



# Saving Silver Lake

Used mainly for recreational purposes, Silver Lake, in Wilmington, Massachusetts, previously received direct discharges of storm-water runoff. Low-impact development features were installed to help runoff enter the soil, thereby reducing pollutant loadings in the aesthetically important lake.

To improve water quality in Silver Lake, a key recreational amenity, the Town of Wilmington, Massachusetts, implemented several measures that figure in low-impact development in an effort to collect and treat storm water before it enters the lake. Subsequent monitoring indicates that the various storm-water management practices are performing as designed. More broadly, the town's actions complement a larger effort to restore the health of the troubled Ipswich River in northeastern Massachusetts.

**By Steven P. Roy and Andrea M. Braga, A.M.ASCE**

**T**he Ipswich River, stretching 45 mi (83 km) from Burlington, Massachusetts, to the Atlantic Ocean, is both a valuable ecological resource and a critical source of drinking water for more than 330,000 residents and businesses in northeastern Massachusetts. Third on the list drawn up by American Rivers in 2003 of the nation's most endangered rivers, the Ipswich suffers from extremely low flows and extended periods of no flow

along much of its upper watershed, threatening groundwater and drinking water supplies. Studies conducted by the Massachusetts Water Resources Commission have classified the Ipswich River as "highly stressed" as a result of water withdrawals from tributary streams and polluted storm-water runoff from impervious areas that are increasing as a result of land development. Parts of the watershed are also chronically affected by fecal coliform

bacteria, largely attributable to pet waste, increasing waterfowl populations, and aging septic systems. In accordance with the provisions contained in section 303(d) of the Clean Water Act, the Massachusetts Department of Conservation and Recreation has included the Ipswich River on its list of water bodies impaired by pathogens. Storm water is believed to be a major source of bacteria in the river.

The Ipswich River project conducted by the Massachusetts Department of Conservation and Recreation supports work that is being undertaken by the state and the U.S. Environmental Protection Agency (EPA) to restore the headwaters region of the river. As part of this comprehensive restoration project, the Town of Wilmington, Massachusetts, carried out the Silver Lake Low Impact Development Retrofit Project, an effort that involved the implementation of several practices that figure in low-impact development (LID) to treat storm water in the Silver Lake watershed, which ultimately drains to Lubbers Brook, a tributary of the Ipswich.

LID is a comprehensive approach to land planning and engineering design that seeks to maintain and enhance the predevelopment hydrologic regime of urban watersheds and watersheds undergoing development. New development, redevelopment, and retrofits can benefit from managing storm water on-site through the use of infiltration and biologically based bioretention.

The Silver Lake project seeks to demonstrate how distributed LID controls can effectively reduce the volume of storm water and nutrients entering lakes. The project aims to quantify the benefits of innovative LID techniques for decreasing the untoward effects associated with non-point-source pollution while increasing groundwater recharge through infiltration and showcasing the benefits of innovative conservation techniques. To this end, the U.S. Geological Survey (USGS) monitored runoff volumes and water quality from the project sites before and after construction.

In 2005 Wilmington hired Geosyntec Consultants, headquartered in Boca Raton, Florida,



Several rain gardens constructed throughout the residential project area are expected to improve the quality of storm-water runoff and facilitate infiltration to recharge groundwater.

to develop storm-water treatment designs for measures that were to be implemented within the Silver Lake watershed. An extensive watershed assessment was conducted to determine how best to retrofit a parking lot and a storm-water drainage system through the installation of the following:

- Porous pavements;
- Bioretention cells;
- Vegetated swales;
- Rain gardens.

The sites selected for the project, which are located on opposite sides of the lake, use land in different ways; one is a parking lot in the vicinity of the Silver Lake town beach and the other is a lakeside residential area surrounding Dexter Street, Silver Lake Avenue, and Lake Street in Wilmington. The project called for the reconstruction of the parking lot and the conversion of two storm-water outfalls into vegetated swales.

The EPA's Targeted Watersheds Grant Program is a nationwide effort designed to encourage and support projects that will protect and restore the nation's water resources through a community-based watershed approach to water quality and water quantity management. The Massachusetts Department of Conservation and Recreation received 1 of 14 grants awarded in the program in 2004. The \$1.04-million grant from the EPA helped to finance the Silver Lake project as well as seven other demonstration projects aimed at restoring the Ipswich River.

