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Adaptive **D**ecision **S**upport **S**ystem (**ADSS**) for the **I**ntegration of Stormwater Source Control into Sustainable Urban Water Management Strategies

Surveying of urban surface materials and impervious areas using remote sensing

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1 Background and aim

The main objective of WP6 is to design a software package for stormwater sources and fluxes simulations, i.e. a Substance Flow Modelling (SFM) tool. Based on a GIS-based topological representation and a hydrological model for runoff water of the studied catchments. This software package will enable an analysis of the sources and fluxes of the priority pollutants identified in WP4.

Development of a sources and flux model (SFM) for analysing substance flows in stormwater systems increases the need of knowledge on material uses in urban areas. Some of the information needed for modelling can be found in databases at municipalities, but in general there are lack of important data on surface materials. Available methods for obtaining the needed data is to compile information in existing databases and complement with field inventories. Field investigations in larger catchments is time consuming and it can be problems to reach roofs and private properties to determine the material uses. Another approach is to use some kind of remote sensing for mapping of the catchment. This report will review the possibilities of using remote sensing for identifying the material composition of surfaces, land uses and impervious surfaces in urban catchments.

The report starts with a brief introduction to the basic concepts of remote sensing in section 2 and continues with an review of the state of the art in remote sensing of impervious areas (section 3.1) and identification of material use (section 3.2). In section 4 a discussion of the possibilities and methods relevant for DayWater are presented. The report includes general methods that are possible to use independent of local databases or archives. Possibilities to determine similar information from local resources is not reviewed since the varying status of such resources make any general conclusions impossible.

2 Introduction to remote sensing

Remote sensing is the art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand *et al.*, 2004). The methods reviewed in this report are limited to information obtained by electromagnetic energy sensors; normally it is the reflected energy that is measured.

Aerial photography with manual interpretations has been used for many different applications in remote sensing for many years. During the last decades the rapid development of computers has opened up the area for automated methods of image interpretation. The images can either be scanned aerial photos or images obtained directly by digital sensors. Colour photos do normally capture information from three wavelength bands in the visible part of the electromagnetic spectrum (see Figure 1), i.e. the blue green and red bands. When colour infrared (CIR) photos are taken the blue band is replaced by the near infrared band.

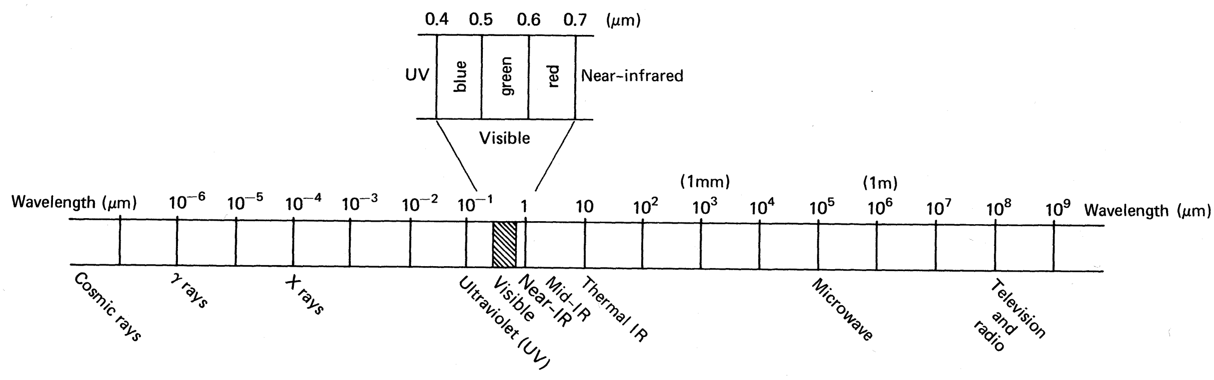


Figure 1 The electromagnetic spectrum

With digital sensors it is possible to capture more than three bands on the same time and such systems are called multispectral. An even more detailed sensor of the electromagnetic spectrum is called a hyperspectral sensor. There is no clear definition of when a sensor should be called multispectral or hyperspectral. Satellite borne sensors providing information from four bands are often called "multispectral", but also sensors detecting tenths of bands are called multispectral. According to Shippert (2003) the definition of a hyperspectral sensor is the narrowness (with a bandwidth of about 10 nm) and contiguous nature of measurements more than the number of measured bands. However, it is common that hyperspectral sensors measure over 200 bands. Hyperspectral sensors operate normally in the visible, near-IR, mid-IR and thermal-IR part of the electromagnetic spectrum.

