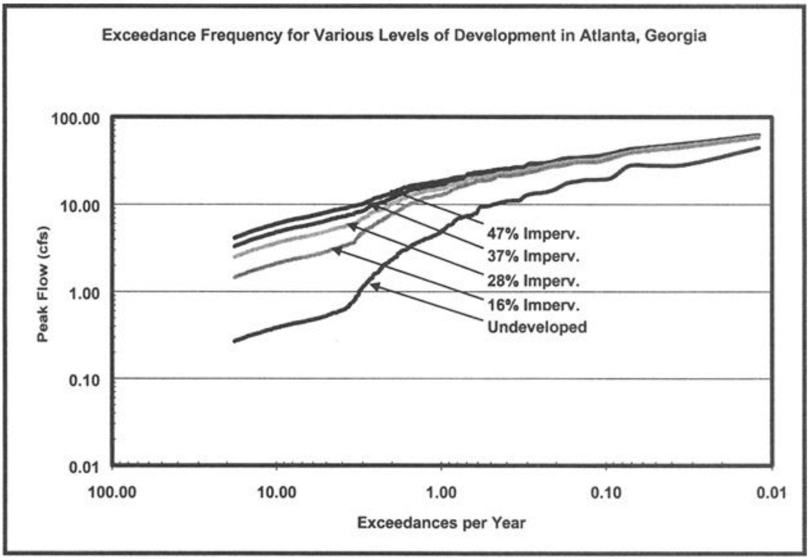

Figure 3b: Effects of development on flow frequency curve for Atlanta, GA

Table 2: Relationship Between Peak Flows and Percent Imperviousness

Ratio of Developed/Undeveloped Peak Flows for Various Return Intervals and Imperviousnesses for Fort Collins,CO					Ratio of Developed/Undeveloped Peak Flows for Various Return Intervals and Imperviousnesses for Atlanta, GA				
Percent		Return Interval			Percent		Return Interval		
Impervious	10/yr	1-yr	10-yr	100-yr	Impervious	10/yr	1-yr	10-yr	100-yr
16%	6	5	2	1	16%	5	3	2	1
28%	9	9	2	1	28%	9	3	2	1
37%	12	13	2	1	37%	13	4	2	1
47%	16	16	2	1	47%	16	4	2	1

The standard practice in many communities requires that the postdevelopment peak from a storm does not exceed the predevelopment peak of a storm with the same exceedance frequency. These flood control standards are often met through the use of detention basins, which effectively lower the postdevelopment peaks. The major drawback associated with these structures, as pointed out by Roesner et. al. (2001), is that the downstream reach is now exposed to the predevelopment peak levels for extended periods, often subjecting the channel to extreme erosion.

The detention basins that were modeled in SWMM effectively controlled the design storm in both Fort Collins and Atlanta, as illustrated in Figs. 4a and 4b. The 100-yr orifice alone essentially reproduces the predevelopment flow frequency curve for storms larger than the 5-yr storm. For higher frequency storms less and less control is exerted until there is virtually no effect on storms in which the flow is exceeded

0.6 times per year in Fort Collins (nearly the 1.5-yr storm), and 1.0 times per year in Atlanta (the 1-yr storm). The Atlanta model showed that both the 100-yr and the combination 100/10-yr orifices controlled the runoff from the respective design storms, and provided some control for storms exceeded less than three times per year. For storms exceeded more often than once per year the addition of the 10-yr orifice to the detention pond had no effect relative to that of the 100-yr control alone (see Fig. 4b). In Fort Collins the 100/10-yr orifices showed good control for exceedance frequencies up to 0.3 times per year (3-yr storm). This control then diminishes until there is no effect on storms occurring more frequently than 4 times per year (3 month storm) (see Fig 4b).

