishment modelling approaches should be carried out in contrasting urban areas;
- A study to utilise these models to test the effects of alternative development strategies (*e.g.* ANGSt) on biodiversity outcomes;
- Further ground-proofing of these models with wider species groups;

- A feasibility study aimed at integrating these biodiversity based models with existing models used in spatial planning (*e.g.* “Spatial Syntax”);
- A programme to further investigate the links between biodiversity and other ecosystem functions in urban areas.

It is possible to envisage a toolkit based on a GIS system enabling planners to make robust decisions in the variety of contexts in which they operate. This will become particularly important if the concept of environmental constraints and limits is accepted as a principle.

Assessing the effect of sealing on urban drainage

Sealing and projected new development

Surface sealing in urban environments significantly alters the hydrological cycle by reducing permeability and infiltration, resulting in increased surface runoff and limited opportunity for groundwater recharge. The loss of connectivity between the atmosphere and hydrosphere significantly impacts on soil functional services that facilitate gaseous and hydrological exchange in the environment (Wood, *et al*., 2005). Sealing will increase with the projected provision of 160,000 new homes by 2010 in south east England growth areas (ODPM, 2005), with a recommended 60% built on Brownfield sites (PPS3, 2005) by 2008. New-build priority on Brownfield sites ('previously occupied land') further increases the proportion of sealed areas in urban areas through urban infill.

Hydrology of urban environments

Hydrological pathways in urban areas are controlled by engineered systems delimited by the spatial arrangement of infrastructure and buildings. The management of water in urban systems is primarily concerned with the routing of surface water from rainfall and disposal of wastewater. Flow and pollutant attenuation of surface waters is necessary to comply with directives that promote the development of more sustainable urban environments (ODPM, 2003; Defra, 2005; European Commission, 2000). Flood management is the responsibility of a number of organisations and stakeholders essentially concerned with controlling flood risk in urban environments (Balmforth *et al*., 2006). New development and the projected increase in precipitation extremes (*e.g.* one-in-100 year events) as a result of climate change will put pressure (in terms of requiring increased capacity) on current engineered drainage systems to manage flooding effectively.

Surface water transport pathways are variable in the urban environment. Large proportions of sealed impermeable surfaces enhance runoff, routing water rapidly into receptor sewer networks or natural fluvial systems. Other surfaces in urban environments have variable permeability depending on the nature of the surface and sub-surface drainage capacity. Unsealed areas indicated by green space have the capacity for slowing water discharge through interception and infiltration. Vegetation in unsealed areas reduces the amount of water entering the hydrological system by interception and evapotranspiration. Unsealed areas are able to receive water and attenuate runoff through infiltration into the urban soil system. Urban soils are highly variable and may range from relatively intact natural profiles to extensively modified systems commonly truncated, compacted and containing a large amount of anthropogenic material *e.g.* Technosols (IUSS Working Group WRB, 2006). The variable nature of surface and sub-surface characteristics will result in different drainage capacities of unsealed areas that are often highly heterogeneous over short distances.

Hydrology of soil types

Urban areas were not included in the original national soil survey used to produce the National Soil Map for England and Wales. However, soil series information in urban areas was added between 1988 and 1990. Mapped information of likely natural soil series in urban environments provides an indication of soil hydrological properties at a resolution of 1 km. In the absence of survey mapping, soil types in urban areas were estimated by interpolation of mapped soils in surrounding peri-urban and rural areas and integration of topographic and geological data. The data provides a 'best case' scenario for unsealed urban areas, where it is assumed that soils are essentially unmodified and retain the natural characteristics of the likely natural soil type expected in the area.

The hydrology of soil types (HOST) is a hydrologically based classification of soils in the United Kingdom (Boorman *et al*., 1995). Soil physical properties and, where appropriate, substrate are linked to catchment responses, in particular base flow and standard percentage runoff. The physical properties of soils affect the storage and movement of water pertinent to surface water catchment responses. HOST reclassifies soil types into 29 HOST classes that have variable impacts on catchment response. The HOST database provides information on the proportion of HOST classes within each 1 km grid across the United Kingdom.

Integration of HOST classes and sealing in Cambridge

Surface water management in urban environments is sensitive to storm water events that may cause exceedence of receptor systems such as sewer networks and (managed) fluvial systems. Calculating the amount of runoff from heavy rainfall events is necessary for the assessment of the likelihood of surface inundation by sewer exceedence (pluvial flooding) and fluvial flooding in urban environments. Standard percentage runoff (SPR) values indicate the proportion of rainfall likely to contribute to surface water runoff. Within the HOST system, each HOST soil class is assigned a SPR coefficient indicating the amount of water unable to infiltrate into the soil system due to constraints determined by soil physics. SPR values for sealed areas can be close to 100% as the majority of rainfall is unable to infiltrate and is therefore redirected as runoff.

The proportion of sealed and unsealed areas within each 1 km grid square across Cambridge were calculated from the 50 m grid summaries of non-green to green space produced from the satellite data (figure 6.6). Although this methodology reduces the spatial representation of sealed to unsealed areas, it is necessary for integration with the 1 km HOST data available for urban areas.

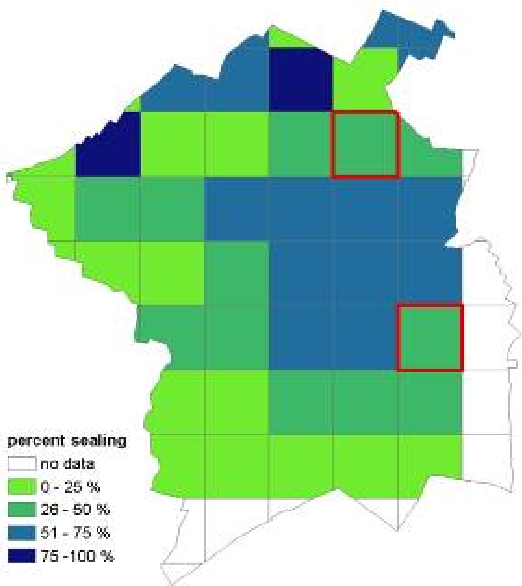

Figure 6.6 Percent sealing on a 1 km grid in the Cambridge urban area derived from satellite data. Highlighted grids (red) indicate areas selected for scenario analysis.

The proportion of HOST classes and corresponding SPR was assigned to unsealed areas and a generic SPR value (0.90) assigned for sealed surfaces. For grid squares <1 km^2 (city-edge polygons) it was assumed that HOST classes were in similar proportions to the land area at 1 km – there is no information on the internal geographical position of the different HOST classes within each grid square, only the relative proportions. Composite SPR values for each grid square were computed by weighting the SPR values from the composite HOST classes to the proportion of unsealed area and the SPR value for sealed surfaces to the proportion of sealed area. Figure 6.7 indicates the relative amount of runoff (SPR values) expected for each grid square for the current sealed/unsealed areas calculated for the Cambridge urban area.

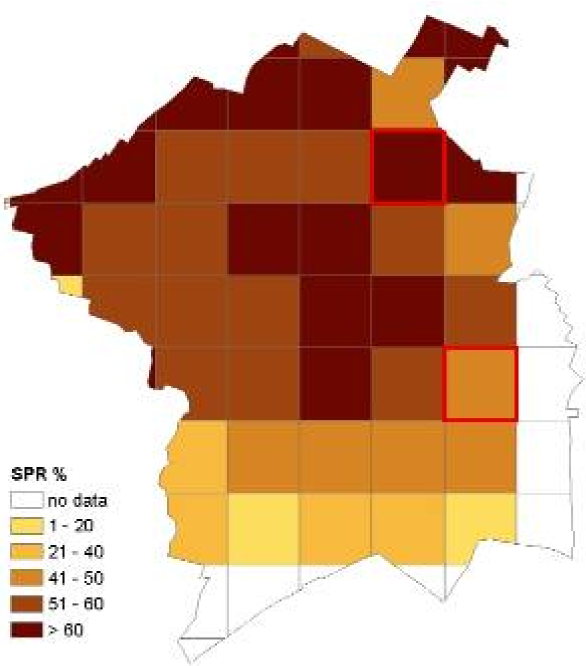

Figure 6.7 Standard percentage runoff (SPR) for each 1 km grid square in Cambridge. Highlighted grids (red) indicate areas selected for scenario analysis.

The north, north west and central Cambridge (city centre) have large SPR values due to a combination of extensive sealing and restricted permeability of unsealed areas due to the natural slow draining characteristics of the soil types. South Cambridge has lower proportions of sealed areas and unsealed soils that are freely drained, indicated by lower SPR values[25].

Scenario analysis

Two areas were selected for scenario analysis to investigate the effects of increasing the proportion of sealed area within the grid square. The two areas currently have a similar proportion of sealed area (45%, figure 6.6) and are located on the periphery of the city centre and hence may be expected to be under pressure from urban infill. Potential infill in grids 195 and 309 include paving private gardens in residential areas and new build in the large

[25] SPR values should be treated with caution as the composite values for unsealed areas (based on the HOST system) assume a 'best case' scenario where soils are assumed to be representative of the soil in their natural, well-structured form. In reality, these unsealed areas are expected to have reduced infiltration capacities due to anthropogenic alteration and hence higher SPR values.

areas of green space adjacent to the river Cam (figure 6.8), although some of this latter area may be protected under current flood and planning legislation. The runoff properties of the unsealed components (estimated by HOST) in the two areas differ significantly due to the HOST classification of soil types within the grid square, resulting in larger current SPR values in grid 195 compared with grid 309 (figure 6.7). Unsealed components in grid 195 are dominated by HOST class 8, indicative of soils with impeded drainage and shallow groundwater tables (within <2 m), resulting in SPR values of 44.3%. Dominant soils in unsealed areas in grid 309 are HOST class 1, with SPR values of 2.0%. The soils are shallow, well-drained, on chalk substrates with groundwater at >2 m and no impermeable layer within the profile.

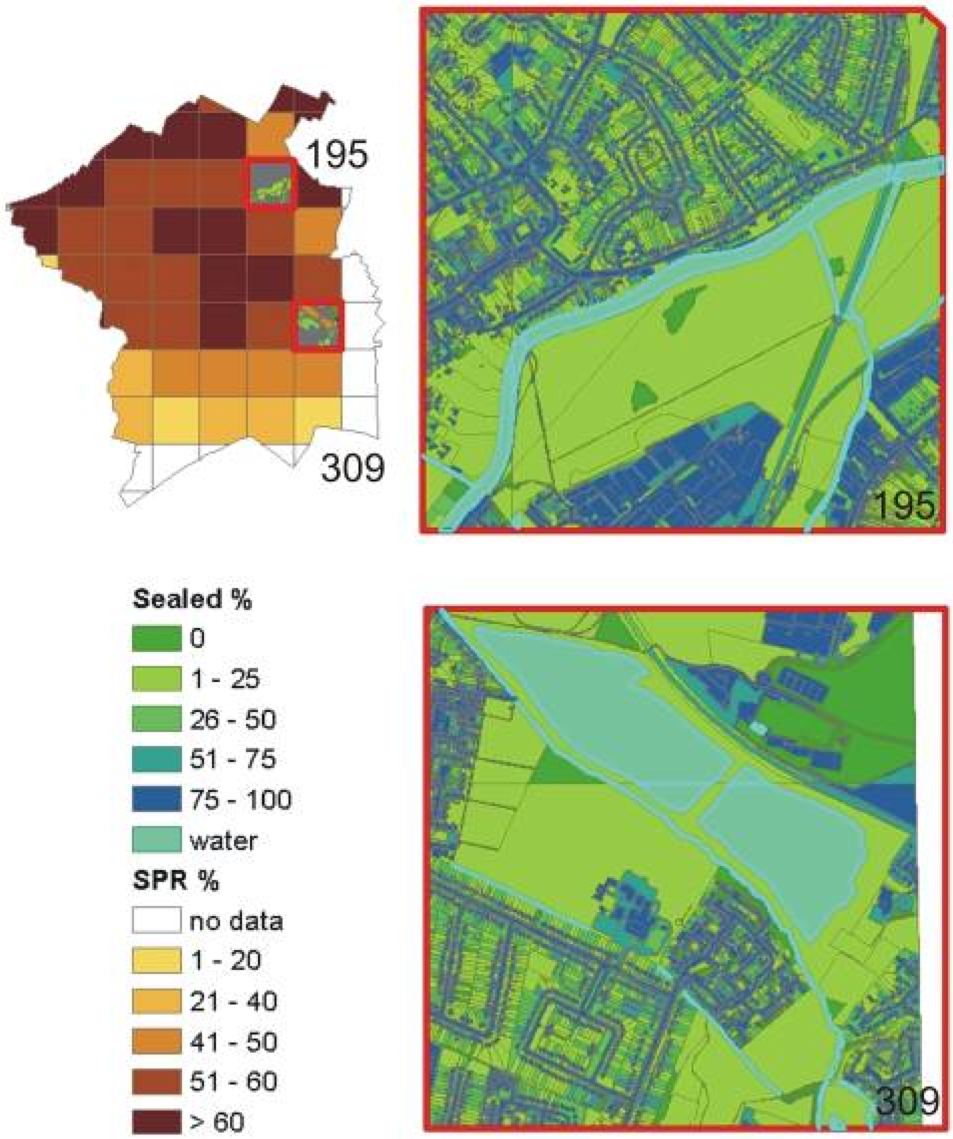

Figure 6.8 Areas selected for scenario analysis. Grids on the right indicate sealing proportions in the selected areas with OS MasterMap® overlay[26].

[26] 'no data' in the legend indicates the area beyond the limits of the satellite image used in this current feasibility study.

The proportion of sealed area in grids 309 and 195 was increased through a scenario of likely urban infill to a proportion of sealed area similar to that currently found in the city centre (65%). Figure 6.9 shows the changes in composite SPR values for grid squares 309 and 195. Increasing sealing has a greater impact on SPR and hence runoff in grid 309, where SPR values are increased by >30% with a 20% increase in the proportion of sealed area within the 1 km grid square. Grid 195 has naturally higher SPR values for the unsealed areas and is less sensitive than grid 309 to the impacts of sealing, although increases in SPR values are evident (figure 6.9). The drainage capacities of unsealed areas are therefore integral to the management of enhanced runoff in urban areas. If sealing is planned in sensitive areas (*e.g.* grid 309), it is essential to increase the permeability of sealed surfaces to effectively manage storm water runoff. Installation of semi-permeable (permeable pavements, porous gravel surfacing) and interception (green roofs) surfaces is necessary to partially offset the drainage capacity lost by sealing areas previously connecting the atmosphere and hydrosphere.

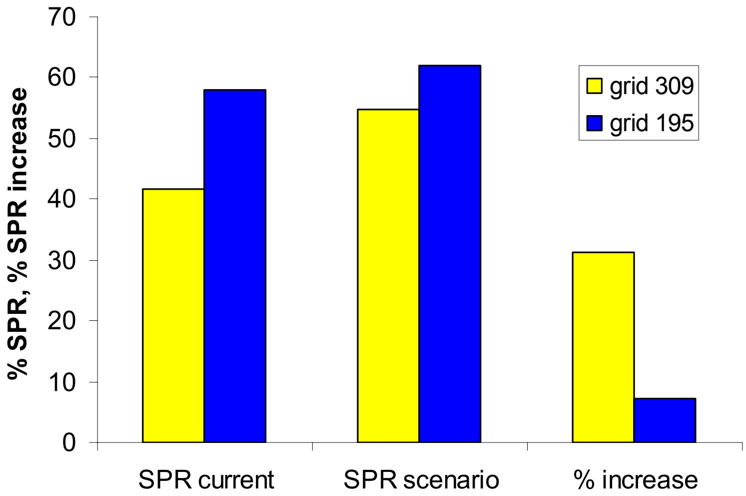

Figure 6.9 SPR values for current (45%) and scenario (65%) proportions of sealed areas in grids 309 and 195

Sustainable Urban Drainage Systems (SUDS) facilitate the attenuation of storm water and improve water quality in urban environments. Exploiting the natural drainage properties of unsealed areas could be used to advise on the implementation of suitable SUDS technologies in different parts of the urban area. Unsealed areas in grid 309 are naturally very well drained and therefore could be suitable for soakaways, infiltration trenches, swales and filter strips. Grid 195 has unsealed soils with impeded drainage that could be exploited for development of detention basins. As much of projected development is anticipated to take place on Brownfield sites an assessment of potential contaminant mobilisation is necessary if natural drainage properties are exploited for SUDS implementation in Brownfield unsealed areas.

Applications of improved SPR coefficients for urban areas

Integration of the proportion of sealing derived from satellite data with the HOST class for unsealed areas provides better estimates of excess runoff during storm events essential for flood risk planning. Assessment of runoff potential is the initial source stage in flood modelling where rainfall intensity coupled with the runoff potential provides the volume of storm water entering transport pathways during extreme events. Numerous commercially available flood models exist that have varying capabilities to model flood risk in urban watersheds (Balmforth *et al.*, 2006). Deterministic models use algorithms to represent processes that connect rainfall to stream (or river) response. Important components of these algorithms are catchment capacity for infiltration and runoff. Therefore, determining SPR values from more robust spatial approximations of sealed and unsealed areas derived from satellite data improves model representation of actual catchment characteristics in urban environments. Routing of storm water and identification of areas of flood impact is facilitated by the integration of digital elevation models (topography), sewer networks and above ground infrastructure. Monitoring change of urban sealing is necessary for continual assessment of engineered sewer capacities and adjustment of flood risk boundaries in urban areas, and impacts of downstream flooding and water quality where urban areas are part of large catchment watersheds.

Limitations and recommendations

Many flood models use generic SPR values for unsealed 'soil' components in urban catchment systems. However, the scenario analysis has shown that large differences exist in the buffering capacity of unsealed areas for peak flows across the urban area. Integrating more realistic SPR values into the spatial assessment of flood risk can highlight sensitive areas that would require effective management of sealed surfaces (*e.g.* adopting semi-permeable surfaces) in order to reduce the impact of sealing on stormwater runoff. The identification of sealed areas derived from the satellite data provides a much improved estimate of the proportion of rapid runoff regions within urban environments.

Summarising the proportion of sealed areas at 1 km loses the spatial resolution intended for monitoring changes in sealing. Assessment of drainage capacity is dictated by currently available soil hydrological information at 1 km resolution that is necessary for realistic prediction of runoff coefficients of unsealed areas. However, 1 km summaries would be useful for large catchment scale modelling to aid catchment management plans for flooding and water quality. In this study, unsealed areas are assumed to retain their natural soil type characteristics and runoff capabilities. Soils in urban environments are commonly modified and spatially heterogeneous and hence SPR coefficients would differ from those predicted for natural profiles. Drainage capacities of subsurface material beneath sealed areas are also likely to be as heterogeneous as unsealed areas. Investigation and consideration of sub-surface characteristics is necessary for optimising the required offset in runoff by increasing infiltration capacities through implementation of porous and semi-permeable sealing media.

Assessing sealing and aesthetic value

Aesthetics of urban green space

Urban planning in the UK is shifting towards development of sustainable communities, and enhancing urban green space is a component of this strategy (ODPM, 2002). However, pressure from increasing housing densities through urban infill and maximising the use of Brownfield land (OPDM, 2005) may be detrimental to the balance of built and green space in the urban environment.

The protocol for differentiating sealed from unsealed areas with satellite data uses vegetation as a proxy for the proportion of unsealed space. Vegetation thereby becomes a surrogate for unsealed areas but is, of course, a more direct representation of urban green space. Urban green space provides cultural and social benefits that include increased well-being, physical and psychological health, and connectivity with nature. Public perception favours green space to built-up urban scenes (Ulrich, 1986). Individuals often perceive green spaces as an escape from formal urban architecture, where a connection with nature can be re-established (Wilson, 1984). Public green space is a focal point in urban communities providing a sense of shared ownership and enhanced social participation between diverse cultural and demographic groups (Burgess *et al*., 1998), encouraging social cohesion and inclusion.

The esoteric nature of aesthetic perception makes qualification and quantification of the benefits of green space difficult, particularly as it varies significantly among individuals and communities. Preferences for different types of natural environments have been linked to socio-demographic variables (van den Berg *et al*., 1998). Some groups will prefer human-influenced settings with structured order potentially linked to vulnerability of individuals such as older people and individuals with low income and education (van den Berg, 2003). Other groups, such as young adults with high income and education levels display stronger preferences for more natural 'wilderness' areas (van den Berg, 2003). Residents in Sheffield, for example, preferred both 'managed' and 'naturalistic' areas for different reasons, although for some respondents both areas were perceived as 'natural', suggesting that managed urban green space does not necessarily lose the perception of 'naturalness' (Özgüner & Kendle, 2006).

Urban spaces should be liveable places providing accessibility and opportunity for use of green space. Accessibility is a necessary precondition for green space use; restriction to it, such as distance (and safety), will determine whether people will visit the space (Van Herzele & Wiedemann, 2003). Green spaces fulfil different functions at spatially different levels (Van Herzele & Wiedemann, 2003). For example, small urban parks may have strong day-to-day functional uses for residents that live in close proximity and peri-urban woodland areas may provide a resource for the whole urban population that frequent the area at weekends for recreation. However, popular urban parks with good accessibility tend to contain a mix of multi-purpose areas providing a variety of experiences for the visitor (Burgess *et al*., 1988).

Assessment of aesthetic value linked to green space accessibility

The nature of the specific methodology for mapping soil sealing provides a binary classification of 'vegetated' and 'non-vegetated' areas as an indication of green and non-green urban space. The incorporation of auxiliary data from OS Mastermap® can further distinguish limited types of green space, *i.e.* park and woodland. OS Mastermap® also provides the spatial arrangement of urban infrastructure, where residential areas can be easily identified by their characteristic building size and spatial organization. The combination of this data provides a spatial framework for assessing the position and accessibility of urban green space within residential communities.

Urban green spaces were identified in a test area in Cambridge city centre (figure 6.10) by integrating the 'unsealed' satellite data with an OS MasterMap® overlay. Eight parks and three woodland areas exist within the test area.

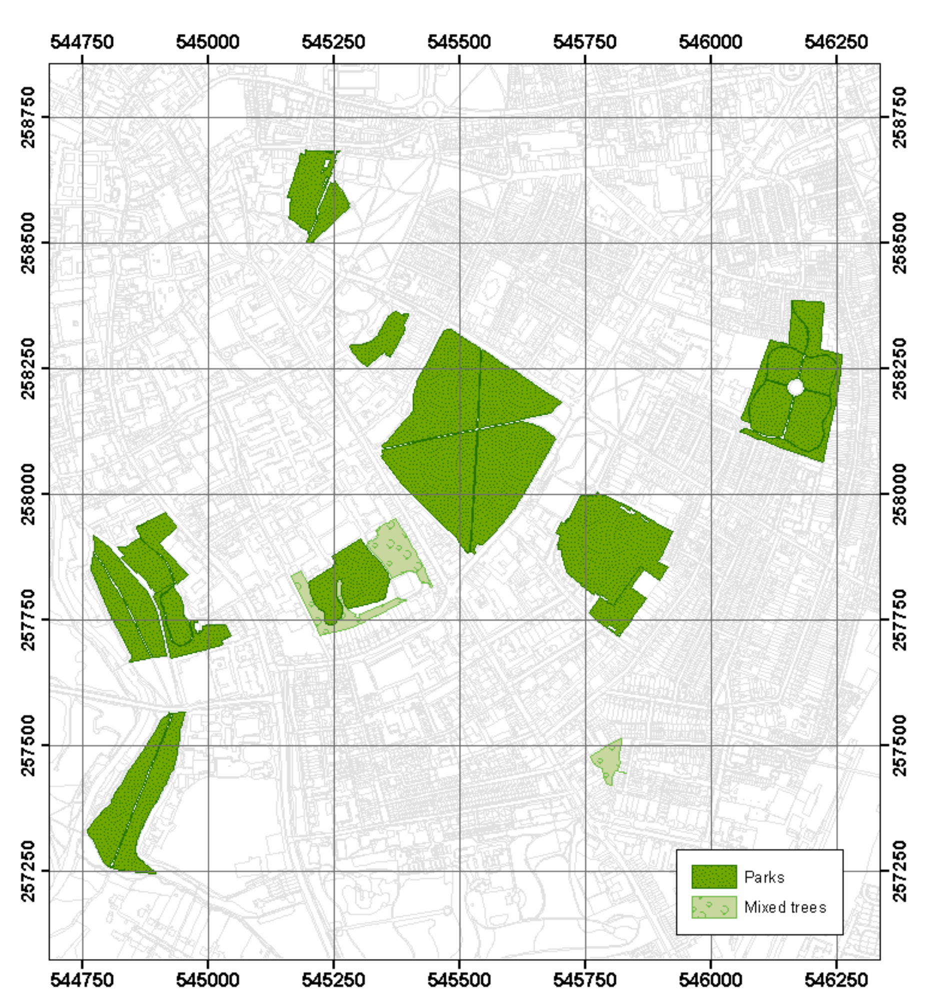

Figure 6.10 Green space in the central area of Cambridge

Accessibility is defined by distance from the green space edge and linear distances were calculated for each of the green space types (figures 11 and 12).

