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Investigations into Urban Creep at 5 Cities

Synopsis

This paper will present some of the findings from a UKWIR funded study for which Richard Allitt Associates were appointed research contractors in 2008. The investigation process will be explained in detail. This used the latest generation of remote sensing data which comprised high resolution, multi-spectrum aerial photography which Infoterra Ltd used in conjunction with other data including Lidar surveys to compile a "Land Cover Classification Map". The study utilised this data for five 100km^2 study areas, in Leicester, Maidstone, Chester, Norwich and Newcastle upon Tyne. Infoterra were also able to supply data from between 4 years and 7 years previously for each of these study areas, again using aerial photography to identify the changes which had occurred in relation to roofs, artificial hard surfaces and vegetation.
Richard Allitt Associates have used this data to undertake a comparison of these changes (urban creep) by removing any changes which have been due to growth. A complex sampling strategy was developed to sample this data according to drainage system type, soil type, house type, house footprint area, depth of front gardens and perhaps most importantly by socio-demographic factors. This resulted in a total of in excess of 8,500 actual samples after the more extreme values have been removed. From this work Richard Allitt Associates have been able to draw conclusions about what the amount of urban creep has been over the past few years according to a variety of different factors and also develop a methodology for predicting future urban creep.
The methodology developed for this study is readily repeatable in future years as more data becomes available.

1. Introduction

"Urban Creep" is the term used to describe the change of permeable areas within the urban environment to impermeable areas. Typical types of urban creep are the creation of patios, paving the front gardens to create hard standing parking areas (See Figure 1) or house extensions.

Figure 1: Example of Urban Creep

It has long been known that "urban creep" was a growing problem but there were relatively few studies quantifying the problem. UKWIR commissioned Richard Allitt Associates Ltd to undertake this study into "Urban Creep" with the objectives of providing data on the degree and rate of "urban creep" and also to develop a methodology for modelling the degree of urban creep within hydraulic models so that future projections of the impact of urban creep on CSO spills, pumping costs, treatment costs and flooding could be determined.

The methodology we followed in this study to measure the urban creep has been developed to be easily reproducible in the future so that future assessments can be undertaken, the methodology used is described in more detail below.

For this study we used five sample locations within England and Wales these were, Leicester, Maidstone, Chester, Norwich and part of Newcastle-Upon-Tyne. Each sample area covered an area of 100 sq km (10km by 10km). The selection of these sample areas was governed by the availability of data to produce the required Land Cover Classification Maps by Infoterra, which was the key dataset for determining the urban creep. It was important that such large sample areas were used in order to sample large numbers of properties and allow for any extremes to be removed avoiding any skewing the results. Overall there were approximately 34,900 samples analysed during this study which equates to just over 2 million properties.

2. Methodology

To undertake this study Richard Allitt Associates Ltd developed a methodology which utilised remote sensing techniques to allow large areas to be sampled and two snapshots in time. This remote sensing technique was a key component of this study and as such was a key decider into which areas were sampled. For this study five sample areas were selected around England and Wales each covering an area of 100 sq km (10km by 10km) which in most cases covered the whole town and in others it covered a large portion of the urban area. For each sample area two snapshots in time were analysed. The locations and timeframes used in the study were:

- Leicester — 1999 and 2006 (a 7 year difference)
- Maidstone — 2003 and 2006 (a 3 year difference)
- Newcastle Upon Tyne — 2002 and 2007 (a 5 year difference)
- Chester — 2003 and 2007 (a 4 year difference)
- Norwich — 1999 and 2006 (a 7 year difference)

For Norwich, Chester and Maidstone the whole of the town and some of the outlying settlements were included within this 100 sq km sample area whereas for Leicester the sample area covered the majority of the city. Newcastle upon Tyne is a very large city and as a result the sample area only covers part of the inner city area. Figure 2 shows the contrast in density between the sample areas of Newcastle upon Tyne and Maidstone.

