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# Project Summary

# Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems

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**When a watershed is physically altered as the result of urban development, local stormwater hydrology and water resources are affected. Using porous pavement in parking lots and other places where stormwater detention is feasible is one way to lessen the harmful aspects of urban runoff. A study of both porous and conventional pavement systems in Austin, Texas, was undertaken. The objectives of the study were to: (1) review past experience with porous pavements, (2) develop an aggregate-asphalt mix design and construction specifications for a porous asphalt pavement system and construct a parking lot, (3) evaluate porous and nonporous pavements, (4) develop a design methodology for porous pavement stormwater storage systems.**

**The report, upon which this summary is based, includes details of preconstruction planning, construction, and post construction testing. Each of the 5 pavements studied was instrumented to sample for climatic, hydraulic, and water quality parameters. Hydrographs of pavement discharge were compared with simulated hydrographs resulting from a revised version of PORPAV, a computer program that models the stormwater hydraulics of a porous pavement facility. The results of the comparison indicate the capabilities of PORPAV and its potential application to similar future porous pavement studies. The hydraulic relationships incorporated into PORPAV were used to develop a method to aid engineers and developers in designing porous pavement systems. Incorporating such items as the hydraulic relationships of rainfall intensity, pavement and base permeability, and soil infiltration rates makes the method versatile enough to apply it to various design objectives.**

***This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, Ohio, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

Impervious urban areas such as roofs, streets, and parking lots reduce infiltration capacity of urban watersheds and produce a corresponding increase in runoff rates and volumes. Stormwater runoff from developed areas has been recognized as a source of contaiminant loading to surface and ground water resources. Impervious areas generally have limited assimilative properties and in some cases tend to yield contaminants that are not amenable to control and removal using standard maintenance procedures. A porous pavement facility is an innovative solution to the problem of stormwater drainage and detention from parking and other low traffic areas in the urban landscape. A schematic cross section of a typical porous pavement facility is presented in Figure 1. This type of pavement can use the natural infiltration capacity of the soil to absorb rainfall and local runoff after accumulation in a porous base consisting of sand or large-diameter, open-graded gravel. If infiltration into the soil is undesirable or not practical, lateral drainage to a sump or channel can be

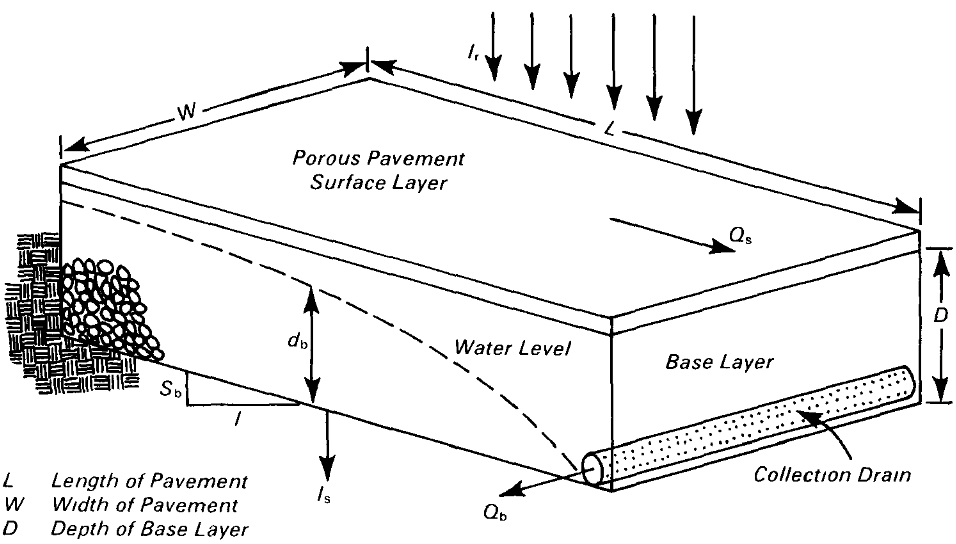


***Figure 1.*** *Cross section of typical porous pavement facility*

provided. This type of pavement can be designed to minimize changes in the runoff characteristics of a watershed during and after development.

## Approach

An extensive monitoring program was initiated in the City of Austin, Texas, to document the hydraulic and pollutant transport characteristics of several porous and conventional pavement facilities. The monitoring network of five parking lots represented a variety of porous pavement surfaces (porous asphalt, lattice block and gravel trench) as well as a conventional asphalt and conventional concrete lot.

