MOA and DOT&PF 2018 Green Infrastructure and Low Impact Development Project Performance Monitoring Report

Prepared for:

The Municipality of Anchorage

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1. Introduction and Project Description

AWR Engineering, LLC (AWR) is assisting the Municipality of Anchorage (MOA) Watershed Management Services (WMS) with performance evaluation of 10 Low Impact Development (LID) and Green Infrastructure (GI) demonstration projects. Five of the LID demonstration projects have not been previously evaluated, and performance monitoring is a requirement of the current MOA and Alaska Department of Transportation and Public Facilities (DOT&PF) Alaska Pollutant Discharge Elimination System (APDES) permit. The remaining five sites have been part of an ongoing performance evaluation program and were discussed in the 2013, 2014, and/or 2015 Low Impact Development Project Performance Monitoring Reports. Although ongoing reporting for these projects is not required, the MOA has elected to continue visual monitoring in order to aid in future LID/GI designs. This report presents the performance evaluation approach and results for each project site and provides recommendations for future projects based on the results and observations.

Of the five new LID demonstration projects, three are owned by DOT&PF. Each of these have drainage areas greater than five acres, and two sites are located in the Campbell Creek watershed. The other two new LID demonstration projects are owned by the MOA, and one is a parking lot retrofit with a rain garden located in the Chester Creek watershed.

A summary of the five 2018 new LID/GI demonstration sites is presented in Table 1, and a summary of the five sites that are part of the ongoing monitoring program are presented in Table 2. Site locations are shown in Figure 1.

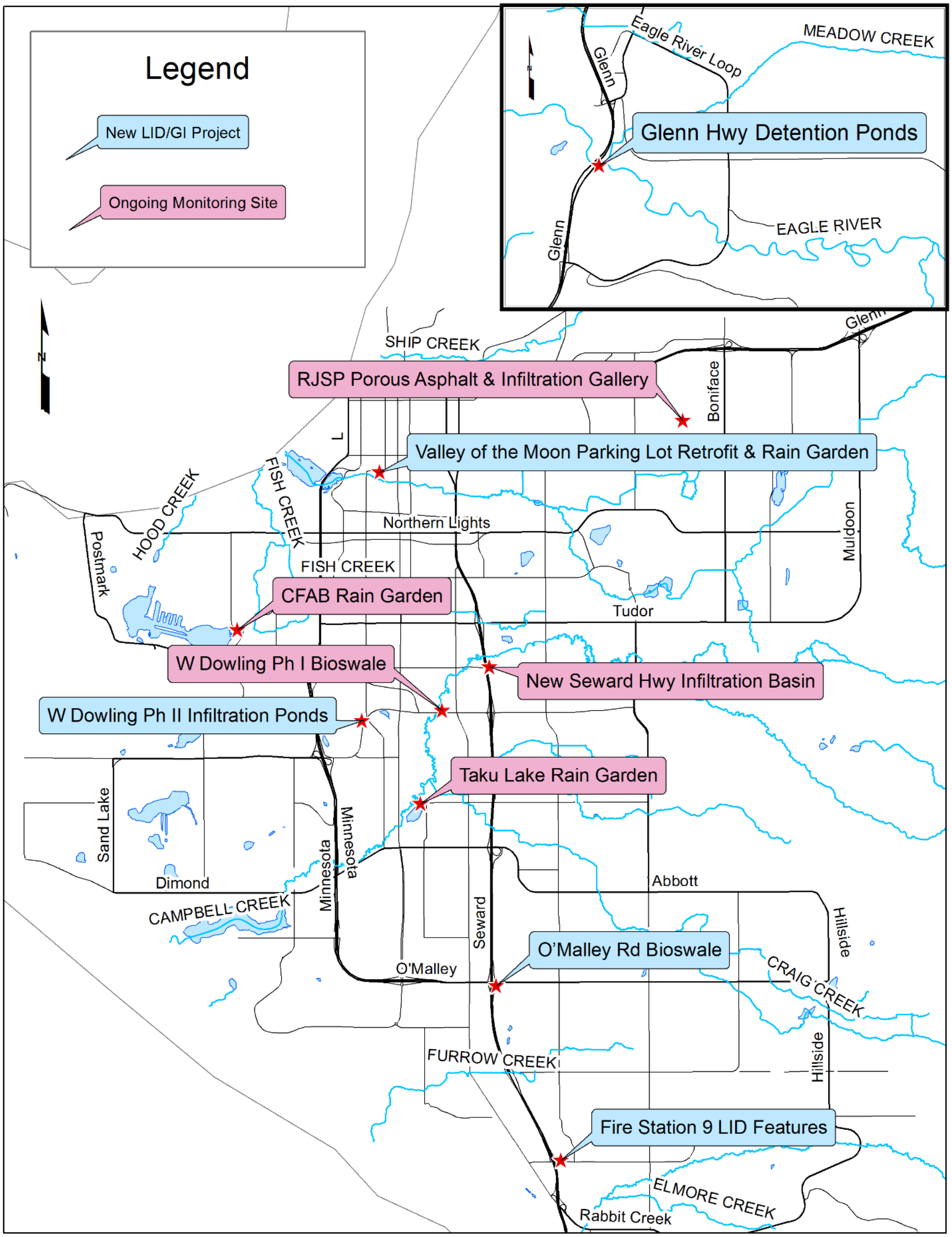
Table 1: 2018 New LID/GI Demonstration Project Sites Summary

Facility Owner	LID/GI Facility	Drainage Area > 5 Acres	Parking Lot Retrofit	Rain Garden	Chester Creek, Fish Creek, Campbell Creek, or Little Campbell Creek Watershed
DOT&PF	West Dowling Road Phase II Infiltration Ponds	✓			✓ Campbell Creek
	Glenn Highway Capacity Improvements: Detention Ponds	✓			
	O'Malley Road Bioswale	✓			✓ Campbell Creek
MOA	Fire Station 9 LID Features				
	Valley of the Moon Parking Lot Retrofit with Rain Garden		✓	✓	✓ Chester Creek

Table 2: 2018 Ongoing Monitoring Site Summary

Facility Owner	LID/GI Facility	Included in Prior Monitoring Report	Rain Garden
DOT&PF	West Dowling Road Phase I Bioswale	2013, 2015 & 2016	
	New Seward Highway Infiltration Basin	2014, 2015 & 2016	
MOA	Russian Jack Springs Park Porous Asphalt and Infiltration Gallery	2013, 2014, 2015 & 2016	
	Taku Lake Rain Garden	2013, 2014, 2015 & 2016	✓
Private Owner	Alaska Commercial Fishing and Agriculture Bank Rain Garden	2013 & 2015	✓

Figure 1: Vicinity Map for New LID/GI Demonstration Projects and Ongoing Monitoring Sites



1.1. APDES Reporting Requirements

The current APDES permit requires that the performance of each LID demonstration project be monitored, evaluated, and documented. The permit requires that changes in runoff quantities be calculated or modeled for each of the demonstration projects and, for new construction projects, compared to a theoretical case of the project constructed without LID practices. The analysis requirements include preparing runoff hydrographs to characterize peak runoff rates and volumes, discharge rates and volumes, and duration of discharge volumes. The evaluation must include quantification and description of each type of land cover contributing to surface runoff, including area, slope, vegetation type and condition (for pervious surfaces), and nature of impervious surfaces (see page 21 of the APDES permit for additional information).

This report presents the monitoring results for the five new DOT&PF and MOA LID/GI demonstration projects as well as an updated status for the five ongoing monitoring sites.

2. Rainfall Data

The MOA/DOT&PF APDES permit requires onsite management of stormwater runoff generated from the 90th percentile rainfall event, which is categorized as 0.52 inches of rainfall in a 24-hour period, preceded by 48 hours of no precipitation. This event is referred to throughout this report as “the water quality event.” During the monitoring period, which was August 21 through October of 2018, this exact event did not occur. However, depending on site location, up to two events that were similar or exceeded this event did occur. Because the water quality event is generally the design threshold, this analysis looked at performance during events equal to or in excess of that event. Although Dates of observation varied by site and are provided in subsequent sections of this report.

The MOA’s Design Criteria Manual (DCM) identifies the 10-year, 24-hour rainfall event as the design criteria for conveyance for minor drainageways and major drainageways. In Anchorage and Eagle River, this event is a base rainfall of 2.28 inches, with an orographic factor applied as needed based on location. Performance evaluation of the LID/GI sites was also evaluated for the 10-year, 24-hour event to characterize how well the sites safely bypass larger events and to aid in future design criteria development.

Rainfall data for characterization of storm event magnitude, duration, and distribution was obtained from several sources, and is discussed for each site in subsequent sections of this report. Rain gauges were selected based on proximity to the monitoring sites and on reliability of the data. Rainfall data used in development of this report is compiled and presented in Appendix A.

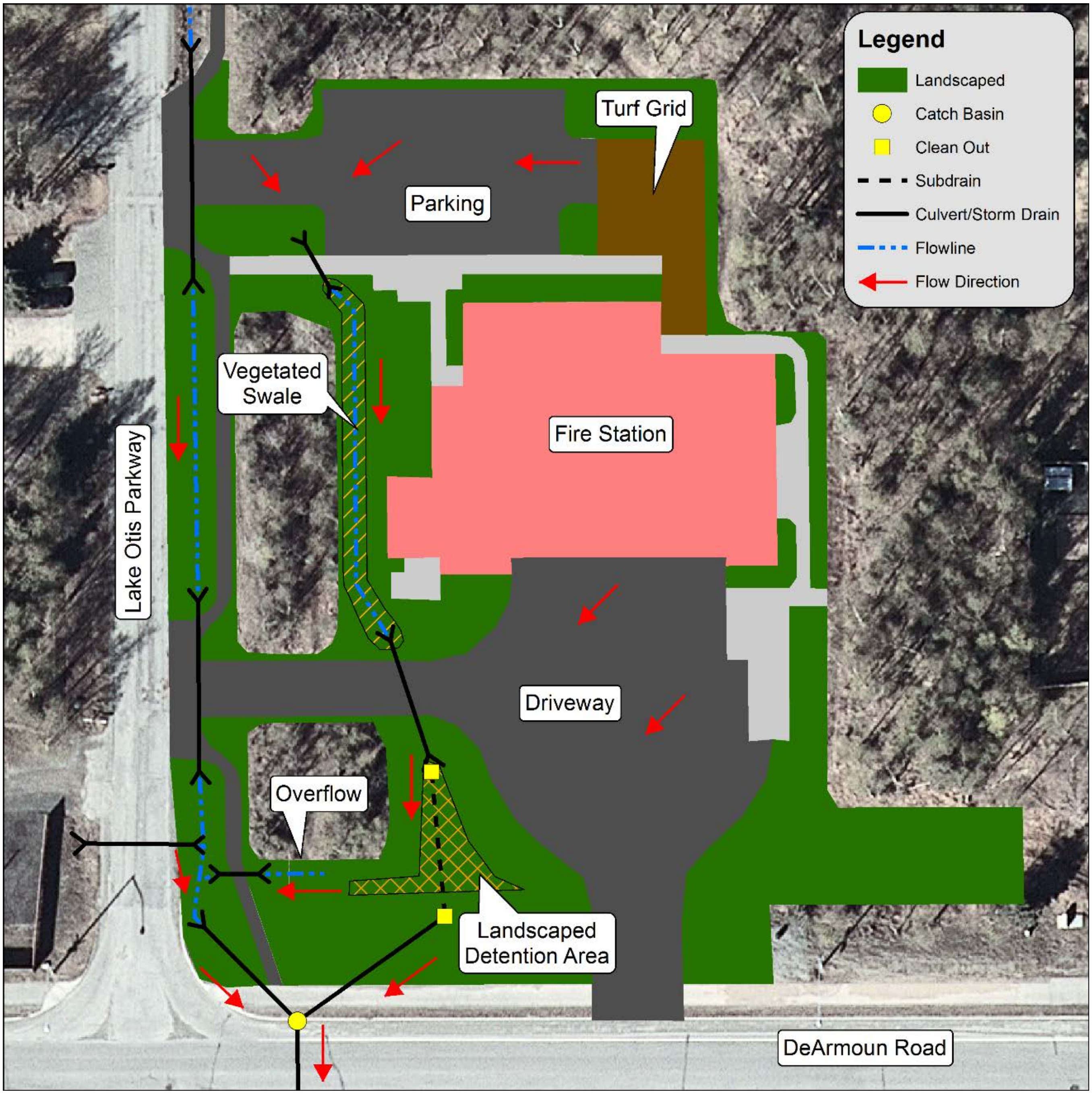
3. Fire Station 9 LID Features (MOA)

The Fire Station 9 Replacement project included construction of a new 11,900 square foot single story fire station facility at the northeast corner of DeArmoun Road and Lake Otis Parkway. The project lies in the Rabbit Creek watershed. Prior to construction, the site was undeveloped land primarily consisting of trees. Construction of the new facility was completed in 2016.

The site includes three LID/GI features which are the focus of this monitoring and reporting discussion. The features include a vegetated swale, a landscaped detention area, and a “permeable pavement” area constructed of turf grid.

These features provide stormwater cleaning and detention prior to discharge of stormwater to an adjacent storm drain system. Figure 2 shows a schematic of the site. (Aerial imagery of this site after construction was not available at the time of this report.)

Figure 2: Fire Station 9 Project Schematic



3.1. LID Feature Details

The LID/GI feature details used in this analysis were based on information from the project's design documents (obtained from the MOA) and from visual observations. The vegetated swale collects runoff from the parking area and a portion of the fire station roof. The swale flows into the landscaped detention area through a 12-inch diameter culvert. The landscaped detention area is connected to a storm drain system running along DeArmoun Road. Together, the vegetated swale and the landscaped detention area provde treatment for runoff from approximately one acre, of which about 0.7 acre is impervious surface. The turf grid area does not accept stormwater runoff from adjacent areas, but was intended to reduce the site's impervious surfaces and provide stormwater treatment for rain that falls on the turf grid surface. Additional details for each LID/GI feature are provided below.

3.1.1. Vegetated Swale Details

The vegetated swale is approximately 140 feet long and is roughly 2 to 3 feet deep. The swale is generally triangular in shape with 2:1 side slopes. The surface vegetation is dense grass, as shown in Figure 3.

