STORMWATER INFILTRATION: A MANAGEMENT TECHNIQUE FOR PRESERVING ECOSYSTEM FUNCTION

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Abstract. In combination with a reduction in point source pollution and the maintenance of riparian buffer zones, urban stormwater infiltration has the potential to preserve ecosystem function by maintaining the natural morphology and flow patterns to which riparian species are adapted. Stormwater detention systems that are commonly required by community ordinances address local flooding, but do not address recharge of ground water, reduction in nonpoint source pollution loads, or stream bank erosion. Compact and cost effective infiltration methods that address all of these decrements to ecosystem function are described. Further research on the application of infiltration techniques to areas with relatively impermeable soils, including the Georgia Piedmont, is recommended.

INTRODUCTION

One result of urbanization has been an increase in impervious surfaces which has led to an increase in stream run off (Dunne and Leopold, 1978). Problems with increased flooding led many communities to adopt ordinances that require detention of storm water (Atlanta Regional Commission, 1993). It has also been known that the increase in impermeable surfaces (the area of roofs and paved surfaces) decreases infiltration of water into the ground (Burby et al., 1983). Some communities, particularly those faced with water shortages, have developed techniques that recharge aquifers by infiltrating stormwater into the water table instead of merely detaining it. Because stormwater infiltration addresses both flooding and lack of ground water recharge (Ferguson, 1994), it more closely mimics the discharge patterns found in undisturbed streams. By maintaining natural discharge patterns, infiltration should control stream bank erosion and reduce secondary sedimentation. Infiltration has also been demonstrated to remove or reduce nonpoint source pollutants normally found in urban stormwater (Yu and Nawang, 1993). When combined with the control of point source pollution and the protection of a vegetated riparian buffer, infiltration has the potential to maintain the ecological integrity of urban streams.

Two approaches to stormwater control have been used: detention and infiltration. Detention structures typically slow the release of stormwater by temporarily impounding it in an excavated basin. These basins can be of two types, wet or dry. Wet basins can remove pollutants but unless they are very large, tend to stagnate and breed mosquitoes, so most are dry. The outlet of the basin is designed with a restricted opening such as a notched dam.

Infiltration structures take three basic forms (Ferguson 1994). Infiltration surfaces are vegetated or constructed of porous asphalt or concrete underlain by gravel. Low traffic areas can be covered with open-celled pavers. Infiltration basins are often open and vegetated. However, where space is limited, subsurface basins can be excavated, filled with crushed stone, and paved over with permeable asphalt to do double duty as parking lots. Infiltration wells are used to absorb the outflow of downspouts and in areas that have limited space and deep water tables. Infiltration structures will be described in more detail later.

PROCESS OF INFILTRATION

This paper examines the potential for stormwater infiltration to preserve the ecosystem function of streams flowing from urban areas. A brief review of hydrological principles will aid in understanding the importance of infiltration in maintaining stream flow. Dunne and Leopold (1978) define infiltration as the movement of water into the soil. The maximum rate at which soil can absorb water is the infiltration capacity. Most rainfall on a naturally forested watershed infiltrates into the ground. Only during heavy storms is the infiltration capacity of the soil exceeded and water forced to flow on the surface of the ground. Woodland streams are fed primarily by seeps and springs, not surface runoff. They remain clear during all but the strongest rains. By contrast, desert soils suffer the impact of raindrops on bare ground. The force of impact breaks up the soil particles and cements them together forming a relatively impermeable surface that absorbs water slowly. When rain falls in the desert, most of it runs off in the form of flash floods that quickly fill drainage channels with a torrent of sediment filled-water that soon drains away, leaving them dry. Complete urbanization in previously vegetated areas has a similar effect. Peak annual discharge of streams draining urban areas with a fifty percent impervious surface is six times greater on average than streams in unpaved areas (Dunne and Leopold, 1978). With urbanization, floods increase in severity, flow during droughts declines, stream erosion and sediment load increases, and the diversity of aquatic life declines.

