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S8.C.3 Effectiveness Monitoring

Final Report

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Clean Water Division

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Summary

Clark County completed an effectiveness study from 2014-2017 at McCord's Vancouver Toyota in Vancouver, Washington to evaluate infiltration performance of a maturing, large-scale interlocking concrete paver block (ICPB) parking lot installation in a region with extended wet seasons and ubiquitous moss growth.

The 7.6 acre parking lot, installed in two phases during 2009 - 2010, is used for temporary storage of new/used vehicles, repaired vehicles, and recreational vehicle trailers, as well as employee and customer parking.

The study included continuous monitoring for precipitation and stormwater collection system flows, monthly observation-well readings, visual estimates of inter-paver moss coverage, and co-located measurements of moss coverage and infiltration rates.

After 7-8 years of operation, the installation continues to infiltrate 100% of rainfall and water levels in the subbase storage area remain consistently more than1-foot below the paver surface. Twice yearly paver cleaning using a vacuum filtering sweeper has effectively maintained the overall parking lot infiltration rates despite significant moss growth between pavers.

Visual estimates and site-specific measurements showed moss coverage and infiltration rates vary considerably across the parking lot, and are likely influenced by their relative exposure to shading, extended damp conditions, tree detritus input, traffic levels, and possibly vehicle cleaning practices. The overall infiltration rate pattern is generally a mirror image of the measured inter-paver moss coverage pattern. A significant inverse linear relationship between measured infiltration and moss coverage suggests that approximately 35 % of the variation in infiltration is explained by moss coverage.

Median moss coverage and infiltration rates were not statistically different between Phase 1 and Phase 2. However, a difference of 22 inches per hour in median infiltration rates between the two phases suggests decreasing infiltration over time based on the 18-month difference between installation dates.

Regardless of inter-paver moss coverage, minimum measured infiltration rates in both phases remained substantially higher than Ecology's corrective maintenance criterion of 10 inches per hour for ICPB surfaces.

Introduction

Clark County completed an effectiveness study at McCord's Vancouver Toyota to evaluate infiltration performance of a maturing, large-scale ICPB parking lot installation. This report is submitted per requirements in section S8.C.3 Effectiveness Study of Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit. The report summarizes monitoring results for:

- Parking lot maintenance
- Precipitation
- Surface runoff from the site
- Subsurface water levels in observation wells
- Estimated inter-paver moss coverage across the entire parking lot
- Measured moss coverage and infiltration rates at 55 sample sites
- Relationship between measured inter-paver infiltration rates and moss coverages
- Observations of the parking lots overall infiltration performance over time

The study was conducted at McCord's Vancouver Toyota (Figure 1), site of the largest permeable paver project in the United States (Meade, 2011, pp. 4-7) with approximately 1.6 million Eco-Loc Permeable concrete pavers covering 7.6 acres. The system is designed to infiltrate all stormwater runoff onsite through the permeable concrete pavers into a stone subbase and soil subgrade, with the 100-year storm filling the subbase 0.37 feet from its bottom (MacKay & Sposito, Inc., 2008, pp.2-3). The eastern half (Phase 1) and western half (Phase 2) of the parking lot were completed in April 2009 and October 2010, respectively.

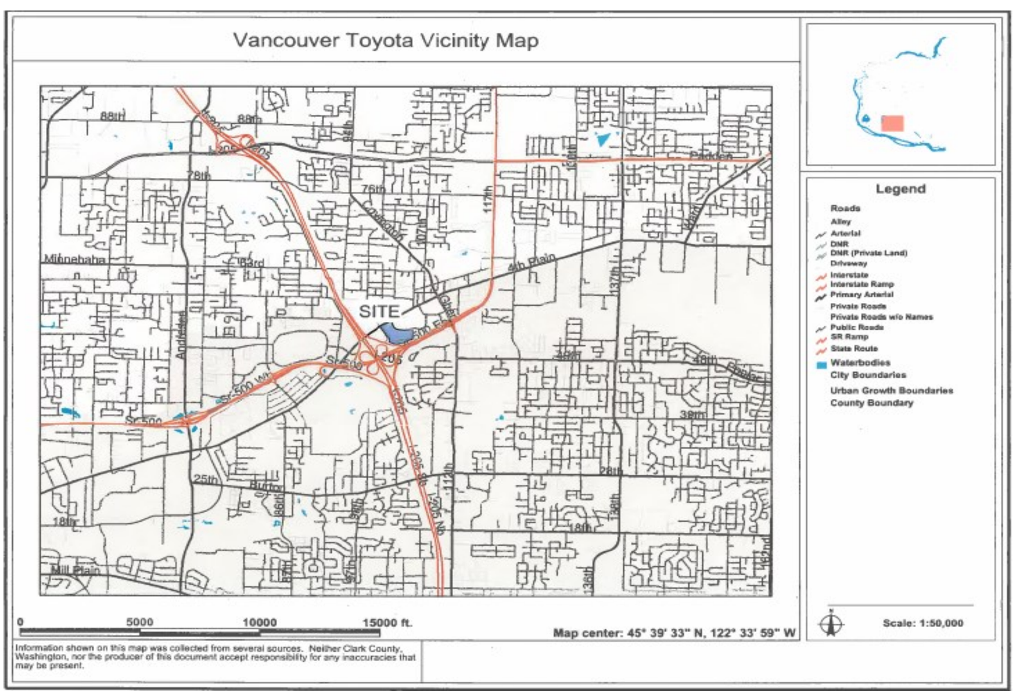

Figure 1 Toyota Low Impact Development ICPB parking lot vicinity map

An opportunity was available to build upon three years of monitoring already completed at the study site from 2010-2013 (Clark County, February 2013). Based on 45 monthly field checks of observation wells, 28 months of continuous outfall flow data, and 26 months of continuous precipitation monitoring, that study found no signs of ponding atop the pavers, no seepage from the perimeter, and no saturation of the subbase material. Discharge from the site was limited to a single event when stormwater likely seeped from the storage subbase into the overflow pipe.

Despite the satisfactory overall paver performance, limited testing during the 2010-2013 study showed that moss growth drastically reduced infiltration rates for the pavers. An area with 100% moss coverage showed a 98% decrease compared to an area with no moss. The measured infiltration rate in the 100% moss area was 4 inches per hour, compared to 209 inches per hour in the no-moss area. Additional tests in areas with approximately 50% and 90% moss coverage showed similar impacts, with rates of 60 inches per hour and 14 inches per hour, respectively.

The low rate (4 inches per hour) in the area with full moss coverage was well below the recommended threshold of 10 inches per hour for corrective maintenance in the Ecology LID Operation and Maintenance Manual (Herrera, 2013, Table 8), and approximately 50% of the paver design rate of 7.8 inches per hour (MacKay & Sposito, Inc., 2008, p. 3).

These results and observed differences in infiltration and moss growth between the Phase 1 and Phase 2 installations suggested moss growth could significantly impair infiltration over time despite ongoing routine maintenance. On the other hand, the lack of runoff from the site as a whole suggested that the 10 inch per hour threshold for corrective maintenance may be overly conservative in large-scale paver applications.

Purpose

This project investigated the question of long-term effectiveness and maintenance needs for a large Pacific Northwest ICPB installation in an area with prolonged wet seasons and ubiquitous moss growth. There is relatively little documentation on the long-term efficacy of modular permeable paver systems during their estimated 40-year design life (Smith, 2011), a fact of some concern with the mandated use of these or similar LID systems under municipal stormwater permits. Given maintenance costs, limited resources, and the need to meet permit-mandated performance levels, there is a need for specific information on long-term effectiveness and the expected maintenance required to maintain performance.

The project specifically sought to assess the effectiveness of a maturing ICPB system at infiltrating stormwater over time, examine the effectiveness of routine maintenance activities and assess how moss coverage affects infiltration rates.

Background

Pre- Construction Site Conditions

The monitoring site is an expansion of McCord's Vancouver Toyota to parcels located to the south and east (Figure 2). The expansion included a new building, installation of sidewalk, 7.6 acres of parking area, and landscaping (MacKay & Spositio Inc., 2008, p. 1). Prior to construction, the 10.33 acre site was an unimproved field with gravel and sparse grass coverage. The western half of the site was used as a parking lot and had a layer of gravel over existing soils. There were no existing structures on the site.

The Final Stormwater Report (MacKay & Spositio Inc., 2008, p. 2) notes three soil types on site; Tisch Silt Loam (ThA), Lauren Gravelly Loam (LgB), and Wind River Gravelly Loam (WrB). Approximately 90% of the site was underlain by ThA, which falls in hydrologic soil group D. Group D soils have a high runoff potential and a very slow infiltration rate. The remaining soil types (A and B) have a high rate of infiltration.

Site designers report (MacKay & Spositio Inc., 2008, p. 4 and Appendix D) that subsurface conditions were explored with fourteen soil test borings or pits. Materials were generally divided into three strata; fill was found three to seven inches below surficial topsoil and up to four to seven feet deep, up to twenty inches of buried peat and topsoil was found about six to twelve inches below the fill, and native silt with gravel deposits were found at eight to twelve feet deep.