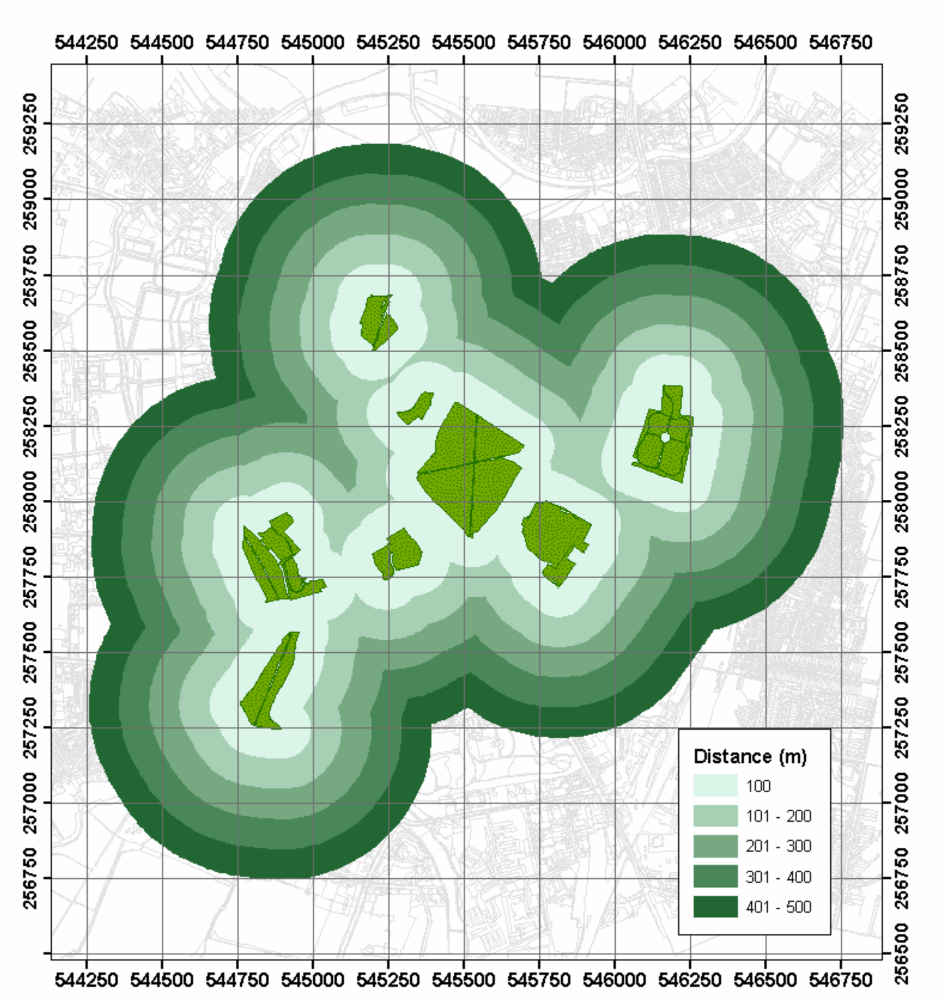

Figure 6.11 Buffer distances from the green parks

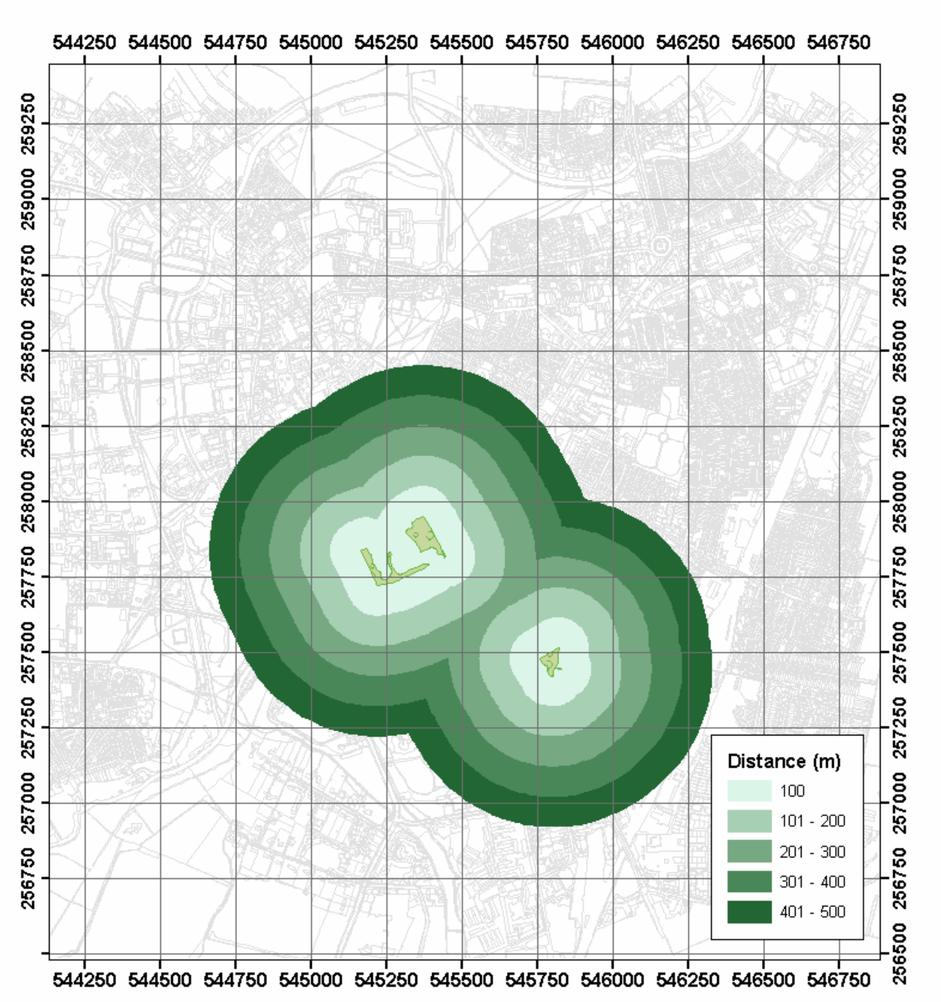

Figure 6.12 Buffer distances from the wooded areas

A classification of aesthetic 'value' based on distances from green areas is detailed in table 6.1. Urban scenes that contain trees and complexity are generally preferred to wide expanses of space where there is no focal point or depth (Ulrich, 1986; CabeSpace, 2004). The woodland areas were therefore weighted higher in terms of aesthetic value compared with parks. Therefore, increasing distance from wooded areas has a greater impact on the assigned aesthetic 'value' than comparable distances from urban parks. A 'value' of 300 indicates very close proximity (<100 m) to a green space and a value of <50 indicates the green space is essentially 'inaccessible' to due to large distances. Figure 6.11 and 6.12 show the buffer zones around the green spaces in the test area.

Distance from wooded area (m)

Distance from park area (m)	0-100	100-200	200-300	300-400	400-500
0-100	300	250	200	150	100
100-200	275	225	175	125	75
200-300	250	200	150	100	50
300-400	225	175	125	75	25
400-500	200	150	100	50	0

Table 6.1 Assignment of aesthetic ‘value’ indices to distances from urban green space (parks and woodland). 300= highest, 0 lowest ‘value’ related to distance from urban green space.

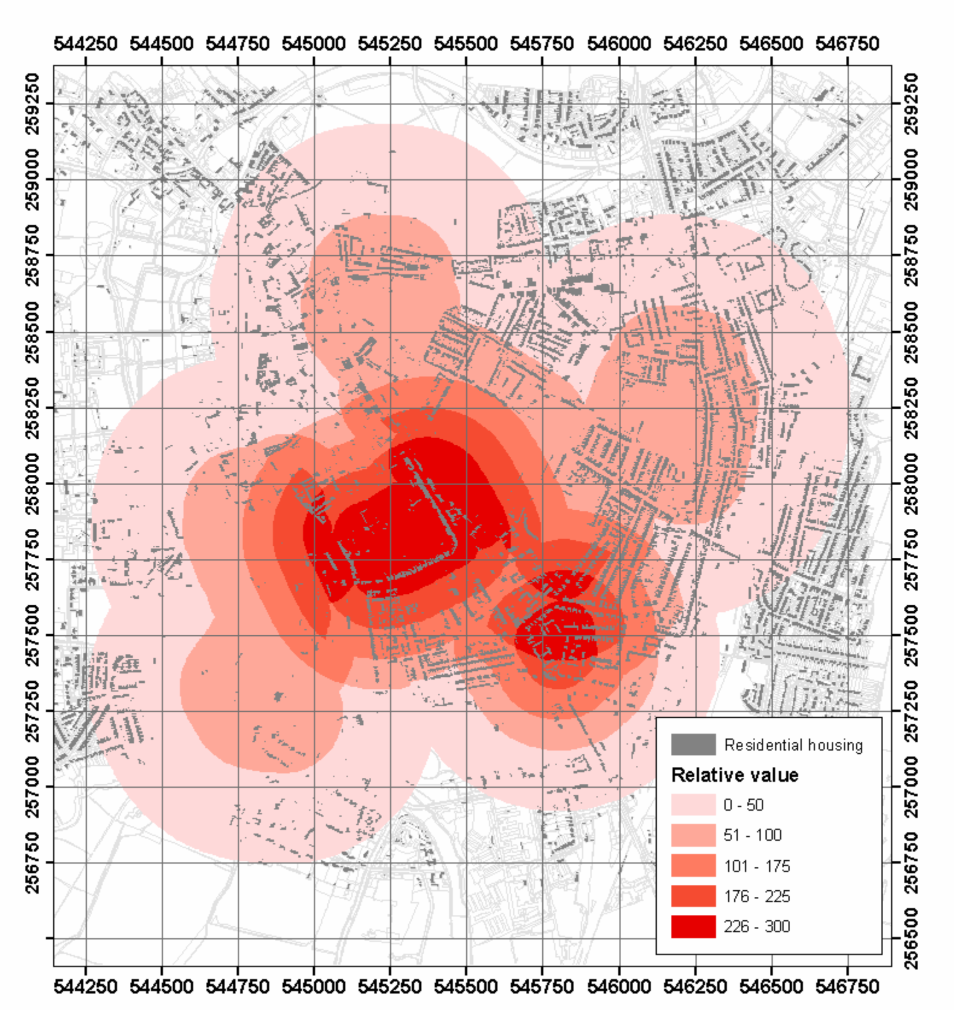

Figure 6.13 Extent of ‘relative’ value indices around green spaces.

The impact on the urban community is investigated by intersecting the value zones with the spatial distribution of residential areas in the test area. Figure 6.14 shows the 'value' of each household across the central Cambridge test area. A large proportion (69%) of households do not have adequate (values <50) accessibility to green space (figure 6.15), although peripheral areas may be close to green spaces that exist outside the boundaries of the test area. These households are generally >400 m from the nearest green space. This distance can be very restricting to individuals with reduced mobility or for parents with young children that use green space for 'everyday' recreation and hence travel to the space by foot. Very few (5%) houses have excellent accessibility (> 200 'value' index) to green space.

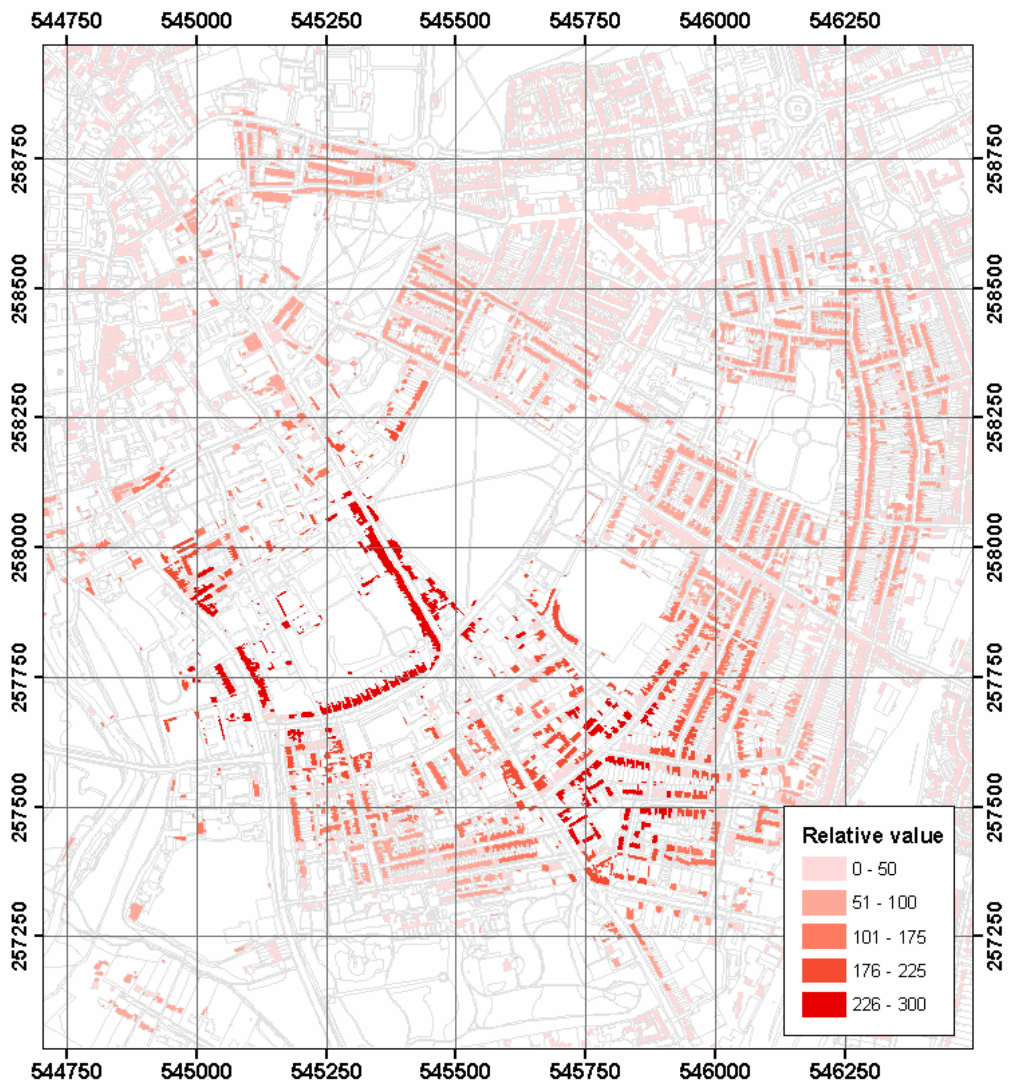

Figure 6.14 Aesthetic 'value' indices (derived from table 6.1) of households within the test area.

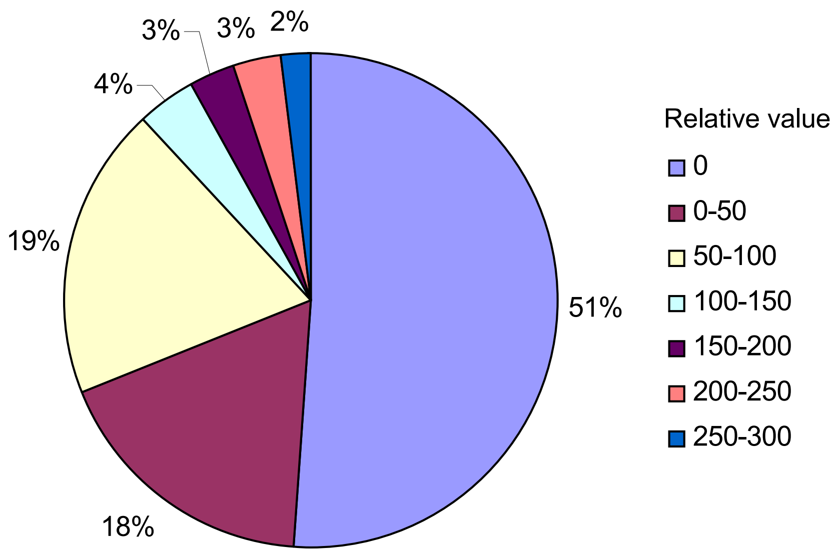

Figure 6.15 Proportion of houses in each value category within the test area.

Limitations and opportunities

Determining sealed areas from satellite data only identifies areas with vegetation and does not provide information on the function of the green space or the vegetation community. Many aesthetic 'values' are based on the mix of uses offered by the green space. Park areas interspersed with woodland and children's play facilities have larger public preference than areas of waste ground with limited recreational benefits. The resolution of the satellite data does not offer such distinctions; however, information from OS MasterMap®, council plans/maps and aerial photographs can significantly improve classification of green spaces and hence provide a better indication of aesthetic preference. Park size may also be a useful surrogate for multi-functional green space use. These additional data sources also provide some indication of vegetation type. Trees can be determined by aerial photography and can be linked to the green space function to identify areas with greater depth and variety, which are more preferable to monocultural vegetated areas.

Accessibility to green space and mobility within the urban environment can be modelled in GIS platforms (Van Herzele & Wiedemann, 2003; Stahle, 2005). Space syntax offers a powerful tool to assess mobility in urban environments where preferential routes are modelled delimited by the spatial arrangement of the urban architecture (Jiang *et al.*, 1999). Decision support systems can be implemented by urban planners to investigate current green space provision and impacts of green space loss on the urban community (Laing *et al.*, 2006) and hence optimise functionality, usage and aesthetic benefit of green space to the urban community. Integration of socio-economic and demographic data from census wards could benefit green space planning to enhance social inclusion and cohesion in potentially sensitive urban areas.

7. Cost benefit of digital image classification

Overview

The overall aim of this work was to assess the use of satellite (space sector) earth observation as a cost-effective method of detecting and quantifying changes in sealed soils in England and Wales. Specifically, according to Task 2.3, it was to include a benefit-cost comparison of the inclusion of satellite derived information within existing (Defra) processes. Defra's existing monitoring does not currently include any methods (mapping or otherwise) of monitoring levels of soil sealing. The benefit-cost comparison presented here, therefore, will estimate the value of applying remote sensing techniques over and above the costs of alternative methods that could be adopted by Defra, *i.e.* full ground survey. However, full-ground survey cannot be achieved in urban areas, unlike in the majority of most rural locations, due to access issues to, for example, private gardens – the very areas where *ad hoc* sealing is taking place. The next-best alternative to full ground survey is to use a surrogate, *i.e.* high resolution air photo interpretation (API).

Relative efficiency

Improvements to both the accuracy and the precision of sealing estimates have been demonstrated using the regression estimator. This improvement, achieved by combining API sample observations with the digital classification of whole city areas, can be calculated for the purposes of cost-benefit analysis by estimating the 'relative efficiency' (η). The relative efficiency can be used to estimate the additional amount of air photo interpretation (or equivalent ground survey) needed to achieve an equivalent improvement in precision of sealing area estimates. In other words, the value of applying remote sensing techniques can be equated to the cost saving achieved by reducing the ground sample for a desired level of accuracy in sealing area estimation. The method described here is derived from Taylor *et al* (*Op Cit).*

The ratio between the variances of the ground survey (equation 4) and the regression estimate (equation 8) gives the relative efficiency of remote sensing, which is:

$$\eta_{reg} = \frac{Var(\hat{Z})}{Var(\hat{Z}_{reg})} = \frac{1}{1 - r_{py}^2} \tag{9}$$

The same reduction in variance can be achieved by increasing the size of the API sample survey, such that:

$$\eta_{reg} = \frac{\frac{1}{n} Var(y)}{\frac{1}{n_1} Var(y)} = \frac{n_1}{n} \tag{10}$$

where n_1 is the increased sample size.

Remote sensing techniques (digital classification using remote sensing and MasterMap®) will be economically efficient if the cost of ground surveying the additional n^1-n segments is greater than the cost of the digital classification part of the project, given by:

$$n(\eta_{reg} - 1)p > R \qquad (11)$$

where *n* is the original sample size, p is the cost of surveying each additional segment and R is the cost of the digital classification part of the project.

Cost-benefit

For the Cambridge example, the relative efficiency is calculated as 23 (table 4.3). In order to achieve the same statistical precision as the regression estimator, 411 samples would need to be taken. This is almost a complete survey of the city (*c.*60%). This immediately demonstrates the potential effort reduction of using automated remote sensing and, therefore, an indication of its value. The cost of completing the additional 393 segments (*i.e.* 411-18) is estimated to be £86,500 (eq. 11). This is based on acquiring orthocorrected, digitally scanned aerial photography by contract-flying a specific aerial sortie for the area of interest; alternatively the cost could be significantly reduced (to £47,000) if appropriate data is available in archives. The figures assume a minimum purchase order of 5 km^2 (20 equivalent segments). Figures will vary according to factors such as the location of the city to be surveyed, but provide appropriate orders of magnitude.

Table 4.3 Summary table of key calculated figures used to estimate cost-benefit

Relative Efficiency	22.8
n_1	411
cost per segment*	£120
cost per segment†	£220
n	18
Total cost*	£47,155
Total cost†	£86,451
Aerial Orthophotography	
*Per segment**	*£50*
Per segment†	*£150*
Cost of API	
Per segment	*£70*

*archived imagery; †contracted flight

According to the estimate of the cost for digital classification presented in Section 5, the ‘unit’ cost per city is £1100[27]. This figure is compared with either £47,000 (archived imagery) or £86,500 (contracted flight) for a sample survey to match the statistical precision.

[27] £250,000 / 9000 km^2 = £28/km^2; this equals £1100 for a city like Cambridge (*n.b.* this assumes economies of scale, where a total area of 9000 km^2 is processed. If an individual city were requested to be surveyed, the cost would be much greater.

It is clear that the cost of the remote sensing methodology (eq. 11) is significantly less, by almost two orders of magnitude.

The additional benefit of using remote sensing is the mapped output; the sample survey will not provide this. A complete survey by API (like the Dresden example), of a city size equal to Cambridge, would be approximately £145,000[28]. The cost of API could be reduced by developing and incorporating automated image segmentation techniques using a synthesis of object based segmentation of aerial photographs and visual interpretation; an estimate of this cost reduction is possible, but is not known currently. A significant advantage, however, of undertaking a complete API of a city would be that the resolution of the mapped output would be orders of magnitude finer than the satellite imagery. The added value of this could only be determined by appropriate survey of the various stakeholders. The higher precision may not be necessary for some groups compared with others, *e.g.*, between groups interested in national policy creation (*e.g.* Defra) and those involved in planning (*e.g.* local authorities). It has not been possible to determine the cost-benefit to this degree, but one could suppose that the additional costs of full API might be acceptable given the advantages of higher resolution that it provides.

[28] equivalent to 651 segments @ £220 per segment. Using an existing source of archived imagery this would be £78,000 (651* £120)

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8. Conclusions

Soil sealing presents one of the greatest threats to soil function. The overall objective of this work was to test the feasibility of using *space*-derived information to support the Defra Soils Team (ST) in monitoring the extent and pattern of soil sealing. Soil sealing in this context describes the sealing-over of land (soil) by expanding urban infrastructure (*e.g.* roads, buildings, pavement, etc).

For the purpose of this work, a discrimination between vegetated and non-vegetated urban surfaces provided a surrogate for making initial assessments of the degree to which an area is either sealed or unsealed. This fact must be borne in mind when interpreting the output maps: the maps estimate an indirect *indicator* of soil sealing. One consequence of this assumption is exemplified by bare soil. Bare soil is a non-vegetated surface and, therefore, if classified as such, will introduce errors to any estimates of sealing. Instances of bare soil in the built environment were assumed to occur infrequently and, therefore, considered negligible.

The processing chain

The work was successful. It demonstrates the capability to map indicators of soil sealing and presents robust statistics that estimate levels of sealing at an accuracy of over 90%. This meets the requirements for monitoring. The initially stated accuracy set-out by Defra ST of $4m^2$ was not achieved, however, this target represented an arbitrary starting point and was not based on any set requirements for policy support, *per se*. The spatial precision of the mapped output summarised on a 50x50 m grid provides a very useful indicator for understanding not only the relative ranking of the degree to which cities in England and Wales are sealed and for monitoring changes over time, it provides a robust way of monitoring the spatial pattern of change within city boundaries.

This work presented maps produced down to the resolution of land parcels equivalent in size to residential gardens – using Ordnance Survey's digital MasterMap® as the underlying basis for defining land parcels. MasterMap® was used for summarising classification output from high resolution satellite data. These maps are presented on a sealing range of 0-100%, in intervals of 25%. Whilst they provide an overview of the spatial sealing patterns within urban areas, the accuracy is variable and ranges from 45% for very small land parcels ($<32\ m^2$) to over 70% for parcels $>300m^2$. Spatial aggregation to larger land unit sizes improves the overall mapping accuracy, hence the aggregation to 50 x 50 m units, and the associated improvement to 90%.

The proposed system uses high resolution infrared satellite sensors such as the 2.8 m Quickbird imagery (equally Orbview-3 data or IKONOS data could be used). The method uses a maximum likelihood pixel classification of the Normalised Difference Vegetation Index (NDVI), which is particularly sensitive to differences between vegetated and non-vegetated cover types. The Ordnance Survey MasterMap® is used both to mask out roads and buildings that are known to be sealed, and to summarise the average number of 'sealed' pixels that fall into each MasterMap® polygon.

Operational feasibility

Considering the logistics of operational scale monitoring, the work positively demonstrated the capability for monitoring all major settlements in England and Wales – with populations over 50,000 (9,000 km^2) – within the five year operating window designated by Defra ST. Taking into account logistical and physical constraints, *e.g.* cloud cover restrictions, the acquisition of high resolution satellite imagery is feasible for the entire area. At the time of this work, the total cost of an operational monitoring programme is estimated to be around £250,000. This will cover the whole 9000 km^2 area and deliver baseline maps of soil sealing to Defra ST in a format compatible with current information systems and conforming to their adopted meta-data protocols, *i.e.* SPIRE.

Cost benefit

The cost-benefit analysis considered undertaking the mapping of soil sealing by detailed interpretation of 0.125 m aerial photography for the whole of a city compared with the satellite remote sensing methods developed in this work; it revealed clear benefits in favour of satellite remote sensing. The digital classification of the satellite data cost approximately two orders of magnitude less than the detailed air photo interpretation. For Cambridge, the costs were £1100 compared to £145,000.

Adding value to soil sealing maps

A number of possibilities for using the mapped output of sealing to evaluate the impact of sealing were investigated

Biodiversity value was determined in two ways: modelling dispersal, using computer models to simulate animal movement from one unsealed area to another; and by measuring fragmentation and the size of the effective interior size of urban green spaces. The 'interior' represent areas where organisms can behave differently than in the buffer zone (edge) between the interior green space and surrounding sealed surface. This work indicates that it is realistic to envisage a toolkit based on a GIS system enabling planners to make robust decisions in the variety of contexts in which they operate. This will become particularly important if the concept of environmental constraints and limits is accepted as a principle. Other data, beyond simple sealing measures, such as a characterisation of above-ground canopy architecture is needed – this is feasible using airborne sensors.

Drainage impact was investigated at a coarse scale of 1 km^2 grids, by integrating national soil data. This indicated the potential contribution of the soil sealing data to large catchment scale modelling to aid catchment management plans for flooding and water quality. Any catchment scale studies that include a hydrological component could potentially benefit from the inclusion of better characterisation of the water-buffering potential of urban areas. The limited scenario testing carried out in this work also indicated the impacts of sealing in relation to the underlying soil type. The sealing maps have potential application, therefore, in designing SUD systems and when developing associated soil management plans for flood alleviation.

Assessment of the 'aesthetic' impacts of sealing was limited, but some useful findings were noted. Limitations exists because aesthetic 'values' are based on a mix of uses offered by the green space. Trees can be determined using aerial photography, and to a large extent from high resolution satellite data, as used in this project; and can be linked to the green space function to identify areas with greater depth and variety, which are more preferable to monocultural vegetated areas. A simple index model linking distance to green space and value is presented allowing summary statistics to be produced and to rank cities of sub-urban subsets according to access to green space. One possible use would be, in areas with a low index restrictions to further increases in sealing could be restricted on the basis of impacts on human health, well-being factors. Conversely, green-space planning could be better informed to enhance social inclusion and cohesion in potentially sensitive urban areas.

Recommendations

Based on the results for the Cambridge City pilot study, we recommend that an operational monitoring system is implemented, but that an extended feasibility study of the methods presented is carried out. This will provide a more robust indication of the levels of certainty that can be delivered nationally. It is not recommended to implement the proposed methods operationally until this verification work has been undertaken. Otherwise, we are confident that a cost-effective monitoring system is possible that satisfies the requirements, set out by Defra's Soil Team, for a five-year rolling system for monitoring changes in sealing within the built environment.

One of the drivers behind the commissioning of this report was the apparent sealing-over of front gardens to provide off-street parking in residential areas. This has been on the increase in recent years and Defra ST wanted to see whether EO data could be used to monitor this as well as the effect of land-take and in-filling by urban development. The contributory effect of sealing over of front gardens is included in the estimates of sealing in as much as it is included in the aggregated estimates, either over a block size of 50 x 50 m, or in the average estimate for a whole city. A specific estimate relating to front gardens vis-à-vis other types of sealed land use is not possible using the current methods. This is mainly due to the spatial resolution of current satellite data.

Some additional opportunities for monitoring soil sealing of front gardens and other smaller, unregulated areas where important sealing occurs, may be afforded by using airborne imagery (*e.g.* with 0.25-0.5 m ADS40 imagery). The space sector derived maps of sealing presented in this report could be used to target airborne surveys more cost effectively in areas where significant changes in sealing have been estimated. Similar methods to those reported here could be used to investigate this further. Other factors would need to be considered such as acquisition cost, processing and storage costs of larger amounts of (higher resolution) data.

Despite offering many advantages for monitoring sealing, optical data essentially measures the first object 'seen' by the sensor, *e.g.* tree canopies, that obscure the potential to determine the properties of underlying surface types. The forthcoming TerraSAR-X image data holds the potential, due to the 1m resolution it will provide, to explore the limits to which surface characteristics below tree canopies could be measured. SAR data is also largely unaffected by cloud cover, which is a great advantage in cloud-affected areas like the UK. These kinds of data should be investigated in future work.

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9. References

Balmforth D., Digman C.J., Butler D. & Schaffer P. (2006) Scoping study: Defra Integrated Urban Drainage Pilots. Department for Environment, Food and Rural Affairs, London, U.K.

Benhamou, S. (2004) How to reliably estimate the tortuosity of an animal's path: straightness, sinuosity, or fractal dimension? *Journal of Theoretical Biology* 229: 209-220.