As part of the same grant, the Massachusetts Department of Conservation and Recreation purchased, delivered, and installed 40 residential rainwater harvesting systems for volunteer participants, four of whom are in the Silver Lake watershed. The rainwater harvesting systems, which range in size from 200 to 850 gal (0.8 to 3.2 m<sup>3</sup>), make it possible to collect water from rooftops to water plants, flowers, and gardens, even during droughts. Because the average residential roof in Massachusetts sheds more than 5,000 gal (19 m<sup>3</sup>) of water during the summer months alone, rainwater collection is an excellent way to conserve water.

Two vegetated swales were designed and installed to replace a storm-water outfall that discharged directly to Silver Lake.



In addition to the residential units, the department funded the installation of an 8,000 gal (30 m<sup>3</sup>) underground system at an elementary school. That system was designed and installed by Rainwater Recovery, Inc., of Waltham, Massachusetts.

Silver Lake is a 28.5 acre (11.5 ha) kettle lake with a watershed area of 132 acres (53 ha) and a maximum depth of 29.5 ft (9 m). Because of its aesthetic importance and its use for recreational purposes, there is a strong desire to keep the lake free of pollutants. Before the Silver Lake LID retrofit project was carried out, storm-water flows were collected and transported via a conventional storm drain system that discharged directly into Silver Lake. Because it contains sediment and other pollutants, the runoff has a high potential for lowering the quality of the lake water. Diminished water quality, in combination with high counts of fecal coliform bacteria in the summer months, occasionally forces the town to close the swimming area at Silver Lake to the public. With the implementation of LID technologies, the goal is to reduce and possibly eliminate beach closures, as well as to increase the supply of groundwater to Silver Lake, thereby increasing the base flow and decreasing the periods of no flow along much of the upper headwaters of the Ipswich River.

Began in January 2006, the improvements in the vicinity of the parking lot at the Silver Lake town beach were the first components of the project. The improvements included the demolition of the asphalt parking lot, which was partially replaced with porous pavement underlain by a bed of stone designed to store and promote the infiltration of storm water. Moreover, bioretention cells were constructed within the parking lot, and two vegetated swales were constructed as part of an effort to “daylight” two storm-water outfalls on either side of the beach by replacing them with open channels. The improvements in the residential area involved the construction of rain gardens along the right-of-way on multiple residential properties. As an added measure, the asphalt pavement along one side of Silver Lake Avenue was retrofitted with porous pavers and underlying infiltration beds. Given the nature of the retrofit in the residential locations, the project included extensive community involvement and an interactive education and outreach program.

**P**ermeable interlocking concrete pavement—also known as porous pavers—and porous asphalt were installed to replace approximately half of the 34,000 sq ft (3,159 m<sup>2</sup>) paved parking lot at the Silver Lake town beach. The porous pavers were installed within the parking spaces, and porous asphalt was installed adjacent to the pavers in the aisles. A 12 in. (31 cm) deep stone infiltration bed was installed continuously beneath both porous surfaces. The voids between the pavers were filled with small crushed stone that allows water to percolate down into the underlying stone bed. The porous asphalt functions in the same way, the voids in the asphalt enabling water to percolate into the subbase. However, since the entire surface of the asphalt is pervious, rainfall can percolate directly through the surface and into the underlying stone basin, eliminating runoff. For financial reasons, the southern half of the parking lot was resurfaced with standard asphalt.



**Because of their ability to directly measure vertical flow into the soil, single-ring and double-ring infiltrometer tests were used to assess surface infiltration rates on two bioretention cells, one rain garden, and all four porous pavement surfaces at the project site.**

The goal in this design was to showcase the two porous surfaces together, making it possible to see how efficient each material is in transmitting storm water through its surface. It is also possible to compare durability and resistance to wear. Furthermore, the stone bed beneath the porous half of the parking lot provides enough storage to hold the first 2 in. (50 mm) of rainfall from the entire parking lot—both the porous section and the nonporous section. Therefore, additional storage beneath the standard asphalt was not necessary, and the standard asphalt was graded to direct runoff onto the porous asphalt, the porous pavers, and the bioretention islands.