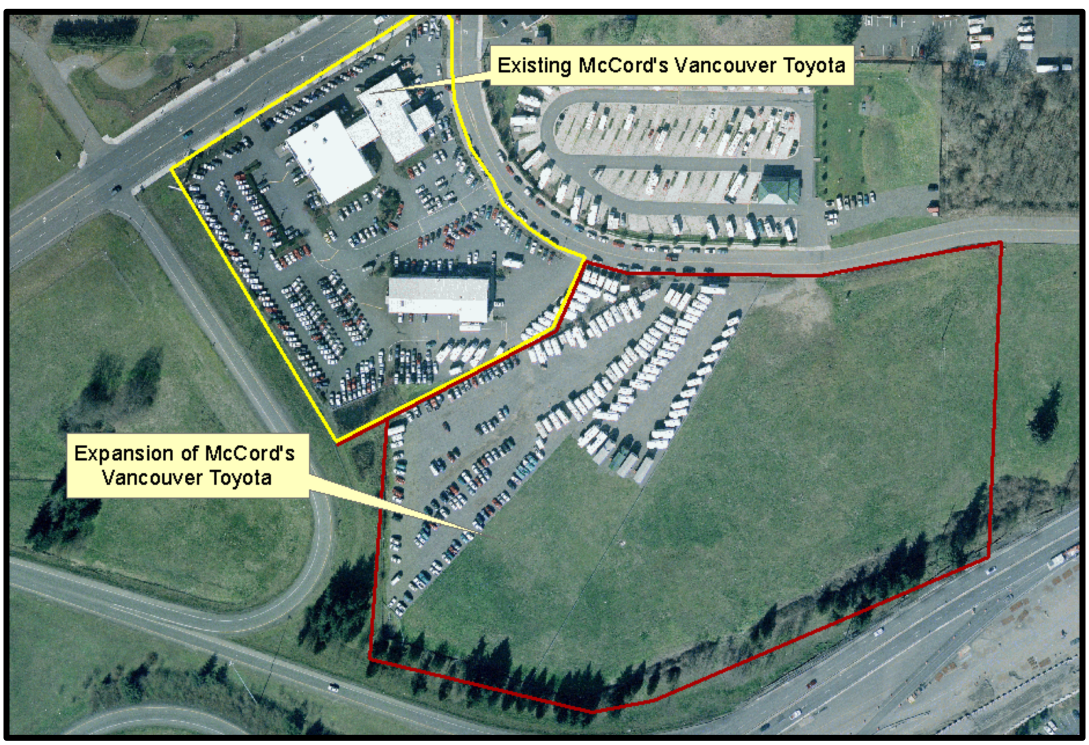

Figure 2. McCord's Vancouver Toyota site's existing land coverage before expansion construction activities

Construction

With 7.6 acres of mechanically installed ICPB (Figure 3), at the time McCord's Vancouver Toyota was the largest permeable paver site in the United States (Meade, 2011, pp. 4-7). Stormwater runoff from the building, parking lots, and the landscaped areas infiltrates onsite using over 1.6 million Eco-Loc Permeable Concrete Pavers. Stormwater is treated by means of filtration as the runoff passes through the stone subbase course materials and underlying soil subgrade (Figure 4).

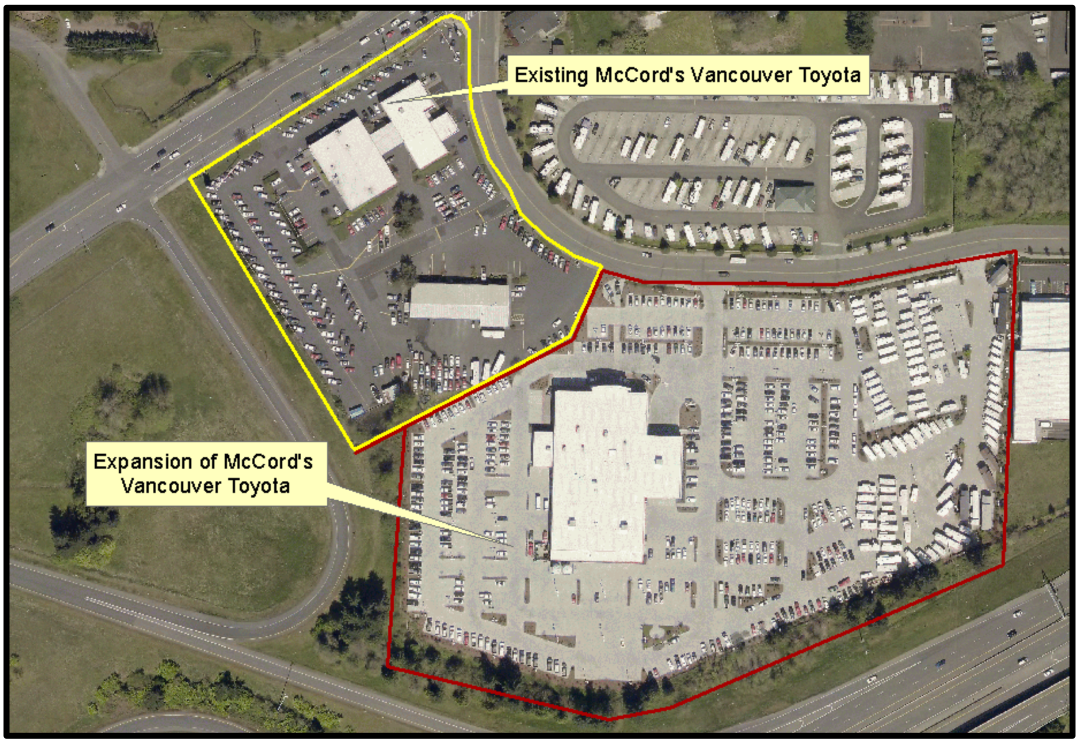

Figure 3. McCord's Vancouver Toyota site, post-construction

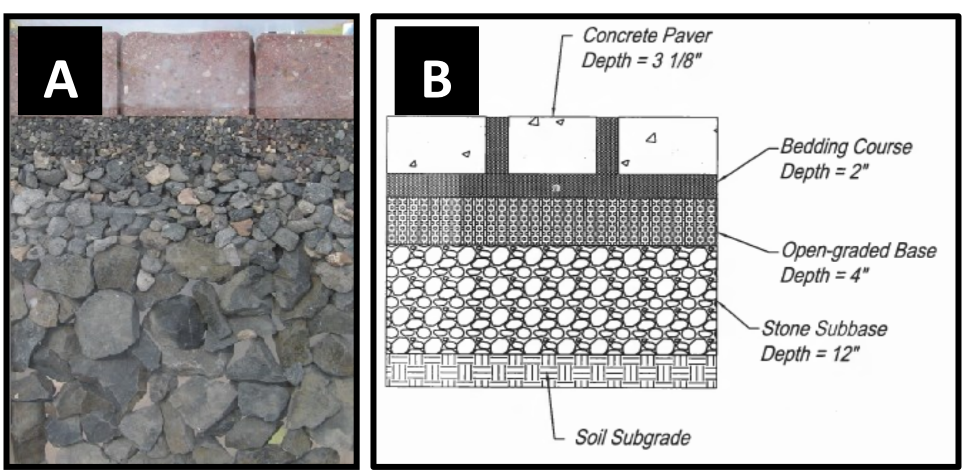

Figure 4. Cross section view of Eco-Loc Permeable Concrete Pavers and underlying base materials in Photo A and Graphic B (original images from MacKay & Sposito, Inc.)

The gravel subbase is designed to store the 100-year storm (24-hr rainfall = 4.30 inches), with that storm filling the base to a height of 0.37 feet above the bottom of the base course (MacKay & Sposito Inc., 2008, pp. 2-4 and Appendix B). The design infiltration rate is controlled by the soil subgrade at 0.5 inches per hour and the void ratio is 0.10.

Construction occurred in two phases. Phase 1 was completed in April 2009, and included the installation of approximately four and a half acres of Eco-Loc Permeable concrete pavers, three observation wells (OW1, OW2, and OW3), and three field inlets with piping (Figure 5). Phase 2 was completed in October 2010, and included the construction of a new building, about three acres of pavers, three observation wells (OW4, OW5, and OW6), and seven field inlets with an infiltration trench connected to a monitoring vault housing the only stormwater outfall from the site.

Stormwater Infrastructure

An overflow drainage system is included in the project that was intended to provide the ability to test the predicted outcome that no runoff will leave the site from storm events less than the 24 hour 100-year event. In the event that rainfall does not infiltrate the pavers, resulting runoff is captured at the south and west margins where curbs prevent surface flow from exiting the site. A field inlet system near these curbs along the south and west perimeter of the site collects and conveys any un-infiltrated stormwater to a concrete monitoring vault with a single outfall at the southwest corner of the site (Figure 5). An infiltration trench system is also connected to the monitoring vault.

The infiltration trench system acts as an emergency overflow in the unlikely event that both the infiltration in the stone subbase, as well as the outfall of the monitoring vault fail to function. To prevent the parking area from flooding, the infiltration trench system is designed to provide an additional way of removing runoff from the site quickly. In the event that that the infiltration trench system became overwhelmed, runoff would be discharged from the site to a Washington State Department of Transportation (WSDOT) drainage ditch which is ultimately connected to Burnt Bridge Creek.