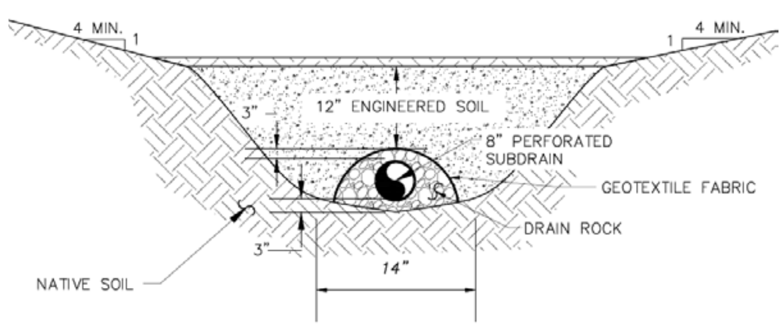
Figure 3: Vegetated Swale

3.1.2. Landscaped Detention Area Details

The landscaped detention area has a footprint of approximately 865 square feet (0.02 acre). Runoff is filtered through 12 inches of engineered soil before entering an eight-inch subdrain which discharges to a storm drain running along DeArmoun Road. The subdrain is surrounded by 3 inches of drain rock wrapped in geotextile fabric and has cleanout risers at both ends. The bottom of the landscaped detention area is not lined. The detention area is designed to allow for approximately 2 feet of ponding. Higher flows are released into the storm drain system through a surface overflow. The surface is landscape rocks with some shrubs, bushes, small trees, and plants around the edges. The landscaped detention area and associated design diagram from the project plans are shown in Figures 4 and 5.

Figure 4: Landscaped Detention Area

Figure 5: Landscaped Detention Area Typical Section



3.1.3. *Permeable Pavement Turf Grid Details*

Approximately 2,200 square feet (0.05 acre) of permeable pavement turf grid was installed in the northeast corner of the site. The turf grid was intended to provide a structurally supportive grassy surface, and the area was designed for only occasional use. Based on the project construction documents, TT24 Tuff Track, manufactured by NDS, was installed over 24 inches of Type II structural fill compacted to 95%. Topsoil infill was placed roughly to the top of the turf grid prior to seeding. Figure 6 shows the turf grid during installation and after approximately two years of use.

Figure 6: Permeable Pavement Turf Grid

During Construction (photo credit Bettisworth North)

October 2018 Site Visit

3.2. Rainfall Events

Performance evaluation of this site was based on rainfall data from a rain gauge located at the intersection of Huffman Road and Elmore Road. This data was provided by the MOA and HDR, Inc. Data was collected using a tipping bucket rain gauge and was converted to hourly intervals as part of this project analysis. During the monitoring period, the rainfall data captured one event in August that met or exceeded the water quality treatment event. Based on rainfall records from other parts of Anchorage, a second event that exceeded the water quality event is expected to have occurred in October, but data for this event from the Huffman/Elmore rain gauge was not available, so the site performance during this event was limited to visual observations. (Available data from other rain gauges was not expected to be a good representation of precipitation at this site due to proximity of the other gauge to the site.) In addition to the August rain event, site performance was also evaluated for the 10-year, 24-hour event. Details for each event are provided below.

1. Event 1 occurred on August 21, 2018. This event resulted in 0.90 inches of rain in a 24-hour period. Approximately 0.19 inches of rain fell in the preceding 17 hours. The rainfall data used for analysis covers a 48-hour period, from 8:00 AM on August 20 through 8:00 AM on August 22, resulting in a total of 1.14 inches of rainfall.
2. Event 2 is the 10-year, 24-hour rainfall event with an orographic factor of 1.075 applied, resulting in 2.45 inches of total rainfall.

Rainfall hyetographs for the two rainfall events are presented in Figures 7 and 8, with supporting data included in Appendix A.

Figure 7: Event 1 August 20-22, 2018 Rainfall Hyetograph

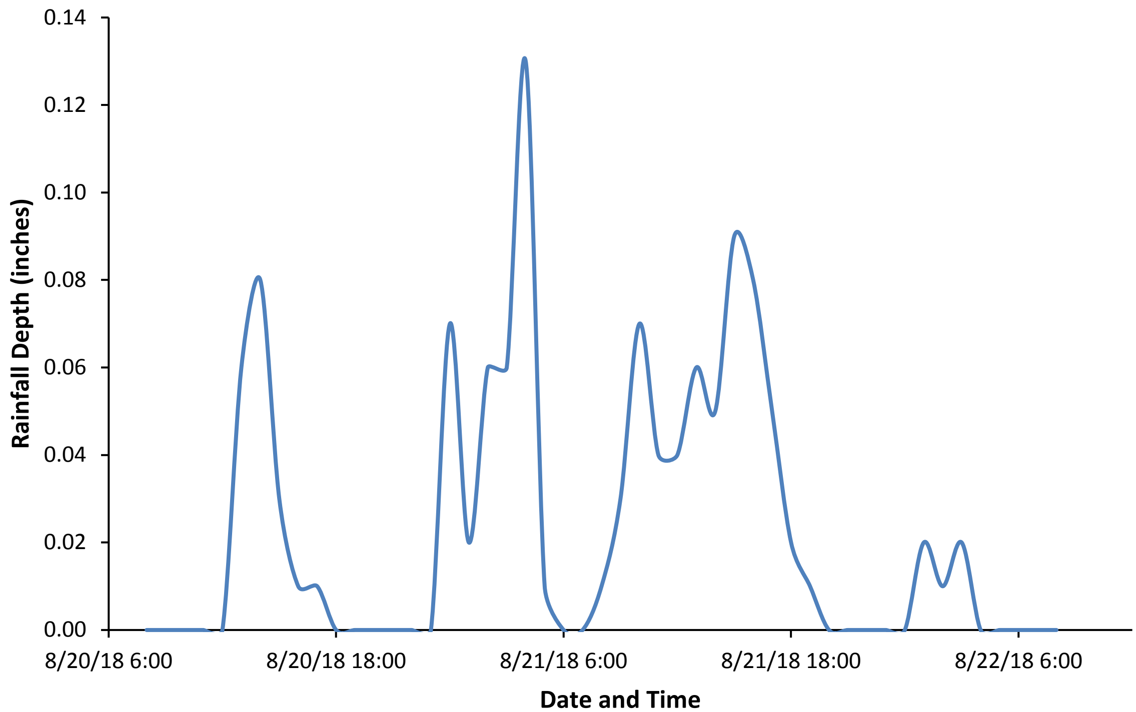
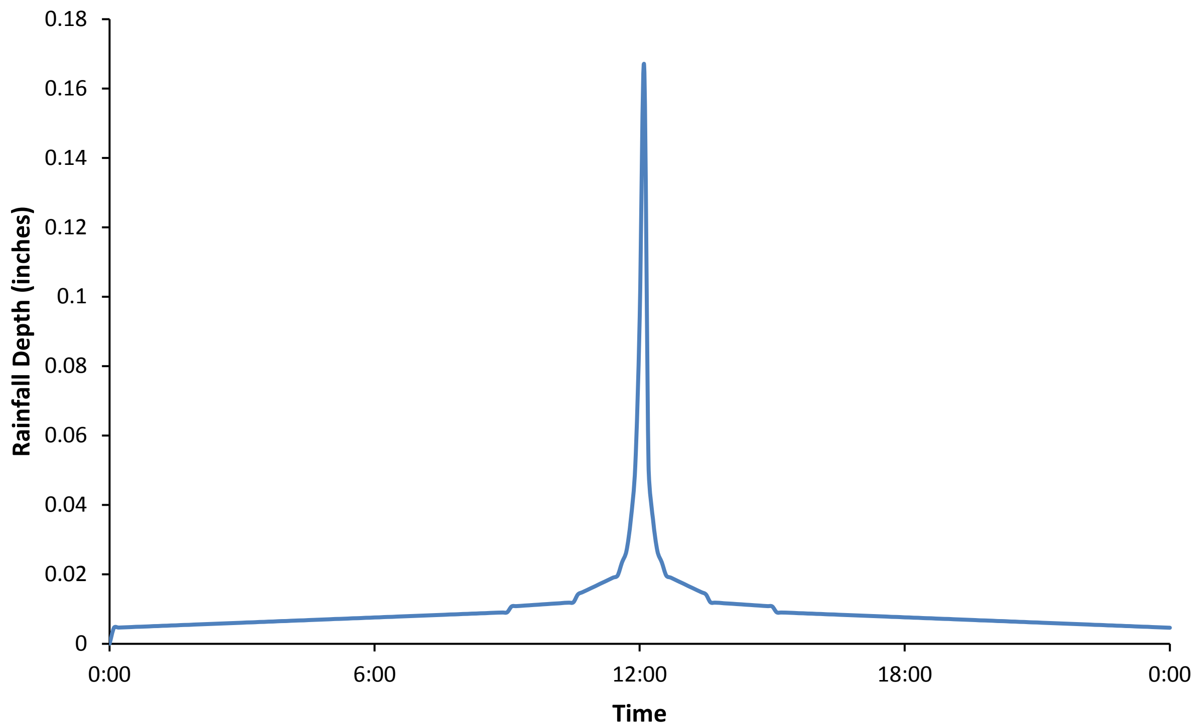


Figure 8: Event 2 10-Year, 24-Hour Rainfall Hyetograph (Orographic Factor 1.075)



3.3. Performance Evaluation

The project performance was evaluated through a combination of visual inspection and hydrologic modeling, as described below.

3.3.1. Visual Monitoring

The LID/GI features were visually inspected during notable rain events in August (Event 1) and October. The vegetated swale and landscaped detention area were performing well. Some performance issues were noted with the turf grid pavement. Details are provided below.

Vegetated Swale and Landscaped Detention Area. During the August 21 site visit, it was actively raining. Water was flowing from the fire station roof structure and from the rear parking lot into the vegetated swale. Only a small amount of water was observed in the vegetated swale, indicating that some of the inflow was successfully infiltrating. The vegetation in the swale was mature and healthy, and was keeping water movement through the swale at a slow velocity to provide opportunity for infiltration and evapotranspiration.

Figure 9: Vegetated Swale during the August 21 Site Visit

Water that was conveyed through the swale was entering the landscaped detention area via a connecting culvert. A small amount of vegetation and organic debris were partially blocking the inlet and outlet of this culvert but did not appear to be impacting performance. Water was also entering the landscaped detention area via direct runoff from the adjacent parking lot. Water was percolating through the treatment layers to the underlying subdrain. Surface ponding (which would indicate a subsurface blockage or slowing of percolation through the treatment media) was not observed in the landscaped detention area, which indicates that the facility is performing very well. Flow in the subdrain could be heard through one of the cleanout risers.

The October 16 site visit occurred after the peak of that rainfall event, and it was not actively raining during the site visit. Facility conditions were similar to the August site visit, except that no standing or moving water was observed in the vegetated swale. The swale and the detention area were in good condition and no issues from the recent rainfall were noted. The Fire Station Chief noted that both the vegetated swale and the landscaped detention area were performing well and that he had never seen standing water in the landscaped detention area.

Permeable Pavement Turf Grid. During both site visits, several performance issues were noted with the turf grid area. The surface of the turf was primarily muddy, as the vegetation was not mature and healthy. In some locations there was ponding on the surface instead of percolating into the subgrade. The grid structure itself was loose and moving under foot traffic. When walked on, water would splash out of the grid surface and subgrade. Vehicle ruts were visible on the surface, and in many areas, no grass was growing. Discussion with the Fire Station Chief indicated that the turf grid area was regularly used by the fire fighters to load and unload their gear and supplies at the beginning and end of their shifts. He also explained that crew members use this area to wash vehicles. The Fire Station Chief also discussed that he had tried to add seeding and fertilizer to the turf grid, but it had not improved the condition of the vegetation.

3.3.2. Hydrograph Development

To demonstrate the impact of the vegetated swale and landscaped detention area on runoff volume and peak flows, discharge hydrographs were developed using the EPA's Storm Water Management Model (SWMM) Version 5.1. SWMM produces hydrographs using the non-linear reservoir method based on user-defined rainfall parameters, soil conditions, and basin features.

Discharge hydrographs were developed for two cases.

1. Case 1 is the as-constructed case with the vegetated swale and landscaped detention area in place. Because the turf grid was not accepting water from adjacent surfaces, it was not included in the overall basin model.
2. Case 2 is the hypothetical case of the project constructed without the LID features. In this case, runoff from the project was routed directly to the DeArmoun Road storm drain system.

To represent Case 1, SWMM's LID modeling tools were used to simulate the vegetated swale and the landscaped detention area. Each LID feature was modeled as a subcatchment with the LID feature occupying the entire area. Contributing areas were modeled as subcatchments that discharge runoff to the LID features. Overflow from the landscaped detention area was incorporated into the model to simulate the bypass of higher flows. Observations from the August rainfall event were compared to model results for ponding depth and subdrain flow, and the LID model parameters were calibrated accordingly.

To represent Case 2, the LID features were removed and the associated areas were modeled as traditional lawn. If the site had been constructed without LID features, site runoff would discharge directly to the storm drain on DeArmoun Road with no cleaning or detention.

Model input parameters are provided in Appendix B.

3.3.3. Results

Figures 10 and 11 present the resulting runoff hydrographs. These hydrographs represent runoff from the fire station site entering the storm drain system for Case 1 and Case 2 for each rainfall event analyzed.