Two porous paving systems—GravelPave, manufactured by Invisible Structures, Inc., of Golden, Colorado, and Flexi-Pave, manufactured by K.B. Industries, Inc., of

Clearwater, Florida—were installed in a section of the overflow parking area that had been a compacted dirt lot. Like the porous pavers and porous asphalt, the GravelPave and Flexi-Pave systems enable storm water to filter through the surface into a stone bed below, providing storage and facilitating infiltration. GravelPave takes the form of gravel contained in small plastic containers that provide structural integrity for use in parking areas. Flexi-Pave is a pour-in-place rubber paving surface developed from a combination of pisolite (peastone) and recycled tires. All of the porous surfaces are designed to promote infiltration, improve groundwater

recharge, and reduce the discharge of pollutants into Silver Lake.

Multiple bioretention cells were constructed along the perimeter and as a center island in the parking lot. The bioretention cells are landscaped depressions designed to store and promote the infiltration of storm-water runoff from the parking lot and to capture and remove sediment and nutrients. The cells include specialized plantings and a bioretentive soil mixture that exhibits a high infiltration rate. The bioretentive soil is engineered

to have a higher hydraulic conductivity than that of conventional planting soil and to possess a much higher sand content and significantly lower amounts of silt, clay, and organic matter. The mix is 50 to 85 percent sand, 0 to 50 percent silt, 5 to 10 percent clay, and 1.5 to 10 percent organic matter. This mixture provides increased porosity and there is less potential for the soil to clog with sediments from the runoff, an important consideration in view of the fact that the bioretention cells are receiving runoff from the impervious asphalt sections of the parking lot. As a result, the cells must be able to accept water quickly during intense storms, when runoff will occur faster and in greater volumes. The bioretention cells will provide additional opportunity for runoff from the parking lot to be captured and absorbed or to be taken up through the vegetation in the cells.

The bioretention cells also provide some storage by virtue of a 12 in. (305 mm) deep stone bed beneath the bioretentive soil. On the northern side of the parking lot, this stone bed ties into the stone bed beneath the porous pavement. On the southern side, the bioretention cells have an underdrain in the stone bed that conveys any storm water that has not infiltrated to the center bioretention island, which has a main underdrain leading to the outlet of the infiltration bed. Storm water will exit the infiltration bed only during high-intensity, high-volume storms, when the storage capacity of the stone bed has been exceeded and the infiltration capacity of the subgrade is lower than the intensity of the rainfall. In that case, the overflow will be directed to a pipe at the outlet of the parking lot that will convey the water to Silver Lake.

Two vegetated swales were



Twelve rain gardens were constructed on right-of-way owned by the Town of Wilmington in the Silver Lake watershed. In choosing the garden sites, preference was given to locations that would make it easy to convey runoff from the street.

designed and installed to replace storm-water outfalls along the northwestern and southeastern boundaries of the town beach. Approximately 10 ft (3 m) wide and 80 ft (24 m) long, each swale collects runoff from the retrofit parking lot and adjacent streets and conveys it into Silver Lake.

Each of the two existing storm-water pipes, which previously had discharged through the outfalls directly to the lake, was redirected into one of the swales. The swales were overexcavated

and backfilled with a soil similar to that used in the bioretention cells. After being lined with a turf-reinforced mat, they were seeded and planted with native plant species. Turf-reinforced mat is a plastic woven fabric that is installed on the swale surface to hold seeds and soil in place and provide immediate, permanent stabilization, preventing the erosion that otherwise would occur when storm water flows through the swale. The swales will decrease the flow rate of the storm water and increase the length of overland flows entering the lake. They will provide an additional opportunity for storm-water infiltration through the soil as well as for filtration and biological uptake through the plant roots. What is more, exposure to natural ultraviolet light has been found to significantly reduce fecal coliform levels in streams that have been daylighted.

Both of the swales discharge into Silver Lake. Because of the fluctuating water level of the lake, portions of each swale will be inundated at certain times of the year. At these times, the swale will act both as a storm-

water conveyance and as a small wetland area. The downstream sections of each swale were planted with species of plants that can survive under wet conditions. Meanwhile, species that prefer drier conditions were planted farther upstream of the swale. These selections were made in an attempt to ensure that storm water will be treated and filtered by the swale under most conditions.