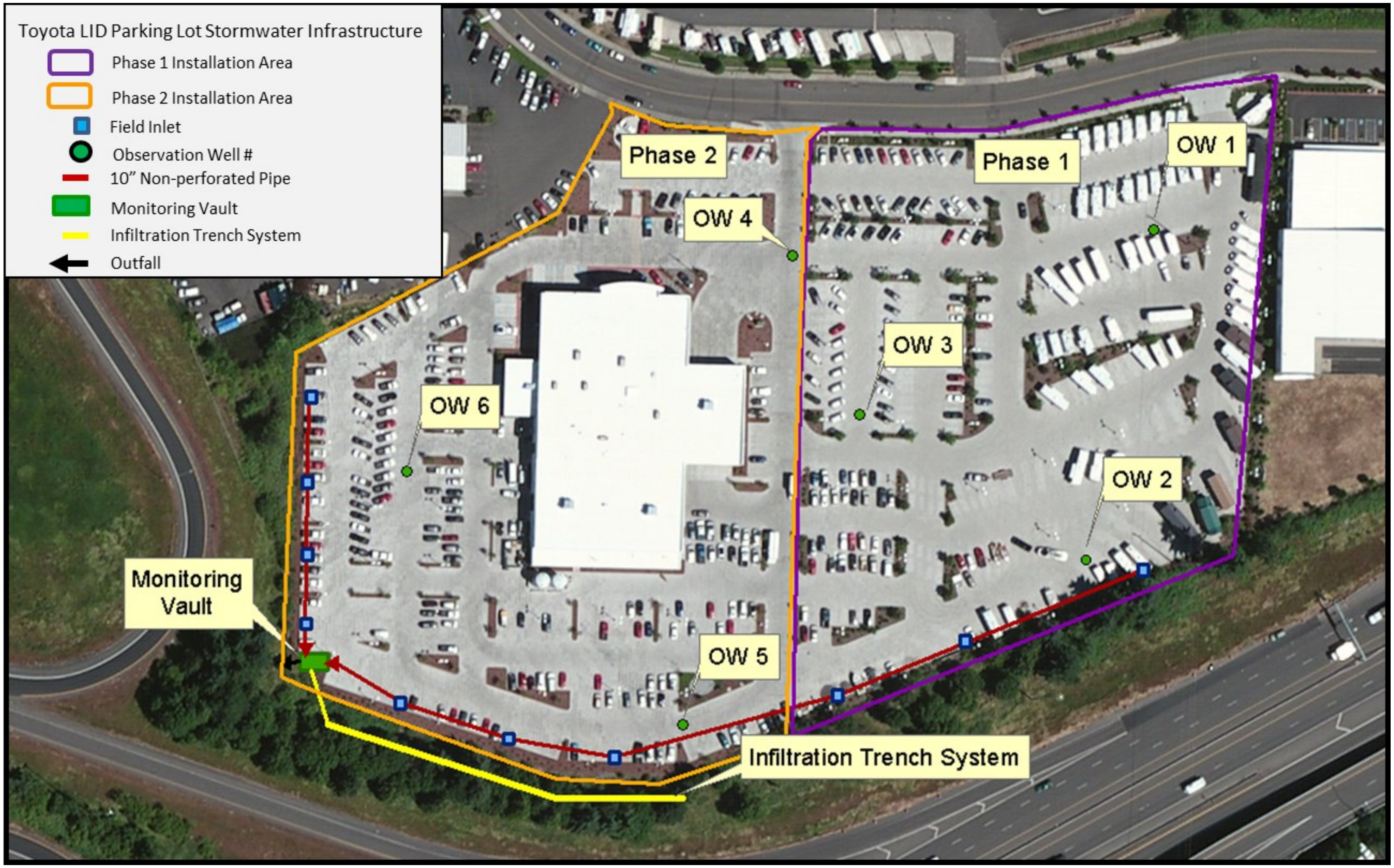

Figure 5 Toyota stormwater infrastructure and monitoring locations across phase 1 and phase 2 installations including six observation wells (OW#), ten field inlets, and monitoring vault

Site Use

Figure 6 shows the primary uses of the paver parking lot are dominated by temporary storage of new/used vehicles and recreational vehicle trailers, with somewhat smaller areas used intermittently but more actively for employee, vehicle repair, and customer parking. The figure also shows the estimated path and relative volume (depicted by red arrow widths) of the majority of traffic across the parking lot based on observations made during fieldwork. The dealership round-trip traffic levels are estimated at approximately 300 per day for service and 20 to 30 per day for vehicle sales while traffic in the recreational vehicle trailer area is estimated at about 100 customers per month (Dave Griffen, October 12, 2017).

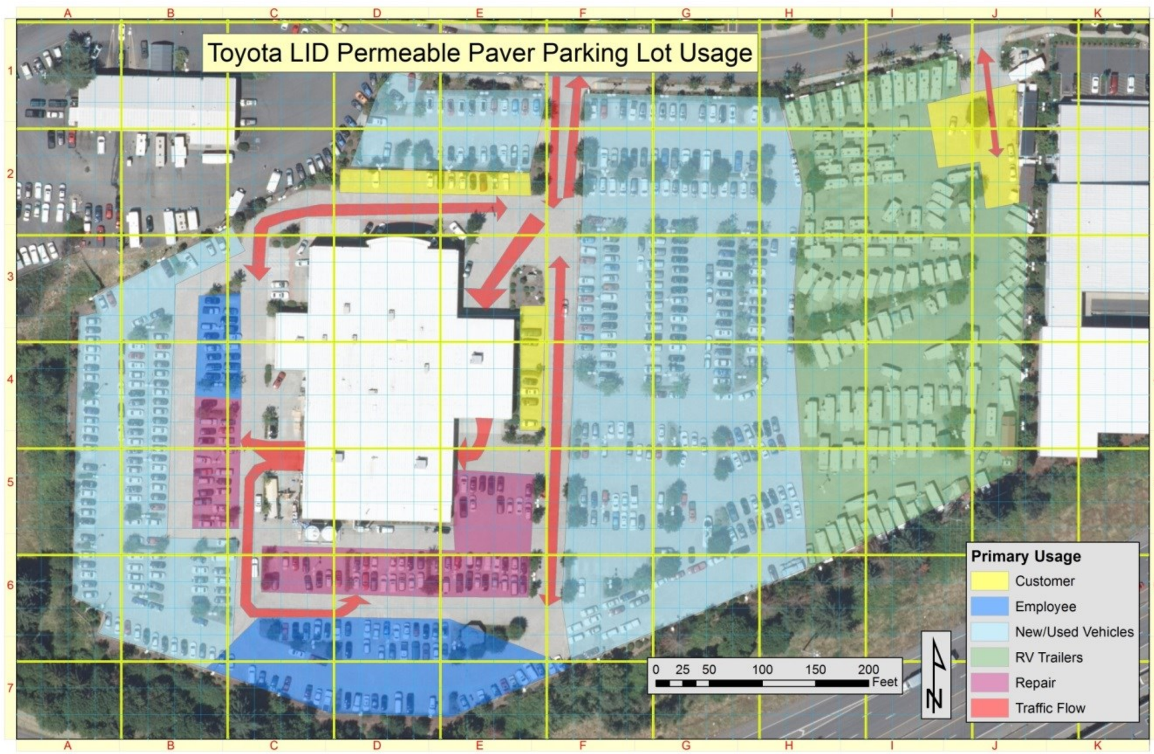

Figure 6 Primary uses of the Toyota LID parking lot

Methods

Maintenance

Parking lot maintenance was performed by trained dealership staff (Dave Griffen, Vancouver Toyota shop foreman, personal communication). A Tennant 6500 vacuum filtering sweeper was used to clean the ICPB parking lot (Figure 7). The RV trailer parking area was swept once per year, and the remainder of the lot was swept two to three times per year (typically during the spring, middle of summer, and after leaf fall in the autumn).

Figure 7 Paver cleaning with a Tennant 6500 vacuum filtering sweeper

Prior to sweeping an area, vehicles were temporarily moved for more efficient sweeping. It takes approximately two weeks to clean the entire parking lot. Weeds growing between the pavers were hand pulled as necessary. Additionally, about once per week, all vehicles for sale in the parking lot were pressure washed in place. This paver maintenance regime meets or exceeds the recommendations in the Ecology LID Operation and Maintenance Manual for ICPB.

Hydrology

Rainfall and field inlet discharge were continuously monitored and logged using telemetered equipment at the vault data collection platform near the parking lot's southwest corner (Figure 8). Rainfall was measured using a Design Analysis Model H-340 tipping bucket rain gage (Clark County, 2013, p. 18). Flow from the ten field inlets (Figure 9) and any net seepage into the piping system was calculated from stage discharge relationships based on bubbler or pressure transducer stage depths recorded from the 10-inch Palmer-Bowlus flume within the vault (Figure 8).

There are six observation wells located throughout the site. These wells have 10-inch perforated pipes that penetrate base material to various depths. Observation well tops are enclosed in a concrete structure and have a solid lid (Figure 9). The observation wells range in depth from 1.69 to 2.08 feet and allow for measurements of water depth in the underlying stone subbase material.

Figure 8. Continuous monitoring data collection platform: left - overall system with electronics enclosure, rain gage and closed vault; center – close-up of electronics enclosure with bubbler and data logger, and right –opened vault showing flume and crest gage

Figure 9 Two photos on left of curb inlets with open grates and two photos on right of paver parking lot shallow observation wells (OW) with solid covers

Onsite Observations

Maximum subsurface water height was estimated monthly by measuring the height of residual cork dust below the rims of the six observation wells (Figure 9). Residual cork dust at the high water mark was rinsed to the bottom of the wells and replenished as necessary. During the monthly field trips or during extreme rain events, field observations were recorded about parking lot field inlets, obvious perimeter seepage, and extent of any ponding.

For orientation during other fieldwork, an aerial image of the study area was divided into fifty-five 100-foot blocks that were each subdivided into sixteen 25-foot grid cells (yellow and blue gridlines, respectively, shown in Figure 10). One application of the 25-foot grid system was for an inventory of the study area's overall inter-paver moss coverage. Each cell's average inter-paver moss coverage was visually estimated (approximated to nearest quartile percentage) from both the perimeter and center of each cell.

Measured Moss Coverage and Infiltration Rate

A random-sampling-within-blocks probability sampling design (Gilbert, 1987, pp. 21-23) was utilized to select representative ICPB sites for measuring inter-paver moss coverage and infiltration. Specific test sites within each of the fifty-five 100-foot blocks were chosen by randomly selecting one of the sixteen 25-foot cells within each block (Figure 10), then during fieldwork blindly tossing an object somewhere within the specified 25-foot cell.

At each test site, inter-paver moss cover measurements were made using a template with a standard grid and circle indelibly marked on a clear plastic sheet (Figure 11 and Figure 12). The reusable template consisted of a grid of squares (having the same width as the inter-paver joint openings) overlain with a one-foot diameter circle (the same diameter as the bucket used for the infiltration tests). The grid template was centered over the specific test site location (marked by push pin in the joint) and rotated until a row of template grid cells aligned with an inter-paver joint. Color-coded pens were used to temporarily mark grid cells within the circle to first delineate the extent of inter-paver joint openings and then demarcate those joint grid cells that were predominately covered by moss. The number of moss-covered grid cells within the joints was divided by the total number of grid cells within the joints to estimate the percent moss coverage within the joints.

Infiltration testing was conducted using ASTM C1701/C1701M-09, designed for pervious concrete. To improve the watertight seal with the pavers, a fitted compressible rubber gasket was attached to the paver-contacting rim of an inverted bottomless five-gallon bucket weighted with a concrete block on top (Figure 12).