Blaschke, T., Lang, S. & Moller, M. (2005) Object-based analysis of remote sensing data for landscape monitoring: Recent developments. *In*: Anon., *Anais XII Simpósio Brasileiro de Sensoriamento Remoto,* Goiania, Brasil, 16-21 April 2005, http://www.definiens-imaging.com/documents/reference.htm:2879-2885.

Bolund, P. and Hunhammar, S. (1999) Ecosystem services in urban areas. *Ecological Economics* 29: 293-301.

Boorman D.B., Hollis J.M. & Lilly A. (1995) *Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom.* IH Report No. 126. Institute of Hydrology, Oxfordshire, U.K.

Burgess J., Harrison C.M. & Limb M. (1998) People, parks and the urban green: A study of popular meaning and values for open spaces in the city. *Urban Studies*, **25**, 455-473.

CabeSpace (2004) The value of public space: How high quality parks and public spaces create economic, social and environmental value. CabeSpace http://www.cabe.org.uk/AssetLibrary/2021.pdf

Coe, S.E., Alberti, M., Hepinstall, J.A. & Coburn, R. (2005) A hybrid approach to detecting impervious surface at multiple scales. *In*: Anon., *ISPRS WG VII/1 "Human Settlements and Impact Analysis" 3rd International Symposium Remote Sensing and Data Fusion Over Urban Areas (URBAN 2005) and 5th International Symposium Remote Sensing of Urban Areas (URS 2005),* Tempe, AZ, USA, 14-16 March 2005, http://www.definiens-imaging.com/documents/reference.htm:

Collinge S.K.(1996) Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. *Landscape and Urban Planning* 36: 59-77

Darwish, A., Leukert, K. and Reinhardt, W. (2003) Urban Land -Cover Classification: An object based Perspective. *IEEE: 2nd GRSS/ISPRS Joint Workshop on "Data Fusion and Remote Sensing over Urban Areas",* 278-282.

Decker, E.H., Elliott, S.Smith F.A., Blake, D.R. and Rowland, F.S. (2000) Energy and material flow through the urban ecosystem. *Annual Review of Energy and the Environment* 25: 685-740.

Defra (2005) *Making Space for Water. Government response to the autumn 2004 Making Space for Water consultation exercise, March 2005.* Department for Environment, Food and Rural Affairs, London, U.K.

Deguchi, C. and Sugio, S. (1994) Estimations for percentage if impervious area by the use of Satellite Remote Sensing imagery. *Water Science Technology,* 29, 135-144.

Elgy, J. (2001) Airborne remote sensing for urban drainage, *Urban Water*, 3, pp287-297.

European Commission (2000) *Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (Water Framework Directive)*. European Commission.

Ewers, R.M., Didham, R.K, Wratten, S.D., and Tylianakis, J.M. (2005) Remotely sensed landscape heterogeneity as a rapid tool for assessing local biodiversity value in a highly modified New Zealand landscape. *Biodiversity and Conservation* 14: 1469-1485.

Frauman, E. & Wolf, E. (2005) Segmentation of very high spatial resolution satellite images in urban areas for segments-based classification. *In*: Anon., *ISPRS WG VII/1 "Human Settlements and Impact Analysis" 3rd International Symposium Remote Sensing and Data Fusion Over Urban Areas (URBAN 2005) and 5th International Symposium Remote Sensing of Urban Areas (URS 2005),* Tempe, AZ, USA, 14-16 March 2005, http://www.definiens-imaging.com/documents/reference.htm:

Gaston, K.J., Smith, R.M., Thompson, K., and Warren, P.H. (2005a) Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation*. 14: 395-413.

Gaston, K.J., Warren, P.H., Thompson, K., and Smith, R.M. (2005b) Urban domestic gardens (IV): the extent of the resource and its associated features. *Biodiversity and Conservation* 14: 3327-3349.

Gilbert, O.L. (1989) *The ecology of urban habitats*. Chapman and Hall, London.

Greiwe, A. & Ehlers, M. (2005) Combined analysis of hyperspectral and high resolution image data in an object oriented classification approach. *In*: Anon., *ISPRS WG VII/1 "Human Settlements and Impact Analysis" 3rd International Symposium Remote Sensing and Data Fusion Over Urban Areas (URBAN 2005) and 5th International Symposium Remote Sensing of Urban Areas (URS 2005),* Tempe, AZ, USA, 14-16 March 2005, http://www.definiens-imaging.com/documents/reference.htm:

Grenzdorffer, G.J. (2005) Land use change in Rostock, Germany since the reunification - a combined approach with satellite data and high resolution aerial images. *In*: Anon., *ISPRS WG VII/1 "Human Settlements and Impact Analysis" 3rd International Symposium Remote Sensing and Data Fusion Over Urban Areas (URBAN 2005) and 5th International Symposium Remote Sensing of Urban Areas (URS 2005),* Tempe, AZ, USA, 14-16 March 2005, http://www.definiens-imaging.com/documents/reference.htm:

Guindon, B., Zhang, Y. and Dillabaugh, C. (2004) Landsat urban mapping based on a combined spectral-spatial methodology. *Remote Sensing and Environment,* 92, 218-232.

Handley, J., Pauliet, S., Slinn, P., Barber, A., Baker, M., Jones, C., and Lindley, S. (2003) *Accessible Natural Green Space Standards in Towns and Cities: A Review and Toolkit for their Implementation* English Nature Report No. 526, English Nature, Peterborough

Harayama, A. & Jaquet, J.M. (2004) Multi-source object-oriented classification of landcover using very high resolution imagery and digital elevation model. *In*: Anon., *Enviroinfo Conference 2004,* Geneva, 21-23 October 2004, http://www.definiens-imaging.com/documents/reference2004.htm:

Harrison, C. and Davies, G. (2002) Conserving biodiversity that matters: practitioners' perspectives on Brownfield development and urban nature conservation in London. *Journal of Environmental Management* 65: 95-108.

Harrison, C., Burgess, J., Millward, A. and Dawe, G. (1995) Accesible Natural Greenspace in Towns and Cities: A review of appropriate size and distance criteria. *English Nature Research Report No. 153. Peterborough,* English Nature.

Herold, M, Gardner, M.E. and Roberts, D.A. (2003) Spectral resolution requirements for mapping urban areas, IEEE Transactions on Geoscience and Remote Sensing, Vol. 41 (0), pp1907-1919

Herold, M, Gardner, M.E., Noronha, V and Roberts, D.A. (2003) Spectrometry and hyperspectral remote sensing of urban road infrastructure, unpublished manuscript provided by the authors to the GIFTSS project, pp29.

Hindmarch, C., Harris, J.A., and Morris, J. (2006) Growth and sustainability: integrating ecosystem services into economics. *The Biologist* 53(3) 135-142.

Hobbs, R.J., Arico, S., Aronson, J., Baron, J.S., Bridgewater, P., Cramer, V.A., Epstein, P.R., Ewel, J.J., Klink, C.A., Lugo, A.E., Norton, D. Ojima, D., Richardson, D.M., Sanderson, E.W., Valladares, F., Vila, M., Zamora, R., and Zobel, M. (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*. 15: 1-7.

Hung, M.C. and Ridd, M.K. (2001) Develpoment of a Supervised Classifier for Subpixel Remote Sensing . *IEEE,*1892-1894.

IUSS Working Group WRB (2006) *World Reference Base for Soil Resources 2006.* 2ND Edition. World Soil Resources Report No.103, Food and Agriculture Organisation of the United Nations (FAO), Rome. www.fao.org/AG/AGL/agll/wrb/doc/wrb**2006**final.pdf

Jensen, R. (2001) Remote sensing of the environment: an earth resource perspective. Prentice Hall series in geographic information science, pp544.

Ji, M. and Jensen, J.R. (1999) Effectiveness of Subpixel Analysis in Detecting and Quantifying Urban Imperviousness form Landsat Thematic Mapper Imagery. *Geocarto International ,* 14, 33-41.

Laing R., Miller D., Davies A. & Scott S. (2006)

Leitao, A.B. and Ahern, J. (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning* 59: 65-93.

Li, F., Wang, R., Paulussen, J., and Liu, X. (2005) Comprehensive concept planning of urban greening based on ecological principles: a case study in Beijing, China. *Landscape and Urban Planning* 72: 325-336.

Lofvenhaft, K., Runborg, S., and Sjogren-Gulve, P. (2004) Biotope patterns and amphibian distribution as assessment tools in urban landscape planning. *Landscape and Urban Planning* 68: 403-427.

McKinney, M.L. (2006) Urbanization as a major cause of biotic homogenization. *Biological Conservation* 127: 247-260.

Meinel, G and Hernig, A. (2005) Survey of soil sealing on the basis of the ATKIS basic DLM – feasibilities and limits, proceedings ISBN 3-901673-12-1, pp359-363.

Mortberg, U., and Wallentinus, H-G. (2000) Red-listed forest bird species in an urban environment – assessment of green space corridors. *Landscape and Urban Planning* 50: 215-226.

Niemela, J. (1999) Ecology and urban planning. *Biodiversity and Conservation*. 8: 119-131.

Nikolakaki, P. (2004) A GIS site-selection process for habitat creation: estimating connectivity of habitat patches. *Landscape and Urban Planning* 68: 77-94.

ODPM (2002) Living places: Greener, safer, cleaner. Office of the Deputy Prime Minister, London. U.K.

ODPM (2003) *Sustainable Communities: Building for the Future.* Febuary 2003. Office of the Deputy Prime Minister, London. U.K.

ODPM (2005) *Sustainable Communities: Homes for All.* January 2005. Office of the Deputy Prime Minister, London. U.K.

Özgüner H. & Kendle A.D. (2006) Public attitudes towards naturalistic versus designed landscapes in the city of Sheffield. *Landscape and Urban Planning*, **74**, 139-157

Phinn, S., Stanford, M., Scarth, P. and Murray, A.T. (2002) Monitoring the composition of urban environments based on vegetation-impervious surface-soil (VIS) model by subpixel analysis techniques. *International Journal of Remote Sensing ,* 23, 4131-4153.

Pickett, S.T.A., Burch, W.R.Jr, Dalton, S., Foresman, T., Grove, J., and Rowntree, R. (1997) A conceptual framework for the study of human ecosystems in urban areas. *Urban Ecosystems* 1: 185-199.

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.C., and Costanza, R. (2001) Urban ecological systems: Linking terrestrial ecological, physical, and socio-economic components of metropolitan areas. *Annual Review of Ecology and Systematics* 32: 127-133.

PPS3 (2005) *Draft Planning Policy Statement PPS3*. Office of the Deputy Prime Minister, London, U.K.

Rashed, T., Weeks, J.R., Gadalla, M.S. & Hill, A.G. (2001) *Revealing the Anatomy of Cities through Spectral Mixture Analysis of Multispectral Satellite Imagery: A Case Study of the Greater Cairo Region, Egypt*. Available at: http://geosciences.ou.edu/~rashed/publications/Revealing%20the%20Anatomy%20of%20Cities.pdf. Accessed 5th August 2005.

Richards, J.A. and Jia, X. (2005) Remote sensing digital image analysis: an introduction, Berlin; London, Springer, pp439.

Ridd, M.K. (1995) Exploring a V-I-S (vegetation-impervious surface -soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. *International Journal of Remote Sensing ,* 16, 2165-2185.

Sandstrom, U.G., Angelstam, P., and Khakee, A. (2006) Urban comprehensive planning – identifying barriers for the maintenance of functional habitat networks. *Landscape and Urban Planning* 75: 43-57.

Smith, A.J. (2000) *Subpixel Estimates of Impervious Surface Cover Using Landsat TM imagery*. Available at: http://www.geog.umd.edu/academic/occasional/wp2000/ajsmith_sp.pdf. Accessed 5th August 2005.

Smith, R.M., Gaston,K.J., Warren, P.H., and Thompson, K. (2005) Urban domestic gardens(V): relationships between landcover, composition, housing and landscape. *Landscape Ecology* 20: 235-253.

Snep, R.P.H., Opdam P.F.M., Baveco J.M.,. WallisDeVries M.F, Timmermans W., Kwak R.G.M. and Kuypers V. (2006) How peri-urban areas can strengthen animal populations within cities: A modeling approach *Biological Conservation,* 127: 345-355.

Stabel, E. and Fischer, P. (2001) Satellite radar interferometric products for the urban application domain, *Advances in Environmenal Research,* 5, pp 425-433.

Thompson, C.W. (2002) Urban open space in the 21st century. *Landscape and Urban Planning* 60: 59-72.

Thompson, K., Austin, K., Smith, R.M., Warren, P.H., Angold, P.G., and Gaston, K.J. (2003) Urban domestic gardens (I): Putting small-scale plant diversity in context. *Journal of Vegetation Science*. 14: 71-78.

Thompson, K., Hodgson, J.G., Smith, R.M., Warren, P.H., and Gaston, K.J. (2004) Urban domestic gardens (III): Composition and diversity of lawn floras. *Journal of Vegetation Science*. 15: 373-378.

Ulrich R.S. (1986) Human responses to vegetation and landscapes. *Landscape and Urban Planning*, **13**, 29-44

van den Berg A. E. (2003) Personal need for structure and environmental preference in Hendrixkx L, Jager W. & Steg L. Human decision making and environmental perception: Understanding and assisting human decision making in real-life settings. Liber Amoricum for Charles Vlek, Groningen: Rijksuniversiteit Groningen. pp

van den Berg A. E., Vlek C.A.J. & Coeterier J.F. (1998) Group differences in the aesthetic evaluation of nature development plans. *Journal of Environmental Psychology*, **18**, 141-157.

Van Herzele A. & Wiedemann T. (2003) A monitoring tool for the provision of accessible and attractive urban green spaces. *Landscape and Urban Planning*, **63**, 109-126.

Vos, C.C., Arens P., Baveco H., Bugter H., Kuipers H., & Smulders, M.J.M. (2005) Ruimtelijke samenhang en genetische variatie van boomkikkerpopulaties in Nederland; Alterra report 1065, Alterra, Wageningen; 54 pp.

Vuillemier, S., and Prelaz-Droux, R. (2002) Map of ecological networks for landscape planning. *Landscape and Urban Planning*. 58: 157-170.

Wang, Z., Wei, W., Zhao, S. and Chen, X. (2004) Object-oriented Classification and Application in Land Use Classification Using SPOT-5 PAN imagery. *IEEE, pp*3158-3160.

Ward, D., Phinn, S.R. and Murray, A.T. (2000) Monitoring Growth in Rapidly Urbanizing Areas Using Remotely Sensed Data. *Professional Geographer ,* 52, pp371-386.

Watson, D.M. (2002) A conceptual framework for studying species composition in fragments, islands and other patchy ecosystems. *Journal of Biogeography* 29: 823-834.

Weydahl, D.J., Bretar, F. and Bjerke, P (2005) Camparison of RADARSAT-1 and IKONOS satellite images for urban features detection, *Information Fusion*, 6, pp243-249.

Wood, G.A., Kibblewhite, M.G., Hannam, J.A., Harris, J.A. and Leeds-Harrison, P.B. (2005) *Soil-based services in the built environment*, a report prepared for the Department of Environment, Food and Rural Affairs by the National Soil Resources Institute, Cranfield University, September 2005, pp51.

Wu, C. and Murray, A.T. (2003) Estimating impervious surface distibution by spectral mixture analysis. *Remote Sensing and Environment ,* 84, pp493-505.

Yli-Pelkonen, V. and Niemela, J. (2005) Linking ecological and social systems in cities: urban planning in Finland as a case. *Biodiversity and Conservation* 14: 1947-1967.

10. Appendices

Appendix 1 – Baseline Map Production

Baseline maps were produced by developing and implementing a key interpretation to selected orthorectified aerial photography. The development of the key interpretation comprised i) a visual aerial photo interpretation, ii) an image segmentation according to the developed typology and iii) a ground verification and refinement of both interpretation and typology.

Data acquisition

The study area is the city of Cambridge. For that purpose orthocorrected aerial images with spatial resolution of 0.125 m, taken in August of 2003, were purchased. Ancillary data such as Ordnance Survey (OS) Master Map, which contains baseline polygons delineating transport network infrastructure and residential and commercial buildings at scale of 1:1250, were also used. The Master Map was overlaid onto the orthorectified aerial photos of Cambridge for the visual interpretation process and the baseline map production (Figure A1.1).

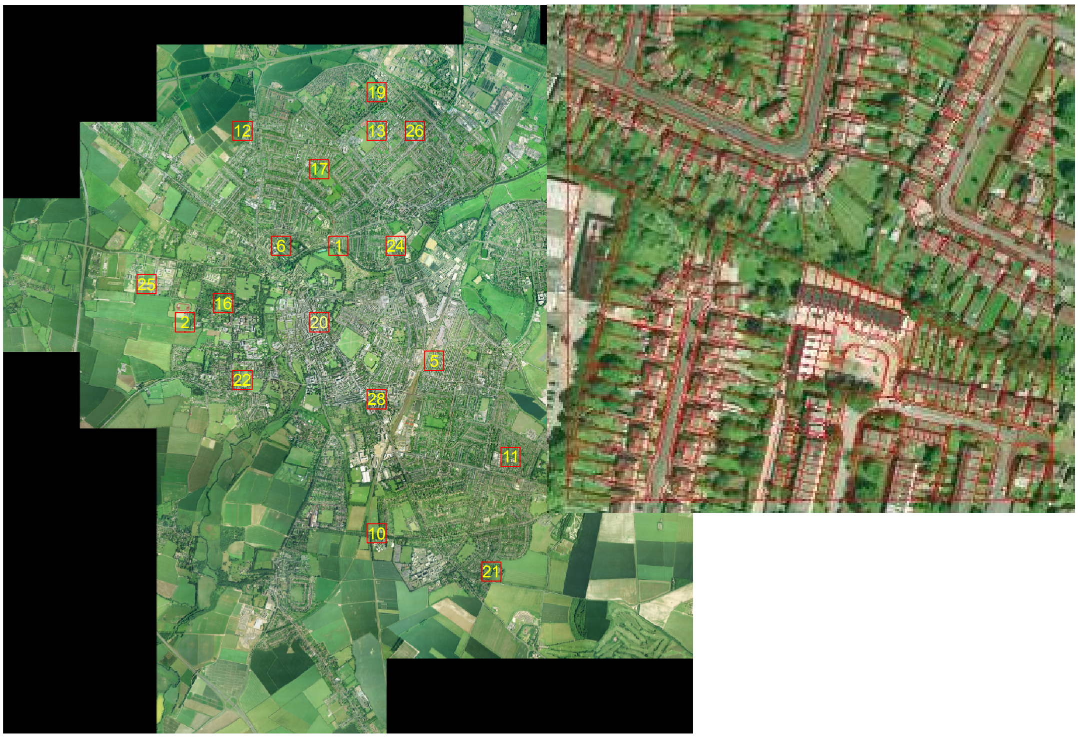

Figure A1.1: Orthophoto mosaic of Cambridge City with the 250 x 250 m 18 sample areas within the city of Cambridge. The example square illustrates the detail of the 1:1250 scale Ordnance Survey Master Map.

Methodology

Aerial photo interpretation

Aerial photo interpretation (API) is an accepted technique for precise mapping of complex features. For that reason API was carried out on 18 sample areas of Cambridge to produce reference maps for comparison with the automated classification of Quickbird images.

The visual interpretation was achieved by overlaying on-screen the Master Map on to the aerial photos of Cambridge. By assessing the land cover of each area (Table A1.1) and according to the definition of sealing, six classes were introduced for the classification process: **i) sealed surfaces, ii) vegetation surfaces, iii) trees, iv) bare soil, v) water and vi) unclassified areas.** Due to limited time, it was decided that every single polygon of each sample area will be perceptibly subdivided into four parts in order to identify the percentage of each class. As it is well known, the aerial photo interpretation is a subjective process, clearly depended of the interpreter. By following the procedure of ¼, it is more likely to have similar results if the interpreter changes.

Class no	Landcover	AP-classes	Sealed/Unsealed/Semi-sealed
1	white roof	sealed	sealed
2	red roof	sealed	sealed
3	grey roof	sealed	sealed
4	artificial sports	sealed	sealed
5	yard/drive	sealed	sealed
6	road (light)	sealed	sealed
7	road (dark)	sealed	sealed
8	car park/playground	sealed	sealed
9	path	sealed	sealed
10	roadside pavement	sealed	sealed
11	patio	sealed	sealed
12	loose chippings	sealed	semi-sealed
13	sealed (other)	sealed	sealed
14	green roof/roof-garden	sealed	sealed
15	arable fields	vegetation	unsealed
16	lawn	vegetation	unsealed
17	mixed garden	vegetation	unsealed
18	playing field	vegetation	unsealed
19	allotment	vegetation	unsealed
20	worn/scrub grass	vegetation	unsealed
21	deciduous trees (green)	trees	unsealed
22	deciduous trees (red)	trees	unsealed
23	coniferous trees	trees	unsealed
24	water	water	unsealed
25	bare soil	soil	unsealed
26	construction ground	soil	unsealed
27	unsealed (other)	unsealed	unsealed
28	railway track/base	soil/mix	semi-sealed
29	unclassified	unclassified	unclassified

Table A1.1. The creation of the classes to be classified, according the land cover of the sample areas

The fact that there were plenty of examples where sealed surfaces, vegetation, trees and bare soil had a percentage smaller than 25% lead to the creation of three more classes: **i) less than 25% sealed, ii) less than 25% grass and iii) less than 25% bare soil.** Whenever one of these classes were part of a polygon's classification a value of 1 was noted to indicate a presence. Furthermore, these classes were not calculated into the total percent of each class.

They just point out the characteristics of each polygon with every possible detail that a human eye can catch. Additionally, one further class was created named as **"notes"** and any comment had to be done was added there. In few examples the description of a polygon didn't match with what could be seen in the photograph and this mismatch was noted in that class (Figure A1.2). The 10 classes were added to the attribute table of the master map into the ArcMap programme where the classification occurred (figure A1.3). Finally, the total percentage (%) of each study area and of each class was calculated (table A1.2).

Figure A1.2: The highlighted polygons according to OS master map data attributes indicate buildings. In the photo on the left it is clear that this is no longer the case (it appears to be lawn), whilst in the photo on the right it is impossible to say whether there is a building or not due to trees obscuring the overhead view – this latter problem will be encountered using satellite imagery.

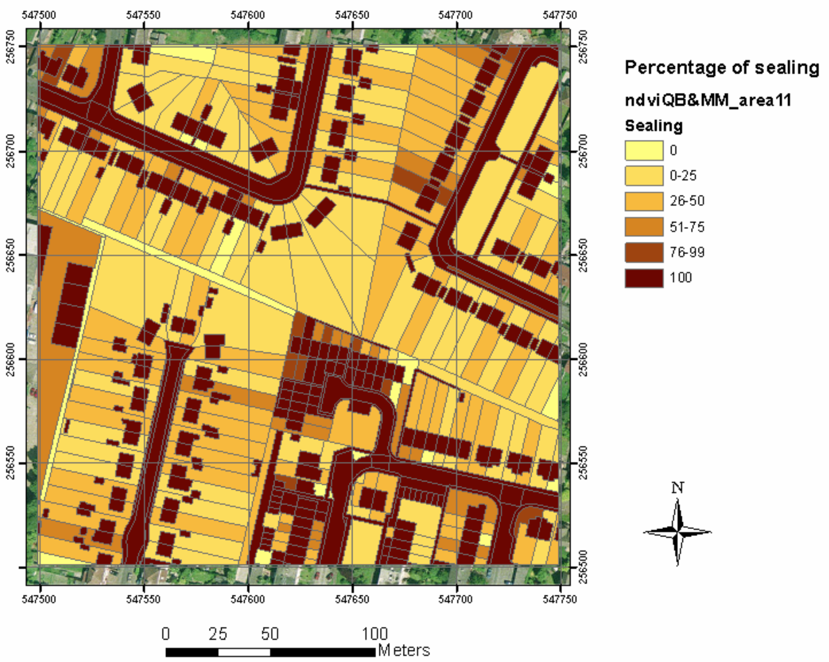

Figure A1.3: The classification of the sample area 11 according to sealing

Sample areas	Area Sealed	Area Surface vegetation	Area Trees	Area Bare soil	Area Water	Area Unclassified
Area 1	53.22	17.30	12.35	6.58	10.31	0.02
Area 2	19.78	67.03	13.19	0.00	0.00	0.00
Area 5	57.27	20.58	14.67	6.49	0.00	0.98
Area 6	65.61	7.85	24.08	1.87	0.00	0.57
Area 10	18.82	45.25	31.16	4.06	0.00	0.71
Area 11	50.41	33.63	15.57	0.32	0.00	0.07
Area 12	21.60	72.41	5.16	0.69	0.00	0.13
Area 13	39.90	44.95	13.75	0.03	0.00	1.39
Area 16	18.78	62.12	18.39	0.62	0.00	0.08
Area 17	21.72	65.45	12.65	0.11	0.00	0.08
Area 19	34.46	41.15	16.37	5.25	0.00	2.76
Area 20	92.29	3.17	4.49	0.01	0.00	0.03
Area 21	19.15	53.88	23.39	3.32	0.00	0.27
Area 22	33.30	43.82	21.87	0.55	0.00	0.45
Area 24	73.84	11.65	14.45	0.00	0.00	0.05
Area 25	41.07	45.46	2.15	11.32	0.00	0.00
Area 26	46.31	34.03	19.62	0.04	0.00	0.00
Area 28	58.90	4.64	36.43	0.00	0.00	0.05

Table A1.2. The total percentage (%) of each class for all the sample areas

Field work

After the completion of the visual classification of the air photographs, a visit to Cambridge served to understand some of the discrepancies against information provided in the MasterMap®. New developments had been found that did not exist in the aerial photographs, but had been commenced between the time of the satellite image acquisition and the aerial survey (*e.g.* figure A1.4). The ground verification is a supporting tool that helped us understand the errors and misclassifications occur during the visual interpretation. Note was made of the time passed between image date (2003) and the field trip (2006). To assist this, City Council planning data were examined to identify the location of the new developments.

Figure A1.4: The sample area 25 as it looks in the area photograph and at the day of visiting Cambridge. Part of the new development has been also detected on the satellite image.

Problems met

Ordnance Survey MasterMap®

One of the biggest and time consuming problems that had to be resolved was the duplication and overlapping of polygons found in the original OS Master Map. The result of this was the incorrect over-estimation of the total area of each sample and class. The problem was solved by exporting the Shapefile® of each sample area to a Geodatabase® and by creating a new topology with the rule "polygons must not overlap" (figure A1.5). The new topology showed where the errors were and resolved by deleting the duplicated polygons. In cases one polygon also belonged to another and could not be deleted the Shapefile® was exported to a coverage® and then the "union" overlay process was followed to join the attribute table from the original feature class with the topology errors to the imported feature class. Finally, all the problematic areas were recalculated.

