Urban creep in Scotland: stakeholder perceptions, quantification and cost implications of permeable solutions

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The impact of urban creep on flood risk and water quality within Scotland

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Abstract

The gradual increase in impermeable surface area within urban conurbations has clear consequences for flood risk. This paper details an investigation into the impact of one element of urban creep (hardstanding/paving provision) on flood risk and water quality within Scotland. Following a review of current hardstanding practice, an extensive stakeholder consultation exercise is presented. The outcomes of this consultation clearly highlight that the installation of impermeable hardstanding within Scotland is sufficiently widespread to justify measures to discourage such development; this is confirmed by the results of a residential survey, which indicates that there has been a near quadrupling of the area of impermeable hardstanding within three typical residential areas of Edinburgh. A number of case studies are presented, and it is concluded that permeable hardstanding solutions offer multiple benefits to the urban drainage cycle and should be promoted through legislation, education and incentivisation. Finally, recommendations for future work are detailed.

1. Background

Urban development generally results in an increase in the overall area taken up by roads, roofs and other impermeable surfaces, causing a corresponding reduction in permeable surface area. Following construction, the impermeable area within any particular development will incrementally increase as residents install/enlarge patios, extensions and driveways (hardstanding); this phenomenon is commonly known as "urban creep". In London it is estimated that around two thirds of front gardens are at least partially paved over, primarily to provide off road parking spaces (London Assembly, 2005). Similarly, it has been reported that between 1971 and 2004 the development of impermeable surfaces within a suburban area of Leeds increased by 13%; 75% of this total is thought to be due to the paving of residential front gardens (Perry et al, 2008). A recent UKWIR funded study using remote sensing technology identified that impermeable surfaces in five areas of the UK increased at a rate of 0.38 – 1.09 m^2/house/year between 1999 and 2006 (UKWIR, 2010).

Within this context, it is clear that the development of impermeable surfaces reduces the opportunity for rainfall to infiltrate into the soil, and consequently lowers the time taken for runoff to enter sewer systems or watercourses. At the catchment scale, the consequences are that peak flows are more pronounced and runoff volumes are greater. This can lead to increased flood risk, increased combined sewer overflow discharges, modification of river morphology (by increased erosion) and habitat degradation. At the site scale, the increase in impermeable area can lead to premature surcharge of the drainage network, and subsequent flooding. Simulation of the impact of hardstanding provision in front gardens indicates that, overall, average annual runoff has increased by some 12% (Perry et al, 2008). When considered within the context of the potential increase in rainfall associated with climate change (Pitt, 2007) and the stressed nature of the UK sewerage network (Arthur et al, 2009), this represents a significant additional load.

In contrast to impermeable hardstanding, the use of permeable options can greatly reduce the amount of water discharged into the environment immediately following a rainfall event. It is reported that the use of porous asphalt rather than impermeable asphalt can, on average, extend runoff durations by a factor of two (Pagotto et al, 2000). It has also been found that, depending on the type of hardstanding and sub-base, relatively moderate rainfall events (<50mm depth) can be totally infiltrated into the soil, whilst significant reductions in total runoff volume can be achieved for more intense events (Bean et al, 2007). A survey conducted on four different types of permeable hardstanding highlighted that the attenuation of moderate rainfall events were of a similar order of magnitude, with a generated runoff volume not exceeding 6% of the total rainfall (Collins et al, 2008); for larger events (>100mm), runoff volume was decreased by at least 65% and the peak flow was significantly delayed.

In addition to the impact on water quantity, urban creep can also have a significant impact on water quality, as deposited pollutants are washed off during rainfall events. The types of pollutants that may be expected are heavily linked to the activities on these urban surfaces, and can include hydrocarbons, herbicides, fertilizers, and heavy metals. Conversely, permeable surfaces retain pollutants, primarily by filtration of the suspended particles and to a lesser extent by absorption to substrate (Scholes et al, 2008); in some cases, microbial activity can play an important role in the degradation of pollutants. The water quality from all types of permeable hardstanding has been shown to rarely exceed 20mg/l of suspended solids (Barrett, 2004); in comparison, average runoff concentration of suspended solids on impermeable car parks has been reported to be 150 mg/l (Gobel, 2007). Similarly, the removal rates associated with permeable surfaces have been reported in numerous surveys, with the rate for suspended particles ranging from 50 to 95% (Balades et al, 1992; Ranchet et al, 1995; Gilbert et al, 2006). In addition, heavy metal removal rates of 20% to 70% have been reported (Pagotto et al, 2000).