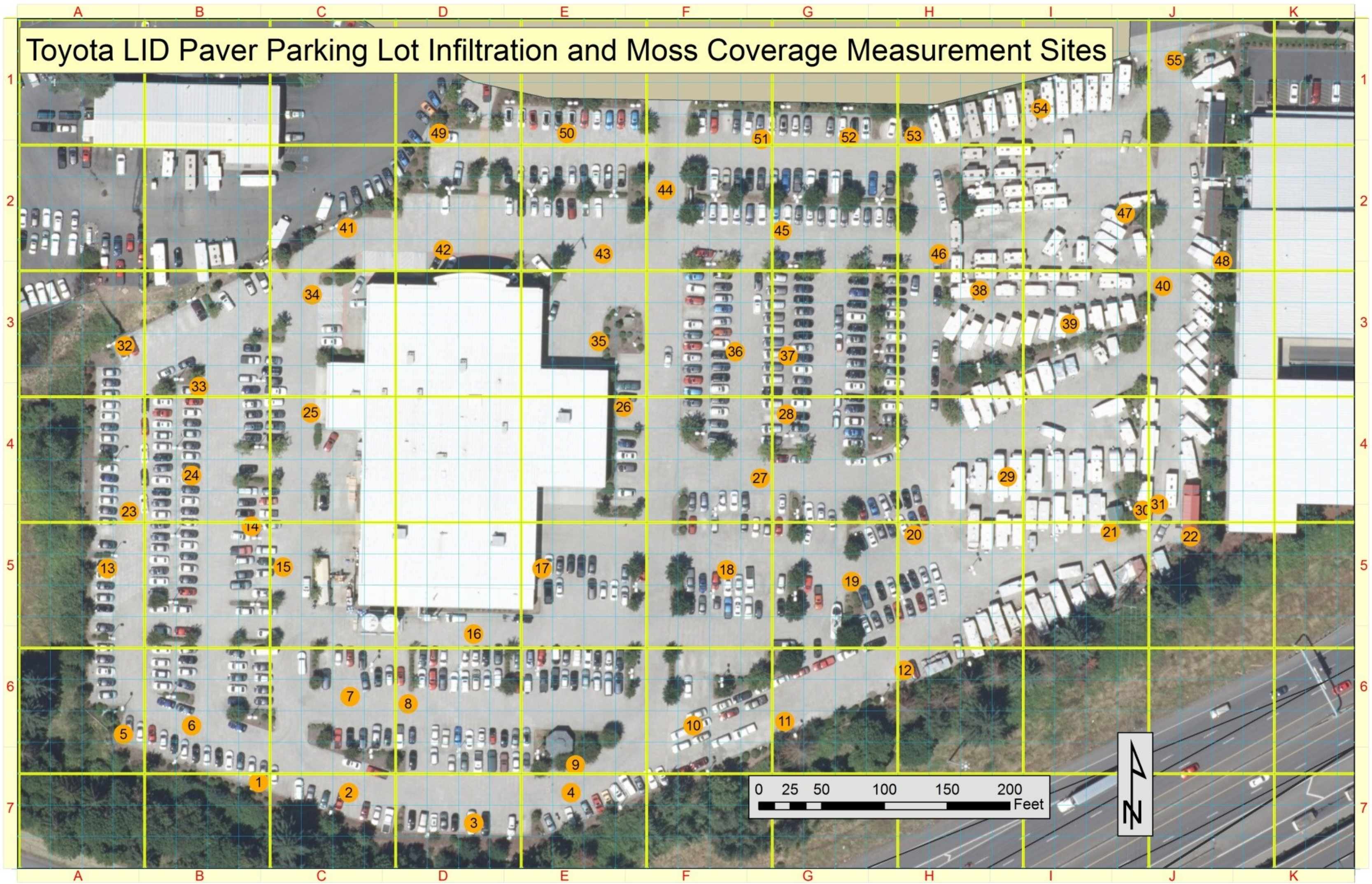

Figure 10. Location of the fifty-five infiltration and moss measurement sites

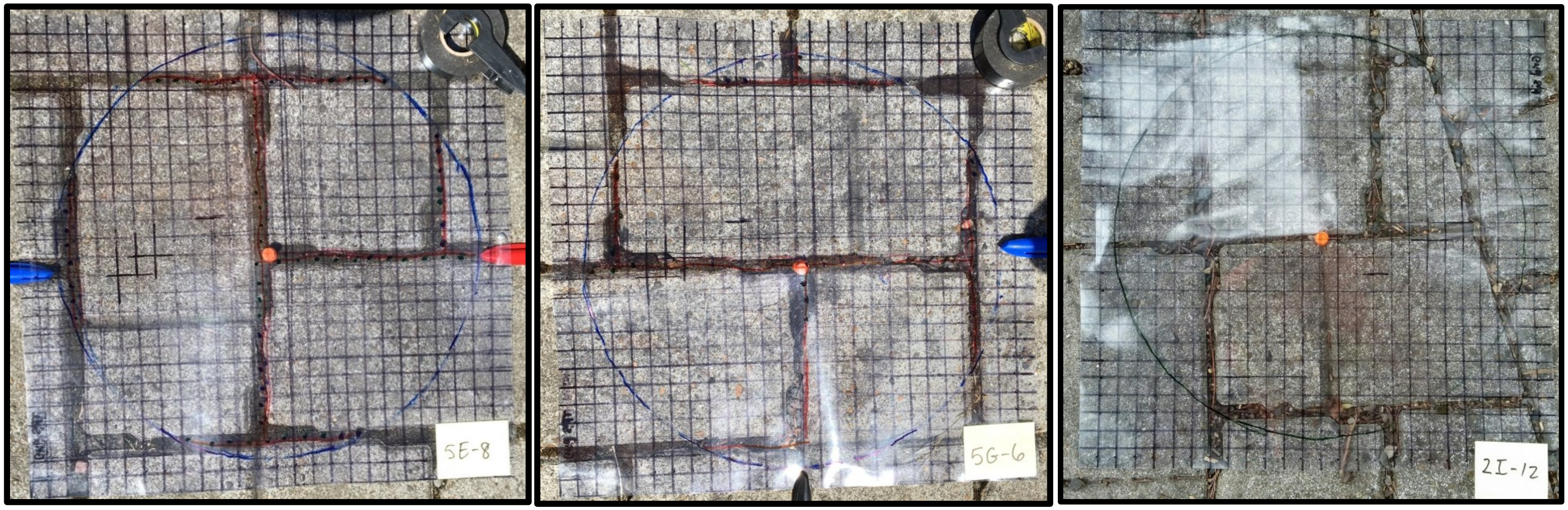

Figure 11. Examples of using inter-paver moss coverage measurement template over different paver block configurations

Figure 12. Composite showing close-up of inter-paver moss, organic debris, and the timed constant head infiltration testing method.

Results and Discussion

Maintenance

Routine vacuum filter street sweeping maintenance was performed as planned over the study period and appears to have kept the parking lot free from accumulation of substantial amounts of debris.

Two conditions noted by field staff could indicate unanticipated effects from the maintenance practices:

- New and used vehicles are frequently moved to rearrange the stock of vehicles for sale. However, replacement vehicles are often parked in or near the previously occupied parking spaces. The relatively continuous, near-complete shading under the vehicles may help to deter moss growth between the pavers in some areas.
- Distinct patterns of lighter-colored pavers with little inter-paver moss are apparent in several parking areas used for vehicle sales (Figure 13). While the cause is unknown, the condition may be due to the pavement surface being unintentionally exposed to pressure-washing as the vehicles are cleaned.

Figure 13. Examples of white appearance on pavers near new vehicles

Precipitation

Daily precipitation at the site peaks in the winter and is minimal in the summer (Figure 14). During water years 2011-2017, the maximum measured 24-hour total precipitation was 3.05 inches on December 6-7, 2015. This rainfall rate is about a 10-year recurrence interval storm for this site and about two-thirds of the 100-year 24-hour storm of 4.30 inches (Clark County, 2014). The maximum measured 1-hour precipitation of 0.76 inches on December 8, 2015 is equivalent to almost a 50-year rainfall intensity recurrence interval storm (ODOT, 2014). These maximum intensities, especially the 0.76 inches/hour, suggest the December 2015 event was an unusually intense and large event for the seven-year study period.

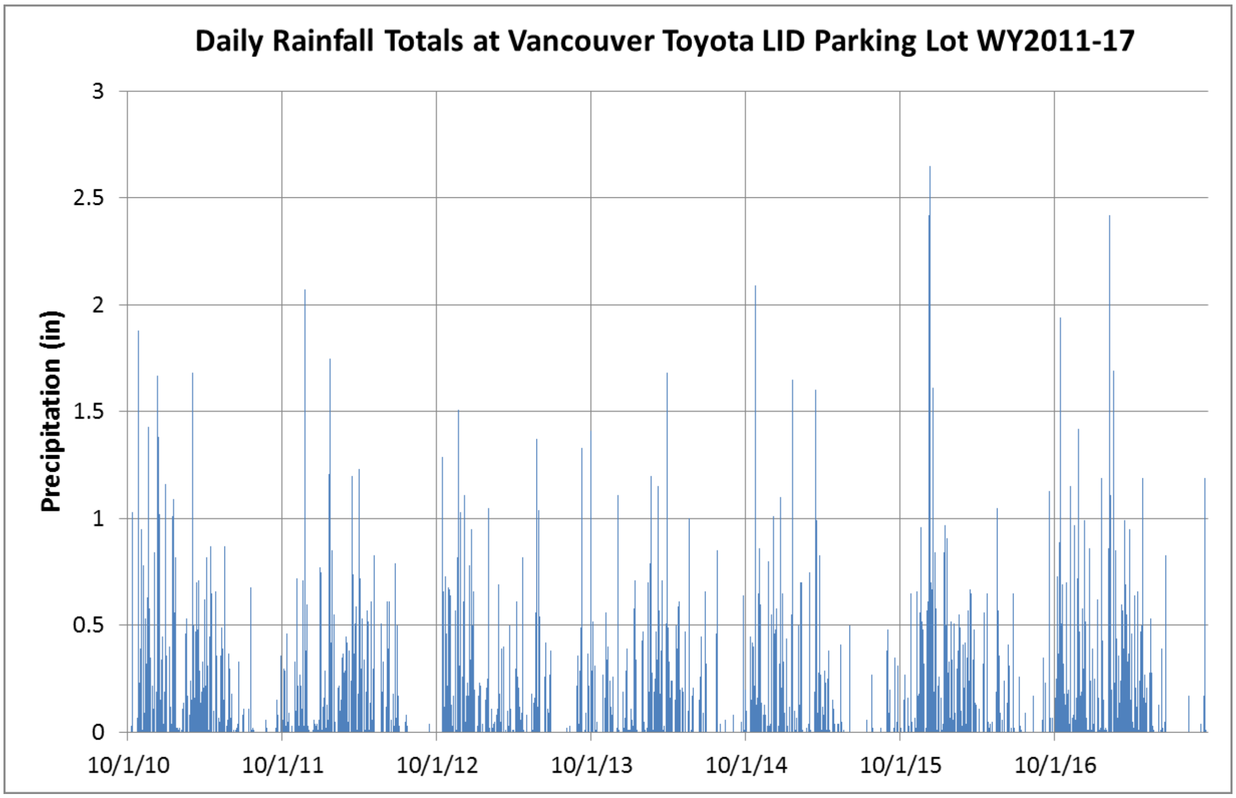

Figure 14. Daily rainfall totals at LID parking lot during water years 2011-2017

Surface Runoff and Monitoring Vault Flow

No surface runoff left the parking lot via the field inlets over the course of the study. In a few cases, a small amount of infiltrated water stored in the subbase appears to have seeped into the conveyance pipes and drained to the monitoring vault. Figure 15 shows infiltrated water seeping into the conveyance system during one of these times. Figure 16 depicts the minimal overall seepage into the field inlet conveyance system and the unusual December 2015 peak.