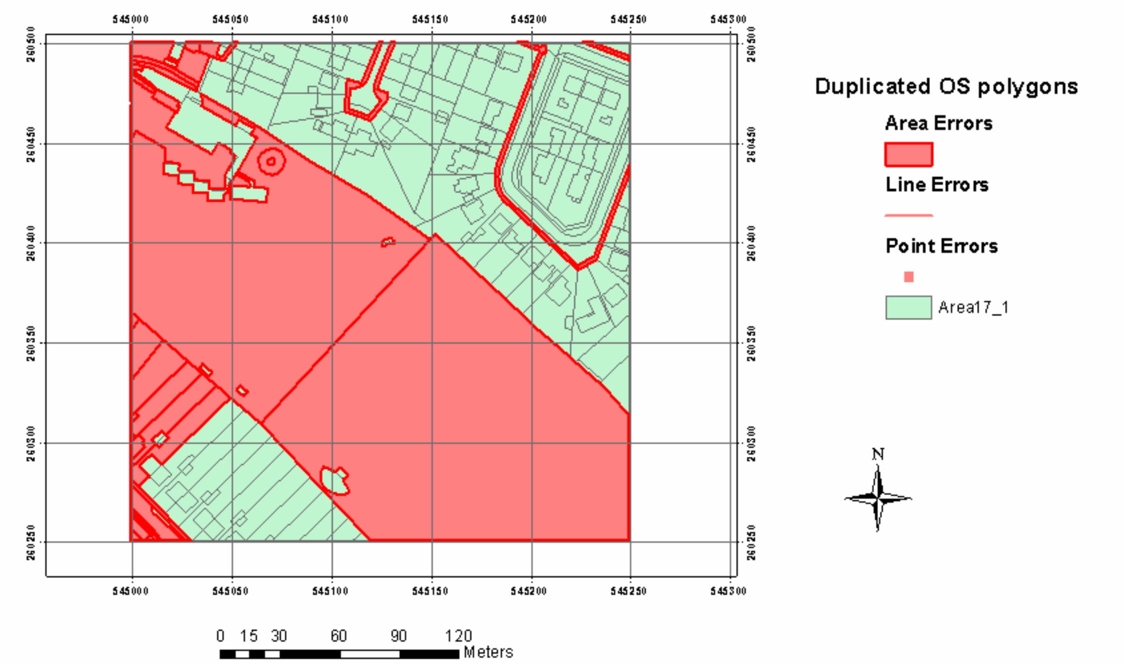

Figure A1.5: The production of typology for area 17 shows us where exactly the problem of the duplicated polygons occurred.

3.1.2 Origin of the duplications at the OS Master Map data

The duplicated polygons are the result of the way Ordnance Survey (OS) includes information in the MasterMap®. In addition to the basic polygons delineating land parcels and attributed with the make of the surface, there can also be additional (spatially matching) polygons that sit on top representing slope, or so-called “landforms” polygons. There are also a few instances of what the OS term "broken" polygons. These features are an artefact of the OS editing environment and will be removed when the OS move to their new editing environment. Normally there is an attribute flagging these but in this case it was not present which made them more difficult to detect and remove. It also appears that some of the features are simple duplicates which are related to the way that the OS delivers data as "hairy" tiles, meaning that the same feature is present twice if it sits on a boundary between two tiles. These can be separated by removing data that shares the same TOID (unique Topographic Identifier in MasterMap®).

3.2 Visual interpretation

The most frequent difficulties in aerial photo classification were due to shadow and roof leaning (relief displacement). The tallest the buildings are, will introduce the greatest mismatch between the air photos and the Master Map (figure A1.6i). Furthermore, tree and building shadow is a common problem in the aerial interpretation and is the reason behind most unclassified polygons (figure A1.6ii). Apart from their shadow, trees can cause problems with their canopy. There were situations where trees covered the whole or a part of a building, paths, roads and road side verges (figure A1.6iii). These areas were classified according to what can be seen (*i.e.* tree canopy) but notes were kept to indicate what, intuitively, was there (*i.e.* if a path reached a tree and then continues after the tree, it is clear to assume the path does not stop and start). Another difficulty was in the front gardens which were often very small and were very difficult to determine the percentage sealed; such small patches would not be spatially resolved in the satellite images (figure A1.6iv).

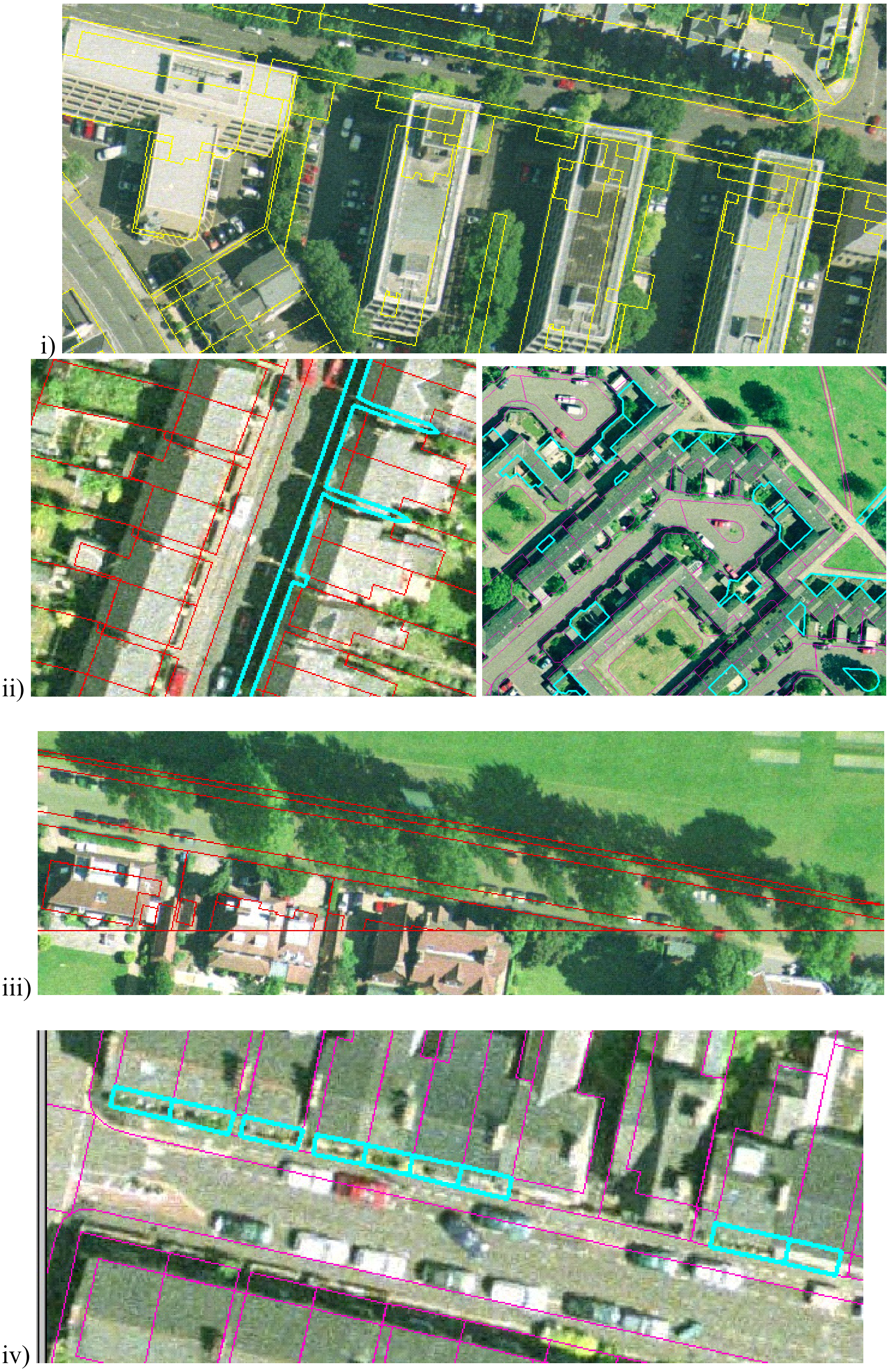

Figure A1.6: i) Building leaning, ii) two examples of the shadow effect, iii) trees canopy cover road & roadside and iv) small front gardens

Appendix 2 – Technology Matching

This represents the key sections submitted by Infoterra after phase 1. A full report is available on request.

1.1 Technology Matching

The Technology Matching process involved matching the key criteria identified during the literature review to Satellites and Instruments. This process utilised Historical Satellites/Instruments and also current Operational Satellites/Instruments. The process did not seek to look at Future Satellites, as project funding and the unavoidable risk of losing satellites during the launch process could identify satellites/instruments that may never become available to the GIFTSS project.

The technology matching was conducted first on thermal infrared (TIR), then shortwave infrared (SWIR), followed by visible and near-infrared (VIS + NIR).

i. Thermal Infrared (TIR)

Infrared (IR) radiation is electromagnetic radiation of a wavelength longer than that of visible light, but shorter than that of microwave radiation. The name means "below red" (from the Latin infra, "below"), red being the colour of visible light of longest wavelength. Infrared radiation spans three orders of magnitude and has wavelengths between approximately 750 nm and 1 mm.

Thermal infrared is the part of the electromagnetic spectrum between 3 and 12 micrometers. In the civilian sector, satellite acquisition of thermal infrared images began in 1960 with the U.S. meteorological Television Infrared Operational Satellite (TIROS).

The technology Matching process identified a total of 47 Sensors that acquire(d) imagery in the TIR spectrum. The results have been split into the spatial resolution ranges previously stated.

1. <2m

Instrument	Description	Satellite	Resolution (m)
N/A	N/A	N/A	N/A

Table 4.2.1 – TIR Instruments with a resolution of <2m

Unfortunately no Instruments were identified that matched the requirements.

2. 2m – 10m

Instrument	Description	Satellite	Resolution (m)
N/A	N/A	N/A	N/A

Table 4.2.2 – TIR Instruments with a resolution of 2-10m

Unfortunately no Instruments were identified that matched the requirements.

3. 10m – 50m

Instrument	Description	Satellite	Resolution (m)
MTI	Multi-spectral Thermal Imager	MTI	20

Table 4.2.3 – TIR Instruments with a resolution of 10-50m

4.> 50m

Instrument	Description	Satellite	Resolution (m)
ETM	Enhanced Thematic Mapper	Landsat 7	60
MSS (LS 1-3)	Multispectral Scanner Landsat 1,2,3	Landsat 1, 2 & 3	79
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	TERRA	90
TM	Thematic Mapper	Landsat 4 & 5	120
IR-MSS	Infrared Multispectral scanner	CBERS-1 & 2	160
HSRS	Hot Spot Recognition Sensor System	BIRD	370
HIRDLS	High Resolution Dynamics Limb Sounder	AURA	500
TES	Tropospheric Emission Spectrometer	AURA	500
MOS	Modular Optoelectronic Scanning Spectrometer	IRS-P3	520
MSU-SK (Resurs)		RESURS-O1-3	548
OLS	Operational Linescan System	DMSP-16	550
MSU-SK		PRIRODA-MIR	600
MSU-SK1		RESURS-O-1	700
OCTS	Ocean Colour and Temperature scanner	ADEOS	700
CZCS	Coastal Zone Colour Scanner	NIMBUS-7	825
AATSR	Advanced Along Track Scanning Radiometer	ENVISAT	1000
AIRS	Atmospheric Infrared Sounder	AQUA	1000
ATSR-1	Along Track Scanning Radiometer	ERS-1	1000
ATSR-2	Along Track Scanning Radiometer	ERS-2	1000
GLI	Global Imager	ADEOS-II	1000
ILAS-II	Improved Limb Atmospheric Spectrometer-II	ADEOS-II	1000
MODIS	Moderate Resolution Imaging Spectroradiometer	AQUA, TERRA	1000
AVHRR/2	Advanced Very High Resolution Radiometer	NOAA-10, 11, 12 & 14	1100
AVHRR/3	Advanced Very High Resolution Radiometer	NOAA_15,16.17 & 18	1100
MVISR	Multichannel Visible and IR Scan Radiometer	Fengyun-1C/1D	1100
VIRS	Visible and Infra red scanner	TRMM	2000
VTIR	Visible and Thermal Infrared Radiometer	MOS-1 & 1B	2700
JAMI	Japanese Advanced meteorological Imager	MTSAR-1R	4000
VIRR	Visible and IR Radiometer	Seasat	4400
SEVIRI	Spinning Enhanced Visible and Infrared Imager	MSG-1 & 2	4800
S-VISSR	S-Visible and IR Spin Scan Radiometer	Fengyun-2A & 2B	5000
VISSR (GMS)	Visible and Infrared Spin-Scan Radiometer	GMS-5	5000

Sounder		GOES - 10, 8, 9, L & M	8000
VHRR	Very High Resolution Radiometer	INSAT-2A, 2b & 2E	8000
CERES	Clouds and Earth's Radiant Energy System	AQUA, TERRA, TRMM	10000
HIRS/4	High Resolution Infra Red Radiation Sounder	NOAA-18	10000
ILAS	Improved Limb Atmospheric Spectrometer	ADEOS	13000
HIRS/2	High Resolution Infra Red Radiation Sounder	NOAA -10, 11& 14	20000
HIRS/3	High Resolution Infra Red Radiation Sounder	NOAA-15, 16 & 17	20000
ERBE	Earth Radiation Budget Experiment	NOAA-10	200000
VISSR	Visible and Infrared Spin Scan Radiometer	Meteosat 5, 6 & 7	2500-5000
Imager		GOES-10, 8, 9 & L	4000-8000
Imager-M		GOES-M	4000-8000

Table 4.2.4 – TIR Instruments with a resolution of >50m

Cranfield UNIVERSITY

ii. Description of Results

TIR imagery has generally been utilized in meteorological applications, and can be mainly found on meteorological satellites. These satellites are designed to provide wide area coverage and as a consequence offer coarse spatial resolution, which is ideal for monitoring cloud patterns and ocean temperatures. However the wide area and coarse resolution of these satellites is not suitable for the GIFTSS project.

- The Multispectral Thermal Imager is the best fits instrument/satellite for the GIFTSS project. The MTI was a single satellite demonstration mission, launched in 2000 into a polar, 360-mile-high orbit, sponsored by the U.S. Department of Energy (DOE), Office of Nonproliferation and National Security.

MTI's primary objective was to demonstrate advanced multispectral and thermal imaging, image processing, and associated technologies that could be used in future systems for detecting and characterizing facilities producing weapons of mass destruction. However the satellite mission was only designed for three years, and is currently no longer operational.

- The Landsat 7 satellite, although still operational, no longer functions as intended due to a Scan Line Corrector (SLC) Anomaly that occurred in August 2003. Therefore although the satellite would provide a historical record back to its launch in 1999, the satellite would not be considered to offer any new data.

- The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument acquires TIR at 90-meter spatial resolution. ASTER was launched in June 1998 which was intended to be the first in a series of missions to measure the health of the Earth. Included on the first mission were two imaging instruments with TIR capability: the Moderate Resolution Imaging Spectroradiometer (MODIS) and ASTER. MODIS is an improved AVHRR, which has operated successfully for many years. As part of the NASA

ASTER remains operational and the mission is expected to remain operational for a number of years. Data from the satellite is available commercially; however the satellite is not operational on a truly commercial basis due to its historical and ongoing “scientific heritage”.

The remaining Instruments are all above the 100m spatial resolution, which would be considered too coarse for the GIFTSS project.

iii. Short Wave Infrared (SWIR)

Short Wave Infrared is the part of the electromagnetic spectrum between 1 and 4.3 micrometers.

The technology Matching process identified a total of 30 Sensors that have SWIR wavebands. The results have been split into the spatial resolution ranges previously stated.

1.<2m

Instrument	Description	Satellite	Resolution (m)
N/A	N/A	N/A	N/A

Table 4.2.5 – SWIR Instruments with a resolution of <2m

Unfortunately no Instruments were identified that matched the requirements.

2.2m – 10m

Instrument	Description	Satellite	Resolution (m)
N/A	N/A	N/A	N/A

Table 4.2.6 – SWIR Instruments with a resolution of 2-10m

Unfortunately no Instruments were identified that matched the requirements.

3.10m – 50m

Instrument	Description	Satellite	Resolution (m)
OPS	Optical Sensor	JERS-1	18.3
HRG	High Resolution Geometric	SPOT 5	20
HRVIR	High Resolution Visible and Infra-red	SPOT 4	20
MTI	Multi-spectral Thermal Imager	MTI	20
LISS 3*	Linear Imagine Self Scanning System	RESOURCESAT-1	23.5
ALI	Advanced Land Imager	EO-1	30
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	TERRA	30
ETM	Enhanced Thematic Mapper	Landsat 7	30
TM	Thematic Mapper	Landsat 4 & 5	30

Table 4.2.7 – SWIR Instruments with a resolution of 1-500m

4.> 50m

Instrument	Description	Satellite	Resolution (m)
AWiFS	Advanced Wide Field Sensor A and B	RESOURCESAT-1	56
LISS 3	Linear Imagine Self Scanning System	IRS - 1C & 1D	70.5
IR-MSS	Infrared Multispectral scanner	CBERS 1 & 2	80
MMRS	MultiSpectral Medium Resolution Scanner	SAC-C	175
WiFS	Wide Field Sensor	IRS-1C, 1D & P3	188
GLI	Global Imager	ADEOS-II	250-1000
MODIS	Moderate Resolution Imaging Spectroradiometer (PFM on Terra, FM1 on Aqua)	AQUA. & TERRA	500
AATSR	Advanced Along Track Scanning Radiometer	ENVISAT	1000
ATSR-1	Along Track Scanning Radiometer	ERS-1	1000
ATSR-2	Along Track Scanning Radiometer	ERS-2	1000
VEGETATION	VEGETATION 2 on Spot 5	SPOT 4 & 5	1000
AVHRR/2	Advanced Very High Resolution Radiometer	NOAA-10, 11, 12 & 14	1100
MVISR	Multichannel Visible and IR Scan Radiometer	Fengyun-1C/1D	1100
OSIRIS	Optical Spectrograph and Infrared Imaging System	ODIN	2000
VIRS	Visible and Infra red scanner	TRMM	2000
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding	ENVISAT	3000
SEVIRI	Spinning Enhanced Visible and Infrared Imager	MSG-1 & 2	4800
HIRS/4	High Resolution Infra Red Radiation Sounder	NOAA-18	10000
CERES	Clouds and Earth's Radiant Energy System	AQUA. TERRA & TRMM	20000
HIRS/2	High Resolution Infra Red Radiation Sounder	NOAA-10, 11 & 14	20000
HIRS/3	High Resolution Infra Red Radiation Sounder	NOAA - 15, 16 & 17	20000

Table 4.2.8 – SWIR Instruments with a resolution of >50m

iv. Description of Results

- The JERS-1 OPS offered the best resolution at SWIR. JERS-1 was launched in February 1992 and was operational until in October 1998, and was a joint Japanese radar/optical mission with NASDA/JAXA lead.

The overall objectives were the generation of global data sets with SAR and OPS sensors aimed at surveying resources, establishing an integrated Earth observation system, verifying instrument/system performances.

Eight Instruments offer a spatial resolution of less than 30m. The MTI and Landsat 7 can be discounted for future acquisitions due to reasons previously listed. Landsat 5 has recently been recommisioned and International Ground Stations have begun to come back online. However the satellite launched in March 1984, is now more than 20 years old and is not expected to continue in useful operational.

- SPOT-5 is the fifth satellite in the SPOT series, and was launched in May 2002 and followed SPOT-4 which was launched in March 1998. The SWIR instrument onboard SPOT-5 is a continuation of the SWIR instrument carried onboard SPOT-4.

- RESOURCESAT-1 was launched in October 2003. The LISS-III, is an improved version of the LISS-III camera which was carried aboard the IRS 1C/1D satellites

- EO-1, launched in November 2000 was originally intended to be a one-year technology demonstration mission. At the end of the original EO-1 Technology Mission in December 2001 the operations of the satellite were extended and the satellite chartered to collect and distribute products in response to customer Data Acquisition Requests.

Although some of the remaining Instruments are below 100m spatial resolution, and maybe considered for the GIFTSS project, the majority of these instruments are no longer operational. The remaining instruments, would be considered too coarse for the GIFTSS project.

v. Visible and Near-Infrared (VIS & NIR)

The visible spectrum is the portion of the electromagnetic spectrum that is visible to the human eye. The Electromagnetic radiation in this range of wavelengths is called visible light or simply light. There are no exact bounds to the visible spectrum.

The Near-Infrared is the part of the electromagnetic spectrum between 0.75–1.4 micrometers.

The technology Matching process identified a total of 35 Sensors that acquire(d) imagery in the VIS & NIR spectrum. The results have been split into the spatial resolution ranges previously stated.

1.<2m

Instrument	Description	Satellite	Resolution (m)
N/A	N/A	N/A	N/A

Table 4.2.9 – VIS/NIR Instruments with a resolution of <2m

Unfortunately no Instruments were identified that matched the requirements.

2.2m – 10m

Instrument	Description	Satellite	Resolution (m)
Quickbird		Quickbird	2.44
Orbview-3		Orbview-3	4
OSA	Optical Sensor Assembly	Ikonos	4
MTI	Multi-spectral Thermal Imager	MTI	5-10
LISS 4	Linear Imagine Self Scanning System	RESOURCESAT-1	5.8
ROCSAT-2		FORMOSAT-2	8
AVNIR-2	Visible and near-infrared radiometer	ALOS	10
HRG	High Resolution Geometric	SPOT 5	10
MSU-E2		PRIRODA-MIR	10
AVNIR-2	Visible and near-infrared radiometer	ALOS	10
MSU-E2		PRIRODA-MIR	10

Table 4.2.10 – VIS/NIR Instruments with a resolution of 2-10m

3.10m – 50m

Instrument	Description	Satellite	Resolution (m)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	TERRA	15
MOMS-2P	Modular Optoelectronic Multispectral Scanner	PRIRODA-MIR	15.9
MOMS-2P	Modular Optoelectronic Multispectral Scanner	PRIRODA-MIR	15.9
CHRIS	Compact High Resolution Imaging Spectrometer	PROBA	18
OPS	Optical Sensor	JERS-1	18.3
HRV	High Resolution Visible	SPOT 1, 2 - 3	20
CCD		CBERS 1 & 2	20
HRVIR	High Resolution Visible and Infra-red	SPOT 4	20
LISS 3	Linear Imagine Self Scanning System	IRS- 1C & 1D	23.5
LISS 3*	Linear Imagine Self Scanning System	RESOURCESAT-1	23.5
BILSAT-MS		BILSAT	26
ALI	Advanced Land Imager	EO-1	30
ALI	Advanced Land Imager	EO-1	30
ETM	Enhanced Thematic Mapper	Landsat 7	30
TM	Thematic Mapper	Landsat 4 & 5	30
AlSat	Standard DMC sensor	AlSat-1	32
BEIJING-1-MS	Standard DMC sensor	BEIJING-1	32
NigeriaSat-1	Standard DMC sensor	NigeriaSat-1	32
UK-DMC	Standard DMC sensor	UK-DMC	32
MSU-E	Microwave Sounding Unit	RESURS-O1-3	34
MSU-E1		RESURS-O-1	34
LISS 2	Linear Imagine Self Scanning System	IRS-1A, 1B & P2	36.25
MESSR	Multispectral Electronic Self-Scanning Radiometer	MOS-1 & 1B	50
RBV	Return Beam Vidicon Camera	Landsat 1	79

Table 4.2.11 – VIS/NIR Instruments with a resolution of 1-500m

4.> 50m

Instrument	Description	Satellite	Resolution (m)
MESSR	Multispectral Electronic Self-Scanning Radiometer	MOS-1 & 1B	50
RBV	Return Beam Vidicon Camera	Landsat 1	79

Table 4.2.12 – VIS/NIR Instruments with a resolution of >50m

vi. Description of Results

- The Quickbird satellite offered the best resolution at both VIS and NIR. Quickbird, launched in October 2001 by DigitalGlobe, is the highest resolution commercial earth observation satellite.

  DigitalGlobe intention is to build a constellation of high-resolution earth imaging satellites – Worldview and Worldview II. The WorldView I telescope will have a 60-cm aperture and collect panchromatic (black-and-white) imagery only. The WorldView II telescope will have a 110-cm aperture and it will provide the same panchromatic half-meter resolution imagery as WorldView I, in addition to 1.8-meter multispectral resolution imagery. The satellite will offer eight multispectral bands: Red, Blue, Green and Near-Infrared in addition to Coastal, Yellow, Red Edge and Near-Infrared. WorldView I is expected to be launched in 2006m with WorldView II to be launched by 2008.

The overall objectives were the generation of global data sets aimed at a variety of applications. However the satellite is driven by user requests, which do not generally require a complete global dataset. Therefore to meet its goal of images of the entire Earth's land surface, DigitalGlobe populates and refreshes its archive by submitting speculative tasking to the collect "missing" geographies or replace outdated data of popular areas.

10 additional Instruments offer a spatial resolution of at least 10m. The Priroda-MIR instruments can be discounted for future acquisitions due to the problems with funding within the Russian Space Agency, as can the MTI instrument.

- SPOT-5 is the fifth satellite in the SPOT series, and was launched in May 2002 and followed SPOT-4 which was launched in March 1998. The VIS instrument onboard SPOT-5 is a return to VIS instrument carried onboard SPOT-1 to 3. While the NIR is a continuation of the NIR instrument carried onboard SPOT-1 to 4.

- IKONOS-2 was launched in September 1999. The Model 1000TM camera carried on the satellite was a clone of the IKONOS-1 satellite that failed on launch in April 1999. The follow-on version of the IKONOS satellite is currently on hold due to funding issues.

- RESOURCESAT-1 was launched in October 2003. The LISS-IV, is an improved version of the LISS-IV camera which was carried aboard the IRS 1C/1D satellites.

- ROCSAT-2 was launched in May 2004. ROCSat-2 is an NSPO (National Space Program Office) of Taiwan Earth imaging satellite with the objective to collect daily high-resolution panchromatic and multispectral imagery of Taiwan and the surrounding region. To offer such daily coverage the satellite is on a fixed track that prevents its coverage of many areas of the world, and offers reduced resolution off its main ground track. It could be used if it had to be but would not be a preferred choice given the very low look angles and resolution: it can provide coverage of England & Wales though resolution drops off to 2.88m (Panchromatic).

- ALOS was launched in January 2006. ALOS was developed by JAXA (Japan Aerospace Exploration Agency) and was intended as a continuation/updated version of instruments carried on the ASTER TERRA, ADEOS and much earlier JERS satellites. The AVNIR-2 (Advanced Visible and Near-Infrared Radiometer - 2), is a JAXA instrument of AVNIR heritage flown on ADEOS),

A further 22 instruments maybe considered for the GIFTSS project, which offer a resolution of less than 50m, the majority of these instruments are still operational, of which a number are considered “small sats”, which is intended to offer lower cost options than the traditional satellite models. While the remaining instruments, would be considered too coarse for the GIFTSS project.

1.2 Coverage Scenario Data Provider Case

A number of factors were listed in the feasibility phase (main report) that would be undertaken by a Satellite Operator before tasking a satellite.

A number of satellite operators were contacted in order to estimate the feasibility of meeting the criteria set out for the GIFTSS project. These included:

- National coverage (England and Wales).
- Reporting period every 5 years
- 2 complete coverage's in a single yr
- Including; 1 Summer scene and 1 winter scene

A number of satellite operators were contacted and although results have not been obtained from each supplier, two coverage Scenarios are shown. These coverage's are from a very-high-resolution supplier; IKONOS, and a Medium-resolution; SPOT Image.

The results from these suppliers can be considered to reflect the issues that would be associated with many of the satellites/instruments that have been identified within the technology matching process.

vii. Very-High-Resolution Scenario (IKONOS)

1. Technical Information

- Orbit: Sun-synchronous at 681 Km
- Ground Sampling Distance: Standard 1m
- Swath Width: 11Km
- Scanning: Pushbroom
- Spectral Band: (Panchromatic) 0.45 - 0.90 microns
- Sampling Depth Transmitted: 11 Bits
- Multispectral Capability: #1: Blue 0.45 - 0.52 microns
  #2: Green 0.52 - 0.60 microns
  #3: Red 0.63 - 0.69 microns
  #4: Near IR 0.76 - 0.90 microns
- Data Link Rate:
- Data Volume: 2MB/km2 - Panchromatic
  375 - 500kb/km2- Multispectral (each band)
  -
- Accuracy: GEO product has 25 m (RMSE) standard horizontal accuracy, excluding effect of terrain displacement.

2. Coverage Scenario

IKONOS is able to collect imagery off-angle. This has the advantage of allowing improved repeat coverage.

