Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

# MONITORING AND RESEARCH DEPARTMENT

REPORT NO. 12-17

STICKNEY WATER RECLAMATION PLANT PERMEABLE PAVEMENT

DEMONSTRATION INTERIM REPORT 2010 AND 2011

June 2012

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# STICKNEY WATER RECLAMATION PLANT PERMEABLE PAVEMENT DEMONSTRATION INTERIM REPORT 2010 AND 2011

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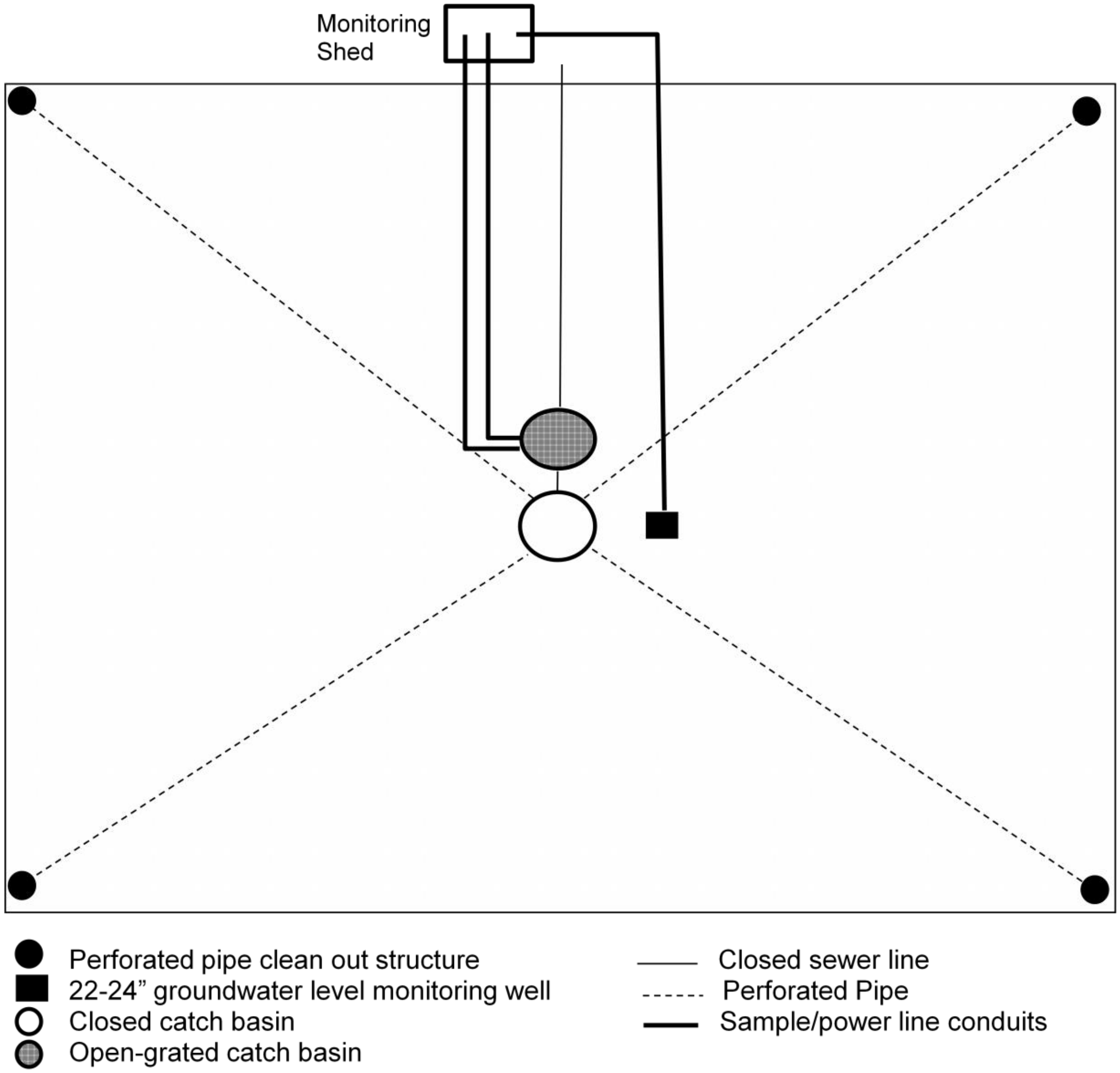
In 2008, the Metropolitan Water Reclamation District of Greater Chicago initiated a plan to evaluate porous surface technology for stormwater flow and pollutant load reduction to the water reclamation plants (WRPs). The Conservation Design Forum designed three test permeable surfaces for this purpose, and they have been installed in the Stickney WRP parking lot. The three test surfaces are: (1) a 14,115 square foot porous asphalt (PA) lot; (2) a 11,413 square foot porous concrete (PC) lot; and (3) a 13,087 square foot porous paver (PP) lot. A 14,050 square foot traditional black top, impervious, asphalt lot was designated as the control for comparison to the permeable lots. Each permeable lot surface which is four to six inches in thickness sits on top of 12 inches of CA-7 gravel aggregate. The bottom and sides of the fill are bordered by a permeable geotextile allowing transfer of water across the fabric, and there is silty clay native soil 16 to 18 inches below grade.

The lots receive different contributions of run-on from permeable and impermeable surfaces during rainfall events and are allowed to drain freely towards the local groundwater. A system of four-inch perforated pipe rests on the bottom of the CA-7 fill in each permeable lot. These pipes collect flow migrating through the fill which drains into a closed catch basin. All four lots have an open-grated catch basin to accept runoff (RO) in the center of the lot as well. In the permeable lots, the infiltration catch basin is connected to the open-grated catch basin via a 12-inch closed pipe. Thus, water collected by the perforated pipes will flow into 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 typical permeable lot layout is shown in Figure 1.