Figure 10: Event 1 August 20-22, 2018 Discharge Hydrographs – Fire Station 9

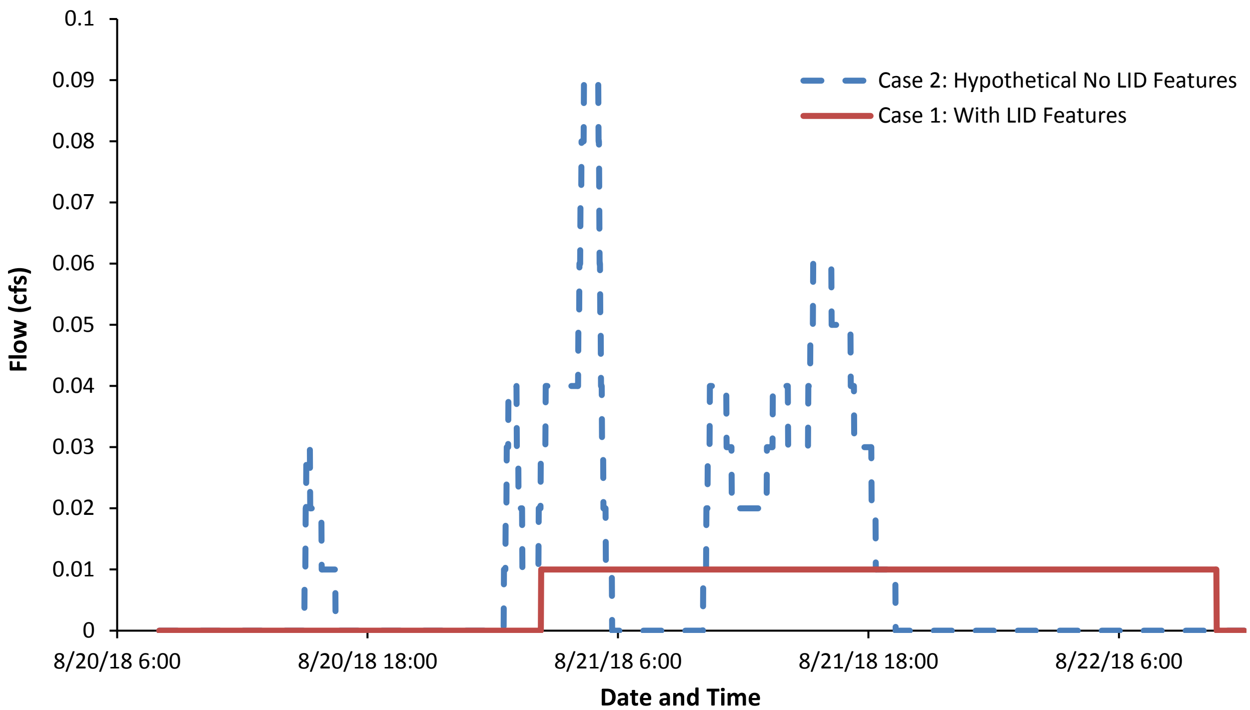
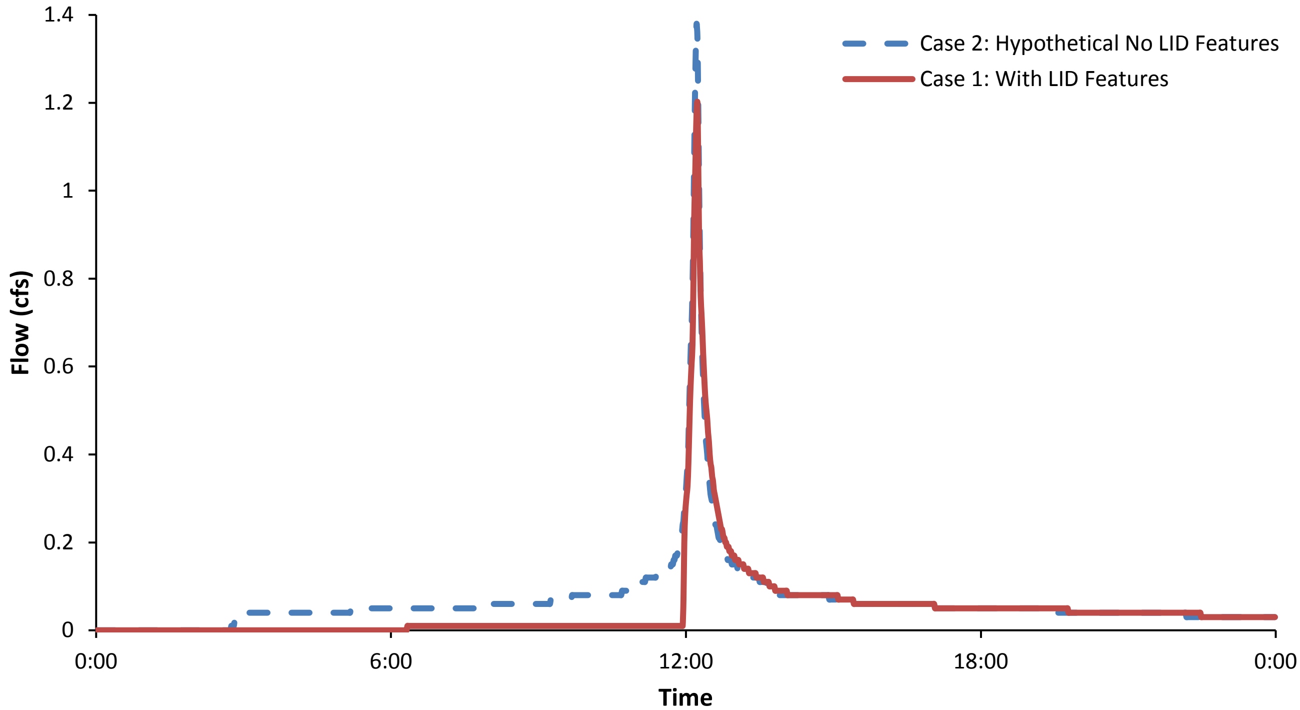


Figure 11: Event 2 10-Year, 24-Hour Discharge Hydrographs – Fire Station 9



The peak flows and runoff volumes are summarized in the table below.

Table 3: Fire Station 9 LID Features Performance Summary

Case	August 21, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 - With LID Features	0.02	1,644	1.21	5,334
Case 2 - Hypothetical No LID	0.09	1,938	1.40	5,962
Percent Decrease	78%	15%	14%	11%

The modeling results show that for both rainfall events, the LID/GI features result in a noticeable reduction of both the total volume and the peak discharge from the site. Much of the runoff from the August event is retained onsite and the remaining runoff is detained and treated before entering the storm drain system. During the much larger 10-year event, the first portion of runoff is retained or treated through filtration. Once the landscaped detention area reaches its maximum ponding depth, flow begins to safely bypass the facility and discharge into the storm drain system through the overflow. This is consistent with the site observations and with how the site is designed to function.

3.4. Conclusions and Recommendations for Future Projects

Conclusions and a summary of recommendations for future projects is provided below.

Vegetated Swale and Landscaped Area

- The vegetated swale and landscaped detention area are successfully providing stormwater treatment, infiltration, and detention of small to moderate rainfall events, and are safely bypassing large events into an adjacent conveyance system. These facilities are providing a significant decrease in runoff volume, peak flow, and pollutant transport from the site. Continued use of these types of facilities is recommended for Anchorage.
- The vegetation in the vegetated swale is both functional and aesthetic, and is expected to be relatively low maintenance. Use of these types of plants is recommended in similar locations, where appropriate.
- The Fire Station chief reported some maintenance issues with keeping grass out of the landscaped detention area, and noted that he pulls grass out of the rocks regularly. Low maintenance vegetation could be considered for this type of facility instead of a rock surface. Vegetation would also enhance the filtration and evapotranspiration potential for this area.
- If additional treatment, storage, or detention is desired, a subsurface engineered soil layer could be added to the vegetated swale.

Permeable Pavement Turf Grid. The performance issues observed with the turf grid area is expected to primarily have been caused by site use that is inconsistent with designer expectations and improper preparation of the soil subgrade.

The turf grid was designed for only occasional loading and was not intended to support every day traffic loading or the surface abrasion and water volume associated with washing vehicles. After completion of the site construction, the needs and uses of the site evolved from what was originally anticipated, and this significantly contributed to the poor performance of the turf grid.

In addition to the site use change, the constructed subgrade does not appear to have been compatible with the turf grid installation. The turf grid was placed over traditional Type II fill material, compacted to 95% of maximum density. NDS generally recommends that this turf grid product be constructed over an open-graded backfill layer such as AASHTO #57, which is generally one-inch minus rock. Some manufacturer literature does discuss using road base as backfill in cases of heavy surface loading, which was expected to the basis of this design. Compacted Type II fill is not expected to percolate water very well, which may have contributed to the soggy conditions at the ground surface. The area was also generally flat, so surface water was not able to shed to adjacent areas.

Other factors that MOA representatives, the Fire Station Chief, and/or the project design team have discussed that could have contributed to the turf grid failure but have not been confirmed include the following: poor quality of the topsoil, lack of sunlight on the north side of the building where the turf grid was located, insufficient depth of topsoil or topsoil that was too compacted, and/or accidental damage from human activity (e.g. snow plowing, salting, soaps, etc.).

Despite the observed performance issues, this turf grid installation provided valuable information about these types of systems that will help ensure success in future applications. Based on lessons learned from this site, the following list of recommendations has been developed for future installations of turf grid or other grassy “pavement” surfaces.

- Ensure that the site use is very clear and will not be changed after the turf grid is constructed.
- Ensure that the site owners and day-to-day users are supportive of the installation and understand the associated limitations and design intent.
- Limit turf grid applications to locations where frequent or heavy traffic loading is not expected, and ensure that the base material is a porous, open-graded rock that is appropriate for the design loading. The open graded rock will provide void space to hold water and allow it to eventually percolate into the natural subgrade. If infiltration is not desired or practical, consider installing a perforated subdrain in the rock layer to collect excess water and direct it to an outlet or to a receiving system.
- Ensure that adequate and appropriate soils and seeding materials are used and that the placement will receive sufficient sunlight to support the vegetation growth.

4. West Dowling Road Phase II Infiltration Ponds (DOT&PF)

Dowling Road is an east-west roadway in Anchorage. The West Dowling Road Phase II (WDII) project upgraded and extended the road from C Street to Minnesota Boulevard. The project widened the road from two to four lanes with a center median/turn lane and bike lanes, provided a bridge over Arctic Boulevard and the Alaska Railroad, and extended West Dowling Road to a new Raspberry Road intersection. The project was completed in 2015.

Five infiltration ponds were constructed as part of the WDII project. The LID performance monitoring focused on the following three infiltration ponds: pond #1, located northeast of the intersection of West Dowling Road and Raspberry Road, and ponds #4 and #5, located west of the overpass at Arctic Boulevard, near Electron Drive.

According to the *West Dowling Road Phase II – C Street to Minnesota Drive Hydraulics and Hydrology Report* (H&H Report), the infiltration basins were designed to capture and infiltrate runoff generated from events up to and including the 100-year, 24-hour rainfall event of 3.59 inches. Figure 12 shows the approximate locations of the three ponds evaluated for this report.

Figure 12: West Dowling Road Phase II Site Overview

4.1. Infiltration Pond Details

Infiltration pond details used in this analysis are based on information from the project design documents (provided by DOT&PF) and from visual observations. Infiltration Pond #1 collects stormwater from approximately 4.8 acres, 2.1 acres of which is impervious surface from the new roadway and pathway and from the business park to the northeast. The infiltration pond is vegetated with grasses and is approximately 90 to 100 feet long by 25 feet wide, with 4:1 side slopes. Approximately one-half acre of forested area lies east of the pond. Riprap is present near the inlet, and the pond has no outlet. Infiltration Pond #1 is shown in Figure 13.

Figure 13: Infiltration Pond #1

Infiltration Ponds #4 and #5 collect stormwater from approximately 6.2 acres. Of this area, Electron Drive, West Dowling Road, and the pathway contribute 1.7 acres of impervious surface. Pond #4 is located west of the southern end of Electron Drive and Pond #5 is located northeast of the intersection of Electron Drive and Howard Holton Court. Ponds #4 and #5 are connected hydraulically via a pipe with a 0% slope. The water surface elevations are designed to be the same in both ponds. Pond #4 is approximately 115 feet long by 50 feet wide, and Pond #5 is approximately 125 feet by 40 feet. As shown in Figure 14, Infiltration Ponds #4 and #5 both have riprap around the pond edges, with vegetated grasses above the riprap. Both ponds have no outlet.

Figure 14: Infiltration Ponds #4 (left) and #5 (right)

4.2. Rainfall Events

Rainfall data was obtained from Anchorage International Airport (AIA) via the National Centers for Environmental Information (formerly the National Climatic Data Center). During the monitoring period of August through October 2018, two rainfall events met or exceeded the water quality treatment event based on a 24-hour event. A 10-year, 24-hour storm event was also considered for this analysis. Each event used for analysis is described below.

1. Event 1 occurred on August 21, 2018. At AIA, this event resulted in 0.72 inches of rain in a 24-hour period. Approximately 0.33 inches of rain fell in the preceding 17 hours. The rainfall data used for analysis covers a 48-hour period, from 7:53 AM on August 20 through 6:53 AM on August 22, resulting in a total of 1.08 inches of rainfall.
2. Event 2 occurred on October 16, 2018. At AIA, this event resulted in 0.52 inches of rain in a 24-hour period. This event was preceded by 0.30 inches of rain on October 15. The rainfall data used for this analysis covers a 48-hour period, from 12:53 AM on October 15 through 11:53 PM on October 16, resulting in a total of 0.82 inches of rainfall.
3. Event 3 was the hypothetical 10-year, 24-hour rainfall event, resulting in 2.28 inches of total rainfall. The orographic factor for this location is 1.0 and does not change the total rainfall from the base depth storm provided in the DCM.

Events 1 and 2 meet the permit requirements for water quality treatment based on a 24-hour event. However, a measurable amount of rain fell preceding both events and a 48-hour event was modeled for Event 1 and 2 in order to capture the total volume of runoff from the storm. Rainfall hyetographs for the three rainfall events are presented in Figures 15 through 17. Supporting data is included in Appendix A.