IKONOS is able to collect up to an off-nadir angle of 35degrees. However this is not a common off-nadir angle for most satellites and at this angle the resolution of the imagery is compromised. As a result the off-nadir angle has been reduced to 25degrees, a more common figure for such collection. Additional results reflecting an off-nadir angle of 35degrees has also been included.

A coverage scenario has been undertaken assuming all parameters within the satellite operator's control (such as power usage, maintenance and imaging capability). This will be known as a Perfect World Scenario. Factors such as cloud cover and competition have been excluded from the original scenario and are reflected in a subsequent scenario.

Perfect World Scenario –

- At a collection angle of 26 degrees the IKONOS satellite is able to cover 3,400 km^2 per pass.

- The UK is approximately 245,000 km^2.

- A total of 75 passes would be required to cover the country.

- Based on the orbital characteristics of the satellite there would be a good imaging opportunity every 1.5 days

- On the assumption of 75 passes x 1.5 days/pass, it would take approximately 112.5 days

Real World Scenario –

European Space Imaging has given the UK a weather weighting of 20. This figure relates to the likely opportunity to acquire a suitable image (an image with less than 20% cloud cover). The weighting is geared against the number of passes. Therefore a rating of 1 means that on any pass you should be able to collect a suitable image. A rating of 20 means that it would take 20 passes to acquire 1 suitable image.

- In a perfect world it would take 75 passes to cover the UK.
- The UK has a cloud cover weighting of 20.
- This results in an estimated 1500 passes to obtain suitable coverage

- Based on the orbital characteristics of the satellite there would be a good imaging opportunity every 1.5 days

- On the assumption of 1500 passes x 1.5 days/pass, it would take approximately 2250 days to collect the UK with a decent cloud cover score

- This figure however does not reflect the winter sun elevation restrictions that exist over the UK. The low sun angle for latitudes such as the UK mean that during the period October to February does not allow the optimum collection of IKONOS imagery.

- Although it is not possible to accurately include this Winter Sun Elevation angle. It has been estimated to increase the collection window by a minimum 400 days.

As previously mentioned IKONOS offers a higher off-nadir collection angle than most satellites, of up to 35degrees.

- In a perfect world it would take 25 passes to cover the UK.
- The UK has a cloud cover weighting of 20.
- This results in an estimated 500 passes to obtain suitable coverage

- Based on the orbital characteristics of the satellite there would be a good imaging opportunity every 1.24 days

- On the assumption of 500 passes x 1.24 days/pass, it would take approximately 620 days to collect the UK with a decent cloud cover score

- This figure however does not reflect the winter sun elevation restrictions that exist over the UK. The low sun angle for latitudes such as the UK mean that during the period October to February does not allow the optimum collection of IKONOS imagery.

- Although it is not possible to accurately include this Winter Sun Elevation angle. It has been estimated to increase the collection window by a minimum 150 days.

viii. Very-High-Resolution Scenario (SPOT 5)

1. Technical Information

- Orbit: Sun-synchronous at 832 Km
- Ground Sampling Distance: Standard 5m
- Swath Width: 60Km
- Scanning: Pushbroom
- Spectral Band: (Panchromatic) 0.48 - 0.71 microns
- Sampling Depth Transmitted: 8 Bits
- Multispectral Capability: #1: Green 0.5 - 0.59 microns
  #2: Red 0.61 - 0.68 microns
  #3: Near IR 0.79 - 0.89 microns
  #4: SWIR 1.58- 1.75 microns
- Data Link Rate:

  Data Volume: 90-Gbit solid-state memory, (~ 210 images with an average decompressed file size of 144 Mb)

-

2. Coverage Scenario

SPOT-5 is able to collect imagery off-angle. This has the advantage of allowing improved repeat coverage. However as most Medium-resolution have a fixed ground track the following analysis has been conducted based on a fixed ground track.

Again the coverage scenario has been undertaken assuming all parameters within the satellite operator's control (such as power usage, maintenance and imaging capability). This will be known as a Perfect World Scenario. Factors such as cloud cover and competition have been excluded from the original scenario and are reflected in a subsequent scenario.

Perfect World Scenario –

- At a fixed collection angle the SPOT satellite would require 149 scenes

- A total of 16 passes would be required to cover the county.

- However the power usage on the satellite and real-time download to a Ground Station would limit the number of acquisitions to 5 per pass.

- This results in certain strips requiring 4 visits.

- Based on the orbital characteristics of the satellite, the revisit period is every 16 days.

- On the assumption of 16 strips x up to 4 passes, it would take approximately 64 days

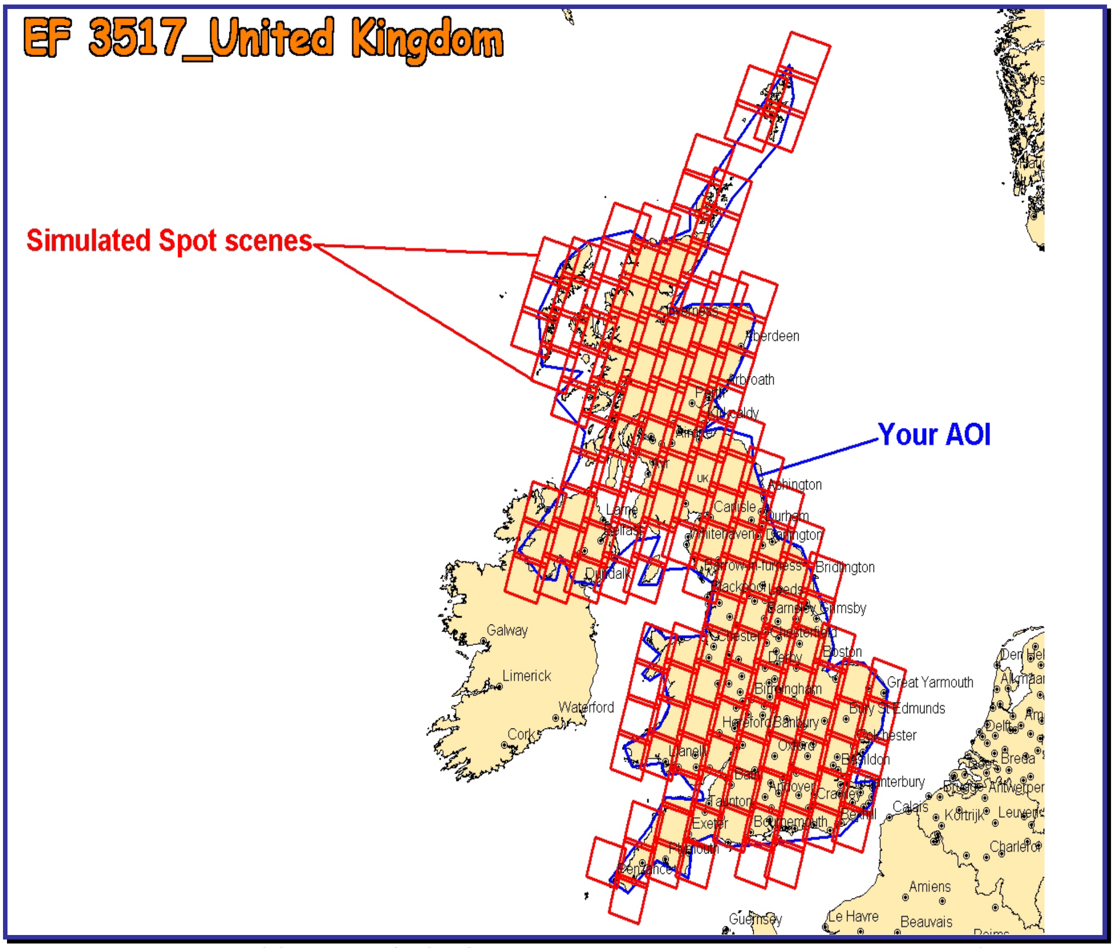

Figure 4.1 – Number of Simulated SPOT Scenes required providing complete coverage of the United Kingdom.

Real World Scenario –

SPOT Image, do not provide information on their programming scheduling, as such it is only possible to obtain a window range.

- Programming with a standard service
- The incidence angles up to 20 degrees.
- Less than 10% cloud cover.
- SPOT Image estimate that it would take a 16month window to acquire imagery over the whole of the UK.

SPOT Image adds that this figure is solely based on the bad climatic conditions over the UK.

Appendix 3 – Extended report, 'Operational Feasibility of EO-Based Soil Sealing Monitoring'.

Operational Feasibility of EO-Based Soil Sealing Monitoring

Ref: BNSC/ITT/54

Prepared for
Cranfield University

June 2006

Report for Cranfield University

Operational Feasibility of EO-Based Soil Sealing Monitoring

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Acronyms and Abbreviations

The following table contains a list of acronyms and abbreviations used in this report.

ADEOS	Advanced Earth Observation Satellite
AOI	Area of Interest
ALOS	Advanced Land Observing Satellite
API	Aerial Photo Interpretation
ATSB	Astronautic Technology (M) Sdn. Bhd. (Kuala Lumpur, Malaysia)
AVNIR-2	Advanced Visible and Near Infrared Radiometer type 2
BNSC	British National Space Centre
CNSA	China National Space Administration
COSMO	Constellation of small Satellites for Mediterranean basin Observation
CREST	Centre for Research in Satellite Technologies
DCS	Data Collection System
DDR	Digital Data Recorder
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DNF	Digital National Framework
DT	Data Transmitter
EO	Earth Observation
ESRI	European Space Research Institute
GIFTSS	Government Information for the Space Sector
IRMSS	Infra-Red Multispectral Scanner
ISO	International Standards Organisation
MACSat	Medium-sized Aperture Camera Satellite
MIUR	Italian Ministry of Research

MODEX	Moving Object Detection Experiment
MTI	Moving Target Indication
MUXCAM	Multi Spectral Camera
NDVI	Normalised Difference Vegetation Index
NGDF	National Geospatial Data Framework
NIMSA	National Interest Mapping Services Agreement
NIR	Near Infra-Red
NTU	Nanyang Technological University
ORFEO	Optical and Radar Federated Earth Observation
OS	Ordnance Survey
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PANMUX	Panmux Camera
PRISM	Panchromatic Instrument for Stereo Mapping
SAR	Synthetic Aperture Radar
SaTReCi	SaTReC Initiative Co. Ltd (Daeieon, Korea)
SIASGE	Sistema Italo Argentina de Satelites para la Gestion de Emergencias
SPIRE	Spatial Information Repository
THEOS	Thai Earth Observation System
TM	Thematic Mapper
TOID	Topographic Identifier
WFI	Wide Field Imager
XML	Extensible Markup Language

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2 The Project

This report forms Phase 2 of the consultancy provided by Infoterra to Cranfield University on the Operational Feasability of an EO-based method of monitoring the extent and pattern of soil sealing, in support of the Defra soils team.

The report from Phase 1 detailed the sensor operational parameters of relevance, presenting their strengths and weaknesses. The processing methods were evaluated and recommendations made as to sensor/processing method combinations that would be tested in Phase 2.

The objectives of Phase 2 are to provide recommendations for the implementation of an operational system including the continuity of data, the reliability and the expected costs of operation.

The feasibility study for the operational system provides an assessment of satellite based EO as a cost-effective method of detecting and quantifying changes in sealed soils and land cover, both for baseline assessment and for routine monitoring.

2.1 GIFTSS Team

This project is being carried out under the BNSC GIFTSS programme. The lead partner is Cranfield University and the sub-contractor is Infoterra Ltd. Infoterra's role in the project is to provide advice on 'technology matching' to undertake basic feasibility studies with satellite data providers. In Phase 2 the specific tasks are to advise on a framework for national scale operations: to assess the logistics of data procurement, constraints and feasibility over large areas under operational conditions; data management and how to integrate with Defra's other spatial data layers; and to advise on Metadata protocols.

3 Cloud Cover Analysis

During Phase 1 the Coverage Scenario Analysis undertaken for IKONOS data showed that the satellite has the technical capacity to acquire imagery of the whole of England and Wales within a four-month window. However once a weighting is introduced for cloud-cover, the `window' could be expected to increase to 75 months. Therefore in England and Wales the biggest influence on the operational collection of optical imagery is considered to be cloud cover.

3.1 Landsat Analysis

To illustrate this point, the following information from the BNSC Earth Observation LINK Programme project "The Use of EO Techniques to Improve Catchment Scale Pollution Predictions" has been reviewed. This information clearly illustrates the importance of cloud-cover when considering large-scale optical imagery collection of England and Wales.

Part of that LINK project conducted a cloud-cover assessment over seven sites around the UK. The seven sites were located around UK Met Office stations (Figure 2-1 and Table 2-1).

Met Office station	Longitude	Latitude
Brize Norton, Oxon	-1.5769	51.7577
Herstmonceux, E. Sussex	0.3178	50.8902
Leeming, N. Yorks	-1.5313	54.2964
Shawbury, Shrops	-2.6645	52.7943
Waddington, Lincs	-0.5216	53.1753
Wattisham, Suffolk	0.9599	52.1233
Yeovilton, Somerset	-2.6400	51.0059

Table 2-1 : Locations of Met Office Stations

This spread of sites reflects a nationwide spread of Areas of Interest (AOI's) of urban areas with populations greater than 50,000.

Figure 2-1: Locations of Met Office Stations

Landsat TM imagery metadata was used to undertake a historical analysis as a surrogate to understand the long-term trend of cloud-cover over the seven sites. The Eurimage Landsat archive was interrogated over the 1984-2001 timeframe for the months March, April, September and October.

Landsat TM satellites operate on a 16-day repeat cycle, which typically provides two scenes per month from one satellite, or four scenes per month from two satellites. For every scene, an overall and a per quarter cloud-cover estimate is produced and listed in the archive. The relevant quarter (quad) cloud-cover estimate for each of the seven AOI's was analysed for this study.

Table 2-3 shows the percentage of scenes with a cloud-cover rating of less than 20%, acquired over the time period Quarter 2 1984 to Quarter 3 1999. The `less than 20%' figure is the standard acceptable cloud-cover rating for all very-high resolution optical imaging satellites. The average score is less than 10%, which means there is roughly a one in ten chance of a scene having a cloud-cover rating of less than 20%.

There is a marked difference between the south and north of England, with the four northern sites (including Shawbury A and B) having a 7.47% chance of a scene having a cloud-cover rating of less than 20%, compared to 11.45% for the four southern sites.

Similar results can be found in Table 2-2, which shows the cloud-free TM acquisitions over the period Quarter 2 1984 to Quarter 3 1999. The Quad scene statistics are summarised in Table 2-4.

Table 2-4, shows a comparison of the results for the period Q2-1984 to Q3-1999 and the period Q4-1999 to Q4-2001. The data shows a marked decline in success even though two Landsats were available, offering an 8-day repeat cycle, reflecting poor weather conditions experienced from mid-1999 to 2001.

Location	WRS	Quad	March	April	September	October
Brize Norton	203-24	2	0% (from 27)	3.3% (1 from 30)	0% (from 29)	3.7% (1 from 27)
Herstmonceux	201-25	1	3.3% (1 from 30)	7.7% (2 from 26)	3.4% (1 from 29)	0% (from 27)
Leeming	203-22	4	0% (from 28)	0% (from 30)	0% (from 30)	0% (from 29)
Shawbury (a)	204-23	2	0% (from 28)	0% (from 29)	0% (from 28)	3.8% (1 from 26)
Shawbury (b)	204-23	4	0% (from 28)	0% (from 29)	0% (from 28)	7.7% (2 from 26)
Waddington	202-23	4	11% (3 from 27)	3.6% (1 from 28)	0% (from 28)	3.6% (1 from 28)
Wattisham	201-24	2	4% (1 from 25)	0% (from 23)	4% (1 from 25)	8.7% (2 from 23)
Yeovilton	203-24	4	3.7% (1 from 27)	3.3% (1 from 30)	0% (from 29)	3.3% (1 from 30)

Table 2-2 : Percentage of cloud-free TM acquisitions over the time period Q2-1984 to Q3-1999

Location	**WRS**	**Quad**	**March**	**April**	**September**	**October**
Brize Norton	203-24	2	3.7% (1 from 27)	10.0% (3 from 30)	3.4% (1 from 29)	7.4% (2 from 27)
Herstmonceux	201-25	1	10.0% (3 from 30)	23.1% (6 from 26)	21.0% (6 from 29)	18.5% (5 from 27)
Leeming	203-22	4	3.6% (1 from 28)	6.7% (2 from 30)	0% (from 30)	0% (from 29)
Shawbury (a)	204-23	2	7.1% (2 from 28)	6.9% (2 from 29)	0% (from 28)	15.4% (4 from 26)
Shawbury (b)	204-23	4	0% (from 28)	3.4% (1 from 29)	10.7% (3 from 28)	7.7% (2 from 26)
Waddington	202-23	4	22.2% (6 from 27)	14.3% (4 from 28)	3.6% (1 from 28)	17.9% (5 from 28)
Wattisham	201-24	2	4% (1 from 25)	17.4% (4 from 23)	12.0% (3 from 25)	21.7% (5 from 23)
Yeovilton	**203-24**	**4**	**11.1% (3 from 27)**	**10.0% (3 from 30)**	**0% (from 29)**	**10.0% (3 from 30)**

Table 2-3 : Percentage of less than 20% cloud TM acquisitions over the time period Q2-1984 to Q3-1999

	Number of <20% cloud acquisitions with 16-day (single satellite) repeat				**Number of <20% cloud acquisitions with 8-day (two satellite) repeat**			
	1984-1999				**1999-2001**			
	March	April	September	October	March	April	September	October
Number of acquisitions	220	225	226	216	61	60	56	58
% <20% Average Worst case Best case	7% 0 22.2%	11% 3.4% 23.1%	6.2% 0 21%	12% 0 21.7%	1.6%	3.3%	7.1%	13.8%
% cloud-free Average Worst case Best case	2.7% 0 11%	2.2% 0 7.7%	1.0% 0 4%	3.7% 0 8.7%	0%	0%	1.8%	3.4%

Table 2-4 : Summarising statistics for all TM scenes

3.2 QuickBird Analysis

3.2.1 Historical Cloud Analysis

For the purposes of this project it has been possible to obtain the historical cloud analysis that DigitalGlobe check when reviewing a tasked order prior to acceptance. The historical cloud cover data influences the timeline DigitalGlobe operate in order to have a high probability of capturing imagery with low cloud cover.

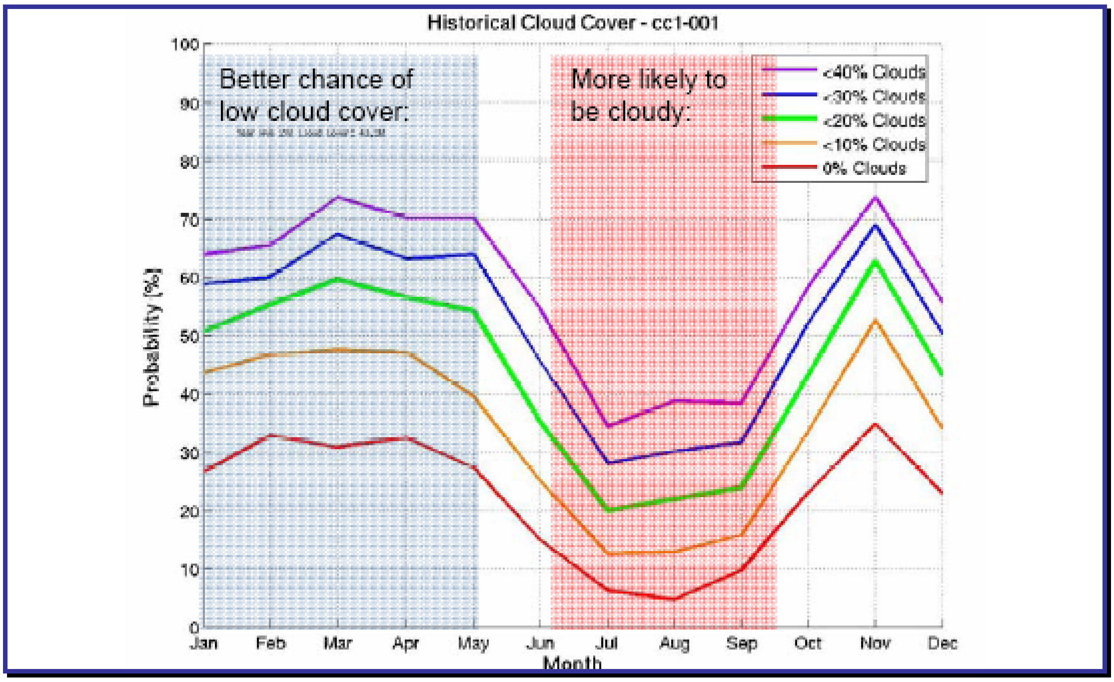


Figure 2-2 : Example DigitalGlobe Cloud cover Estimate

Figure 2-2 describes the probability of capturing imagery at different cloud cover percentages over a year and shows that for orders placed in this nominal geographic area, there is a:

- Higher probability of low cloud cover: January – April
- Lower probability of low cloud cover: June – September

When tasking the satellite DigitalGlobe would be willing to accept/suggest a shorter acquisition window to acquire an image between January to May, excluding other factors such as competing orders. However during June to mid-September it is unlikely that DigitalGlobe would accept a short acquisition window, but would suggest a longer window to acquire an “acceptable” image.

Figure 2-3 shows a similar cloud-cover analysis over the whole of England and Wales. The average chance of acquiring an image with a cloud-cover rating of less than 20%, over the whole year, is 3.24%. Overall there is:

- Higher probability of low cloud cover: April - May
- Lower probability of low cloud cover: almost equally shared for rest of year.

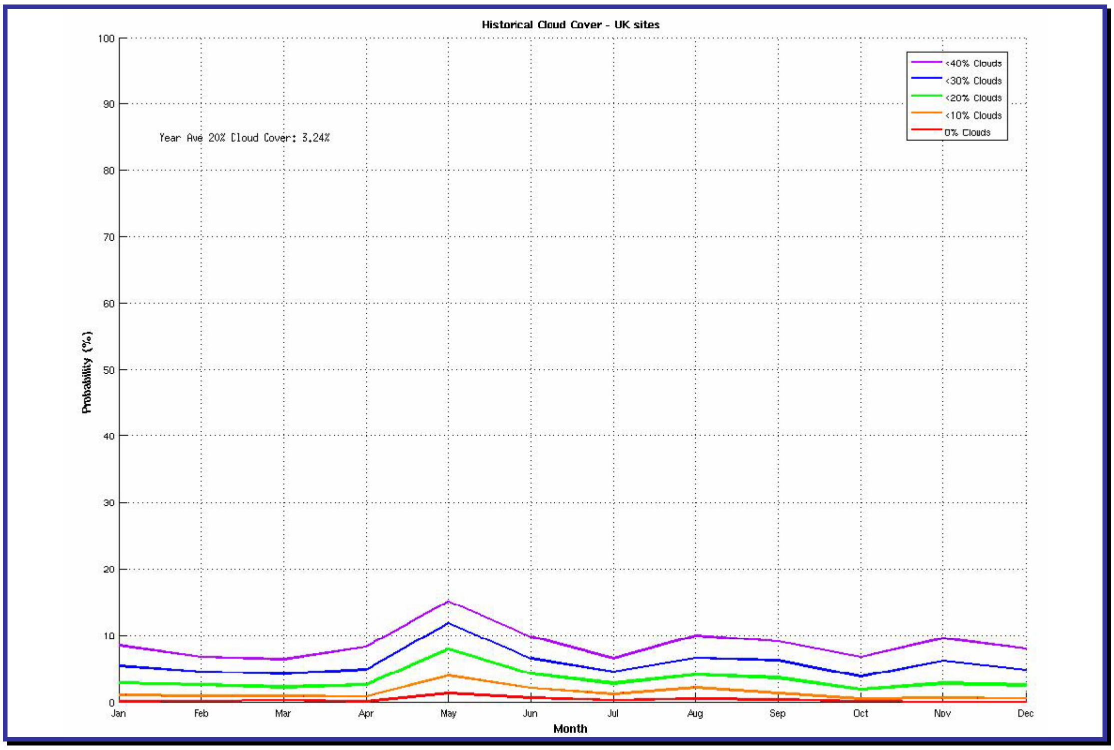


Figure 2-3 : Actual DigitalGlobe Cloud-cover Estimate for U.K.

Overall this confirms statistically that England does experience a problem with cloud-cover, with a low probability of cloud-free or low-cloud (less than 20%) imaging opportunities.

- The "best" imaging opportunities are available in the month of May, when there is a 2% chance of acquiring a cloud-free image.
  - The probability of acquiring an image with 20% cloud-cover peaks at 8%.

- The "worst" imaging opportunities are available over the winter months.
  - The probability of acquiring an image with 20% cloud-cover drops to 4% between October to January.

Unfavourable weather conditions over a short timescale can further increase the problems experienced with cloud-cover, such as in May 2006.

3.2.2 2005 Acquired QuickBird Imagery over the UK

However issues with cloud-cover can be overcome. During the year 2005, QuickBird acquired a total of 1048 scenes over the United Kingdom. Of these 1048 scenes, 275 scenes have a cloud-cover rating of less than 20% and a subsequent 110 scenes are rated cloud-free.

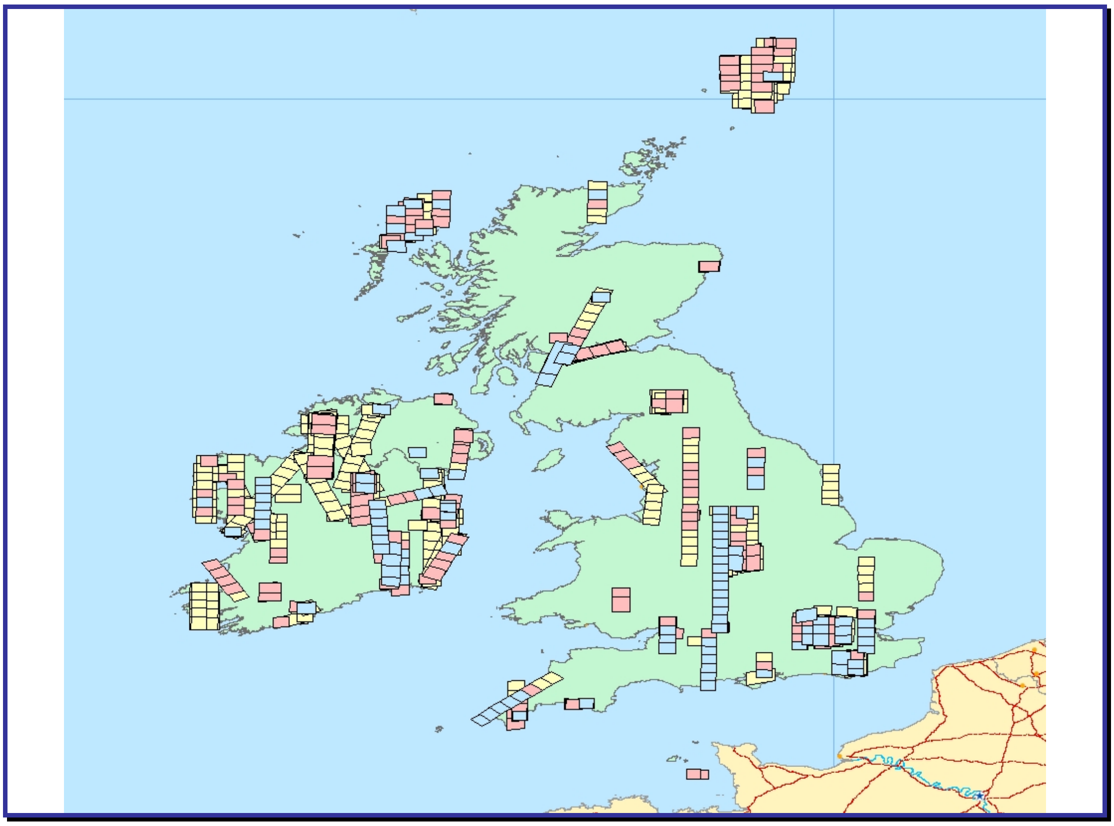


Figure 2-4 : Distribution of QuickBird Images over the UK in 2005

- Greater than 20% cloud-cover (YELLOW)
- Less than 20% cloud-cover (ROSE)
- Cloud-free (BLUE)

The 110 scenes cover a nominal area of 28,160 sq km, while the total urban area under investigation is likely to be less than 9,000 sq kms (Section 3.3.1.1). This shows that while cloud-cover remains a significant issue with regards to large-scale optical imagery collection, it can be possible to acquire sufficient suitable imagery over targeted areas that are historically cloud-cover poor areas for image acquisition.