Huff & Huff Incorporated developed a monitoring plan for the four test lots in order to track rainfall, flow measurements, water level measurements, and water quality. This plan includes two rain gauges that were installed to continuously monitor rainfall. Shallow 12-inch diameter wells are located at each permeable lot (Figure 1). The wells are 22 to 24 inches deep and contain a Hach area velocity (AV) sensor to continuously measure the subsurface water levels within each lot.

In the permeable lots, Thelmar V-notch weirs are 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. Only one weir is installed in the control lot downstream of the catch basin. Sigma 950 Bubbler Flow Meters were installed for each weir to monitor the infiltrated and total flow for each lot. A Sigma 900 MAX auto sampler is synchronized with the flow meters associated with the total flow for each lot to collect first flush and secondary water quality samples downstream of the total flow PMD; the sample line inlet is placed either in the open grated catch basin sump or downstream of the total flow monitoring point in the outgoing 12-inch closed pipe. The monitoring equipment for the PC and PP lots are housed in a shed between the two lots (east), and the equipment for the PA and control lots are housed in a shed between the two lots (west).

FIGURE 1: TYPICAL PERMEABLE LOT LAYOUT



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

Monitoring and Research Department (M&R) staff collected all rainfall, flow, and AV sensor data from April 20, 2010, through November 15, 2010, and July 11, 2011, through November 9, 2011. M&R staff also collected all water samples during this study period and submitted the samples to the Stickney Analytical Laboratory for analysis. M&R staff downloaded all relevant data and performed ringed infiltrometer tests on the permeable lots. 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.

## Results and Discussion

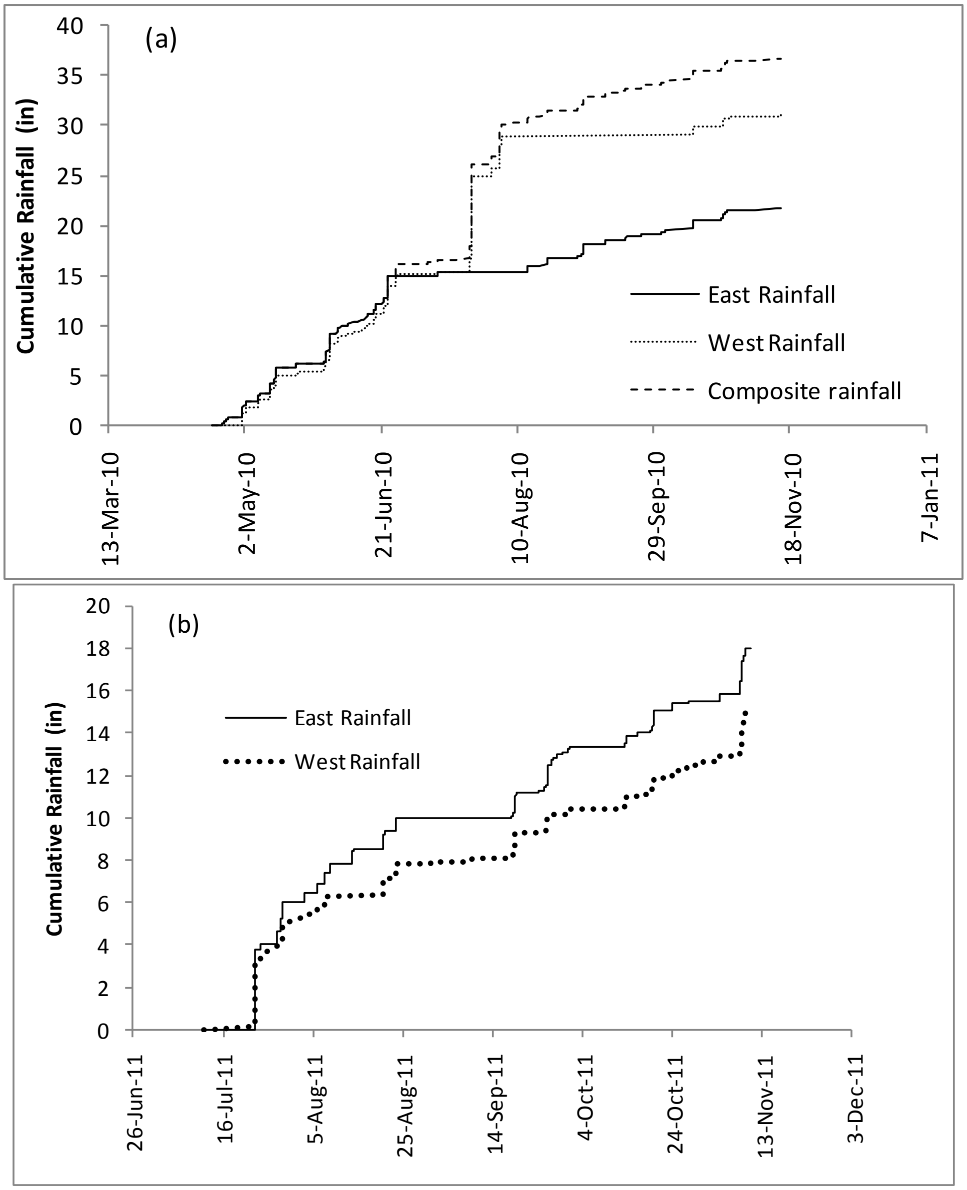
During the 2010 monitoring period, electrical maintenance work at the Stickney WRP caused extended power outages in both monitoring sheds. Simultaneous monitoring in all four lots only occurred from April 27, 2010, through June 25, 2010, and October 22, 2010, through November 15, 2010. Damage to multiple Thelmar weirs prevented the 2011 monitoring season from 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.