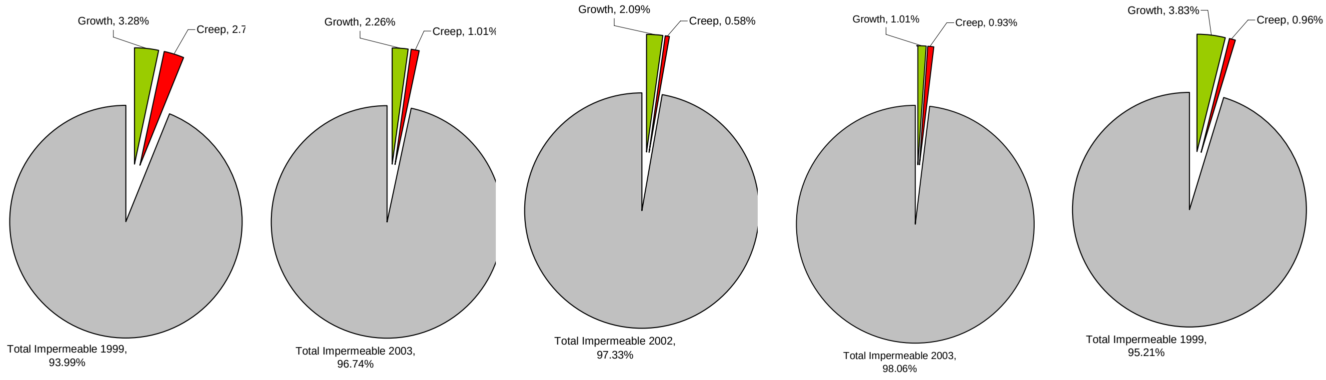
One of the key datasets which is used in the production of the Land Cover Classification Maps is high resolution aerial photography. As a result of this Infoterra could only produce the high resolution Land Cover Classification Maps for the most recent period for each of the five sample areas. In addition to this Infoterra also produced a change map which showed the areas of creep and growth, this allowed us to calculate the impermeable areas for the previous snapshot in time. Further details about the Land Cover Classification Maps can be found in Section 3 below.

As this study was focused on urban creep it was important that the growth within the sample areas was removed early on. For this study the definition of growth was as follows:

"Growth is either the addition of a new property where there was no previous property or the addition of paved areas associated with new properties. Major highway improvement schemes which may not be directly linked to a new development are also to be considered as 'growth'".

The amount of growth and creep within each sample town differed, the pie charts below show how the impermeable surface has changed over there respective timeframes.

Figure 2: Example of Sample Areas



Leicester (1999 - 2006)	Maidstone (2003 - 2006)	Newcastle Upon Tyne (2002 - 2007)	Chester (2003 - 2007)	Norwich (1999 - 2006)

Graph 1: Percentage split of current Impermeable Area

Once the growth had been removed the next stage was to generate the samples within each of the five sample areas which we were going to analysis to indentify any links with the degree of urban creep. Details of the sample strategies used in this study are discussed in more details in section 4 below. Once the samples were generated the next step was to use MapInfo to calculate the area of each sample that is covered by paved surfaces or buildings both from the latest Land Cover Classification map and from the creep map. In addition to the areas of paved surfaces and buildings the area of the sample was also measured along with a count of the number of properties within the sample. This data was then exported into Excel to allow further analysis to be undertaken to identify any trends.

3. Land Cover Classification Maps

In order to identify urban creep features from remote sensing data it is necessary to execute a change detection analysis between two or more multi-temporal images. Such an approach may yield useable estimates of gross change from medium to high resolution imagery. However specific change identification may only be achieved by classifying gross change into a target (such as urban creep) and other changes such as deforestation. In order to identify features required for this study very high resolution imagery is needed which compounds the problem of irrelevant change by introducing many false positives due to shadowing, local illumination and parallax.

Infoterra used GeoPerspectives^{TM} imagery as the basis to map urban creep. Initiated in 1999 GeoPerspectives^{TM} is a rolling programme delivering up to date, map accurate imagery and height information nationwide. For each mapped area two dates of aerial imagery captured at 25cm ground resolution were sourced with the greatest time lapse (4 to 7 years) between acquisitions.

