Chapter 24

Provision of Parking-Lot Pavements for Surface Water Pollution Control Studies

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Impervious areas are associated with increased contaminant loads, while porous pavement, by allowing water to infiltrate into the subsurface layers, may reduce pollutants reaching receiving waters. This paper describes the design, construction, and instrumentation of pavements, where traffic speed is less than 50 km/hr, e.g. in parking lots and certain roadways. Four different, instrumented pavement structures were installed in a typical parking lot and also tested under laboratory conditions, for the study of the flux of 23 contaminants including heat.

24.1 Introduction

Impervious pavement such as asphalt is commonly used in roads and parking lots in North America, but, by contributing contaminants from vehicular activities, air deposition and the surrounding environment to its receiving waters, it has detrimental impacts on the surrounding environment. Contaminants include: oils and greases, heavy metals, nutrients,

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suspended material and elevated temperatures. Increased stormwater flows are also of concern.

Alternatives to asphalt are not utilized extensively in North America. Porous pavement allows stormwater to infiltrate, thus reducing the amount of surface runoff (Field et al., 1982). This reduction in volume depends upon the storm duration and intensity. Porous pavement utilizes subsurface soils to reduce the volume of contaminants reaching receiving waters. An additional benefit of porous pavement is the potential reduction of runoff temperature.

As shown in Figure 24.1, four different test pavements were constructed and instrumented in the parking lot at the University of Guelph: one asphalt (AS), one concrete paver (CP) and two UNI ECO-STONE® using two different filter materials (E3 & E4). Each pavement was instrumented to record temperature, quantity of runoff and to sample runoff quality. In addition, the same four test pavements were constructed in the laboratory to assess the difference between contaminants leaching from the pavement materials and contaminants transported from the parking lot environment. Initial proposal development was done with the assistance of Sargo (1993).

24.2 Background

A study similar to the proposed work, where test porous pavements were constructed using various materials, was conducted in England (Pratt et al., 1989). Results from their study showed stormwater runoff volume reductions and peak flow attenuation. With appropriate design, construction and material selection, discharge quality was found to be better than impermeable highway surfaces.

Because asphalt is a petroleum product, the types of substances from asphalt that are found in the runoff and adjacent areas, range from polynuclear hydrocarbons (PAH), to benzoprene, and heavy metals (Munch, 1992). Asphalt also increases turbidity, pH, and conductivity. All these adverse chemicals were found to be in greater concentrations in the initial stages of runoff, known as the first flush phenomenon (Spangberg and Niemczynowicz, 1993). Studies by the International Agency for Research on Cancer (1985) have found that there is the potential, but inconclusive evidence, that asphalt is carcinogenic to humans.

Investigations of four street inlets in a residential area in Germany revealed that pollution concentration from street runoff exceeded the

Figure 24.1
Parking Lot Pavements

water quality guidelines (Xanthopoulos and Hahn, 1993). Stormwater runoff has both short-term and long-term impacts. Short-term impacts, include toxicity and algae growth; long-term impacts are shown on juvenile trout associated with particles transported by runoff, resulting either from the physical effect of gill clogging or irritation created by toxins sorbed on the particles (Chui et al., 1982).

Temperature is now a growing concern in stormwater management. Urbanization (through deforestation and increased impermeable surfaces) raises the temperature of receiving waters to levels where it may prove lethal for certain aquatic organisms (Xie and James, 1994). Galli (1990) also showed that watershed imperviousness increased the average water temperature of urban streams. Increased imperviousness reduces

the storm size needed to produce large stream temperature fluctuations. Infiltration was found to be the foremost urban Best Management Practice (BMP) to reduce this effect, outperforming other BMP's by a wide margin.

Schueler (1987) cites a number of factors that influence and increase water temperatures in urban headwater streams. Three of these factors combine to dramatically increase water temperatures:

1. as the urban landscape heats up on warm summer days, it tends to impart a great deal of heat to any runoff passing over it;
2. fewer trees are present on the stream bank to shade the stream channel; and
3. runoff stored in shallow wet ponds and other impoundments is heated between storms, and then may be released in a rapid pulse, during a storm.

Pluhowski (1970) and Xie and James (1994) concluded that man-made modifications of the natural environment of streams increased average stream temperatures in summer by as much as 5° to 8° C. Causes were increased stormwater runoff to streams, and reduction in the amount of ground-water inflow. Heat from direct street runoff where runoff is a significant part of stream flow also elevated stream temperatures. All this led to the observation that the level of watershed development had the single, greatest anthropogenic influence on the temperature regime of urban, headwater streams.