4 Technology Matching – Phase 2

4.1 Introduction

During the Technology Matching study of Phase 1 of the project, a literature review identified the key criteria of satellites and instruments. In Phase 2 this process has been extended to reflect certain instruments and satellites not considered during Phase 1.

During Phase 1, the project was to examine what could currently be achieved and not to speculate on future satellites, thus the Technology Matching process only utilised historical and current operational satellites/instruments. Phase 2 reviews future satellites, which are anticipated to become available in the next few years in order to address the issue of long-term data continuity.

4.2 Overview

Satellites can be naturally grouped into two sensor types; optical sensors and active sensors (radar). These can then be sub-grouped by major features of interest such as ground resolution, spectral coverage, revisit capability, stereo mode, etc.

The technology matching process in Phase 1 involved matching the key criteria identified during the literature review to satellites and instruments. The technology matching exercise was restricted by the literature review to optical satellites. This exercise has now been extended to address active sensors as well as their most important feature is the ability to acquire image data in cloudy conditions.

4.3 Coverage Scenario Data Provider Case Study - Updated

During Phase 1 a number of satellite operators were contacted in order to evaluate the feasibility of meeting the criteria originally set out for the GIFTSS project. These included:

- National coverage (England and Wales).
- Reporting period every 5 years
- Complete coverages in a single year
    - Including; 1 Summer scene and 1 winter scene

Two coverage scenarios were shown in Phase 1. One from a very-high-resolution supplier, IKONOS, and one from a medium-resolution supplier, SPOT Image. The results from these suppliers illustrate the issues associated with most of the optical satellites/instruments that have been identified within the technology matching process.

At the end of Phase 1 the criteria were revised to reflect the results of Phase 1 and the requirements of Defra Soils Team.

The principal change was to revise the AOI's to:

- Urban Areas with a population greater than 50,000 (England and Wales).

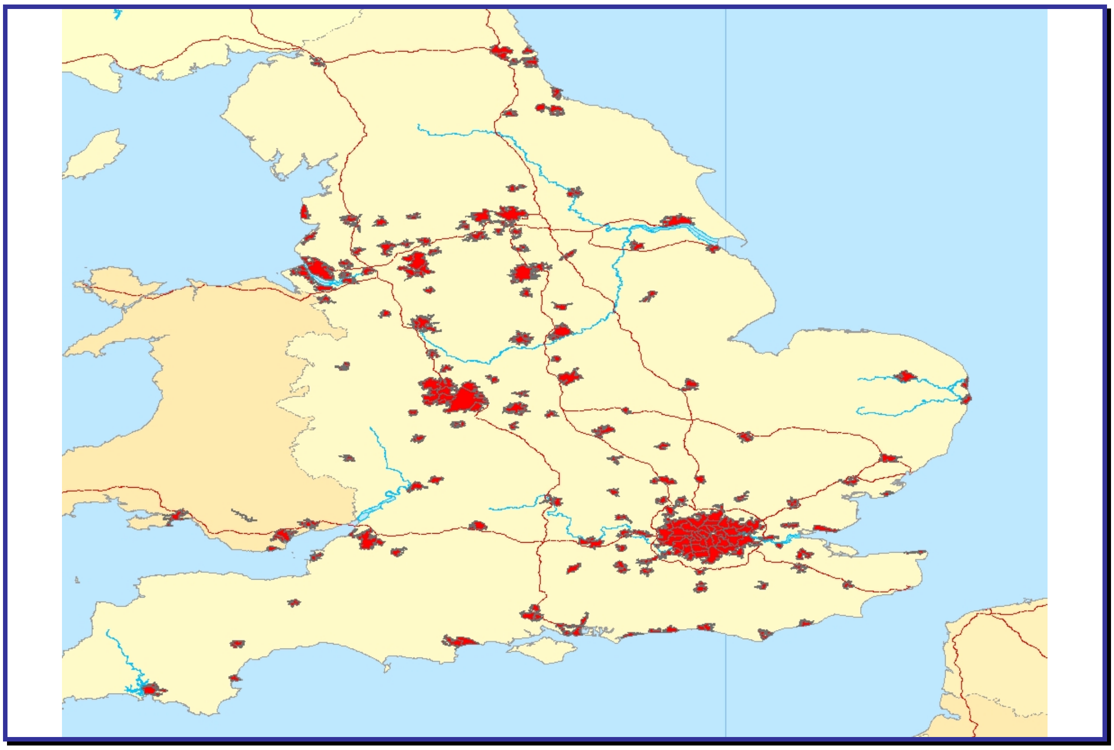


Figure 3-1: Urban Areas with Population greater than 50,000

The reporting period was also modified and analysis has been conducted on a choice of two criteria:

- One complete coverage in a single year window (May to October)
- Even split of acquisitions over 5 years.

Both the revision of the AOI's and the modification of the reporting period necessitate a re-analysis of the tasking scenarios for acquiring EO Data.

4.3.1 Very-High-Resolution Scenario (IKONOS)

The perfect world and real world scenarios were re-addressed.

In the perfect world scenario it had been assumed that there was no issue with cloud-cover and the satellite was always available for each possible collection attempt over the AOI. Based on the assumption of 75 passes and 1.5 days/pass, it would take approximately 112.5 days to cover the whole of England and Wales.

However in the real world scenario, the frequent cloud cover over the UK was taken into account. European Space Imaging has given the UK a weather weighting of 20. This figure relates to the likely opportunity to acquire a suitable image (an image with less than 20% cloud cover). The weighting is geared against the number of passes. On the assumption of 75 passes a weighting of 20 and 1.5 days/pass, it would take approximately 2250 days to collect data of the UK with a good cloud cover score.

4.3.1.1 Implications of Revision of AOI

Based on the new criteria the total sq km area to be imaged was reduced from 151,013 sq kms to 9,000 sq kms.

Splitting up the "total" area into smaller AOI's decreases the efficiency of the image acquisitions. It is more efficient to task a large region, where it could be possible on every satellite pass to choose to collect an area where there are no clouds present. Smaller separated AOI's means that not every satellite pass is a potential collection pass.

However this issue is significantly reduced in impact by the revision of the AOI, which is a reduction in extent of 94%, and has a positive influence on increasing the probability of acquiring suitable imagery.

4.3.1.2 Single Year Collection

A requirement to collect all 9,000 sq kms of imagery within a single year would however still be a significant tasking requirement. European Space Imaging has estimated that a tasked AOI of 6,000 sq kms would be the best feasible option that could be achieved within the May to October collection window. As such it is considered that there would be insufficient capability to acquire all 9,000 sq kms from a single satellite. Multiple satellites working together could provide sufficient capacity. However there are few examples of shared collections between different very-high-resolution satellite operators.

Discussions on the format of any such collection sharing between operators have indicated that there is tentative agreement between satellite operators. It is considered that an even split of the AOI's between operators would be the most likely scenario for how this could be achieved.

4.3.1.3 Even spread of tasking over 5 years

Splitting the collection of imagery into equal chunks across the five year reporting period reduces the area to be collected to 1,800 sq kms per year window. European Space Imaging has indicated that they would see “no major problems” in acquiring an annual AOI of this size.

To date no preference has been indicated on how to split the AOI’s evenly across the five year reporting period. If priority ranking was required, it is likely that London would be ranked for collection in Year 1.

However, through discussions with various satellite operators, it is recommended that the AOI’s should not be ranked into a preferred collection order in order to minimise the effect of cloud-cover difference across the five year reporting period,

The ideal approach would be to consider a fully flexible approach. By submitting all the AOI’s into an operator’s tasking system at the beginning of the project, it would enable the operator to select AOI’s for tasking based on the most favourable cloud-cover conditions available. The annual tasking could be capped at 20% of the total AOI, but it maybe preferable to allow collection to continue beyond the 20% limit in a good year, but with any additional tasked imagery be held over for analysis in the following year. This could allow balancing between years with low cloud-cover and years when imaging conditions are consistently poor.

If the Urban Areas were to ranked then it would be preferable to group AOI’s based on regions and not to have a split of AOI’s across the whole of England and Wales.

4.4 Future Missions (Optical Satellites)

In order to identify what further satellites could be available over the next ten years a review of named programmes that are planning to develop and launch satellites within this period has been undertaken.

Instrument	Satellite	Resolution (m)
Orbview 5	Orbview 5	1.64
WorldView II	WorldView II	1.8

Table 3-1: VIS/NIR Instruments with a resolution of less than 2m

Table 3-1 shows planned satellites with resolutions better than 2m and Table 3-2 shows those planned satellites with resolutions of between 2m and 10 metres.

Instrument	Satellite	Resolution (m)
EROS-C1	EROS-C1	2.8
EROS-B1	EROS-B1	3.68
LAPAN-Tubsat	LAPAN-Tubsat	5
CBERS-3	CBERS-3	5
CBERS-4	CBERS-4	5
RazakSat	RazakSat	5
Resourcesat-2	Resourcesat-2	5.8
RapidEye	RapidEye	6.5
X-Sat	X-Sat	10

Table 3-2: VIS/NIR Instruments with a resolution of 2-10m

4.4.1 Description of Results

Two instruments that match the VIS/NIR up to 2m resolution criterion were identified. These will offer an improvement on the “best” instruments currently available (2.4m resolution data). Both of these instruments offer a continuity of services from existing sensors (Quickbird to WorldView II and Orbview-3 to Orbview-5). Both also have funding in place and are scheduled to be launched within the next two years.

Orbview-5		2007

Scheduled for launch in early 2007, OrbView-5 will simultaneously acquire 0.41m panchromatic and 1.64m multispectral imagery. It will be able to collect in excess of 800,000 square kilometres of imagery in a single day,

WorldView II		2008

WorldView II will offer half-metre panchromatic resolution and 1.8-metre multispectral resolution. Added spectral diversity will provide the ability to perform precise change detection and mapping. WorldView II will incorporate the standard four multispectral bands (red, blue, green and near-infrared) and will also include four new bands (coastal, yellow, red edge, and near-infrared 2).

A further nine instruments are planned to offer a resolution of at least 10m, which would match the resolution criteria currently available to the project.

LAPAN-Tubsat		2006

Based on the German DLR-Tubsat and a follow-on from the MAROC-TUBSAT satellite, LAPAN-Tubsat will carry a 3-Band high-resolution (5m over a swath of 3.5km) and a 3-Band Wide-angle (200m over a swath of 81km) camera. The satellite has the ability to point off-nadir, shortening its revisit capability.

RazakSat		2006

RazakSat, formerly MACSat (Medium-sized Aperture Camera Satellite), is a mini-satellite Earth imaging mission, an international cooperative project between ATSB [Astronautic Technology (M) Sdn. Bhd.] of Kuala Lumpur, Malaysia, and SaTReCi (SaTReC Initiative Co. Ltd.) of Daejeon, Korea. The satellite will carry a Medium-sized Aperture Camera acquiring panchromatic imagery at a resolution of 2.5m and 4-band multi-spectral imagery at 5m, over a swath of 20km.

X-Sat		2007

X-Sat is a micro-satellite technology demonstration mission of CREST (Centre for Research in Satellite Technologies), a joint venture of NTU (Nanyang Technological University), and DSO National Laboratories, Singapore. The camera is built by SatReCi and designed as a push-broom scanner with three individual scan lines in the green (520 nm – 600 nm), red (630 nm – 690 nm), and near-infrared (760 nm – 890 nm) wavelength range. The three linear detectors each consist of 5000 active elements, which were all manufactured on the same wafer and subsequently coated with different interference filters to select the appropriate spectral characteristic. The design provides a high degree of band-to-band alignment, i.e. 0.1 pixels. The provided spatial resolution will be 10m for the nominal altitude of 685 km, thus enabling a swath width of 50 km.

EROS-B1		2006

EROS B1 expected to be launched in 2006 will deliver 0.82m resolution from an altitude of 600 km, covering swaths of 16.5 square kilometres. EROS-B1 was originally intended as a six satellite constellation, with five following satellites in a series able to acquire panchromatic imagery at 0.82m and 3.68m multi-spectral imagery.

RapidEye		2007

The RapidEye satellite constellation is a commercial mission being undertaken by the German company RapidEye AG, which will consists of five identical satellites. Each satellite will be equipped with an identical 5 band multi-spectral optical camera with a 6.5m resolution and an 80km swath. The constellation will be positioned in the same polar orbit and evenly distributed over the orbital plain. This will mean every point on Earth can be overflown and observed on a daily basis. The RapidEye spacecraft are small low mass satellites with a proposed launch date of 2007 and an anticipated mission lifetime of 7 years. The RapidEye business model, with particular focus on the agricultural and cartographic segments, was envisaged to be satisfied with only a 4-satellite constellation offering daily revisit capability, with the fifth satellite acting as a redundant satellite. It will also be capable of producing DEMs.

THEOS		2007

THEOS (Thai Earth Observation System) will be fully owned and operated by the Thai Ministry of Science and Technology's Space Agency (GISTDA). THEOS will provide access to any part of Thailand in less than 2 days. The THEOS contract includes the production and launch of one optical satellite, as well as the development of the ground segment necessary to operate and control the satellite directly from Thailand. The THEOS satellite payload consists of a 2m panchromatic and a 15m 4-

channel multi-spectral imaging system. The satellite will be launched mid 2007 on a sun synchronous orbit at an altitude of about 820km.

CBERS		2008

CBERS is a bilateral collaboration between Brazil and China which began in 1988, when both countries signed a cooperation agreement to develop two remote sensing satellites. CBERS is mainly used to monitor land resource changes of China and Brazil, renewing the two countries' national land use map every year.

Due to the success of CBERS-1 and 2, the two governments decided, in 2002, to give continuity to the CBERS programme by signing a new agreement for the development and launch of two more satellites, CBERS-3 and 4. The two second-generation CBERS satellites will include an improvement in the imaging to a resolution of better than 5 meters against CBERS-1's 20 meters. The CBERS-3 and 4 satellites are similar to CBERS-1 and CBERS-2, composed of two modules. The payload module houses the optical system: PanMux Camera (PANMUX), Multi Spectral Camera (MUXCAM), Infra-Red Multispectral Scanner (IRMSS), the Wide Field Imager (WFI), and other equipment such as the Image Data Transmitter (DT), Digital Data Recorder (DDR) and Data Collection System (DCS).

Resourcesat-2		2008

Resourcesat-2 will carry the same three sensors as those on Resourcesat-1.

Pleiades-HR		2008-2010

Pleiades-HR: Pleiades developed by CNES, are the high-resolution optical imaging component of the French-Italian Orfeo system. It will be composed of two satellites, offering a spatial resolution at nadir of 0.7m.

EROS-C1		2009

EROS-B1 will be followed by EROS-C1 in 2009 producing both panchromatic imagery at a standard resolution of 0.70 m, and multispectral imagery at a standard resolution of 2.8 m, with a swath of 11 km at nadir.

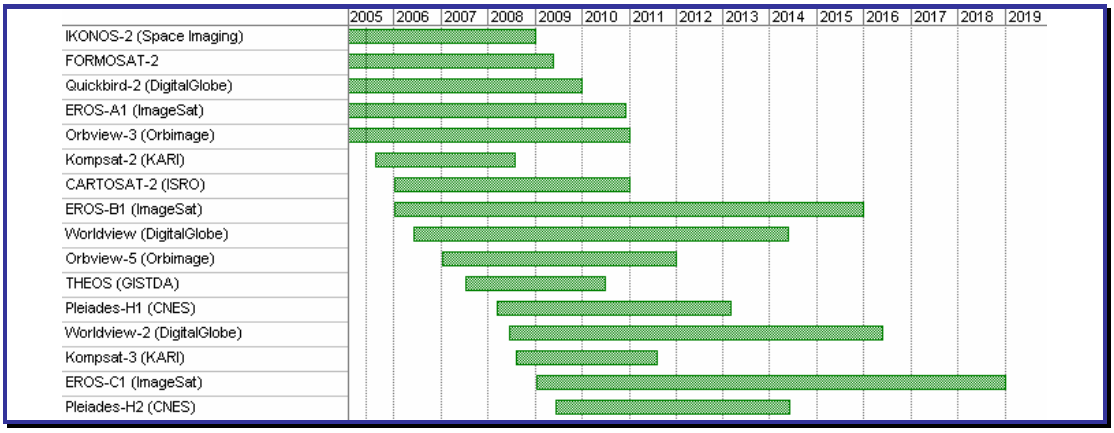


Figure 3-2: Future High-Resolution Optical Satellites

The design life of existing and future instruments allows for a continuity of service until at least 2019. As the vest majority of instruments operate beyond their design life, the continuity of service can therefore be considered to extend well beyond 2019 (Figure 3-2).

4.4.2 Recommendations

Data users need to have data sources stable over long periods of time, because the development of applications can be lengthy and costly. Customers with an operational requirement will not allow themselves to become dependent on a measurement system that does not have a clear commitment to provide the required information for the foreseeable future.

Data continuity also allows users to spread their system costs over time and reduce expenditure by avoiding having to "chase" replacement data sources or changing data formats. Continuity of measurement capability and data availability are crucial to motivate investments in operational data utilisation. This requires a commitment from the satellite operators for the replacement satellites, an operational budget, and backward compatibility of observations with inter-calibration when new systems are implemented. When planning the launch schedule for new satellites, continuity of operational and backup service must be preserved.

To allow for the sometimes lengthy commissioning phases, a new backup satellite must be launched well before the satellite's lifetime fuel limit has been reached. But continuity cannot be guaranteed until a community of users has expressed a sustainable demand and a mechanism to support the provision of information.

As has been shown in the list of high-resolution future optical satellites the issue of data continuity has been acknowledged and satellites such as EROS-B1/C1, Orbview-5, Resourcesat-2 and Worldview II have already been confirmed and will launch in the next few years to enable continuity of measurements.

It is believed that these identified long-term plans for future satellites will go a long way towards satisfying these requirements. These are, therefore, appropriate for development of an operational service.

4.5 Technology Matching – Active Sensors

For completeness and also due to its inherent advantages over Passive (Optical) sensors in cloudy regions such as England and Wales, a review of Active Sensors has been conducted.

In order to allow easy comparison between the Active and Passive Sensors results the same analysis was conducted.

The Technology Matching for Passive Sensors required analysis at specific spatial resolutions:

- Below 2m,
- 2m to 10m
- 10m to 50m
- More than 50m.

4.5.1 Active sensors

Synthetic Aperture Radar (SAR) sensors are active imaging systems which means they transmit a signal in the microwave portion of the spectrum and measure the strength and other characteristics of the return signal after it reflects off the Earth's surface.

A typical radar (RAdio Detection and Ranging) system measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1cm to 1m, which corresponds to a frequency range of about 300 MHz to 30 GHz) and polarisations (waves polarised in a single vertical or horizontal plane). At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back towards the antenna. This backscatter returns as a weaker radar echo and is received by the antenna in a specific polarisation (horizontal or vertical, not necessarily the same as the transmitted pulse).

Often imagery is acquired during periods of inclement weather, as often appears to be the case in the UK. Whilst the presence of clouds, fog, smoke, dense foliage and to some extent darkness can render optical satellites ineffective, SAR sensors can provide such a capability. As a result, SAR sensors can complement optical sensors because of the minimum constraints on time-of-day and atmospheric conditions and because of the unique responses of terrain and cultural targets to radar frequencies.

The technology matching process identified a total of 23 current and planned SAR sensors. The results have been split into the spatial resolution ranges previously stated. Current and planned SAR's are reviewed in the following paragraphs.

4.5.1.1 Spatial Resolution below 2m

Instrument	Description	Satellite	Resolution (m)
	SAR-X (To be launched)	TerraSAR-X	1
	SAR-X (To be launched)	COSMO-Skymed	1
	SAR-X (To be launched)	SAR-LUPE	1
	SAR-L (To be launched)	TerraSAR-L	1

Table 3-3: Active Sensor Instruments with a resolution below 2m

Unfortunately no Instruments were identified that matched the requirements historically or currently. Such systems are planned for the future.

4.5.1.2 Spatial Resolution 2m to 10m

Instrument	Description	Satellite	Resolution (m)
	SAR-C (To be launched)	RADARSAT-2	3
	SAR-C (To be launched)	RISAT	3
	SAR-C	RADARSAT-1	8.4

Table 3-4: Active Sensor Instruments with a resolution of 2-10m

Only one Instrument was identified (historically/currently operational) that matched the requirement.

4.5.1.3 Spatial Resolution 10m to 50m

Instrument	Description	Satellite	Resolution (m)
PALSAR	SAR-L Phased Array L-band SAR	ALOS	10
	SAR-C (To be launched)	Surveyor	10
EKOR	SAR-S Sword	ALMAZ-1	15
SAR	SAR-L	JERS-1	18
	SAR-L	Seasat	25
	SAR-X	SIR-C/SLR	25
	SAR-L	SIR-B	25
AMI	SAR-C Active Microwave Instrument	ERS-1/ERS-2	30
ASAR	SAR-X Advanced SAR	ENVISAT	30
	SAR-L	SIR-C/SLR	30
	SAR-C	SIR-C/SLR	30

OSTA-1	SAR-L Office of Space and Terrestrial Applications	SIR-A	40

Table 3-5: Active Sensor Instruments with a resolution of 10-50m

4.5.1.4 Spatial Resolution more than 50m

Instrument	Description	Satellite	Resolution (m)
Travers SAR	SAR-L	PRIRODA-MIR	150
Travers SAR	SAR-S	PRIRODA-MIR	150
	SAR-K	Seasat	1600
	SAR-C	TOPEX/Poseidon	6000

Table 3-6: Active Sensor Instruments with a resolution of more than 50m

4.5.2 Description of Results

Radar imagery has generally been utilised in such fields as disaster management, agriculture, cartography, hydrology, forestry, oceanography, ice studies and coastal monitoring.

During Phase 1 the methodology and spatial resolution of the final results moved the technology matching exercise to look for instruments that fell into the "below 2m" resolution category.

Within the "below 2m" resolution category no radar satellite data is currently available. A number of future satellites are scheduled to offer this resolution in the future, and are described in Section 3.6.

Only two currently Operational Instruments offers a spatial resolution of at least 10m.

- RADARSAT-1 when operated in Fine Beam mode (8.4m) is the best fit currently operational instrument/satellite for this application. RADARSAT-1 was developed to monitor environmental change and to support resource sustainability.

Launched in November 1995, RADARSAT-1 was designed to last for around 5 years and is currently operating beyond its official design life, which was completed during February 2000. RADARSAT-1 operations are due to continue until the full commissioning of its successor, RADARSAT-2.

RADARSAT-1 has a 24-day repeat cycle. This means that for most geographic regions, it would take 24 days to obtain exactly the same image (same beam mode, position and geographic coverage). When combined with Radar's inherent "all weather" capability this does offer advantages in the timescale to acquire complete imagery of the project AOI's. For comparison an Operational Scenario has been undertaken to illustrate the collection advantages of Radar imagery.

- The Advanced Land Observing Satellite (ALOS), carries three remote sensing instruments; the Panchromatic Instrument for Stereo Mapping (PRISM), the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), and the Phased Array type L-band Synthetic Aperture Radar (PALSAR). PALSAR is an improved L-band sensor based on the JERS-1's SAR sensor.

ALOS was launched in early 2006, and has a design life of three years, but with enough fuel for 5 additional mission years.

The combination of optical and radar instruments onboard ALOS offers the possibility of utilising the benefits of both instruments within one satellite.

AVNIR-2 is a successor to the AVNIR on the Advanced Earth Observation Satellite (ADEOS) launched in August 1996. AVNIR-2 provides 10-meter multi-spectral resolution images compared with 16 m of AVNIR.

4.6 Future Active Sensor Satellites

In the Phase 1 analysis only instruments with a resolution of less than 10m were considered during the operational scenario, as such all other operational instruments are above this spatial resolution, and would be considered too coarse for this soil sealing application.

A number of radar missions are planned to be launched in the future. These are, as with optical missions, increasingly designed as high to very-high resolution instruments. The launch of TerraSAR-X and RADARSAT-2 is planned for 2006/7. Both will offer higher resolution imagery than has been available from previous commercial radar satellites.

4.6.1 Description of Results

Four instruments were identified that match the 0 to 2m resolution criterion. These instruments offer an improvement on the current "best" instrument available. Three of the satellites are due to be launched in the next two years. The data availability from the SAR-LUPE and COSMO-Skymed instruments to commercial customers has not been confirmed; however TerraSAR-X will be operated by a commercial company.

TerraSAR-X		2006

TerraSAR-X is a German national mission realised through a public/private partnership. Due for launch in 2006, it will carry an X-band SAR instrument capable of operating in SpotLight (up to 1m resolution) StripMap (3m) and ScanSAR (16m) configurations.

The satellite also has the capability to operate in fully polarimetric mode and produce along track interferometric products; but these are experimental rather than operational modes. The satellite can also operate in a non-nominal left looking mode for limited periods of time. The standard repeat period of the satellite will be 11 days. It will be able to increase revisit times to every 4.5 days; 90% of these points are covered every 2 days.

COSMO-Skymed		2006-2008

COSMO-Skymed is a low-orbit planned EarthWatch mission based on a constellation of four satellites with X-band SAR instruments. The system is partly funded by the Italian Ministry of Research (MIUR) and Ministry of Defence. The first satellite will be launched in late 2006, followed by the others at 8-month intervals. The system will be fully operational in 2008. The four satellites will be equipped with high-resolution X-band SAR and it will be possible to integrate the system with the optical satellites of the French Pleïades-HR optical constellation.

- Optical and Radar Federated Earth Observation (ORFEO): The Orfeo is a dual-use (civilian and military) Earth Observation satellite network developed jointly between France and Italy. The system consists of two satellites, known as Pleiades, being developed by France, and four satellites, known as Cosmo (COnstellation of small Satellites for Mediterranean basin Observation)-Skymed, being developed by Italy.

SAR-Lupe-1		2006
SAR-Lupe-2-4		2007
SAR-Lupe-5		2008

SAR-Lupe will consist of five identical small satellites and a ground segment. The launch of the first of five satellites is planned for 2006. The overall system will be completed in 2007 to deliver 1m radar images for the German Armed Forces for at least ten years. The angle between orbital planes of the 5 satellites, together with the phase angles will be positioned to minimise revisit time periods.

Two instruments were identified that match the 2 to 10m resolution criterion. RADARSAT-2 offers some continuation of RADARSAT-1 data, which is the highest resolution currently available commercial data.

RADARSAT-2		2007

RADARSAT-2 incorporates advanced technologies such as higher resolution and polarmetric modes, to ensure continuity in radar data supply. RADARSAT-2 will provide all imaging modes of the current RADARSAT-1 satellite, to ensure continuity in radar data supply, as well as some new modes that incorporate significant technical innovations and improvements; such as higher resolution and a polarimetric modes.

Technical improvements relate to the look-direction switching, higher spatial resolution, multi-polarisation, enhanced orbital control and an experimental Moving Object Detection Experiment (MODEX) allowing moving target indication (MTI). The satellite will offer data continuity to RADARSAT-1 users, with its design life of 7 years.