Figure 15: Event 1 August 20-22, 2018 Rainfall Hyetograph

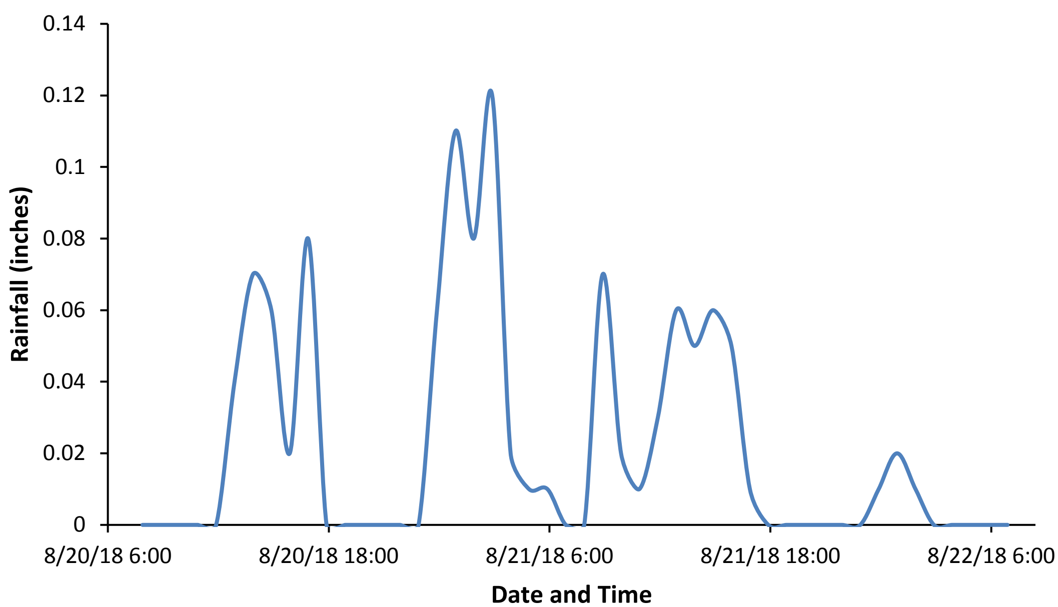


Figure 16: Event 2 October 15-16, 2018 Rainfall Hyetograph

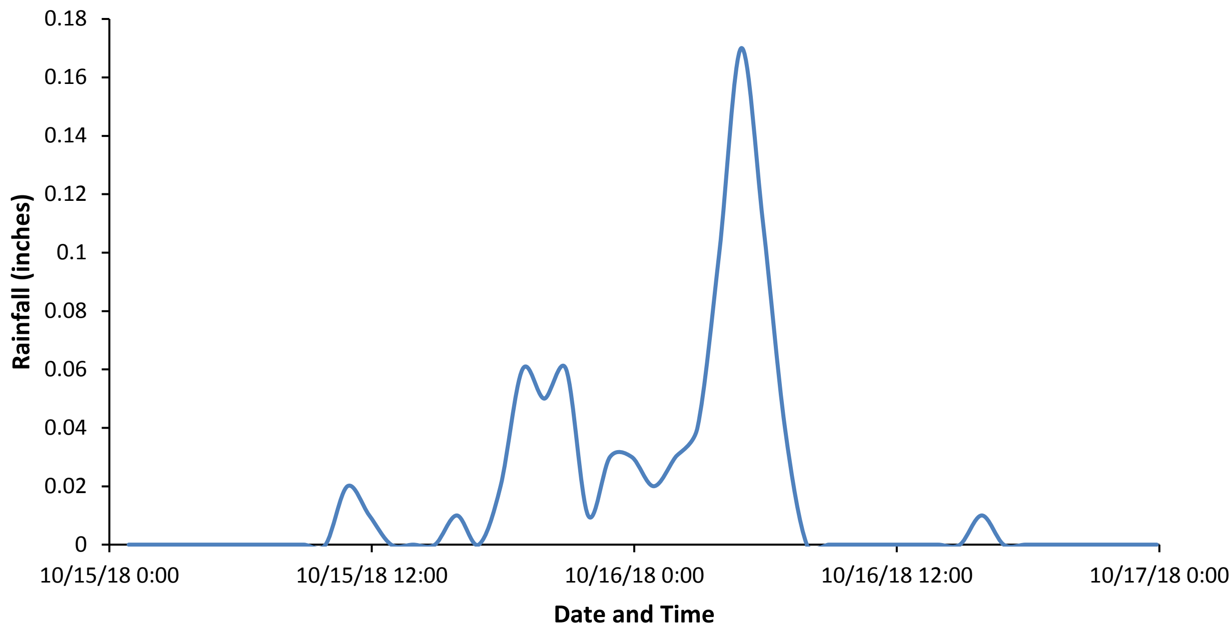
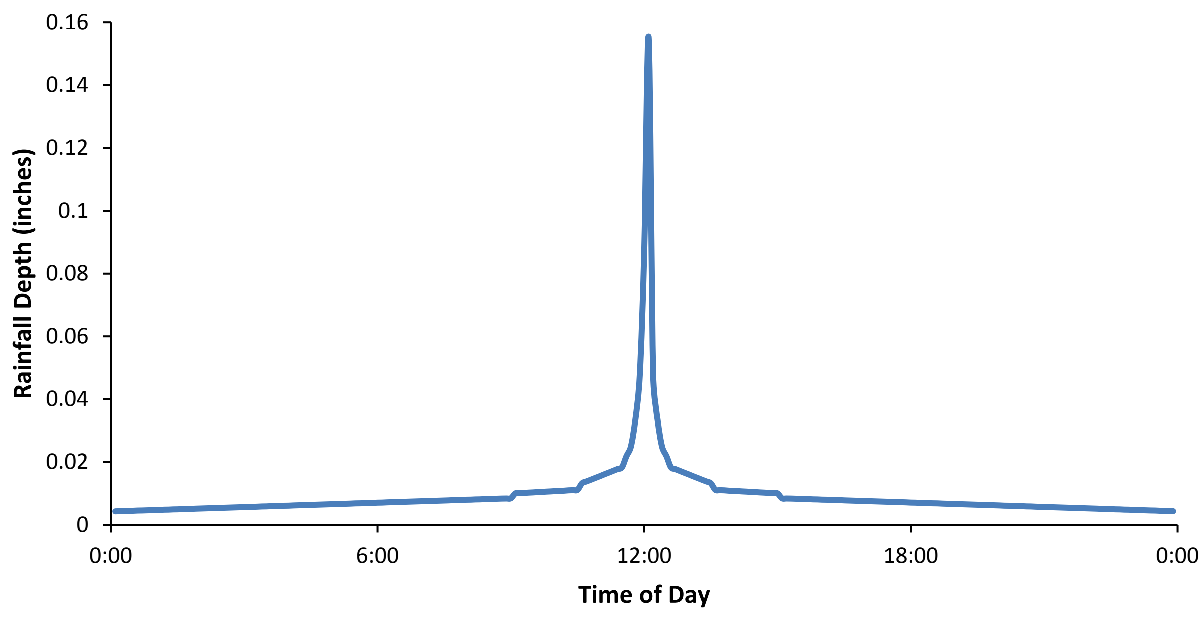


Figure 17: Event 3 10-Year, 24-Hour Rainfall Hyetograph



4.3. Performance Evaluation

The project performance was evaluated through a combination of visual inspection and hydrologic modeling, as described below.

4.3.1. Visual Monitoring

The infiltration ponds were visually inspected during Event 1 and Event 2, and other than a few inches of difference in pond water level, observations were similar for both events. Overall, the three ponds were performing well.

During the August 21 site visit, it was actively raining, and water was flowing into the ponds via inlet culverts that were partially submerged. It was partly cloudy during the October 16 visit, with no active precipitation. Pond depths for both visits are shown in Table 4. There was no overflow observed from any of the three infiltration ponds during either of the site visits.

Table 4: West Dowling Road Phase II Infiltration Pond Depths During Site Visits

Pond Depth (feet)	August 21, 2018	October 16, 2018
Pond #1	2.06	1.71
Pond #4	2.17	1.90
Pond #5	2.25	1.95

It was observed during both site visits that vegetation surrounding Infiltration Ponds #1 and #5 had grown into tall grasses, but the grass around Pond #4 was fairly short. Figure 18 and Figure 19 show inlet culverts for each of the three ponds.

Figure 18: Infiltration Pond #1 Inlet, August 21, 2018

Figure 19: Infiltration Ponds #4 (left) and #5 (right) Inlets, October 16, 2018

4.3.2. Hydrograph Development

To quantitatively evaluate the ponds' performance, inflow hydrographs were developed for each of the three rainfall events. The hydrographs were developed using SWMM. The contributing areas were represented with two subcatchments, "BasinA" and "BasinB." BasinA represents the area contributing runoff to Infiltration Pond #1, and BasinB represents the area contributing runoff to Infiltration Ponds #4 and #5.

Because the ponds do not have outlets and are designed to capture large events up the 100-year event, actual model simulation of the pond storage volumes was not necessary for hydrograph development or comparison. However, one pond was simulated as a storage unit in the model in order to calibrate the model to match observed conditions. To do this, a storage unit representing Pond #1 was connected to accept inflow from BasinA. The storage unit's area-volume relationship was approximated based on the project design drawings. The model's estimate of pond water surface elevation and depth was then compared with actual observations, and adjustments to the model parameters were made such that modeled results and observed conditions were similar. Infiltration ponds #4 and #5 were not specifically modeled, but the two modeled subcatchments have similar characteristics and the calibration adjustments were applied to both subcatchments. Storage unit depth in the model for the August 21, 2018 rainfall showed a depth of 1.96 feet at 2:00 PM, which corresponds well with site observations on that date/time showing a depth of 2.06 feet. Storage Unit depth in the model for the October 16, 2018 rainfall showed a depth of 2.0 feet at 11:30 AM, which corresponds well with the observed depth of 1.7 feet.

4.3.3. Results

The SWMM modeling results show that the infiltration ponds held all of the stormwater runoff for the three events analyzed. Pond inflow and outflow hydrographs are shown in Figures 20 through 25. If no LID/GI had been incorporated into this project, it is assumed that the pond inflow hydrographs would have been routed directly to other stormwater receiving systems and eventually into Campbell Creek. As such, the inflow hydrograph can be considered the hypothetical case of no LID, and the outflow hydrographs represent the as-constructed case.

Tables summarizing the peak flows and runoff volume results for each subcatchment area for the three rainfall events are provided in Tables 5 and 6.