The bandwidth is often referred to as the spectral resolution. The spectral resolution determines the possibilities of identifying surfaces with different reflectance and absorption across wavelengths, which can be used for identifying e.g. different materials. Another parameter that limits the possibilities in identifying objects and materials are the spatial resolution. The spatial resolution is the size that a pixel (picture element) in the image represents on the ground. Too large pixel size causes pixels that contain spectral information from several different surface types. Especially in analysis of urban areas both the spectral and spatial resolution are of crucial interest because the urban landscape consists of a large mix of different surfaces with limited aerial extension. Welch (1982) recommended spatial resolution less than 5 m for detailed urban mapping, depending on the size and structure of the urban landscape to be studied.

The availability of data with the necessary resolution has for many years been limited to aerial photos and aerial photos are still the most available source of high-resolution data. But after the end of the cold war commercial high resolution satellites have been developed and launched and the availability of satellite data is growing fast. There are now several commercial satellites operating or to be launched that are, or will be, producing multispectral data with a spatial resolution of less than 5 m, like Ikonos (Space Imaging, 2004), QuickBird (DigitalGlobe, 2004), OrbView-3 (Orbimage, 2004) or the still not launched Eros-B (ImageSat International, 2004). The availability of hyperspectral data is even more limited. There are no satellites with hyperspectral sensors that provides data with sufficient spatial resolution for urban applications, and data from flight-campaigns are still rare.

3 Applications

Remote sensing has been used in many different applications such as forestry (Ekstrand *et al.*, 2001a; Ekstrand *et al.*, 2001b), monitoring of water quality (Ekstrand, 1998; Liljeberg and Ekstrand, 1999), different geological applications (Kellgren, 2002; Kuehn *et al.*, 2000), different agricultural and hydrological applications. What is common for all the mentioned applications is that they all are characterised of relatively large areas with similar land-use (except some detailed forest studies). In the following sections a more detailed review of studies on possibilities to use remote sensing for detection of impervious surfaces and mapping of surface materials in urban areas will be done. Only automatic or semi-automatic methods using digital data are reviewed.

3.1 Detection of impervious surfaces

In hydrological models a key input factor is the impervious surface. Therefore there have been quite a few studies in the area of remote sensing of impervious surfaces. When the first Landsat satellites were launched in the early 1970's the interest to use satellite data for hydrologic modelling arouse. The spatial resolution of the early satellites was over 60 m and it was impossible to make any detailed mapping of the urban landscape. Ragan and Jackson (1975) published one of the first studies on the use of satellite data in urban hydrology. Their approach to deal with the coarse resolution was to identify different land use categories and assign a representative imperviousness for the different land use classes. Jackson *et al.* (1977) used this approach in a modelling project and concluded that it was useful for large watersheds, but not for small ones. Slonecker *et al.* (2001) made a review of studies on remote sensing of impervious surfaces. Of the 26 reviewed studies, 16 had used satellite data with too coarse resolution to give really useful information of the urban environment. Another 6 had not reported the accuracy of the method. Slonecker *et al.* (2001) pointed out a few approaches having the potential to increase the accuracy and applicability of remote sensing of impervious areas. The development of hyperspectral sensors and methods for analysing these data is believed to "yield significant new mapping capabilities" and the use of thermal infrared imagery and radar imagery have been overlooked and should have a potential for use in the mapping of urban areas.

Automatic classification of remote sensed data has been performed by Blagojevic *et al.* (1998), who used airborne videography for estimating parameters to model urban runoff. They concluded that aerial videography had satisfactory spatial and spectral resolution for recognition of urban features and that acceptable runoff simulation results could be expected. Fankhauser (1999) used digitised colour and CIR photos for determining imperviousness in Swiss catchments. Accuracies were compared to manually interpreted panchromatic aerial photos and the absolute deviation varied from 1–10 %. Conclusions were that other classification methods should be tested for enhancement of the results, but the obtained accuracy should meet the requirement of rainfall-runoff models. Also Myeong *et al.* (2001) used CIR-photos for mapping urban surfaces. For the class "impervious surfaces" they reached an accuracy of 83 %.