The recognition of the cumulative impact that many, relatively small areas of impermeable hardstanding can have on flood risk and water quality within urban areas has lead to a re-examination of relevant legislation governing such developments. For example, recent changes in England now mean that the installation of impermeable surfaces greater than $5m^2$ (on the principal, front elevation) requires planning permission; no planning permission is required if permeable hardstanding is used or if the "…*rainwater is directed to a lawn or border to drain naturally"* (Communities and Local Government, 2007). Within Scotland, the relevant legislation was changed in 2009, reducing the area of hardstanding exempt from mandatory standards from $200m^2$ to $50m^2$ (Scottish Buildings Standards, 2009). Further afield, regulations vary widely; in France, the construction of a driveway does not require planning permission, whilst in Finland, planning permission is required for the construction of a parking area, irrespective of its construction.

2. Aims and objectives

The primary aim of the research reported herein was to investigate the impact of hardstanding provision on flood risk and water quality within Scotland, and hence contribute to the evidence base necessary to support any proposed future changes to relevant Scottish building regulations.

In order to achieve the primary aim, the following objectives were identified:

- Identify current practice related to the provision of hardstanding through a literature review.
- Establish the key challenges related to the provision of hardstanding through a stakeholder consultation exercise.
- Quantify the extent of urban creep and public perception of the related issues through a residential hardstanding survey.
- Determine any cost differentials between impermeable and permeable hardstanding through the development of case studies.

3. Current practice

The use of permeable hardstanding options is not a recent phenomenon, and gravel driveways were common in UK properties constructed before 1990. However, since that time there has been a growth in the installation of impermeable hardstanding surfaces, with concrete and block paving being key examples. Recent years have also seen the introduction of more sophisticated permeable hardstanding options, such as porous asphalt.

Within the context of the work reported herein, the term permeable hardstanding refers to hardstanding where rainfall can either infiltrate through the entire surface of the material (porous hardstanding) or via the spaces left between the material (permeable hardstanding). Typical examples of porous hardstanding include granular material reinforced using geo-synthetic cellular systems and small porous elemental surfacing blocks. Typical examples of permeable hardstanding include surfacing blocks with small gaps and continuous-laid concrete systems that provide a surface with large voids.

3.1 Performance, design life and maintenance

A review of manufacturer's data would indicate an expected design life of 20-25 years for permeable hardstanding (Interpave, 2008), which is similar to that associated with impermeable developments; after this time, it would be expected that some elements would require removal and replacement. This data broadly corresponds to results from the small number of independent studies that have been reported in this area (e.g. Daywater, 2003; Ferguson, 2005).

Clearly the main factor affecting the long term performance of permeable options is the degree of clogging of the structure. A recent Australian study has identified the formation and gradual spread of a "clogging front" at the upstream end of permeable developments, where the detritus load of the runoff is highest (Pezzaniti et al, 2009); the same study also identified that permeable developments reach some form of equilibrium a number of years after initial construction, after which the rate of "permeability loss" decreases markedly (Pezzaniti et al, 2009). Cost benefit analysis of permeable hardstandings undertaken by CIRIA concluded that, although such surfaces may lose up to 90% of their permeability within the first few years of installation, their very large initial infiltration capacities (up to 2600mm/hr) mean that the remaining 10% is more than adequate to deal with the type of rainfall intensities that occur in the UK over their expected 20 year design life (CIRIA, 2009).

Assuming permeable systems are correctly designed and installed, the ongoing maintenance should be a matter of keeping the surface clean and free from the type of debris (e.g. mud, silt and leaves) that can lead to reduced permeability. This would typically involve sweeping and low pressure water hosing of the type typically undertaken by householders to maintain visual amenity of driveways; this is a cost that could be expected in maintaining any type of hardstanding. For communal access areas, conventional street sweeping should maintain the permeability of the surface (CIRIA, 2009).