Once in the soil, water from rainfall enters the pore spaces between soil particles. The ability of soil to store water depends on the relative proportion of pore space (porosity) compared to the total volume. The following soils are listed by porosity in descending order; clay, loam, sand, and mixed gravel (Ferguson, 1994). Permeability is the rate at which water can be made to move through soil. An unconsolidated glacial soil composed of sand and gravel is very permeable, but may have little pore space and does not retain water well. By comparison, clay soil tends to retain water well because it has a porosity of fifty percent, but it has low permeability since the pore spaces are relatively small and poorly connected. Every soil material has a characteristic primary porosity depending on the amount of pore space it contains. Openings created by earth worms, root holes, decaying organic debris, and cracking from drying form connected secondary pores that greatly increase the porosity and permeability of soils.

In upland areas pore spaces are saturated only during a heavy rain. At all other times the pores remain unsaturated. The area immediately below the soil surface is known as the vadose zone. Water moves down through the vadose zone until it encounters a saturated area called the phreatic zone. The boundary between the vadose and phreatic zones is the water table. Below the water table pore spaces within the phreatic zone are essentially filled with water. As water percolates down through the ground it moves from pore spaces in the soil into pore spaces in the underlying rock. Most rock has at least some pore space or secondary fissures that liquid water can move through. Water within the phreatic zone moves horizontally at a very slow rate until it encounters a low point or an impermeable strata. There it is discharged into the bottom of a stream, or to the surface in the form of a spring or seep. Over six thousand times more water exists in the ground than in flowing rivers at any one time (Horne and Goldman, 1994). The slow release of stored ground water maintains a relatively constant base flow in surface streams that is essential for aquatic life.

The impact of urbanization on stream flow in Peachtree Creek, which drains a watershed area of 87 square miles in metropolitan Atlanta, was documented for a thirty year period between 1958 and 1988 (Ferguson and Suckling, 1990). In the first year of the period studied, the United States Geological Survey constructed a gaging station on the creek. Records from the station were analyzed for a period of rapid growth in which the population in the watershed nearly doubled. The watershed is underlain by nearly impervious granitic rock that holds very little ground water. Clay soils that cover the bed rock also have low permeability, but are able to absorb and release precipitation that infiltrates through vegetated surfaces. Increasing peak flows and declining base flows were measured during the period of study.

A series of severe droughts and floods in the last decade has focused national attention on identifying the root causes of these disasters. Atlanta has special cause for concern because, most of its water supply comes from surface water. As have many other cities, Atlanta has developed, used, and then abandoned local supplies from streams, springs, and wells (Leslie, 1987). After despoiling the smaller supplies, it has moved the site of its major withdrawals to the largest available source flowing into the Metro area, the Chattahoochee River. Peachtree Creek which drains a large portion of Metro Atlanta and receives sewage outflows from the city, enters the Chattahoochee River just fifty feet downstream from the city's water intake line.

The downstream states of Alabama and Florida recently filed suit against the Army Corps of Engineers to prevent allocation of more water to communities in Metropolitan Atlanta. Unless Atlanta can find ways to develop without decreasing the flow of the Chattahoochee River, its citizens could face water use restrictions and economic constraints. Infiltration techniques could help to reduce both flooding and low flow conditions downstream of Atlanta.

In addition to water quantity, water quality is an important issue. Natural streams have the ability to gradually purify water passing through them. Pollution discharge permits are based on this principle (Mills et al., 1985). However, the ability of streams to purify water assumes that they have functioning ecosystems within them. Next we will examine the effect of urbanization on these ecosystems.

IMPACT OF URBANIZATION ON AQUATIC ECOSYSTEMS

The treatment of raw sewage and control of industrial effluent in the past three decades has greatly reduced the impact of point source pollution on urban streams, but many of these waterways have failed to recover. In some cases the cause is obvious. Where streams have been channelized or piped underground there is no habitat . Toxic spills from accidents such as overturned tanker trucks or ruptured pipelines continue to poison some streams. Poor construction practices can release large surges of sediment that smother organisms. Still there are many urban streams that look relatively clean, yet they remain biologically degraded.

Despite the widespread decline of aquatic life in urban streams (Klein, 1979), ecologists have neglected to study and document the specific reasons for the phenomena. Urban streams are often unpleasant and potentially dangerous environments where work on degraded ecosystems has little appeal. A report on the urban streams in the state of Georgia found them to be the most degraded aquatic systems (Mikalsen, 1993). For a better understanding of the reasons for the decline we must turn to ecological theory.