Hodgson *et al.* (2003) complemented digitised colour aerial photos with surface cover height information from Lidar (Light detection and ranging) data for studying imperviousness on parcel level. The method of calculating and reporting the accuracy of this study is totally different from what is common, but they reported "overall low errors".

Multispectral data from an airborne sensor was used by Elgy (2001) for mapping an urban catchment in Birmingham, England. Classes used in the classification were road, water, roof and permeable. Five different classification techniques were tested and the polygon classification (using textural information in the images) yielded the best results with an overall classification accuracy of 80 % and an accuracy of 90 % for the permeable areas. Also Thomas *et al*

(2003) used multispectral data from an airborne sensor for mapping urban areas for stormwater management. They assessed three different classification methods and concluded that an image segmentation classification was the best. Obtained accuracies were 70-80 % for the 5 classes studied (water, pavement, rooftop, bare ground and vegetation). If just permeable and impermeable classes were used the accuracy should be better.

The possibilities of using data from high resolution satellites and airborne multispectral sensors for mapping of urban imperviousness was discussed by Bayer and Hilz (1997). They foresaw that the launch of high-resolution satellites and the decreasing costs of data would make digital data from satellite or air-borne sensors attractive for analysing urban areas. Today we have reached the point where it starts to be possible to use data from high-resolution satellites. The use of data from the Ikonos satellite for classification of urban land cover was studied by Davis and Wang (2002) who used seven urban land cover classes: woods, grass, water, bare land, commercial building, impervious and shadow. They reached an overall accuracy of 83 % using a pan-sharpened multispectral image (a fusion of a panchromatic image with a multispectral image to achieve a higher spatial resolution) from Ikonos and standard classification methods. Another study using Ikonos data for detecting impervious surfaces has been made by Cablk and Minor (2003) who reached an overall accuracy of 93 % for the studied area in California. Shackelford and Davis (2003) used Ikonos data for identifying different land-uses in urban areas. For dense urban areas they were able to identify buildings with 76 % accuracy, roads with 99 %, impervious surfaces with 81 %, grass with 91 % and trees with 100 % accuracies.

In all of the studies mentioned in section 3.2 it should be possible to obtain the amount of impervious surfaces in the studied area with at least the same accuracy as for surface materials. In many of the methods used, impervious surfaces is directly obtained in the step before the classification of different materials.

3.2 Detection of urban surface materials

The possibilities of mapping surface materials in urban areas have been limited by the spectral and spatial resolution of available data. During the last few years, developments of new sensors have opened up the field for research in methods for automatic or semiautomatic identification of urban surface materials.

One of the first attempts to use remote sensing to identify different surface material in urban areas was made in Stockholm in 1997. The aim of this study was to map roofs with copper plating (Ekstrand *et al.*, 1997; Ekstrand *et al.*, 2001c). Digitised aerial CIR (colour infrared) photos with a spatial resolution of 0.4 m were used. Conclusions drawn from that study was that it is possible to map copper roofs after some manual editing and that it is a potential to map other surface materials after further method development. Obtained accuracies for patinated copper was 90 % and for new copper 73 %. For other surface materials the accuracy were lower and varied a lot. Another early attempt to classify urban surface material was made in the US in 1994, here multispectral data were used (Ford and McKeown, 1994). The goal of that study was primarily to compare two classification techniques, and the classification accuracy was poorer than in the Stockholm study.

All other studies that have been successful in identifying different urban surface materials by automated methods have been using hyperspectral data, since the spectral resolution of multi-spectral data limits the differentiation of material properties (Heiden *et al.*, 2003; Lillesand *et al.*, 2004; Roessner *et al.*, 2001). Herold *et al.* (2003b) studied what spectral resolution that is necessary for mapping urban areas. They used hyperspectral data for mapping urban land use and investigated which bands of the hyperspectral data that was most suitable for identification of urban land use. The conclusion was that most of the suitable bands lie outside or near the boundary of the spectral range of sensors on available commercial satellites (Ikonos and

Landsat) and that the required spectral resolution could not be provided by common multi-spectral remote sensing systems.