Whipple and Hunter (1979) determined that urban runoff is the largest remaining source of petroleum pollution. The petroleum in urban runoff resembles used crankcase oil in composition, and contains toxic chemicals such as polynuclear hydrocarbons. Constituents found in highway runoff may be attributed to traffic deposition, dust-fall from the surrounding environs, pavement wear, maintenance operations, accidental spills, and littering. Thomson et al. (1994), found that particulates in the form of heavy metals represent a large component of the particulate matter found in highway runoff. Friction and automobile deterioration are significant contributors of heavy metals. Deicing salts may contribute to the deterioration of automobiles and other highway structures. Hydrocarbon combustion may contribute nutrients in the form of carbon compounds. Use of fossil fuels contributes petroleum hydrocarbons (PHC) and the incomplete combustion in vehicles can contribute to the formation of polycyclic aromatic hydrocarbons (PAHs).

In field tests, the separation of asphalt emissions from vehicular emissions can be difficult. Most of the work in this area has been performed on runoff from urban areas. This runoff is affected by the type

of pavement being used, atmospheric deposition, the surrounding environment and the vehicles. Parente and Hulley (1994) found that lead, zinc, iron, copper, cadmium, chromium, nickel and manganese in runoff from pavement, are primarily from vehicular traffic.

The most significant pollution loads are due to the use of petroleum-based fuels and lubricants in vehicles. Although these are more volatile, they remain on pavements until turbulent conditions during rainfall wash the drainage system, and ultimately reach the receiving water with little or no treatment (Barnes et al. 1979).

Compared to asphalt, porous surfaces have the potential to reduce contaminants reaching receiving waters (Nawang and Saad, 1993). Porous pavement is a means of reducing the design size parameters of storm sewer systems, by allowing storm runoff to percolate back into the ground (Thalen et al., 1972). Roads with porous pavements were found to have reduced pollution and runoff volume. Combined with immediate relief of flash flooding and the aesthetic benefits, porous pavements were found to be more economical than conventional roads (Thalen et al., 1972).

Porous pavement reduces both storm runoff pollution and quantity. Sztruhar and Wheeler (1993) showed that a pavement grid pavement has excellent behaviour in terms of reducing both surface runoff and delaying subsurface drainage. The porous pavement exhibited excellent storm runoff reduction and pollution abatement.

Smith (1984) evaluated the use of porous pavements for stormwater reduction. The results demonstrated the ability of porous pavement surfaces to reduce the need for sewer pipes. Reduced quantities of stormwater also reduced the amount of pollutants washed from a drainage area. Infiltration of runoff allows pollutants in the water to be filtered in the soil. An additional benefit of porous pavement is reduction of stormwater temperatures as it passes through the subsurface filter media.

Examples of pervious pavements include asphalt and concrete made with no fines in order to increase the void volume. Concrete pavements are also available which have large openings filled with a mixture of joint sand and topsoil, so as to permit the growth of grass. Trade names for these concrete grid pavements include "Turfstone" or "Grasscrete." These pavements have been successfully used in driveways, parking areas, airfields, boat ramps, fire lanes, and for erosion protection.

Concrete block pavements are also used with infiltration being permitted between the joints by use of appropriately sized joint material. One system, developed in Germany and known as UNI ECO-STONE®,

has much higher values of permeability than natural soils (Rollings and Rollings, 1993). Voids that are large reduce the surface runoff and therefore reduce the need for large stormwater conveyance systems. With the larger voids, a highly durable and permeable pavement surface is provided, capable of supporting vehicular loads. UNI ECO-STONE® typically has a drainage of 10% of the total surface area (Von Langsdorff, 1992).

Water permeability of UNI ECO-STONE® was tested at the Research Institute for Water Resources of the Karlsruhe University of Engineering. Experiments revealed that precipitation rates to 200 l/s/ha can be drained completely. The volume of storage is greater than standard concrete pavers (Muth, 1988).

Results of tests for phosphorus, nitrogen, organic carbon, and metals, revealed that the masses of pollutants found in the runoff from the impervious surface were much greater than those in the runoff from the porous pavements. The soils beneath the grid pavement were effective in detaining pollutants from the water that infiltrated (Day et al., 1981).

24.3 Instrumented Pavements

Construction of our parking lot pavements took place during the months of November to December, 1993. Figures 24.1 and 24.2 show the four 9.0 m square test pavements that were constructed at the rear of the School of Engineering, at the University of Guelph in parking lot P10, by excavating the existing pavement to a depth of approximately one metre. An impermeable plastic liner was placed around each of the four test pavements to isolate the parking lot experiment from the surrounding area and from each pavement. Sub-base material was laid and packed to approximately 98% standard proctor density according to the University of Guelph requirements for sub-base compaction. Table 24.1 shows the thickness of the levels as well as the material used.