The River Continuum Concept (Vannote et al., 1980) views a river "From headwaters to mouth...(as a) continuous gradient of physical conditions...(that) should elicit a...continuum of biotic adjustments." Based on this view the severe alteration in flow pattern as a direct result of urbanization should be reflected in the biotic community of a stream. Orster and Shure (1972) supported this view by demonstrating that scouring and erosion caused by increased runoff reduced or eliminated salamander populations in urban streams in Atlanta.

The River Continuum Concept holds that a stream is strongly influenced by the riparian (from Latin *rip* for bank of a stream) vegetation that borders it. Trees anchor the banks and provide shade that stabilizes water temperature. Logs that fall into the stream create a series of pools interspersed by riffles, providing refuge and feeding areas for a wide variety of species. Amphibians, waterfowl and other wildlife depend on stream side vegetation as well as the stream for their existence. The fall of leaves and woody debris entering a stream provides food for invertebrates that consume microbes growing on the coarse particulate organic material. In the process of consuming the microbial coat they shred the coarse material into fine particulate organic material (FPOM) that feeds collecting and filtering organisms in larger creeks downstream. Complex assemblages of species have adapted to this flow of food energy. Riparian vegetation serves such a vital role in maintaining stream ecosystem function that it should be thought of as an extension of the stream itself.

Urbanization is accompanied by the clearing of trees along streams. With the trees gone, water temperature becomes elevated. Leaves and woody debris no longer feed invertebrates. Deprived of a food source, native fish and other aquatic vertebrates die out. Exotic species that are adapted to the harsh conditions invade. With vegetation replaced by pavement, the scouring and erosion that accompany the resulting flash floods washes out many pools and riffles. It also exports large amounts of sediment downstream where it smothers the remaining habitat provided by spaces between rocks and piles of debris.

Pavement retains the pollutants that fall on it. When it rains, a scum of motor oil, heavy metals, chemicals and pet feces enters urban streams with storm runoff. Lawns release pesticides and excess fertilizers. These nonpoint source pollutants and silt replace the FPOM normally exported downstream from headwater streams to rivers. There, filter feeding organisms remove the contaminated sediments and concentrate heavy metals to potentially toxic levels. Nutrients fertilize algal growth in streams and rivers that are shallow enough for light to reach the bottom. These findings may explain the fish species found in a survey of an urban Atlanta stream. The most numerous fish in the stream was an herbivorous stoneroller, *Campostoma anomalum*, and the second most numerous species found was the exotic red shiner, *Cyprinella lutrensis* (Cunningham et al., 1993). The Index of Biological Integrity lists a dominance by herbivorous and exotic species as indicators of a degraded stream (Karr, J. R., 1981).

The Flood Pulse Concept (Junk et al., 1989) explains aquatic ecosystem structure in large river-floodplain systems. According to this ecological theory, species in rivers have become adapted to the seasonal flood pulse. The natural rise of water which usually takes place in the winter, inundates the flood plain and creates a moving littoral zone (shoreline). This prevents stagnation and makes organic matter accessible as a food source to aquatic organisms. Dams, channel alterations and development on the flood plain are known to decouple the river-floodplain system.

The hydrological impact of urban development within a river basin is less well studied. As previously discussed, urban development increases flooding and decreases base flows to tributary streams. The potential impact of the widespread use of stormwater detention, and reduced infiltration from impervious surfaces in upstream urban development, deserves further research.

One specific effect of reduced upstream infiltration would be the concentration of pollution downstream. It is current practice to issue point source discharge permits based on the volume of surface water flow (Mills et al., 1985). The flow measurement for large streams and rivers is based on historical data obtained from gaging stations. With increasing urbanization, the base flow of certain waterways could be declining and reducing the dilution of permitted discharges, allowing them to reach toxic levels for organisms downstream. Stormwater infiltration recharges ground water and contributes to base flows.

In 1979, Klein observed that detention structures are used most frequently even though they do not contribute to base flow and have minimal impact on water quality. He also pointed out the potential benefits of infiltration, and lamented that "...infiltration systems make up only a small portion of the control strategies outlined in stormwater management plans. This fact is said to be due to the difficulty involved in designing these systems." Experience in designing infiltration systems has now been gained by a number of municipalities, particularly those facing water shortages.