## Rainfall

Plots of the cumulative rainfall for the eastern and western rain gauges are shown in Figure 2a and 2b for 2010 and 2011, respectively. 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; for 2011, a total of 15–18 inches of rainfall was estimated over the course of the shortened monitoring season. Periodic site visits during periods of rainfall indicated no visible standing water or RO on any of the permeable lots during both monitoring seasons. RO and standing water were observed in the impermeable control lot.

Additional water input to the test lots can result from run-on from both permeable and impermeable surfaces. Run-on was estimated via the rational formula which is a function of runoff coefficients, rainfall intensity and the area of the contributing areas such as bordering sidewalks and grassy areas. This total water input from rainfall and run-on is used in the evaluation below. Typically, run-on contributed less than three percent of the total water input for the PA, PP, and control lots. The PC lot has a 9,381 square foot ($ft^2$) contributing run-on area and typically receives 25 percent of the total water input from run-on; the other three lots only have a contributing run-on area of less than 412 $ft^2$.

FIGURE 2: (a) 2010 CUMULATIVE RAINFALL FOR THE EASTERN AND WESTERN STICKNEY WATER RECLAMATION PLANT LOTS, AND (b) 2011 CUMULATIVE RAINFALL FOR THE EASTERN AND WESTERN STICKNEY WATER RECLAMATION PLANT LOTS



**Infiltration and Runoff Evaluation Using Flow Meters**

**2010.** The near subsurface water level increased during rainfall as indicated by the AV sensor data for each lot when daily cumulative rainfalls were greater than 0.1 inches (Figures 3a–3c). (Please note that cumulative daily rainfalls were recorded 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 PP lots, water levels were significantly higher than the depth of water input (Figures 3a and 3b). It is unknown why greater water input is reflected in the lot 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 is not expected and cannot be verified.

For the PP lot during the beginning of the monitoring period, good agreement was observed between water levels and water input, but no discernable trend was observed after June 2010. 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 lots 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 Figures 4a–4d. (Please note that cumulative daily rainfalls were plotted at the beginning of the day and therefore may not correlate exactly with the peaks shown in the figures.) 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 the points where conduits and pipes enter the catch basin (break-ins); (3) poor pump performance in flow meters; (4) poor precision of the flow meters provided unreliable data to calculate RO in the permeable lots; and (5) low resolution of flow meters at low flows. Numerous attempts by M&R personnel were made to solve 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.

FIGURE 3: 2010 NEAR-SURFACE WATER LEVEL INCREASES AND RAINFALL FOR THE (a) POROUS ASPHALT, (b) POROUS CONCRETE, AND (c) POROUS PAVER LOTS