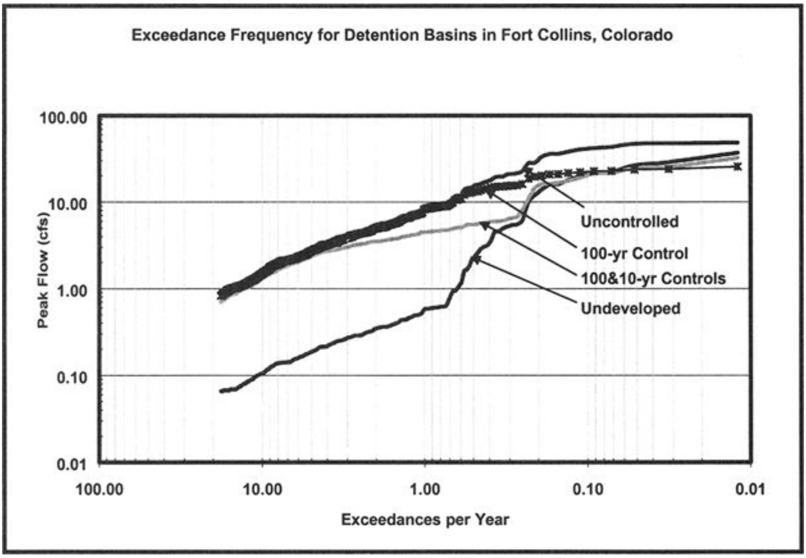

Figure 4a: Effects of detention basins on flow frequency curve for Fort Collins, CO

The slight flow attenuation that occurs for storms more frequent and smaller in volume than the design storm can be attributed to the fact that the detention basins were modeled with stacked orifices. The smaller controls were placed on the bottom, causing a slight restriction in flow for the higher frequency storms. It has been shown that orifice controls exhibit little control on high frequency events, especially when compared to riser or siphon type outlets, Somes and Wong (1997).

One of the emerging regulations in municipalities across the country is the use of BMPs to control pollutant delivery and provide some flow reduction. In this study a single stage, stacked BMP was designed (see Fig. 2). The BMPs modeled were extended detention basins sized according to the ASCE MOP (1998) to capture 85% of the runoff volume with a draw down time of 24 hours. The BMP was placed in a detention pond containing stacked orifices capable of controlling the 10-yr and 100-yr design storms. The effectiveness of this combination was compared to a triple orifice detention pond containing controls capable of reducing flows to predevelopment levels for the 100, 10 and 2-yr design storms.

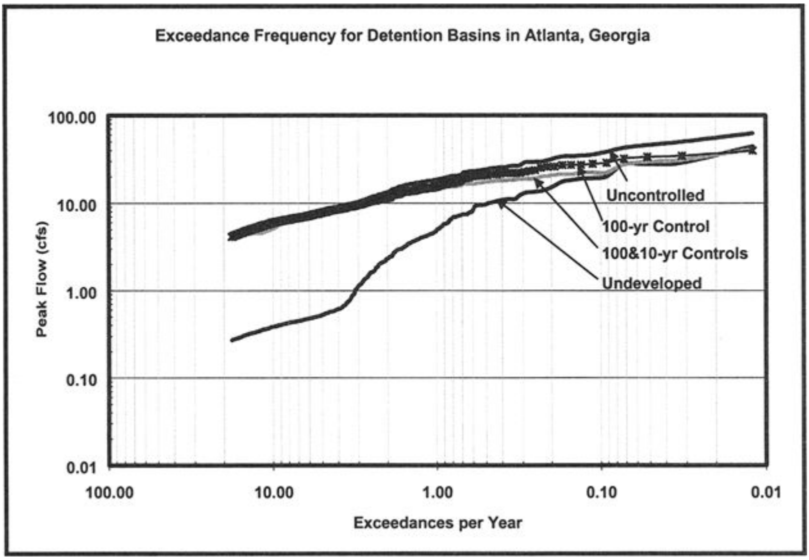

Figure 4b: Effects of detention basins on flow frequency curve for Atlanta, GA

It can be seen in Figs. 5a and 5b that the 2-yr control is not sufficient for controlling high frequency events. This orifice effectively controls the flow that is exceeded 0.5 times per year. From this point the curve continues further away from the undeveloped state, exhibiting very little control on any storm with an exceedance frequency greater than 0.5 times per year.

