Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

MONITORING AND RESEARCH DEPARTMENT

REPORT NO. 13-49

PERFORMANCE OF PERMEABLE PAVEMENTS INSTALLED AT THE EMPLOYEE PARKING LOT AT THE STICKNEY WATER RECLAMATION PLANT

December 2013

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PERFORMANCE OF PERMEABLE PAVEMENTS INSTALLED AT THE EMPLOYEE PARKING LOT AT THE STICKNEY WATER RECLAMATION PLANT

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December 2013

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INTRODUCTION

Green infrastructure (GI) technologies are based on the general principle, “collect, treat, and freely infiltrate any surface runoff (RO) to recharge groundwater” such that the stormwater bypasses the collection system (Andersen et al., 1999). In comparison to traditional drainage systems, GI technologies are deemed sustainable and are often cost effective for urban areas. Permeable pavement is a GI technology which is being adopted to manage stormwater in many urban areas in both Europe and the United States. The infiltration performance throughout the service life of permeable pavement is of significance, as entrapment of fine particulate matter (both organic and inorganic) in the pores of the pavement surfaces may cause potentially irreversible reduction of water permeability and ultimately reduce their effectiveness. Nevertheless, permeable pavement systems may have a significant positive impact on diverting RO. Even if a fraction of the rainfall is retained, this fraction is not added to the total RO entering the collection system. A reduction in RO peaks can also occur because of the delaying effects of the pavement.

In 2008, the Metropolitan Water Reclamation District of Greater Chicago (District) initiated a plan to evaluate permeable surface technology for stormwater flow and pollutant load reduction at the Stickney Water Reclamation Plant (WRP). Conservation Design Forum designed three test permeable surfaces for this purpose in the plant employee parking lot. The three test surfaces consisted of: (1) a 1,311 m^2 permeable asphalt (PA) lot; (2) a 1,060 m^2 permeable concrete (PC) lot; and (3) a 1,216 m^2 permeable paver (PP) lot. A 1,305 m^2 traditional blacktop, impervious asphalt lot was designated as the control for comparison to the permeable lots.

SITE DESCRIPTION AND METHODS

Site Description

The permeable parking sections were constructed on the existing employee parking facility, measuring approximately 245.8 m x 82.1 m (Photograph 1). The existing parking facility had six sections. Each parking section is separated by a north-south running 6.3 m wide grassed median, with through traffic moving east-west between different sections at the north side of the parking sections. The east section was divided into two by a 4.05 m wide east-west running grassed median with the PP lot on the south side and a PC lot on the north side. The PA lot was located on the south side of the third from the west parking section (Photograph 1). The actual sizes of the permeable parking and control lots and the number of parking stalls in each lot are given in Table 1. The PC and PP lots do not have through traffic; cars enter and leave from the same direction. The PA lot has regular asphalt to its north without any physical barrier for separation. However, this section is graded in a manner that separates the respective catchment areas of the PA lot and the traditional asphalt lot while receiving car traffic from both sides. All cars leave the parking lot from the south side only.

Permeable Asphalt. The PA used resembles conventional asphalt; it consists of open-graded asphalt (4-inch layer) over an open-graded fill base one-foot deep, consisting of coarse aggregate (CA)-7 fill above native soil (Figure 1; Photograph 2a). The aggregate base was separated from the subgrade native soil by LINQ 180 EX separation geotextile.

Permeable Concrete. The PC pavement (6-inch thick) was set in place using CA-16 Class A coarse aggregates, which are freeze-thaw durable, and a Portland cement binder over an open graded CA-7 aggregate base one-foot deep. The porosity of the pavement is a result of the omission of fine aggregates in the concrete mix. The aggregate base was separated from the subgrade native soil by LINQ 180 EX separation geotextile (Figure 1; Photograph 2b).

Permeable Pavers. The PPs used were made of concrete pavers, one-inch thick overlaying an ~1.89-inch thick layer of CA-16 paver fill bed. The pavers were interlocking with apertures between the pavers that were filled with CA-16. Similar to permeable asphalt and concrete, the base consisted of one-foot deep CA-7 aggregates separated from the native subgrade soil by LINQ 180 EX geotextile (Figure 1; Photograph 2c).

For all lots, the bottom and sides of the fill are bordered by a permeable geotextile allowing transfer of water across the fabric, and silty clay native soil is encountered 16 to 18 inches below grade. The lots can receive different contributions of run-on from permeable and impermeable surfaces during rainfall events (Table 1) and were designed to drain freely towards the local groundwater. The typical permeable lot layout is shown in Figure 2. A system of 4-inch perforated pipes rests upon the bottom of the CA-7 fill in each permeable lot. During a rainfall event or run-on

PHOTOGRAPH 1: PHOTOGRAPH OF THE EMPLOYEE PARKING FACILITY OF THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO’S STICKNEY WATER RECLAMATION PLANT AND LOCATIONS OF THE PERMEABLE AND CONTROL LOTS

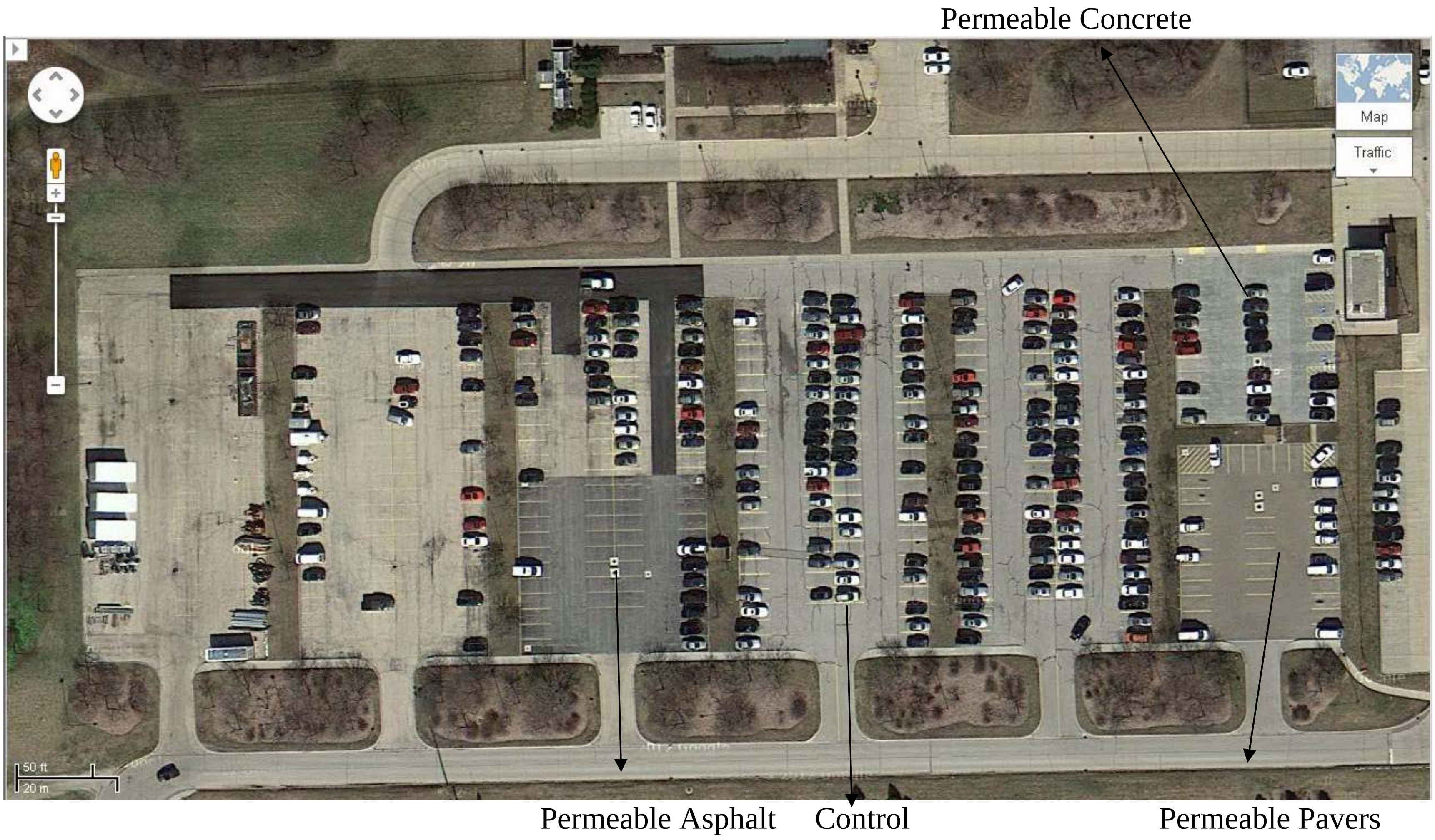
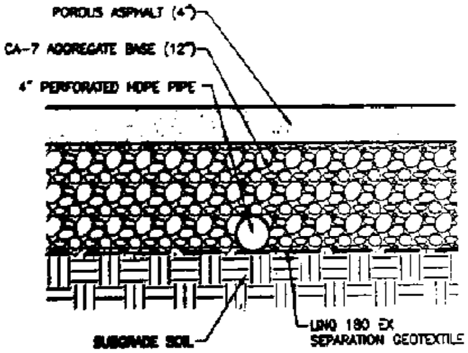


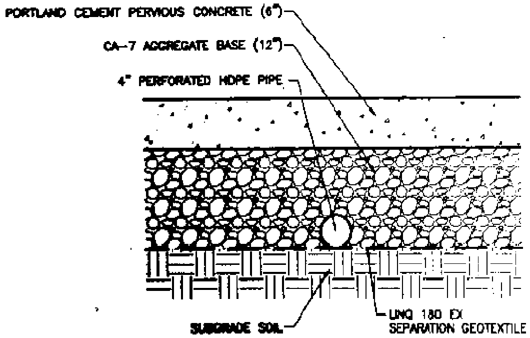
TABLE 1: DESCRIPTION OF THE PERMEABLE PAVEMENT AND CONTROL LOTS AT THE STICKNEY WATER RECLAMATION PLANT

Characteristics	Control	Permeable Pavers	Permeable Concrete	Permeable Asphalt
Total area (m^2)	1,305.3	1,215.8	1,060.3	1,311.3
Additional Run-on Area				
Impervious (m^2)	0	38.3	335.7	30.6
Pervious (m^2)	0	0	538.8	0
Number of Parking slots				
Regular (3.05 m x 5.80 m)	36	43	38	23
Disability (4.88 m x 5.80 m)	0	0	0	5
Through Traffic	Yes	No	No	Yes

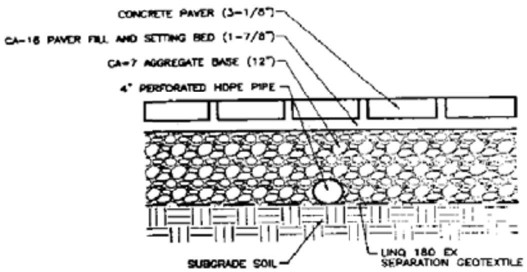
FIGURE 1: DESIGN DETAILS OF THE PERMEABLE ASPHALT, PERMEABLE CONCRETE, AND PERMEABLE PAVER LOTS AT THE STICKNEY WATER RECLAMATION PLANT



DETAIL OF POROUS ASPHALT PAVING
SCALE: 1.5"= 1'



DETAIL OF PERVIOUS CONCRETE PAVING
SCALE: 1.5"= 1'



DETAIL OF POROUS UNIT PAVING

SCALE: 1.5"= 1'

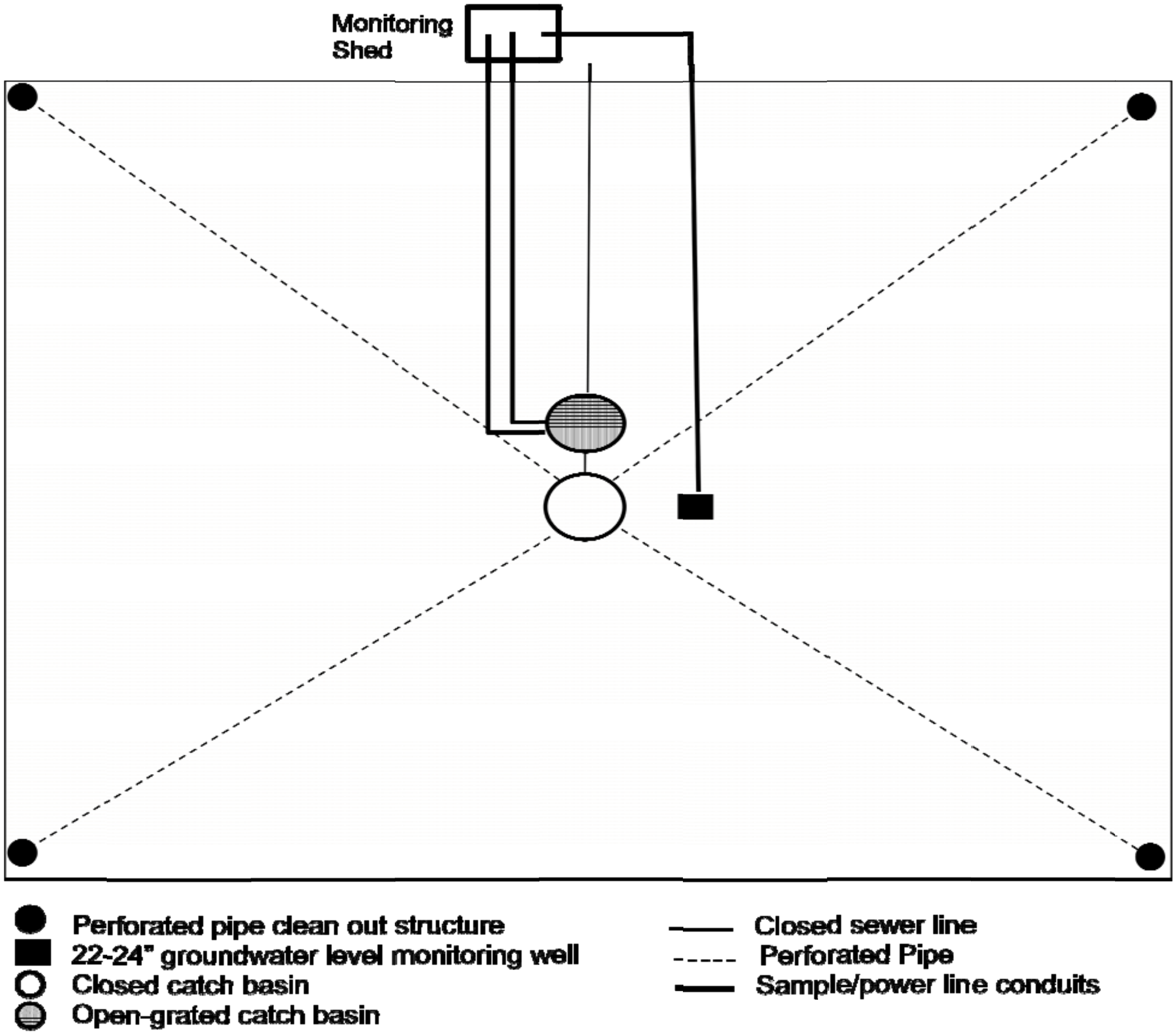
PHOTOGRAPH 2: PERMEABLE PAVEMENT LOTS (a) ASPHALT, (b) CONCRETE, AND (c) PAVERS AT THE STICKNEY WATER RECLAMATION PLANT OPENED FOR USE IN MAY 2009

(a) Permeable Asphalt

(b) Permeable Concrete

(c) Permeable Pavers

FIGURE 2: TYPICAL PERMEABLE LOT LAYOUT



event, water can infiltrate through the permeable surfaces. The perforated pipes in Figure 2 receive the infiltrated water migrating through the fill and coalesce into a closed catch basin. Additionally, all four plots have an open-grated catch basin to accept RO in the center of the plot as well. The closed infiltration catch basin is connected to the open-grated catch basin via a 12-inch closed pipe. Thus, water collected by the perforated pipes flows into the closed catch basin and then downstream to the open-grated catch basin. A second 12-inch closed pipe leads away from the open-grated catch basin and conveys water off site. The construction of permeable lots was completed in early 2009 and was opened to traffic in spring 2009.

Water input to the test lots can result from run-on from both permeable and impermeable contributing surfaces. Run-on was estimated via the rational formula, which is a function of RO coefficients, rainfall intensity, and contributing areas, such as bordering sidewalks and grassy areas, based on a survey of the site during the design of the permeable parking lots. Typically, run-on contributed less than 3 percent of the total water input for the PA, PP, and control lots. The PC lot has a 874 m^2 contributing run-on area and typically receives about 25 percent of the total water input from run-on. The other three lots have a contributing run-on area of less than 38 m^2.

MONITORING DETAILS

The Environmental Monitoring and Research Division (EM&RD) in cooperation with support from the Industrial Waste Division (IWD) and Analytical Laboratories Division monitored the four test lots beginning in 2009. Monitoring occurred between April 1 and October 31 each year, unless otherwise indicated. Huff & Huff Incorporated developed a monitoring plan for the four test lots used during the study period in order to track rainfall, flow measurements, subsurface water level measurements, water quality, and infiltration capacity (Appendix A).

Rainfall, Subsurface Water Level, and Flow Measurements

Two rain gauges were installed to continuously monitor rainfall. One rain gauge was placed on top of a shed between the PP and PC lots (east), and the other rain gauge was placed on a shed between the PA and control lots (west). These rain gauges were able to register precipitation equal or greater than 0.01 inches; all data were recorded by a Sigma 900 MAX auto sampler housed in the respective sheds. This data was downloaded periodically during the study period.

A shallow 12-inch diameter well was installed (22 to 24 inches deep) in each permeable lot (Figure 2). Each well had a Hach area velocity (AV) sensor to continuously measure the subsurface water level above the reference elevation of native soil. Similar to the rain gauges, the data were recorded by the Sigma 900 MAX auto sampler and were downloaded periodically during the study period. Finally, Thelmar V-notch weirs were installed and used as the primary measuring device (PMD) upstream (infiltrated flow) and downstream (total flow) of the open-grated catch basin in the 12-inch closed pipes (Figure 2) for each permeable lot. Only one weir was installed in the control lot downstream of the catch basin. One-quarter inch bubbler tubing attached to a fitting at the bottom of each weir was connected to the Sigma 950 Bubbler Flow Meters housed in the respective sheds to continuously measure flows. The flow data were downloaded periodically during the study period.

