TOWARDS AUTOMATION OF IMPERVIOUS SURFACE MAPPING USING HIGH RESOLUTION ORTHOPHOTO

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Information on the amount and pattern of impervious surface is important for hydrological modelling of urban areas. As cities expand and/or develop, hydrologic models will become outdated unless information on impervious surfaces is kept up to date. At the moment, the mapping teams are faced with choosing from among a range of alternative approaches/tools/software products to achieve this. We report here, the results of experiments conducted for a range of mapping approaches applied to high resolution orthophoto imagery covering part of the residential zone of Monash City, a local government area in Melbourne, Victoria, Australia. The application of the Expert Classification (EC) or Feature Analyst (FA) approaches requires initial human involvement to set the knowledge/learner function, which, then can be applied to any areas of similar spectral patterns. The Feature Analyst (FA) approach yielded superior results compared these 'pixel-by-pixel' methods. All of these approaches refer to mapping in aid of distributed and connectivity modelling. In the absence of access to EC or FA tools, application of the (sampling-based) Precision Method (PM), (after careful consideration of sampling stratification) will offer total impervious surface data-input estimates for lumped hydrological modelling.

INTRODUCTION

Well-planned urbanisation brings rapid, mappable and “permanent” terrain changes (e.g. see Morisawa and LaFlure 1979), amongst which are those referring to the very significant increases in run-off ratios (Goudie 1990). These can be dealt with by building better storm-water drainage networks. Designed to cope with increased run-off that flows from sealed road surfaces, roofs and driveways, this storm-water pipe, and open-channel network intensifies run-off peak flows so that, in many cases, urban design options like retarding basins (Aitken 1977, O’Loughlin 1983, Wong and Somes 1997), infiltration basins (Guo 2004), water sensitive urban design (e.g. see Victorian Stormwater Committee 1999, Wong 2001, Lloyd et al. 2001) and constructed wetlands (Moshiri 1993, Wong et al. 1998) have to be included in the flood control works. The impervious surface pattern changes bring the need for monitoring/updating records of flow regimes for water pollution (e.g. Bannerman et al. 1993).

Inevitably, the pre-urbanisation years of the record become less and less relevant as houses, roads and factories replace the open fields. Under the new land cover regime, answers to questions about flash-flood vulnerability will vary from street to street, but will not be offered with confidence unless the local pattern of stream connectivity (proportion of impervious areas that connects to streams through storm water pipes) and storm water pipe capacity (segment by segment e.g. see Yoo 2004, in press) is known.

The integration of GIS and lumped hydrological models such as HEC-1 (Shea et al. 1993), TR-20 ('An Assessment' 1974), HSPS (Ross and Tara 1993) and SWMM (Cowden 1991; Shamsi 1993) has shown the significance of impervious surface mapping. For flash-flood control in the "new" landscape, distributed hydrological modelling emerges as an option if archives (such as old maps, parcel plans, aerial photos) and/or resources support the building of detailed impervious pattern maps. Apart from resorting to field mapping of impervious surface boundaries, all the methods for such database building will refer to making use of archival spatial data. Inevitably, the spatial database for such a study will be assembled in digital form, and will involve a certain amount of analogue-to-digital data conversion, some of which may already have been carried out during corporate database establishment, although progress towards corporate database adoption varies from one local government area to another (Peterson and Wigan 1995).

We report here the results of experiments in the application of a range of approaches to impervious surface pattern mapping. Each such application relies on access to high-resolution imagery, and the expertise needed to interpret it. All refer to access to digital spatial data and most to comparatively new software tools that are attracting interest among researchers and IT managers dealing with urban drainage infrastructure. One of the methods, by contrast, offers a way forward for groups who must deal with the problem of supplying the drainage engineers with an impervious surface pattern while not calling on any special software resources.