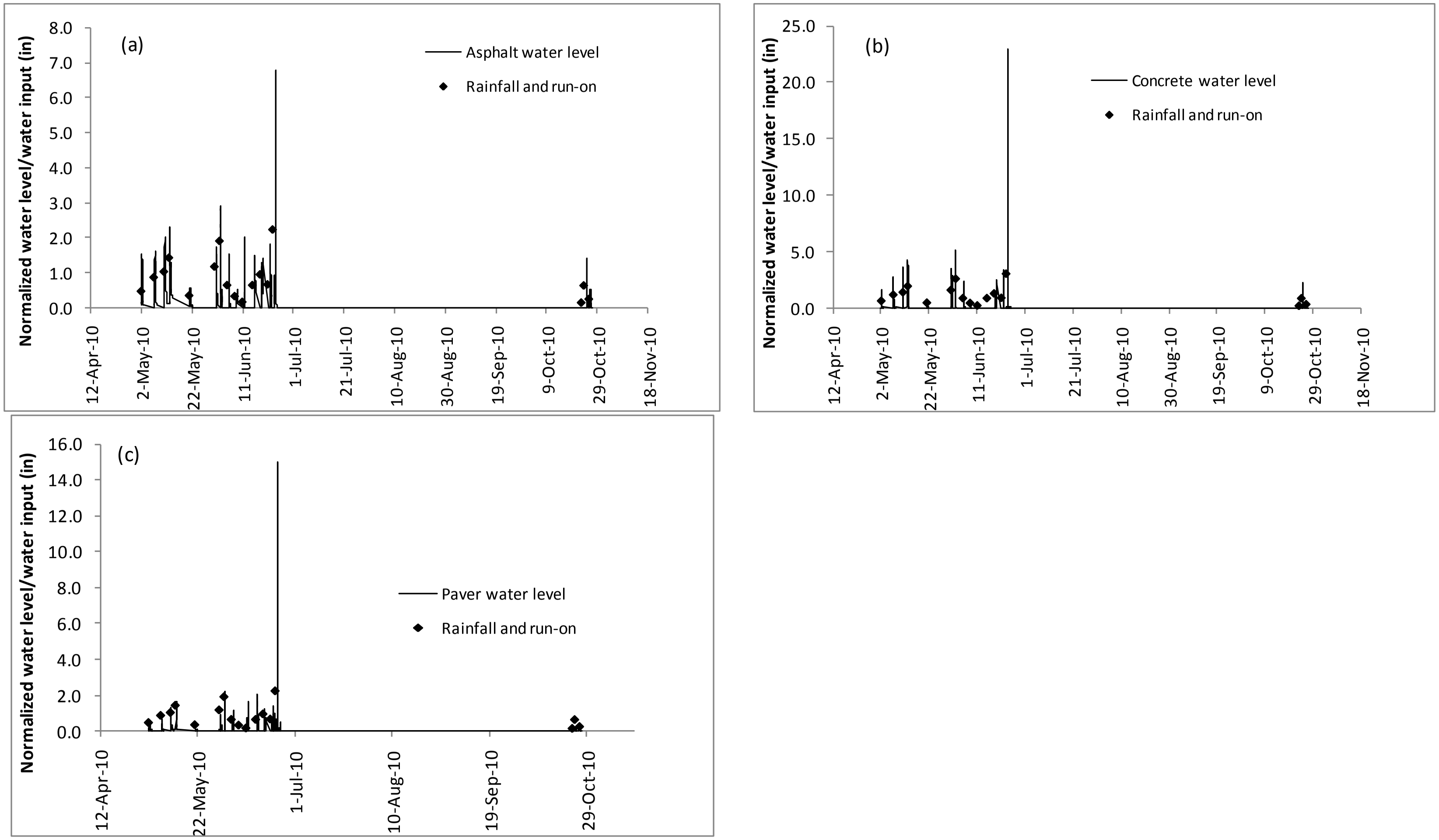
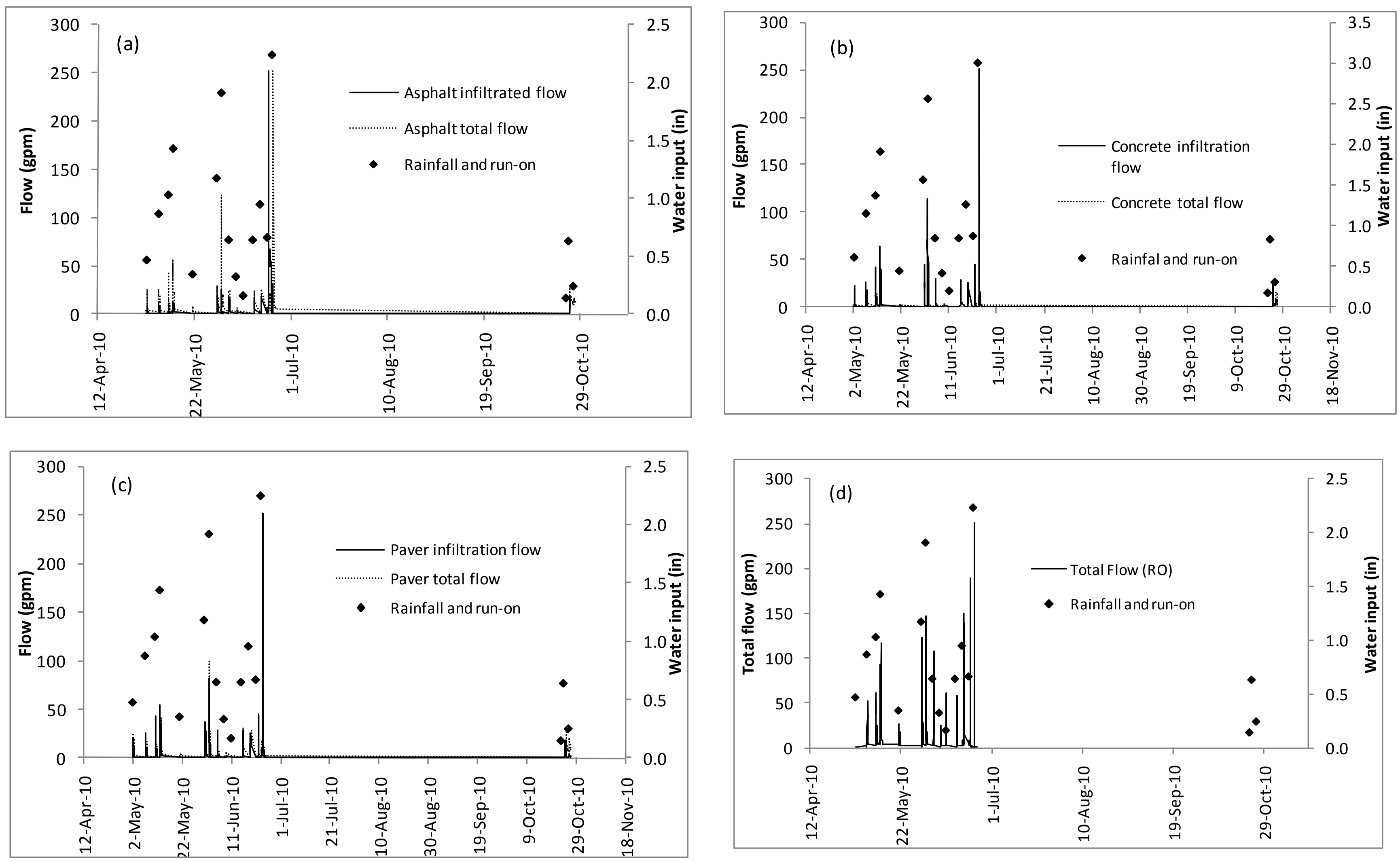


FIGURE 4: 2010 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE (a) POROUS ASPHALT, (b) POROUS CONCRETE, (c) POROUS PAVER, AND (d) CONTROL LOTS



**2011.** Much like the 2010 data, during times of rainfall and run-on, increases in water levels were observed (Figures 5a–5c); a malfunctioning auto sampler in the PC lot 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.

The infiltrated and total flow response for the three permeable lots showed a similar pattern to 2010 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 Figures 6a–6c and the control lot as shown in Figures 7a–7c. Unfortunately, much like 2010, problems with flow measurements were continually encountered for reason cited above. Additionally, the control lot which should only register flow during rainfall and runoff events indicated flow without said events.

The same problems encountered during 2010 were observed during the 2011 monitoring period. M&O and Engineering Departments were consulted about the logistical monitoring difficulties encountered, but solutions such as lining the catch basins and the outgoing pipe in each lot or acquiring better-suited monitoring equipment are currently cost prohibitive.