Water Quality Characterization

The Sigma 900 MAX auto samplers were un-iced and synced to the Sigma 950 flow meters associated with the total flow for each lot to collect first flush and secondary water quality samples during rainfall events; the sample line inlet was placed either in the open-grated catch basin sump or downstream of the total flow monitoring point in the outgoing 12-inch closed pipe. Each sampler was equipped with four one-gallon containers between rainfall events. The first gallon filled was considered first flush; the other three gallons were composited and considered a secondary sample.

For each sampling event, the collected water was to be analyzed for total suspended solids (TSS), volatile suspended solids, pH, and chemical oxygen demand (COD). On select occasions during the annual monitoring season, samples were analyzed for nutrients, chloride, heavy metals, and polycyclic aromatic hydrocarbons (PAHs). The heavy metals analyzed were lead, copper, cadmium, zinc, and nickel.

Infiltration Rate Measurements

In general, American Standard Testing Method D3385, the Standard Test Method for the Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, was employed to measure the pavement infiltration rates during the study period. This test measures infiltration rates for soils with hydraulic conductivities between 10^{-6} cm s^{-1} to 10^{-2} cm s^{-1}. The double-ring infiltrometer used in this study consisted of two 16-gauge galvanized steel rings. The inner ring had an inner diameter of 11.8 inches and was 29.5 inches tall, while the outer ring had a diameter of 23.6 inches and was 23.6 inches tall. The rings were sealed to the permeable surface using plumber's putty or Alginate. During preliminary testing in 2009, it was found that infiltration rates on all the permeable pavements were too high to maintain a hydraulic head using the double-ring infiltrometer test. Thus, a modified test, known as the Surface Inundation Test, was performed at these surfaces to evaluate their respective performance with time. For this test, after sealing the inner ring to the test surface, a rubber impermeable membrane (~11.7-inch inner diameter) was attached to a pull-nylon string and placed inside the ring, thereby providing a false bottom. A pressurized hose mounted on a water-tanker truck was used to fill the ring until it was filled to the top of the ring and water started overflowing to the outer ring. When full and overflowing, the rubber septum was pulled to start the water infiltration test time (t0). Since the infiltration rates were too high to accurately record a drop in water level with time, the time it took to drain from completely full to completely empty (te) was recorded. The infiltration rate (height of inner ring/(te-t0)) obtained from these tests allowed us to compare the three permeable pavements and to evaluate their performance for the four years following construction and use. The tests were repeated at four random spots in each lot for the first two years. During the third and fourth years, tests were conducted separately on drive areas and within the parking slots of each lot with four and five replications, respectively. It is noteworthy that these surface inundation tests do not prevent the horizontal migration of water once it enters the pervious surface. However, it is assumed that most of the water drained directly downward into the pavement and underlying fill.

Pavement Condition Evaluation

The Maintenance and Operations Department (M&O) documented the condition and maintenance performed on each lot such as sweeping, repair, catch-basin cleanout, weeding, and snow removal twice per year, normally in the spring and fall.

RESULTS

Rainfall, Subsurface Water Level, and Flow Measurements (2009 - 2012)

Year 2009. Plots of the 2009 cumulative rainfall for the eastern and western rain gauges are shown in Figure 3. The eastern and western lots received similar total rainfall during the 2009 monitoring season (23.66 inches and 23.88 inches, respectively). Periodic site visits during periods of rainfall indicated no visible standing water or RO on any of the permeable lots.

The near-surface water level response paralleled rainfall events as indicated by the Area Velocity (AV) sensor data for each lot (Figure 4). During rainfall events, increases in water levels were observed. As the water either drained into the soil or into the infiltration perforated pipes, the water levels decreased.

The infiltrated and total flow response for the three permeable plots showed a similar pattern. Flow increase was observed during rain events. At the end of the rainfall event, flows decreased to a base-line level. Unfortunately, the flow meters and PMDs on each lot failed periodically. Numerous efforts were made by IWD, EM&RD, and District contractors to troubleshoot the following problems: (1) pump failure in the bubbler flow meters; (2) rapid desiccant use in the bubbler flow meters; (3) weld and seem failures on the Thelmar weirs; (4) significant drift and anomalous readings in the flow meter data during wet-dry cycles; (5) inability to accurately calibrate in-situ flow meter orifices due to weir locations; and (6) sporadic power failures due to plant shutdowns. Due to these problems, the majority of the flow meter data collected over the study period is not considered reliable and are therefore used to evaluate the permeable lot performance.

In April 2009, only the flow data from the first two rainfall events were considered reliable. Table 2 summarizes the expected volume of water received by each lot, the calculated RO, and the percent RO based on the volume received. The April 13, 2009, event indicates that the lowest RO was observed in the PP lot, followed by the PA lot. The April 19, 2009, event indicates that the lowest RO was observed in the PP lot followed by the PC lot.

Year 2010. During the 2010 monitoring period, electrical work was being performed causing extended power outages in both monitoring sheds. Simultaneous monitoring in all four lots only occurred from April 27, 2010, through June 25, 2010, and October 22, 2010, through November 15, 2010.

Plots of the cumulative rainfall for the eastern and western rain gauges are shown in Figure 5 for 2010. Due to the electrical problems in 2010 cited above, an off-site rain gauge located at the intersection of south Western Avenue and Blue Island Avenue in Chicago, Illinois (approximately five miles from the site) was used to supplement the missing data providing a composite rainfall used in the analysis below. For 2010, a total of 36.7 inches of rainfall was estimated over the course of the entire monitoring season.

FIGURE 3: 2009 CUMULATIVE RAINFALL FOR THE EAST AND WEST PERMEABLE PAVEMENT LOTS AT THE STICKNEY WATER RECLAMATION PLANT

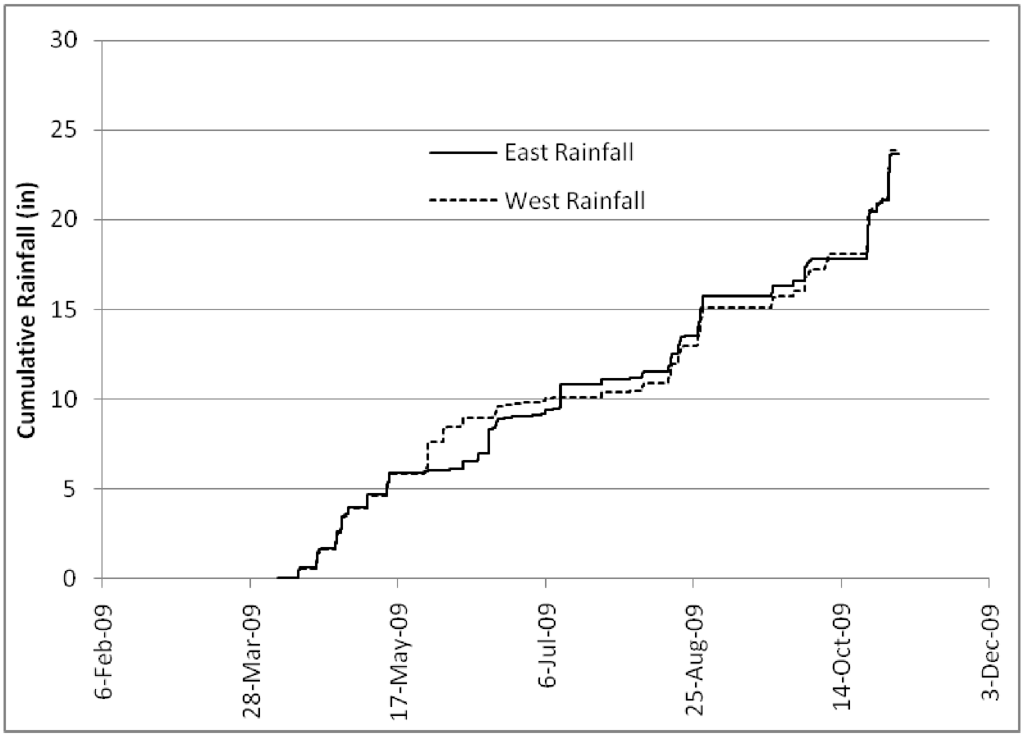


FIGURE 4: 2009 NEAR-SURFACE WATER LEVELS FOR THE (a) PERMEABLE ASPHALT, (b) PERMEABLE CONCRETE, AND (c) PERMEABLE PAVER LOTS

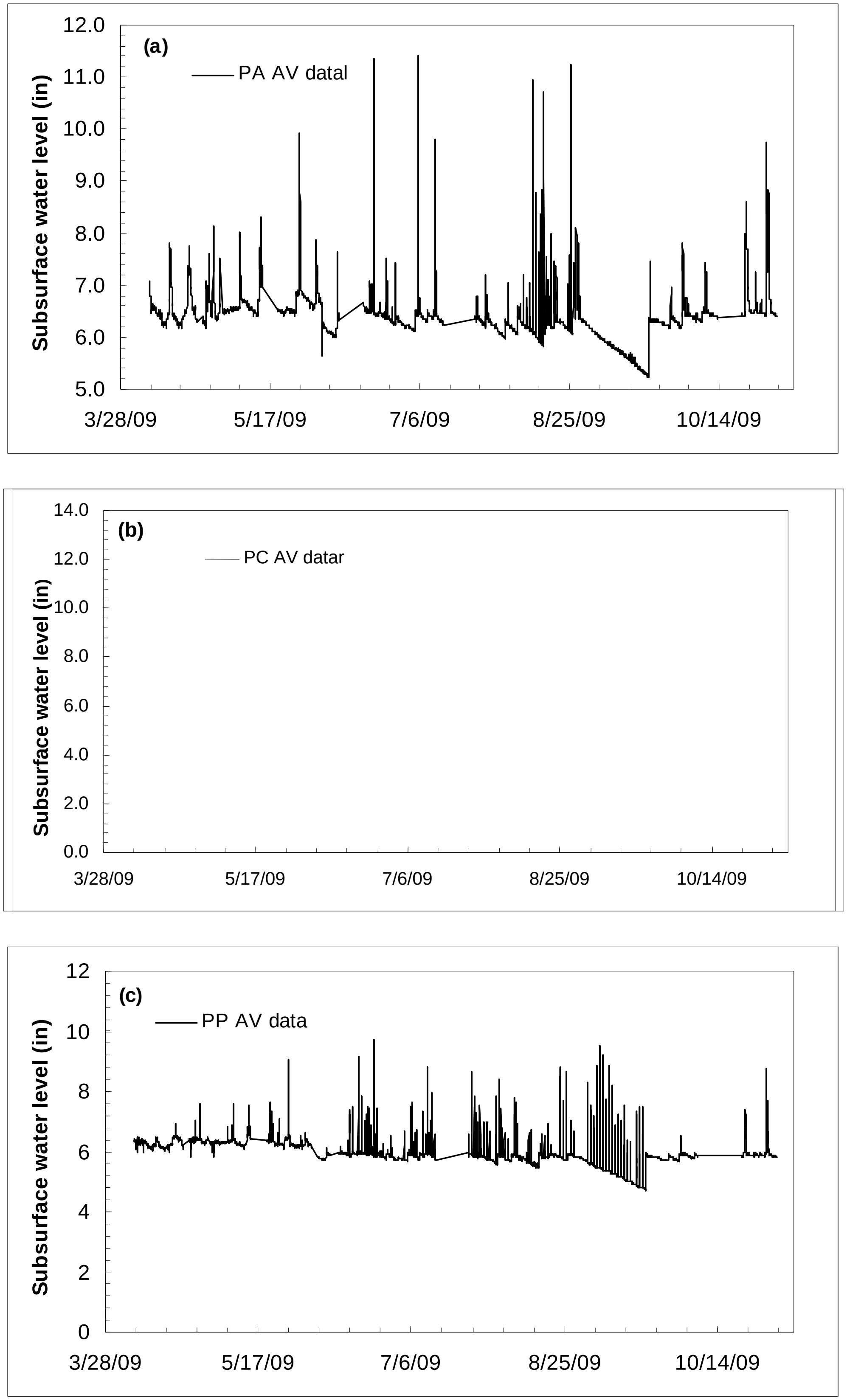
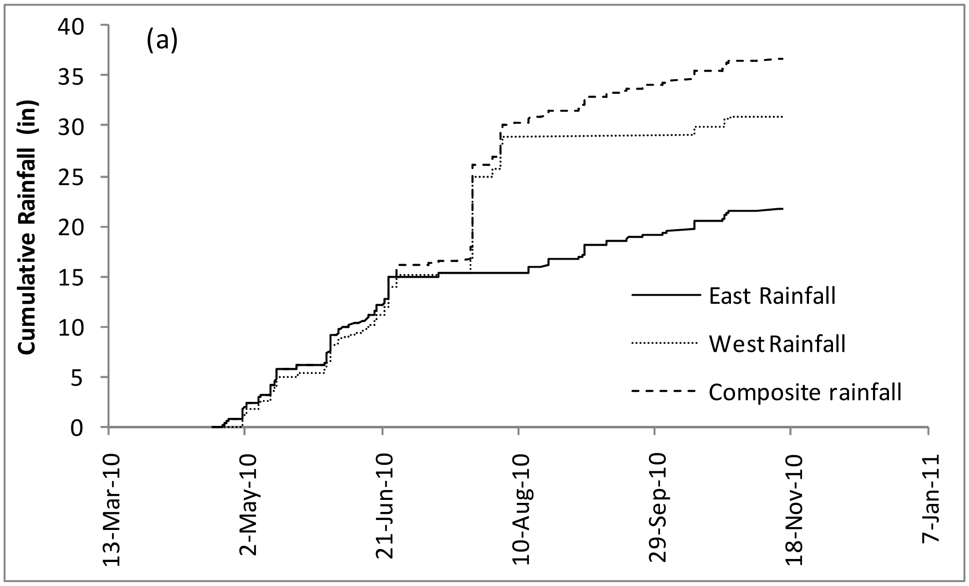


TABLE 2: LOT RUNOFF EVALUATION FOR THE APRIL 13 AND APRIL 19, 2009, RAINFALL EVENTS

Lot	Date	Expected Total Gallons	Measured RO Gallons	% RO
Asphalt	4/13/2009	670.8	27.7	4.1
Concrete	4/13/2009	694.4	51.7	7.4
Paver	4/13/2009	625.9	18.9	3.0
Control	4/13/2009	667.1	484.7	100.0
Asphalt	4/19/2009	1,168.3	210.4	18.0
Concrete	4/19/2009	1,218.3	178.6	14.7
Paver	4/19/2009	1,090.1	119.8	11.0
Control	4/19/2009	1,161.8	1,251.9	100.0

FIGURE 5: 2010 CUMULATIVE RAINFALL FOR THE EAST AND WEST PERMEABLE PAVEMENT LOTS AT THE STICKNEY WATER RECLAMATION PLANT



The near subsurface water level increased during rainfall as indicated by the AV sensor data for each lot (only daily cumulative water inputs greater than 0.1 inches were plotted [Figure 6]). Please note that cumulative daily rainfalls were plotted at the beginning of the day and therefore may not correlate exactly with the water-level peaks). Water levels were normalized to reflect the changes in the baseline water levels for each lot; the baseline level was determined from the residual perched water that remained in the sensor well throughout the monitoring period.

Generally, during times of rainfall and run-on, increases in water levels were observed. It was expected that the increase in water level would be slightly lower than the depth of total water input due to the simultaneous drainage through the perforated pipes as well as out of the bottom of the profile. However, this was generally not observed. For both the PA and PC lots, water levels were significantly higher than the depth of water input (Figures 6a and 6b). For the PP lot, good agreement was observed between water levels and water input during the beginning of the monitoring period, but no discernable trend was observed after June 2010. It is unknown why greater water input is reflected in the lot's water levels; lateral flow through the soil into the lot basin may be occurring or run-on may be underestimated. The invert elevation of the closed 12-inch drain pipe between the drain catch basin and open-grated catch basin is between 28 to 30 inches below grade for each permeable lot. A hydraulic dam may occur if this or the perforated pipe is not draining quickly enough causing increased water levels inside the lot; however, this cannot be verified nor is it expected. Upon the cessation of rainfall, water levels decreased to baseline levels through perforated pipe and profile drainage.

The infiltrated and total flow response for the three permeable plots showed a similar pattern whereby flow increase was observed during rainfall and run-on events. Upon conclusion of the rainfall event, flows decreased to a baseline level for all permeable lots as shown in Figure 7 (please note that cumulative daily rainfalls were plotted at the beginning of the day and therefore may not correlate exactly with the figure peaks). Unfortunately, problems with flow measurements were encountered. For example, recorded infiltrated flows were often higher than the recorded total flows, and RO estimations (total flow minus infiltrated flow) were often higher than the water input for the lot even though no RO was ever observed; this would produce a negative calculation for RO, which is impossible. Specific problems encountered during the monitoring period were as follows: (1) leaking Thelmar weirs; (2) leaking catch basins and pipe break-ins; (3) poor pump performance in flow meters; (4) poor precision of the flow meters to provide reliable data to calculate RO in the permeable lots; and (5) low resolution of flow meters at low flows. Numerous attempts by IWD and EM&RD personnel were made to solve and counteract these problems. For example, concrete and chalk patching of the catch basins and break-ins were performed during the monitoring season, but leakage was still observed.