All outcomes were compared with those derived from the "best" but most expensive/labour-intensive option: the on-screen geo-referenced digitising of impervious surface area boundaries. Our experiments were designed to demonstrate results of interest in the on-going debate about which methods will conform to the principle of economy in survey and mapping, and if, when, and how the principle might be or have to be re-defined for a particular organisation in a particular circumstance. "The principle of working economically implies the acceptance of risk. At some future date, every system, even that is currently the best in the world, will need to be upgraded. In accordance with the principles of economy, present standards must be set that are reasonable but not excessive" (Dale and McLaughlin 1988, p. 102).

Approaches to mapping impervious surfaces have been evolving over several decades, and many of the results are being incorporated into industry standard tools via the "third-party software" route after software engineers have selected promising outcomes from the work of research groups interested in exploring the utility of various theoretical approaches. Amongst these, must be listed those calling for remotely sensed data: Sub-pixel classification (Civco et al. 2002; Justice et al. 2003), artificial neural networks (Mokken 1996, Flanagan and Civco 2001), and Classification and Regression Trees (CART) (Herold et al. 2003, Yang et al. 2003). In addition, index-based methods and models such as Normalised Vegetation Difference Index (NDVI) (Carlson and Ripley 1997, Hebble et al. 2001, and Xie et al. 2003) and Vegetation-Impervious Surface Soil (VIS) (Hung and Ridd 2002) have been used. Application of all these particular methods assumes routine access to spatial data infrastructure such as digital elevation models, and/or to timely image data sets, including those captured in the infrared region of the electromagnetic spectrum. Some call on complex algorithms and particular expertise and analytical capabilities that are beyond the reach of the non-scientific organisations called on to deliver a particular flood-control model/service. Thus there is a gap between the "ideal" and the "currently economical" as recently implied in the call by Walsh (2000) for ease and efficiency in deriving impervious surface patterns for mapping in the service of urban water quality management. Our

study is an attempt to answer this call. The objectives of the paper can be listed as follows: (a) to identify the advantages and the difficulties associated with mapping impervious/pervious surface patterns using high resolution aerial imagery, (b) to identify simple process flow diagrams (PFDs) to map impervious/pervious surface patterns with the help of most readily available GIS dataset i.e., parcel data, (c) to find a less time consuming, alternative sampling approach to estimate residential impervious surface percentage, and (d) to discuss the cost effective nature of the above approaches.

STUDY AREA AND DATA USED

Figure 1 Location map of the study area showing ortho-rectified aerial photo with cadastral overlay.

An area of 225206.90 m² lying between latitudes 37° 53' 13" to 37° 53' 24" S and longitudes 145° 10' 44" to 145° 11' 09" E covering a part of City of Monash, Victoria, Australia has been used for the study (Figure 1). The aerial photos were taken on 3rd and 5th May 1999 at a flying

height of 13,000 ft. The image has comparatively low sun angle/noticeable shadows. These offer some advantages to the photo interpreter, but complicate the automation of feature recognition. The other key data set used in this study is an extract from early 2004 version of VicMap digital property layer (also known as cadastre/parcel layer), a Victorian Spatial Database Infrastructure (VSDI) dataset.

IMPERVIOUS SURFACE MAPPING

The ortho-rectified aerial photo of 20 cm resolution, provided by the Monash City Council, encompassing the study area has accuracy of ± 30 cm to the State cadastral database. The same “clip” image (Figure 1) was used for all mapping approaches tested in this study.

APPROACH 1: ON-SCREEN DIGITISATION (OSD)

Figure 2 ImperVIOUS/pervious surface pattern derived from application of the On Screen Digitisation (OSD) approach.