The area adjacent to the northwestern swale was a grassy area bordering the sandy beach. The grass provided an attractive nesting and feeding ground for Canadian geese and other waterfowl, promoting an accumulation of droppings that contributed to bacteria loading in the public swimming area.

Tire stops made of recycled plastic were included at each parking space.



To alleviate this problem, the grass was excavated and replaced with sand. Since then, waterfowl have stopped congregating in this area, and in the two summer seasons since the project was completed there have been no beach closures because of high bacteria counts in the lake. To prevent similar problems in the future, the water quality swales were planted with native shrub species that are not favored by grazing waterfowl.

In the spring of 2006, the last component of the project, namely, the installation of 12 rain gardens on the town-owned right-of-way in the Silver Lake watershed, was undertaken.

The construction of several rain gardens throughout the residential project area is expected to improve the quality of storm-water runoff and facilitate groundwater recharge by disconnecting flow paths—in this case, roofs, driveways, and roadways—from the storm drain system. Runoff from roofs, driveways, and roadways will enter the rain gardens rather than flow directly to the storm drain system.

Like bioretention cells, rain gardens are shallow landscaped depressions designed to accept the first flush of storm-water runoff and capture and remove sediment and nutrients. They incorporate specialized plantings and an engineered bioretentive soil mixture with a high infiltration rate. Used to control the volume and timing of runoff, rain gardens can remove pollutants through the physical, chemical, and biological processes that occur in plants, soil, and mulch. For this project, the lowest levels of the rain gardens were made up of porous aggregate material.

The rain garden sites were placed where the storm-water runoff is most easily conveyed from the street. The gardens were also spaced so as to collect the maximum amount of runoff. This neighborhood was particularly challenging because on one side of the street the lawns were approximately 4 to 6 in. (100 to 150 mm) above the roadway. Because the rain garden was initially designed to be 6 in. (150 mm) lower than the road, the grade difference appeared to render those locations unsuitable. However, the rain gardens were redesigned in a longer, narrower fashion to create a gradual slope from the rain garden up to the lawn area.



One of two porous paving systems installed in an overflow parking lot, GravelPave consists of gravel contained in small plastic containers that provide structural integrity.

from 80 to 300 sq ft (7 to 28 m<sup>2</sup>). Homeowners were encouraged to treat the gardens as landscape features and to maintain them with periodic replacements of mulch.

In addition to the planned storm-water improvements, the Silver Lake project involved a significant public outreach and education effort intended to provide homeowners with information on “watershed-friendly” practices for water conservation and reuse. The practices had to do with lawn care, wildlife management, the disposal of hazardous household waste, and the management of pet waste. A brochure explaining the storm-water improvement project and the steps that homeowners could take to protect the lake was developed and mailed to watershed residents with their utility bills. Public meetings were held to give Silver Lake watershed residents a better understanding of the design and construction of the LID improvements.

On June 26, 2006, a ribbon-cutting ceremony was held to celebrate the completion of the project. The event focused on displays of the different LID techniques used at Silver Lake to reduce runoff and provide some treatment of storm water before it enters the lake. As part of the ceremony, buckets of water were poured on the different porous surfaces to demonstrate how well the LID techniques control storm-water runoff by helping it to enter the ground at the source rather than enter the lake as runoff.



At sites at which lawns were higher than the roadway, rain gardens were redesigned in a longer, narrower fashion to create a gradual slope from the rain garden up to the lawn area.

On July 15, 2008, two years after the project was completed, the Massachusetts Department of Conservation and Recreation hosted what was called a rain garden day at Silver Lake to encourage residents to care for their rain gardens. The department donated 200 plants and 5 cu yd (3.8 m<sup>3</sup>) of mulch for the event. Residents were invited to work on the rain gardens along with representatives from the Massachusetts Department of Conservation and Recreation, the Town of Wilmington, Geosyntec Consultants, and the Cali Corporation, of Natick, Massachusetts, which served as the general contractor for the project.

In addition to its LID features, the project included significant components related to storm-water sampling and modeling so that the benefits conferred by LID technology can be gauged. Beginning in July 2005 and continuing through October 2006, the USGS measured runoff volume and various water quality parameters on 10 occasions from monitoring wells installed beneath the parking lot and equipment on Silver Lake Avenue. The agency is now analyzing the samples. Because of uncertainty regarding the time needed for contaminants to travel through the subgrade of the parking lot, groundwater samples were taken monthly and the water level was monitored to help uncover patterns in the groundwater level relative to storm events.