The BMP provides excellent control for small storms in both Colorado and Georgia. In Fort Collins (Fig. 5a), the BMP overtops at flows greater than 0.44 cfs, which is evidenced by the sharp increase in peak flows associated with storms occurring less than four times per year. In Atlanta (Fig. 5b), the BMP overtops much more frequently, about nineteen times per year, when flows exceed 0.75 cfs. In both locations for storms producing runoff volume less than that of the BMP the peak flows are effectively drawn back towards predevelopment levels.

The 100/10/BMP combination does not provide significant control for storms that overflow the BMP. This lack of control is illustrated in Figs. 5a and 5b, where the curve depicting the BMP rises steeply, and actually crosses the curve depicting the 100/10/2-yr controls. This means that the 2-yr configuration provides better control for storms greater than the 6-month storm (flow exceedance 2 times per year) in Fort Collins. In Atlanta the 100/10/2-yr detention system provides about the same control as the 100/10/BMP system for storms larger than the 3-month storm (exceeded 4 times per year).

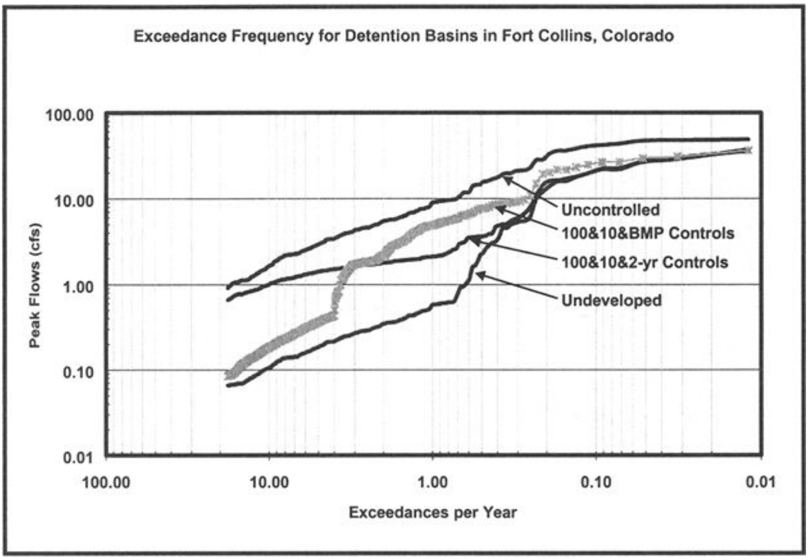

Figure 5a: Effects of detention and extended detention basins in Fort Collins, CO