The operating frequencies for RADARSAT-1 and RADARSAT-2 are slightly different, i.e. 5.3 GHz and 5.405 GHz respectively. This change in operating frequency was dictated by a recent decision by the Radio Regulations Board of the International Telecommunication Union to designate the 5.3 GHz channel for use in telecommunications.

RISAT-1		2006

RISAT-1, India's Radar Imaging Satellite, is the first of the IRS-3 Series, which will have all-weather capabilities and will have multi- frequency and multi-polarisation microwave payloads and other passive instruments. RISAT-1 will be used to support agricultural and disaster related applications. RISAT will carry a C-band operating in multipolarisation, multi-modes (ScanSAR, Strip, and Spot modes). The satellite will provide spatial resolutions of 3 to 50 metres with swaths varying from 10 km to 240 km. RISAT is expected to be launched into a polar sun-synchronous orbit of 609 km and is expected to have a design life of 5 years.

The following instruments have been included for reference. Three of the future sensors listed will comprise a constellation of satellites; "Surveyor" - a constellation of 5 low-cost satellites, COSMO-SkyMed (Constellation of Small Satellites for Mediterranean basin Observation) - a 4-spacecraft constellation, and RADARSAT-3. These constellations will enable more rapid collection of AOI's by reducing the revisit timescales.

Although the constellations will reduce timescales they will not necessarily impact greatly on reducing the operational scenarios for collecting radar imagery of the urban area AOI's, which will be shorter than that for optical imagery, they will reduce the level of risk to the continuity of data.

Surveyor		2007-2009

Tuyuan Technologies, a commercial company in China, are planning to build and launch a commercially based constellation of SAR satellites called Surveyor. The constellation will consist of roughly five low cost satellites each carrying a medium resolution C-band SAR sensor. The first sensor is due for launch in 2007 although, as yet, no contract has been awarded to build the constellation. The concept behind the constellation is to use the data to provide agricultural crop information to financial companies, commodities traders and governmental clients in near real time.

The idea is to design each satellite to be identical with 10m and 25m resolution modes operating at 100km and 250km swath widths respectively. In such a case, full coverage of the Earth's surface by two of the five satellites will be achieved in less than fourteen days providing information on floods and other episodic events as they impact on global food crops. It is expected that the cost of the constellation will be less than $150 million and take less than two years to build. The five satellites are proposed to be in place by 2009.

RADARSAT-3		2009-2013

RADARSAT-3 will consist of a constellation of six satellites (SS1-SS6). The Government of Canada as part of their federal budget for 2005 announced funding for Canada's "next generation" of radar satellites. It was proposed that a constellation of small radar satellites instead of a single large satellite would be developed and launched. Two identical satellites will be launched every two years from 2009 to 2013. This constellation would provide more frequent coverage over Canada, enabling any part of Canada to covered at least once a day and also mitigate the risk of an interruption to service.

Environment and Disaster Monitoring and Forecasting Constellation		TBC

In 2004, the CNSA, announced plans for "The Environment and Disaster Monitoring and Forecasting Constellation". The constellation will consist of a SAR satellite and two optical satellites.

SAOCOM-1A		TBC

SAOCOM-1A would be the fourth mission within Argentina's National Space Plan. The SAOCOM satellite series is Argentina's first Remote Sensing mission carrying a SAR as main payload. The two satellites, 1A and 1B, are to be launched consecutively. Saocom-1A is a 1.5-ton satellite whose payload will consist of a L-Band SAR with a resolution ranging from 7 m to 100m with single, dual and polarimetric capabilities as well as dual and scanSAR operation. It will be integrated in an Italo-Argentina constellation called SIASGE (Sistema Italo Argentina de Satelites para la Gestion de Emergencias). The SIASGE system will use Italy's Cosmo-SkyMed constellation, consisting of four 500-kg X-band SAR satellites and three optical imaging satellites, along with Argentina's planned constellation of two Saocom L-band SAR spacecraft. This constellation is expected to be operational by 2007. An identical Saocom-1B is expected to be launched within two years.

4.7 Radar Operational Scenario

While an operational scenario could have been conducted utilising RADARSAT-1, as RADARSAT-2 is expected to start delivering imagery by March 2007, the scenario has used RADARSAT-2.

RADARSAT's orbital characteristics determine the specific date when an acquisition can made and the number of days between subsequent acquisitions. RADARSAT-2 will have the same orbital characteristics as RADARSAT-1, and will be placed to precisely match its ground track.

Figure 3-3 shows the AOI's (populations above 50,000), overlain with a generalised coverage of 3-metre Ultra-Fine resolution data from RADARSAT-2.

A total of 133 individual scenes would be required to cover all the AOI's. This equates to 85 individual segments.

RADARSAT would require a 28 day period to acquire all the AOI's shown.

The analysis has been conducted on an idealised collection schedule. RADARSAT's collection requires that the instrument is switched on prior to the start of the desired scene and switched off shortly after the end of the desired scene. This necessitates a larger scene segment being acquired than specified by the user. This has implications on the technical feasibility of the tasking and is liable to result in a longer tasking window. However since this is not liable to greatly increase the tasking window beyond a few additional orbits, and would easily fit into a May to October window, this additional step has not been included in the analysis.

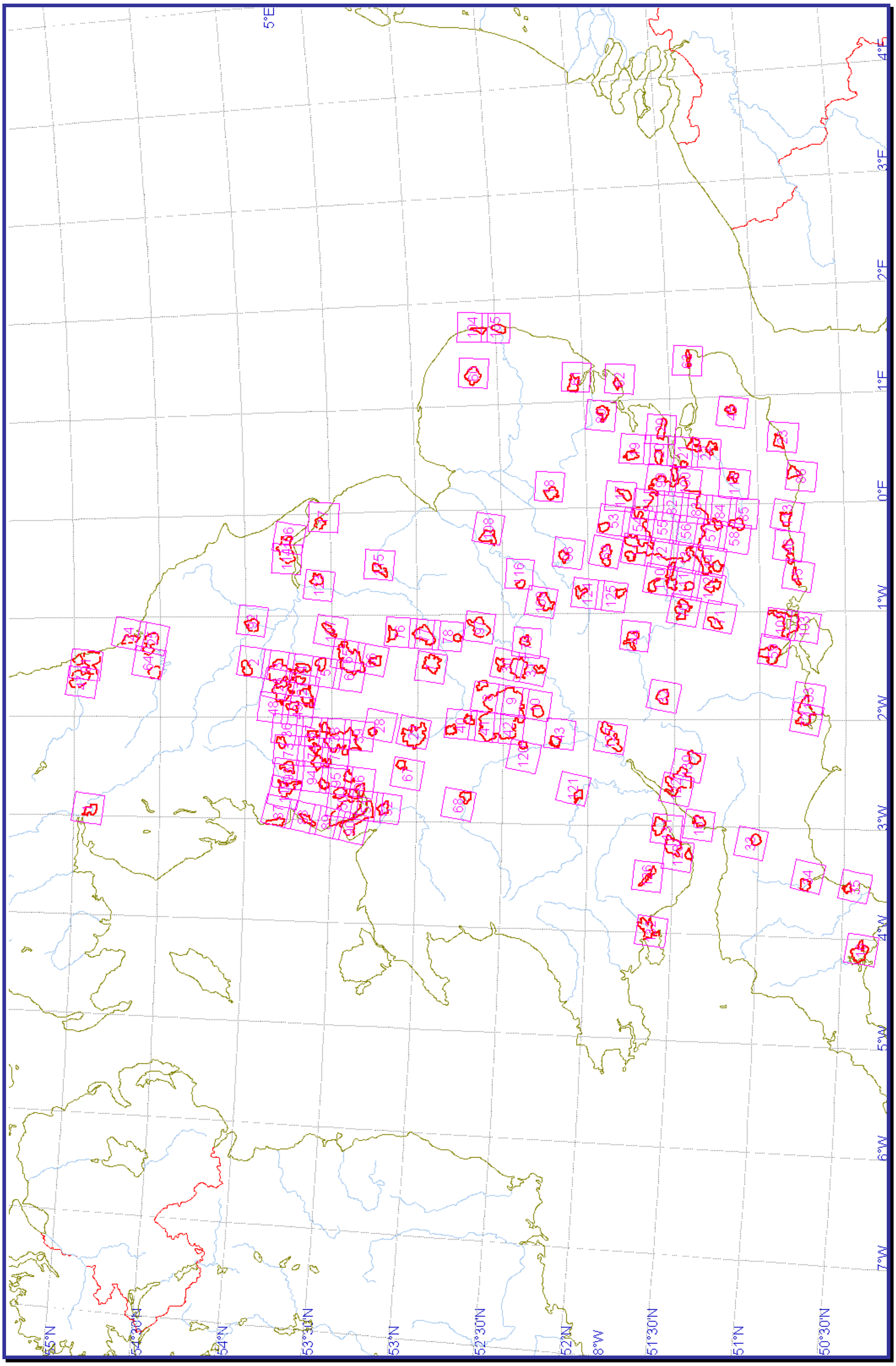


Figure 3-3: RADARSAT-2 Coverage of AOI's

5 Metadata Protocols

5.1 MetaData Standards

There are currently a number of Metadata standards that are available to data providers. However in the UK the principal current standards are:

- ISO 19115
- UK Gemini
- Defra SPIRE Standard

The ISO 19115/19139 Geographic Information: Metadata standard is currently still under development but is becoming the international standard for geoinformation metadata. The content of the standard is defined by ISO 19115 which has already been released and the XML schema implementation is defined by ISO 19139 which is due to be released in 2006. There is also an extension, ISO 19115-2 Imagery Extension, under development covering imagery metadata. The ISO standard will supersede the current GI-Gateway / NGDF specification via the UK national profile UK Gemini.

The UK Gemini (Geo-spatial Metadata Interoperability Initiative) was launched in October 2004 after a year-long consultation process. As a profile of ISO 19115 it is a subset of these standards, adopting elements, structures and rules relevant to the UK geoinformation community. The UK Gemini profile will replace NGDF as the national geospatial metadata profile, allowing metadata creation that is compliant to both ISO 19115 and the national e-Government Metadata Standard. The UK Gemini profile is also being supported through the redevelopment of the MetaGenie tool that has been made publicly available by the GI-Gateway thorough Central Government funding via the National Interest Mapping Services Agreement (NIMSA).

Defra is currently developing its own spatial information repository under the SPIRE programme (Spatial Information Repository). As part of the programme it was necessary to develop the existing UK Gemini standard to incorporate additional elements, following a Defra Data Standards workshop in October 2004, to make the metadata more appropriate for SPIRE and hence spatial data management use. The SPIRE standard is a development of the UK Gemini standard and in complying to the standard, compliance with UK-Gemini and ISO 19115 is achieved. The modifications are additions to the UK Gemini standard and not a replacement of any elements. Therefore, conformity to the SPIRE standard will mean conformity to the UK Gemini standard.

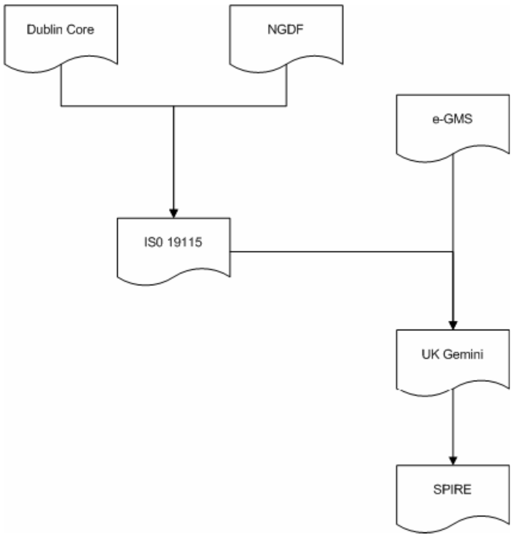


Figure 4-1: Derivation of SPIRE metadata from existing standards.

As part of any operational service that would be provided it is important that data being captured on behalf of Defra is captured with metadata and that this metadata complies with nationally recognised standards. Any operational data capture should conform to Defra's SPIRE standard as this is the most comprehensive standard, is the *de facto* spatial standard for Defra and ensures full compliance with other national profiles like UK-Gemini.

Further the operational service will ensure that the GI Gateway which acts as a central repository for metadata relating to spatial datasets within the UK is populated with the metadata that is captured for the service. This ensures that users are aware that the data is available and conforms to best practice as laid out by e-government initiatives. Metadata will also be supplied to the SPIRE programme to ensure a consistent record is held for Defra.

5.2 Data Quality

As well as defining metadata standards a key foundation for SPIRE was the desire by Defra to ensure that all of their spatial data met known data quality standards and that their data was fit for re-use within the department. The SPIRE programme in consultation with interested parties within Defra has defined a set of standards that datasets should meet. As part of an operational service Infoterra would ensure that these standards are met.

The data standards include both geometry standards and attribute standards. The standards consist of a number of mandatory elements and non-mandatory elements. The only mandatory standard is that no polygon should be unclosed, so the last point and the first point of any polygon should be identical. The remaining standards check for common geometry problems such as self intersections, spikes and overlaps. The attribute standards check to ensure that attribute values are correctly formatted to ISO standards and that there are no incorrectly formatted records.

SPIRE Geometry Standards:

Loop backs – self intersections	Optional
Unclosed Polygons/Ring	Mandatory
Internal Polygons with Incorrect Rotation	Optional
Duplicated Points	Optional
Kick Backs	Optional
Spikes	Optional
Minimum Area	Optional
Slivers or Gaps	Optional
Overlapping Polygons	Optional
Duplicate Polygons (duplicate polygons with same attributes)	Optional
Short Segments	Optional
Null Geometry –Table records with Null Shape	Optional
Segment Orientation	Optional
Empty Parts – geometry has multiple parts and one is empty	Optional

SPIRE Attribute Standards:

All attribute headings are described in the attribution look-up table	Mandatory
Each feature is described by a name and/or description	Mandatory
Each feature within a dataset has a unique identifier / reference code	Mandatory
All mandatory fields are populated	Mandatory
Each area or linear feature has a measurement and a unit of measurement specified	Mandatory
Blank and zero values have been qualified	Mandatory
Date and time values conform to ISO 8601 standard	Mandatory
References to countries or their subdivisions conform to ISO 3166 standard	Mandatory
References to language conform to ISO 639-2 standard	Mandatory
Fields are populated appropriately including coding and formatting	Mandatory
Addresses conform to BS7666 part 3 standard	Mandatory

As the SPIRE standards are aimed at improving the quality and the re-usability of all spatial data within Defra, any new dataset generation should conform to these standards. As part of the operational service the data will be tested to ensure compliance to these standards and ensure that any soil sealing products generated conform to Defra's spatial standards.

5.3 Data Management

As part of the operational service it will be ensured that best geospatial practice is followed. This will ensure that all data management is carried out to a high standard and to ensure that the data is fully re-useable.

The OS MasterMap data will be sourced from the SPIRE programme and will be sourced with sufficient attribution to ensure that each feature can be uniquely identified both as a feature and at the correct point within the feature's life cycle.

Geographic information is increasingly underpinning main stream information services, and to enable this process traditional geo-information has to be transformed from relatively unintelligent maps and pictures to computer records that information technologies can recognise and handle easily. By ensuring that data is captured to these standards it will be possible to provide better end user services based on improved data integrity and lower operational costs.

A key principle that the operational service will look to adopt to ensure that the data is re-useable is that of the emerging Digital National Framework (DNF). The vision of DNF is to enable and support easy and reliable integration of business and geographic information regardless of who is responsible for its maintenance and where this is undertaken, achieving the goal of "plug and play information". The DNF introduces the idea of having a national base reference dataset that other information can be tied to through a consistent set of unique identifiers. Additional data layers become a derivation of the base layer, either directly or thorough intermediary layers. The use of a common reference and unique identifiers allow data to be shared between users and organisations and processed by automated information technologies. It addresses interoperability between organisations and can, as in the case of the EU InSPIRE initiative, be extended to a trans-national level.

During the capture process it will be ensured that all data captured has a unique identifier and that the records are properly life-cycled allowing the dataset to be maintained and updated in the future. This process shall ensure that the when updates are carried out there is a traceable history of the change that has occurred and when it occurred. Given that the data will be captured over a number of years, ensuring that there is a robust life cycle held within the data is imperative to ensure that the data can be shared with multiple users. As part of the process any data that is captured will in addition to metadata will also have a unique layer identifier allocated to it that conforms to SPIRE layer naming standards. This will allow the layer to be uniquely identified when and if it is shared between organisations or a repository such as SPIRE. The use of a unique layer ID allows the dataset and any data layers within it to be clearly identified.

The operational service captures the data and when it has been quality checked the data will be passed to Defra's central spatial repository for storage. This will allow the data to be held centrally enabling use by any of the Defra family with permissions to access the dataset. It will also remove the burden of responsibility for managing and storing the dataset from the Soils Team and place this task with a single point of contact. The operational service will pass all of the appropriate derived soil sealing products into the repository as well as providing a copy to the Soils Team. The operational service will also coordinate with the SPIRE Team over any issues arising from data formats, data quality and SPIRE standards during the production of the soil mapping products.

The satellite and other raster imagery produced or acquired by the operational service will also be passed to SPIRE for storage. However, currently Defra has no operational standards for such imagery, though there are a number of initiatives including the production of Defra's Earth Observation strategy that are currently under development. The operational team will continue to liaise with these initiatives to ensure that the data returned to Defra will fit with these initiatives and that sufficient metadata is provided to enable the inclusion of this data into any future Earth Observation catalogue service within Defra.

The operational service will return a final product to SPIRE for hosting and delivery to other relevant users. The service will also provide any relevant intermediary data that has value as a dataset in its own right to SPIRE, so that this can be held within the repository. This should ensure that Defra gets the maximum return from its investment in the soil sealing mapping.

6 Operational Feasibility

Phase 1 of the project outlined the existing evidence relating to satellite systems and processing methods for monitoring soil sealing, and proposed a recommended configuration for a demonstration system. Phase 2 extended the procedures tested in Phase 1, reporting on the opportunities and limitations for scaling-up the trial study to a routine, national operational activity. This Operational Feasibility will deal with technical issues, such as the continuity of current sensors and future technologies, as well as logistical, economic and human resource issues.

6.1 Project datasets and Methodology

The OS MasterMap methodology has been refined and amended as a result of the work in Phase 2. Examples of the refinement to the methodology can be found in the segmentation process, when individual TOIDs based on specific attributes and polygon sizes, are dissolved with adjacent TOIDs of the same type.

It was not intended that the operational feasibility would require that all possible recommended methodologies be analysed. The project currently envisages an agreed methodology. This methodology could potentially be improved through the refinement of certain steps, such as by introducing a block grid. However as these are for the moment only recommended refinements, it is not considered relevant to try to estimate either the operational feasibility of such recommendations.

The methodology developed for soil sealing monitoring is described here. The operation has two main inputs and a number of principal processes.

The inputs are:

- Proposed sensor:
  - 2.8 m Quickbird imagery (IKONOS or Orbview-3 imagery would be viable alternatives)

- Surface datasets:
  - Ordnance Survey MasterMap topographic data

An additional input for accuracy assessment is:

- Supporting data:
  - Visual interpretation orthophotography for ‘ground-truth’ validation and Ortho-correction

The principal processes are:

- Identification of land cover/training data
- Maximum likelihood pixel classification of Normalised Difference Vegetation Index (NDVI)
- Accuracy assessment

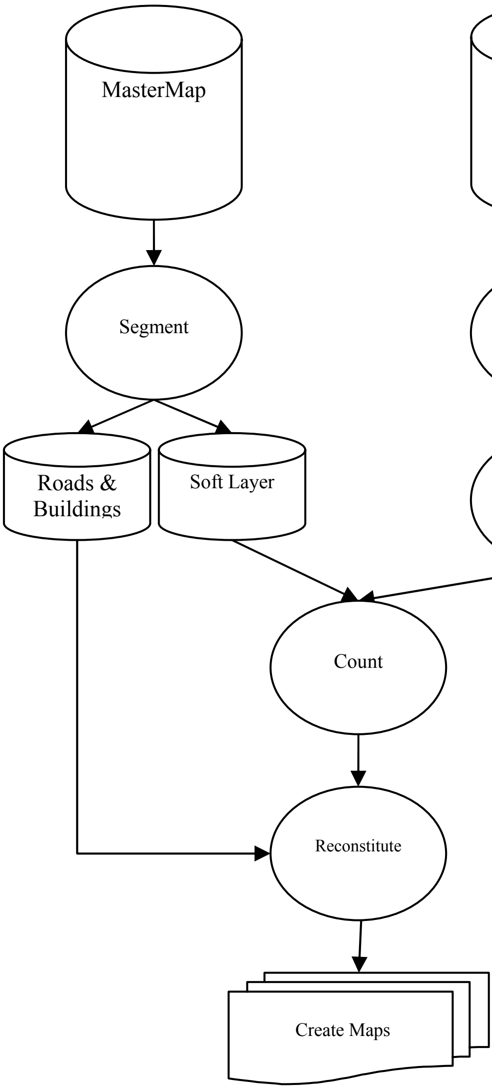


Figure 5-1: Soil Sealing – Project Methodology

In addition to the main processes some additional processes must be undertaken:

- Image Segmentation based on Image Classification (into 'Vegetated' vs. 'Non-Vegetated')
- Segmentation of MasterMap (Extraction of Man-made roads and buildings)
- Count (score each polygon on its % vegetated)
- Produce a final image with 0, 25, 50, 75 or 100% vegetated ("sealed") classification

6.2 Project Schedule

During discussions with the Defra Soils Team a requirement for delivery of the final "soil sealing" maps has focused on estimating a worst case scenario for how long the project may take to complete. Using a worst case scenario enables an analysis of whether the timescales fall within acceptable limits for Defra and re-scaling of the project schedule if the timescales are not acceptable.

To assist this, each process has been broken down to give a per unit time value, the number of units estimated from the coverage scenarios and the dependence of each process upon another element in the chain.

Where possible through the processes, the file size of the inputs has been identified. This has been included to reflect any data management issues that could be expected. In each case an assumption based on the expected maximum file size for that input has been shown.

This approach allows the project to be scoped from a single test AOI to an operational system over the whole of the UK. The totals listed in the following sections are for all AOI's in England and Wales.

6.2.1 Review of Processes

6.2.1.1 Ortho-Correction

QuickBird imagery is provided with a range of corrections applied depending on the product purchased. The prices used within this report are based on the standard product which is supplied with radiometric, sensor and basic geometric corrections. The imagery has a spatial accuracy of 23m at *c*.90% which is not accurate enough to be used with existing UK mapping. The ortho-rectification process therefore needs to be undertaken to georeference the imagery accurately. Ortho-correction is the process of correcting the geometry of an image so that it appears as though each pixel was acquired from directly overhead. Ortho-rectification uses elevation data to correct terrain distortion in aerial or satellite imagery.

During ortho-correction the satellite scene is ingested, and the scene metadata is interpreted. This information is used to calculate an *a priori* acquisition model for the scene, including the orbital elements and attitude angle offsets. Corrections to the *a priori* model parameters are determined by least squares adjustment of the control point observations.

In the ortho-correction, parallax errors in spatial positioning caused by oblique viewing are corrected. A Digital Elevation Model (DEM) is used to determine the parallax size. The DEM is first resampled to the image output space, and the terrain displacement vector is then calculated for each output pixel. In the resampling of the scene, the original image is transformed to the desired frame, pixel size and map projection, taking into account the acquisition model and parallax corrections. The resampling kernel used is cubic convolution.

In the quality control of the final product the corrected scene control points are digitised from source mapping and compared with the location of the corrected scene.

- Inputs :
    - Raw Satellite Imagery
    - Reference Source Mapping/Imagery
    - Digital Elevation Model

- Example Quickbird Scenes
    - 16x16kms
    - 4 Band Multispectral image is 150Mbs

- Estimated number of Scenes required
    - Total 198 Imagettes / 80 Segments
    - Total File size : 29.7Gbs

- Total Operator Time : 297hrs
- Total Processing Time : 396hrs

- Outputs :

- Ortho-Rectified Satellite Imagery

6.2.1.2 Image Classification (maximum likelihood)

During Phase 1 it was identified that a supervised, per-pixel classification approach would be undertaken. This would require individual pixels being classified based on their spectral properties and with reference to known land cover. The intent of the classification process is to categorise all pixels in a digital image into one of several land cover classes, or "themes". This categorised data may then be used to produce thematic maps of the land cover present in an image.

- Inputs :
  - Ortho-Rectified Satellite Imagery
  - Ortho-Aerial Photography

- Example Quickbird Scenes
  - 16x16kms
  - 4 Band Multispectral image is 150Mbs

- Estimated number of Scenes required
  - Total 198 Imagettes / 80 Segments
  - Total Filesize : 29.7Gbs

- Total Operator Time : 396hrs
- Total Processing Time : 792hrs

- Output :
  - Classified Data

6.2.1.3 Image Segmentation

The Image Classification categorised all pixels according to land cover types. This disaggregation of classes allowed the assessment of the spectral separability of land cover for accuracy assessment. For the purpose of an operational system this step would be amended to segment the classified image into two classes, “vegetated” and “non-vegetated”.

6.2.1.4 Segmentation of OS MasterMap

During Phase 1, the satellite-derived map of sealing was amended by the use of existing topographic information from OS MasterMap data. MasterMap includes attributes that describe the 'MAKE' of the surface material, e.g. it will state 'manmade', to represent surfaces that have been constructed.

To improve the accuracy of the derived map, if a land parcel feature had the attribute, 'manmade' it was assumed to be 100% sealed. By overriding the satellite classification in this way in Phase 1, it removed a number of omission errors, and increased the overall accuracy.

It would be requested that Defra supply MasterMap data on a per tile basis. Each tile would be 25x25kms, based on a nominal coverage of the UK. The tiles should be cropped to the extents of AOI's to remove additional TOIDs that would not be required by the project.

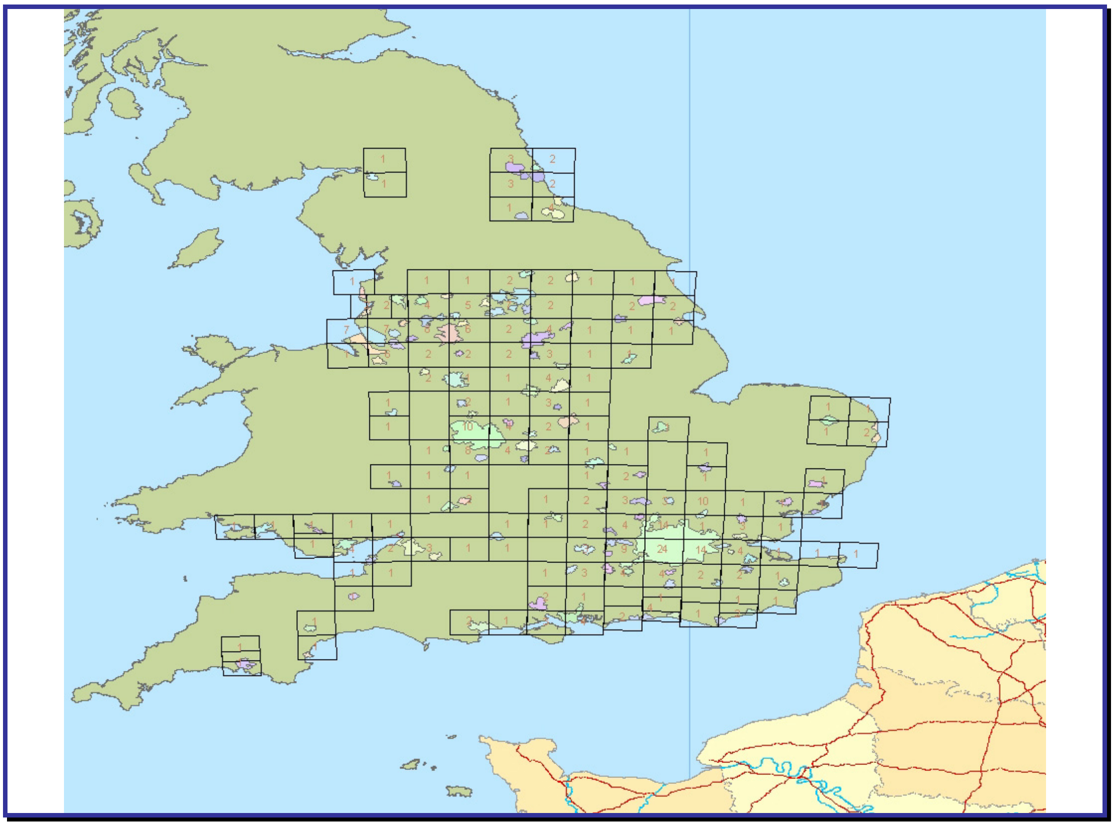


Figure 5-2: Distribution of 25km Tiles

The Data will be requested to be supplied as “hairy” polygons.