Year 2011. The same problems encountered during 2010 were observed during the 2011 monitoring period. The M&O and the Engineering Department were consulted about the logistical monitoring difficulties encountered, but solutions, such as lining the catch basins and outgoing pipe in each lot or acquiring better-suited monitoring equipment, were considered cost-prohibitive. Damage to multiple Thelmar weirs prevented the 2011 monitoring season from

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FIGURE 6: 2010 NEAR-SURFACE WATER LEVEL INCREASES AND RAINFALL FOR THE (a) ASPHALT, (b) PERMEABLE CONCRETE, AND (c) PERMEABLE PAVER LOTS

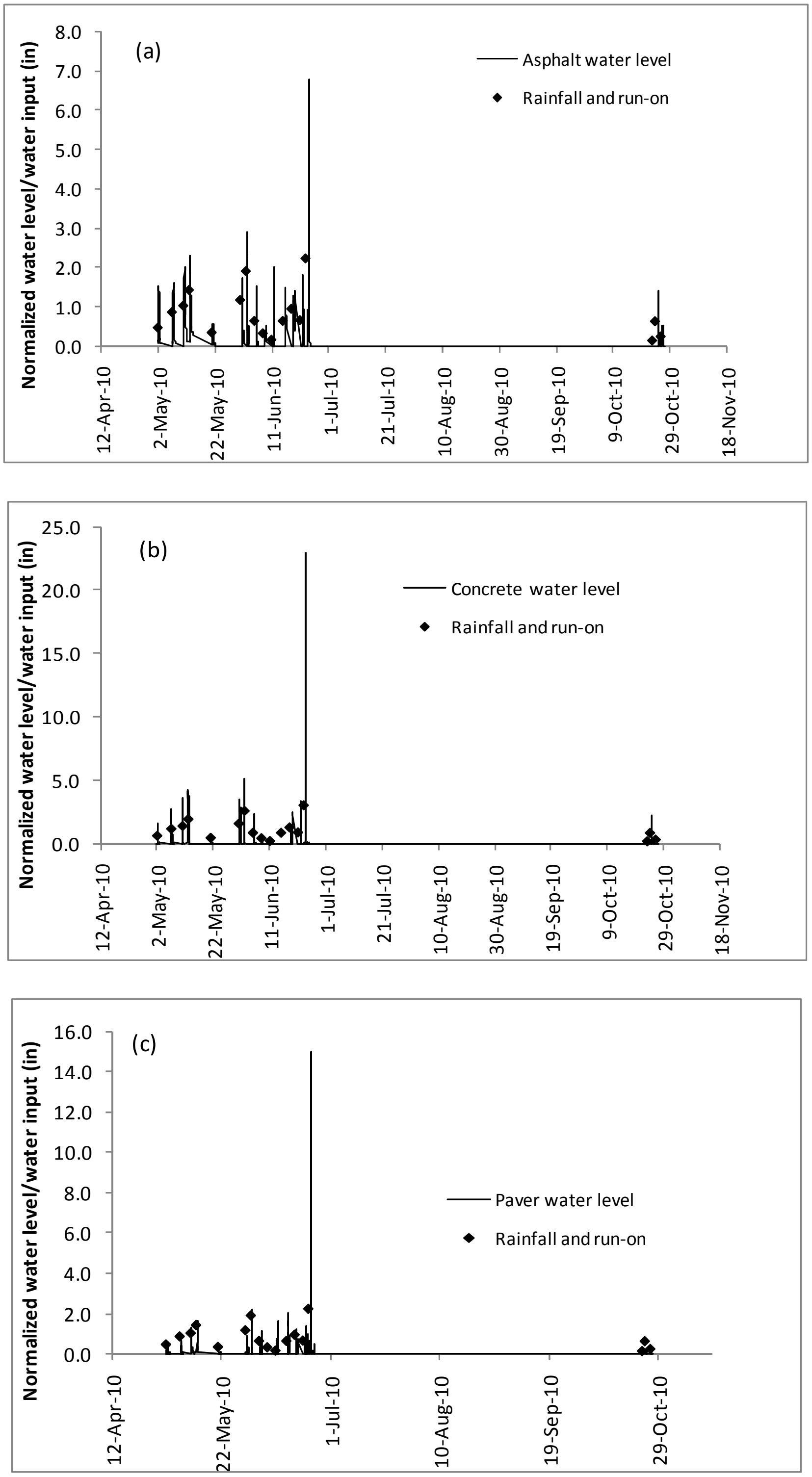
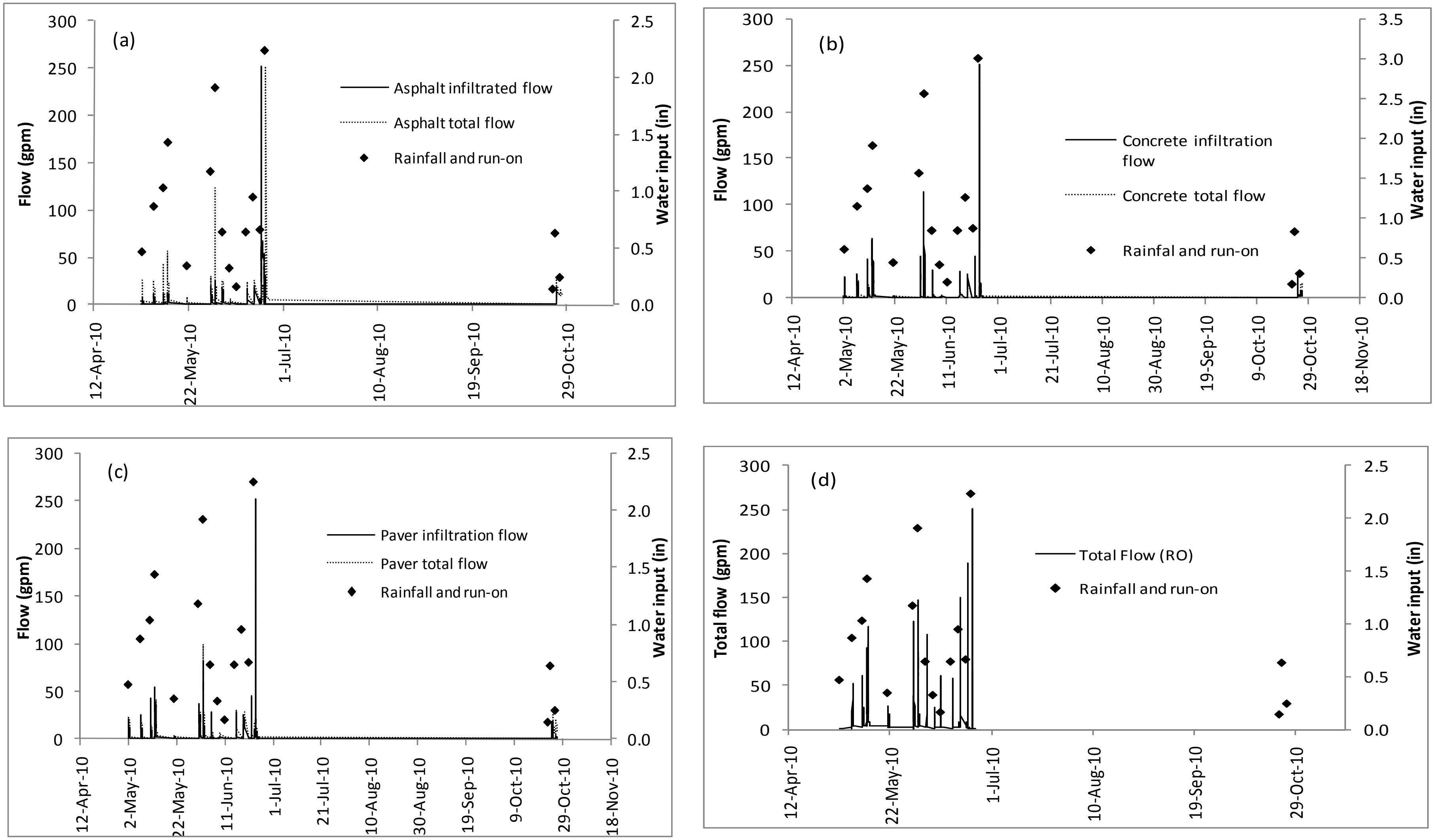


FIGURE 7: 2010 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE (a) PERMEABLE ASPHALT, (b) PERMEABLE CONCRETE, (c) PERMEABLE PAVER, AND (d) CONTROL LOTS



starting at the proposed April 1, 2011, start date; monitoring only occurred from July 11, 2011, through November 9, 2011. For the following data evaluation, only these time periods are considered

A total of 15 - 18 inches of rainfall was estimated during the shortened monitoring season (Figure 8). Similar to the 2010 data, during times of rainfall and run-on, increases in water levels were observed (Figure 9) during the 2011 monitoring season; a malfunctioning motherboard in the PC lot auto sampler prevented data collection after August 25, 2011. Upon the cessation of rainfall, water levels generally decreased to baseline levels, but this was not always observed. Throughout the monitoring period, great fluctuations in water levels were observed in all three permeable lots not previously seen in 2009 or 2010, i.e. increases in water levels were observed without rainfall or run-on input. It is unknown why these fluctuations are occurring; it is suggested that lateral flow through the soil into the lot basin may be occurring, but this could not be confirmed.

The infiltrated and total flow response for the three permeable plots showed a similar pattern to 2009 and 2010 whereby flow increase was observed during rainfall and run-on events. Upon cessation of the rainfall event, flows decreased to a baseline level for all permeable lots as shown in Figure 10 and the control lot as shown in Figure 11. Unfortunately, similar to 2010, problems with flow measurements were continually encountered for reasons cited above. Additionally, the control lot, which should only register flow during rainfall and RO events, indicated flow without said events.

Year 2012. Due to the malfunctioning auto samplers and replacement part availability, sampling began in September. A total of 7 - 8 inches of rainfall was estimated during the shortened monitoring season in 2012 (Figure 12). Also, as in previous years, during times of rainfall and run-on, increases in water levels were observed (Figure 13). The odd fluctuations in water levels observed in 2011 were not observed in 2012. It was decided that the flow meters would not be used because of the problems and inaccuracies they presented in previous years.

Periodic site visits during periods of rainfall indicated no visible standing water or RO on any of the permeable lots during all monitoring seasons. RO and standing water were observed in the impermeable control lot.

Water Quality Evaluation (2009 - 2012)

Because the flow meter function directly impacts the autosampler operation, only nine water quality sampling events occurred during the 2009 season. Of the nine events, samples were collected in all four lots on only four occasions (April 20, April 28, May 8, and August 28, 2009). The TSS and COD results for the first flush samples for all four lots and these events are summarized in Table 3 (please note that the bold italic values indicate the highest concentration among the studied lots). All three permeable lots showed significantly lower water quality concentrations relative to the control lot. The PA lot showed the highest reductions in TSS concentrations on average, and the PC lot showed the highest reductions in COD concentrations.

FIGURE 8: 2011 CUMULATIVE RAINFALL FOR THE EAST AND WEST PERMEABLE PAVEMENT LOTS AT THE STICKNEY WATER RECLAMATION PLANT

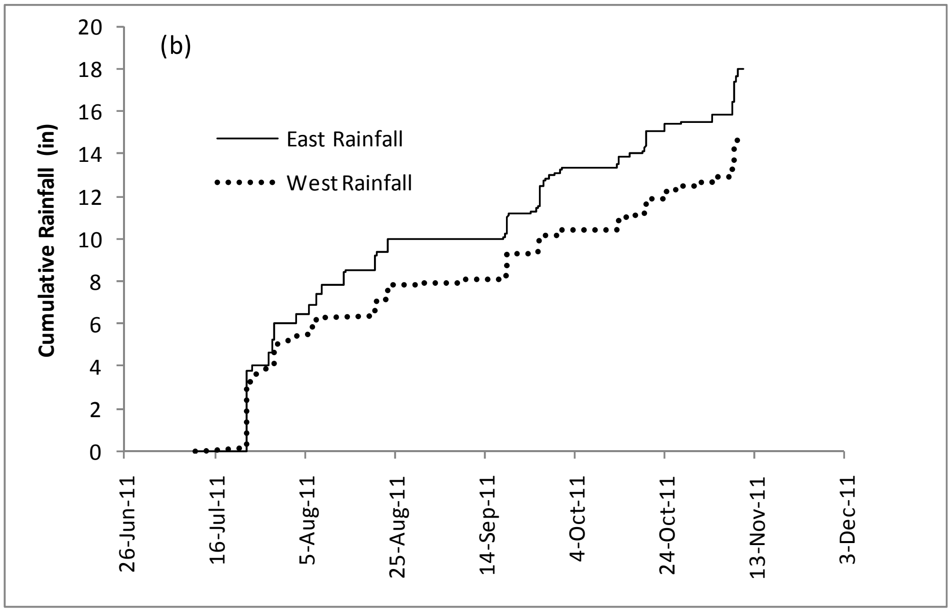


FIGURE 9: 2011 NEAR-SURFACE WATER LEVEL INCREASES AND RAINFALL FOR THE (a) PERMEABLE ASPHALT, (b) PERMEABLE CONCRETE, AND (c) PERMEABLE PAVER LOTS

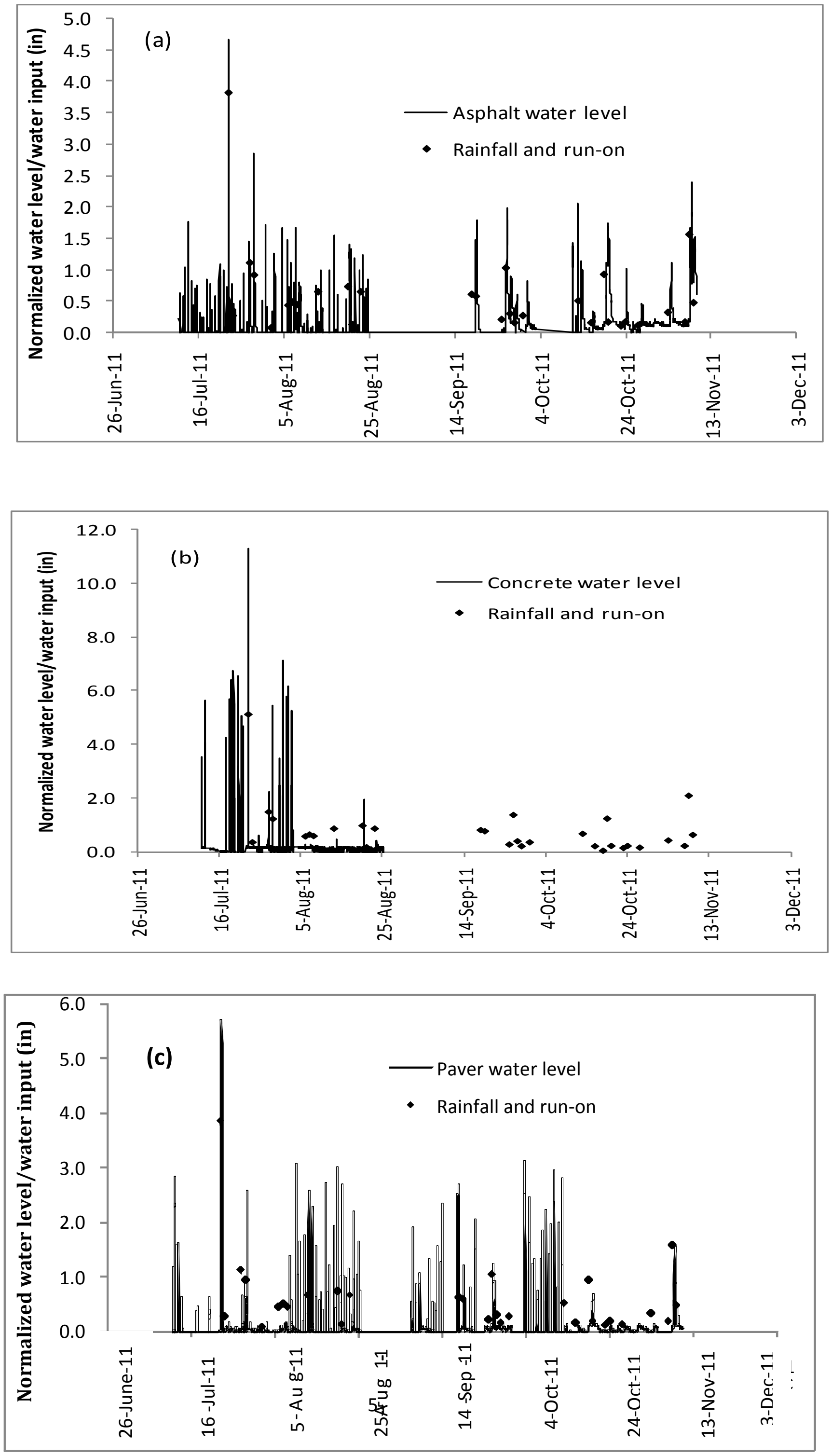


FIGURE 10: 2011 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE (a) PERMEABLE ASPHALT, (b) PERMEABLE CONCRETE, AND (c) PERMEABLE PAVER LOTS

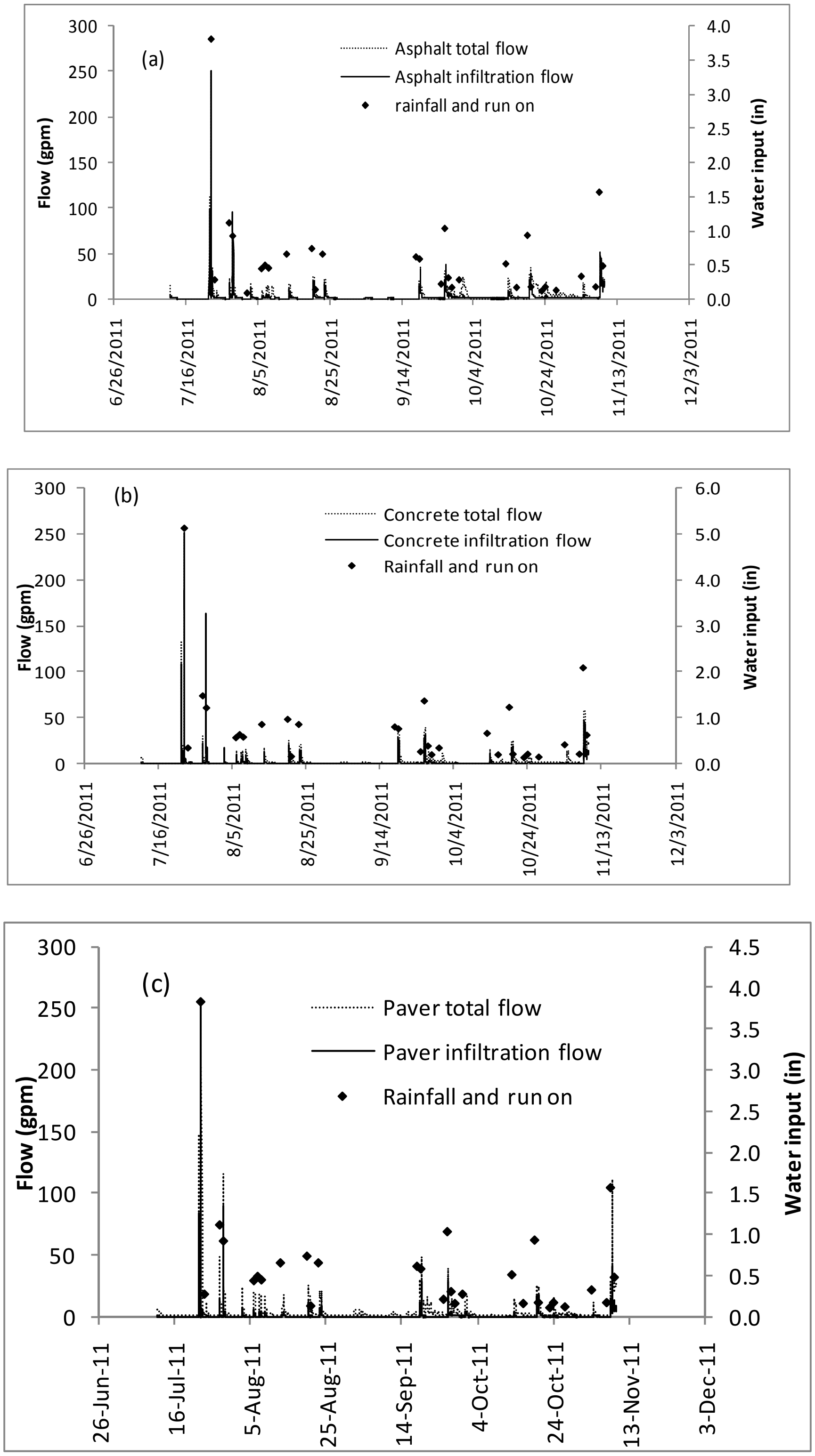


FIGURE 11: 2011 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE CONTROL LOT FROM (a) JULY 11 THROUGH AUGUST 23, 2011, (b) JULY 24 THROUGH OCTOBER 6, 2011, AND (c) OCTOBER 7 THROUGH NOVEMBER 9, 2011