4. Stakeholder consultation

The stakeholder consultation process was based primarily on a questionnaire based survey, supplemented by a small number of targeted interviews and a stakeholder workshop. Key details of the survey are presented below, whilst further information about the overall consultation can be found elsewhere (Wright et al, 2010).

4.1 Questionnaire survey format

The questionnaire was distributed to 350 individuals and organisations within Scotland, and included all of the main stakeholders (see Table 1).

Table 1: Questionnaire respondents[#]

Organisation/interest category	Number of respondents
Architect	76
Central Government	13
Developer of non-residential buildings	1
Developer of residential buildings	12
Hardstanding contractors and associated trades organisations	3
Hardstanding designer	4
Hardstanding materials manufacturer	2
Householder (not specifically invited to contribute)	5
Housing association	9
Landscape architect	8
Local Authority – building standards	9
Local Authority – drainage engineer	8
Local Authority – facilities management	2
Local Authority – planning	12
Scottish Environmental Protection Agency	22
Scottish Water	2
Other (academics, consultants, surveyors, charities, etc)	50

A total of 221 valid questionnaire attempts were logged, which comprised of 135 complete submissions and 86 partial attempts; this represents an overall response rate of 63% and a completion rate of 39%. Whilst respondents did not have to specify their contact details, analysis of those that did indicates that twenty three of the thirty two Scottish Local Authorities were represented in the questionnaire submissions. Whilst the response rate may appear modest, these figures exceed what could have been reasonably expected; for example, a similar survey undertaken by CIRIA within England and Wales received a total of 22 responses from an initial distribution list of some 600 contacts (4%), and was considered to be *"… about average for this kind of survey"* (CIRIA, 2009).

The widely varying number of respondents in each category renders general inter-category analysis difficult. However, where a reasonable sample was available (i.e. at least 5 responses to a particular question), the results from individual categories tended to mirror the overall results.

4.2 Results

The key messages to emerge from the consultation phase of the project were that there was a clear understanding of the risk that the cumulative impact of small areas of impermeable hardstandings pose to flood risk in Scotland, and that there was a broad recognition that the problem could best be solved by changing how hardstanding provision was regulated and by encouraging the use of permeable options. However, it was also identified that there is a general lack of technical knowledge concerning the design and construction of permeable solutions, and a number of stakeholders felt that poor initial construction was the main cause of performance problems. There also appears to be uncertainty concerning the maintenance requirements associated with permeable hardstanding. Whilst the majority of stakeholders perceive permeable hardstanding solutions to be more costly than impermeable alternatives, this is based on initial construction costs, and there is a feeling amongst some stakeholders that the whole system costs

[#] These figures include those respondents who specified more than one organisation/interest category. The only exception was where a respondent specified two or more categories including *householder*; as the vast majority of stakeholders would classify themselves as householders, the responses of these submissions were not counted towards the *householder* category.

associated with permeable solutions could actually be less than equivalent impermeable approaches (which require supplementary infrastructure, such as gullies, underground drains, etc).

Finally, the majority of stakeholders feel that, in addition to hardstanding, other forms of urban creep (e.g. garages, extensions, etc) should also be subject to stricter standards to encourage the use of SuDS techniques.

5. Residential hardstanding survey

A number of representative areas within Edinburgh were surveyed to determine both the degree of urban creep and public perceptions of the relevant issues. Two categories were surveyed:

- Private housing developments, where the as-built design incorporated an area of hardstanding sufficient to accommodate one car parking space.
- Social housing developments, that have been subsequently sold to private home owners, where the as-built design did not generally incorporate any hardstanding for car parking.

Three areas were surveyed (Bonaly, Buckstone and Colinton-Mains), all of which are located in South West Edinburgh. Both Bonaly and Buckstone areas consist of mostly detached housing and represent typical private housing developments circa 1970. In contrast, Colinton-Mains consists mostly of small blocks of 4 flats (2 upper, 2 lower), and was originally built as social housing; over time, the majority of properties have been sold and now form part of the private market. These developments were selected on the basis of the "uniformity" of the building curtilages, which allowed relatively straightforward identification of curtilage modifications (see Figures 1a to 1c), and because they were considered typical of the type of developments which would have undergone changes to their original configurations; modern residential developments normally incorporate a substantial area of hardstanding (e.g. space for two cars), and it is considered unlikely that many such developments would undergo significant urban creep.