## Infiltration Evaluation Using Infiltrometer Tests

As an alternative method for evaluating infiltration potential, ringed infiltrometer tests were performed in June 2010 and September 2011. In each lot, up to four tests at two different locations (driving area and parking slot) were performed during dry weather each year.

The results of the ringed infiltrometer tests for 2009 through 2011 are summarized in Table 1. For 2010, the average infiltration rates were 1.20, 1.27, and 0.95 inches per second for the PA, PC, and PP lots, respectively; for 2011, average infiltration rates were 0.95, 0.90, and 0.28 inches per second for the PA, PC, and PP lots, respectively. The infiltration rates have decreased for all three lots, but especially for the PP lot which decreased from 1.00 inches/second in 2009 to 0.28 inches/second in 2011. These decreased infiltration rates are most likely due to clogging issues.

Based on these results, unless the subsurface water level at each site was just below grade thus inhibiting infiltration, rainfall intensities would have to exceed these infiltration capacities of over a quarter inch per second in order for ponding or RO to occur. From the rainfall data, the maximum intensity observed during 2010 and 2011 was less than $10^{-3}$ in/sec. As such, it is doubtful that any RO would have occurred during the 2010 or 2011 study period for the permeable lots. Rainfall may still enter directly into the open-grated catch basin or via the small concrete pad around the catch basin, but this is assumed to be negligible.

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

FIGURE 5: 2011 NEAR-SURFACE WATER LEVEL INCREASES AND RAINFALL FOR THE (a) POROUS ASPHALT, (b) POROUS CONCRETE, AND (c) POROUS PAVER LOTS

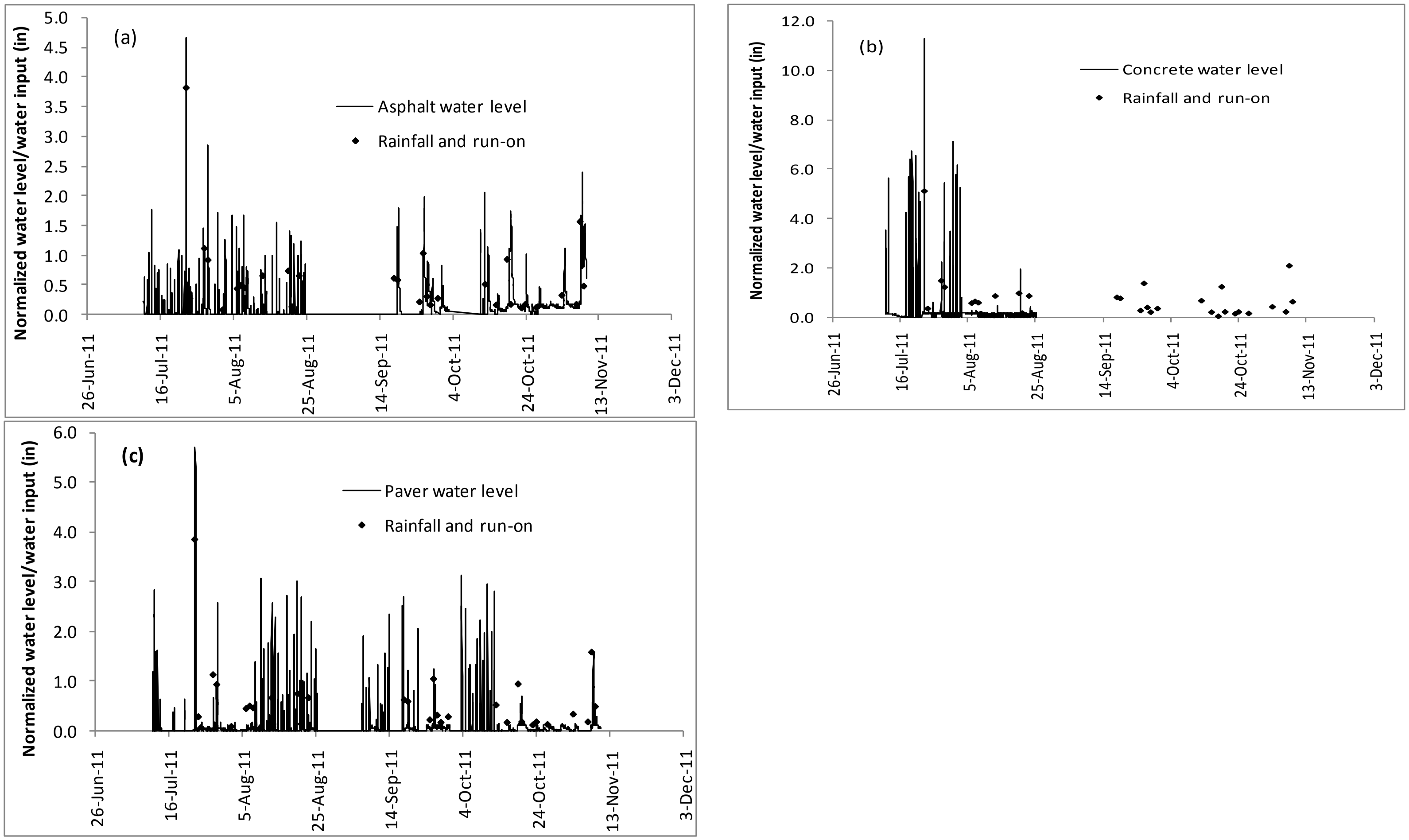


FIGURE 6: 2011 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE (a) POROUS ASPHALT, (b) POROUS CONCRETE, AND (C) POROUS PAVER LOTS