Figure 20: Event 1 August 20-22 Pond #1 Hydrographs – WDII

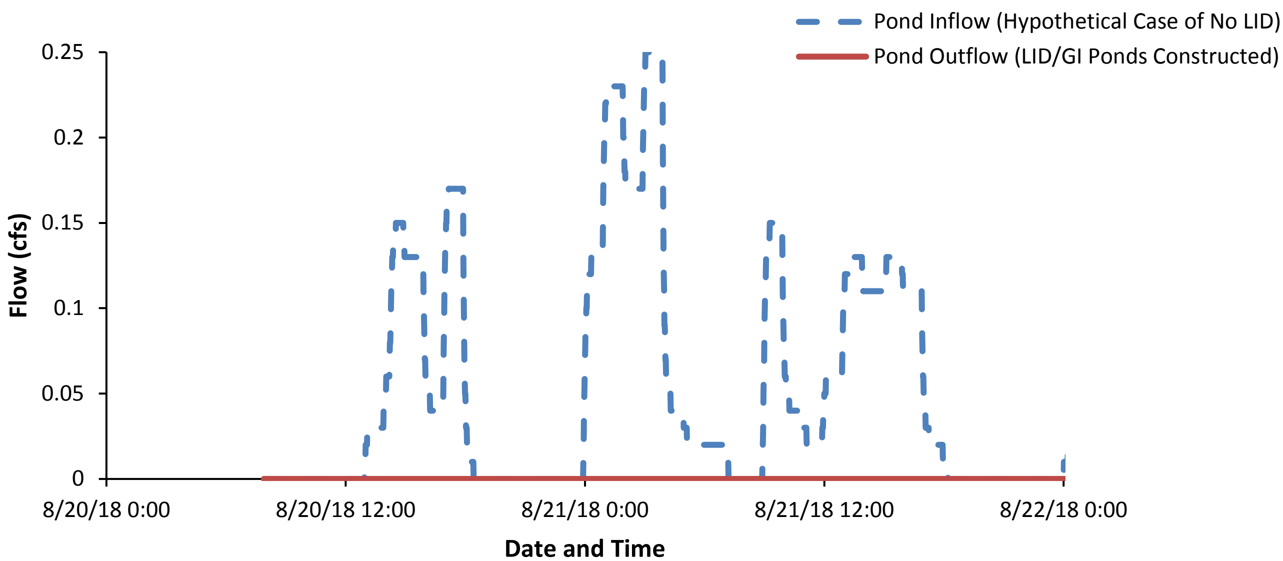


Figure 21: Event 1 August 20-22 Ponds #4 and #5 Hydrographs – WDII

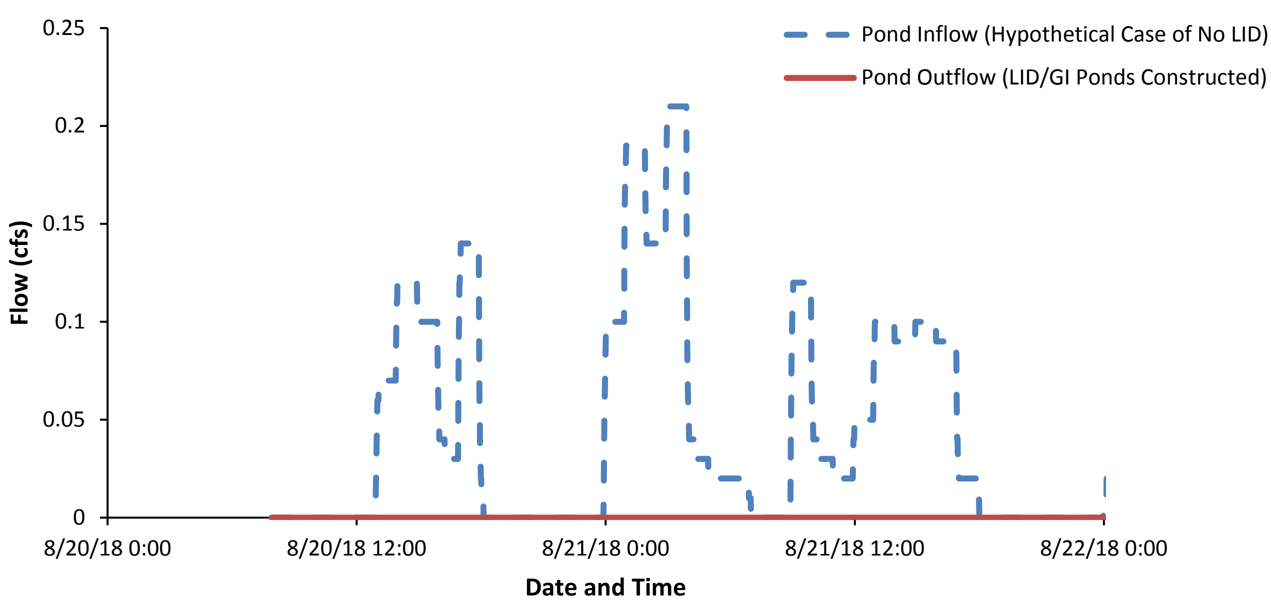


Figure 22: Event 2 October 15-16 Pond #1 Hydrographs – WDII

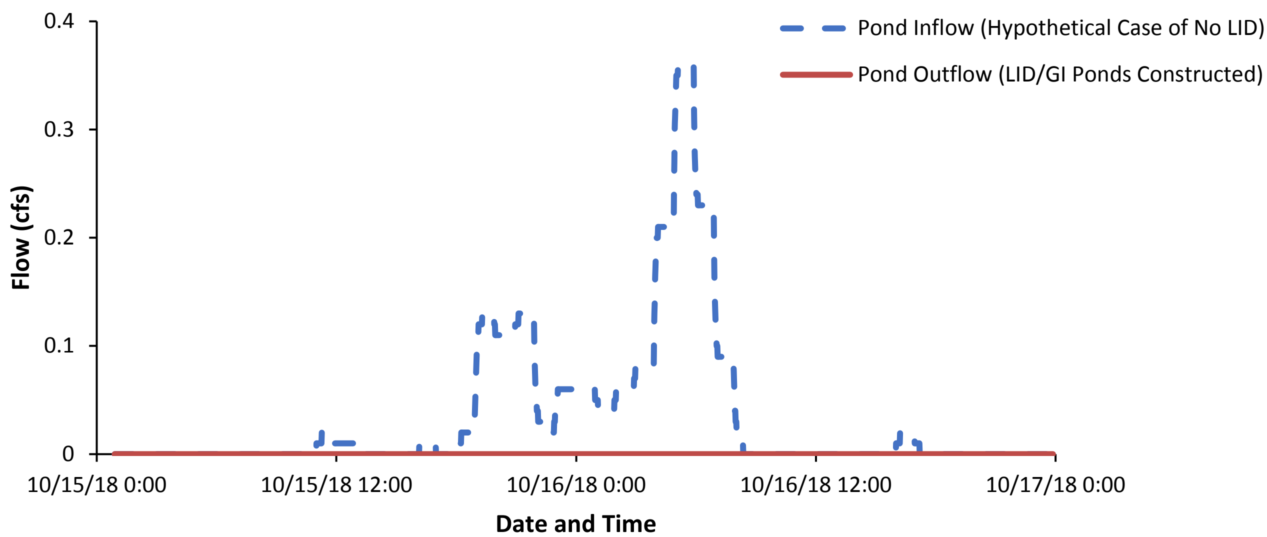


Figure 23: Event 2 October 15-16 Ponds #4 and #5 Hydrographs – WDII

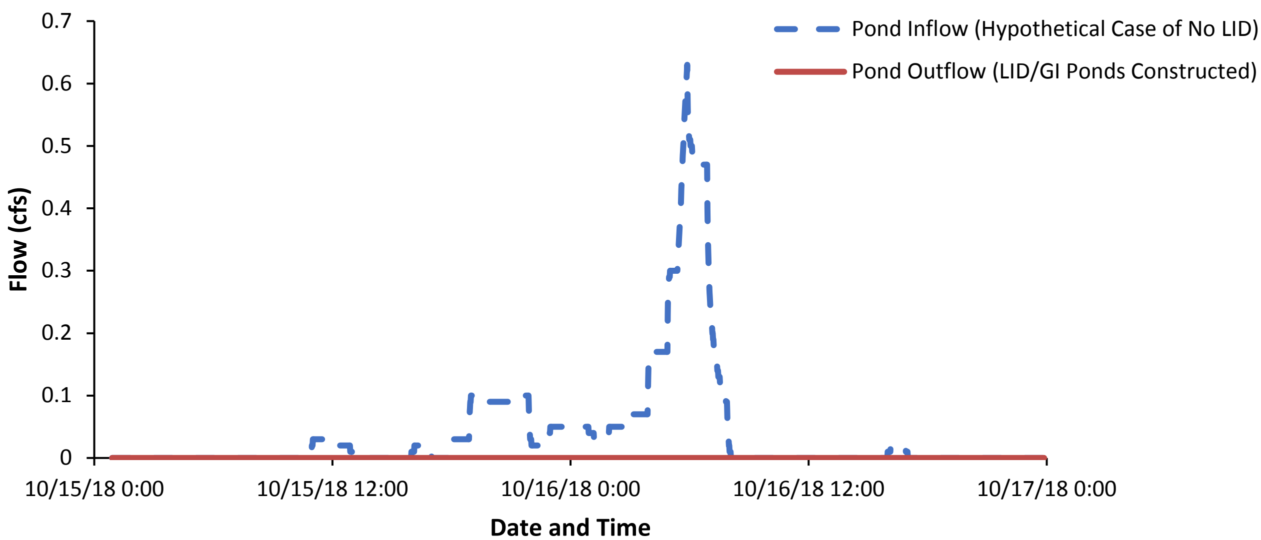


Figure 24: Event 3 10-Year, 24-Hour Pond #1 Hydrographs – WDII

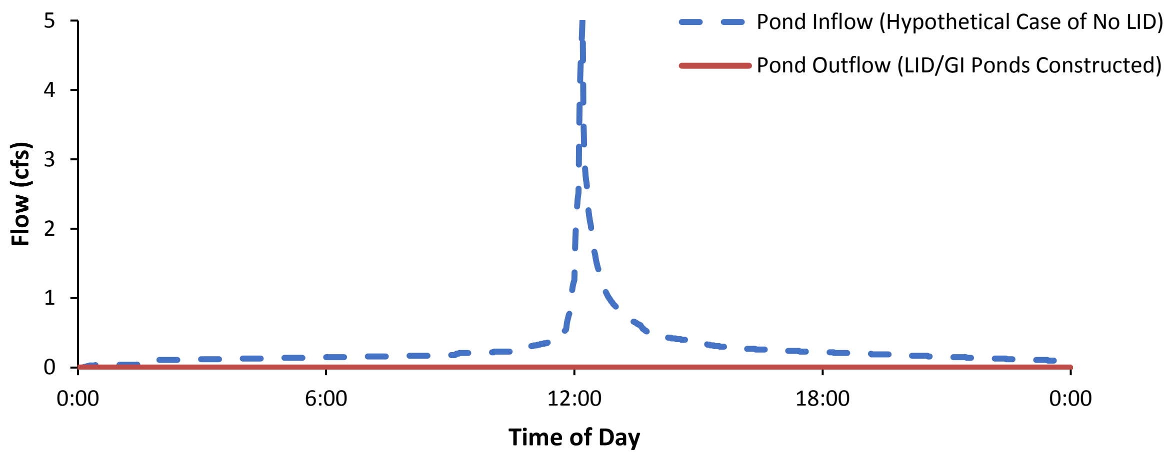


Figure 25: Event 3 10-Year, 24-Hour Ponds #4 and #5 Hydrographs – WDII

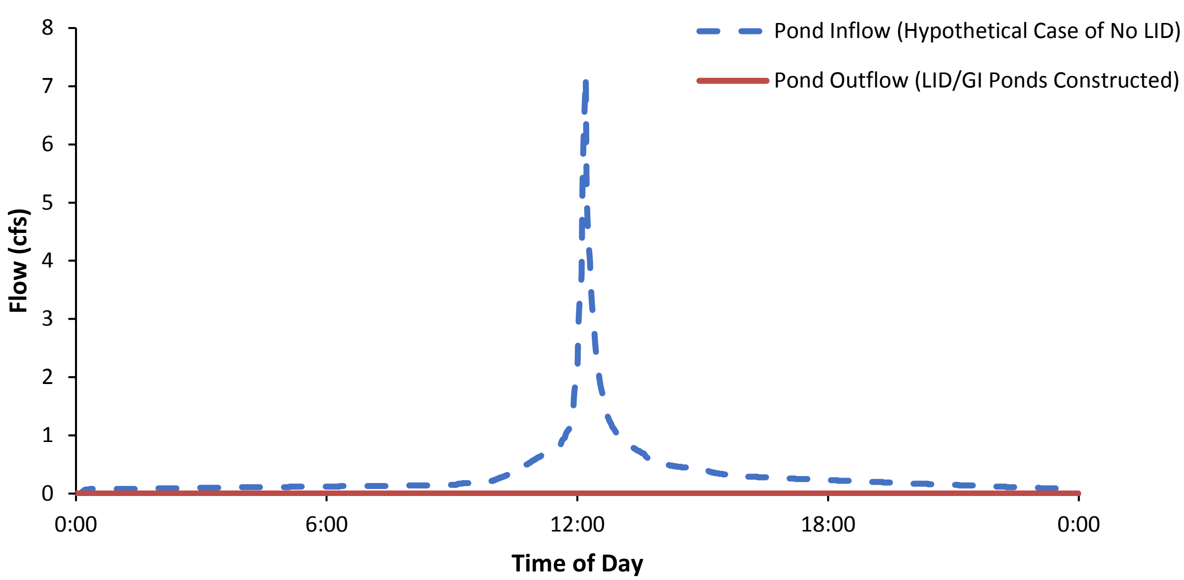


Table 5: WDII Pond #1 Performance Summary

Case	August 21, 2018		October 16, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 – Pond Inflow (No LID)	0.25	8,021	0.36	5,347	4.99	24,063
Case 2 – Pond Outflow	0.00	0	0.00	0	0.00	0
Percent Decrease	100%	100%	100%	100%	100%	100%

Table 6: WDII Ponds #4 and #5 Performance Summary

Case	August 21, 2018		October 16, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 – Pond Inflow (No LID)	0.21	6,684	0.63	6,684	7.14	29,410
Case 2 – Pond Outflow	0.00	0	0.00	0	0.00	0
Percent Decrease	100%	100%	100%	100%	100%	100%

4.4. Conclusions and Recommendations for Future Projects

The infiltration ponds provided for the project are performing well and are a good LID/GI tool when adequate space is available. As demonstrated with these ponds, this type of facility can also work well to manage runoff from rain events much larger than the water quality event in cases where traditional conveyance infrastructure is not practicable or desired.

Both ponds have similar features, but the longer grasses in Pond #1 and Pond #5 are expected to improve overall pond performance. Longer grasses provide more opportunity for evapotranspiration, and the root structures help keep the pond floors open to infiltration. Allowing grasses to grow also reduces pond maintenance.

The planned maintenance for these ponds is not known, but sediment removal activities may eventually be required. The ponds accept stormwater from significant impervious areas with no pretreatment for sediment. Sediment settling areas/forebays could be provided at the inlets to concentrate sediment removal to a specific location.

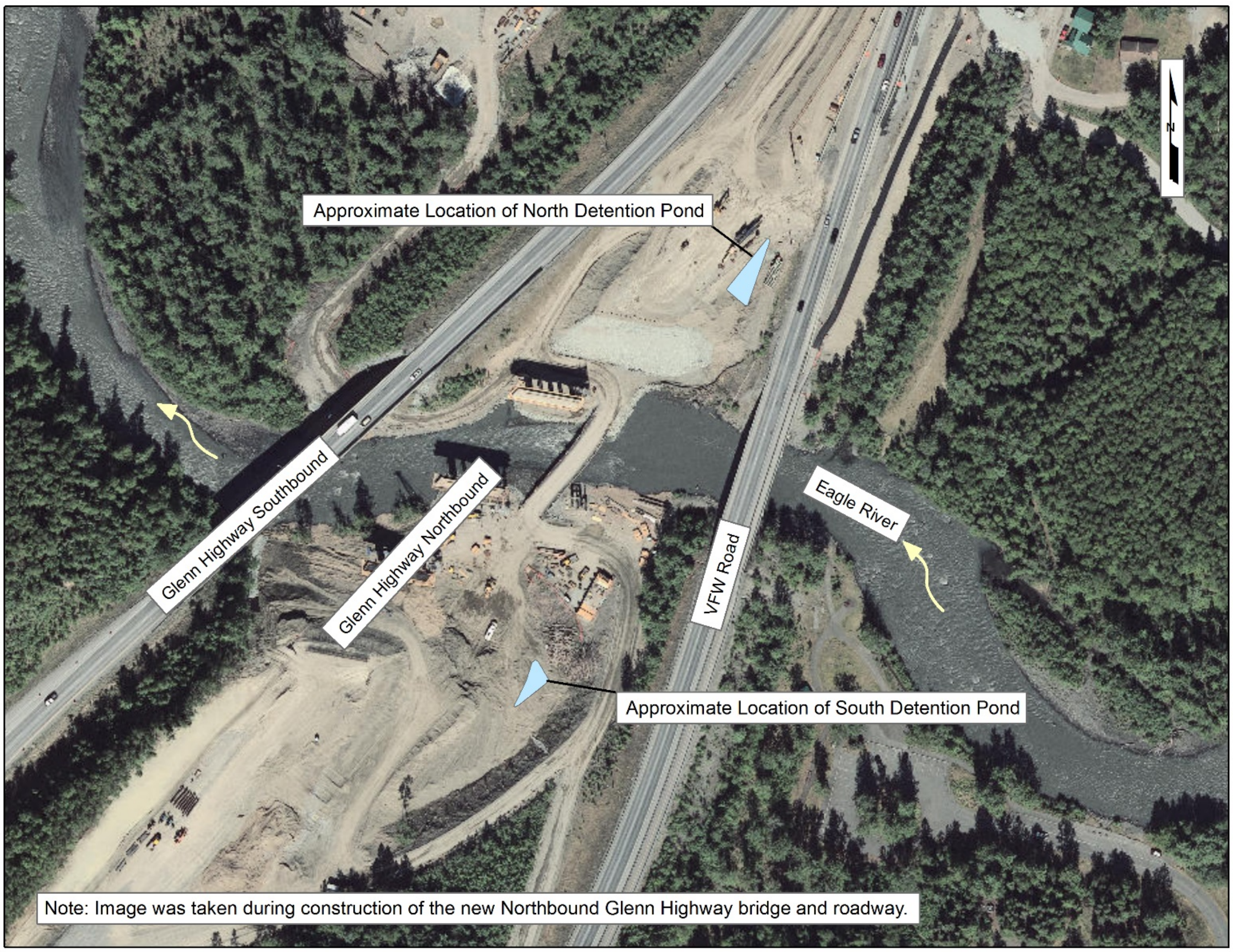
5. Glenn Highway Capacity Improvements: Detention Ponds (DOT&PF)

The Glenn Highway is a north-south highway connecting Anchorage to Eagle River, the Mat-Su Valley, and eventually to Glennallen. The *Glenn Highway Capacity Improvements DB Phase I – Northbound Hiland to Artillery Project* is located in Eagle River, a community 10 miles northeast of Anchorage which is part of the Municipality of

Anchorage. The project constructed a new bridge over the river by the same name (Eagle River), relocated a portion of the highway to the new bridge crossing, and widened a three-mile segment of the northbound highway to three lanes. The project was completed in 2015.

Stormwater runoff from the project is directed into Eagle River, and stormwater treatment is provided via two detention ponds that were constructed as a part of this project. One pond is on the north side of the river and one is on the south side. The ponds are understood to be designed to capture and treat runoff from the water quality event of 0.52 inches of rain in a 24-hour period. Events greater than this safely overflow to Eagle River. Figure 26 shows the locations of the detention ponds and the location of the new northbound Glenn Highway bridge.