To help overcome some of the problems identified with image to image change detection Infoterra used LandBase^{TM} land cover classification maps. These maps utilise the latest generation of digital airborne imagery available to include colour infra-red imagery, Digital Surface Models (DSM), Digital Terrain Models (DTM) in addition to the natural colour imagery to give data 'stack'. This stack is combined within an object orientated classification system to semi-automatically generate a high resolution land cover map depicting core features such as buildings, trees and artificial surface. Artificial surface and buildings were utilised in this study as impermeable whereas all other LandBase classes are defined as permeable. The accuracy of this split between artificial surface & buildings (assumed impermeable) and all other land cover types is approximately 95% (Tewkesbury & Hinchliffe 2009)[1]. Where available (typically city centres) Lidar DTM & DSM data was used to improve the classification accuracy of height dependant features. LandBase was created from the latest image of the two date pairs and so accurately maps the land cover state of that time. It was not possible to create LandBase from the older imagery due to incompatible technologies. However, comparing the old imagery against LandBase allows a focused change detection process and automatic classification of identified change. This technique also bypasses topological errors associated with the direct comparison of multiple land cover maps.

The urban creep feature extraction is performed using a routine built by Infoterra within Definiens Developer. The two dates of imagery along with LandBase is semi-automatically classified using an object orientated approach whereby each image is divided into meaningful objects via a segmentation process. The classification and comparison of objects verses image pixels has the distinct advantage of reducing spectral variability and allowing the integration of contextual information such as shape and proximity.

Impermeable regions identified in LandBase are compared against the old imagery and tested for 'greenness' by using image ratios. For highly 'green' areas in the old imagery it can be assumed that it was vegetated and is now impermeable in the latest imagery. Once these green candidates are identified they are subjected to two further verification tests. Firstly they are compared against the 'greenness' of the latest imagery and only the candidates where the two dates of imagery appear to differ significantly are retained. Secondly the image brightness is tested to eliminate deep shadows which may yield unreliable results. The remaining candidates are then compared against LandBase to classify into vegetated objects which have changed to building or artificial surface. An inverse procedure is used to identify impermeable areas which have become vegetated although this is seldom seen. The results of this process can be seen in Figure 3.

Using this semi-automatic image analysis allows the mapping of very large areas which would not be possible from manual image interpretation alone due to the complexity and abundance of target features.

Figure 3. GeoPerspectives imagery over Leicester from 1999 (top left) and 2006 (top right) along with corresponding LandBase (bottom left) and urban change (bottom right). All imagery courtesy of Infoterra Ltd. and GeoPerspectives.

4. Other Data requirements

The Land Cover Classification Maps were not the only dataset used in this study. To help us with the sampling strategies the respective sewerage undertakers were asked to provide the following datasets:

- Mastermap™
- Address Point Data
- Sewer Records
- Postcode Boundaries
- Soil Maps
- ACORN™ data (socio-demographic data by postcode)
- Property Age data (only available for 2 of the 5 samples areas)

The Mastermap™, Address Point Data, postcode boundaries and Sewer Record datasets were easy to obtain for all five of the study areas. It was not possible to obtain detailed soil maps from each of the sewerage undertakers so it was decided to use the WRAP maps in the Wallingford Procedure for all five areas.

The ACORN™ dataset was only available for four of the five sample areas. This dataset is a geodemographic dataset which is produced by CACI and groups the entire UK population into five categories, 17 groups and 56 types. For this study it was decided that it was not necessary to break down the sample areas into the 56 types so the 17 groups were used as shown below:

ACORN™ Category	% UK Population	ACORN Group	% UK Population
1 – Wealthy Achievers	25.4	A – Wealthy Executives	8.6
		B - Affluent Greys	7.9
		C – Flourishing Families	9.0
2 – Urban Prosperity	11.5	D – Prosperous Professionals	2.1
		E – Educated Urbanites	5.5
		F – Aspiring Singles	3.8
3 – Comfortably Off	27.4	G – Starting Out	3.1
		H – Secure Families	15.5
		I – Settled Suburbia	6.1
		J – Prudent Pensioners	2.7
4 – Moderate Means	13.8	K – Asian Communities	1.5
		L – Post-Industrial Families	4.7
		M – Blue-collar Roots	7.5
5 – Hard-Pressed	21.2	N – Struggling Families	13.3
		O – Burdened Singles	4.2
		P – High-Rise Hardship	1.6
		Q – Inner City Adversity	2.1
		U - Unclassified	

For two of the samples areas, property age data was also provided but both sets were based on different methods of determining the age. One set used data from the Valuation Office and gave us the age of the oldest property within a postcode in 2007 and the age with the highest frequency in 2007. The other dataset was derived by studying historical mapping and identifying when the property first appeared on the available mapping.