A few small, isolated puddles were noted during intense rainfall events, and residual sediment on some paver surfaces appeared to indicate other small puddles. The dealership foreman was notified about these small areas for corrective maintenance.

Figure 15. Close-up image of subsurface seepage under a south curb inlet between green reducer and black vertical pipe (taken during heavy rain event on 10/22/2014)

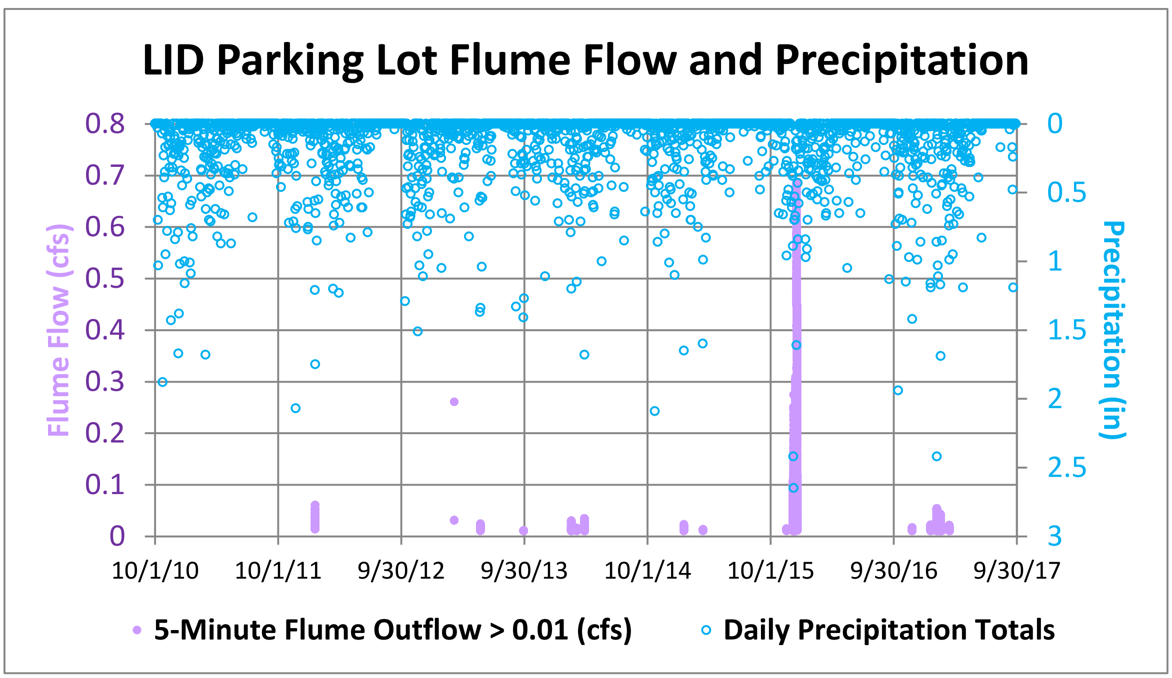

Figure 16. Monitoring vault flume 5-minute interval outflow and daily total precipitation WY2011-2017

Over the 7-8 year period since installation, the flow control and treatment benefits of this parking lot have been consistent and substantial. Single event modeling in HydroCAD indicates the 7.6 acre lot would generate peak flows of nearly 21 cfs from traditional impervious pavement during a 2.25" inch, 24-hour rainfall event, and nearly 1.7 cfs from small, frequent events of 0.3" in 24 hours. On average the site infiltrates over 20 acre-feet of water annually.

Observation Well Water Depth

Observation well high-water marks generally paralleled the seasonal precipitation pattern but remained well below the pavers. As expected, peak high-water marks occurred during the winter with much lower marks measured during the summer, often at the bottom of a well. Figure 17 shows observation well depths, measured subsurface water heights, and monthly rainfall during the study. Across all six observation wells, the high-water marks always remained at least one foot below the paver surface except for a single measurement slightly less than one foot in well #4. These measurements indicate that the stone filled subbase performed as designed.

Visually Estimated Moss Coverage

Visual estimates of inter-paver moss coverage varied considerably across the site. Figure 18 shows the spatial distribution of estimated inter-paver moss cover by quartiles. Larger areas of contiguous high moss coverage tended to occur along or near the southern boundary and to a lesser extent along the northwestern and northern boundaries. The trailer parking area in the eastern third of the lot also tended to have more inter-paver moss coverage. Low moss coverage areas were most prevalent in the western new vehicle parking area where frequent vehicle cleaning occurs and in the more heavily traveled primary traffic flow areas. The site's moss coverage pattern may be due to relative amounts of traffic, shading, prolonged damp conditions, and organic input from nearby trees. Overall, since the earlier study, moss growth in much of the newer Phase 2 area appears to have caught up with the Phase 1 area.

Measured Moss Coverage and Infiltration Rates

During May through July 2017, inter-paver moss measurements and infiltration tests were conducted at fifty-five randomly selected sites (see appendix). These measurements were used to estimate overall infiltration effectiveness and help evaluate the potential clogging impact of moss growth.

Figure 19 shows the measured percentages of inter-paver moss coverage. Measured moss coverage across the parking lot was highly variable but generally tended to be the lowest in isolated spots along the southwestern border, the heavy traffic areas between the entrance and vehicle service bay entrance (northeast of building), and the northern part of the recreational vehicle trailer area. Conversely, the highest moss coverages were measured in the northern half of the new vehicle parking area with slightly lower moss coverages closer to the southern tree border. This overall pattern for the measured moss is generally consistent with that of the visually estimated moss coverage.

Figure 20 shows the measured infiltration rates for the same fifty-five sites. The overall infiltration rate pattern tends to mirror the pattern of measured inter-paver moss coverage. Many of the highest infiltration rates along the southwest border, northeastern trailer, and to a lesser extent the north central high traffic areas coincide with the lowest measured moss coverages. Conversely, many of the lowest measured infiltration rates coincide with the highest measured moss coverages in the center of the eastern new / used vehicle and southeast trailer parking areas.

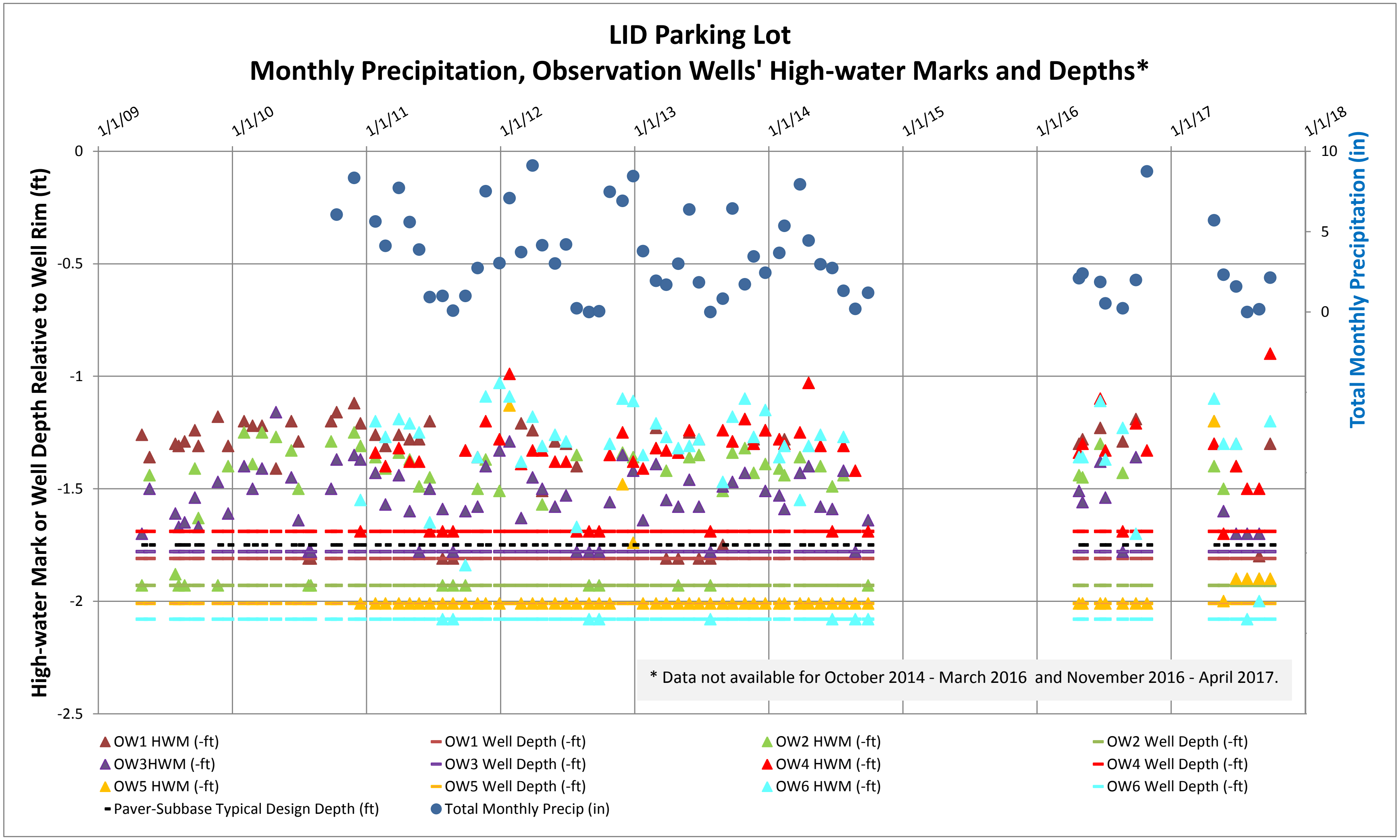

Figure 17. Monthly precipitation, observation well high-water marks (e.g., OW#1-6HWM) and well depths