The data are intended to help determine whether any potential contaminants attributable to the pervious parking lot are present in excess of background levels. At the monitoring stations along Silver Lake Avenue, storm flows were tested both for quantity, using continuous flow monitoring, and for quality, using grab samples. Tests at the Silver Lake monitoring sites looked for the following:

- Nutrients (nitrite, orthophosphate, phosphorus [filtered and unfiltered]);
- Metals (cadmium, chromium, copper, lead, nickel, zinc);
- Petroleum hydrocarbons.

In addition to the constituents listed above, the following parameters were measured for all samples: barometric pressure, pH, specific conductance, and temperature. When they become available, the results will be posted on the Web by the Massachusetts Department of Conservation and Recreation (visit [www.mass.gov/dcr/waterSupply/ipswichRiver/demo4-lakewater.htm](http://www.mass.gov/dcr/waterSupply/ipswichRiver/demo4-lakewater.htm)).

Using the information gathered from Silver Lake Avenue and the parking lot locations, the USGS will develop a model called the Hydrological Simulation Program—Fortran in the hope of relating precipitation, land use, and water withdrawals to stream flow over the entire Ipswich River watershed. The model will be adjusted to represent hypothetical scenarios of alternative water pumping and

land use patterns, including broader application of the water conservation and LID practices demonstrated under the grant. A technical advisory committee will work with the USGS to develop scenarios and to help determine the best way to translate the collected data into model adjustments.

The model will be adjusted to reflect the reduced runoff and increased recharge over selected areas of the watershed to represent LID retrofits or new development. The adjustments will be made using data related to the reduction of runoff during storm events as a result of the LID retrofits installed as part of the Silver Lake project and the construction of a 20-unit subdivision incorporating a range of LID components and open-space design elements. The adjustments will also reflect various assumptions about recharge associated with these data. Reduced water withdrawals at public water supply wells will be modeled based on data from the water conservation demonstration projects, including the rainwater harvesting project, implemented in the Ipswich River watershed as part of the funding provided by the EPA's Targeted Watersheds Grant Program. The model will translate these adjustments into

flow benefits to the river and tributaries and will define the techniques and combinations of techniques that offer the greatest potential flow benefits. Rather than being factored into the model, the water quality data will be used to answer questions about the safety of pervious pavement and other infiltration practices with respect to the potential for contaminants from runoff leaching into groundwater.



Permeable interlocking concrete pavement units, also known as porous pavers, were installed within the parking spaces at the Silver Lake town beach, and multiple bioretention cells were constructed along the perimeter and as a central traffic island.

Surface infiltration rate tests were conducted on two bioretention cells, one rain garden, and all four porous pavement surfaces at the project site. Single-ring and double-ring infiltrometer tests were chosen to determine infiltration rates at the sites because of their ability to directly measure vertical flow into the soil.

A double-ring infiltrometer test was used to determine the infiltration rate for the rain gardens and bioretention cells. The infiltrometer includes two 16-gauge galvanized steel rings with adjustable level floats, which can be adjusted to modify the water depth in the rings, and two graduated cylinders used to contribute flow to each of the rings.

The inner ring had a diameter of 12 in. (305 mm) and the outer ring a diameter of 24 in. (610 mm). The locations selected as test sites had to have a level ground surface and had to represent the entire feature. After the locations were selected, the outer ring of the double-ring infiltrometer was driven into the soil to a depth of approximately 6 in. (153 mm). This depth was chosen to prevent

water from moving horizontally. The inner ring was placed in the center of the outer ring and driven into the soil to a depth of approximately 2 to 4 in. (51 to 102 mm). A level was used to ensure that the tops of the two rings were level. Once the rings were in place, the height of the constant-level float valves in each ring was adjusted to ensure that the water level in the infiltrometer would remain approximately 2 in. (51 mm) above the soil surface. Approximately 5 to 10 minutes before the test, enough water was poured into the area between the two rings to saturate the soils.