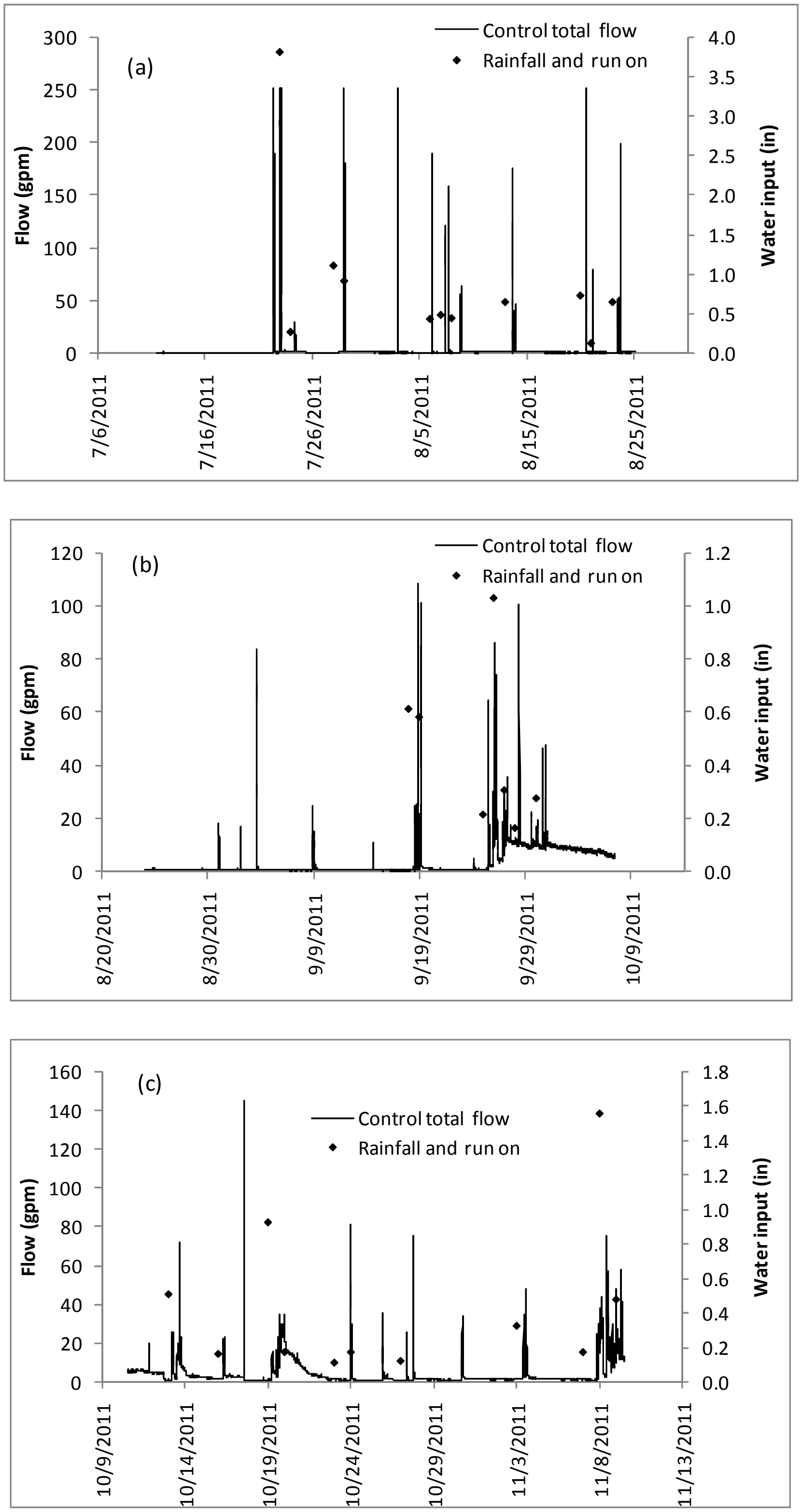


FIGURE 12: 2012 CUMULATIVE RAINFALL FOR THE EAST AND WEST PERMEABLE PAVEMENT LOTS AT THE STICKNEY WATER RECLAMATION PLANT

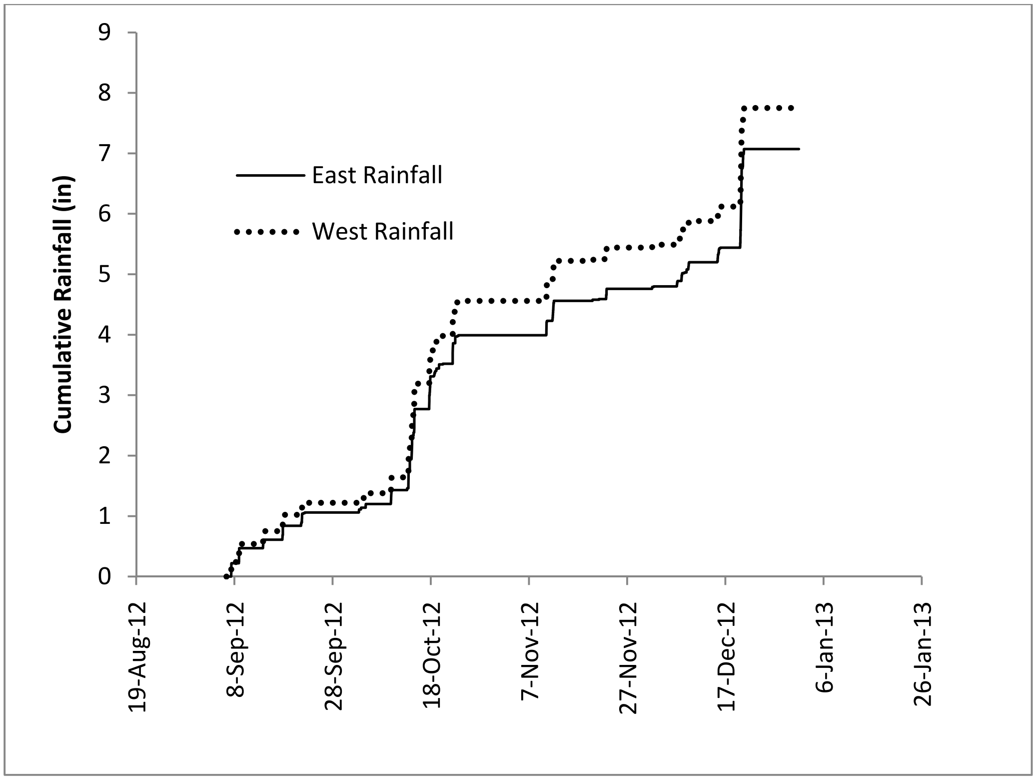


FIGURE 13: 2011 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE (a) PERMEABLE ASPHALT, (b) PERMEABLE CONCRETE, AND (c) PERMEABLE PAVER LOTS

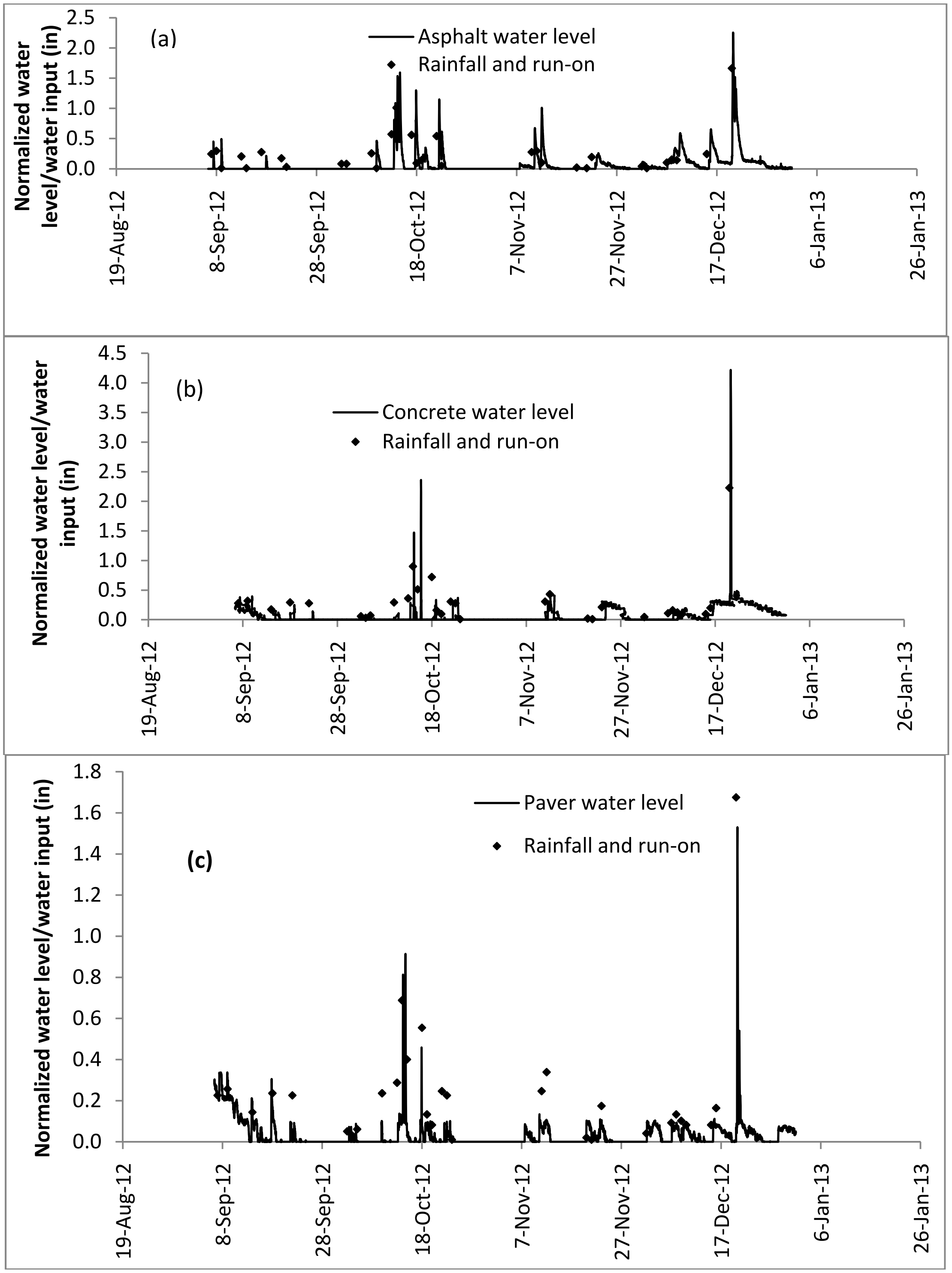


TABLE 3: TOTAL SUSPENDED SOLIDS AND CHEMICAL OXYGEN DEMAND ANALYSIS FOR COMMON 2009 THROUGH 2011 RAINFALL EVENTS IN FIRST FLUSH OF PERMEABLE PAVEMENTS AT THE STICKNEY WATER RECLAMATION PLANT

	TSS (mg/L)				COD (mg/L)			
Date	PA	PC	PP	Control	PA	PC	PP	Control
20-Apr-09	9	5	4	***101***	48	26	***99***	91
28-Apr-09	70	13	45	***410***	45	32	54	***169***
8-May-09	10	21	63	***291***	71	34	<25	***210***
28-Aug-09	5	20	18	***33***	32	64	34	***146***
3-May-10	586	***689***	52	596	106	142	55	***167***
12-May-10	71	20	***73***	6	***89***	26	47	41
14-May-10	72	38	92	***99***	72	<25	38	***98***
2-Jun-10	36	***47***	26	10	***116***	44	69	65
7-Jun-10	20	***89***	40	45	45	29	26	***91***
17-Jun-10	17	16	***36***	28	***85***	<25	42	<25
22-Jun-10	10	15	31	***117***	***63***	<25	<25	35
25-Jun-10	11	***103***	24	8	***85***	39	39	<25
22-Jul-11	54	214	***243***	67	62	***102***	27	41
28-Jul-11	22	19	43	***152***	50	33	37	***111***
8-Aug-11	6	24	14	***31***	43	<25	<25	***62***
15-Aug-11	8	22	13	***132***	27	<25	<25	***75***
22-Aug-11	18	21	18	***136***	<25	<25	***90***	66
19-Sep-11	29	***39***	7	31	<25	44	<25	***73***
24-Oct-11	4	***7***	5	***11***	<25	<25	<25	***41***

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[1] PA = permeable asphalt; PC = permeable concrete; PP = permeable pavers.

*Note: Bold italic data indicate the highest concentration among all lots.

Table 3 also provides the water quality results for the common sampling events in 2010 and 2011. The trends of lower TSS and COD concentrations in the permeable lots relative to the control lot were only observed in 2011 but occurred rather infrequently in 2010. Reduced TSS and COD concentrations in the permeable pavement lots were expected as less overland flow occurs relative to the control lot, i.e. fewer particles are entrained and able to enter the sewer via RO. Small particles and soluble water quality parameters can enter the subsurface of the permeable lots while larger particles may clog the pavement pores. The pollutants entering the permeable lot system can (1) drain through the lot profile and into the native soil where they can be conveyed into the local groundwater; (2) be sorbed or trapped by the media of permeable pavements, lot fill, geotextile, or underlying soil; or (3) transformed by indigenous microorganisms. These mechanisms are the potential reasons for lower pollutant concentrations in the permeable lots relative to the control lot in 2009 and 2011.

Table 4 summarizes the pH data for all three monitoring seasons. The higher 2009 pH values are observed for the three permeable lots, possibly due to the effect of the calcium carbonate of the limestone CA-7 fill. Dissolution of calcium carbonate elevates pH levels. The pH values decreased towards more neutral levels by mid summer 2010, which may indicate that the readily dissolvable calcium carbonate was diminished through extended leaching. By 2011, the pH values were maintained at a neutral level.

For the intensive sampling events in 2009, August 28, 2009, was the only common sampling event for the four lots. Significant differences were not observed for any of the analytes (data not shown). Slightly higher ammonia-nitrogen concentrations were observed in the control lot relative to the permeable lots, and slightly higher nitrate-nitrogen concentrations were observed in the permeable lots relative to the control lots. All metals and PAHs were near or below detectable concentrations.

For the one common 2010 special sample analysis, very low ammonia-nitrogen (<0.02 mg/L) and total phosphorus concentrations (<0.08 mg/L) were observed in all the lots. Chloride was approximately 200 - 350 mg/L for all the lots, except for the PP lot (85 mg/L). Nitrate-nitrogen was slightly higher in the permeable pavement lots (~1.0 mg/L) relative to the control lot (0.58 mg/L), possibly due to subsurface nitrification. It is expected that nitrogen inputs to the system are from organic matter and biomass contributions and atmospheric deposition. All metals and PAHs were near or below detectable concentrations.

For the three common 2011 special sample analyses, very low ammonia-nitrogen (<0.4 mg/L) and total phosphorus concentrations (<0.14 mg/L) were observed in all the lots. Chloride concentrations averaged 73 mg/L, 77 mg/L, 150 mg/L, and 114 mg/L for the PA, PP, PC, and control lots, respectively. Nitrate-nitrogen was slightly higher in the permeable pavement lots (~0.8 mg/L) relative to the control lot (0.35 mg/L). All metals and PAHs were near or below detectable concentrations. However, zinc concentrations were above the detection limit (0.06 mg/L) during the July 22, 2011, event for all three permeable lots; nickel concentrations were above the detection limit (0.008 mg/L) during the same event for the PA and PP lots.

Water quality evaluations were not conducted during 2012 because the flow meters that triggered the sample collection were not operational.

TABLE 4: pH FOR COMMON 2009 THROUGH 2011 RAINFALL EVENTS IN FIRST FLUSH OF PERMEABLE PAVEMENTS AT THE STICKNEY WATER RECLAMATION PLANT

	pH			
Date	PA[1]	PC[1]	PP[1]	Control
20-Apr-09	8.1	10.4	8.4	7.5
28-Apr-09	8.2	9.9	8.3	7.4
8-May-09	8.2	9.6	8.3	7.6
28-Aug-09	8.4	9.5	8.2	7.8
3-May-10	8.4	9.4	8.2	6.5
12-May-10	8.4	10.1	8.9	8.1
14-May-10	8.3	10.0	8.5	6.9
2-Jun-10	8.0	9.3	8.3	6.8
7-Jun-10	7.0	8.0	9.3	8.1
17-Jun-10	8.2	9.2	7.2	8.1
22-Jun-10	7.8	9.2	7.9	7.4
25-Jun-10	7.9	9.3	7.9	7.5
22-Jul-11	7.2	7.1	7.0	7.5
28-Jul-11	7.0	6.9	7.0	7.4
8-Aug-11	6.7	6.6	6.6	6.3
15-Aug-11	7.5	7.5	7.6	7.6
22-Aug-11	6.4	6.8	6.3	7.0
19-Sep-11	6.5	6.7	6.5	6.9
24-Oct-11	7.2	7.4	7.5	6.9

[1] PA = permeable asphalt; PC = permeable concrete; PP = permeable pavers.