Because the parking lots were small and, when it rained, the runoff was rapid, sampling had to be done quickly. This coupled with the lack of rainfall during the study period prompted the decision to use simulated rainfall. With sprinkler-induced "storms," the intensity, duration, and timing of the rainfall was controlled. Impact-type sprinklers, furnished by the City of Austin Parks and Recreation Department, were used during the test with fire hydrants supplying the water. The number of sprinklers was varied for each simulated storm, and care was taken to provide uniform coverage of the lots. The gravel trench lot was too large for sprinkler coverage so large water trucks provided by the City of Austin were used. Different storm (or rainfall) intensities were obtained by varying the number of trucks used, trips made, and number of trucks releasing water at one time. Estimates of the runoff were obtained from water level measurements at a 90-degree V-notch weir at each lot except for the gravel trench lot, which incorporated a collection basin with an outflow pipe.

Sample collection and handling and analytical techniques conformed to recommended EPA or American Public Health Association methodology. Laboratory analyses were conducted by the Guadalupe-Blanco River Authority, Seguin, Texas. To determine the potential for ground water contaimination from trace organic substances in the discharge from the porous asphalt and lattice block lots, samples were analyzed for volatile and semivolatile priority pollutants. Laboratory analyses were conducted according to EPA methodology.

Being able to predict the hydraulic characteristics of stormwater runoff is a valuable tool for assessing control strategies. Stormwater hydraulic characteristics of the porous and nonporous pavement study sites were evaluated using a revised version of the computer model PORPAV. The data collected during this study and the resulting model calibration and verification effort provide an insight into the capabilities of PORPAV as a model of the stormwater hydraulics of a porous pavement facility and its potential application to future studies where similar pavement projects are desired.

## Results

The review and evaluation of the porous and conventional pavements resulted in development of

- an aggregate-asphalt mix design for the porous asphalt surface
- design specifications for porous pavement systems, and
- a tentative set of construction specifications.

Constructing the porous asphalt parking lot provided valuable experience in preconstruction planning, installing the aggregate reservoir base course, and placing the porous asphalt surface course. In addition, the results of indirect tensile strength testing, in situ permeability, and a visual inspection of the parking surface after 18 months of vehicle use should aid future porous asphalt construction. The extensive stormwater monitoring surveys documented the hydraulic and pollutant transport characteristics of the two paving systems.

The gradations for the stone base, the stone topping course, and the porous asphalt that have been developed in the past and used on this project with some modifications are quite adequate. The recommended reservoir base course consists of aggregates with a maximum size of 2.5 inches (6.3 cm) and a minimum size of 1 5 inches (3.8 cm), which should provide a void space of 40 percent of its volume for water retention. Two inches of gravel top course over the base course is recommended to provide a better surface for applying the porous asphalt surface course. The recommended gradation of the aggregate for the top course of gravel is ⅝-inch (1.6-cm) maximum and ⅜-inch (0.9-cm) minimum to provide an essentially uniform aggregate of approximately ½-inch (1.3-cm) diameter A 2.5-inch (6.3-cm) depth of the porous asphalt surface course (5.5 to 6.0 percent asphalt) with the following specifications is recommended:

| *Sieve Size* | *Percent Passing* |
|---|---|
| *½" (1 3 cm)* | *100* |
| *⅜" (0.9 cm)* | *90-100* |
| *#4* | *35-50* |
| *#8* | *15-32* |
| *#16* | *2-15* |
| *#200* | *2-5* |

The type of compaction for the porous asphalt pavement was less important than compacting the surface at a temperature near 180°F (82.2°C). It was apparent from this project that conventional mixture temperatures in the order of 260° to 280° F (126.7° to 137.8°C) should be used for laydown; however, compaction should always be delayed until this type of mixture has cooled down to near 180 °F (82.2 °C). A reasonable surface can be had by a variety of compaction methods as long as the mixture is not too hot when compacted. Several rollers were utilized to yield a satisfactory surface, including an 8-ton (7.3-metric ton) pneumatic roller, a 1-ton (0 9-metric ton) pneumatic roller, and a 1-ton (0 9-metric ton) flat-wheel tandem roller.