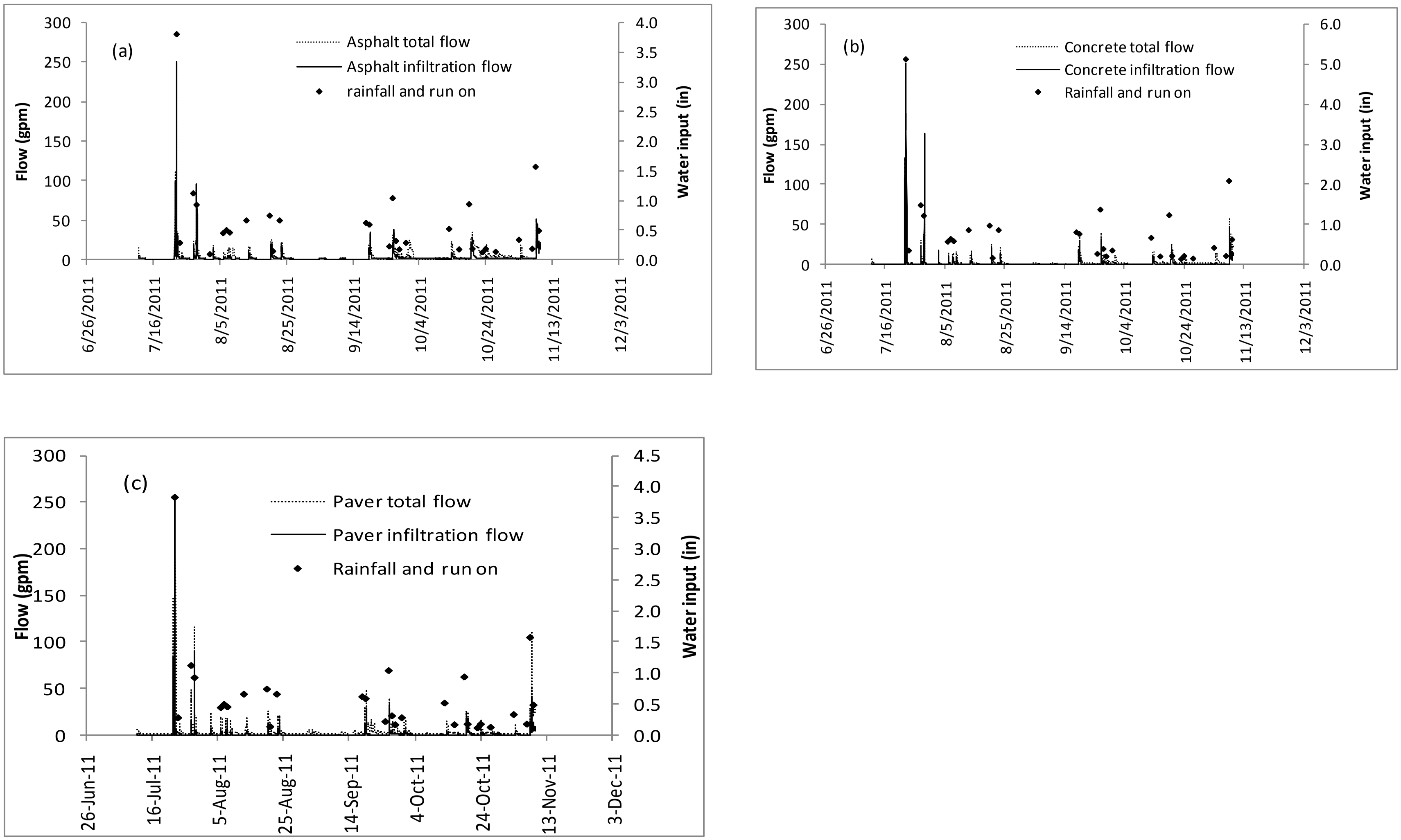


FIGURE 7: 2011 TOTAL FLOWS, INFILTRATED FLOWS, AND RAINFALL FOR THE CONTROL LOT FROM (a) JULY 11 THROUGH AUGUST 23, 2011, (b) JULY 24 THROUGH OCTOBER 6, 2011, AND (c) OCTOBER 7 THROUGH NOVEMBER 9, 2011