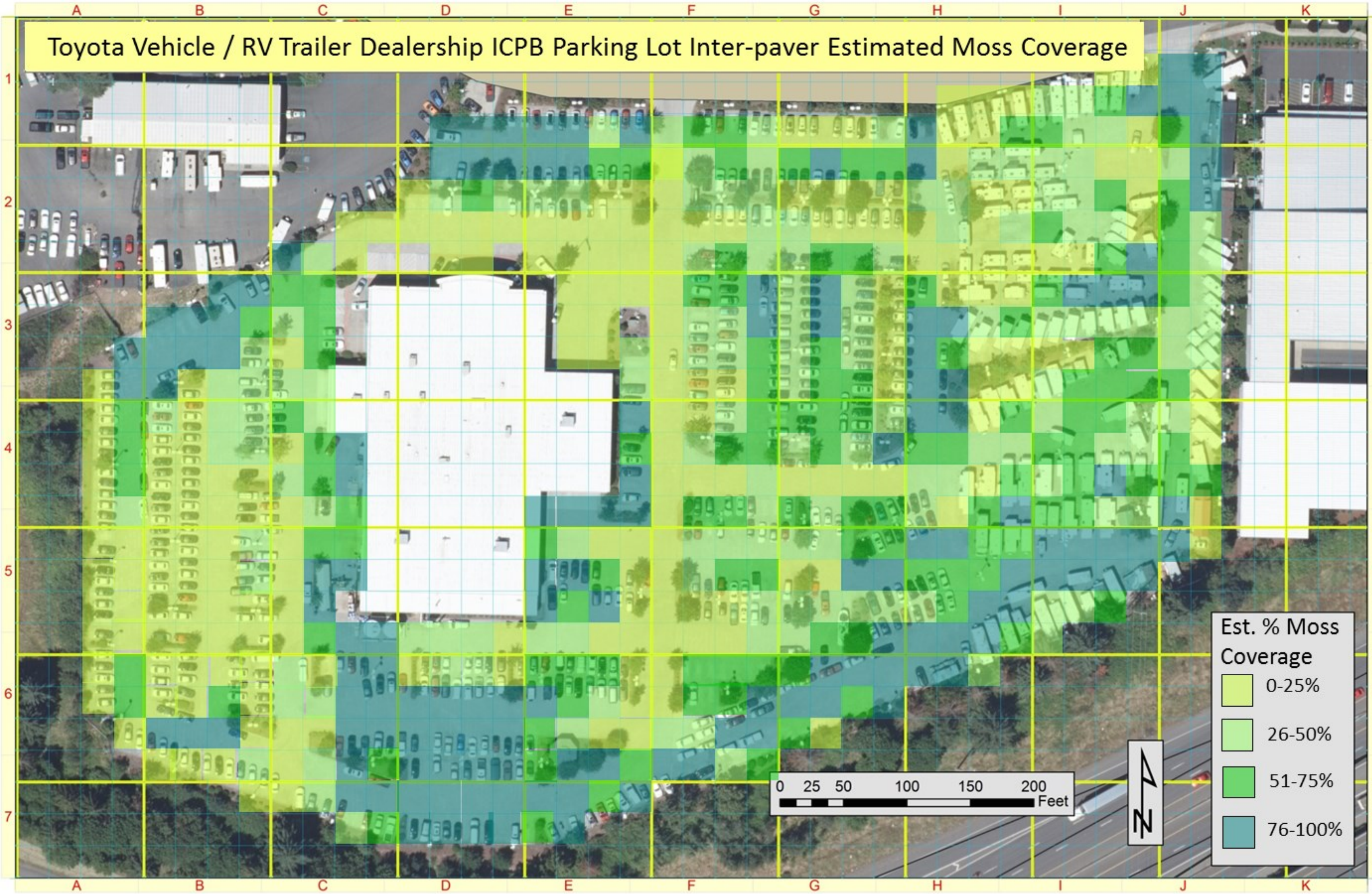

Figure 18. LID parking lot's estimated average inter-paver percent moss coverage within 25-foot grid areas