Infiltration Evaluation Using Infiltrometer Tests (2009 - 2012)

As an alternative method for evaluating infiltration potential, ringed infiltrometer tests were performed from 2009 - 2012. In each lot, up to four tests at two different locations (driving area and parking). The overall infiltration performance of the permeable pavements was considered to depend on the permeability or porosity of the surface permeable layers (concrete, asphalt, and pavers) evaluated in this study. The infiltration rates of these surfaces were very high immediately following construction of these parking lots. In 2009 when use of the lots began, the average infiltration rates in decreasing order were: concrete (38.2 mm sec^{-1}) > asphalt (31.1 mm sec^{-1}) > pavers (25.4 mm sec^{-1}) (Table 5). Infiltration rates after one year of use (2010) did not decline significantly for the paver and asphalt lots; however, the rate declined significantly for the concrete lot, from 38.2 to 32.5 mm sec^{-1}. For 2010, infiltration rates of the concrete and asphalt lots were similar but still significantly higher than pavers (Table 5). During the third year of use (2011), the infiltration rates of all three permeable surfaces declined significantly, but the decline was much more drastic for the paver lot, which declined from 24.1 mm sec^{-1} in 2010 to 7.1 mm sec^{-1} in 2011 (Table 5). Additionally, during the fourth year (2012), the infiltration rates declined for all lots; the rate declines were much greater for the concrete and asphalt lots (Table 5).

The infiltration rates were similar in the drive area and parking slot for all three pavement lots for the first two years (2009 and 2010). However, during the third year (2011), infiltration rates were significantly lower in the drive areas (15.2 mm sec^{-1}) as compared to 20.9 mm sec^{-1} in the parking slots (Table 6). This difference between the drive areas and parking slots became more prominent during the fourth year (2012), i.e. the infiltration rate was more than 50 percent lower in the drive areas as compared with the parking slots (Table 6). The decline in the infiltration rates with time is most likely due to the clogging of the pores of the pavements. This clogging not only reduces the total pore space volume but may also block the pores, thereby reducing their connectivity and ultimately hindering the flow of water.

The results from the present study showed only marginal (2 - 15 percent) declines in the infiltration rate after one year of usage (2009 - 2010), after which the declines were much steeper for all three surfaces (2010 - 2012). In the fourth year (2012), the infiltration rates had declined by as much as 82 - 90 percent in the drive areas and by 60 - 79 percent in the parking slot areas relative to year one (2009). Nonetheless, the minimum infiltration rate of 3.8 mm sec^{-1} observed after four years of usage of the worst performing lot (permeable pavers lot) was 4.75 times higher than the average 0.8 mm sec^{-1} intensity of a five-year, one-hour rainstorm in the study area. From the rainfall data, the maximum intensity observed during 2009 and 2012 was less than 0.03 mm sec^{-1}. Thus, no RO is expected, and was never observed during site visits, in these permeable lots at the Stickney WRP.

These infiltrometer results further indicate that the flow data recorded during the study period was unreliable and corroborates the observation that no standing water or RO was observed during periodic visits to the lots in wet weather.

TABLE 5: INFILTRATION RATES OF PERMEABLE PAVEMENTS DURING THE FOUR YEARS OF USE OF A CAR PARKING LOT AT THE STICKNEY WATER RECLAMATION PLANT

Year	Permeable Pavers	Permeable Concrete	Permeable Asphalt
	------ mm/sec ------		
2009	25.4cA[1]	38.2aA	31.1bA
2010	24.1bA	32.5aB	30.6aA
2011	7.1bB	22.7aC	24.4aB
2012	3.8cC	6.0bD	9.1aC

[1] Numbers followed by a different small letter in a row and capital letter in a column are significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

TABLE 6: MEAN INFILTRATION RATES OF THE PERMEABLE PAVEMENTS IN DRIVE AREAS AND PARKING SLOTS DURING THE THIRD AND FOURTH YEAR OF USE AT A CAR PARKING LOT AT THE STICKNEY WATER RECLAMATION PLANT

Year	Drive Area	Parking Slot
	---------------------------- mm/sec	-------------------------
2011	15.2aB[1]	20.9aA
2012	3.9bB	8.7aB

[1] Numbers followed by a different small letter in a row and capital letter in a column are significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

Pavement Condition Evaluation (2009 - 2012)

Wear and tear were observed after the permeable parking lots were constructed and used from 2009 for employee car parking as discussed below (Table 7).

Permeable Asphalt. A few longitudinal cracks were observed at the end of 2009. The end of the 2010 evaluation indicated that this lot was in relatively good condition. There was no vegetation growth on the surface, but there was some surficial sediment buildup in small areas along the eastern border and northwest corner of the lot. Additionally, cuts and scours caused by snow plowing were observed. Minor raveling, i.e. progressive disintegration of the pavement causing large particles to dislodge, was also observed. The 2011 evaluation revealed no vegetative growth but that raveling had increased, especially in the driving lanes and southern entrance. The raveling increased significantly in the drive areas in 2012 as compared to previous years, and some raveling was also observed in the parking slots.

Permeable Concrete. At the end of 2009, a crack appeared near the monitoring well area, and also small spalled areas were observed near Northeastern corner of the lot. At the end of 2010, this lot was in relatively good condition with only very little vegetative growth along the edges of the lot. Minor raveling and some cracking were also observed. In 2011, there was vegetative growth along the borders of the lot, necessitating weeding, major raveling around the control joints along the perimeter of the lot, and two large cracks in the center of the lot. By the end of 2012, increased raveling was observed in the drive areas as compared to previous years, and the area between the parking slots had only minor raveling (Photograph 3).

Permeable Pavers. At the end of 2009, a few chipped and cracked pavers were observed and loose CA-16 Paver fill gathered at a few locations. At the end of 2010, this lot was the most degraded among the three permeable pavement lots. Multiple locations of chipped pavers and vegetation were observed. Pronounced depressions were noted throughout the lot. Additionally, fill between the pavers was missing in a number of locations. The 2011 evaluation revealed weeds in the corners of the lot, necessitating weeding, and an increased number of chipped, spalled, and cracked pavers. The 2012 evaluation showed more degradation than was observed in 2011. Also an oil leak patch in a parking slot was observed as well as a little vegetation that needed weeding (Photograph 3).

By the end of 2012, the condition in decreasing order was: permeable concrete > permeable pavers > permeable asphalt. The poor condition of the asphalt is probably due to higher traffic in the asphalt lot because vehicles leave and enter from both sides of the lot, while the pavers and concrete lots were isolated and did not have through traffic. The depressions observed in the paver's lot may be due to the relatively heavier utility vehicles parked in this lot as compared to passenger cars in the other sections.

TABLE 7: DETERIORIATION OF PERMEABLE AND CONTROL LOTS FOLLOWING EACH SEASON DURING 2009 - 2012

Experimental Permeable Lots	Winter 2009/2010	Summer 2010	Winter 2010/2011	Winter 2011/2012	Fall 2012
Permeable Pavers	1) Varying chipped and cracked pavers throughout lot 2) Loose CA-16 paver fill gathered along the east, north, and west sides of parking lot 3) Dead plant material between paver joints	1) Varying chipped and cracked pavers throughout lot 2) Dying vegetation in all four corners of lot 3) Pronounced depressions throughout lot (large depression in southern entryway to lot)	1) Varying chipped and cracked pavers throughout lot 2) Dead plant material located in all four corners of lot and along the perimeter 3) Pronounced depressions throughout lot (including parking space areas) 4) Snow blade scrapes/gouges 5) Concrete collar corners for manholes and monitoring well are damaged (snow plow damage)	1) Chipped, worn/spalled, and/or cracked pavers throughout lot 2) Depressions throughout lot 3) Dirt and debris accumulation and vegetative growth in paver joints	1) Chipped, worn/spalled, and/or cracked pavers 2) Depressions throughout lot 3) Dirt and debris accumulation and vegetative growth (dead or dying) in paver joints (vegetation is concentrated in all four corners and along the perimeter of lot) 4) Low levels of paver fill (CA-16) in lot
Permeable Concrete	1) Concrete crack developing in corner of monitoring well 2) Spalled area (roughly ½” deep) in handicap parking space near northeast corner of lot	1) Two concrete cracks (one in corner of monitoring well and one in the field of the parking lot [in the center and northern end of lot]) 2) Raveling concrete aggregate located along concrete control joints	1) Raveling concrete aggregate located at control joints and along perimeter of lot. Raveling throughout lot. 2) Plant debris and loose gravel in all four corners of lot 3) Snow plow gouges in northern portion of lot 4) Two developing concrete cracks in lot (one in corner of monitoring well and one in the field of the parking lot)	1) Raveling concrete aggregate has significantly increased over time. Raveling aggregate throughout the lot (i.e. control joints, concrete cracks, and field of lot) 2) Snow plow gouges	1) Raveling concrete aggregate at concrete control joints, cracks, field of lot, etc. 2) Snow plow gouges in lot 3) Accumulated dirt & debris are clogging the pores of the lot 4) Vegetative growth (dead or dying) is concentrated along the east, west, and southern perimeter of the lot (between curb and pavement)

TABLE 7 (Continued): DETERIORATION OF PERMEABLE AND CONTROL LOTS FOLLOWING EACH SEASON DURING 2009 - 2012

Experimental Permeable Lots	Winter 2009/2010	Summer 2010	Winter 2010/2011	Winter 2011/2012	Fall 2012
		3) Dying vegetation along the four perimeters of lot. 4) Snow- plow gouges (northeast corner of lot between parking pavement and concrete curb)	5) Residual deicing salt in lot (center of parking lot – located around the manholes)		
Control Asphalt	1) Longitudinal/Joint Cracks are reflected throughout Lot	1) Snow plow scrapes are prevalent throughout lot 2) Roughly seven longitudinal/joint cracks with associated minor transverse cracking are reflected 3) Spot vegetation found on western and eastern perimeter of lot	1) Existing longitudinal/joint cracks with associated transverse cracks are getting wider 2) Snow plow scrapes are prevalent throughout lot 3) Dead plant material/debris located along perimeter	1) Miscellaneous cracks associated with sealed (in November 2011) longitudinal cracks and/or transverse cracks, which need to be sealed	1) The crack sealant (installed in Nov. 2011) for the longitudinal and transverse cracks has failed or is starting to fail 2) Miscellaneous cracks associated with sealed longitudinal cracks and/or transverse cracks, which need to be sealed 3) Shrinkage cracks are developing throughout lot 4) Sunken pavement area within the lot 5) Small spalled/pothole areas have appeared

TABLE 7 (Continued): DETERIORATION OF PERMEABLE AND CONTROL LOTS FOLLOWING EACH SEASON DURING 2009 - 2012

Experimental Permeable Lots	Winter 2009/2010	Summer 2010	Winter 2010/2011	Winter 2011/2012	Fall 2012
Permeable Asphalt	1) Spalling/raveling asphalt surface course material concentrated in the drive aisles along the eastern half of the lot	1) Spalling/raveling asphalt concentrated along the eastern drive aisle of lot and developing in the northwest corner (western drive aisle) of lot	1) Snow plow scrapes/gouges throughout Lot 2) Raveling aggregate located in drive aisles (centralized along snow plow direction/path) and along installation (longitudinal) joints 3) Longitudinal/joint crack developing at the southern main entrance of the lot (center of entryway)	1) Raveling asphalt aggregate has significantly increased over time. Rraveling aggregate is evident throughout the lot (i.e. drive aisles/lanes and associated with installation/longitudinal joints) 2) Snow plow scrapes in lot	1) Heavy deterioration/raveling asphalt aggregate throughout lot (i.e. drive aisles/lanes, installation joints, etc.) 2) A crack has developed along an installation joint within the lot 3) Snow plow scrapes

*Note: The four seasons were defined as follows - spring (March - May), summer (June - September), fall (October and November), and winter (December - February). All visual inspections were conducted by Stickney Water Reclamation Plant/Maintenance & Operations/Buildings & Grounds (B&G) Section personnel. Also, note that all visual inspections took place after the indicated season (i.e. the winter season inspection usually took place in March, etc.). B&G personnel were inspecting the physical condition of the permeable lots after the lots had been exposed to that specific climate season.

PHOTOGRAPH 3: PHOTOGRAPHS OF PERMEABLE PAVEMENT LOTS (a) ASPHALT, (b) CONCRETE, AND (c) PAVERS TAKEN IN DECEMBER 2012 SHOWING DETERIORATION OF SURFACE IN DRIVE AREAS AS COMPARED TO PARKING SLOTS

Drive Area Parking Slot

(a) Permeable Asphalt

Drive Area Parking Slot

(b) Permeable Concrete

Drive Area Parking Slot Permeable Pavers

(c) Permeable Pavers

SUMMARY

The permeable lots are still in decent condition with some minor vegetation, raveling, cracking, and gouges from snow plows. By the end of 2012, the condition of the lots in decreasing order was: permeable concrete > permeable pavers > permeable asphalt. The poor condition of the asphalt may be due to higher traffic in the asphalt lot as vehicles leave and enter from both sides of the lot, while the pavers and concrete lots were isolated and did not have through traffic.

Rainfall, subsurface water levels, infiltrated flow, and total flow were intermittently measured from 2009 - 2012. In general, increased water levels within the lots and infiltration flows during rainfalls suggested that significant infiltration was occurring at the permeable lots. However, due to the unreliability of the data collected from the flow meters and the potential unknown water sources, reliable comparisons between the infiltration potential of the lots could not be made using this data. Significant reductions in TSS and COD were observed under the permeable pavement system as compared to the control.

The results of the infiltrometer tests showed only marginal (2 - 15 percent) declines in the infiltration rate after one year of usage (2009 - 2010, after which the declines were much steeper for all three surfaces (2010 - 2012). In the fourth year (2012), the infiltration rates had declined by as much as 82 - 90 percent in the drive areas and by 60 - 79 percent in the parking slot areas relative to year one (2009). Nonetheless, the minimum infiltration rate of 3.8 mm sec^{-1} observed after four years of usage of the worst performing lot (permeable pavers lot) was 4.75 times higher than the average 0.8 mm sec^{-1} intensity of a five-year, one-hour rainstorm in the study area. From the rainfall data, the maximum intensity observed during 2009 and 2012 was less than 0.03 mm sec^{-1}. Therefore, no RO was expected to occur during the 2009 to 2012 study period for the permeable lots, and no RO was observed during site visits.

REFERENCES

Andersen, C.T., I.D.L. Foster, and C.J. Pratt. 1999. The role of urban surfaces (permeable pavements) in regulating drainage and evaporation: development of a laboratory simulation experiment. Hydrol. Process. 13:597-609.

APPENDIX A

PERMEABLE PAVEMENT MONITORING PLAN

PERMEABLE PAVEMENT
MONITORING PLAN

Prepared by:
James Huff, P.E.
Daniel Blum, P.E.

April 2008

Huff & Huff
incorporated

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FIGURES

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APPENDICES

1.0 INTRODUCTION

The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) is evaluating porous pavement technology for storm water control in the Chicago Metropolitan Area. As part of the evaluation, Conservation Design Forum is designing three test surfaces and a control area in the parking lot located on the northeast side of the MWRD Stickney Facility.

The study will evaluate the effect on the water quality parameters and the effect of retention and detention on the affected parameters.

2.0 MONITORING PLAN

Monitoring will consist of rainfall measurements, flow measurements, water level measurements within the test area gravel base, and water quality measurements.

Monitoring will be conducted at four designated test locations including:

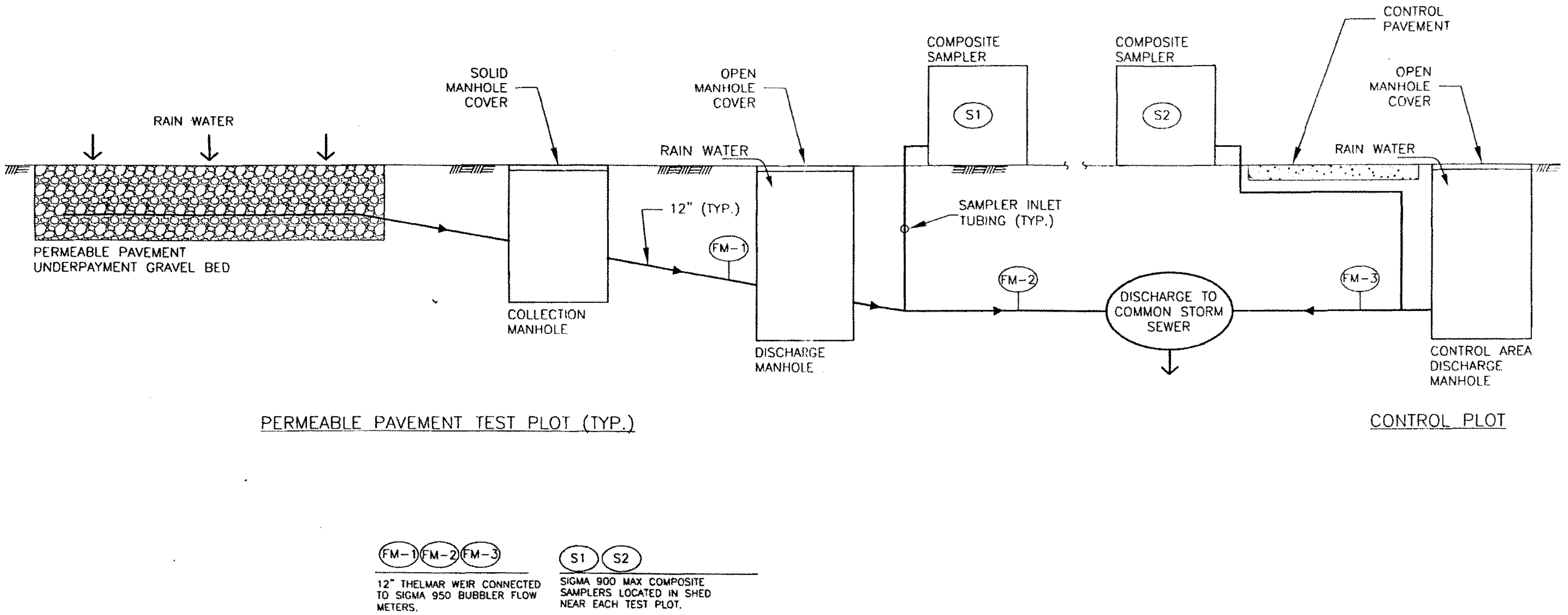
- Porous asphalt test area
- Porous concrete test area
- Permeable pavers test area
- Control area

2.1 Installation Requirements

Each permeable pavement test area is provided with an underlayment gravel bed for collection of the incoming storm water infiltrated through the permeable pavement test surface. The accumulated storm water flows through a four-inch HDPE perforated pipe to the *collection manholes* provided with a solid manhole covers. The exit sewer pipes from each *collection manhole* is equipped with a flow meter to measure the flows from each permeable pavement test area. The *collection manholes* are also installed with utility conduits suitable for future installation of composite samplers.