This is the most accurate but least attractive approach to impervious surface pattern mapping because it is so labour intensive. However, the results constitute a bench-mark against which other approaches can be assessed. Four land cover classes (“Outside Parcel – Green Areas”, “Outsider Parcel – Impervious Surfaces”, “Within Parcel – Green Areas” and “Within Parcel - Impervious Surfaces”) were identified, and their boundaries digitised on screen using the Editing tools of ArcGIS (ESRI 2004) (Figure 2). The parcel layer is used as a reference while digitising

these classes on screen. The relatively high percentage of shadows hid many features (Figure 1). From photo interpretation, the assumption that “outside parcel” shadows were (nearly all) on the roads was made, and so they are considered as belonging to the class “Outside Parcel – Impervious Surfaces”. By contrast, underlying features of the shadows within parcels were, most of the time, seen to be “green areas” and so they are generalised to the class “Within Parcel – Green Areas”. Swimming pools are easily distinguished and are considered as impervious surfaces in this study. They are added to the class “Within Parcel – Impervious Surfaces”. Application of the on-screen digitisation approach for the study area of 271 parcels took 4 hours (including quality check). Results are among those tabulated in Table 1a.

Residential parcels are identified by reference to the land use planning scheme boundaries, and respective onscreen-digitised impervious surfaces are tabulated as another class namely, “Within Residential Parcel – Impervious Surfaces” to be used as a bench mark for the application of the precision method approach (Table 1b).

Class Name	Area in m ²	Area in %
Outside Parcel – Green Areas	8013.80	3.56
Outside Parcel – Impervious Surfaces	39764.89	17.66
Within Parcel – Green Areas	78164.48	34.71
Within Parcel – Impervious Surfaces	99263.73	44.08
Total	225206.90	100

Table 1a Relative coverage of the defined land cover classes derived by query of areas within polygons defined by boundaries interpreted and digitised on-screen from the display of the (coloured) orthophoto.

Class Name	Area in m ²	Area in %
Within Residential Parcel – Impervious Surfaces	85016.91	37.75

Table 1b Relative coverage of the residential impervious surface patterns identified by reference to the land use planning scheme boundaries.

APPROACH 2: EXPERT CLASSIFICATION (EC)

This approach is made with a combination of procedures: multispectral classification decision rule and expert classification (with ERDAS Imagine software tools: ERDAS 2003). Multispectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values, which, in this case, referred to the image colour patterns (RGB). If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criterion. This process is also referred to as image segmentation. In this study, four multispectral classification algorithms viz., Parallelepiped, Minimum Distance to Means, Mahalanobis and Maximum Likelihood are tested, using ERDAS Imagine tools, to map impervious/pervious surface boundaries. Both the parallelepiped and minimum distance to means decision rules deploy uni-variate statistics only. They were found unsuitable because they left many unclassified pixels. The Mahalanobis distance algorithm is similar to that used in the minimum distance classifier tool, except that the covariance matrix is used in the equation. In the current study, the Maximum Likelihood decision rule offered the best results, because, unlike the other

decision rules, it takes both uni-variate and multi-variate statistics into consideration (Equation 1).

Equation 1:

$$D = \ln(ac) - [0.5 \ln(|Covc|)] - [0.5 (X-Mc)^T (Covc^{-1}) (X-Mc)]$$

Where: D= weighted distance (likelihood), c= a particular class, X= the measurement vector of the candidate pixel, Mc= the mean vector of the sample of class c, ac= percent probability that any candidate pixel is a member of class c, (defaults to 1.0, or is entered from a priori knowledge), Covc= the covariance matrix of the pixels in the sample of class c, |Covc|= determinant of Covc (matrix algebra), Covc⁻¹= inverse of Covc (matrix algebra), ln= natural logarithm function, T= transposition function (matrix algebra). The pixel is assigned to the class, c, for which D is the lowest (Hord 1982).

Although the maximum likelihood decision rule was found to be the best amongst the others, it still could not resolve the problem of separating road pixels from the roofs of similar spectral reflectance (Figure 3). Roads and roofs belong to the same class: 'impervious surface'. But mapping them as separate classes would be useful for water quality studies because run-off waters from roads carry more pollutants than does run-off from roof areas (Duncan 2004). Moreover, the decision rule alone cannot distinguish the shadows outside a parcel from the shadows inside a parcel. For our particular study, this was a crucial requirement. During on-screen digitisation the shadows outside parcels are considered as impervious surfaces and the shadows within parcels are considered as pervious surfaces. To achieve these separations, a simple task list/process flow is identified as shown in the process flow diagram (Figure 4).