5.1 Survey format

The survey comprised of two distinct elements;

- Walking survey
  This consisted of a subjective, visual appraisal of the type and extent of hardstanding visible from the street perspective. As such, it could only identify the nature of the surfacing to the front and/or side gardens of a curtilage, and did not account for the impact of extension to properties.
- Postal survey
  Whilst undertaking the walking survey, a postal questionnaire was left at each house, to identify if/why/how modifications to hardstanding areas had been undertaken. The questions were also intended to canvas opinion on the general subject of hardstanding provision.

a. Bonaly **b. Buckstone** **c. Colinton-Mains**

Figure 1: Typical building curtilages (Google Maps, 2009)

5.3 Results

In total, some 600 building curtilages were surveyed in the Bonaly, Buckstone and Colinton-Mains catchments. The results of the walking survey are shown in Figure 2. Local knowledge of these areas suggests the as built designs of properties within the Bonaly and Buckstone catchments incorporated hardstanding of approximately 18m^2, which comprised of 12m^2 of permeable gravel and 6m^2 of impermeable concrete paving slabs. The properties within the Colinton-Mains catchment did not originally include any areas of hardstanding, with the area at the front/side of each block of flats being laid to lawn.

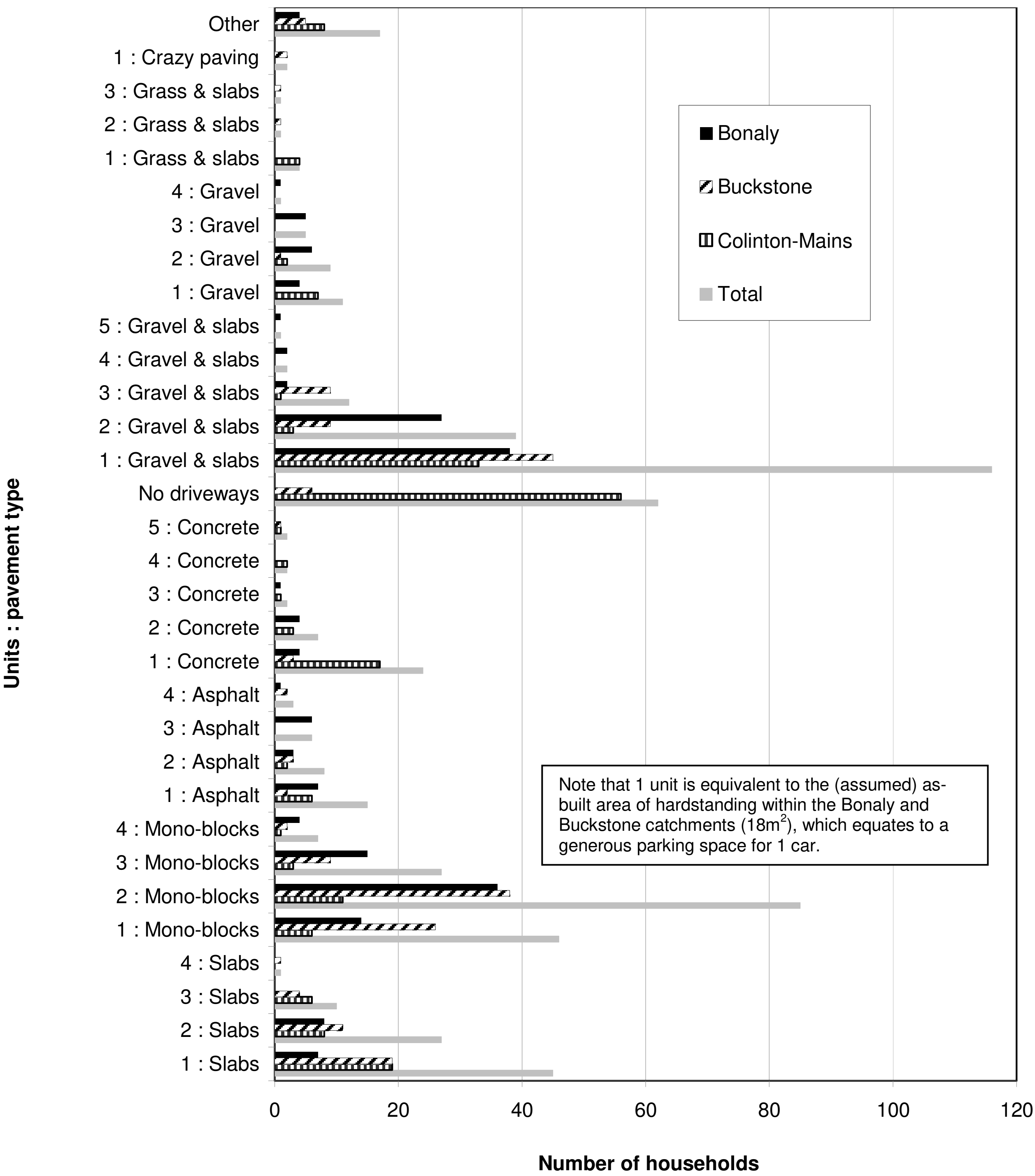

Figure 2: Results of walking survey

The survey results may be summarised as follows:

- 81%, 76% and 72% of the surveyed building curtilages in Bonaly, Buckstone and Colinton-Mains respectively have modified their driveway and/or front garden since initial construction (average of 77%).
- 63%, 49% and 72% of the surveyed building curtilages in Bonaly, Buckstone and Colinton-Mains respectively have increased the area of hardstanding in their driveway and/or front gardens since initial construction (average of 61%)
- 57%, 64% and 47% of the surveyed building curtilages in Bonaly, Buckstone and Colinton-Mains respectively have replaced their totally permeable garden (lawn) or partially permeable driveway (gravel/slab) and/or front garden with totally impermeable materials since initial construction (average of 56%)[#1].