The tensile strengths of the open-graded, porous, hot-mix asphalt concrete (HMAC) cores were lower than for those conventional, dense-graded HMAC cores. Tensile strengths for asphalt concrete mixes are considerably affected by the temperature of the mix. The strengths at lower temperatures are still relatively high, however, and those at the more critical higher temperatures did not vary greately from those for dense-graded mixes

The permeabilities of the porous asphalt surface after 18 months of use ranged from 152 in./hr (386 cm/hr) to 5290 in./hr (13,437 cm/hr) with an average rate of 1766 in./hr (4486 cm/hr). Permeabilities notably lower than the average rate occurred where the asphalt was rolled at a temperature higher than 180 °F (82.2 °C).

Based on the Austin experience, porous asphalt construction costs are comparable to costs for conventional asphalt construction: a porous asphalt lot incorporating a storage reservoir can be constructed (including engineering, inspection, and testing) for about $10 per square yard ($12 per square meter). In Austin, standard practice in the design and construction of conventional parking lots is to incorporate stormwater detention into the parking lot area with a 6-inch (15-cm) curb and restricted outlets. Construction cost for this type of conventional system is about $8.50-$8.75 per square yard ($10.00-$10.50 per square meter). If engineering, inspection, and testing are added to this (assuming 17 percent of the construction costs), the total cost is again about $10 per square yard ($12 per square meter). Should the site specifics (i.e., topography, size, slope, etc.) necessitate grading or an offsite detention structure, the conventional system cost would, of course, be higher.

The hydraulic results of the runoff surveys are summarized in Table 1. The runoff-to-rainfall ratios greater than unity resulted from measurement error. Because the porous asphalt and gravel trench lots were hydraulically open, their runoff ratios do not reflect the potential stormwater storage of the facility. A relationship between 7-day antecedent rainfall and the runoff ratio was not discernible. Detention times were calculated as the time difference between the inflow and discharge center of mass. The detention times at the porous surface facilities were characteristically longer than at the impervious lots. Areas of hard-packed sand at the lattice block lot contributed to anomalously rapid detention times. Ponding in surface depressions on the concrete lot resulted in longer duration times than expected at that facility.

Stormwater hydraulics for each pavement type were simulated with the revised PORPAV. PORPAV was calibrated for each lot with the use of one set of observed runoff data. The calibrated coefficients were held constant during the simulation of the remaining events for model verification. Calibration was initialized by varying values of the estimated parameters to reproduce the observed runoff volume. Generally, to do this, the volume of surface storage for the impervious lots and the base storage (the product of depth and porosity) for the pervious lots was adjusted. The estimates of slope and the roughness coefficient were varied to reproduce the observed peak runoff rate. For the porous asphalt and gravel trench lots, the coefficient of permeability for the base layer was varied to reproduce the observed peak base discharge rate. Overall, there were not enough data sets to definitively assess the ability of PORPAV to simulate the hydraulic response to each lot. Generally, however, observed hydrographs were reasonably simulated after calibration with a prior set of data.

## Design Methodology

The greater volumes of stormwater runoff that result from paved areas often degrade the quality of the receiving water. Some municipalities require that an initial volume of stormwater runoff be retained to remove accumulated pollutants. The design criteria of stormwater detention facilities reflect these concerns. The porous pavement design methodology was developed to be flexible enough to satisfy a variety of design criteria.