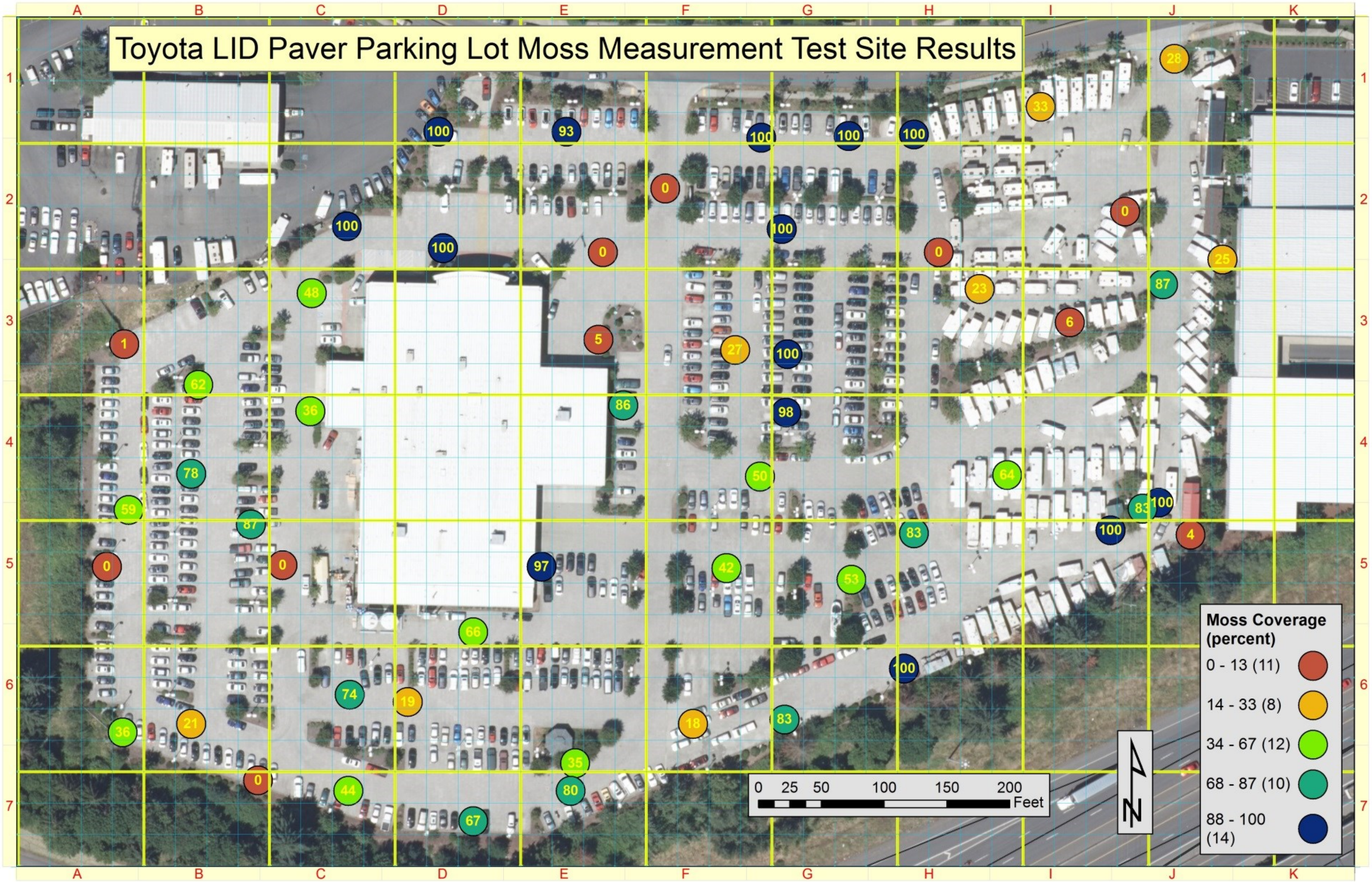

Figure 19. Inter-paver moss measurement results

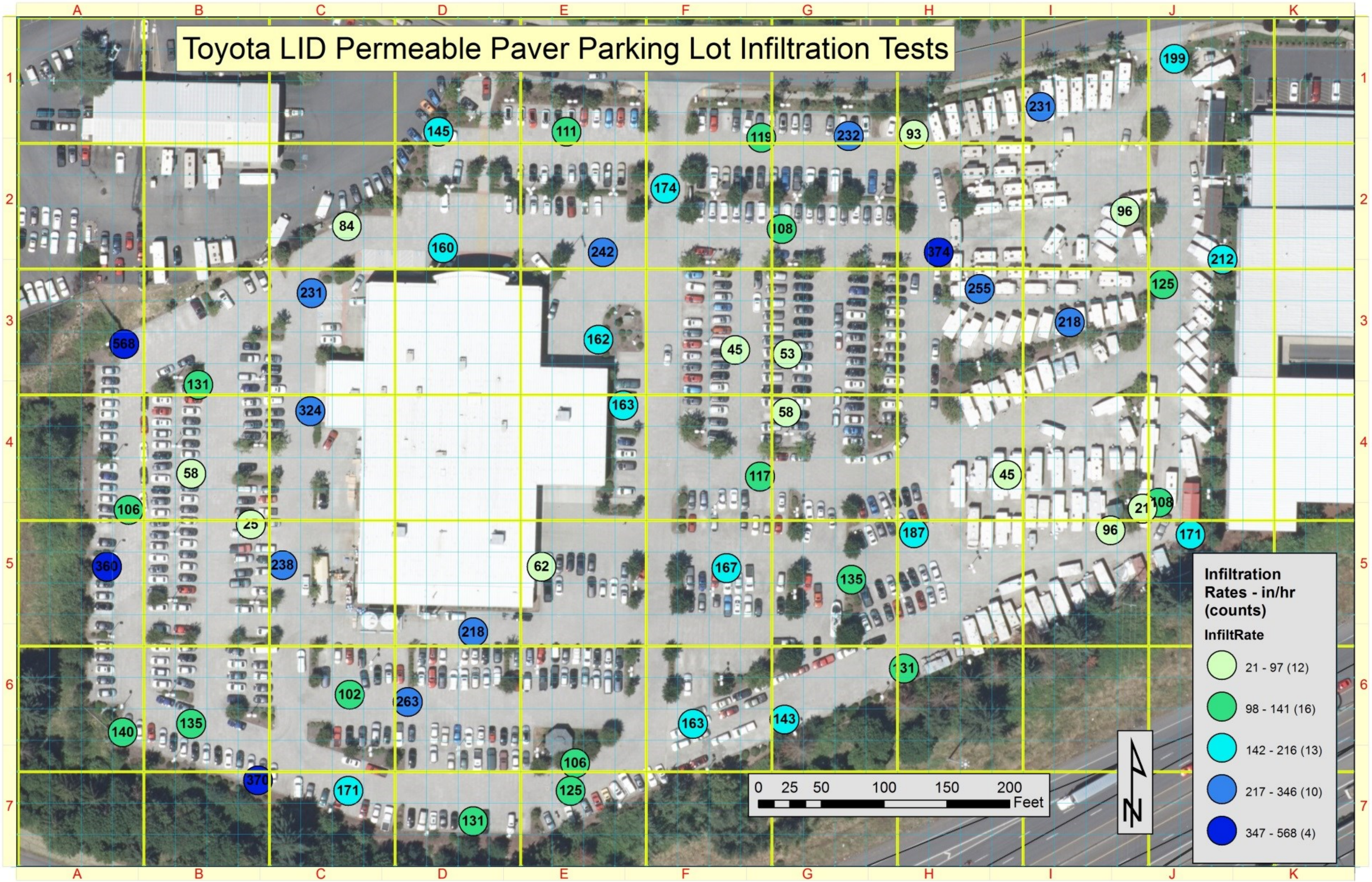

Figure 20. Infiltration test results

Figure 21 depicts the significant inverse linear relationship (negative slope of 1.58 and p-value of 0.00) found between pairs of measured infiltration and inter-paver moss coverage. The R-Sq (R^2 or coefficient of determination) of 35.2% suggests this model fits the data moderately well and that 35 percent of the variation in infiltration rate is explained by the measured percent of moss coverage. Other tested variables, such as moss height and distance to larger trees bordering the parking lot, were found not to be significant explanatory variables for infiltration rates.

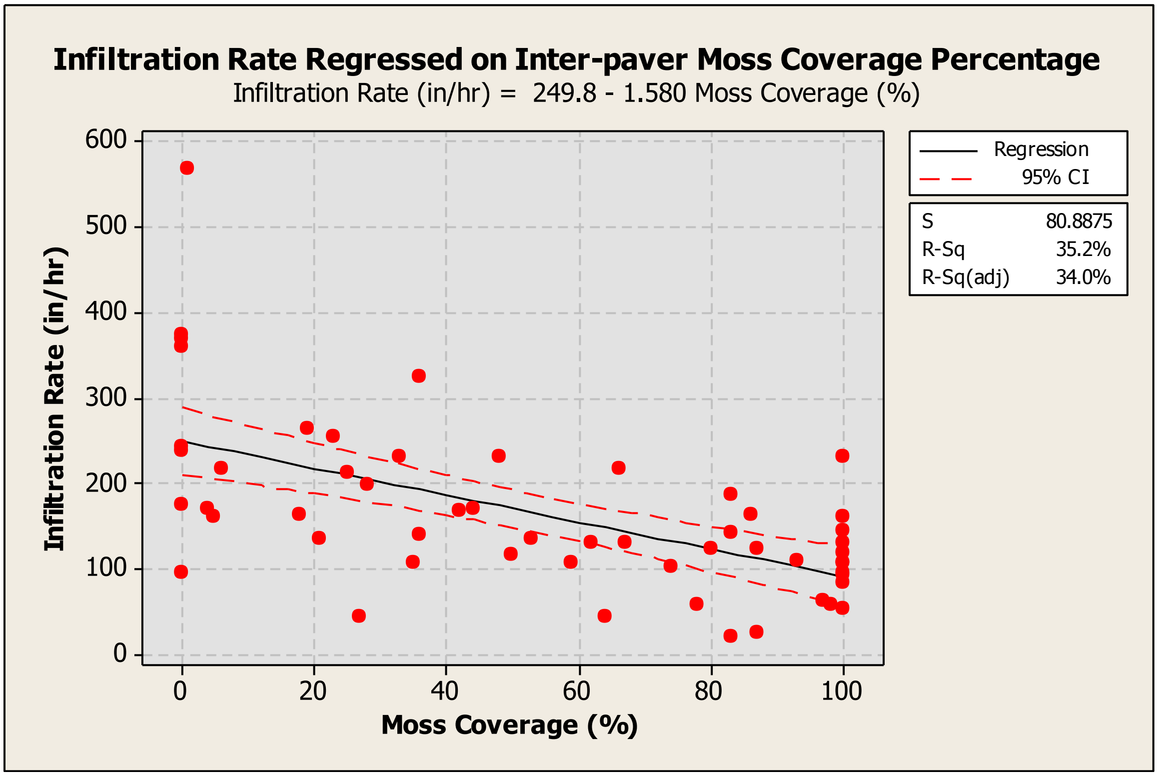

Figure 21. Measured infiltration rates regressed on inter-paver moss coverage

Boxplots in Figure 22 and Figure 23 compare values of moss coverage percentages and infiltration rates for phase 1 and phase 2 installations based on the fifty-five measured sites. The red values and inner boxes indicate, respectively, the median values and 95% confidence limits around the medians for each phase.

Median values for moss coverage and infiltration rates were not statistically different between the phases. However, the general pattern in the boxplots suggests moss may have affected infiltration rates to an increased extent in the older area.