From the *collection manhole*, the water is routed to the *discharge manhole*. The *discharge manholes*, equipped with open sewer covers, receive any uncontrolled flow in excess of the capacity of the permeable pavement test surface, and the flow from the *collection manholes.* The combined flow discharges to sewer through a twelve-inch sewer pipe equipped with its own flow meter and an automatic sampler. The *discharge manhole* for the control area is provided with an open cover and receives storm water run off from conventional asphalt pavement. Figure 2-1 provides the flow diagram for a typical permeable pavement test area and the control area.

The automatic samplers and flow meters located in two equipment sheds will be connected to the *collection* and *discharge manholes* using underground conduits for installation of the sampling tubes and bubbler tube connections. One sampler in each shed will be provided with an input from a roof-top rain gauge. The samplers and flow meters will be provided with power supplies for connection to 115 VAC electrical power.



PLOT DATE: 04.25.2008

FIGURE 2-1
FLOW DIAGRAM FOR PERMEABLE PAVEMENT MONITORING PLAN

REV.	DESCRIPTION	BY	DATE

DR. BY: SB
DSNG. BY DB
CHK'D.

HUFF & HUFF, INC.
OAK BROOK, IL

DATE 04.25.2008
SCALE NONE
DWG. # MWH SALT CREEK
SHEET OF

CADFILE: MWH\SLAT CREEK PERMEABLE PAVEMENT\MWH_SC_PERMEABLE_PAV

Monitoring wells will be provided at the low point of each gravel bed suitable for installation of a submerged level transducer. The monitoring wells will consist of twelve-inch diameter ADS drain basins including two four inch diameter, 2 foot long perforated pipe sections provided with an end cap. The perforated pipe allows the level equalization with the gravel bed. The cable connecting the sampler to the level transducer will be installed in a two inch underground conduit.

2.2 Flow Meter Selection

Flow meter selection alternatives included an Area Velocity Flow Meter suitable for installation in the existing twelve-inch sewer line and a Thelmar combination volumetric weir. The flow meters and samplers as manufactured by Sigma were specified because they are used by the MWRD.

The Sigma Velocity/Flow Meter was evaluated compared to the Sigma 950 Bubbler Flow Meter in combination with a Thelmar V-notch Weir. The Sigma 920 Area Velocity Flow Meter has an operating range for level of 0.018 to 34.6 ±0.07 feet and a Doppler ultrasonic velocity sensor with no published accuracy statement. This was compared to a Thelmar combination weir, connected to a Sigma 950 Bubbler Flow Meter with an operating range of 0.01 to 11.75 ±0.011 feet. Appendix A provides the specifications for the two flow meters evaluated. The limiting factor for flow rate measurements, on both meters was determined to be the level transducer component.

The sewer flow rates for the meter comparison were calculated based on the drainage area of the test surfaces of 12,000 square feet and a range of rainfall of 0.1 to 1.2 inches per hour.

The operating levels in the twelve-inch sewer were calculated using a conservative estimate for the sewer velocity of 1 foot per second. The flow rates for the Thelmar weir are based on published manufacturer data. The summary of the flow rates and the projected reading errors, calculated based on the manufacturer published accuracy data is presented in Table 2-1.

The results indicate that for a rainfall of 0.1 inch per hour the reading error for the Area Velocity Flow Meter is significant. The data from Table 2-1 also indicate that the reading error decreases with increasing flow rates, for both meters.

The Thelmar weir in combination with the 950 Bubbler Flow Meter is recommended since it provided the lowest error throughout the operating range. The Thelmar Weir specification is provided in Appendix B.

2.3 Sampler Selection

The Sigma 900 MAX portable samplers were selected based on their versatility and because this sampler is routinely used by the MWRD. Each sampler will be connected to the 950 Bubbler flow meter for flow measurements in the twelve-inch sewer line. The Sigma 900 Max will also

TABLE 2-1
FLOW METER COMPARISON DATA
STICKNEY WATER RECLAMATION PLANT

		Area Velocity Meter in 12" Sewer				Thelmar Weir			
		Operating Level,	Reading Error,			Operating Level,	Reading Error,		
Rainfall, in/hr	Flow, gpm	ft	ft	gpm	Percent	ft	ft	gpm	Percent
0.10	13	0.079	0.070	19.9	153.2	0.121	0.011	3.6	28.1
0.16	20	0.106	0.070	21.8	109.0	0.141	0.011	3.5	17.7
0.40	50	0.199	0.070	26.6	53.3	0.210	0.011	5.2	10.4
0.80	100	0.325	0.070	30.1	30.3	0.297	0.011	9.7	9.7
1.20	150	0.441	0.070	31.4	20.9	0.356	0.011	13.3	8.9

R:\MWH\Upper Salt Creek Watershed\[Flow meter comparison.xls]HW record the water elevation within the porous pavement connected to the Sigma No. 77065-075 level transducer. The sampler will require the integral flow meter option in order to read the signal from the level transducer.

One sampler in each shed will be equipped with an input from a roof-top rain gauge.

The optional 12 VDC power supply will be used to power the samplers from the 115 VAC power. See Appendix C for detailed sampler specification.

2.4 Sequence of Operations

1. Sigma 950 bubbler flow meters will be connected to Thelmar Weirs located at the collection manholes from each permeable pavement evaluation area using 1/8" tubing.

2. Sigma 900 MAX portable samplers connected to Sigma 950 bubbler flow meters will monitor and sample the discharge from each permeable pavement area combined with any uncontrolled flow from the open sewer manhole. The samplers will be connected to inlet strainers using 3/8" tubing.

3. The samplers and flow meters will be located in two equipment sheds located in the east and west areas of the parking lot. The shed at the west parking lot will contain two samplers and three flow meters. The shed in the east parking lot will contain two samplers and four flow meters.

4. One sampler in each shed will have an input for connection of a roof-top rain gauge.

5. The samplers will also be connected to level transducers located in the gravel bed of each test area to collect the water level information. The samplers will not be controlled by this input.

6. The samplers and bubbler flow meters will be powered by 115 VAC power supplies provided by Sigma.

7. Scheduled site visits will insure proper working condition of the samplers and rain gauges.

8. Adequate supply of ice will be maintained in the samplers for sample preservation prior to the prediction of rain.

9. The sampler inlet strainer will be cleaned to insure proper sampler operation. Rope will be tied to the strainer and to the side of the manhole inlet to facilitate strainer removal for cleaning.

10. The sampling sequence will be initiated by flow (5 gallons per minute).

11. The samplers will also be programmed to take flow proportioned samples.

12. The collected composite samples will be analyzed using EPA approved methods. Additional grab samples may be collected manually for Fats Oils and Grease analysis.

13. The information on the rain, sewer flow, levels and sampling times will be uploaded to data transfer units (DTUs) after each rain event.

14. Suggested operating schedule for the monitoring program is March through October annually.

2.5 Equipment List and Cost Estimate

A complete equipment list is provided in Appendix D and the cost estimate is provided in Table 2-2.

2.6 Sampler Programming

The samplers are to be programmed for Flow Proportioned sampling, triggered by high flow condition in the sewer. The sampler will be programmed to collect four samples per bottle. The first bottle will be used as the ***first flush*** sample. The samples collected in bottles No. 2, 3 and 4 are to be composited representing the rest of the storm.

2.6.1 Basic Programming Setup

Sampling Trigger	High Flow
High Flow Trigger	5 Gallons Per Minute
Dead Band for Flow	2 Gallons Per Minute
Sample Type	Constant Volume / Variable Time
Sample Collection	Flow Proportional
Flow Pacing Mode	Constant Volume / Variable Time
Take Sample Every	1,250 gallons
Timed Override	12 Hours
Take First Sample	After First Interval
Sample Volume	1,000 ml

TABLE 2-2
COST ESTIMATE
STICKNEY WATER RECLAMATION PLANT

Quantity	Description	Cost
4	900 MAX Portable Samplers Including Power Supply, 100' Intake Tubing, Strainer, Integral Flow Meter with Depth Sensor and (4) 1 Gallon Sample Bottles.	$27,000
7	950 Bubbler Flow Meter with Power Supply and Bubbler Tubing	$29,000
7	12" Thelmar Weirs	$3,000
2	Catalog No. 2149 Rain Gauge with 25' Cable	$2,000
2	Catalog No. 3516 DTU-II data trasfer units w/cables	$2,000
1	Installation of hoses and cables	$3,000
1	Start-up and Training (Hach)	$6,000
	Subtotal	$72,000
	Contingency 15%	$11,000
Total:		$83,000

R:\MWH\Upper Salt Creek Watershed\[Cost estimate.xls]#1

7

04/22/08

- Intake rinses 1

2.6.2 Sample Distribution Setup

- Run Mode ....Run Continuously
- Deliver Samples to All Bottles? ....No
- Samples per Bottle ....Yes
- Number of Samples per Bottle 4

2.7 Sample Collection

1. Two samples will generally be submitted for laboratory analysis from each automatic composite sampler. Bottle No. 1 will contain the First Flush sample.

2. Bottles No. 2, 3, and 4 representing the rest of the storm will be manually composited prior to analyses. The composite sample would be combined proportional to the volume in each sample jar. For example, if Bottle 4 is only 50% full, the composite should represent 2 parts Bottles 2 and 3 and 1 part Bottle 4.

3. Additional grab samples may manually be collected for Oil and Grease analysis from the open manhole from each test area. The required sample preservation is cooling to 4 degrees C and pH adjustment to less than 2 using sulfuric acid. The samples will be submitted to laboratory for analysis using EPA method 1664A.

4. The other monitoring parameters will be obtained from the composite samples, which are divided into two groups. The first listing provides the parameters to be routinely monitored for each significant storm event:

Parameter	**Methodology**	**Preservation**	**Maximum Holding Times**
TSS	2540D	Cool to 4°C	7 days
pH	4500-H+B	Cool to 4°C	Within 15 minutes
COD	410.3	Cool to 4°C, H_2SO_4 to pH<2	28 days

5. In addition there is a group of parameters to be monitored on various sized storm events. This would include the following list:

Parameter	**Methodology**	**Preservation**	**Maximum Holding Times**
Ammonia	4500-NH_3-C	Cool to 4°C, H_2SO_4 to pH<2	28 days

Parameter	**Methodology**	**Preservation**	**Maximum Holding Times**
Nitrates	300.0	Cool to 4°C	48 hours
Nitrites	300.0	Cool to 4°C	48 hours
Chlorides	300.0	None	28 days
Dissolved reactive phosphorus	GLC	Cool to 4°C	48 hours
Total Phosphorus	4500-P F	Cool to 4°C, H_2SO_4 to pH<2	28 days
Zinc	200.8	HNO_3 to pH<2, 24 hours prior	6 months
Lead	200.8	HNO_3 to pH<2, 24 hours prior	6 months
Cadmium	200.8	HNO_3 to pH<2, 24 hours prior	6 months
Copper	200.8	HNO_3 to pH<2, 24 hours prior	6 months
Nickel	200.8	HNO_3 to pH<2, 24 hours prior	6 months
Polynuclear aromatic hydrocarbons	610	Cool to 4°C, 0.008% Na_2SO_3	7 days prior to Extraction, 40 days after extraction
Particle size	No EPA Method	No requirement	No requirement

It is anticipated that the above list would be analyzed on four storm events of varying intensities, ranging from less than 0.2 inches to greater than 1.0 inches.

6. The sample volume required to complete the indicated testing is four liters.

2.8 Data Analysis

Analysis of the collected data will include a comparison of the water quality and run-off volumes for the three types of porous pavement to values as discharged from the control pavement. The analysis will also include the quantifying of the run-on and run-off for each test area as provided below.

2.8.1 Correlation of Parameters

Sample and flow information will be uploaded into data transfer units (DTUs) from the samplers and flow meters after each rain event. As depicted on Figure 2-1, each permeable pavement test area is provided with two flow meters and one composite sampler. The control area is provided with one flow meter and one sampler.

The flow meters located at the *collection manholes* measure the flow from the permeable pavement test areas. The flow meters located downstream of the *discharge manholes* measure the flow from the permeable pavement area, combined with the uncontrolled flow entering through the open sewer manhole. For the vast majority of rainfall events, 100 percent of the flow is expected to pass through the porous pavement. Only when the rainfall intensity exceeds the infiltration rate capacity will storm water produce surface runoff.

A larger flow rate measured at the *discharge manhole* compared to the *collection manhole* indicates the entrance of uncontrolled storm water flow at the open sewer manhole. For those cases, the measured water quality values for the combined flow can be used to estimate the water quality as discharged through the permeable pavement test area using the difference in the measured flows at the *discharge* and *collection manholes.*

The volume of flow from each flow meter will be calculated by integrating the flow information over the entire sampling period: $V_1*t_1 + V_2*t_2 + \ldots\ldots V_x*t_x =$ total volume of flow, where t_x is the length of the flow sampling interval and V_x is the flow rate recorded over the interval. The volume V_1 indicated by flow meter FM-1 on Figure 2-1 provides the flow discharged from the permeable pavement test surface. The volume V_2 indicated by flow meter FM-2 provides the flow from the test area combined with the flow from the open cover at the *discharge manhole.* The flow meter FM-3 provides the flow from the control test plot.

Using the measured water quality concentration from the combined flow C_2 and the measured concentration from the control test plot C_3 we can estimate the concentration as discharged through the permeable pavement test plot C_1:

$$C_1 = \frac{V_2 * C_2 - (V_2 - V_1) * C_3}{V_1}$$

where:

V_1 – Volume of flow from the permeable pavement test area (cubic feet)
V_2 – Total accumulated volume of combined flow (cubic feet)
C_1 – Adjusted parameter for the test area (mg/L)
C_2 – Measured concentration of combined flow (mg/L)
C_3 – Measured concentration from the control test surface (mg/L)

2.8.2 Quantifying Run-on

Each of the three permeable paving areas and the control area have small areas of run-on. As opposed to constructing barriers to route this run-on away from or around the plots, Table 2-3 quantifies the square footages of run-on and cover type for each area of run-on. In addition, the table includes the square footages of the permeable paving plots and the control area. These areas and cover types, in conjunction with the NRCS Curve Number method or the Runoff Coefficient method, can be used to estimate the fraction of precipitation that is converted to runoff. If the

conversion sqft to sq m
0.0929

TABLE 2-3
STICKNEY WATER RACLAMATION PLANT
TRIBUTARY AREAS TO MONITORING PLOT

Monitoring Plot	sq m.	Paving, sf	sq m	Impervious Run-on, sf		Pervious Run-on, sf
Porous Asphalt Paving	1311.3	**14,115**	30.6	**329**	sq m.	**0**
Pervious Concrete Paving	1060.3	**11,413**	335.7	**3,614**	538.8	**5,767**
Prous Unit Paving	1215.8	**13,087**	38.3	**412**	0	**0**
Conventional Asphalt Paving, (control)		**14,050**		**311**		**0**

R:\MWH\Upper Salt Creek Watershed\[run-on.xls]Sheet1

Runoff Coefficient method is used, initial abstractions of 0.2" and 0.02" should be used for pervious and impervious areas, respectively. Initial abstraction is the rainfall depth (or volume when the area is known) required for a surface to produce runoff. This volume of water can then be compared to the flow measurements to determine the volume of runoff lost to subgrade soil infiltration and evaporation, which can then be used to develop Curve Numbers or Runoff Coefficients for the three types of permeable pavements.

2.9 Infiltration Measurement

To gather infiltration measurements through the surface of the permeable pavements, infiltration measurements should be taken every two months (March through November). The infiltration measurements should be taken in accordance with ASTM D 3385-03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, as modified by the following. The inner ring of the double-ring infiltrometer shall be used alone, without the outer ring. The inner ring shall be mounted on a plywood base plate with a 12-inch diameter hole. The gaps between the inner ring and plywood base shall be filled with silicone caulk. A 1-inch thick foam strip shall be attached to the bottom of the plywood base immediately outside the circumference of the hole. The corners of the plywood base shall be weighted to create a seal between the plywood base and the permeable pavement.

APPENDIX B

FLOW METER SPECIFICATIONS

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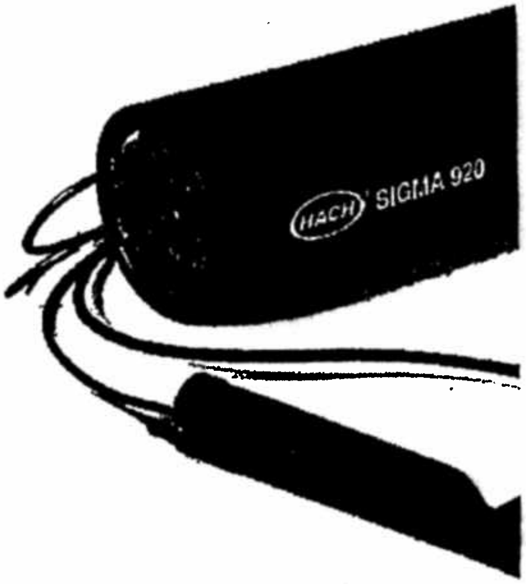
Sigma 920 Area VelocityFlow Meter Specifi

Model Sigma 920 Area Velocity Flow Meter



Specifications General:

- **Dimensions:** 6.625" dia. x 17.625" L (16.8 cm dia. x 44.7 cm L)
- **Weight:** 16.5 lbs. (7.5 kg) with battery.
- **Enclosure Material:** PVC
- **Operating Temperature Range:** 0° o 140°F (-18° to 60° C).
- **Storage Temperature Range:** -40° o 140°F (-40° to 60°C).
- **Power Source:** Two (6V) Alkaline Lantern Batteries.
- **Battery Life:** 90 days typical with a 15-minute recording interval. 1 level and 1 velocity, data download once per week, 50° F/10° C, also affected by site conditions
- **User Interface:** IBM compatible PC.
- **Monitoring Intervals:** 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, 60-minutes.
- **Program Memory:** Non-volatile, programmable flash, can be updated via RS-232 port.
- **Time Based Accuracy:** ±1 second per day.