- The increase in impermeable area associated with modifications to driveways and/or front gardens in Bonaly, Buckstone and Colinton-Mains (due to increases in both driveway size and the use of impermeable materials) is 17m^2, 16.7m^2 and 14.3m^2 respectively; this represents a total increase within the three study areas of approximately 9600m^2. In Bonaly and Buckstone, these increases equate to a near quadrupling of the area of impermeable hardstanding[#2], and bring the average total area of impermeable hardstanding to approximately 23m^2 per curtilage. As there was no impermeable hardstanding on the curtilages of the as built Colinton-Mains properties, the average total area is the same as the average increase.

A total of 162 postal surveys were received; 69 from Bonaly, 58 from Buckstone and 35 from Colinton-Mains. This represents an overall response rate of 27%, which is again an excellent response for this type of survey. As background to these results, three quarters of questionnaire respondents were over 45, which may reflect the importance of environmental issues to this age category, or simply the greater inclination/opportunity to participate in such a survey. The results of the postal survey may be summarised thus:

- The number of cars per household was found to be catchment specific, and areas with higher average car ownership correspond to those with larger areas of hardstanding (Table 2). Despite the presence of good public transport links on all sites, the relatively high car ownership in all areas reflects the high degree of dependence on private transport, and thus the need for appropriate areas for car parking purposes.

Table 2: Household car ownership

Catchment	% no car	% 1 car	% 2 cars	% more than 2 cars
Bonaly	3	41	53	3
Buckstone	4	61	33	2
Colinton-Mains	18	41	35	6

- The overwhelming majority of respondents (94%) had some form of driveway; 86% of these stated that the driveway was in place prior to their purchase of the property, whilst 41% had re-built the existing driveway since purchasing the property. The majority of those who have not already re-built their driveway had no plans to do so (72%). Only 2% of respondents stated that they were planning to turn their driveway back into a garden.
- The costs associated with installation and/or rebuilding of driveways varied enormously, from £100 to £6000 where a contractor was used, and from £100 to £2200 where householders undertook the work themselves; it can only be assumed that the examples of extremely low cost

[#1] This assumes that all slab, mono-block, asphalt, concrete and crazy paving areas are 100% impermeable.