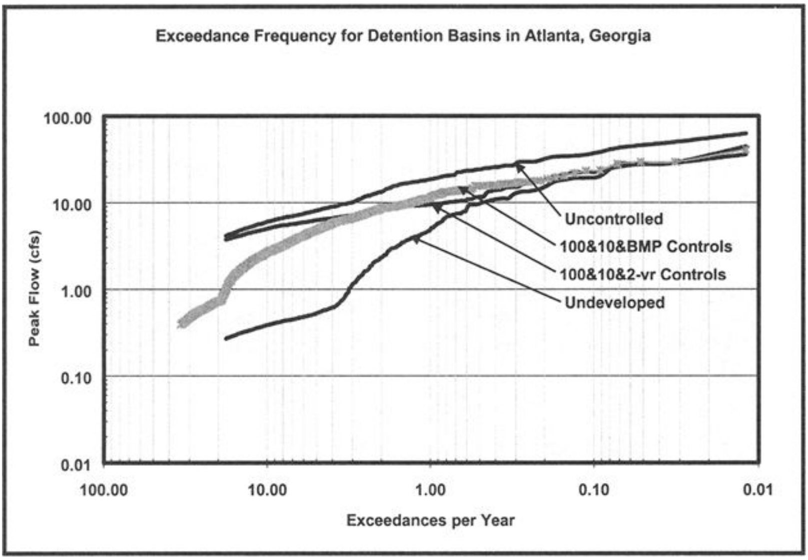

Figure 5b: Effects of detention and extended detention basins in Atlanta, GA

CONCLUSIONS

The design and implementation of storm water quality/quantity control devices is still in the developmental stage with respect to protecting receiving streams. It has been demonstrated in this study that increasing levels of imperviousness effect high frequency events much more than low frequency events. These results are true for small levels of imperviousness (16 percent) to large levels of impervious (47 percent). This is significant because the majority of annual rainfall occurs in small storms, as shown by Roesner et. al. (2001) in a study that included widely varying climates. Thus, in terms of protecting receiving water ecosystems, control of the small storm peak flows is just as important, if not more important, than control of the very large storms (≤ 10-yr storm).

BMP design criteria were developed around removal of pollutants from runoff, and not for runoff control of small storms. Yet they do exert significant runoff control over most of the storms that occur on an urban watershed. In the case of Atlanta, Georgia, which averages seventy-eight storms per year (Table 1), the BMP overflows only nineteen times per year, which means that the BMP exerts at least some flow control over 75% of the runoff events. For Fort Collins, the BMP proves effective at reducing flows in 90% of the events.

Analysis of the behavior of the integrated BMP/flood control system showed that the BMP combined with 100/10-yr flood control lowers the flow frequency curve for storms smaller than the 6-month storm much better than the system that adds 2-yr peak flow control to the 100/10-yr system. However, for storms larger that the 6-month storm, the 100/10/BMP system is significantly less effective at lowering the flow frequency curve than is the 100/10/2-yr system. In Fort Collins, this lack of control is especially true in the range of the 6-month to 2-yr storm. It is not nearly as noticeable in the Atlanta case. The drainage configuration containing the BMP in conjunction with the 100/10-yr orifice controls lowers the postdevelopment peaks of high frequency storms towards predevelopment levels.

It was also shown that for small storms, the increase in the peak flow is directly proportional to the increase in imperviousness. For larger storms it was demonstrated that the most rapid increase in flows with respect to imperviousness occur at low levels of development (<16% impervious). This makes the authors question whether the so-called "limit on imperviousness" is truly a limit, or simply the lowest imperviousness level at which there is a detectable departure of stream ecosystems communities from their predevelopment condition. By demonstrating that the largest increases in runoff peak flows occur at levels of imperviousness between zero and sixteen percent, we come again to the conclusion that flow control should be implemented on even the smallest developments and when dealing with the full range of storms.

Regarding the effectiveness of flood control detention facilities in lowering the post-development flow frequency curve to its predevelopment state, the study confirms the findings of Wong and Somes (1997). It has been demonstrated that flood control detention returns the flow frequency curve to the predevelopment status for that portion of the curve between the smallest and largest storm controlled. This is evidenced in the case for storm return periods larger than the smallest design storm.

However, for storms smaller than this, the flow frequency curve is essentially flat, meaning that smaller storms are not controlled at all. Thus, to control the entire flow frequency curve, it is necessary to control storms between the smallest storm required for drainage and the maximum storm controlled by the BMP. Multi-outlet controls that regulate the discharge over the entire spectrum of the flow frequency curve are required. The question is what is the minimum number of design storms that must be specified to achieve full control.

NEXT STEPS

It has been demonstrated in this paper that extending urban drainage systems beyond traditional urban drainage design practices to include extended detention BMPs results in significant reduction of flows for high frequency storms (i.e. storms smaller that the 3-month storm for Fort Collins, and smaller than the 1-month storm for Atlanta). It remains to be seen how other BMPs affect the flow frequency curve, and how different climates affect the results. It is expected that, having used an arid area and a fairly wet area in this test case, other areas would fall within the limits revealed in this study. Further analyses are planned to confirm this.