With hyperspectral data it is possible to create a library of spectral characteristics of different material and use this for automatic classification (Heiden *et al.*, 2001; Herold *et al.*, 2003b; Marino *et al.*, 2001). Herold *et al.* (2004) developed a library of spectral characteristics of urban materials in the Santa Barbara region in California. Figure 2 shows examples on how spectral characteristics from different materials can look like. In theory it is possible to use the same approach with multispectral data but for most applications there are too few and broad wave-length bands available.

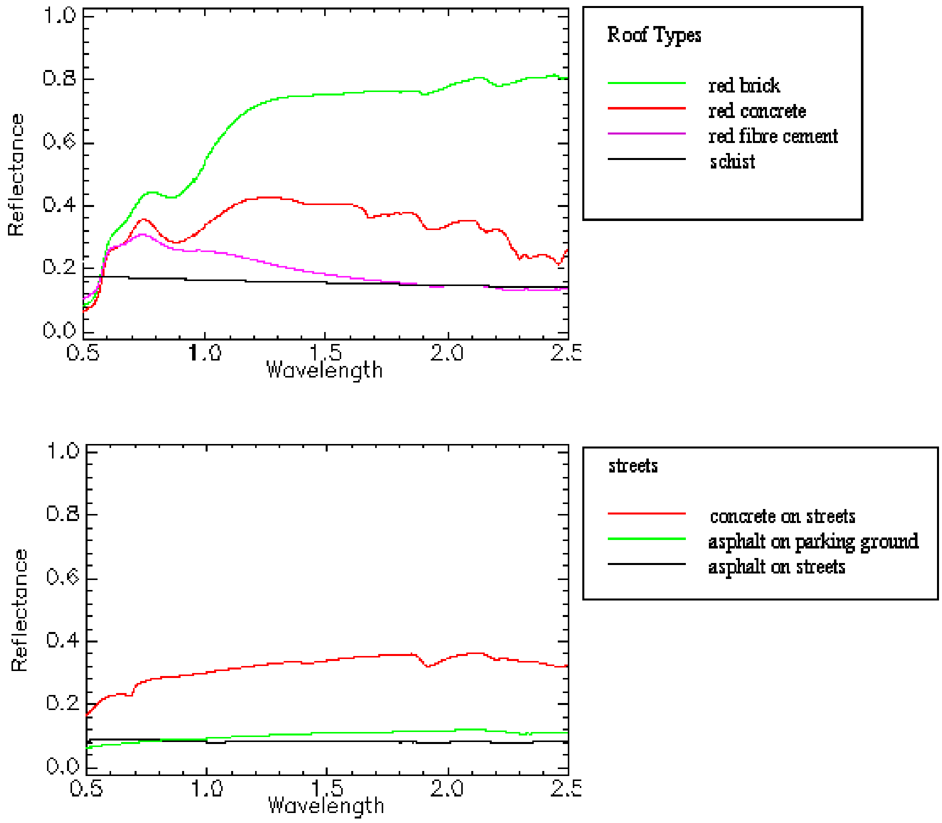


Figure 2 Examples of spectral signatures for different materials, measured with a field spectrometer on ground (GFZ, 2004)

In Italy a couple of studies using hyperspectral remote sensing for identifying materials has been performed. The emphasis in these studies have been on identification of surfaces covered by asbestos concrete, with classification accuracies for asbestos concrete of about 90 % (Fiumi, 2001; Marino *et al.*, 2001). Also other materials were classified, but with lower accuracies. Herold *et al.*, (2003a) tried to map roads using hyperspectral data. They reported problems with confusion between some roofing materials and asphalt, but concluded that “it is possible to describe general pavement age and specific surface defects”. Roessner *et al.* (2001) tried to identify different classes of urban surfaces in Dresden, Germany, classes such as “roofs”, “areas of traffic”, ”trees and bushes”, “lawn and meadow”, “bare soil” and “other open spaces” were classified with a high accuracy. A more detailed classification was made by Herold *et al.* (2003b) who used 26 different land cover classes for mapping an area in Santa Barbara, California. The reported overall accuracy was 74 %, which increased to 82 % when weighted by class area. But if classes that could be considered as "non-urban" (vegetation, bare soil and water) were excluded the accuracy decreased to 67 %.