5. Sampling Strategies

A series of sampling strategies were derived using the various datasets discussed above. The sampling strategies are broken down into two main categories, Category 1 – Whole Area and Category 2 – Smaller sub areas, within these two main categories there were a number of sampling strategies, this are listed below:

Category 1 – Whole Area

- Whole Area
- Soil Type
- System Type

Category 2 – Smaller sub areas.

- Building Footprint
- Property Density
- Depth of Front Gardens
- Property Type
- ACORN™ (Geodemographic)

For the category 1 sampling the whole 100 sq km sample area was used, in the case of the whole area sample this gave us a single figure for the urban creep which was then divided by the number of properties within the sample area and then divided by the number of years between datasets. This provided an average value per house per year for urban creep in each of the five sample areas. Similarly for the Soil Type sampling the whole 100 sq km sample area was used but in some cases the sample area was covered by more than one soil type so the 10km by 10km square was subdivided into the different soil types. For each soil type within the sample area the average urban creep per house per year was calculated. For the system type sampling, postcode boundaries were used to subdivide the whole 100 sq km sample area and each postcode was assigned one of the following system types:- combined, partially separate or separate. For example if there was a combined sewer within the sub area the postcode was assumed to be combined and if there was a surface water sewer present then it was assumed the postcode was separate.

For the category 2 sampling a number of smaller sample areas (typically 30) were derived for each sample range within each sample strategy. Each of these 30 smaller sample areas contain between 40 and 50 properties; this generated a very large number of samples.

The Building Footprint sampling was carried out using the Mastermap™ dataset, which already had the area of the buildings as part of it. From this dataset 6 ranges were selected, (which were consistent across all 5 towns), these were 20 to 45m^2, 45 to 70m^2, 70 to 95m^2, 95 to 120m^2, 120 to 145m^2 and 145 to 170m^2. It was found that there were no residential properties larger than 170m^2 in any of the 5 sample towns. Where it was possible for each of these 6 ranges 30 sample areas were defined in MapInfo, each containing between 40 and 50 properties. The total number of properties sampled was 30,689.

The methodology used in the Property Density sampling was to sub-divide the whole 100 km^2 sample area into a series of 200m by 200m squares (a total of 2,500 squares). Once these squares had been created the next stage was, using the address point data, to add up the number of properties (address points) within each square to give a density. Once the property density had been calculated for all 2,500 squares the next stage was to select 40 samples (where possible) for each of the 16 selected ranges. The selected ranges started at 0 to 25 and then increased in increments of 25 up to 375, the 16th range was 375 to 1000. The samples were randomly selected from the entire sample area; however we did try to avoid having samples of the same range adjoining each other. The total number of properties sampled was 223,104.

The Depth of Front Garden sampling was also carried out using the Mastermap™ dataset, although it was found beneficial to extract the “Buildings” and the “Road and Paths” to work with. The methodology for calculating the depth of front gardens for each property was to buffer off the road and path layer in 1 metre increments (up to and including 12 metres). The next stage was to update a copy of the extracted buildings with the value of the buffer for which the building was first intersected with a buffer. Once the depth of front gardens had been calculated, the next stage was to define 30 sample regions (with 40 to 50 properties in each) within each town for each of the three selected ranges. The ranges selected for analysis were 1m to 6m (insufficient room to park a car perpendicular to property), 6m to 9m (room to park a single car perpendicular to property) and 9m to 12m (room to park more than one car perpendicular to property). The total number of properties sampled was 25,481.