STORMWATER INFILTRATION TECHNIQUES

As urbanization increases, the amount of natural ground available for infiltration decreases. Klein (1979) estimated that for a site in the Northeast, an impairment in the biotic quality of streams is first evidenced when watershed imperviousness reaches twelve percent. He calculated that half of a watershed could be developed for residential use if the lots were one acre in size, without degrading water quality. Higher densities of development require stormwater management.

As previously discussed, an intact, vegetated, riparian ecosystem reduces erosion, stabilizes stream water temperature, creates wildlife habitat, and provides an essential flow of fine particulate organic matter that supports life downstream. It also serves an essential role in infiltration and pollution reduction. Water infiltrated into the soil profile passes through the roots of vegetation as it moves down slope and reemerges in streams. Typical alluvial soils found in riparian areas are also deep and store large amounts of water contributing to base flow. Research has shown that preserving a riparian buffer strip along streams in agricultural areas greatly reduces nonpoint source pollution from sediment and fertilizers. Although specific research is lacking, it is postulated that buffer strips remove pesticides as well (Lowrance 1985). In areas with low density development, preservation of riparian buffer strips may be adequate to maintain infiltration and control nonpoint runoff. Riparian buffers combined with point source pollution reduction will also help to protect streams in urban areas, but due to the large amount of impermeable surface area must be combined with stormwater control. Three types of structures that infiltrate stormwater will be described: permeable pavements, basins, and wells (Ferguson, 1994).

Infiltration Pavements

Infiltration pavements reduce stormwater runoff at the source, and reduce or eliminate the need for constructing basins downstream. Porous asphalt is composed of open-graded stone aggregate and asphalt binder. It differs from typical non-porous asphalt in the use of stone sieved to one size. Without the fine aggregate particles that normally fill the voids between larger particles, the asphalt mix remains permeable to rainwater. The asphalt is applied to a bed of open-graded, crushed stone that serves to distribute the load and store water while it infiltrates into the ground. During construction it is important to avoid driving heavy equipment over the site that would compact the underlying soil surface. Porous concrete is a mix of graded aggregate without the fines, combined with portland cement. The cement content is higher than in regular non-porous concrete (Ferguson, 1994).

Porous pavements have been used successfully in low-traffic areas, primarily parking lots. Steep grades require that the underlying gravel be terraced to slow subsurface runoff, so pavement of relatively level surfaces is most cost effective. Freezing temperatures have not caused damage as long as the soil underneath is well drained. Pavement twenty years old has stood up well. Because water drains away quickly, porous pavement is very skid resistant and requires less use of deicing salt in the winter. Dirt and sediment build up can usually be removed via vacuuming or high pressure hosing. Since gutters and culverts are not necessary, the cost of installing porous pavement is less expensive than impermeable pavement when incorporated into an overall site design.

Open-celled pavers filled with seeded soil or aggregate are set in a sand bed over a base of open crushed stone. In residential use, the crushed stone base can be eliminated when the soil is stable. They have been used successfully in Germany for parking lots, road shoulders, and walkways. In the United States they are used for light duty and temporary parking lots.

Infiltration Basins

Where sufficient space is available, surface runoff can be directed into infiltration basins. Basins are constructed by excavation, or by placing check dams in swales. For a given volume of stormwater, areas with low soil permeability will require a larger basin surface area to infiltrate the water. Basins that are undersized, pond water for prolonged periods. After a week of ponding water, the microbes in the soil on the bottom of a basin begin to shift from aerobic to anaerobic. When deprived of oxygen, the soil tends to form an impermeable surface crust. The solution is to construct the basin so that it is large enough to infiltrate standing water within a few days of a storm (Shaver, 1986).

Basins that are sized properly support a healthy growth of vegetation that keeps the soil pores open. Planting can be done with native vegetation but basins in public use areas have been planted with bermuda grass or fescue and used as recreation fields. Both of these grasses withstand temporary submergence well and thrive in the frequently inundated, nutrient-rich basin soils. Shallow basins in dry areas can be lined with gravel and used as open air patios by restaurants. Unlike detention basins, infiltration basins are best constructed with a flat floor. A sloped floor concentrates runoff in the lowest area which then becomes saturated, loses its permeability, and becomes permanently wet. Water balance is an important concept that must be applied when sizing a basin. A residual amount of runoff from a heavy storm may preempt some of the capacity of a basin to absorb rain from a second event. Again, proper sizing avoids this problem.