[#2] This is a conservative estimate of the increases as it assumes that the original small areas of concrete slabs within the Bonaly and Buckstone curtilages (6m^2) act as impermeable surfaces; in reality, any runoff from these surfaces would probably have runoff to the surrounding gravel and infiltrated into the ground.

installations (£100) were for minor repair work. Overall, the price paid to install a mono-block driveway varied between £44 and £155 per $m^{2,}$ with an average price of £79 per m^2.

- Concrete mono-blocks tended to be rated as the most aesthetically pleasing type of hardstanding, followed by gravel, cement slabs and finally grasscrete. Confusingly, when hardstanding images where not shown, respondents identified that permeable hardstanding can add to the aesthetics of the property/area; perhaps this indicates a mismatch in peoples perceptions of permeable hardstanding, or a specific dislike of grasscrete in general. The beneficial impact on environmental issues was also cited as an advantage of permeable hardstanding, whilst safety, cost and the potentially detrimental impact on house foundations were not perceived as particularly strong disadvantages.
- 78% of respondents felt that a strengthening of existing legislation could be justified; of these, 41% felt that the installation of impermeable hardstanding should be subject to planning permission, whilst 35% believed that such developments should be totally prohibited. Where respondents offered their own suggestions as to how to tackle urban creep, the responses included: awareness raising, promotion and development of suitable and cost effective products, provision of a grant for permeable developments, increased council tax charges for impermeable developments.

6. Case studies

In order to determine the potential implications of any change to existing legislation regarding hardstanding provision, case studies were developed to identify the fundamental cost and performance differentials between impermeable and permeable hardstanding.

The cost benefit analyses presented below do not account for the costs associated with the traditional, supplementary drainage infrastructure required downstream (outside the curtilage) for impermeable developments, e.g. gullies, underground drains. The analyses may therefore be considered to represent the maximum cost differentials between impermeable and permeable hardstanding developments.

6.1 Case study details

The case studies were drawn from actual projects suggested by respondents to the stakeholder questionnaire survey. Case study data was supplied by contractors and comprised of priced bill of quantities sections and specification information for both permeable and impermeable hardstanding in the each of the developments, allowing for direct comparison in each case. The case studies represented different development types, ground conditions and vehicle loadings; as groundwater contamination was not an issue in any of the case studies, it has not been possible to account for this element in the analysis that follows.

- Case Study 1 – new-build private housing development
  This is a new-build low rise private housing development in West Lothian, designed and priced in 2009. It comprises 62 semi-detached dwellings on a site of approximately 18300m^2, with 83 permeable paving driveways (each of 12.5m^2), and a smaller quantity of traditional impermeable rectangular block paving for comparison.
- Case study 2a – new-build mixed private and social rented housing development
  This development is situated in Stirling and was designed and priced in 2009. It comprises 108 flats, in 36 low rise blocks, and 82 detached and semi-detached dwellings on a site of approximately 43000m^2 in total. Approximately 800m^2 of the site is permeable hardstanding to residential driveways. This was very similar to case study 1 in terms of scenario, but having a simpler design solution due to more favourable ground conditions.
- Case Study 2b - new-build mixed private and social rented housing development
  The same housing development introduced in Case Study 2a also includes approximately 1100m^2 of permeable paving to shared courtyards; these areas are designed for higher vehicular loadings from commercial and refuse collection vehicles.

- Case Study 3 – supermarket
  This is a mid-sized supermarket located in a small town in East Scotland. The site includes an area of permeable paving for 57 private vehicles, representing an area of approximately 500m^2.
- Case Study 4 – single residential dwelling
  This case study differs from the others in the scale of the works, comprising 60m^2 of permeable paving to the driveway of a single domestic dwelling carried out by a small landscaping contractor. This represented the simplest design of all the case studies.