The "within" and the "outside" parcel pixels are handled separately. An attempt is made to distinguish classes within impervious surfaces. For example, outside parcel "White Surfaces" are the markings on the roads, and the (mostly concrete) path ways and drive ways. Likewise the "White Surfaces" within parcel are often driveways but some times white colour roofs. Training sites are defined using the "Seed tool" of ERDAS Imagine and multiple training sites are defined for a class if it is depicted by more than one colour. In the current study, for example, for the "Roofs" class, 8 training sites are defined (roof1, roof2 ... roof8), to represent the range of roof colours. Output from application of the maximum likelihood decision rule can then be recoded to merge classes for assembling data on roof cover patterns (roof1 – roof 8 becomes "Roof"). Likewise, coverage patterns for Roads, White surfaces, Shadows and Green Areas (all "outside parcel" classes) as well as Roofs, Shadows, White Surfaces, Swimming Pools and Green Areas (all "Within Parcel" classes) were assembled. These two classified output images are coded (Figure 5) to be input variables for the application of the Knowledge Engineer (the expert classification tool in ERDAS Imagine). Another variable, named as "Is Parcel", is created by converting "Parcel layer" into a raster image and by coding its value to 1. A simple model with hypothesis and rules is created using the variables with the help of the easy-to-use Knowledge Engineer module as shown in Figure 5. Maps (Figure 6) and statistics (Table 2) are generated from this output.

Figure 3 Part of the study area showing similar spectral reflectance for the roof and the road: information on the location of the surface, i.e., whether it was inside or outside a parcel, was used to distinguish between roofs and roads.

Figure 4 Process flow diagram for mapping impervious/pervious surface pattern using the Expert Classification (EC) approach.

Figure 5 Hypothesis, rules and the variables used in application of the Expert Classification (EC) approach.

Figure 6 Impervious/pervious surface pattern derived from application of the Expert Classification (EC) approach.

Class Name	Area in m ²	Area in %
Outside Parcel – Green Areas	7856.52	3.49
Outside Parcel – White Surfaces	12022.24	5.34
Outside Parcel – Shadows	10813.64	4.80
Outside Parcel – Roads	17220.08	7.65
Within Parcel – White Surfaces	6961.76	3.09
Within Parcel – Green Areas	60714.96	26.96
Within Parcel – Roof	76106.72	33.80
Within Parcel – Swimming Pool	2728.64	1.21
Within Parcel – Shadows	30596.48	13.59

Table 2 Relative coverage of the defined land classes derived by application of the EC approach.

APPROACH 3: FEATURE ANALYST (FA)

Visual Learning Systems (VLS) market Feature Analyst (VLS 2001) as an extension to ArcGIS (<http://www.featureanalyst.com>). The concept behind the FA is the adaptive agent known as the “learner”. The learner uses the adaptive agent to extract other features that closely resemble the examples provided, and returns them in the form of a shape file (an ESRI propriety format for vector data). It is designed to apply information about user-defined (by on-screen digitisation) feature shapes (as opposed to “pixel-by-pixel classification”) to feature extraction. Defining

shape representation of the feature of interest and its spatial aggregation are key factors in achieving results when using this approach. “Hierarchical learning” (a sequence of learning passes to remove clutter and add missed features) is deployed during the extraction exercise. For the present application, extraction of each class as a separate layer using “hierarchical learning” returned intriguing patterns of promising utility. However, it was found that after combining all the classes into a single layer, the output contained unclassified areas. To achieve impervious/pervious mapping of the entire area, the classification task was re-designed as shown in Figure 7.

Figure 7 Process flow diagram for mapping impervious/pervious surface pattern using the Feature Analyst (FA) approach.