But one very important area that has not been explored in this paper is the change in the flow-*duration* curve due to urbanization, and the consequences of this change on the geomorphic stability of urban streams and the aquatic habitat therein. Even if a drainage system is designed so that the predevelopment flow-*frequency* curve is exactly reproduced for the postdevelopment condition (which appears possible based on the results of this study), the flow-*duration* curve will change due to the added volume of stormwater that runs off in the postdevelopment condition. Since the sediment transport is a function of the duration of the flow, as well as the critical shear stress (a function of velocity) and the particle size, the particle size distribution of a streambed can be expected to change as a result of small differences in the flow-duration curve. Preliminary analyses indicate that even a change in base flow rate can change the particle size distribution of the bottom sediments. The resulting change has strong implications on the stability of the benthic community index. These hypotheses will be addressed further in the near future.

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WET-WEATHER POLLUTION PREVENTION BY PRODUCT SUBSTITUTION

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ABSTRACT

A literature review of urban stormwater runoff and building/construction materials has shown that many materials such as galvanized metal, concrete, asphalt, and wood products, have the potential to release pollutants into urban stormwater runoff, and snowmelt. However, much of this previous research cannot be directly applied to estimating pollutant loadings from runoff. One limitation is that the studies were not performed using actual stormwater runoff. A second limitation is that they did not mimic the cyclic wet-dry weathering to which these materials are exposed. The weathering phenomena, which may result in the weakening of the strength of the materials, may significantly impact the release of these pollutants. This paper will discuss an ongoing research project that is investigating the pollutant releases from typical materials used for infrastructure construction.

INTRODUCTION

Past studies have identified urban stormwater runoff as a major contributor to the degradation of many urban streams and rivers (such as Field and Turkeltaub 1981; Pitt and Bozeman 1982; EPA 1983; Hoffman, *et al.* 1984; Pitt and Bissonnette 1984; Fram, *et al.* 1987; Pitt 1995). Roof, vehicle service area, and parking lot runoff samples were found to have the greatest organic toxicant detection frequencies and the highest levels of detected metals. These areas are subject to spills and leaks of automotive products, and to exhaust emissions from frequently starting vehicles (Pitt, *et al.* 1995 and 2000). It has been hypothesized that the vast majority of pollutants entering the stormwater from these sources is attributable to these spills, leaks, and atmospheric deposition events.

Relative pollutant contributions from various roofing, wooden, and paving materials should also be a concern, and it is one that has not been adequately addressed. Material substitutions should be part of the investigation. Around the nation, there is growing interest in the development and use of environmentally sensitive construction materials as a low-cost component to stormwater management. It is thought that more appropriate selection of materials that are exposed to the environment should result in significant reductions of many toxicants in stormwater. Unfortunately, there is little data for specific building materials and their alternatives. The following is a summary of some of the literature available on building material contributions to stormwater and on the building material compositions.

Investigation of Pollutant Sources in Urban Stormwater Runoff

Boller (1997) identified heavy metals such as cadmium, copper, lead, and zinc as the critical metals in local wastewaters and, based on his flow studies, concluded that stormwater from roofs and streets contribute 50-80% of these metals to the total mass flow in Swiss combined sewer systems. Roof stormwater samples (tile, polyester, and flat gravel roofs) also were analyzed and metal concentrations were found to vary significantly with roof type. First flush analyses showed polyester roofs contributing the highest concentrations of copper (6,817µg/L), zinc (2,076 µg/L), cadmium (3.1 µg/L), and lead (510 µg/L). Concentrations in stormwater from tile roofs were for copper (1,905 µg/L), zinc (360 µg/L), cadmium (2.1 µg/L), and lead (172 µg/L). Runoff from flat gravel roofs also contributed copper (140 µg/L), zinc (36 µg/L), cadmium (0.2 µg/L), and lead (22 µg/L). Roof stormwater was found to contain not only heavy metals, but also polycyclic aromatic hydrocarbons (PAHs) and organic halogens as well.