6.2 Comparison of Case studies

The case study capital cost analysis of the five permeable hardstanding designs is shown in Table 3; in each case, a cost comparison is made with equivalent traditional paving, also using price and specification data provided by the contractor. Case studies 1 and 2a are based on very similar performance requirements; the higher cost of the permeable option can be attributed largely to the significantly deeper sub-base required, which also necessitates greater excavation and disposal costs, and the permeable paving itself. Case study 2b also forms part of a housing estate, but is of an enhanced specification for the type of heavier loading conditions that shared access parking courts are subjected to; this upgraded specification takes the form of significantly deeper base layers as well as the installation of membrane layers to reinforce aggregates and control movement of the sub-base. Case study 3 is a supermarket car park and it is notable that the costs are very similar to that of a housing development (case study 2a), suggesting that different types of development does not necessarily equate to different installation costs. Case study 4 is distinct from the others in that it relates to a domestic scale paving contract for a single driveway.

Table 3: Summary of costings for permeable and impermeable hardstanding specifications

Hardstanding type	Case study 1	Case study 2a	Case study 2b	Case study 3	Case study 4
Permeable specification	£81.91/m^2	£58.95/m^2	£90.51/m^2	£57.95/m^2	£48.39/m^2
Conventional comparator	£52.12/m^2	£31.31/m^2	£58.99/m^2	£33.73/m^2	£39.96/m^2
Conventional as % of permeable	64%	53%	65%	58%	83%

Where the case study data allows for detailed analysis of the rate build up, the cost breakdown in each case broadly conforms to *Paretos law* (sometimes termed 80:20 rule), where most of the value (approx 80%) is contained in just a few items (approx 20%). For the lighter loading private driveway examples, the two high value items are the permeable paving blocks and the sub-base. In both cases, permeable paving is substantially more expensive, but not quite double, the price of traditional hardstanding comparators on the same site. The higher specification shared access example also shows a similar price differential between permeable and traditional options. It is notable that the groundwork rates (excavation and disposal of material) differ significantly in the two projects. Disposal of excavated material off site, as opposed to on site, in case study 1 raises groundwork costs substantially.

Although the costs/m^2 differ between case studies, there is a significant price differential in each case between the permeable and impermeable options (65% average). Whilst there is no discernible pattern to the cost differentials for case studies 1 to 4, there is clearly a lower differential between the permeable and impermeable options in case study 4. This is considered to be due to the small scale of this case study development; for example, the extra excavation work required for a 60m^2 permeable installation is insignificant compared to the resources required to transport the excavator to site.

6.3 Whole life cost implications

The cost analyses presented are based solely on capital cost. With greater emphasis on sustainability and achieving value for money in public or private sector investment it is important to consider through life performance, maintenance and cost issues associated with the installations. In general, one of the main limitations in applying whole life costing in practice is the lack of actual through life performance and cost data to inform whole life cost analyses. This is also the case for permeable systems due to their relative novelty, both in the UK and internationally, and consequent lack of experience of performance over time.

As outlined in Section 3.1, the maintenance requirements and costs associated with permeable hardstanding should not differ significantly from those associated with impermeable hardstanding. In practice, there is no planned cyclic maintenance requirements over the design life of permeable or impermeable paving assuming these have been installed according to manufacturer's instructions.

7. Conclusions

From the work reported herein, it is clear that the installation of impermeable hardstanding within Scotland is sufficiently widespread to justify measures to discourage such development; the majority of stakeholders share this opinion, whilst the results of the residential hardstanding survey spell out the scale of urban creep. Although the general public are aware of the impact that impermeable hardstanding has on flood risk, and would generally support a change in legislation to mitigate against detrimental environmental impacts, very few households are planning to turn their driveway back into a garden.

One measure to discourage impermeable development is to actively encourage the more widespread use of permeable hardstanding, as it is clear that such solutions offer multiple benefits to the urban drainage cycle. To be successful, such promotion will require changes to existing legislation as well as improved stakeholder education; in particular, improved guidance on the design, specification and installation of permeable hardstanding is required, both to allay concerns over long term operational performance and to ensure that such developments realise their cost effective potential. Given that the initial construction costs of permeable options are approximately a third higher than equivalent impermeable developments, there may also be an important role for some form of incentivisation scheme, particularly for householders; whereas developers are obliged to consider the "whole picture" when it comes to surface water drainage (e.g. minimise total runoff from a particular site), and may also be better placed to absorb any cost differentials, it can be difficult to convince individual householders to select the more costly permeable solution on the basis of the general societal benefits that may accrue.