Even if the hyperspectral data gives opportunities to identify different materials purely from the spectral signature using libraries with spectral signatures from different materials, there are still problems when different materials have similar spectral signatures (e.g. roofing bitumen/tar paper versus asphalt pavement or bare soils versus concrete roads) (Heiden *et al.*, 2001; Herold *et al.*, 2003a; Herold *et al.*, 2004; Segl *et al.*, 2003). In order to solve this problem different approaches of combining the spectral information with other data to identify different objects, such as roads and buildings, have been investigated. Herold *et al.* (2003b) points out that the accuracy they reached on a purely spectral basis could be improved: "Object-oriented or other classification techniques as well as spatial, textural or contextual information might provide a further significant improvement of map accuracy and help to overcome spectral similarities between specific classes." Digital elevation models (DEMs) have been used to supplement hyperspectral data (Madhok and Landgrebe, 1999; McKeown *et al.*, 1999). Extraction of buildings, either directly from the hyperspectral data or from other data sources (Segl and Kaufmann, 2001), in combination with the spectral information have also been used to increase the classification accuracy (McKeown *et al.*, 1999; Mueller *et al.*, 2003; Segl *et al.*, 2003). The best results with this approach were obtained by Mueller *et al.* (2003). The largest error was for concrete with a predicted value of 0.1 % compared to the mapped 8.3 % for one test site and 0 % predicted compared to 9.4 % mapped for the other. All other materials shows very good prediction accuracies. The results presented by Segl *et al.* (2003) are in the same order of magnitude. None of the areas in these studies contained any metal roofing, but Heiden *et al.* (2003) used a similar method and presents results for aluminium (predicted 1.3 %, mapped 1.7 %) and zinc (predicted 0.8 %, mapped 1.2 %).

It should be pointed out that in most of the mentioned studies the results for the surface material are presented as portions of the total, not as areas. The only study that has been calculating the area of a surface material is the study on copper roofs by Ekstrand *et al.* (2001c). When the area is to be calculated, information of the sloping of the roofs has to be taken into account. Ekstrand *et al.* (2001c) used a DEM for this calculation.

4 Conclusions and discussion

When reviewing the literature on remote sensing of urban areas it is striking that the reporting of obtained accuracies for different methods are difficult to interpret and compare between different studies. Sometimes manual interpretation of aerial photos have been used as the "true" result, sometimes random investigations in the studied area have been used and sometimes the obtained result of impervious area has been used as data to hydrologic models and the modelled flow has been compared to measured flow. To solve this problem there have been some attempts to standardise the accuracy assessments. Story and Congalton (1986) suggested that error matrices should appear in the literature whenever accuracy is assessed. Congalton (1991) evolved this and discussed other methods to be able to better assess accuracies. This has also become the most common method to assess accuracies. The basis for this technique is a pixel by pixel comparison of the classified data with the reference data. This creates problems when new methods for analysing data on a sub-pixel level have been developed; new ways to assess the accuracies have to be introduced in such studies.