The design methodology consists of a series of curves that depict the hydraulic

***Table 1*** *Hydraulic Summary of Stormwater Surveys*

| Pavement Type | Event Date | No of Sprinklers* | Total Inflow (in) | Duration (min) | Average Intensity (in/hr) | Peak Discharge (cfs) | Time to Peak (min) | Total Discharge (in) | Runoff Ratio† (in/in) | Detention Time (min) | 7-day Antecedent Rainfall‡ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Porous Asphalt§ | 03/22/82 | 8 | 0 94 | 60 | 0 94 | 0.269 | 58 | 0.58 | 0 73 | 42 | 0 02 |
| | 04/05/82 | 9 | 0 50 | 62 | 0 48 | 0.253 | 54 | 0.64 | 1 28 | 42 | 0.09 |
| | 06/01/82 | 8 | 1 53 | 55 | 1 67 | 0 237 | 53 | 0 56 | 0 37 | 42 | 0 00 |
| Lattice Block Lot | 03/02/82 | 4 | 1 06 | 75 | 0 85 | 0 034 | 55 | 0 19 | 0.18 | 11 | 4.03 |
| | 03/11/82 | 6 | 1 08 | 60 | 1 08 | 0 078 | 40 | 0,39 | 0 36 | 12 | 0.00 |
| | 03/18/82 | 8 | 1 08 | 34 | 1 90 | 0 113 | 24 | 0.25 | 0.23 | 11 | 0.03 |
| Gravel Trench | 03/03/82 | 3 | 0 64 | 94 | 0.41 | 0 440 | 60 | 0 49 | 0 76 | 29 | 4.03 |
| | 03/19/82 | 4 | 0 64 | 70 | 0 56 | 0.580 | 66 | 0 41 | 0 64 | 24 | 0.03 |
| | 04/04/82 | 4 | 0 64 | 59 | 0 65 | 1 667 | 55 | 0 49 | 0 77 | 19 | 0 12 |
| Asphalt | 06/03/81 | # | 0 34 | 46 | 0.44 | 0.84 | 53 | 0 40 | 1 18 | 1 | 2 48 |
| | 05/11/82 | 8 | 0 21 | 10 | 1.26 | 0.223 | 7 | 0 15 | 0 71 | 5 | 0 99 |
| Concrete | 03/03/81 | # | 0 85 | 120 | 0 43 | 0 20 | 58 | 0 46 | 0.55 | 18 | 0 53 |
| | 06/03/81 | # | 0.57 | 33 | 1 04 | 0 10 | 30 | 0.28 | 0 48 | 14 | 2.48 |
| | 10/07/81 | # | 0 45 | 90 | 0.30 | 0.07 | 30 | 0.17 | 0.38 | 17 | 3.71 |

**Values for the gravel trench are the number of water trucks used*

*†Runoff to rainfall ratio Subsurface runoff (underflow) measurements are used in the porous asphalt and gravel trench lots Surface runoff measurements are used for the lattice block, conventional asphalt and conventional concrete lots*

*‡Precipitation amounts recorded at the Austin Airport within the indicated number of preceding days.*

*§Discharge results influenced by infiltration lines along trenches*

*#Denotes natural precipitation event The remainder were sprinkler-induced events*

characteristics of porous pavement facilities under the influence of various rainfall events and site specific factors. A range of magnitudes of descriptive physical properties for the pavement system are represented in the multiple curves. The design algorithm was developed to facilitate the design of a porous pavement system without the necessity of computer simulation, and hence, incorporates analytical simplifications. In general, the design procedures can be employed for any porous pavement system that the model PORPAV can analyze. Appropriate physical and hydraulic characteristics are

- The pavement is a single or set of single uniformly sloping surfaces.
- The surface is underlain by a base layer of uniform media. This layer may or may not be of uniform thickness and is usually separated from the surface by a permeable filter course.
- Discharge from the base layer can be completely restricted, or occur via infiltration to the underlying soil, or exit horizontally through seepage to adjacent soils or through a set of collection drain pipes located within the base.
- If a collection drain is present, the base layer cannot contain baffles or other mechanisms that restrict the lateral movement of the water within the base However, a multiple drain pipe system with these controls may be analyzed as individual units
- Impermeable seals may or may not be placed along the boundary to prevent leakage to the adjacent soil.

A small computer program, PAVDES, was developed to execute the methodology Persons with a microcomputer or larger facilities can use PAVDES for its convenience and greater accuracy in place of the design curves.

Although the PAVDES design methodology incorporates the flow-governing equations used in PORPAV, the two procedures provide distinctly separate functions PORPAV is a computer simulation program that models detailed intra-event hydraulic characteristics of both pervious and impervious pavement facilities PORPAV can be used alone as a pavement design tool through iterative executions in a trial and error technique, i.e., alternative values of the facility's physical characteristics can be modeled for the same inflow condition, and the resulting hydraulic responses can be compared. The iterative process will continue until specified criteria, e.g., discharge rates, are achieved. As a more direct, albeit less detailed, solution, the design methodology was developed to yield the optimal depth of the pavement storage facility with a single application. Given the known characteristics of the lot, contributing area, average storm intensity, and limiting discharge rates or volumes, the design methodology will determine the design depth of the base layer and estimate the resulting discharge hydrograph. If a greater degree of detail is desired, PROPAV can then be used to simulate the hydraulic response of the designed pavement facility under a variety of storm conditions. Confidence in the analytical procedures used in the design methodology stems from the success PORPAV has demonstrated in simulating hydraulics for a variety of pavement facilities.

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***John N. English** is the EPA Project Officer (see below).*
*The complete report, entitled "Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems," (Order No. PB 84-123 728; Cost: $25.00, subject to change) will be available only from:*
*National Technical Information Service*
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