Mastermap™ was also used as the basis for the property type sampling. For this it was necessary to manually identify the property types and group them. Four property types were selected, these were Detached Houses, Semi-detached Houses, Terraced Houses in narrow streets and Terraced Houses in wide streets. The reason for the two terraced house types was to try and identify if there was more of a driver for urban creep if the road was narrow (defined as "if the road is not wide enough to have parked cars on both sides and still have free flowing two way traffic") compared to if the road was wide. As with the other category 2 sampling for each for the four property types, 30 sample areas were defined within each town with each sample area having 40 to 50 properties within it. The total number of properties sampled was 29,922.

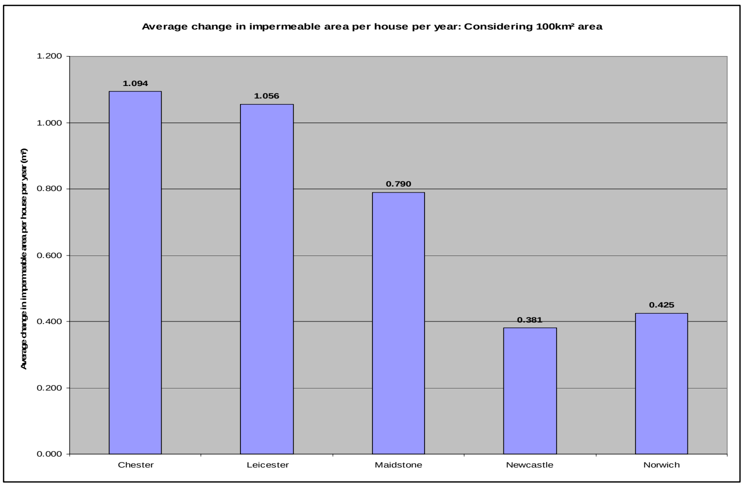
For the ACORN™ sampling both the postcode boundary data and the ACORN™ datasets were used. The first stage was to update the postcode boundaries with their corresponding ACORN™ group, for some of the sample towns the postcode boundaries already had the ACORN™ group assigned. It was found that the number of postcodes within each ACORN™ group differed between each town, so it was decided that all of the postcode boundaries within each town should be used as the sample regions. The total number of properties sampled for this was 366,494.

Once all of the samples had been defined the next stage was to calculate what area of the sample was currently paved (Artificial Surface) and what area was roof (Buildings). This is where the Land Cover Classification Maps purchased from Infoterra were used. From the outset of this project we planned to use readily available industry standard software, with this in mind we aimed to use InfoWorks CS to undertake the area measurements. However it was found that InfoWorks at the time could not handle the LandBase™ data due to the horizontal lines. To get round this we resorted back to using MapInfo to measure the areas, even with MapInfo there were issues with the size of the data being processed and workstations with a 64bit operating system and 8GB of RAM were needed to crunch the data. Once the current paved and roof areas had been calculated for the sample areas the next stage was to repeat the exercise with the creep maps. With this completed, each sample area now contained the areas which are currently paved and roofed along with the area which was deemed to be creep for both paved and roof areas. The data was then exported out of MapInfo as a text file and imported into Excel for further analysis. Once the data was in Excel it was easy to calculate what the paved and roof areas would have been at the time of the older aerial photographs by subtracting the creep from the current areas.

6. Results

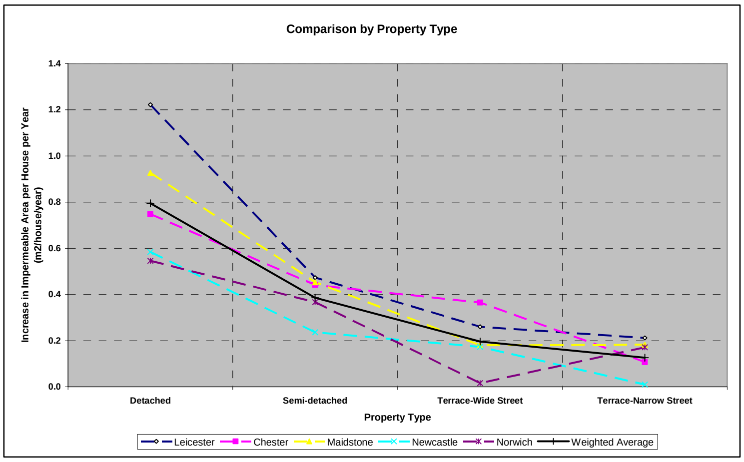
Analysis of the data has been carried out within Excel. To start with we focused on single variables to try and find any possible relationship to the amount of urban creep. At the time of writing this paper work was still ongoing with analysing the data and some complex regression analysis modelling was been undertaken to help identify any key independent variables.