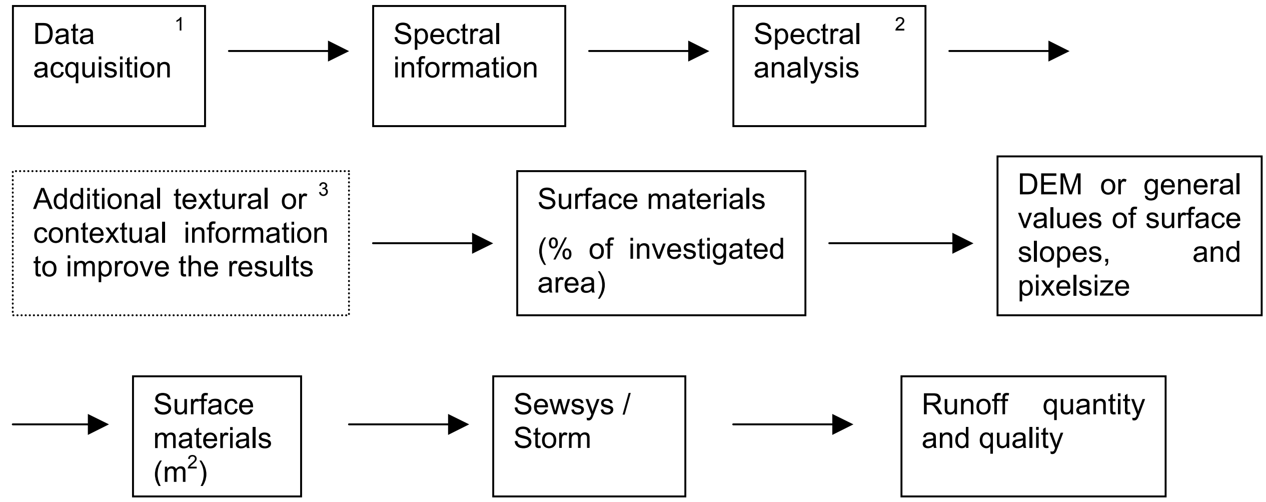
Despite the difficulties of assessing the accuracies of different studies it is possible to draw the conclusion that it is possible to determine material uses in the urban landscape. This has been done on an experimental level for some materials. If it is possible to map different materials it is also possible to determine the imperviousness of the studied area. To be able to identify different urban surface materials with automated methods and a satisfactory accuracy, it is necessary to use hyperspectral data and combine the spectral information with identification of different structures to be able to distinguish between materials with similar spectral signatures. The limitation in practical use of such methods is the limited availability of hyperspectral data and the costs of obtaining data. There are no satellites that provide hyperspectral data with enough spatial resolution for urban studies available today. To provide hyperspectral data for a study of an urban area today, it is necessary to make new flights with a hyperspectral scanner. Tukiainen (2002) reviewed costs for hyperspectal scanning of mining sites, the costs was expected to be 10,000-20,000 USD for mobilisation/demobilisation of the equipment, 10,000-20,000 USD for equipment rental per day, rental cost during standby of 5,000 USD per day and aircraft costs of 700-900 USD per hour. An estimation of the costs per square km gave that a one-day flight should cover 2660 km^2 and cost about 50,000 USD (Tukiainen, 2002). A flight-campaign is also dependent on very good weather conditions and some post-processing of the data is necessary before starting with the spectral analysis.

Hyperspectral data is believed to have large possibilities in remote sensing, Lillesand *et al.* (2004) predict that “hyperspectral sensing holds the potential to provide a quantum jump in the quality of spectral data obtained by earth surface features”. They also mention that “ultra-spectral” sensors that will provide data from thousands of narrow spectral bands are under development. Heiden (2004) concludes that “The identification of small objects is expected to be improved by using hyperspectral data with a higher spatial resolution. Further, the addition of thermal channels and the integration of 3D surface models would allow surface mapping on an extremely high accuracy level”.

Mapping of impervious areas is possible to do with high accuracies with data from high-resolution satellites. Availability of high-resolution satellite data is still limited, but is growing fast. The best available data is from the QuickBird satellite where multispectral (four bands: red, green, blue and near infrared) with a spatial resolution of 2.8 m are available and panchromatic (grey-scale) images with 0.7 m spatial resolutions (DigitalGlobe, 2004). Multispectral data from QuickBird costs about 2100 USD for 8x8 km^2 according to Lantmäteriet (the Swedish distributor of satellite images, personal communication)

To propose one method to be used for determining surface materials in urban landscapes is impossible. The choice of method is dependent on local conditions, such as availability on digital maps, quality on existing data, size of the catchment to be studied, purpose of the study, required accuracy, etc. In Figure 3 a flowchart of how remote sensing could be used for providing information necessary for the DayWater project are outlined. The main limitation of using remote sensing and automated methods for determining surface materials is the costs for achieving and processing data with required accuracy, and not the available technology. But the fast development of this technique will doubtless make it more competitive and more commonly used in the future.

In most cases today it is probably necessary to use more pragmatic techniques. In small catchments it is possible to use manual surveying, but when the size of the studied area increases it will be too time consuming. If digital maps and aerial photos are available it is possible to calculate areas of different land uses either manually or semi-automatic using GIS-tools. Manual surveys of parts of the catchment are probably necessary in all cases to ensure the quality of the mapping.



[1]with an airborne hyperspectral scanner for identifying surface materials or data from a high-resolution satellite for identifying imperviousness (less expensive)

[2]using an image analysis software with suitable algorithms and a library over different spectral signatures for urban materials, or training sites with identified materials in the area of interest

[3]Either with extended processing of the data or from other sources (such as a DEM)

Figure 3 Flowchart on how to obtain data on urban surface cover for use in hydrologic and/or substance flux models.

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