As with the application of the EC approach, the “Within Parcel” classes and the “Outside Parcel” classes are handled separately. It was noted that the “Outside Parcel” features are linear in nature, whereas the features “Within Parcel” are non-linear in nature. This was a key factor while defining input representations during deployment of the FA approach. For the “outside parcel”, an input representation known as “Bull’s Eye” is used, and for “Within Parcel”, “Manhattan” is used (VLS 2001). The cadastral land-parcel layer boundaries are used as the “Regions to Exclude” (i.e., a “mask”) for distinguishing areas outside parcels, and also when defining the “Regions of Interest” during “Within Parcel” analysis. Spatial aggregation of 50 pixels is defined at this stage. The “wall-to-wall” classification option is used for both the sets so that no area is left unclassified. The resultant output class shape files are then combined. To resolve ambiguity in overlap regions and unclassified regions (if any), the VLS feature analyst provides an option to allow the “learner routine” to handle it.

After application of the VSL Feature Analyst, the resultant classes are “Roads”, “Outside Parcel – White surfaces”, “Outside Parcel – Shadows”, “Outside Parcel – Green Areas”, “Roofs”, “Within Parcel – Shadows”, “Within Parcel – White surfaces”, “Swimming Pools” and “Within

Parcel – Green Areas”. Using the Douglas and Peucker, 1973 algorithm, the resultant shape file was generalised to have smooth edges. Maps (Figure 8) and statistics (Table 3) are generated from this output.

Figure 8 Impervious/pervious surface pattern derived from application of the Feature Analyst (FA) approach.

Class Name	Area in m ²	Area in %
Outside Parcel – Green Areas	12736.27	5.66
Outside Parcel – White Surfaces	6066.81	2.70
Outside Parcel – Shadows	8234.04	3.66
Outside Parcel – Roads	20656.63	9.19
Within Parcel – White Surfaces	8875.43	3.95
Within Parcel – Green Areas	56483.44	25.12
Within Parcel – Roof	96367.26	42.86
Within Parcel – Swimming Pool	1846.41	0.82
Within Parcel – Shadows	13591.67	6.04

Table 3 Relative coverage of the defined land classes derived by application of the FA approach.

APPROACH 4: PRECISION METHOD (PM)

The previous approaches refer to pattern recognition and image processing. The PM approach, on the other hand, is based on application of sampling theory. The PM approach assumes that averaging typical residential impervious surface areas with OSD can be successful if undertaken

in a way that is informed by sampling theory. Clearly the sample building size digitised will only represent some of the characteristics of the population, but the sampling theory enables us to predict the probability, so that our local sample offers a good indication (Dixon and Leach, 1977; Som, 1996). We adopted the concept of randomised testing, whereby each occurrence of sample has the same probability of being included in the sample test (Dixon and Leach, 1977): as the population of buildings is sampled repeatedly (i.e. we steadily increase the number of data points) the average value calculated from the sample data will approach the actual value (Hill et al. 2001). Sample point accumulation eventually achieves an adequate precision AP (Equation 2).

Equation 2:

$$AP = SE / SM = (SD / \text{Sqrt}(n)) / SM$$

Where SE is the standard error, SM is the sample mean, SD is the standard deviation, and n the sample size. As the sample size increases, the estimate of the mean will be more precise (i.e. AP will be smaller) (Equation 2). The application of the PM approach was depicted in the process flow diagram (PFD) (Figure 9).

Because the residential building sizes are not being measured (one by one as with deployment of OSD) but rather are being estimated sampling must refer to land parcel aggregates of similar pervious/impervious ratio. Accordingly, sampling is stratified in reference to the land-use planning zone map. This planning zone scheme layer (spatial data obtained from VSDI) was overlaid onto the cadastre layer to identify residential parcels that can be included in each sampling exercise. Random points are generated on the study area using the `rand()` function in Microsoft Excel. Based on the location of the random points, a parcel was selected, and the impervious surface within that parcel was digitised to represent the residential impervious surface. Identification of a level of precision that is acceptable requires a trade-off between sampling effort and the need to achieve a more precise estimate of the mean. An optimal number of sample points can be deduced by examining the relationship between AP and the number of samples. One hundred random points were generated in a test residential suburban study area, and the nearest building to each point was chosen for digitisation. Only 75 points were only found to be “within parcel” points. Of these, more than one point was found within some single parcels. Ultimately, 60 samples were plotted using Equation 2 (Figure 10, Series 1). The resulting samples were randomised 10 times and plotted (e.g. Figure 10, Series 2 to series 10). A sample of 20 appears to be sufficient to achieve a precision of <0.05 , and further sampling results in only a very small improvement. For this test study area, therefore, a sample of 20 was considered an optimal size for estimation of mean building size. The mean sample size calculated for the study area was 419.26 m². Using the radius of the sample, size buffers are generated from the centroids of the parcels to depict/approximate impervious surface patterns (Figure 11) and statistics are generated (Table 4). The application of the PM approach yielded 83013.34 m² of area for the class “Within Residential Parcel – Impervious Surface”.