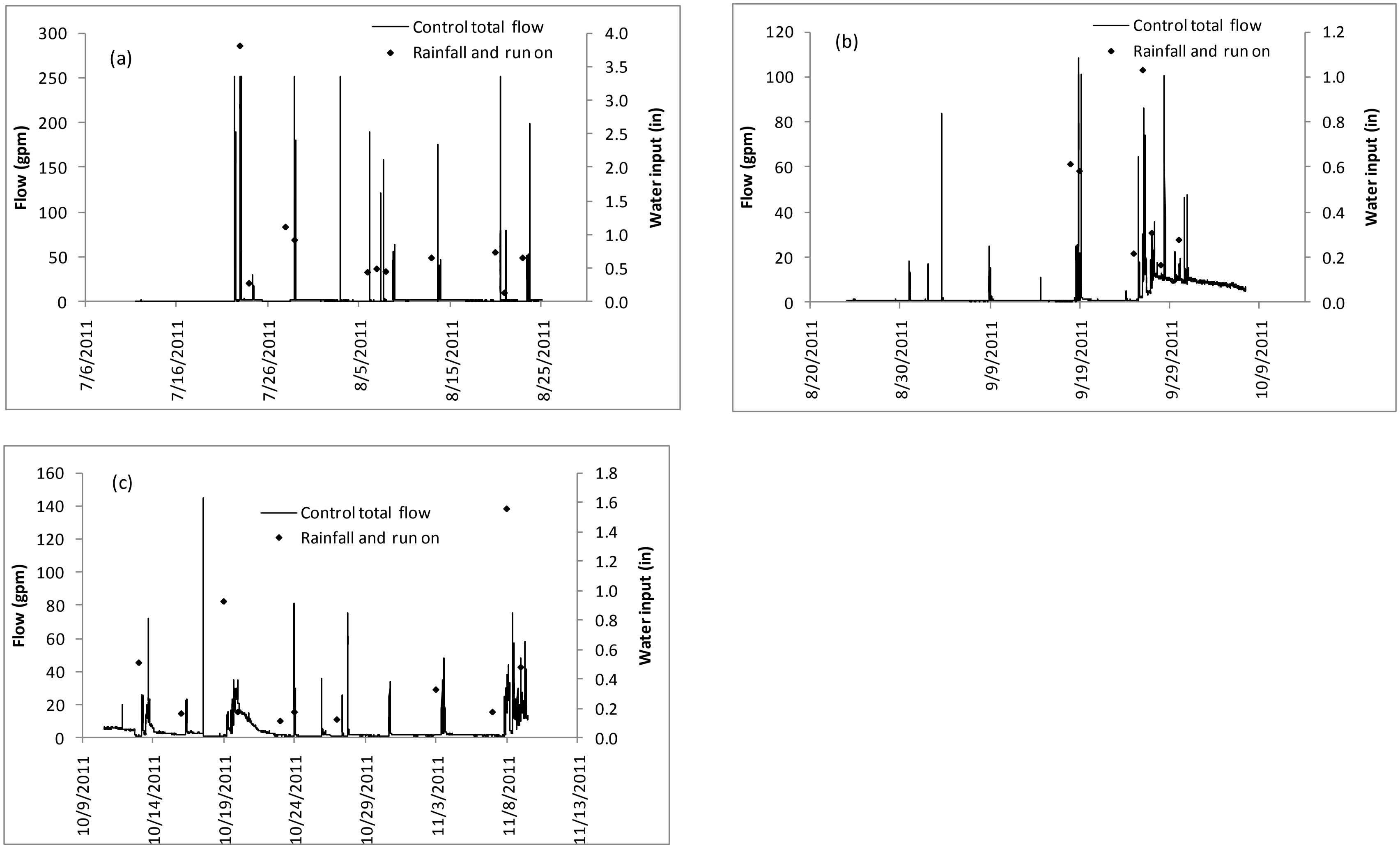


TABLE 1: RINGED INFILTROMETER TEST RESULTS FOR THE THREE STICKNEY WATER RECLAMATION PLANT PERMEABLE PAVER LOTS IN 2009, 2010, AND 2011

| | | Infiltration Rate (in/sec) | | | | |
|---|---|---|---|---|---|---|
| Date | Lot | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Average |
| 11/19/09 | PA | 1.25 | 1.20 | 1.15 | 1.30 | 1.23 |
| 11/19/09 | PC | 1.50 | 1.43 | 1.58 | 1.50 | 1.50 |
| 11/19/09 | PP | 1.03 | 1.00 | 1.00 | 0.97 | 1.00 |
| 6/1/10 | PA | 1.20 | 1.30 | 1.11 | ND | 1.20 |
| 6/1/10 | PC | 1.25 | 1.15 | 1.42 | ND | 1.27 |
| 6/1/10 | PP | 0.96 | 1.00 | 0.88 | ND | 0.95 |
| 9/15/11 | PA | 0.90 | 0.98 | 0.96 | 0.99 | 0.95 |
| 9/16/11 | PC | 0.91 | 0.97 | 0.82 | 0.87 | 0.90 |
| 9/17/11 | PP | 0.29 | 0.26 | 0.29 | 0.27 | 0.28 |

ND = No data.

observed during periodic visits to the lots during precipitation. Given that the infiltrometer tests are considered simple and reliable, performing more tests during the 2012 monitoring season should be performed as an alternative and/or back up to the flow meter measurements as a measure of lot performance.

**Water Quality Evaluation**

Flow-weighted water quality samples were collected in the sump of the open grated catch basin or downstream of the total flow monitoring point during rainfall events. During 2009, first flush samples were collected in all four lots on four separate dates. The TSS and COD results for the first flush samples for all four lots are summarized in Table 2. (Please note that the bold italic values indicate the highest concentration among the lots.) In general, the three permeable lots showed significantly lower TSS and COD concentrations relative to the control lot. The PA lot showed the lowest TSS concentrations on average, and the PC lot showed the lowest COD concentrations.

Table 2 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 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 subsurface of the lot and into the native soil where they can be conveyed into the local groundwater; (2) be sorbed or trapped by the porous pavements, the lot fill, geotextiles, or underlying soil; or (3) be sorbed or transformed by indigenous bacteria. These mechanisms are the potential reasons for lower pollutant concentrations in the permeable lots relative to the control lot in 2009 and 2011.

With respect to the 2010 results, as the subsurface soil below the fill has very low permeability ($10^{-6}$ to $10^{-4}$ cm/s), there can be occasions when the underlying soil may be acting as a barrier to drainage causing a "bathtub" effect within the lot. This bathtub effect may be enhanced when smaller particles are sieved out as the infiltrated water drains through the native soil thereby reducing the porosity and flow pathways of an already relatively impermeable underlying soil. As the water levels rise in the fill during rainfall events, infiltrated and captured pollutants may be entrained and enter the lot's collection system through the perforated drains or leaking catch basins. As such, pollutants leaving the permeable lot system via groundwater can be bypassed, and the infiltrated pollutants are being sampled during subsequent wet weather events, thereby leading to elevated water quality concentrations in the permeable lots in 2010 as summarized in Table 2. Continued monitoring is necessary to determine whether 2010 water quality results were an anomaly.