Although the research presented herein has focussed on hardstanding provision, the results of the consultation exercise also show that the majority of stakeholders are supportive of measures that would encourage the more widespread use SuDS techniques to mitigate against other forms of urban creep (garages, extensions, etc).

The project findings have also highlighted the need for a number of follow-up activities, chief amongst these are further work to corroborate the findings of the residential hardstanding surveys. In addition, further surveys are required to determine the effectiveness of different forms of incentives to encourage the public to select more sustainable, permeable options. Finally, the evidence base surrounding the long term performance of permeable hardstanding is not comprehensive, and there is therefore a very real need for further research and/or long term monitoring programmes to gather more data; to be credible, any such work must be totally independent of interested parties.

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References

1. Arthur S, Crow H, Pedezert L and Karikas N (2009). The holistic prioritisation of proactive sewer maintenance. *Water Science Technology*. Vol 59, No 7, pp 1385-1396.
2. Balades J D, Bourgogne P and Madiec H (1992). Evaluation des flux de pollution transitant dans un type de solution compensatoire. *Novatech*. Lyon, France.
3. Barrett M (2004) BMP SuDS water quality performances. *Performance and whole life costs of best management practices and sustainable urban drainage systems*.
4. Bean E Z, Hunt W F and Bidelspach D A (2007). Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts. *Journal of Irrigation and Drainage Engineering*. Vol 133, No. 6, pp 583-592.
5. CIRIA (2009). *Understanding permeable and impermeable surfaces*. London: CIRIA.
6. Collins K A, Hunt W F and Hathaway J M (2008). Hydrologic Comparison of Four Types of Permeable Pavement and Standard Asphalt in Eastern North Carolina. *Journal of Hydrologic Engineering*. Vol 13, No 12, pp 146-1157.
7. Communities and Local Government (2007). *Guidance on the permeable surfacing of front gardens*. London.
8. Daywater (2003). *Review of the use of stormwater BMPs in Europe*. Report 5.1. EU RTD 5th Framework Programme.
9. Ferguson B K (2005). *Porous Pavements*. Taylor and Francis Group.
10. Gilbert K J and Clausen J C (2006). Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. *Water Research*. Vol 40, pp 826-832.
11. Gobel P, Dierkes C and Coldewey W G (2007). Stormwater runoff concentration matrix for urban areas. *Journal of Contaminant Hydrology*, Vol 91, pp 26-42.
12. Interpave (2008). *Permeable pavement, guide to the design, construction and maintenance of permeable pavements*. Edition 5. Leicester.
13. London Assembly (2005). *Crazy Paving, the environmental importance of London's front gardens*. London: Greater London Authority.
14. Pezzaniti D, Beecham S and Kandasamy J (2009) Influence of clogging on the effective life of permeable pavements. *Proceedings of the Institution of Civil engineers – Water Management*. Vol 162, No3, pp 211-220.
15. Pagotto C, Legret M and Le Cloirec P (2000). Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement. *Water Research*. Vol 34, No 18, pp 4446-4454.
16. Perry T and Nawaz R (2008). An investigation into the extent and impacts of hard surfacing of domestic gardens in an area of Leeds, United Kingdom. *Landscape and Urban Planning*. Vol 86, No 1, pp 1-13.
17. Pitt M (2007). *The Pitt review: lessons learned from the 2007 floods*.
18. Scholes L, Revitt D M and Ellis J B (2008). A systematic approach for the comparative assessment of stormwater pollutant removal potentials. *Journal of Environmental Management*. Vol 88, No 3, pp 467-478.
19. Scottish Buildings Standards (2009*). Domestic Handbook May 2009*: Scottish Buildings Standards.

20. UKWIR (2010). *Impact of Urban Creep on Sewerage Systems*.
21. Wright G B, Arthur S, Bastien, Bowles G and Unwin D (2010). *Extent and cost of designing and constructing small areas of hardstanding around new and existing, domestic and non-domestic buildings*. Report commissioned by Directorate for the Built Environment, Building Standards Division.