Each test was conducted so as to ensure that a sufficient number of reading points (approximately 10 to 20) were achieved. The infiltration rate was calculated for each location using ASTM International's standard D3385-94 (*Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer*). For soils in which infiltration is faster, it became difficult to keep graduated cylinders sufficiently full to collect an appropriate number of data points during each trial. Therefore numerous trials were completed and the results were averaged in accordance with the methodology detailed in ASTM International's standard.

A single type of infiltrometer infiltration test was conducted to determine infiltration rates on the four porous pavements surfaces. A 12 in. (305 mm) diameter pipe was used to expose an 11 in. (280 mm) diameter pavement area. The pipe was affixed to the pavement by means of plumber's putty to create a leak-free seal, helping to ensure that all the water entering the pipe entered the pavement. Water was added to a 5 gal (0.02 m<sup>3</sup>) bucket that had been marked to reflect depth by increments; this was used to calculate volume. This known volume of water was then slowly added to the pipe affixed to the pavement, and a constant head of approximately 1 in. (25 mm) above the porous surface was maintained. For porous pavement surfaces on which this constant head could not be maintained using a 12 in. (305 mm) diameter pipe, a 4 in. (100 mm) diameter pipe was used instead to expose a 3 in. (75 mm) diameter pavement area.

Time was calculated using a stopwatch. The watch was started when the first drop of water hit the porous pavement and stopped when the last drop of water infiltrated. Minimal leaking occurred around the putty seal. Leaks were addressed and more putty was applied during each trial run to ensure an accurate infiltration rate.

The results of the infiltration test for the two bioretention cells and the rain garden are presented in table 1. This table shows each

Table 1 Infiltration Rates for Bioretention Cells and Rain Gardens

Location	Rate
Bioretention cell 1	22.73 in./h (577 mm/h)
Bioretention cell 2	21.94 in./h (557 mm/h)
Rain garden	12.38 in./h (314 mm/h)

test site location and the corresponding average infiltration rate, which is based on one infiltration test per site conducted in 2008 between June 20 and July 15. The values range from an infiltration rate of 22.73 in./h (577 mm/h) to 12.38 in./h (314 mm/h). ASTM International's standard D3385-94 provides accurate results for soils with infiltration rates between 0.0014 and 14.17 in./h (0.04 and 359.9 mm/h). Therefore, for the soils that exhibit an infiltration rate greater than 14.17 in./h (359.9 mm/h), in this case bioretention cells 1 and 2, an approach designed for faster rates of infiltration will be used in the future to ensure accurate results.

To ensure that they retain a void space of 40 percent, the stone beds beneath the bioretention cells and rain garden are separated from the bioretentive soil by a geotextile material, which prevents the stone bed from becoming clogged. The stone bed provides a storage area for water before the water makes its way into the underlying soil. Therefore, the infiltration rate shown in table 1 is the rate of the bioretentive soil. When a stone bed is not present, the bioretention media act as the storage before water infiltrates into the underlying soil. In this case, the infiltration rate would be limited by the infiltration rate of the native soils, which would accept water at a much lower rate than would the bioretentive soils.

The results show higher infiltration rates for the bioretention cells than for the rain garden. This is expected because the rain gardens are located in the residential area and are subject to higher runoff pollutant loads, particularly total suspended solids, than are the bioretention cells. Maintenance could be another issue causing lower infiltration rates. Because most of these systems have not been maintained, their surfaces may be clogged with sediment from the watershed as well as with salt and sand applied during winter; the latter constituents would be expected in higher concentrations on roadways than in parking lots.

The results of the infiltration tests of the porous surfaces are presented in table 2. This table shows each porous surface at the site and the corresponding average infiltration rate, which is based on infiltration tests performed between September 9, 2006, and June 10, 2008. The number of tests completed for each porous surface is given in the table. According to *Porous Pavements*, by Bruce K. Ferguson (Boca Raton, Florida: Taylor and Francis Group—CRC Press, 2005), infiltration rates for porous asphalt immediately after construction range from approximately 170 in./h (4,000 mm/h) to more than 500 in./h (13,000 mm/h). After three to four years, the infiltration rate tends to decrease to approximately 15 to 39 in./h (381 to 991 mm/h), typically because of inadequate maintenance and clogging of the pore space.