Figure 9 Process flow diagram for mapping impervious/pervious surface pattern using the Precision Method (PM) approach.

Figure 10 Precision plot of sample points.

Figure 11 Depiction of residential impervious surface pattern derived from application of the PM approach.

Class Name	% OSD	% EC	% FA	% PM
Outside Parcel – Green Areas	3.56	3.49	5.66	-
Outside Parcel – Impervious Surfaces	17.66	17.79	15.52	-
Within Parcel – Green Areas	34.71	40.55	31.12	-
Within Parcel – Impervious Surfaces	44.08	38.10	47.55	-
Within Residential Parcel – Impervious Surfaces	37.75	-	-	36.86

Table 4 Comparative statistics of impervious/pervious surface mapping using OSD, EC, FA and PM.

DISCUSSION

For the purpose of comparison with respect to results derived by on-screen digitisation, both the EC and the FA approaches were applied for mapping the same land-cover classes: white surfaces, shadows and roads of the outside parcel are grouped as “Outside Parcel – Impervious Surfaces”. White surfaces, roofs and swimming pools within land parcels are grouped as “Within parcel – Impervious Surfaces”. Shadows and green areas within land parcels are grouped as “Within Parcel – Green Areas”. Statistics reveal that the process flows implemented (see PFDs: Figure 4, 7 and 9) returned satisfactory results (Table 4).

The EC approach yielded higher accuracy for the classes “outside parcel” (3.49 % of Green Areas and 17.79 % of Impervious Surfaces) with respect to OSD results (3.56 % of Green Areas and 17.66 % of Impervious Surfaces) (Table 4). This is due to the fact that the “outside parcel” classes (Roads, White Surfaces, Shadows and Green Areas) are spectrally separable, and so scope for encountering ‘mixed pixels’ is lessened (Figure 12 (c)). However, the approach offered lower accuracy for “Within Parcel” classes (40.55 % of Green Areas and 38.10 % of Impervious Sur-

faces) with respect to OSD results (34.71 % of Green Areas and 44.08 % of Impervious Surfaces) (Table 4). In this case, some of the roofs are classified as green areas, and some as shadows (Figure 12 (c)). This is due to the fact that parts of the roofs have shadows due to the low sun angle, and some of the green area pixels (mainly canopies) have overlap with the roof pixels.

Figure 12 Detailed view of part of aerial photo (a) and its impervious/pervious surface patterns using (b) On Screen Digitisation, (c) Expert Classification and (d) Feature Analyst approaches respectively

Application of the FA approach yielded satisfactory results for both “within”, and “without” parcel classes (Table 4, Figure 12 (d)). It offered superior results compared to those obtained from use of the “pixel-by-pixel” method. Application of input representation and spatial aggregation algorithms allowed the shapes of the defined features to be identified and extracted. Due to the spatial aggregation applied in implementing the FA approach, some of the tree-canopy occupies road-space because the algorithm will try to preserve the shape of the “canopy” object. For example, shadows within the “canopy/tree” feature will be aggregated to the class “green areas”. Thus the percentage of “Outside Parcel – Shadows” is less and “Outside Parcel – Green Areas” is more (Table 3) compared to results derived from application of the EC approach (Table 2). The FA approach yielded higher accuracy of “Within Parcel” classes.