Working in Zurich, Mottier and Boller (1996) found average values in road stormwater of 300 µg/L for lead, 4 µg/L for cadmium, 150 µg/L for copper, and 500 µg/L for zinc. However, no information on pavement material type was included. Averaged roof stormwater concentrations (from tile and polyester roofs) were also measured at 16 µg/L for lead, 0.17 µg/L for cadmium, 225 µg/L for copper, and 42 µg/L for zinc. Boller concluded that copper installations on buildings seem to represent the largest source for the emission of this metal into the environment. Stark, *et al.* (1995) had a similar conclusion, estimating that stormwater from roofs may be responsible for more than 60% of the copper in Austria's combined sewers.

Researchers in Marquette, Michigan detected discernable differences in stormwater quality between a variety of impervious source areas. Commercial and residential rooftops produced the lowest concentrations of suspended solids, but the highest concentrations of dissolved metals such as lead, zinc, cadmium, and copper. Parking lots produced the highest concentrations for all PAH compounds and high concentrations of zinc, total cadmium, and total copper. Low traffic streets were also identified as a major producer of total cadmium (Steuer, *et al.* 1997).

Forster (1996) sampled and analyzed roof stormwater for heavy metals (cadmium, copper, zinc, and lead). The experimental roof systems allowed the influence of different roof materials (concrete tiles, zinc sheet, pantiles, fibrous cement) on stormwater quality to be compared. Extremely high values of zinc and copper were measured when the roof system, or parts of it, were made of metal panels, flashing, and gutters. For example, stormwater concentrations from zinc sheet roofing started almost three orders of magnitude higher and remained more than twenty times above the values measured for the roof sections affected only by atmospheric deposition. Mean stormwater concentration values at his study sites exceeded by about two orders of magnitude the local toxicity thresholds; peak values exceeded thresholds by 1000 or more.

Good (1993) reported the results of sampling of stormwater from a rusty galvanized metal roof, a weathered metal roof, a built-up roof of plywood covered with roofing paper and tar, a flat tar-covered roof which had been painted with a fibrous reflective aluminum paint, and a relatively new anodized aluminum material at a sawmill facility on the coast of Washington. Differences in copper, lead, and zinc were noticed between each roof type. Built-up roofing contributed the highest concentrations of dissolved copper (128 μg/L) and total copper (166 μg/L), approximately 10 times higher than levels detected in stormwater from the other roofs. Runoff from the rusty galvanized metal roof contained the highest concentrations of dissolved lead (35 μg/L) and total lead (302 μg/L), dissolved zinc (11,900 μg/L) and total zinc (12,200 μg/L). High concentrations of zinc were noted in stormwater from each type of roof sampled at the site. Acid rain and the high ionic content of the coastal atmosphere contributed to the rapid corrosion of the galvanized metal roofs and the release of zinc. Plastic rain gutters were a source of lead in stormwater.

Thomas and Greene (1993), working near Armidale, Australia, found differences in metal contaminant levels between urban and rural roofs associated with variations in atmospheric deposition and differences related to antecedent dry periods. They also found stormwater water quality was influenced by different roof types. Zinc concentrations were significantly higher in galvanized iron roof catchments, while pH, conductivity, and turbidity levels were higher in concrete tile roof catchments.

As seen in Table 1, Pitt, *et al.* (1995) found high concentrations of organic constituents in stormwater from several types of impervious areas. Differences noted between sampling sites for the pavement may indicate potential differences in contribution of organics from paving materials themselves. PAHs, in particular, are of concern, because they are known to have potential for adverse effects to a large number of invertebrates, fishes, birds, and mammals (Kennish, 1992). The toxicity results in Table 2 demonstrate the potential problems caused by urban stormwater from various sources. What cannot be determined from these results is the contribution to toxicity of the materials themselves.