As shown in table 2, the porous asphalt at the parking lot of the Silver Lake town beach has an average infiltration rate of 78 in./h (1,981 mm/h). The porous asphalt has been installed for approximately two and a half years. The parking area is plowed, salted, and sanded during the winter months, necessitating street sweeping to keep the pavement clean. Typical maintenance procedures for the site include sweeping the area with a vacuum street sweeper twice a year, in the spring and the fall. The rates show that the porous

Table 2 Infiltration Rates for Porous Surfaces

Site	Number of trials	Rate
Porous asphalt	24	78 in./h (1,981 mm/h)
Porous pavers	9	57 in./h (1,448 mm/h)
Flexi-Pave	8	9,872 in./h (250,749 mm/h)

asphalt is performing as designed and is exceeding the infiltration rates given by Ferguson.

Ferguson also reported that porous pavers have an infiltration rate of as much as 50 in./h (1,270 mm/h) with maintenance but only 3 to 4 in./h (76 to 101 mm/h) without maintenance. The porous pavers at the site have an average infiltration rate of 57 in./h (1,448 mm/h). The porous pavers received the same maintenance as did the porous asphalt. It appears that, even with minimal maintenance, the porous asphalt and paver areas are achieving their design performance rates.

Because Ferguson's work included no category similar to Flexi-Pave, this surface type was compared with unbound aggregate having a similar stone size for the purpose of this project. Flexi-Pave was found to have an infiltration rate of approximately 15,000 in./h (381 m/h). The results in table 2 show an average infiltration rate of approximately 9,872 in./h (250,749 mm/h). This is about half the infiltration rate suggested by Ferguson. However, maintaining a head of 1 in. (25 mm) per hour during the infiltration rate test on the Flexi-Pave surface proved to be challenging. Therefore, the actual infiltration rate of the surface may be greater than recorded.

The GravelPave was the most difficult porous surface to monitor. The single-ring infiltrometer was used to determine the infiltration rate, which was estimated to be approximately 7,100 in./h (180,300 mm/h). However, this estimate may not be entirely accurate, as a seal could not be established between the infiltrometer and the porous surface because of the inability to tamp the infiltrometer into the surface or affix plumber's putty to the gravel. Moreover, the water infiltrated into the GravelPave so quickly that maintaining a constant head of 1 in. (25 mm) became quite difficult. In fact, it was nearly impossible to maintain any standing water in the infiltrometer. Therefore, the actual rates of infiltration might be underestimated and hence are not displayed in table 2.

Overall, the performance of the porous surfaces appears to be meeting or exceeding their design infiltration rates. Surface infiltration tests will continue to be conducted at the site to address potential clogging effects from winter pavement maintenance in Massachusetts.

The Silver Lake retrofit demonstrates to other lakeshore communities the various LID methods and techniques that can help protect

lakes and rivers. The technology used at this site is intended to collect storm water and improve its quality by filtering it through bioretention media, by enabling it to enter the soil and become part of the groundwater table, or both. Instead of conventional storm drains that collect storm water and send it directly to the lake, the vegetated swales, bioretention cells, rain gardens, and infiltration beds work to retain the water headed toward the lake, to enable sediments to settle out, to filter contaminants through the soil, and ultimately to improve the lake's overall water quality. The Silver Lake project also demonstrates how important public involvement is in demonstration projects and how public education can lead to a successful project outcome. Finally, the project, in tandem with other efforts in the Ipswich River watershed, offers a means to evaluate the extent to which greater infiltration of storm water may contribute to increased groundwater levels and base flows in the river.

The economic benefits of LID include reducing and in some cases eliminating the system of pipes traditionally used to collect storm water. Although excavation and rock infiltration bedding can be expensive, the amount saved on piping reduces the price difference. On a watershed scale, these systems return storm water to the natural hydrologic cycle, increasing the amount of water available for groundwater recharge and ultimately the water available for human consumption. Engineering design costs for this project totaled \$92,000, including permitting, designs, and construction management. The construction costs for all elements totaled just \$340,000.

LID also has the benefit of being visually more appealing than conventional storm-water designs. Bioretention and rain garden features not only are functional, providing storage and water quality benefits, but also confer aesthetic benefits, adding to the overall design of the project. Of course, maintenance is necessary to ensure that infiltration rates do not decrease substantially over time. Thanks to the sampling and modeling by the USGS, the benefits of employing LID techniques to reduce storm-water volumes and improve water quality are expected to be better understood. ■

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