Due to the different timeframes between the five sample towns we have calculated the urban creep in m^2 per house per year. Graph 2 shows the average change in impermeable area <u>per house per year</u>



Graph 2: Average Change in Impermeable area per house per year (across whole 100km^2 sample area.)

across the whole sample area. As can be seen on the graph there is a difference between the five towns, for example Chester has the largest average change at 1.094 m^2/house/year whereas Newcastle upon Tyne has the lowest at 0.381 m^2/house/year. If we take a straight average across the five towns, the average urban creep is 0.749 m^2/house/year (the weighted average is 0.687 m^2/house/year), which is a significant increase and could have a greater impact on sewerage networks than climate change will have.



Graph 3: Average Change in Impermeable area per house per year (for different property types.)

Another example of the results found during this study are shown in graph 3, which illustrates the average increase in impermeable area per house per year for each of the four property types across the five sample towns. The results show that for detached properties there is a larger increase in the impermeable area per year than for terraced houses, which is as expected. If we look at the weighted averages of the five sample towns the increase for a detached property is four times that of a terraced house.

7. Statistical Analysis

As no clear relationship was found between an individual variable and urban creep it has been necessary to undertake more complex analyses. This work is currently ongoing and is being undertaken by Scottish Water. Preliminary indications from this work are that by means of a regression analysis it will be possible to derive a "regression tree" to identify the urban creep values to be used by means of inputting a range of different variables. The degree of fit which has been found so far is extremely encouraging.

The final results and findings from this study will be presented at the UKWIR Technology Transfer Workshop on the 24th November 2009. It is hoped that the "regression tree" will be available at that time.

8. Modelling

Another important part of this study was to develop a methodology for including allowances for urban creep within hydraulic models which is clearly auditable. The methodology for this phase of the study has been finalised and is summarised below. However, the actual values to be used are still to be finalised following the ongoing statistical analysis.

At the current time the majority of hydraulic models are built using three or four of the 12 available runoff surfaces within InfoWorks. The proposed methodology for including urban creep within the hydraulic models is to use an extra one or two of the runoff surfaces for the area to be due to urban creep and also to add the design horizon to the network name.

The intention would be that the network file name will include within it the date of the flow survey used to verify the model (eg Network_2009). Then if for example we wanted our hydraulic model to reflect the operation of the sewerage network in 2020 (11 years time), we would add the additional area due to urban creep over the 11 years and we would rename are network from "Network_2009" to "Network_2020". The proposed data structure in a model would be:-

Column 1	Paved Areas (no change)
Column 2	Roof Areas (no change)
Column 3	Urban Creep
Column 4	Permeable Areas

For existing models which are being updated for a particular planning horizon the permeable areas in column 3 would be moved to column 4. The calculations for the urban creep can either be done externally using a spreadsheet program or alternatively can be done within Infoworks using the "User Number" fields. The value for the urban creep allowance over the planning horizon period should be added to column 3 and should also be subtracted from column 4.

It will also be necessary for the "Land Use Index" to be changed to give the correct runoff indexes in relation to the different surfaces.

9. Conclusions

Urban Creep is a serious problem for the Sewerage undertakers and it is unlikely to go away for many years to come. It is also clear that there are many drivers for urban creep and there is a complex mixture of different variables acting as drivers.

The use of remote sensing technology to detect urban creep has been very successful and has allowed large samples to be studied in various locations across England and Wales which has enabled large and statistically valid sample sets to be extracted and analysed.

10. Acknowledgements

The authors would like to thank UKWIR for permission to publish this paper. The opinions expressed in this report are those of the authors and do not necessarily represent the views of UKWIR nor of their respective organisations.

11. References

[1] Tewkesbury, A & Hinchliffe, G 2009. LandBase User Guide.