Figure 26: Glenn Highway Eagle River Bridge Site Overview



5.1. Detention Pond Details

Information regarding the detention pond details was based on the project design documents (provided by DOT&PF) and on visual observations. The north detention pond is located between the northbound Glenn Highway and VFW Road, immediately north of the river. The north pond collects stormwater from approximately 6.4 acres, 3.7 acres of which is impervious surface from the northbound Glenn Highway and VFW Road. The detention pond is vegetated with grasses and is approximately 120 feet long by 50 feet wide. Side slopes vary. The pond inlet is a storm drain pipe that collects water from the northwest side of the northbound Glenn Highway. The south edge of the pond is an earthen berm six feet above the pond bottom with a riprap-lined, trapezoidal spillway that outfalls to Eagle River. The pond and the top of the spillway are shown in Figure 27.

Figure 27: North Detention Pond Berm and Outfall

The south detention pond is located between the northbound Glenn Highway and VFW Road, south of Eagle River. The pond collects stormwater from approximately 29.7 acres, 5.7 acres of which is impervious surface from the northbound Glenn Highway. The detention pond is vegetated with grasses. The pond is approximately 220 feet long by 70 feet wide at the top and has 4H:1V side slopes. Stormwater enters the pond via a riprap-lined inlet ditch on the pond’s south side. An 8.3-acre forested area lies south of the pond. The pond’s north edge is an earthen berm 13 feet above the pond bottom with a riprap-lined, trapezoidal spillway that outfalls to Eagle River. The pond and spillway are shown in Figure 28.

Figure 28: South Detention Pond Inlet Ditch (top) and Outfall (bottom)

5.2. Rainfall Events

Performance evaluation of the ponds was based on rainfall data collected at nearby Anchorage Regional Landfill and provided by Solid Waste Services. During the monitoring period, one rainfall event met or exceeded the 90th percentile water quality event. The 10-year, 24-hour storm event was also considered for this analysis. Each event is described below.

1. Event 1 occurred on August 21, 2018. This event resulted in 0.82 inches of rain in a 24-hour period. Approximately 0.11 inches of rain fell in the preceding 17 hours. The rainfall data used for analysis covers a 48-hour period, from 7:46 AM on August 20 through 6:46 AM on August 22, resulting in a total rainfall of 0.99 inches.
2. Event 2 is the 10-year, 24-hour rainfall event for Anchorage with an orographic factor of 1.02 applied, resulting in 2.32 total inches of total rainfall.

Hyetographs for the two rainfall events are presented in Figures 29 and 30, with supporting data included in Appendix A.

Figure 29: Event 1 August 20-22, 2018 Rainfall Hyetograph

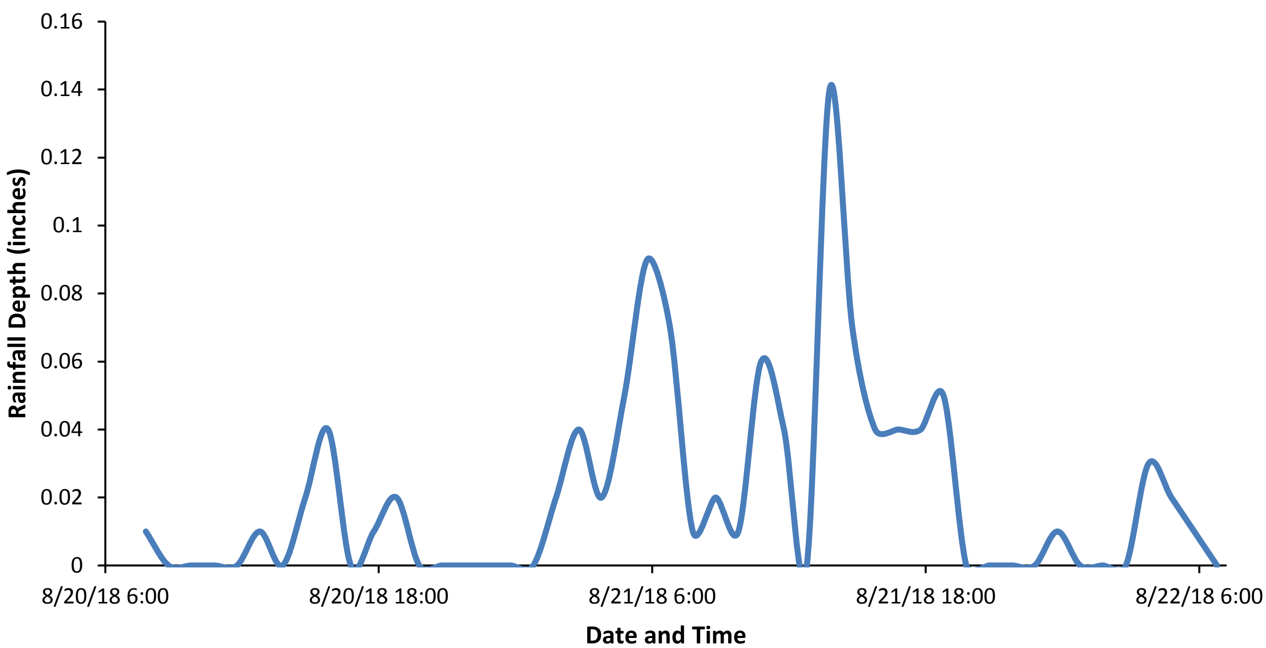
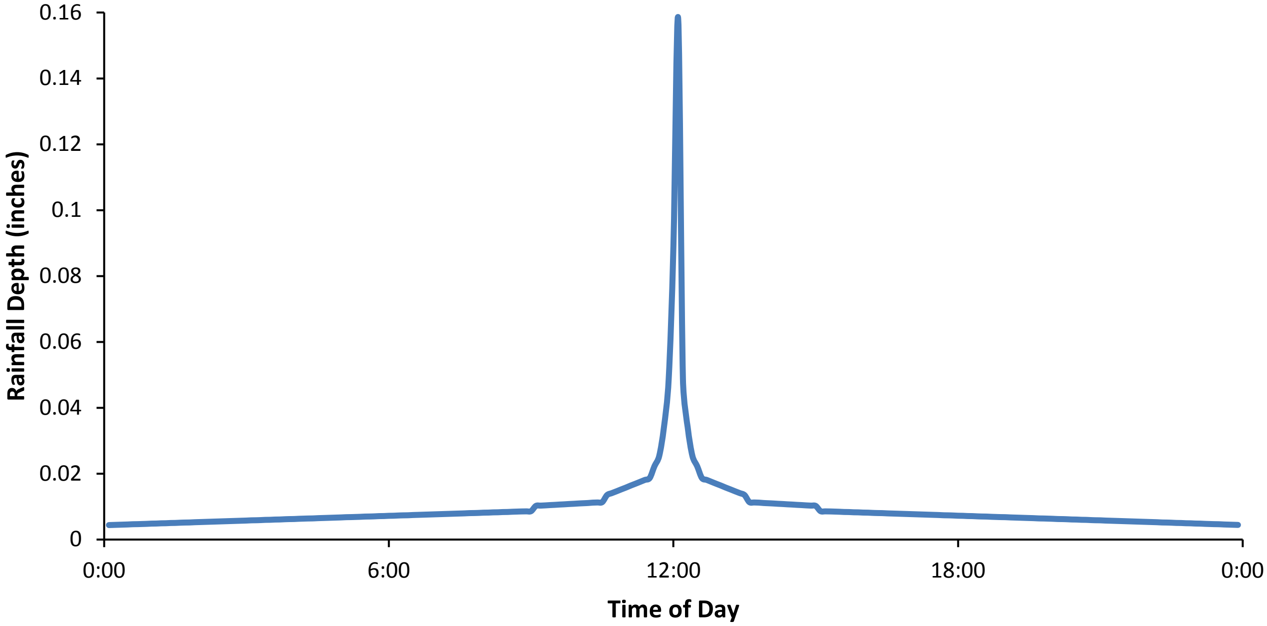


Figure 30: Event 2 10-Year, 24-Hour Rainfall Hyetograph



5.3. Performance Evaluation

The project performance was evaluated through a combination of visual inspection and hydrologic modeling.

5.3.1. Visual Monitoring

Three site visits were completed on August 8, August 21, and October 16, 2018. At the time of the August 8 site visit, it had rained earlier that morning but was no longer raining. There was standing water in the north pond and the culvert inlet was observed to be about two-thirds submerged, correlating to an approximate pond depth of 3.2 feet. There was no outflow from the pond. The south pond had no standing water, but the bottom of the pond was wet. There was no inflow or outflow from the south pond. Tall grasses between the rocks of the riprap-lined spillway were standing vertical, indicating that the spillway had not recently seen overflow. Photos from the site visit are shown in Figure 31.

Figure 31: North Detention Pond (left) and Spillway Outfall from South Detention Pond (right), August 8, 2018

It was actively raining at the time of the August 21 site visit. Water was flowing into the north pond via the submerged inlet culvert and direct runoff from VFW Road. Outflow from the north detention pond was observed in the overflow spillway to Eagle River. Figure 32 shows the submerged pond inlet and water leaving the pond via the spillway. The south detention pond had approximately one foot of standing water, but no visible inflow was observed. Saturated soils above the water surface were observed, along with a visible difference in vegetation based on elevation. It was estimated that there was a high water elevation earlier in the day of approximately five to six feet above the water surface elevation at the time of the site visit. There was no evidence of current or prior outflow from the south detention pond. Figure 33 shows the standing water in the south pond during the site visit. Long grasses and other vegetation lined the slopes of both ponds.

Figure 32: Outflow (left) and Submerged Inlet Culvert (right) – North Pond, August 21, 2018

Figure 33: Standing Water in the South Detention Pond, August 21, 2018

The ponds were observed again on October 16. It had rained overnight but skies were partly cloudy and there was no precipitation at the time of the site visit. Standing water was observed in the north pond, with an estimated depth of approximately 1.5 feet. Water was flowing into the north pond via the inlet culvert and there was no outflow. The south pond had discontinuous standing water, estimated at a maximum depth of three to four inches. The south detention pond had no inflow or outflow. Figure 34 shows the north pond's inlet and standing water in south pond during this site visit.

Figure 34: North Pond Inlet (left) and Standing Water in South Pond, October 16, 2018

5.3.2. Hydrograph Development

To demonstrate the impact of the detention ponds on runoff volume and peak flows, discharge hydrographs for the two rainfall events were developed for each pond using SWMM for the two cases described below.

1. Case 1 is the as-constructed case with LID/GI detention ponds on the north and south sides of the river.
2. Case 2 is the hypothetical case of the project constructed without an LID/GI feature. In this case, runoff from the project would be routed directly to Eagle River.

To represent Case 1, the detention ponds were modeled as storage units, and the earthen berms with overflow spillways were modeled as weirs. A subcatchment representing the northern contributing area was connected to the storage unit representing the north pond, and two subcatchments representing the southern contributing area were connected to the storage unit representing the south pond. Modeled estimates of pond depths were compared with actual observations and adjustments to modeling parameters were made to calibrate model estimates to observations. Calibrated parameters include subcatchment properties and the initial starting depths of both ponds. Model results after calibration showed a north pond depth of 5.03 feet at 5:20 PM for the August 21 rain event, which corresponds well with site observations on that date/time showing an approximate depth of 4.7 feet in the north pond. The model showed a maximum depth in the south pond of 7.64 feet, which corresponds well with the estimated high water depth of approximately six to seven feet in the south pond.

To represent Case 2 with no LID/GI features, the storage units were removed from the model and the subcatchment runoff was routed directly to Eagle River. Model parameters are provided in Appendix D.

5.3.3. Results

Figures 35 through 38 present the discharge hydrographs for Case 1 and Case 2 for the north and south detention ponds for each of the two rainfall events analyzed. The results show that for both rain events, the north detention pond notably reduced the peak flow and runoff volume to Eagle River, and that the south detention pond eliminated discharge to the river altogether.