Subsurface basins are more expensive to construct than surface basins, but combine stormwater control with other functional structures. They are most often used as parking lots, but could serve as tennis or basketball courts. Construction begins with the excavation of a reservoir which is lined with permeable sand or filter cloth. Next, the excavation is filled with open-graded aggregate that has a void space of forty percent of the total volume. Subsurface basins are sized to account for the storage volume lost to aggregate, and constructed with one or more inspection wells. The surface can be covered with porous pavement that infiltrates water directly into the reservoir below. Where heavy traffic conditions require an impermeable surface, gutters or an exposed gravel berm with curbs can communicate runoff into the subsurface infiltration reservoir.

Infiltration Wells

Small subsurface basins or "dry wells" are constructed to receive the runoff from downspouts where insufficient space exists to construct a surface basin. The design is basically the same as that for a subsurface basin, except that instead of being covered with permeable pavement, the surface of the aggregate filled reservoir is left exposed, or covered with filter fabric and then soil. Once vegetation becomes established over the well, it blends into the surroundings.

Large, cased infiltration wells have been used to penetrate impermeable strata where permeable strata exists below. They have also been used to drain isolated areas where space is very limited and in the floor of infiltration basins that have become clogged and no alternate site is available. These large wells have had a mixed record of success. It is hard to predict how well a particular site will work and contamination of ground water has been a concern in some locations. Other infiltration techniques have had a good record of success. We will now examine the results in more detail

EVALUATION OF RESULTS

Considerable experience has been gained in the use of infiltration techniques. California first instituted infiltration a century ago to recharge ground water. However, infiltration for the most part has been part of large public works projects that serve narrow interests. Los Angeles uses spreading grounds totaling 1,300 ha in size to infiltrate diverted stream water as well as urban runoff for later withdrawal as industrial and municipal supplies. Fortunately, infiltration techniques that are compatible with overall environmental quality have been used in other locations. The experience gained in programs instituted on Long Island and Maryland will be examined.

Long Island, New York is underlain by permeable glacial soils and relies exclusively on ground water supplies. In 1935 Nassau County (later joined by Suffolk County) instituted a program to design and install recharge basins to conserve stormwater by infiltrating it into the ground. To date, over 3,000 basins have been constructed. Most drain residential areas and highways. Three percent drain industrial areas. Most have overflow structures that release water from heavy storms to other basins or streams. Some basins have settling areas at a different elevation that collect trash and sediment. Water is directed into the basins by short storm sewers some of which have dry wells as part of their inlets.

Over ninety percent of the basins are dry within five days of a 2.5 cm rainfall. Most of those that hold water intersect the water table or are clogged with sediment. The quality of groundwater draining from basins was sampled in representative land use areas. It met drinking water standards with the exception of road salt. Recharge from 2,100 basins operating in 1969 was greater than the groundwater withdrawn to supply residents (Ferguson, 1994). Stormwater infiltration has been very successful on the permeable soils of Long Island.

The state of Maryland developed a very creative infiltration program during the 1980's. The program is reported to be partly the result of the leadership of one man, Earl Shaver. The program had a broad range of environmental objectives including the reduction of salt water intrusion in aquifers. By 1992 about a thousand basins had been built. Two studies, one conducted in 1987 and another in 1991, found that about a third of the basins held some water that reduced their capacity. (Lindsey et al., 1991). The study results, combined with an administration reorganization and the departure of Earl Shavers to another state, curtailed the infiltration initiative.

Not considered in the review of basin performance was the adequacy of basin design or the effect of soil crusting. Basin failure was attributed to sedimentation, inadequate maintenance, and soil compaction during construction. All of these problems could have been corrected through implementation of better construction and maintenance practices. Soil crusting occurs when surface pores of the soil become clogged. Experience has shown that it can be corrected by removing the thin superficial layer of soil, by raking in an organic mulch, and in some cases by applying gypsum. Sometimes an impenetrable surface crust forms when sediment from new construction washes into a basin. It is essential that discharge of sediment from soil disturbance be controlled. The one problem found that related to basin design was inadequate soil conductivity. Based on experience, this must be tested on site and the basin sized accordingly.

Experience from Long Island shows that given time and a long term commitment, solutions were found for most problems. Concern that basins represent an attractive nuisance and therefore a legal liability could also have been a problem in Maryland. Long Island legally designated all its basins as groundwater recharge areas in about 1990, and plans to fence them in. Fencing could address the liability problem, but would restrict the movement of wildlife that could benefit from nearby riparian corridors.