Units of Measurement:

- **Level:** in., m, cm, ft.
- **Flow:** GPS, GPM, GPH, LPS, LPM, LPH, MGD, AFD, CFS, CFM, CFH,

CFD, M3S, M3M, M3H, M3D.
- **Totalized Flow:** gal., ft.³, acre-ft., L, m³.

Data StorageCapacity (optional):

- 240 days of 2 level readings, 2 velocity readings and rain at a 15-minute recording interval
- **Data Types:** Level, velocity and rainfall
- **Storage Mode:** Wrap or slate.

Sampler Output Conditions (optional):

- Set point on level, velocity, rainfall, flow, or flow rate of change

Sampler Output (optional):

- 6 - 12 VDC pulse, 100mA max. at 500 ms duration flow proportional.

Communications:

- RS-232 serial connection to IBM-compatible computer with American Sigma Data Management Software
- Optional Modem: Bell 212
- Baud: 14400
- Transfer protocol: Binary -OR- 14400, V.32bis, V.42, MNP2-4 error correction. V.42, MNP5 data compression. MNP10EC Cellular Protocol
- Local Terminal: RS-232 at 19.2k baud

Submerged Depth / Velocity Measurement Accuracy:

- ± .007 m) ;
- Extended: .018' to 34.6' ft. ± .07' ft. (.005 m - 10.5 m ± .021 m)
- Compensated Temperature Range:

32° to 86°F (0 to 30°C).
- Temperature Error: .018 - 11.5 ft. ±.004' ft./°F (.005 - 3.5 m ± .0022 m/°C). .018' - 34.6' ft. ± .012 ft./°F (.018 - 10.5 m ± .006 m/°C) (maximum error within compensated temperature range - per degree of change).
- Velocity Induced Error on Depth (patent pending): 0' to 10' ft/sec. (0 to 3.05 m/s) = .085% of reading.
- Air Intake: Atmospheric pressure reference is desiccant protected.

Velocity Measurement:
Method: Doppler ultrasonic.

- Transducer Type: Twin 1 MHz piezoelectric crystals.

Level Measurement:
Level Measurement (non-linearity and hysteresis):

- *Standard* : .018' to 11.5' ft. ± .023' ft. (.005 m - 3.5 m
- Typical minimum depth *for* velocity: 0.8" in. (2 cm).
- Range: -5 to 20 fps (-1.52 to 6.10 m/s).
- Zero Stability: <0.05 fps. (.015 m/s).
- Accuracy: ±2% of reading.
- *Operating Temperature:* 0° to 140°F (-18° to 60° C).

General:

- Material: Polymer body with stainless steel diaphragm.
- **Cable:** Urethane sensor cable with air vent.
- *Cable Length:* 25' (7.6 m) standard. 250' (76 m) maximum.
- Dimensions (combination sensor): 0.8" H x 1.5" W x 5" L (2 cm x 3.8 cm x 12.7 cm).

Velocity Sensor:

- Dimensions: .44" H x 1.5" W x 2.7" L, (1.12 cm H x 3.81 cm W x 6.86 cm L)

Ultrasonic Level Sensor (In-Pipe):

- Accuracy: At 72°F (22° C) still air, 40-70% relative humidity from .125 to 15' ±.01', (.038 to 4.57 m ± .003 m)

Note: Specifications are subject to change without notice.

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» SIGMA 920 Area Velocity Flow Meter

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SIGMA 950 Bubbler Flow Meter

Specifications

Sigma 950 Series Flow and Water Quality Meter

General:

- **Dimensions:** 13.5" H x 10.0" W x 9.5" D, (34.3 cm x 25.4 cm x 24.1 cm)
- **Weight:** 15 lbs. (6.8 kg) including power source
- **Enclosure Material:** ABS, UV resistant, stable from -40° to 176°F (-40°C to 80°C)
- **Enclosure Rating:** NEMA 4X,6 with front cover open or closed
- **Operating Temperature Range:** +14° to 150°F, (-10°C to 65.5°C)
- **Storage Temperature Range:** -40° to 176°F, (-40°C to 80°C)
- **Power:** 12 VDC
- **Power Options:** 6 amp-hr. gel electrolyte rechargeable battery, 4 amp-hr. Ni-Cad rechargeable battery, lantern battery case with (2) 6-Volt lantern batteries, 115 VAC, 230 VAC or 100 VAC power converter w/battery charger
- **Graphics Display:** Back lit LCD, auto-off when not in use. 8 line x 40 character in ASCII mode, 60 dot x 240 dot in graphics mode. Dimensions 1.5" H x 5" W (3.8 cm x 12.7 cm); displays level vs. time, flow vs. time. Optionally, may display rainfall, pH, ORP, temperature, DO, conductivity vs. time, sampler events and alarm events
- **Keypad:** 21 position sealed membrane switch with blinking green LED to indicate power on; 4 "soft keys", functions defined by display
- **Totalizers:** 8-digit resettable and 8-digit nonresettable LCD software totalizer; 6-digit nonresettable mechanical totalizer optional
- **Time Based Accuracy:** ±1 second per day
- **Battery Life:** 150 days typical with a 15 minute recording interval, 1 level and 1 velocity, data download once per week, at 50°F (10°C) (also affected by site conditions)

Units of Measurement:

- **Flow:** GPS, GPM, GPH, LPS, LPM, LPH, MGD, AFD, CFS, CFM, CFH, CFD, CMS, CMM, CMH, CMD
  Totalized Flow: gal., ft.3, acre-ft., lit., m3.

Primary Devices:

- **Flumes:** Parshall, Palmer Bowlus, Leopold-Lagco, H, HL, HS, Trapezoidal
- **Weirs:** V-notch (15 - 120°) Contracted/Non-contracted rectangular, Thelmar, compound Cipolletti
  Manning Equation: Round, U and Rectangular Trapezoidal Channels

- **Flow Nozzles:** Kennison, Parabolic, California Pipe Head vs. Flow: Custom programmable curve of up to 99 points

Datalogging:

- **Capacity:** Up to 512k bytes: 402 days of level, velocity and rainfall readings at 15 minute intervals plus 300 events
- **Monitoring Intervals:** 1, 2, 3, 5, 15, 30 or 60-minute intervals
- **Program Memory:** Non-volatile, programmable flash; can be updated via RS-232 port

Sampler Output:

- 12-17 VDC pulse, 100 mA max at 500 ms duration

Communications:

- **RS-232:** up to 19,200 baud SCADA Modbus communication protocol via RS-232 or optional modem
- **Modem (optional):**14,400 baud
- **Cellular Communications (optional):** 14,400 bps, MNP 10-EC Cellular Protocol
- Pager Alarms

Sigma 950 Bubbler:

- **Level Measurement Accuracy:** (linearity and hysteresis at 72°F, 22°C) from .01 to 11.75' - ±0.011' (±0.003m) Range: .01 to 11.75', (.003 - 3.6 m)
- **Ambient Operating Temperature Range:** 0° to 145°F, (-18° to 63°C)
- **Compensated Temperature Range:** 32° to 138°F ,(0° to 59°C)
- **Temperature Error:** ±.0003'/°F (maximum error within compensated temperature range - per degree of change)
- **Air Intakes:** Bubble source and reference port desiccant protected. Fittings provided for remote intakes
- **Filters:** 10 micron on bubble source intake Line Purge: Bubble line is high pressure purged at programmed intervals, or in manual mode on demand
- **Line Size:** 1/8", (.32 cm) ID standard

950 Ultrasonic:

50 kHz Ultrasonic Transducer:

- **Level Measurement Accuracy:** (at 72°F, 22°C, still air, 40 - 70% relative humidity) from 1 to 10' ± .01'.)(±.003 m)
- **Range:** Minimum distance from sensor to liquid 15" (38.1 cm). Maximum distance from sensor to liquid 30' (9.1 m)
- **Span:** 50kHz, 0 - 29'
- **Ambient Operating Temperature Range:** 0° to 140°F, (-18° to 60°C)
- **Temperature Error:** ±.000047'/F° (maximum error within compensated temperature range - per degree of change)
- **Resolution:** .0011'
- **Material:** PVC housing with Buna-N acoustic window
- **Cable:** 4 conductor with integral stainless steel support cable
- **Cable Length:** 25' (7.6 m) standard
- **Crystal Specification:** 50 kHz, 11.5° included beam angle
- **Dimensions:** 3.75" H x 2.75" D, (9.5 cm x 7 cm)
- **Weight:** 1.5 lbs.

75kHz Ultrasonic Transducer:

- **Level Measurement Accuracy:** (at 72°F, 22°C, still air, 40 - 70% relative humidity) from 1 to 10'. ± .01')(±.003 m)
- **Range:** Minimum distance from sensor to liquid 14". (23 cm). Maximum distance from sensor to liquid 1' (3.3 m)
- **Span:** 0 - 15'
- **Ambient Operating Temperature Range:** 0° to 140°F, (-18° to 60°C)
- **Temperature Error:** ±.000047'/F° (maximum error within compensated temperature range - per degree of change)
- **Resolution:** .0011'
- **Material:** PVC housing with Buna-N acoustic window
- **Cable:** 4 conductor with integral stainless steel support cable
- **Cable Length:** 25' (7.6 m) *standard*
- **Crystal Specification:** 5° beam angle with horn
- **Dimensions:** 75 kHz, 5.0" H x 2.25" D, (12.7 cm x 5.7 cm)
- **Weight:** 1.5 lbs.

In-Pipe Ultrasonic:

75 kHz Ultrasonic Level Sensor (In-Pipe):

- **Accuracy:** At 72°F (22°C), still air, 40-70% relative humidity from .125 to 15' - ±.01' (.038 to 4.57 m ±.003 m)
- **Range:** 0" (0 cm) - 11' (3.35 m)
- **Span:** .125 - 15', (.038 - 4.57 m)
- **Ambient Operating Temperature:** 0 to 140°F, (-18 to 60°C)
- **Temperature Error:** ±.0001'/°F (±.00005 m/°C) (maximum *error within compensated temperature range - per degree of* change)
- **Resolution:** .0075" (.019 cm)
- **Material:** Stainless steel housing with Buna-N acoustic window
- **Cable:** 4 conductor
- **Cable Length:** 25' (7.6 m) standard, 1000' (305 m) using RS-485 two wire remote sensor option
- **Crystal Specification:** 75 kHz, 7° included beam angle
- **Dimensions:** 2.0" diameter x 12" L (3.81 x 30 cm)

950 Submerged Pressure:

- **Level Measurement Accuracy:**(non-linearity and hysteresis) ±0.1% full scale
- **Transducer Type:** Differential piezo resistive with balanced bridge
- **Transducer Orientation:** Inverted
- **Maximum Range:**
  - **P/N 2963:** 2.5 psi .04 - 5.75', (.01 m - 1.75 m)
  - **P/N 2343:** 5.0 psi .04 - 11.75', (.01 m - 3.58 m)
  - **P/N 2333:** 10.0 psi .04 - 23', (.01 m - 7.0 m)
  - (Maximum Allowable Level: 6x over pressure)

- **Operating Temperature Range:** 32° to 160°F, (0 to 71°C)
- **Compensated Temperature Range:** 32° to 96°F, (0 to 36°C)
- **Temperature Error:**
  - **P/N 2963:** .04 to 5.75' ±.006'/F°
  - **P/N 2343:** .04 to 11.75' ±.0012'/F°
  - **P/N 2333:** .04 to 23' ±.0024'/F°
  - (Maximum error within compensated temperature range - per degree of change)

- **Air Intake:** Atmospheric pressure reference is desiccant protected
- **Material:** 316 stainless steel body with titanium diaphragm
- **Cable:** 4 conductor polyurethane sensor cable with air vent
- **Cable Length:** 25' (7.6 m) standard. 250' (76 m) maximum
- **Dimensions:** 1" D x 6.75" L, (2.54 cm x 17.2 cm)
- **Probe Frontal Area:** 0.875 in2.
- **Weight:** 1.5 lbs.

950 Area x Velocity:

Submerged Depth/Area Velocity Sensor:

- **Method:** Doppler Principle/Pressure Transducer
- **Level Measurement(non-linearity and hysteresis):**
  - **Standard:** .018 to 11.5'. ±.023' (.005 m - 3.5 m ±.007 m)
  - **Extended:** .018 to 34.6' ± .07' (.005 - 10.5 m ± .021 m)

- **Maximum Allowable Level:** 3x over pressure
- **Operating Temperature Range:** 32 to 160°F, (0 to 71°C)
- **Compensated Temperature Range:** 32 to 86°F, (0 to 30°C)
- **Temperature Error:** .018 - 11.5'. ±.004'/°F (.005 m - 3.5 m ± .0022 m/°C). .018 - 34.6' ±.012'/°F (.018 - 10.5 m ±.006 m/°C) (maximum error within compensated temperature range - per degree of change)
- **Velocity Induced Error on Depth (patent pending):** 0 to 10'/sec. (0 to 3.05 m/s) = .085% of reading.
- **Air Intake:** Atmospheric pressure reference is desiccant protected

Velocity Measurement:

- **Method:** Doppler Ultrasonic
- **Transducer Type:** Twin 1 MHz piezoelectric Crystals
- **Typical minimum depth for velocity:** 0.8" (2 cm)
- **Range:** -5 to +20 fps (-1.52 to 6.10 m/s)
- **Zero stability:** <.05 fps (.015 m/s)
- **Accuracy:** ±2% of reading
- **Operating Temperature:** 0 to 140°F, (-18 to 60°C)

General:

- **Material:** Polymer body with stainless steel diaphragm
- **Cable:** Urethane sensor cable with air vent.
- **Cable Length:** 25' (7.6 m) standard. 250' (76 m) maximum
- **Dimensions (combination sensor):** .8" H x 1.5" W x 5" L, (2 cm x 3.8 cm x 12.7 cm)

Bubbler Level/Area Velocity Sensor:

- **Method:** Doppler Principle/Pressure Transducer
- **Level Measurement:** (linearity and hysteresis at 72°F, 22°C): from .01 to 11.75' - ±0.011' (.033 m)
- **Range:** .01 to 11.75' (.003 - 3.6 m)
- **Ambient Operating Temperature Range:** 0 - 145°F, (-18 - 63°C)
- **Compensated for changes in ambient Temperature Range:** 32 - 138°F (0 - 59°C)
- **Temperature Error:** ±.0003'/°F (maximum error within compensated temperature range - per degree of change)

- **Air Intakes:** Bubble source and reference port desiccant protected. Fittings provided for remote intakes
- **Filters:** 10 micron on bubble source intake
- **Line Purge:** Bubble line is high pressure purged at programmed intervals, or in manual mode on demand

Velocity Measurement:

- **Method:** Doppler Ultrasonic
- **Transducer Type:** Twin 1 MHz piezoelectric CrystalsTypical minimum depth for velocity: 0.8" (2 cm)
- **Range:** -5 to +20 fps (-1.52 to 6.10 m/s)
- **Zero stability:** <.05 fps (.015 m/s)
- **Accuracy:** ±2% of reading
- **Operating Temperature:** 0 to 140°F, (-18 to 60°C)

General:

- **Cable Length:** 25' (7.6m) standard, 250' maximum
- **Cable Diameter:** 0.4" (1cm)
- **Dimensions (combination sensor):** 0.8" H x 1.5" W x 3.7" L, (2 cm x 3.8 cm x 9.7 cm)

Velocity Sensor:

- **Method:** Doppler Principle
- **Accuracy:** ±2% of reading;
- **Zero Stability:** ±0.05 fps (±1.52 cm)
- **Dimensions:** .44" H x 1.5" W x 2.7" L, (1.12 cm x 3.81 cm x 6.86 cm)
- **Nose Angle:** 20 deg from horizontal
- **Cable Length:** Standard range probe - 25' (7.6 m); custom cable lengths to 250' (76 m); cable diameter - .225" (.57 cm)

Materials:

- **Sensor:** Polymer;
- **Cable:** Urethane;
- **Sensor Mounting Hardware:** Stainless steel
- **Dimensions:** 0.5"H x 1.5" W x 3.7"L (1.5 cm x 3.8 cm x 9.7 cm)

American Sigma 950 Series Flow and Water Quality Meter Factory Installed Options:

pH-Temperature/ORP Meter:

- **Control/Logging:** Field selectable to log pH-Temperature or ORP independent of flow or in conjunction with flow; also controls sample collection in response to value exceeding low/high set points
- **Recording Intervals:** 1, 2, 3, 5, 6, 10, 12, 15, 30, and 60 minutes
- **Probe Pre-Amplifier/Junction Box:** NEMA 4X with labeled terminal strip
- **pH/Temperature Sensor:** Temperature compensated; impact resistant ABS plastic body; combination electrode with porous Teflon® junction
- **Measurement Range:** 2 to 12 pH within specifications, 0 to 14 pH maximum range
- **Operating Temperature Range:** 0 to 176°F, (-18°C to 80°C)
- **Dimensions:** 0.75" diameter x 6" long with .75" mpt cable end (1.9 cm x 15.2 cm long with1.9 cm mpt cable end)

Integral Dissolved Oxygen / Temperature Meter:

- **Control/Logging:** Field selectable to log dissolved oxygen independent of flow or in conjunction with flow; also controls sample collection in response to value exceeding low/high set points
- **Recording Intervals:** 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, and 60 minutes
- **Measurement Method:** Polargraphic
- **Sensor:** Temperature compensated; impact resistant polypropylene body
- **Range:** 0-20 mg/L
- **Resolution:** .01 mg/L
- **Accuracy:** ±0.2 mg/L
- **Operating Temperature Range:** 32 to 122°F, (0 to 50°C)
- **Dimensions:** 0.65" diameter x 5" long with .75" mpt cable end, (1.65 cm diameter x 12.7 cm long with 1.9 cm mpt cable end)

Integral Conductivity / Temperature Meter:

- **Control/Logging:** Field selectable to log conductivity independent of flow or in conjunction with flow, also controls sample collection in response to value exceeding low/high set points
- **Recording Intervals:** 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, and 60 minutes
- **Sensor:** Temperature compensated; impact resistant polypropylene body
- **Range:** 0-20 mS/cm
- **Resolution:** 0.01 mS/cm or 0.01 µS/cm (user selected)
- **Accuracy:** ±1% of reading +0.05 mS/cm
- **Operating Temperature Range:** 32 to 122°F, (0 to 50°C)
- **Dimensions:** 0.67" diameter x 5" long with .75" mpt cable end, (1.70 cm diameter x 12.7 cm long with 1.9 cm mpt cable end)

Rain Gauge Input:

- For use with American Sigma Tipping Bucket Rain Gauge. Flow Meter records rainfall data in 0.01" increments. Flow measurement can be initiated based upon field selectable rate of rain.