For each of the four sub-bases, a tile drainage system was installed as shown in Figures 24.3 and 24.4. Runoff from the sub-base level was captured via the sub-base tile drainage system. The initial assumption was that the ground at this level was unsaturated, therefore runoff from this level would be difficult to capture. Runoff was therefore captured using a 100 mm diameter plastic perforated pipe system that was installed and placed over a plastic strip underlay approximately 0.5 m wide. Sub-base material for all four pavements was a soil mixture of granular “A” as

Figure 24.2
Parking lot pavements.

Table 24.1
Pavement thickness and materials used.

	Asphalt		Paver		Eco-Stone 4"		Eco-Stone 3"	
	Thickness (mm)	Material (mm)	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)	Material
Surface	75	H18	60	Concrete	80	Concrete	80	Concrete
Base	90	Gran "A"	75	Gran "A"	100	C.L.S.S.	75	C.L.S.
Sub-base	400	Gran "A"	400	Gran "A"	400	Gran "A"	400	Gran "A"

C.L.S. - clear washed stone

C.L.S.S.-clear washed stone and sand

Gran "A"- Granular "A"

shown in Table 24.1; this was also the same base material specified for the existing asphalt surface.

Runoff from the base level was captured differently from the sub-base level: a strip of plastic 0.5 metres wide was placed in the same configuration shown in Figures 24.3 and 24.4, but without any perforated pipe system, due to the limited depth to the surface. Placed on the plastic liner was 4 to 5 cm of crushed stone, which allowed runoff from the base layer to be captured and conveyed via the plastic liner to the instrumentation chamber. Appropriate base material, as shown in Table 24.1, was then laid on this drainage system and brought up to surface level.

Table 24.1 also shows the materials used for the surface layer. Immediately below the paver surface a layer of sand 50 mm thick was placed as per the design requirements for the concrete paver (CP) (Unilock, 1991). All three interlocking stones required additional fill material between the stones to secure the surface layer. The Hollandstone Paver (CP) required sand to be added, while the Eco-stone 4" (E4) located in the north east section required a mixture of clear washed stone and sand, and the Eco-stone 3" (E3) located in the south east section required clear washed stone. Runoff from the pavement surfaces was sampled using inlet grates as shown in Figures 24.1 and 24.2. All four pavement surfaces were graded toward the inlet grate with slopes ranging from 0.5% to 5% as shown in Figure 24.2. This is a standard commonly used in grading pavements for parking lots in Southern Ontario.

Figure 24.5 and Figure 24.6 show the instrumentation chamber that was installed to capture runoff. All thirteen runoff collectors drained to the instrumentation chamber. A runoff collector located below the three collectors was installed for drainage from the adjacent grassed area from

Figure 24.3
Parking lot subsurface drainage system

the west side of the pavements. Placed just off the edge curb of the parking lot test pavements, in the grass verge, and connected to the instrument chamber by a 200 mm dia. concrete pipe, was a second instrument vault, where dataloggers and multiplexers were housed in a dry environment. Figures 24.5 and 24.6 show the dimensions of the instrumentation chamber. Overflow from the parking lot pavements was handled by the instrumentation chamber and a 200 mm diameter concrete pipe laid from the instrumentation chamber to an existing catchbasin as shown in Figures 24.1 and 24.2.

Four laboratory experimental pavements were prepared in the same fashion as the instrumented pavements. The purpose of these laboratory pavements was to separate the chemicals originating from the pavement and their respective fill materials from those due to the parking lot environment. The laboratory pavements were subjected to simulated rainfalls. For information on this work, see Shahin (1994).

During the construction of the parking lot pavements, thermocouples were installed at three levels for each of the four pavements, a total of twelve thermocouples. Each thermocouple was wired through the maintenance hatch to a datalogger located in the 1.0 m diameter instrumentation vault adjacent to the site. A continuous power source was necessary for the datalogger and pump. 110 volt power was supplied via a trench dug from the School of Engineering to the instrumentation vault. Within the same trench, a conduit was installed for computer connections to access the datalogger from the School. Figures 24.1 and 24.2 show a 9.0m long 200mm diameter concrete pipe that was installed to handle

Figure 24.4
Grading for parking lot subsurface drainage system.

future cables that would be needed to supply power to the maintenance hatch.

One power requirement for the instrumentation chamber is for a submersible pump. In discussions with University of Guelph electricians as well as an inspector from Ontario Hydro, it was decided that the best method to service the instrumentation chamber was to power the submersible pump from the instrumentation vault with an electrical cord of suitable length. Overflow within the instrumentation chamber was pumped to the 13.2m long 200mm diameter storm sewer and away from the system. Additional equipment located in the instrumentation chamber are two ISCO water samplers supplied by the Ministry of Environment and Energy (MOEE). To power the water samplers at 12 volts, an electrical connection was extended from each of the water samplers located within the instrumentation chamber to a power supply located within the instrumentation vault and powered by the 110 voltage supply.