The PM approach offered higher accuracy for the class “Within Residential Parcel – Impervious Surface (36.88 %) with respect to OSD results (37.75 %) (Table 4). The stratification of residential parcels from other parcels was found to be useful in achieving homogeneity of the study area and in offering an indicator of the value of sample stratification and of the best way of stratifying. For the purpose of lumped hydrological modelling, the class “Outside Parcel – Green Areas” (3.56 %) can be ignored and the “Outside Parcel” areas can be treated as impervious surfaces, although, in order to improve the result, a percentage adjustment might be applied by taking into account the “nature strips” (Figure 12 (a) and (b)).

In the study area, it was found that not all the trees are green in colour. Some trees (pinkish) have similar spectral reflectance to some of the roof tops. The EC approach failed to assign these to the class ‘green areas’. The FA approach could group most of these pixels to green areas based on feature shape. But, with data from the IR (Infra Red) band of the electromagnetic spectrum, such ambiguity would be resolved whichever of these approaches was deployed. Such data is currently available from both Quick bird and IKONOS. In these terms the satellite data vendors have more to offer than do the aerial photo vendors.

The above methods would have to be modified if impervious/pervious surface pattern mapping of areas with both concrete surfaces (impervious) and bare sand areas (pervious) was desired. In such cases, the PFDs might be modified to allow data integration, perhaps referring to “bare sand” maps, derived from OSD by image interpreters, or from terrain attribute generation. The latter might be automated if Radar or LiDAR data is available.

Pervious/impervious pattern mapping at a land-parcel scale is likely to play a very important role when Local Government Authorities (LGAs) are coping with the transition from “static to dynamic storm water management” strategies as might be required when population densification policies in aid of sustainability and containment of urban sprawl are being brought to practice. The LGAs and other stake holders in key assets and infrastructure have to manage and monitor urban storm water run-off from the catchments and will have to call upon the most current methods for precise mapping of impervious and pervious surfaces. Implementation of information age data handling offers local government administrators the option of imposing an annual levy upon property owners based on the amount of land parcel impervious surface area. Such a method of utility tax rate determination is being proposed by some of the municipal governments in the USA (Tullis et al. 2003). Environmental concerns arise from contemplation of the increasing impervious surface areas in our rapidly expanding cities (particularly outer suburban areas). They include those referring to the climatic effects of the urban heat island and declining air quality. The local governments are now being faced with the challenge of impervious and pervious surface balancing when dealing the re-development/new-development planning permit applications. Results of such study as reported here will be relevant to GIS teams charged with providing the necessary decision support.

CONCLUSION

Results of automated impervious surface pattern mapping compared to those derived from OSD, refers to mapping methods that can be applied in a day or so every time new orthophoto coverage for a LGA is acquired. In contrast, to implement the OSD approach for the City of Monash (approximately 75000 parcels) would take 140 man days. Updating with an automated approach is more feasible. It could be part of corporate database management, and would facilitate deployment of change detection methods. Application of either of the image pattern analysis methods tested in this study will yield economically assembled and repeatable, up-datable impervious surface patterns fit for input to connectivity modelling and to “distributed hydrological modelling”.

Though the application of the Expert Classification (EC) or Feature Analyst (FA) approach requires initial set up of the knowledge/learner, it is repeatable to any areas of similar spectral characteristics. The Feature Analyst (FA) approach yielded superior results compared to ‘pixel-by-pixel’ classification methods. In the absence of access to EC or FA tools, application of the precision method, (after careful consideration to sampling stratification) will offer acceptable total impervious surface estimates, sampling zone by zone, for lumped hydrological modelling. However, the boundaries between the sampling zones and the sub-catchments will not necessarily be conveniently compatible. This may impose problems during the process of merging zone totals during aggregation of zone results for sub-catchment modelling. The ease and speed with which the PM approach can be applied (after careful area stratification) is clearly appealing if there is no call for distributed hydrological or connectivity modelling.

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