Figure 35: Event 1 August 20-22 Discharge Hydrographs – North Detention Pond

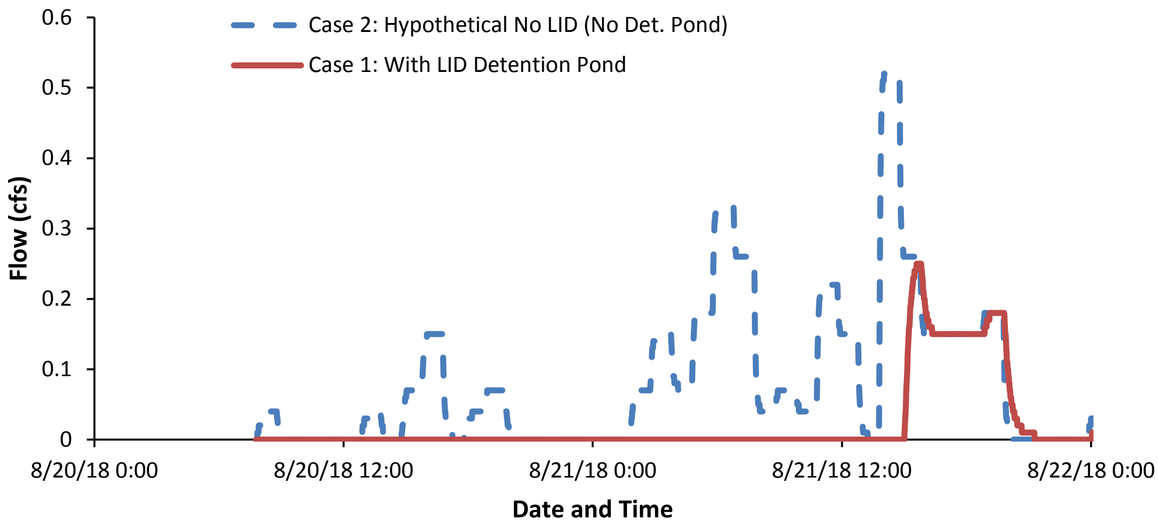


Figure 36: Event 1 August 20-22 Discharge Hydrographs – South Detention Pond

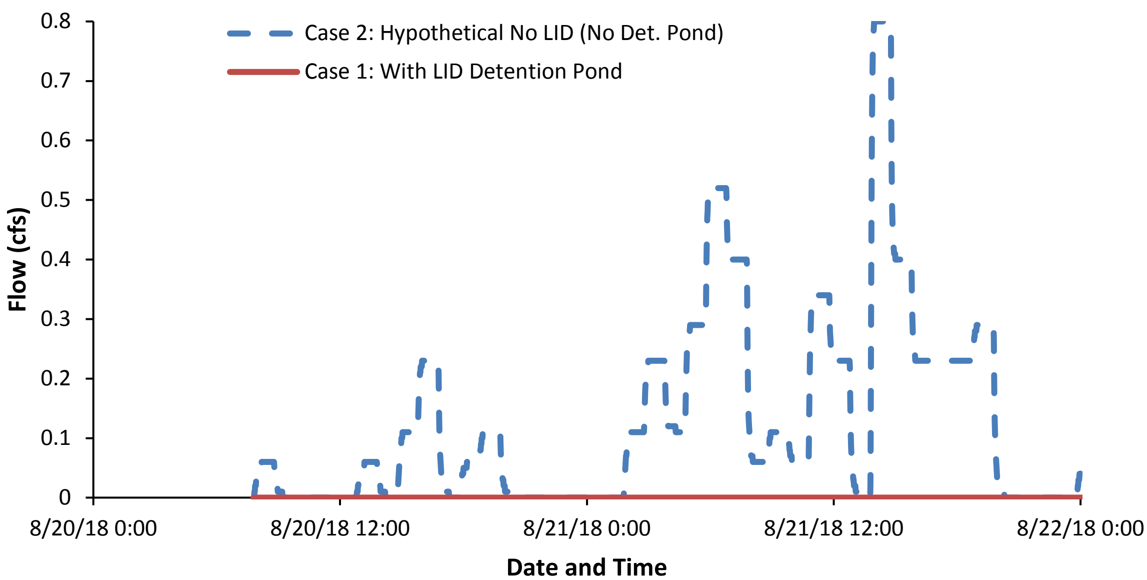


Figure 37: Event 2 10-Year, 24-Hour Discharge Hydrographs – North Detention Pond

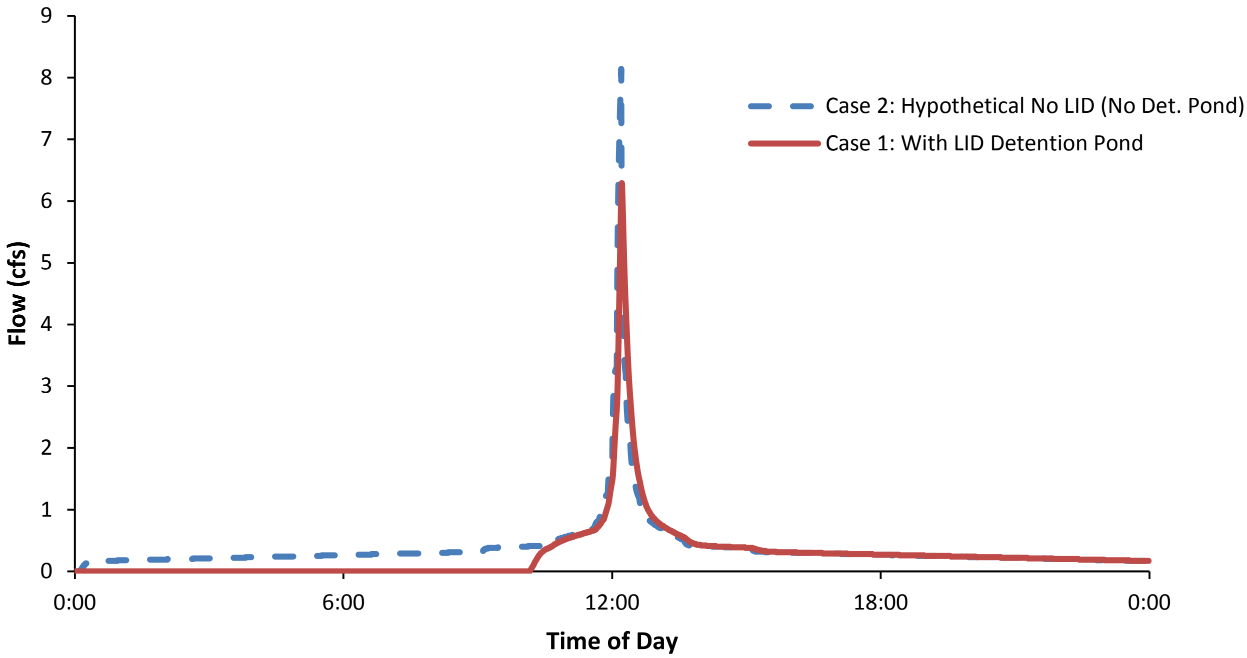
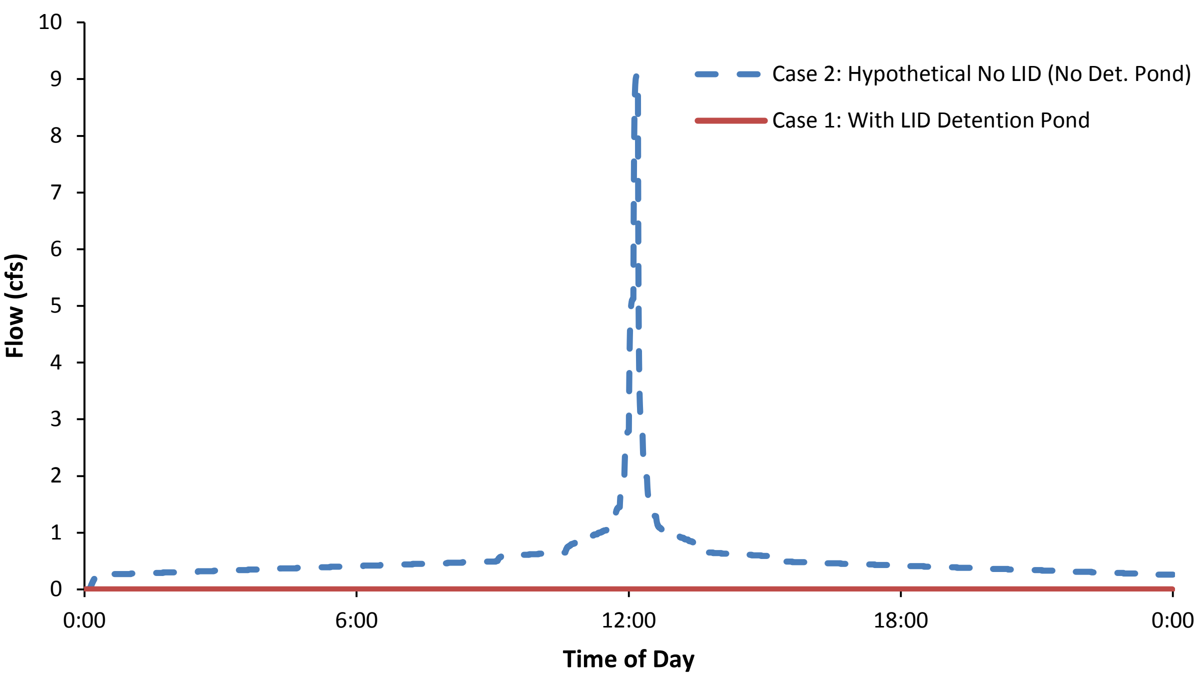


Figure 38: Event 2 10-Year, 24-Hour Discharge Hydrographs – South Detention Pond



Tables 7 and 8 provide a summary of peak discharges and runoff volumes for the north and south detention ponds.

Table 7: Glenn Highway North Detention Pond Performance Summary

Case	August 21, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 - With LID Detention Pond	0.25	3,877	6.29	23,662
Case 2 - Hypothetical No LID	0.52	13,368	8.14	33,420
% Decrease	52	71	23	29

Table 8: Glenn Highway South Detention Pond Performance Summary

Case	August 21, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 - With LID Detention Pond	0.00	0	0.00	0
Case 1 - Hypothetical No LID	0.80	20,052	9.08	48,125
% Decrease	100	100	100	100

5.4. Conclusions and Recommendations for Future Projects

Both ponds are performing well and appear to be providing both water quality treatment and reduction of peak flows, even for larger rain events. These types of ponds are a good solution in locations where adequate space is available.

The riprap-lined inlet ditch on the south pond is expected to be providing some sediment reduction and potentially some infiltration before water reaches the pond. This may improve the pond performance and decrease the need for maintenance activities like sediment removal.

The scope of this project did not include monitoring drain-down times of either pond, but this may help provide a better understanding of overall pond performance. The south pond is expected to be fully infiltrating incoming water at a faster rate than the north pond, since standing water was observed in the north pond when the south pond was empty. Understanding the expected drain-down times may help maintenance personnel more quickly identify performance issues.

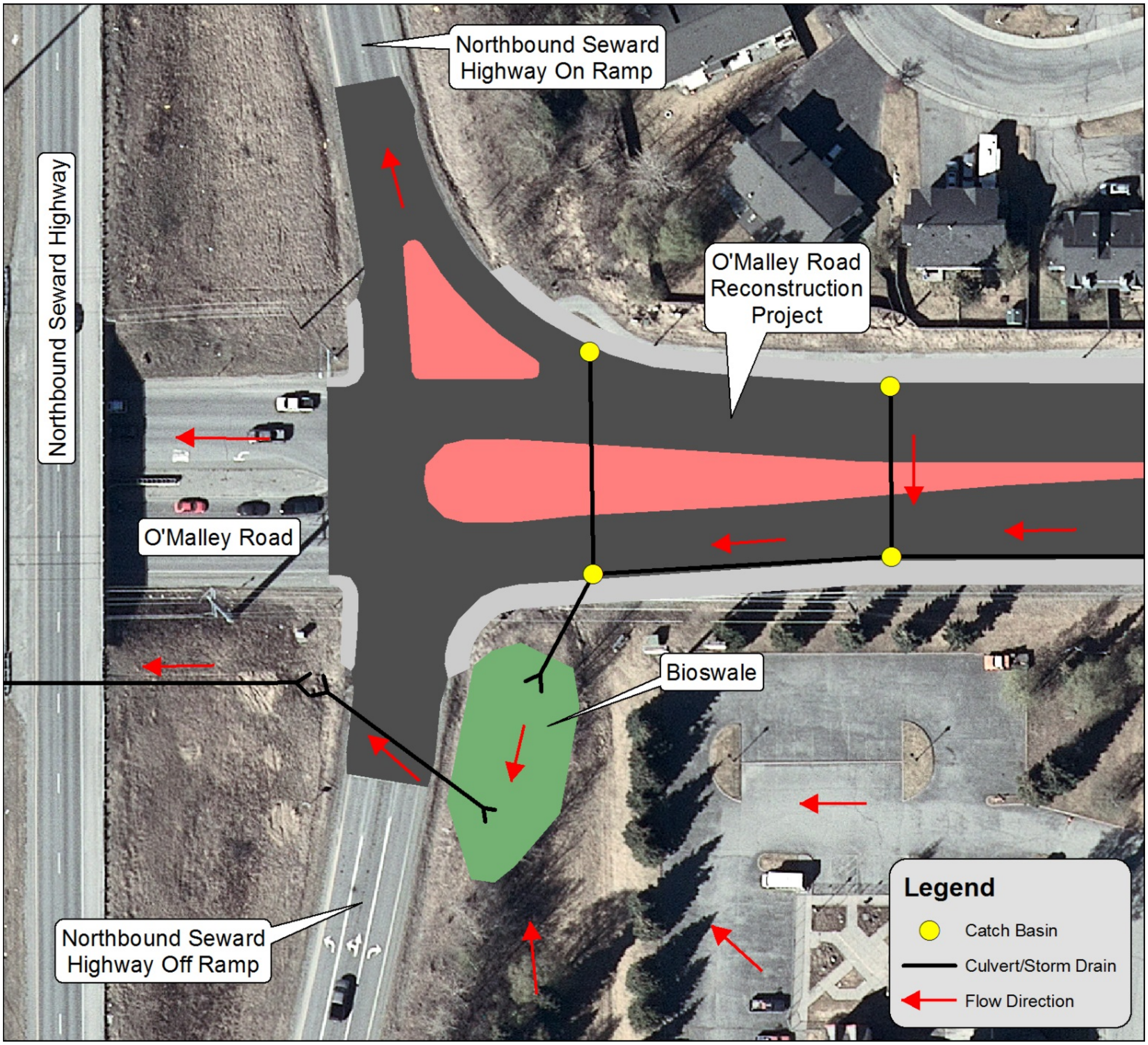
The depth of both ponds generally exceeds recommended depth for ponds that rely on infiltration, since the weight of the water in the pond has the potential to compact the underlying soils and reduce the infiltration rate. The pond performance over time could be evaluated to determine if this is having an impact on long-term performance.

6. O'Malley Road Bioswale (DOT&PF)

O'Malley Road is an east-west roadway located in the southern part of Anchorage, connecting Hillside Drive to Minnesota Boulevard. The O'Malley Road Reconstruction Project Phase I Seward Highway to Livingston Street widened the road to four lanes with a raised median, curb and gutter, and bike lanes. The project also added a pathway and drainage improvements, and was completed in 2018. The project lies in the Campbell Creek watershed, near the edge of the Furrow Creek watershed.

The O'Malley Road project included construction of a bioswale at the southeast corner of O'Malley Road and the Seward Highway. The purpose of the bioswale is to treat stormwater collected by the new O'Malley Road storm drain pipes, and to reduce the peak flow as it discharges into an existing downstream storm drain system to the west of the Seward Highway. Treatment is achieved via infiltration, transpiration, and filtration to remove sediment and associated pollutants. An overview of the bioswale site is presented in Figure 39.

Figure 39: O'Malley Road Bioswale Site Overview



6.1. Bioswale Details

Information regarding the bioswale design and construction was based the project design documents (provided by DOT&PF) and on visual observations. The bioswale has a longitudinal slope of approximately 1% and is estimated to have a functional area of approximately 0.13 acres. The bottom of the swale is lined with compost socks, and grasses line the side slopes. Stormwater runoff from the new O'Malley Road storm drain system enters the bioswale through a metal grate-type inlet structure at the north end of the swale. Stormwater also enters the bioswale from the southeast neighboring residential and commercial area via overland flow. The total contributing area is estimated at 48.4 acres, of which 13.9 acres is impervious surface. The bioswale outlet is a Seward Highway crossculvert at the southern end of the bioswale. Figure 40 shows the inlet in the foreground and compost socks and the culvert outlet in the background.