Air temperature, precipitation and solar radiation affect atmospheric deposition as well as the removal of contaminants from urban areas (Thomson et al., 1994). Air temperature, precipitation and solar radiation data was collected from the University of Guelph Transgenic Greenhouses Environment System (UGTGES) weather station, located on the roof of the greenhouse approximately 50m east of the test site.

Constituents found in highway runoff may be attributed to dust fall from the surrounding environs (James and Boregowda, 1986; Thomson et al., 1994). It is necessary therefore, to investigate atmospheric fallout. For this, a wet/dry precipitation sampler, which supplied rainfall and dry fall samples for quality analysis was supplied by the MOEE and installed on the roof of the School of Engineering approximately 50m west of the test site.

24.4 Instrumentation, Sampling and Monitoring

Sample collection and instrumentation are probably the largest source of variation in reported removal efficiencies of BMPs. Instrumentation for this study utilized numerous devices, including: water samplers; tipping bucket runoff gages (TBRGs); thermocouples, datalogger and multiplexer, as well as supporting programming and wiring; weather station; and a wet/dry precipitation sampler.

Due to the space limitations, only two ISCO Water Samplers, supplied by the MOEE, were used for sampling runoff from the surfaces.

Figure 24.5
Plan of instrumentation chamber.

Figure 24.6
Sections through instrumentation chamber.

They were operated in accordance with the user manuals for the models 2700 and 2100 (ISCO, 1982, 1985). Each of the samplers contained one large 10 L container that collected surface runoff. Runoff was collected in cleaned plastic containers from all the pavements and layers. Both automatic samplers and the containers were placed in the instrumentation chamber. Tipping bucket runoff gages, supplied by Agriculture Canada, were used for the measurement of surface runoff volume from the four surfaces. Each TBRG was placed under the appropriate outlet in the instrumentation chamber. The TBRGs were made by the staff of the School of Engineering work shop for Agriculture Canada. Problems that developed included:

1. Accumulation of sediment in the tipping bucket, which alters the calibrated bucket volume; the system had to be cleaned and inspected frequently.
2. Debris on the pivot pin, which restricts the free movement of the system and sends an improper signal to the datalogger.
3. The magnetic pulse inducer occasionally would not send a signal to the datalogger.

Remedying the difficulties required frequent inspection of the system and performing some tests on, or cleaning, the tipping buckets.

The wet/dry precipitation collector supplied by the MOEE is an instrument that collects atmospheric fallout from both wet and dry events. Each bucket has a capacity of 15.9 L. During a wet event, rainfall is collected in the wet bucket for the duration of the event. The wet bucket is then covered when the event ceases. During periods of no rainfall, atmospheric fallout is collected and stored in the dry-fall bucket. The dry bucket is then covered during rainfall events. The precipitation collector is a model 301 and manufactured by Aerochem Metrics, Inc. of Florida.

Runoff samples were analyzed for the various parameters shown in Table 24.2. Constituents that were investigated were categorized into three characteristic properties: chemical, biological, and physical.

24.5 Conclusions and Recommendations

Literature is available on porous pavement, yet no reports on Canadian studies of porous pavements as an alternative to impervious pavements were found. This study prepared a facility for future research on porous pavement for application in North America. The purpose here was to investigate porous pavement as an alternative to impermeable

Table 24.2
Contaminants investigated

Physical Properties	Chemical Constituents	Organic
Conductivity Solids Residue, Total (Total Solids) Residue, Particulate (Suspended Solids) Temperature	Inorganic Heavy Metals Copper Nickel Lead Zinc Iron Cadmium Chromium Chlorides Chloride Nutrients Phosphorus Phosphates Nitrogen, Total Kjeldal Ammonium, Total Nitrates Nitrite	Refractory Phenolics Biodegradable: BOD COD E.Coli Solvent Extractable (Oils and Grease)

pavement for parking lots where traffic speed is less than 50 km/hr. This study designed, constructed and instrumented four test pavements in parking lot P10 at the University of Guelph.

Preliminary results showed that contaminant loads from the asphalt surface were always greater than other pavements and surfaces. This is due to the asphalt being 100% impervious, which of course increases the amount of runoff and pollutant reaching the sewers and ultimately receiving waters. Uni Eco-Stone® effectively reduces the amount of surface runoff, because runoff was only generated from the surface when the rainfall intensity exceeded infiltration rates of the pavement. Because of the high infiltration rates, the exceedances are likely to be rare.

These facilities are expected to be available for research for many years. Your inquiries should be directed to W. James.

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