Analog Input Data-logging Channels:

- Up to seven additional data-logging channels record data from external sources; field assignable channel name(s) and units; - 4 to +4 VDC 0 - 20 mA, ±0.5% full scale voltage accuracy, ±0.2% full scale 4-20 mA accuracy with 200 ohm impedance

4 - 20 mA Outputs:

- Up to 2 integral field assignable outputs, optically isolated, up to 600 ohm load, per output 0.1 % FS error.

Mechanical Totalizer:

- 6-digit non-resettable mechanical totalizer; selectable units: gal., lit., ft.3, m3, acre-ft.

Alarm Relays:

- Up to 4 integral alarm relays, 10 amp, Form C, user assignable to any internal or external data channel.

Modem:

- 14,400 baud rate, CRC auto to check sum, FCC approved, cellular compatible.

Expanded Memory:

- Increase memory from 18,432 data points to 116,736 data points.

AC Power Backup:

- Provides power in the event of an AC power failure; internal trickle charger maintains 6 amp-hour battery.

Note: Specifications are subject to change without notice.

Note: Teflon is a registered trademark of E.I. Dupont de Nemours Inc.

MAIN PRODUCT PAGE

» SIGMA 950 Bubbler Flow Meter
» SIGMA 950 Bubbler, Area Velocity Flow Meter
» SIGMA 950 Submerged Pressure Flow Meter
» SIGMA 950 Submerged Pressure Area Velocity Flow Meter
» SIGMA 950 50 kHz Ultrasonic Area Velocity Flow Meter
» SIGMA 950 75 kHz Ultrasonic Flow Meter
» SIGMA 950 Optiflo Area Velocity Flow Meter
» SIGMA 950 Optiflo Flow Meter
» SIGMA 950, 75 kHz Ultrasonic Area Velocity Flow Meter
» SIGMA 950 50 kHz Ultrasonic Flow Meter

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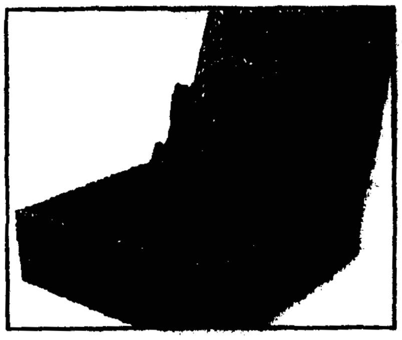
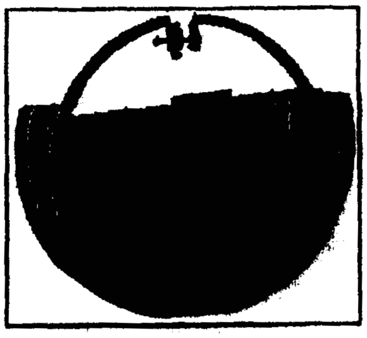
APPENDIX C

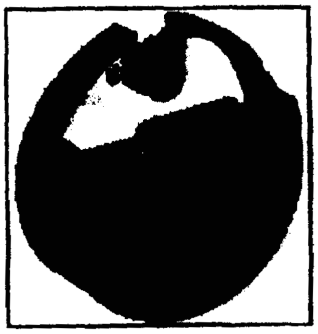
THELMAR WEIR SPECIFICATIONS

VOLUMETRIC WEIRS

For measuring flows in Manholes and Open End Pipes


WEIR SET
(refer to back page for details)


18" WEIR WITH 18" ADAPTER


WEIR WITH BUBBLER TUBE

The most practical, economical instrument for testing new sewer lines - night flow studies of existing lines – free flow from open end pipe.

A VOLUMETRIC calibrated weir is a portable flow measuring device that is used to determine infiltration in newly installed sewer lines, or measure substantial flows in existing lines.

THE THEL-MAR VOLUMETRIC weir is basically a compound weir that incorporates the advantage of a 90° V-notch for measuring small infiltration flow where accuracy is of prime importance. The V-notch section measures from 57 gallons to 3700 gallons per 24 hours, which is the range of normal Acceptance Test Requirements. The rectangular section of the weir is capable of measuring in gallons per day up to 35% of pipe capacity.

A BUBBLE LEVEL is mounted at the top of the weir's face plate for easy visibility. Thel-Mar weirs are calibrated in U.S. GALLONS PER 24 HOURS (METRIC WEIRS CUBIC METERS PER HOUR) in large, easy to read type. Calibration lines are in 2 millimeter increments.

DISCHARGE CALIBRATIONS for the Volumetric Weir were accurately determined in a hydraulic laboratory where manhole conditions were duplicated. Therefore, there are no induced errors by insufficient drop of the nappe or by contractions, velocity of approach, submergency, or drawdown.

RUGGED CONSTRUCTION and noncorroding materials make the Thel-Mar weir extremely reliable. There are no loose parts that require assembly. Installation is quick and positive and the weir requires a minimum of care.

A COMPOUND WEIR offers minimum restriction to flow and is relatively free from becoming clogged by debris from sewage. Thel-Mar weirs can be installed for extended periods of time without accumulation of sediment.

ERRORS IN EXCESS OF 100% exist in other calibrated V-notch weirs. Unlike the Thel-Mar weir these were calibrated by the cone formula.

EASY TO READ FLOW RATE Simply check water level at the face plate. The figure above the line matching the water level gives you the rate of flow in GALLONS PER 24 HOURS (METRIC WEIRS-CUBIC METERS PER HOUR).

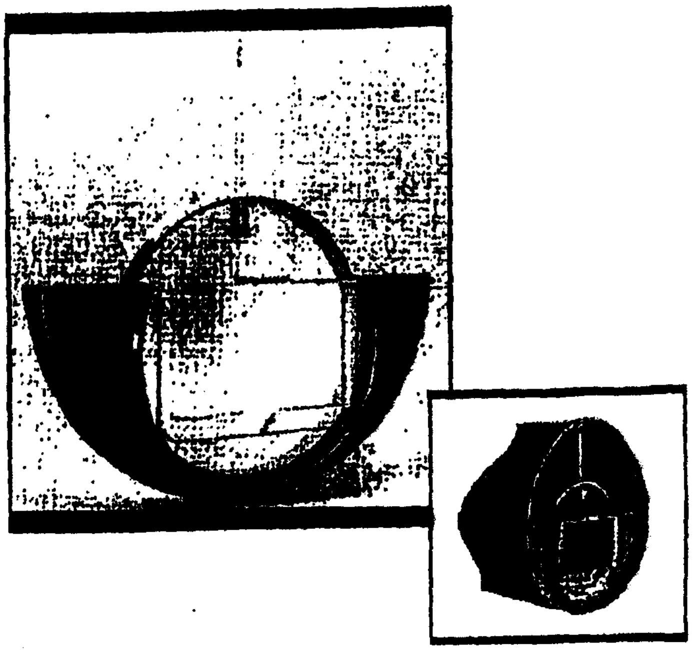
BUBBLER FLOW METERS Especially designed for use with Bubbler Flow Meters, all Volumetric Weirs are now available with an attached "Bubbler Tube". These weirs are manufactured with a 1/8 inch O.D. stainless steel tube attached to the right side of the adjustable ring. The bubbler tube protrudes forward approximately two inches from near the top of the ring for easy connection to a line. It runs from there down the inside of the ring to approximately 1 3/8-inch behind and below the V-notch. This bubbler tube does not in any way affect the function of the Volumetric Weir.

INSTALLATION INSTRUCTIONS Prior to installation, the interior edge of the incoming pipe should be cleared of sediment and foriegn matter to assure seal of the gasket.

Turn thumb-wheel to extreme right. Place hand through weir opening, wiht thumb and index finger compress spring. Insert weir into incoming pipe about 1", and release tension from spring. Secure by turning thumb-wheel to left and finger tighten.

Allow sufficient time for water to back up and behind the weir and establish a uniform flow; five to ten minutes for existing flow to an hour for accurate infiltration readings.

15" WEIR WITH ADAPTOR INSTALLED IN 24" PIPE



Individual Volumetric Weirs are available for 6", 8", 10", 12", 14", 15" and 16" pipe. The 14" weir uses a 12" face plate. Adaptors for 18", 21", 24", 27", 30", 36", 42" and 48" pipe are used in conjunction with the 15" weir.

Volumetric Weirs are also available in a set. Set A consists of 6", 8", 10', 12" and 15" weirs with an 18" adaptor and carrying case with handle and hasp. It measures 191/2"W x 191/2"D x 71/2"H. Set B is similar and designed to be used with Bubbler Flow Meters.

Adaptors are available individually or in a set. Set C consists of 21" through 48" adaptors. No carrying case included.

WEIR CAPACITIES AND HEAD

CAPACITIES*			HEAD**
6"	57 to 3700 GPD within V-notch,	rectangular to 46,000 GPD	2.8437
8"	57 to 3700 GPD within V-notch,	rectangular to 124,000 GPD	4.0000
10"	57 to 3700 GPD within V-notch,	rectangular to 234,000 GPD	5.1250
12"	57 to 3700 GPD within V-notch,	rectangular to 361,000 GPD	5.8125
14"	57 to 3700 GPD within V-notch,	rectangular to 361,000 GPD	5.8125
15"	57 to 3700 GPD within V-notch,	rectangular to 610,000 GPD	7.3125
16"	57 to 3700 GPD within V-notch,	rectangular to 610,000 GPD	7.3125
Bulkhead Weir	57 to 3700 GPD within V-notch,	rectangular to 610,000 GPD	7.3125

* Calibration lines are in 2 millimeter increments.
** In inches from top of rectangular opening to bottom of V-notch.

PARSON
ENVIRONMENTAL

Parson Environmental Products, Inc. * P.O. Box 4474 * Reading, PA 19606
Toll Free: (800) 356-9023 * Voice: (610) 582-6060 * Fax: (610) 582-6064
WEB SITE: www.parsonenvironmental.com

APPENDIX D

SIGMA 900 MAX PORTABLE SAMPLER SPECIFICATIONS

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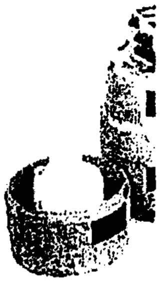
SIGMA 900 MAX Portable Sampler

Sigma Portable Sampler Specification



Model 900 Portable Sampler Specifications

General Specifications:

Dimensions:

- Compact Base - Diameter 17-3/8" (44.1 cm), Height 24" (61 cm).
- Standard Base - Diameter 19-7/8" (50.1 cm), Height 27-3/16" (69.4 cm).

Sample Pump:

- High speed peristaltic, dual roller, with 3/8" (.95 cm) ID by 5/8" (1.6 cm) OD pump tube.

Pump Body:

- High impact, corrosion resistant, glass reinforced Delrin*.

Vertical Lift:

- 27 ft. (8.2 m) maximum (note: Remote Pump Option recommended for lifts from 22 ft. (6.7 m) to 35 ft. (10.7 m).

Sample Transport Velocity:

- 2 ft./sec. (.6 m/sec.) minimum at 15 ft. (4.6 m) vertical lift in a 3/8" (.95 cm) ID intake tube.

Pump Flow Rate:

- 60 ml/sec at 3 ft. vertical lift in a 3/8" (.95 cm) ID intake tube.

Liquid Sensor:

- Single sensor, non-contact.

Sample Volume:

- Programmed in milliliters, in one ml increments from 10 to 9,999 ml.

Sample Volume Repeatability:

- ±5% typical.

Sample Bottle Capacity:

- **Composite:** 2.5 gal. glass, 3 gal. polyethylene, 4 gal. polyethylene, 5.5 gal. polyethylene, and 6 gal. polyethylene. **Multiple Bottle:** (2) 1 gal. glass, (2) 1 gal. polyethylene, (4) 1 gal. glass, (4) 1 gal. polyethylene, (8) 950 ml glass, (8) 1.9 liter glass, (8) 2.3 liter polyethylene, (12) 950 ml glass, (24) 350 ml glass, and (24) 575 ml polyethylene and (24) 1 liter polyethylene.

Sampling Modes:

- Multiple Bottle Time,
- Multiple Bottle Flow,
- Composite Time,
- Composite Flow,
- Flow with Time Override,
- Variable Interval,
- Start/Stop,
- Level Actuation.

Interval Between Samples:

- Selectable in single increments from 1 to 9,999 flow pulses (momentary contact closure 25 msec. or 5-12 VDC pulse; 4-20 mA interface optional), or 1 to 9,999 minutes in one minute increments.

Multiplex:
Multiple Bottle Mode:

- multiple samples per bottle and/or multiple bottles per sample collection.

Intake Purge:

- Air purged automatically before and after each sample; duration automatically compensated for varying intake line lengths.

Pump/Controller Housing:

- High impact injection molded ABS; submersible, watertight, dust tight, corrosion & ice resistant; NEMA 4X,6.

Control Panel:

- 18 key membrane switch keypad; 24 character alphanumeric liquid crystal display.
- **Internal Clock:** Indicates real time and date; 0.007% time base accuracy.
- **Diagnostics:** Tests RAM, ROM, pump, and distributor.
- **Program Delay:** Sampler start at time of day or delay in minutes.
- **Manual Sample:** Initiates a sample collection independent of program in progress.
- **Intake Rinse:** Intake line automatically rinsed with source

liquid prior to each sample, from 1 to 3 rinses.

- **Intake Fault:** Sample collection cycle automatically repeated from 1 to 3 times if sample not obtained on initial attempt.
- **Multiple Programs:** Stores up to five sampling programs.
- **Cascade:** Allows using two samplers in combination where the first sampler at the completion of the program initiates the second.
- **Data Logging:** Records program start time and date, stores up to 400 sample collection times/dates, all program entries, operational status including number of minutes or pulses to next sample, bottle number, number of samples collected, number remaining, sample volume collected, volume remaining, sample identification number.

Status Output:

- Low main battery,
- Low memory power
- Plugged intake
- Jammed distributor arm
- Sample collected
- Purge failure.

Automatic Shutdown:

- **Multiple Bottle Mode:** After complete revolution of distributor arm (unless Continuous Mode selected).
- **Composite Mode:** After preset number of samples have been delivered to composite container, from 1-999 samples, or upon full container.
- **Program Lock:** Access code protection precludes tampering.
- **Intake Tubing:** 3/8" ID vinyl.1/4" ID vinyl.3/8" ID Teflon and polyethylene.
- **Intake Strainer:** Teflon® and 316 stainless construction.All 316 stainless steel in standard size and low profile for shallow depth applications.
- **Sampler Case:** High impact ABS, 3 section construction; double walled insulated base.

Power Requirements:

- **12 VDC** (supplied by 12 VDC battery or AC adapter).
- **Optional AC Power Backup:** Rechargeable 6 Amp-hour gel lead acid battery takes over automatically with AC line power failure. Integral trickle charger maintains battery at full charge.
- **Internal Battery:** 5 year lithium battery maintains program settings and real time clock.
- **Overload Protection:** 5 amp DC line fuse 1 amp DC line fuse (AC power converter).

Temperature Range:

- **General use:** 32° to 120°F (0° to 49°C)
- **Liquid Crystal Display:** Operating - 14° to 158°F (-10° to 70°C)
- **Storage:** -40°F to 176°F (-40° to 80°C).

Note: Specifications are subject to change without notice.

MAIN PRODUCT PAGE

- SIGMA 900 MAX Portable Sampler
- 900 MAX Portable (Controller Only)

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APPENDIX E

EQUIPMENT LIST

EQUIPMENT LIST

PERMEABLE PAVEMENT MONITORING PLAN
MWRDGC, STICKENY PLANT

The following is the equipment list for the Permeable Pavement Monitoring Plan for the Stickney plant:

1) Qty. 7 – 950 Sigma Bubbler flow meter, (Catalog No. 2672). Each with:
    - a) 100 feet tubing 1/8" ID (Catalog No. 2921)
    - b) 100-120 VAC Power converter (Catalog No. 4455100) with
        - i) Power plug (Catalog No. 4455118)

    As manufactured by Hach, 5600 Lindbergh Drive, P. O. Box 608, Loveland Co 80539-0608. Tel. (800)227-4224, distributed by Lee Engineering Sales Co., Tel. (847)398-7055.

2) Qty. 4 – 900 MAX Portable Sampler (Catalog No. 8930). Each with:
    - a) 100-120 VAC Power converter (Catalog No. 4455100) with
        - i) Power plug (Catalog No. 4455118)
    - b) Retainer (required for 2 and 4 bottle sampling) (Catalog No. 2190)
    - c) Bottles set of (4) 1 gallon polyethylene, with caps (Catalog No. 2217)
    - d) Distributor w/arm, 2/4 bottles (Catalog No. 8584)
    - e) Pump tubing 15 feet (Catalog No. 4600-15)
    - f) Low flow strainer. Stainless steel (Catalog No. 2071)
    - g) 100 feet of intake tubing 3/8" ID (Catalog No. 923)
    - h) Battery 12 VDC 6 AH (Catalog No. 1414)
    - i) Base (Catalog No. 8976)

j) 3 of the 4 samplers will have these additional options:

  i) Integral flow meter (requires depth sensor) (Catalog No. 4041)

  ii) AV Sensor (used for monitoring level) with 75' cable (Catalog No. 77065-075)

  iii) Multipurpose cable, 10 feet, 6 pin auxiliary connector on ends (Catalog No. 940)

k) 2 of the 4 samplers to have the Rain Gauge Input option (Catalog No. 8800)

As Manufactured by Hach Company, 5600 Lindbergh Drive, P. O.
Box 608, Loveland Co 80539-0608. Tel. (800)227-4224. Regional
Sales Manager, Paul Gauger, Tel. (800)227-4224 ext. 2060.

3) Qty. 7 – 12" V-notch Thelmar Volumetric Weir

As manufactured by Parson Environmental Products Inc., Redding Pa., Tel. (610)391-1449.

4) Qty. 2 – Rain Gauge with 25' of cable (Catalog No. 2149)

As Manufactured by Hach Company, 5600 Lindbergh Drive, P. O.
Box 608, Loveland Co 80539-0608. Tel. (800)227-4224. Regional
Sales Manager, Paul Gauger, Tel. (800)227-4224 ext. 2060.

5) Qty. 2 – DTU-II data transfer units with cables and 115 VAC adaptor (Catalog No. 3516)

As Manufactured by Hach Company, 5600 Lindbergh Drive, P. O.
Box 608, Loveland Co 80539-0608. Tel. (800)227-4224. Regional
Sales Manager, Paul Gauger, Tel. (800)227-4224 ext. 2060.