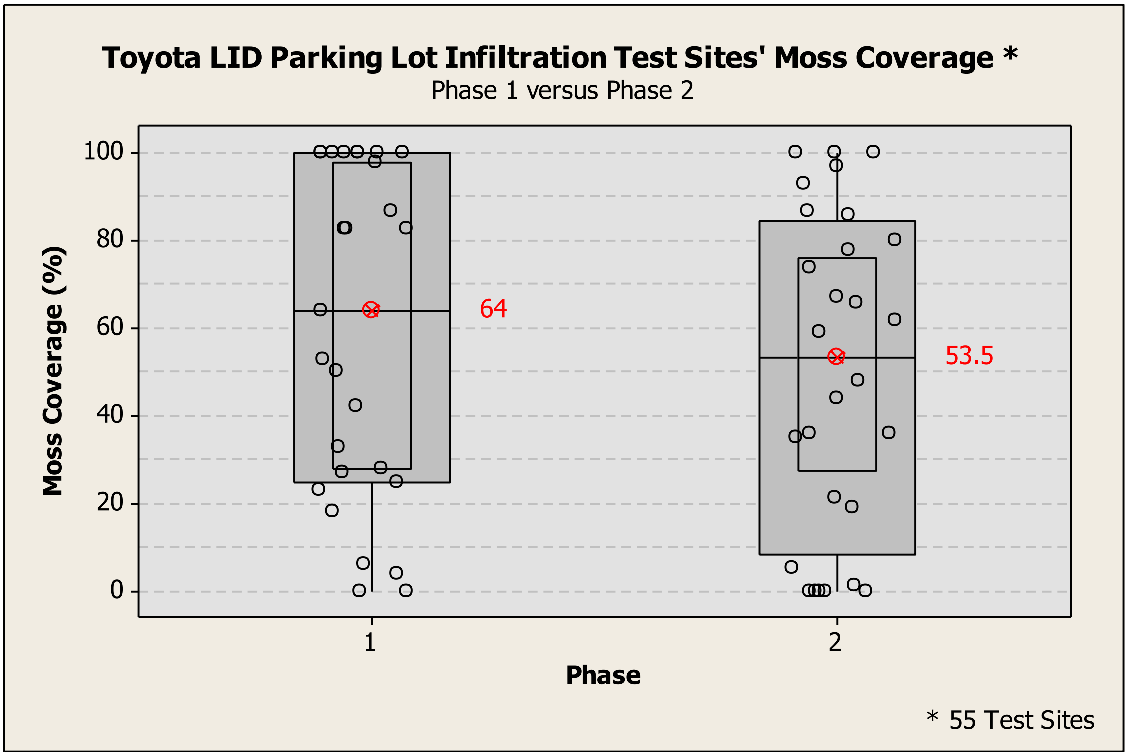

Figure 22 LID parking lot phases 1 and 2 measured inter-paver moss coverage

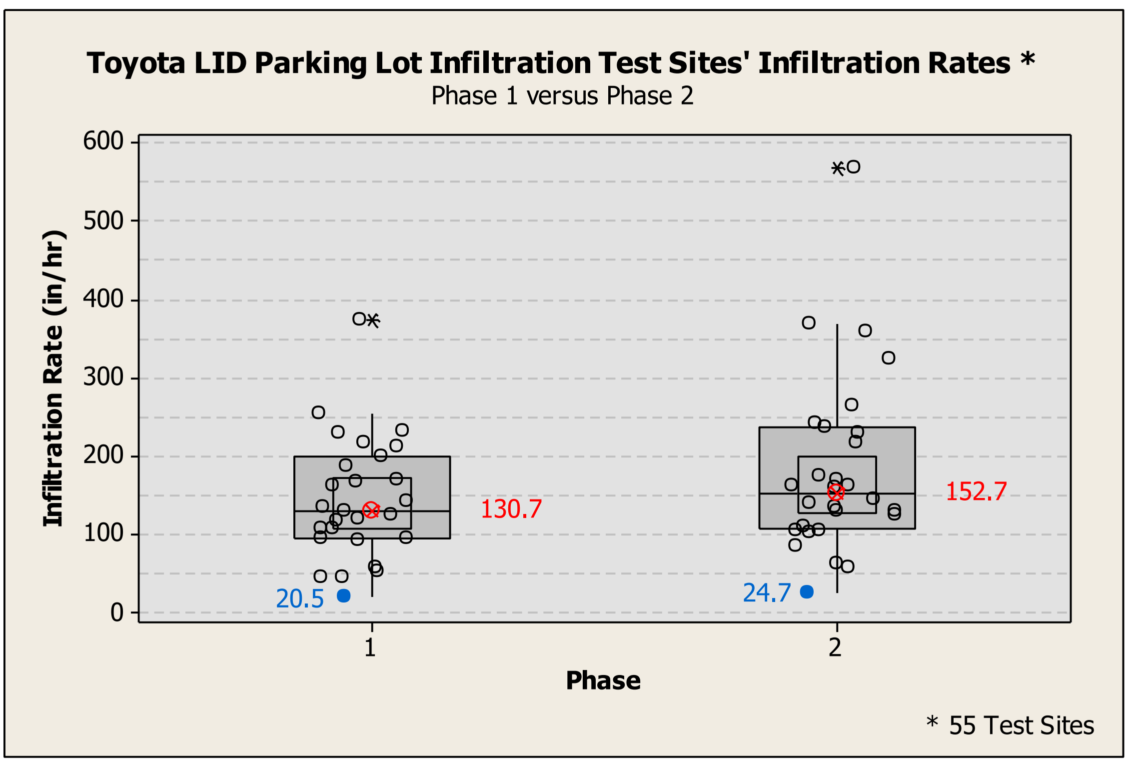

Figure 23 LID parking lot phase 1 and 2 measured inter-paver infiltration rates

Regardless of measured inter-paver moss coverage, even after seven to eight years of site operation, the minimum measured infiltration rates of 20.5 for phase 1 and 24.7 for phase 2 (blue dots in Figure 23) remain substantially higher than Ecology's Guidance maintenance standard action criterion of 10 inches per hour for ICPB. This was an unexpected result given the minimum of 4" per hour measured in the initial study. A more significant overall reduction in observed infiltration rates was anticipated as the facility matured. Due to the high rates of measured infiltration, we are not able to effectively evaluate the appropriateness of Ecology's 10 inches per hour guidance for corrective maintenance.

Notably, moss coverage and infiltration measurements were made during early to mid-summer when moss is more desiccated. The ASTM infiltration test method includes a pre-wet soaking procedure for determining the volume of water used for the subsequent infiltration test. All of the pre-wet infiltration rates were higher than the actual infiltration test rates, suggesting moss and inter-paver debris may swell and reduce infiltration rates. However, the seasonal effect of moss growth on infiltration rates was not examined in this study.

Infiltration Changes Over Time

While median infiltration rates are not statistically different between the newer phase 2 and older phase 1, the difference in medians of 22 inches per hour (152.7 minus 130.7) does suggest decreasing infiltration over time based on the 18 month difference in their completion dates (April 2009 and October 2010).

This difference between phases installed 1.5 years apart suggests a possible annual decrease in median infiltration of 15 inches per hour. Assuming such a change continued at a constant rate into the future, it would take approximately another eight years for the Phase 1 median infiltration rate to approach Ecology's corrective maintenance criteria of 10 inches per hour. However, given substantial infiltration rates even at 100 percent measured inter-paver moss coverage, it does not appear that moss growth alone could result in such a continued decrease in performance. Substantial build-up of fine sediment and / or organic matter between pavers or in the storage subbase would likely also be required.

Conclusions

Performance

- After 7-8 years of operation and routine maintenance, the system continues to infiltrate 100% of annual rainfall and subsurface water remained well below the paver surface.
- Isolated small puddles observed during intense rain events were not a good indicator of overall site performance. No water left the site during these events.
- Routine maintenance using a vacuum filtering sweeper did not appear to eliminate moss growth between pavers. Regardless, cleaning using a vacuum filtering sweeper two to three times per year has been more than adequate to maintain the overall, long-term infiltration performance. This level of maintenance exceeds the recommended guidance and could potentially be reduced while still maintaining effective function.
- Measured moss coverage and infiltration rates were highly variable. However, moss coverage was a statistically significant predictor of infiltration rates. Percent moss coverage explained 35 percent of infiltration variation for the fifty-five collocated measurements of moss coverage and infiltration.
- Moss growth contributed to reduced infiltration rates; however, all measured rates remained well above the recommended corrective maintenance level and did not result in runoff leaving the site, suggesting significant moss is not necessarily detrimental to overall site performance.

Monitoring Methods for Pavement Systems

- Given regular spatial patterns within parking lots, a random sampling within blocks probability sampling design is suggested for similar ICPB uses to target test sites for measurements. This will help acquire detailed, representative data for hypothesis testing of variable relationships such as inter-paver moss coverage and infiltration rates.
- Test site moss coverage measurements can easily be made using a transparent plastic template demarcated with a one-foot diameter circle (same diameter as used for ASTM infiltration tests) subdivided by a grid width equal to the average inter-paver joint space.
- Infiltration tests can be successfully performed on ICPB using a slightly modified ASTM method that includes a rubber gasket to improve the watertight seal with pavers.
- Trained personnel can adequately inventory overall moss coverage by performing visual quartile estimates (cumulative percentage in twenty-five percent groupings) of inter-paver moss coverage for limited subareas. These subareas should be limited to practical size areas of no more than twenty-five foot grids that won't miss important usage patterns, easily allow summarizing targeted variables (e.g. moss coverage), and allow orientation using readily observable permanent features (e.g. light posts, landscape islands, etc.) or high resolution GPS.

Recommended Future Actions

- Side-by-side collocated moss coverage measurements and infiltration tests across the phase 1 and phase 2 boundary would allow for paired comparisons and reduce the impact of potential confounding variables.
- Additional paired moss coverage measurements and infiltration testing during the wet season would allow evaluation of the seasonal effects on moss growth and respective infiltration rates.
- Interlocking concrete paver installations should be explored for more widespread use in low to moderate traffic areas.

References

ASTM International. 2014. *Standard Test Method for Infiltration Rate of In Place Pervious Concrete* ASTM Designation C1701/C1701M-09. West Conshohocken, PA. 3 p.

ASTM International. 2015. *Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems* ASTM Designation C1781/C1781M-15. West Conshohocken, PA. 6 p.

Clark County. June 30, 2014. *Clark County Stormwater Manual Book 1 Applicability, BMP Selection, and Submittal (Final Draft)* Appendix 1-C Hydrology. Vancouver, WA. 275 p.

Clark County Department of Environmental Services, Clean Water Program. February 2013. *Attachment F S8F.7 Flow Reduction Strategy Monitoring Final Report*. Vancouver, WA. 31 p.

Gilbert, R. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York, New York. 320 p.

Griffen, David, McChord's Vancouver Toyota Shop Foreman, October 12 and 16, 2017 in-person interview. Vancouver, WA.

MacKay & Sposito, Inc. May 2008. *Vancouver Toyota Final Stormwater Report*. Vancouver, WA. 6 p.

Meade, J. February 2011. PICP supports Toyota dealership in attaining LEED certification. *Interlocking Concrete Pavement Magazine* Vol. 18 Number 1. International Concrete Pavement Institute, Herndon, VA. 20 p.

Oregon Department of Transportation Highway Division – Engineering and Assessment Management Unit Geo-Environmental Section. April 2014. *Hydraulics Design Manual Chapter 7 – Hydrology* Appendix A Rainfall Intensity – Duration – Recurrance Interval Curves. Salem, OR.

Smith, D. 2011. *Permeable Interlocking Concrete Pavements: Design, Specifications, Construction, Maintenance,* 4th Edition. International Concrete Pavement Institute, Herndon, VA.

Washington State Department of Ecology, Herrera Environmental Consultants, Inc. and Washington Stormwater Center. July 2013. *Guidance Document Western Washington Low Impact Development Operation and Maintenance*, Washington State Department of Ecology, Olympia, WA. 107 p

Appendix

Toyota Low Impact Development ICPB Parking Lot
Collocated Measured Inter-paver Moss Coverages and Infiltration Rates

Construction Phase	Location	Moss Coverage (%)	Infiltration Rate (in/hr)
2	7B-4	0	370
2	7C-3	44	170.5
2	7D-6	67	130.7
2	7E-2	80	124.5
2	6A-12	36	140.1
2	6B-10	21	135.2
2	6C-6	74	101.9
2	6D-8	19	263.2
2	6E-15	35	106
1	6F-10	18	163.4
1	6G-9	83	142.6
1	6H-1	100	130.7
2	5A-6	0	359.8
2	5B-4	87	24.7
2	5C-8	0	237.7
2	5D-14	66	217.9
2	5E-8	97	62.3
1	5F-6	42	166.9
1	5G-6	53	135.2
1	5H-1	83	186.8
1	5I-3	100	95.7
1	5J-2	4	170.5
2	4A-13	59	106
2	4B-10	78	58.1
2	4C-2	36	324.1
2	4E-4	86	163.4
1	4F-12	50	117.1
1	4G-1	98	57.7
1	4H-12	64	44.8
1	4I-13	83	20.5
1	4J-16	100	107.5
2	3A-12	1	568.4

2	3B-15	62	130.7
2	3C-2	48	230.7
2	3E-11	5	162.1
1	3F-11	27	44.6
1	3G-9	100	52.6
1	3H-3	23	254.7
1	3I-7	6	217.9
1	3J-1	87	124.5
2	2C-11	100	84.3
2	2D-15	100	160.1
2	2E-14	0	242.1
2	2F-8	0	174.3
1	2G-9	100	107.5
1	2H-15	0	373.5
1	2I-12	0	95.7
1	2J-14	25	212
2	1D-15	100	145.3
2	1E-15	93	110.5
1	1F-13	100	118.9
1	1G-14	100	232.1
1	1H-16	100	93.4
1	1I-9	33	230.7
1	1J-8	28	199.1