All infiltration designs are prone to clogging by washed in sediment during the construction phase. One practice that has worked well to prevent this problem is the initial use of partially excavated, on-site basins for detention of water and trapping of sediment. After buildings are constructed and bare earth is covered, the final phase of construction is completed by converting the basins to infiltration. This is done by completing excavation and spreading accumulated sediment on the surface where it is seeded and mulched. The basin is then finished and planted. Inspection should be done to determine if surface crusting is occurring, and if so corrected. Where sediment is a problem, sediment traps can be constructed upstream or within the basin.

During the early development phase of stormwater management techniques, concern was expressed that infiltration could trade contamination of surface water for contamination of aquifers (Klein, 1979). Now that long term results are available, this concern appears unfounded. In addition to the favorable experience reported in humid Long Island, results are available for arid Fresno, California. As part of the EPA's Nationwide Urban Runoff Program, a two year study was conducted of the quality of water percolating into the water table from five representative basins (Nightingale, 1987). The oldest basin was constructed in 1962. No contamination by trace elements, or organic pollutants was found, with the exception of traces of diazinon in three samples. Water entering the basins was contaminated with both inorganic and organic pollutants.

Infiltration can be adapted to local conditions by combining it with other stormwater management methods. The "first flush" of stormwater contains most of the contaminants. Oil, heavy metals, and other pollutants that accumulate on the surface of pavement are washed off by the first runoff from a storm. Additional runoff gradually approaches the background levels of atmospheric contamination found in rainfall. Current municipal codes are primarily concerned with infrequent peak storms that lead to serious flooding. By installing infiltration systems that can absorb the first 1.25cm (1/2 inch) of rainfall, most of the pollution can be removed from runoff. Calculations by the Maryland Sediment and Stormwater Administration (1986) showed that: (1.) Sixty-five to seventy percent of total annual runoff in their area could be infiltrated by capturing only the first 1.25cm of runoff from impervious surfaces, and (2.) this first flush of runoff contained ninety five percent of the pollution.

By sizing infiltration structures to capture the first flush of runoff, much of the rain falling on impervious surfaces can be infiltrated and most of the nonpoint pollution removed. Location of infiltration basins next to culverts or drainage channels allows for the first flush of a major storm to be diverted by a low weir. Once the basin fills, the remainder of the stormwater bypasses the infiltration basin and discharges into a stream. It could also enter a detention basin designed to handle the overflow. Occasional floods are often essential to ecosystem health. The problem is that urban development increases the frequency and severity of floods beyond the ability of organisms to adapt (Klein, 1979). Retaining a portion of stormwater in infiltration basins, combined with restoration of riparian buffer zones that include the flood plain of streams, has the potential to restore water quality in urban areas. Restoration of downstream wetlands that provide water quality improvement (Hey, 1987) can be combined with infiltration basins upstream. Construction of basins that capture the first flush of runoff could be very feasible even on slowly permeable soils. The main concern is to size the basin to take into account the water balance of the area so that standing water does not result. A comparison of the relative cost of detention versus infiltration was made for both a residential and a commercial development in Atlanta. Calculations showed that although detention was the method used, infiltration systems of equal capacity could have been installed for the same or less cost (Ellington and Ferguson 1991).

Infiltration has been demonstrated to be effective in permeable and moderately permeable soils, but there is no reason to believe that it will not work in slowly permeable soils as well. Clearly the infiltration surfaces will have to be greater for a given volume of water and other adjustments made to existing designs. Atlanta, Georgia is located on the southeastern Piedmont, a region of thick, semi-permeable clay soils overlying relatively impermeable bedrock. The potential for water shortages and use restrictions imposed by downstream states provide an economic incentive to conduct research on the use of stormwater infiltration techniques. A survey of Atlanta streams being conducted as part of a nationwide program by the U.S. Geological Survey is disclosing biotic degradation (personal observation of preliminary results 1994). If infiltration can be demonstrated to work in the relatively impermeable soils of the Georgia Piedmont, it can be applied to urban areas almost everywhere. Based on its potential for restoring ecosystem function and maintaining water supplies, wider application of stormwater infiltration is recommended.

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