Table 3 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 limestone CA-7 fill which is composed of calcium carbonate. Dissolution of calcium carbonate elevates pH levels. The pH values are decreasing towards more neutral levels by midsummer 2010, which may indicate that

TABLE 2: TEST LOT FIRST FLUSH TOTAL SUSPENDED SOLIDS AND CHEMICAL OXYGEN DEMAND ANALYSIS FOR COMMON 2009 THROUGH 2011 RAINFALL EVENTS

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

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

TABLE 3: TEST LOT FIRST FLUSH pH ANALYSIS FOR COMMON 2009 THROUGH 2011 RAINFALL EVENTS

| Date | pH | | | |
|---|---|---|---|---|
| | PA | PC | PP | Control |
| 4/20/09 | 8.1 | 10.4 | 8.4 | 7.5 |
| 4/28/09 | 8.2 | 9.9 | 8.3 | 7.4 |
| 5/8/09 | 8.2 | 9.6 | 8.3 | 7.6 |
| 8/28/09 | 8.4 | 9.5 | 8.2 | 7.8 |
| 5/3/10 | 8.4 | 9.4 | 8.2 | 6.5 |
| 5/12/10 | 8.4 | 10.1 | 8.9 | 8.1 |
| 5/14/10 | 8.3 | 10.0 | 8.5 | 6.9 |
| 6/2/10 | 8.0 | 9.3 | 8.3 | 6.8 |
| 6/7/10 | 7.0 | 8.0 | 9.3 | 8.1 |
| 6/17/10 | 8.2 | 9.2 | 7.2 | 8.1 |
| 6/22/10 | 7.8 | 9.2 | 7.9 | 7.4 |
| 6/25/10 | 7.9 | 9.3 | 7.9 | 7.5 |
| 7/22/11 | 7.2 | 7.1 | 7.0 | 7.5 |
| 7/28/11 | 7.0 | 6.9 | 7.0 | 7.4 |
| 8/8/11 | 6.7 | 6.6 | 6.6 | 6.3 |
| 8/15/11 | 7.5 | 7.5 | 7.6 | 7.6 |
| 8/22/11 | 6.4 | 6.8 | 6.3 | 7.0 |
| 9/19/11 | 6.5 | 6.7 | 6.5 | 6.9 |
| 10/24/11 | 7.2 | 7.4 | 7.5 | 6.9 |

the readily dissolvable calcium carbonate has been diminished. By 2011 the pH values are maintained at a neutral level.

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. At or near below detect concentrations were observed for all metals and PAHs. However, zinc was slightly above detection limits (0.018 mg/L) in the control lot.

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). At or near below detect concentrations were observed for most metals. However, zinc concentrations were above 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.

**Pavement Condition Evaluation**

The end of season 2010 evaluation indicated that the PA lot was in relatively good condition. There was no vegetation identified, but some surficial sediment buildup in small areas along the eastern border and northwest corner of the lot was observed. 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 has increased, especially in the driving lanes and at the southern entrance.

The end of season 2010 evaluation indicated that the PC lot was in relatively good condition with only minor vegetative growth along the edges of the lot. Minor raveling and some cracking was also observed. The 2011 evaluation revealed vegetation along the borders of the lot requiring weeding, major raveling around the control joints along the perimeter of the lot, and two large cracks in the center of the lot.

The end of season 2010 evaluation indicated that the PP lot was in the worst condition of the three permeable pavement lots. Multiple locations of chipped pavers and significant vegetative growth were observed. Pronounced depressions were noted throughout the lot. Additionally, fill between the pavers was noticeably missing in a number of locations. The 2011 evaluation revealed weeds in the corners of the lot requiring weeding, and an increased number of chipped, spalled, and cracked pavers.

The end of season 2010 evaluation indicated that the control lot, which is approximately one year older than the permeable lots, was still in good condition. Spot vegetation requiring weeding was observed as well as some joint, longitudinal, and transverse cracking along the pavement. The 2011 evaluation revealed plow scoring, and the cracks identified in 2010 were treated with chemical sealant.

Manhole cleanouts were not performed at any of the lots as sediment deposition was considered minor.

**Summary**

On April 20, 2010, the second phase of the effort to evaluate three permeable surfaces with respect to stormwater flow and load reduction at the Stickney WRP was initiated. The third phase of this project began on July 11, 2011. The four lots are still in decent condition with some minor vegetation, raveling, cracking, and scores from snow plows. However, the PP lot is also showing chipped pavers, lost fill, and surface depressions which may affect the performance of the lot, and the control lot cracked and required a sealer application.

Rainfall, subsurface water levels, infiltrated flow, and total flow were continuously measured in both years for each lot through mid November except for June 26 through October 21, 2010, due to power loss. Additionally, water quality of the total flow collected at each lot was monitored during rainfall events. Generally, 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 via the flow meters and potential unknown water sources, comparison between the infiltration potential of the lots could not be made. Results from infiltrometer tests in 2009 and 2010 did indicate that all three permeable lots could accept over one inch of rainfall per second before RO would occur. The PC lot had the highest infiltration capacity, and the PP lot had the lowest. Infiltration capacities measured in 2011 were significantly lower than the 2009 results, possibly due to clogging. However, no standing water or RO was ever observed during site visits during wet weather.

The lower pollutant concentrations observed in the permeable lots relative to the control lot during the 2009 and 2011 monitoring seasons was not observed during the 2010 monitoring season. It is suspected that pollutants are entering the sampling system through the perforated drain pipes and leaking catch basins, but further investigation is needed.

The scope of monitoring will be reduced for future evaluation of the permeable lots to include only: (1) quarterly infiltrometer testing as a metric for lot permeability and performance; (2) continuous rainfall and permeable lot water level monitoring; (3) periodic grab samples and water quality analysis during rainfall events; and (4) semiannual maintenance inspections of all lots.