Figure 5-3: Example of Hairy Polygon

MasterMap data reflects real-world objects, such as roads, buildings and land parcels, which do not conform to existing administrative boundaries. A road polygon, for example, may extend well beyond a district boundary, and an agricultural field may be bisected by it. It is impractical and unacceptable to split MasterMap polygons at district boundaries due to the huge amount of processing required. However, the use of hairy polygons gives the appearance of a very irregular district boundary and ensures that, even with broken polygons removed, the total area statistics differ slightly from the area of the district polygon.

- Input :
  - MasterMap Data

- Example MasterMap Tile
  - 25x25kms
  - 25x25km tile is 625Mbs

- Estimated number of Scenes required
  - Total 139 Tiles
  - Total Filesize : 90.625Gbs

- Total Operator Time : 76hrs
- Total Processing Time : 290hrs

- Outputs :
  - MasterMap “Hard Layer”
  - MasterMap “Soft Layer”

6.2.1.5 Count (score each polygon on its percentage of vegetated cover)

In order to standardise the format of the results and to allow easier comparison of the final derived map with other datasets, each MasterMap TOID will be attributed a “percentage sealed” value. The process will involve an automated pixel count of the “sealed” pixels as a proportion of the total pixels within each TOID.

During the segmentation process outlined in section 5.2.1.4, the OS MasterMap "Soft Layer" will be amended. A command during the segmentation will dissolve certain features based on a recommended set or rules. At present this will be undertaken on the attribute "Multi-surface". These TOIDs will be dissolved with adjacent TOIDs that share this attribute. However the dissolve will only occur if the TOID in question has an area less than a stated minimum size. This size can be set to match the minimum size that is recommended to meet the accuracy requirements as defined by Defra. For nominal purposes this would be set to 3,000 sq meters.

TOIDs that would remain that are less than the minimum size stated, even after the dissolve process has taken place during segmentation, would be automatically given the rating of "unclassified". This setting would acknowledge that the accuracy of the sealed rating is too low to be attributed with confidence.

All dissolved TOIDs will require that an additional attribute field is added. This attribute field will contain the list of all TOIDs that were utilised in the dissolve. For example if Polygon "A", "B", "C" and "E", were dissolved into Polygon "Dissolve1" then the individual TOID numbers would be retained. This will allow the reconstruction of individual TOIDs, including the ability to maintain an attribute link which would state all the TOIDs that were utilised in a dissolved polygon.

For the purposes of future analysis and to allow increased use of the data the value will be the archived percentage value obtained and will not be amended to arbitrary classes.

- Inputs :
  - MasterMap “Segmented” Data
  - Classified “Segmented” Data

- Example MasterMap Tile
  - 25x25kms
  - 25x25km tile is 625Mbs

- Estimated number of Scenes required
  - Total 139 Tiles
  - Total Filesize : 90.625Gbs

- Total Operator Time : 69.5hrs
- Total Processing Time : 417hrs

- Output :
  - MasterMap “Soft/Count Layer”

6.2.1.6 Reconstitution of MasterMap

After the segmented data has been attributed, the OS MasterMap "Hard Layer" and OS MasterMap "Soft Layer" will need to be reconstructed to allow the creation of maps and delivery of the final dataset.

This will be undertaken on the same 25x25kms tiles that the OS MasterMap data was originally supplied in. A comparison of the supplied MasterMap data and the Reconstituted MasterMap data will be undertaken. This will ensure that the processing has not amended the original TOIDs or introduced errors into the dataset.

It is envisioned that this will be the basis of the dataset that will be passed to SPIRE for storage.

- Inputs :
  - MasterMap “Hard Layer”
  - MasterMap “Soft/Count Layer”

- Example MasterMap Tile
  - 25x25kms
  - 25x25km tile is 625Mbs

- Estimated number of Scenes required
  - Total 139 Tiles
  - Total Filesize : 90.625Gbs

- Total Operator Time : 76hrs
- Total Processing Time : 290hrs

- Outputs :
  - Reconstituted MasterMap Data

6.2.1.7 Produce a final image map

The Defra Soils Team has requested that "paper" maps be provided to allow greater utilisation of the derived maps within the team. After looking at various options this is considered a step that would involve significant costs and implications for the project. The use of high resolution satellite mapping and large scale mapping products such as OS MasterMap® mean that the resulting maps produced by the operational service are detailed. In order to preserve the detail that is present within the final mapping product when it is printed it is necessary to maintain a large scale. In doing so, though, this increases the size of the final maps for an area and thus the number of map sheets required to cover an urban region. This results in a final product that is not user friendly, and also that is limited to a paper format. There are currently a number of initiatives underway both within Defra and government in general to increase the shareability of data and to make information as widely available as possible. To ensure that the soils project meets the Defra GeoInformation Strategy and is able to make its data as widely available as possible within Defra it is recommended that the final mapping products are created digitally, possibly using ESRI ArcPublisher.

ArcPublisher (ArcGIS Publisher) is an extension of ArcMap. It can be used to publish completed maps as published map files (.pmf). These files contain all the information required to display the map, but can be easily transported and distributed.

ArcGIS Publisher controls the appearance of the ArcReader application when it opens a map. The published map files contain metadata about data source locations and drawing instructions (symbology and rendering rules, scale dependencies, etc.). The .pmf file maintains the settings defined by the author in ArcMap: for example, layer properties (hyperlinks, joins, etc.), data frame properties (bookmarks, extents, projections, etc.), and page layout configuration.

The .pmf file also has properties that define how the user of the file interacts with the map. For example, the .pmf can be password protected and ArcReader functionality can be disabled

Despite these files being produced in ArcMap, a licence to that program is not necessary for viewing them. The primary benefit of ArcPublisher is that maps can be made more accessible and easily available to a potential audience that may not have ArcMap.

ArcReader is a free program available from ESRI for viewing published map files (.pmf) from ArcMap/ArcPublisher. ArcReader is a free desktop application that helps provides a way to share and deliver interactive maps based on dynamic content.

Map navigation tools are provided for zooming and panning around the map and switching between map view and page layout view ArcReader can also print high-quality maps. However, maps cannot be edited (colours changed, etc.) in this program.

The .pmf format allows the final derived maps to be displayed in a format that can be controlled. Therefore, as a first step it would be necessary to decide upon a common look for the final derived maps, this format could then be used for all maps.

- Inputs :
  - Reconstituted MasterMap Data

- Example MasterMap Tile
  - 25x25kms
  - 25x25km tile is 625Mbs

- Estimated number of Scenes required
  - Total 139 Tiles
  - Total Filesize : 90.625Gbs

- Total Operator Time : 74hrs
- Total Processing Time : 74hrs

- Outputs :
  - Digital Maps

6.2.1.8 Accuracy assessment.

During Phase 1 the accuracy of the classification was assessed by comparison with baseline maps that were produced by visual interpretation of 0.125m resolution orthorectified air photos. The Aerial Photo Interpretation (API) was implemented on-screen by overlaying 1:1250 scale Ordnance Survey topographic data (MasterMap) onto the orthophotos of the test area. Defra has access to the UK Perspectives dataset which could provide the aerial photography for the air photo interpretation needed for accuracy assessment . However the satellite imagery could also be used for accuracy assessment; by using a manual photo interpretation approach, it is possible to cross check to see if the automatic classifiers are correctly classifying the satellite imagery.

During the operational phase of the project it is planned to conduct the accuracy assessment on approximately 5% of the total urban area under investigation. The 5% threshold is based on Infoterra's experience from the pilot study and it is felt that this threshold provides the most effective balance between cost and accuracy. The accuracy assessment is aimed at verifying the quality of the maps and not of the individual classifiers for each image as this methodology has been tested during the pilot phase, and is assumed to be accurate. The assessment would be undertaken to verify the quality of the final maps for each urban region rather than the classification of each image within an urban region. The accuracy assessment is designed to measure the overall quality of the map and ensure that it is of a sufficient standard.

The accuracy assessment investigation undertaken for the test area utilised the same QuickBird image for the selection of the training data, classification and accuracy assessment. It is considered important for the accuracy assessment to utilise a random sample across all images processed. The process would randomly select 5% of the TOIDs from the "soft layer", during the initial segmentation, against the area of the applicable QuickBird scenes. Then for accuracy assessment the operator would step through each randomly selected TOID and attribute the soil sealed value.

- Inputs :
  - MasterMap "Soft/Count Layer"
  - Ortho-Rectified Satellite Imagery
  - Ortho-Aerial Photography

- Total Operator Time : 92.5hrs
- Total Processing Time : 55.5hrs

6.3 Project Timescale

Using the estimates for each stage and simplifying it for a project that was split evenly across five years, utilising one member of staff it is possible to calculate the timescale for running a project as outlined.

Since the segmenting of the MasterMap data is not necessarily dependent upon external factors it is considered that this could be started first. The selection of tiles however is dependent upon which AOI's are tasked and acquired, therefore it is possible that this could alter the start date for this process. Also the start date for beginning this process is dependent upon the lead time that Defra would need to supply the required MasterMap tiles.

Two timescales have been provided based on:

- acquiring all imagery in one window
- acquiring an even split of imagery across 5 years

6.3.1 One Collection Window

The Start date for the main processing has been moved to begin at the end of the collection window for the Satellite Data. The collection window is stated to run from May to October, and the main processing has been set to begin on the 01-November. The timescales are based on a single operation using a single calculation.

- Ortho-Correction :
  - The Ortho-correction process is due to last for a total of 110 days.

  - Start Date : 01-November
  - End Date : 09-April

- Classification :
  - The Classification process is due to last for a total of 105 days.

  - Start Date : 10-April
  - End Date : 08-October (Year2)

- Count :
  - The Count process is due to last for a total of 75 days.

  - Start Date : 09-October (Year2)
  - End Date : 21-January (Year2)

- Reconstitute:
  - The Reconstitute process is due to last for a total of 50 days.

  - Start Date : 21-January (Year2)
  - End Date : 31-March (Year2)

- Map Creation:
  - The Map Creation process is due to last for a total of 25 days.

  - Start Date : 01-April (Year2)
  - End Date : 30-April (Year2)

- Accuracy Assessment:
  - The Accuracy Assessment process is due to last for a total of 25 days.

  - Start Date : 04-March (Year2)
  - End Date : 30-April (Year2)

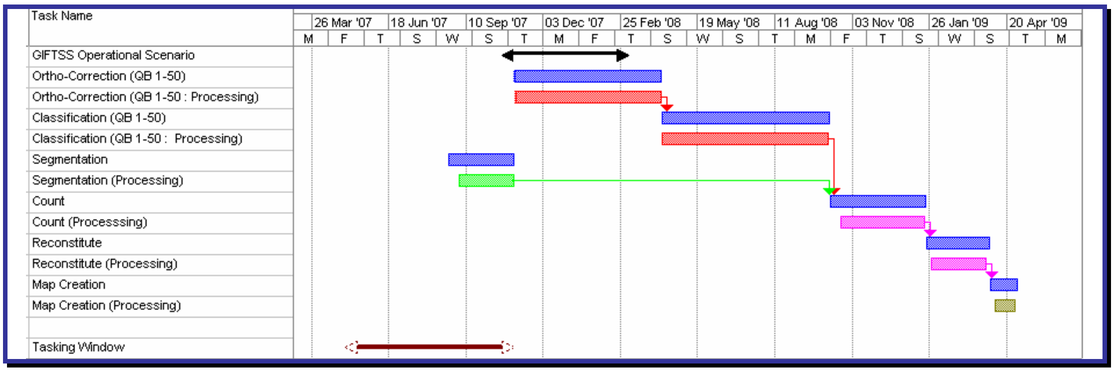


Figure 5-4: Project Timeline for a Single Window Collection, using one operation

6.3.2 Split Across five Years

The Start date for the main processing has been moved to begin at the end of the collection window for the Satellite Data. The collection window is stated to run from May to October, and the main processing has been set to begin on the 01-November.

- Ortho-Correction :
  - The Ortho-correction process is due to last for a total of 22 days.
  - Start Date : 01-November
  - End Date : 30-November
- Classification :
  - The Classification process is due to last for a total of 21 days.
  - Start Date : 03-December
  - End Date : 17-January
- Count :
  - The Count process is due to last for a total of 15 days.
  - Start Date : 18-January
  - End Date : 08-February
- Reconstitute:
  - The Reconstitute process is due to last for a total of 10 days.
  - Start Date : 11-February
  - End Date : 22-February
- Map Creation:
  - The Map Creation process is due to last for a total of 5 days.
  - Start Date : 25-February
  - End Date : 03-March
- Accuracy Assessment:
  - The Accuracy Assessment process is due to last for a total of 3 days.
  - Start Date : 04-March
  - End Date : 06-March

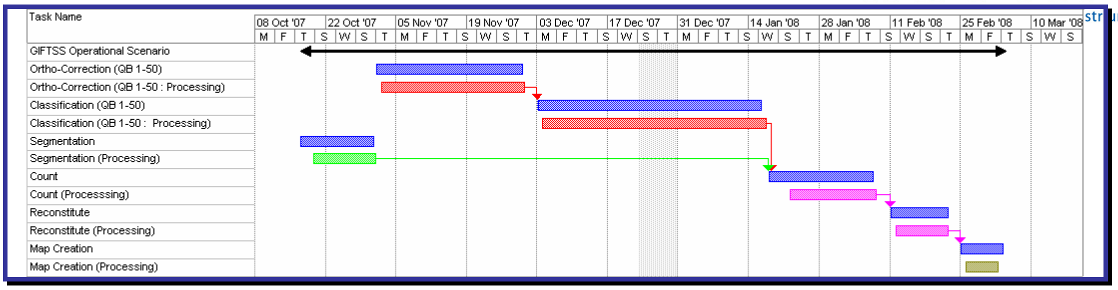


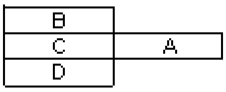
Figure 5-5: Project Timeline for a 5 Year Split Collection

6.3.3 Implications on timescale

During the estimation of the timescale it has been appropriate to assume a worst case scenario in which the image acquisition conditions are at their least favourable.

Additional worst case assumptions have been made on data acquistion. The largest time component on the project is the ortho-correction and classification of the data. During these processes it has been assumed that only individual scenes would available.

During the QuickBird analysis for the operational scenario it was estimated that a total of 198 individual QuickBird imagettes would be required to cover all of the AOI's. However this could be reduced to some 80 segments of imagery if scenes are acquired in a strip.



For example, if one of the AOI's required four QuickBird scenes to cover the whole AOI, in a worst case scenario it would require four separate scenes acquired on four separate dates However if "A" could be acquired as a single scene on Day 1, then on Day 2 "B, C & D" could all be acquired together, which would mean ideally there would be two segments of imagery. Spectrally "A" and "B-D" would be acquired under different conditions so they would need to be treated separately. However "B-D" could be treated as one image, which would improve on the processing timescales; this would reduce processing from four sets of images to two sets of images.

6.4 Project Costs

The estimated final cost for the project has been broken down into Data costs and Production costs.

The Data costs have been estimated using current DigitalGlobe QuickBird pricing (Appendix 1) and a long-term dollar currency rate.

6.4.1 Data Costs

Product prices for high-resolution data are calculated by selecting the product type and product options, and multiplying that price by the area (in scenes or square kilometres).

The Final Total Price is calculated by adding the Product Price and multiplying by any applicable Licence Uplifts.

The total sq km area of data required is 9,000 sq kms

The current DigitalGlobe QuickBird Ortho-Ready Standard tasking price is $22.00 per sq km for a Multispectral image.

- The total data costs would be : $198,000
- The long-term exchange rate used was 1.75USDollars: 1GBP.
- The total data costs would be : £ 113,000

At the time of ordering discounted prices may be available.

6.4.2 Processing Costs

The following budgetary price has been estimated using Infoterra's standard costs and conditions. The final figure reflects a standard value for a single person undertaking all the required processing stages, contingency, appropriate hardware and software costs, applicable data storage costs, as well as project management and interaction with the customer. The estimate is correct as of May 2006; the stated price is not a formal Infoterra price offer. No annual inflation of fee rates is included in this estimate.

- The total costs for processing 9,000 km^2 of imagery would be around £137,000.

The price breakdown for the processing costs, which would be the same for both five years or one year, includes fixed costs such as hardware and software required to analyse the data. Workstations are assumed to be standard image processing workstations. These costs do not include any costs of aerial photography used for accuracy assessment; this could, for example, be provided through Defra's existing UK Perspectives licence at no additional cost to the soil sealing project. Assuming that aerial photography is available, the costs for accuracy assessment are included in the total processing costs, using the methodology described in Section 5.2.1.8 of Appendix 3 – the report on operational feasibility.

Defra would need to consider the costs of purchasing the necessary data processing tools if they wanted to do the image processing, analysis and accuracy assessment work in-house, including the purchase of the relevant hardware and image processing software applications.

The assumption present in the report is that SPIRE, as a Defra programme, would provide data storage and processing at no cost. This is a point that is under discussion within Defra, who has yet to decide how it wants to charge projects for access and storage costs. However, the storage costs for this particular data set would not be great and if SPIRE development were to cease, then the soils team could store the data themselves at little additional cost, given the current low costs of electronic data storage.

A more significant potential cost would be in sourcing OS MasterMap® in a suitable format. A key goal of SPIRE is to remove the cost overhead of each individual project processing MasterMap® and to provide projects with data in a format they can use. If SPIRE was unable to provide this service then the soils team, or their contractor, would need to undertake the necessary preparation work which would incur an additional pre-processing cost for converting OS MasterMap® data. Depending on the configuration required and the software used, this could add a cost of £2k to £5K for pre-processing time.

6.4.3 Total Costs

The total budgetary price for an operational sealing project would be £250,000, including satellite data purchase and data processing and analysis and excluding any additional data storage, air-photo purchase and MasterMap® pre-processing, as outlined above. It is noted that the costs that are included within the report are based on the use of Quickbird imagery, therefore, the £250k value is based on this imagery price. Changing the type of imagery used will change the data costs and the overall price. However, Quickbird provides an indicative cost – the prices of comparable sensors are similar; all are subject to change.

7 Conclusions and Recommendations

7.1 Technology Matching

Data continuity and data availability are important factors to consider when undertaking a project of the scale of the soil sealing exercise. Users' enthusiasm to utilise EO data has been hampered in the past by the fact that EO data has traditionally not been made available with sufficient commitment to continuity of measurement.

The current availability of IKONOS, Quickbird and Orbview-3 data, and a commitment to the launch of satellites such as Worldview-II and Orbview-5 shows that a continuity of measurements does now exist. A stable of satellites up to and beyond 2019 indicates that should one satellite fail then there are alternatives to fill the data collection requirements.

The availability of radar instruments will shortly begin to offer the spatial resolutions offered by optical satellites with the launch of TerraSAR-X. The inherent all-weather advantages of radar instruments over optical are well understood, however in the initial literature review the use of radar was not described and this project has not been able to evaluate high-resolution radar for the assessment of soil sealing.

7.2 Scenario's

The UK is in a 'poor' area for cloud cover. The revision of the size of the area under investigation has helped in limiting impact of this factor. However the acquisition of all of the AOI within one year would still require a collaboration of collections between competing suppliers.

It is therefore recommended that it would be advantageous to split the collections across the five year reporting period. Splitting the collections has the advantage of setting a total annual acquisition requirement that Data Suppliers confirm should be achievable.

A cloud cover limit would still apply to any EO Data acquisitions. The industry standard is 20%, but it has been agreed that either a 10% cloud cover limit could be applied or the 20% limit would apply but, where cloud cover was close to this figure, the AOI would be selected for re-acquisition. However both of these would partly depend upon the overall size of the data order. Smaller overall orders are more likely to have standard tasking criteria applied, whereas larger orders gain increased flexibility.

Its is recommended that providing there is no priority scheme within Defra Soils Team that the entire AOI be submitted at the outset of any project to the selected data supplier. The data collection could be capped at 20% for the first year and the remaining AOI's be passed onto the next year's collection. This flexibility would allow a greater chance of success for acquisitions.

The costing scenario outlined is concurrent with a worst case scenario for data collection and thus subsequent processing. The worst case scenario was selected as it would show the maximum budgetary costs that would be applicable. There is scope for cost savings in the processing where image segments are acquired on the same date. These cost savings could be passed on to Defra in the form of a discount, but they are impossible to calculate until the exact pattern of image acquisitions has been confirmed.

Appendix 1 DigitalGlobe Price List

The following price was obtained from DigitalGlobe in May 2006, and is the suggested commercial retail price list (issued July 2005; Rev 1.1)

DIGITALGLOBE QuickBird® Commercial Suggested Retail Price Version 1.1

Panchromatic (Black & White), Multispectral, Natural Color and Color Infrared Imagery

Product Type	Product Priority: ImageLibrary	Rush ImageLibrary	Standard Tasking	Priority Tasking	Rush Tasking
Basic (Pan or Multispectral Only)	$4,896/scene $9,792/stereo	$7,616/scene $15,232/stereo	$5,984/scene	$8,704/scene $26,340/stereo	$11,424/scene
Standard; Ortho Ready Standard	$18.00/km² $46.60/mi²	$28.00/km² $72.50/mi²	$22.00/km² $56.95/mi²	$32.00/km² $82.85/mi²	$42.00/km² $108.75/mi²
1:50,000 Orthorectified	$30.00/km² $77.70/mi²	N/A	$30.00/km² $77.70/mi²	$40.00/km² $103.60/mi²	N/A
1:12,000 Orthorectified	$32.00/km² $82.90/mi²	N/A	$32.00/km² $82.90/mi²	$42.00/km² $108.80/mi²	N/A
1:5,000 / 1:4,800 Orthorectified	$34.00/km² $88.05/mi²	N/A	$34.00/km² $88.05/mi²	$44.00/km² $113.95/mi²	N/A
Custom Orthorectified	$34.00/km² $88.05/mi²	N/A	$34.00/km² $88.05/mi²	$44.00/km² $113.95/mi²	N/A
DG DOQQ United States	$576/DOQQ*	N/A	$576/DOQQ*	$896/DOQQ*	N/A

Pan-sharpened (4 band) and Bundle (Panchromatic + Multispectral) Imagery

Product Type	Product Priority: ImageLibrary	Rush ImageLibrary	Standard Tasking	Priority Tasking	Rush Tasking
Basic (Bundle Only)	$6,528/scene $13,056/stereo	$9,248/scene $18,496/stereo	$7,616/scene	$10,336/scene $29,604/stereo	$13,056/scene
Standard; OrthoReady Standard	$24.00/km² $62.15/mi²	$34.00/km² $88.05/mi²	$28.00/km² $72.50/mi²	$38.00/km² $98.40/mi²	$48.00/km² $124.30/mi²
1:50,000 Orthorectified	$36.00/km² $93.25/mi²	N/A	$36.00/km² $93.25/mi²	$46.00/km² $119.15/mi²	N/A
1:12,000 Orthorectified	$38.00/km² $98.40/mi²	N/A	$38.00/km² $98.40/mi²	$48.00/km² $124.30/mi²	N/A
1:5,000 / 1:4,800 Orthorectified	$40.00/km² $103.60/mi²	N/A	$40.00/km² $103.60/mi²	$50.00/km² $129.50/mi²	N/A
Custom Orthorectified	$40.00/km² $103.60/mi²	N/A	$40.00/km² $103.60/mi²	$50.00/km² $129.50/mi²	N/A
DG DOQQ United States	$768/DOQQ*	N/A	$768 /DOQQ*	$1,088/DOQQ*	N/A

Licensing

Commercial License	Included
Civil Government License	Included
Educational License	$4/km² discount off Basic and Standard Imagery
Global License	+ 35% of Imagery order total

Additional Options

Copies of Ordered Products	$25 per additional media delivered; $500 for firewire
Delayed ImageLibrary (Available on Tasked Orders)	$3,000 / Six Months $6,000 / Twelve Months

July 2005; Rev 1.1 Prices subject to change without notice Page 1 of 2

DIGITALGLOBE

QuickBird®
Commercial Suggested Retail Price **Version 1.1**

Pricing:
- Product Price is calculated by selecting the product type and product options, and multiplying that price by the area (in scenes, square kilometers, or square miles).
- The Total Price is calculated by adding the Product Price and the License Uplift.

Notes:
- Minimum order for Basic Imagery (both ImageLibrary and Tasking) is 1 scene ($272km^2$).
- Minimum order size for Standard Imagery is $25km^2$ for ImageLibrary, $64km^2$ for Standard and Priority Tasking, and $100km^2$ for Rush Tasking orders.
- Minimum order size for Orthorectified Imagery is $100km^2$. Call for quote for smaller order sizes.
- Minimum order size for DG DOQQs is 6 contiguous DOQQs.
- Cloud cover specification for all tasking orders is ≤20%, except for DG DOQQs which are offered cloud free. cloud free products may be purchased for a 50% uplift. Products with up to 10% cloud cover may be purchased for a 25% uplift.
- Orthorectified Imagery may be available cloud free for an additional 20% uplift on the Product Price (depending on weather, collection timelines, and spacecraft competition), contact your DigitalGlobe Reseller or Customer Service to confirm cloud free availability for your order.
- Basic Stereo Pair prices for tasking will be discounted 50% if cloud cover or image quality specs are not met.
- Basic Stereo Pair not available as Standard Tasking or Rush Tasking.
- Orthorectified Imagery Products (except Custom and DG DOQQs) may have an additional support data cost.
- All orthorectified Imagery Products are subject to the availability of DEMs and/or GCPs.
- Custom Ortho requires customer supplied DEMs and GCPs.
- The DG DOQQ is a Cloud free 1:12,000 scale ortho tiled to the USGS DOQQ boundaries, not available as Multispectral or Bundle.
- Off-nadir options are 0° - 15° or 0° - 25°, with no price uplift.
- The Commercial license offers multiple users within up to ten organizations within a single country access to QuickBird Imagery.
- The Civil Government license offers multiple users within up to 25 Federal, State, and Local government organizations in a single country access to QuickBird Imagery.
- The Educational license offers multiple users within a single educational institution access to QuickBird Imagery. Not available on Orthorectified Imagery.
- The Global license offers multiple users within a single organization in multiple countries access to QuickBird Imagery.
- An organization is defined as:
  - One corporation (but not subsidiaries).
  - One county government (all departments).
  - One federal agency (below cabinet level in the U.S.).
  - One state or provincial government agency.
  - One city government (all departments).
  - One university system.
  - One school district.

ImageLibrary:
- By default, all new image acquisitions are placed in the DigitalGlobe ImageLibrary.
- Customers can opt to delay their new successfully acquired images from appearing in the ImageLibrary by utilizing the delayed ImageLibrary option.
- Images that are acquired and do not pass quality assurance standards for cloud cover and environmental standards are not delivered to customers and are not eligible to be delayed from appearing in the ImageLibrary.

For further information
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