Figure 40: O'Malley Road Bioswale

6.2. Rainfall Events

Performance evaluation of this site was based on the rainfall events presented in Section 3.2.

6.3. Performance Evaluation

The project performance was evaluated through a combination of visual inspection and hydrologic modeling, as described below.

6.3.1. Visual Monitoring

The bioswale was observed at approximately 4:00 pm during the August 21 rainfall event, and it was actively raining at the time of the site visit. Water was flowing into the swale at the inlet and via runoff from the surrounding area. Incoming water was flowing through the swale and exiting the swale via the downstream culvert. The swale did not appear to be providing substantial stormwater treatment, as the water leaving the swale was discolored. This may be attributed to the recently constructed status of the swale, and is expected to improve with time. Additionally, the quality of the stormwater inflow may be impacted by the fact that contributing areas may not have reached final stabilization at the time of this report.

There was limited vegetation in the swale, though surrounding grasses were long and were observed to be in good condition. Some grasses were growing near the inlet. It is expected that bottom vegetation of the swale may not be fully established yet at the time of this performance monitoring. Establishment of bottom vegetation would notably improve the treatment properties of the swale. Slight ponding was also observed in a grassy area east of the bioswale. Figure 41 shows the swale's outlet and the facility bottom.

Figure 41: Bioswale Outlet and Bottom, August 21, 2018

The bioswale was also observed on October 16. There was no active precipitation at the time of the site visit, but the ground was wet. The bioswale was mostly empty, with some standing water near the inlet structure. As observed during the August site visit, there was limited vegetation in the swale's flow area. The bioswale during the October site visit is shown in Figure 42.

Figure 42: O'Malley Road Bioswale, October 16, 2018

6.3.2. Hydrograph Development

To demonstrate the impact of the bioswale on peak flows and runoff volume, discharge hydrographs were developed using SWMM for two cases, described below.

1. Case 1 is the case with the LID bioswale constructed.
2. Case 2 is the hypothetical case of the project constructed without an LID feature. In this case, runoff from the project would be routed directly to the existing storm drain system west of the Seward Highway.

To represent Case 1, the contributing runoff area was divided into three subcatchment areas. The subcatchments representing the O'Malley Road portion and the portion to the southeast of the swale were routed to a subcatchment representing the bioswale itself. From there, water discharged directly to an outlet pipe representing the outlet culvert. Event 1 model results correlated well with August field observations.

In the Case 2 model representing no LID feature, runoff from the three subcatchments was routed directly to the outlet culvert. Model parameters are presented in Appendix E.

6.3.3. Results

Hydrographs representing the discharge to the outlet culvert for the two rainfall events are shown in Figure 43 and Figure 44, and Table 9 shows the peak flow and total volume of runoff for each case. Results show that the bioswale is not notably reducing peak flow or peak runoff volumes during the two events analyzed.

Figure 43: Event 1 August 20-22, 2018 Discharge Hydrograph – O'Malley Road

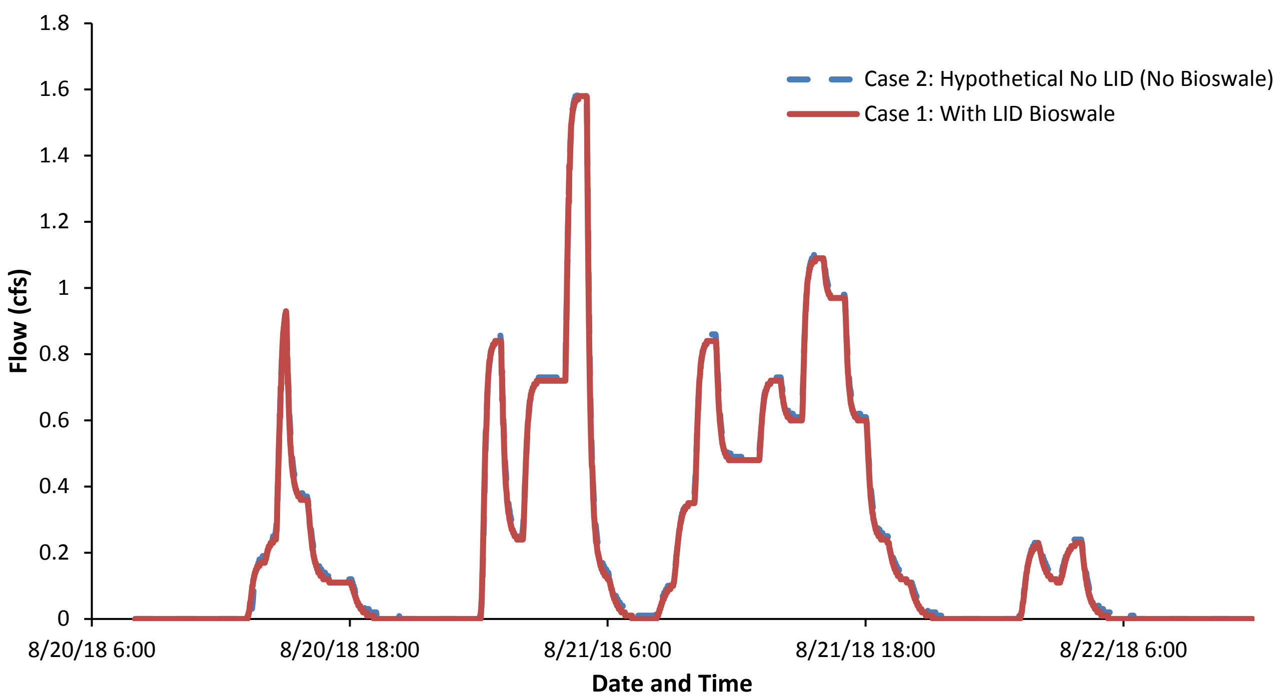


Figure 44: Event 2 10-Year, 24-Hour Discharge Hydrograph – O'Malley Road

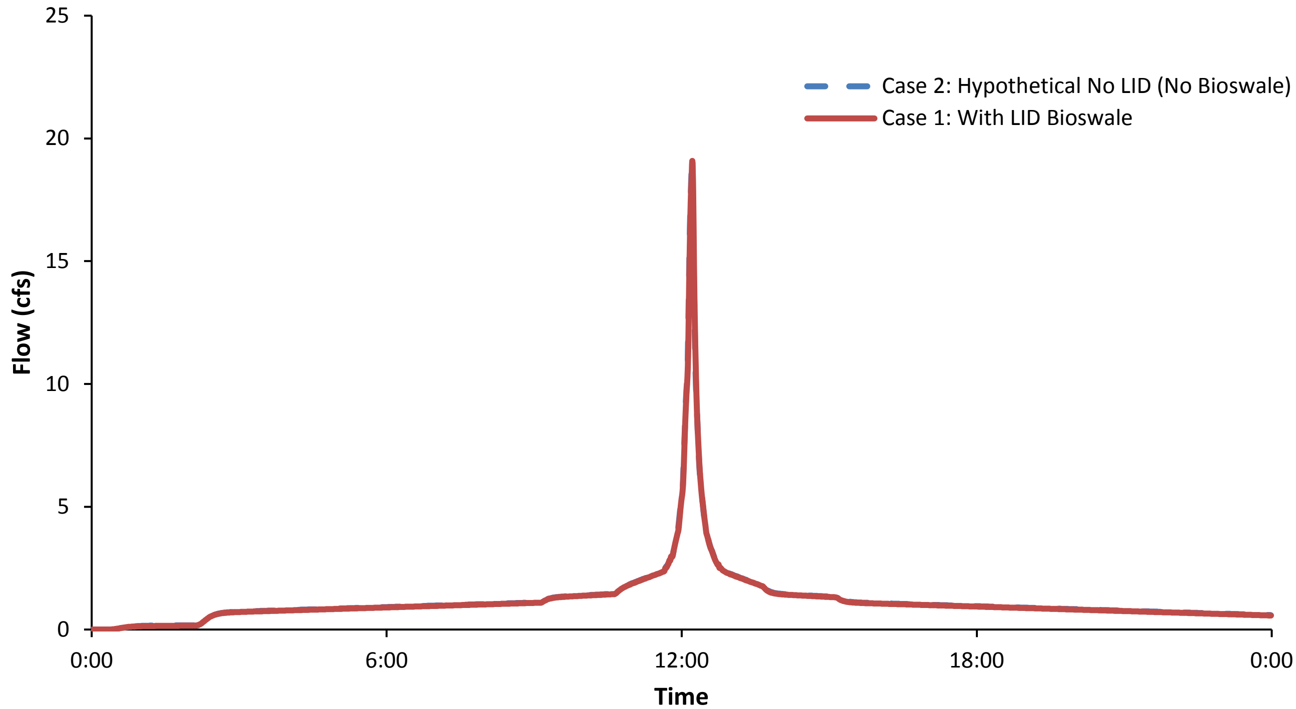


Table 9: O'Malley Road Bioswale Performance Summary

Case	August 21, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 - With LID Bioswale	1.58	45,318	19.13	103,335
Case 2 - Hypothetical No LID	1.59	46,788	19.21	104,672
% Decrease	0.6	3.1	0.4	1.3

6.4. Conclusions and Recommendations for Future Projects

Although the bioswale was not providing notable stormwater benefits at the time of this report, performance is expected to be substantially enhanced if/when bioswale vegetation or non-mowed grasses are grown to maturity along the bioswale floor/flow area. To maximize performance, vegetation should be taller than the expected flow depth of the swale. This would slow the incoming flow, allowing an opportunity for infiltration and filtration by the vegetation. Vegetation roots also provide a pathway for infiltration and help prevent the facility floor from becoming compacted over time.

In addition to the vegetation recommendations, other design features that could potentially be incorporated into future designs (depending on the site-specific constraints) are summarized below.

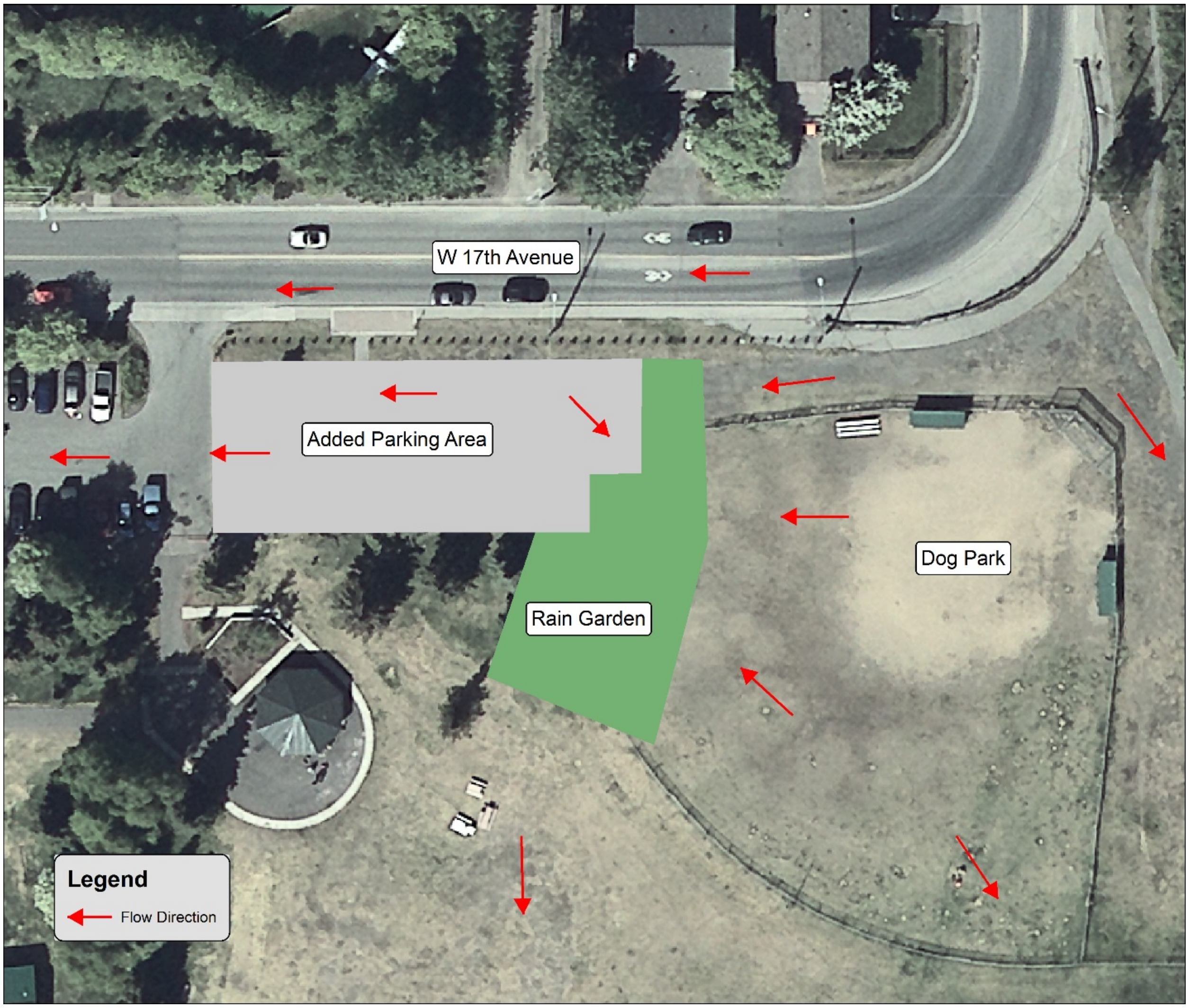
- Provide an elevated outlet or a lower facility floor, such that ponding to an acceptable depth would occur before water is able to leave the facility. This would provide more time for infiltration or filtration.
- Set the facility inlet above the flow/ponding elevation. This may require a vegetated or riprap lined area at the inlet to prevent erosion. An elevated inlet would help prevent future mature vegetation from blocking the inlet, and would incorporate some sediment pretreatment before water reaches the main flow area.
- Incorporate check dams or sinuous flow paths within the swale to help slow the movement of water and allow sediment to drop out of the water.

7. Valley of the Moon Rain Garden (MOA)

Valley of the Moon Park is one of Anchorage's largest community parks and is located on 17th Avenue along the Chester Creek Greenbelt, east of Arctic Boulevard. Park amenities include a rocket ship play structure, a playground, picnic shelters, large open spaces, a dog park, and a community garden. A popular pathway paralleling Chester Creek winds through the park and is used by runners, walkers, bikers, skiers, and others. The Valley of the Moon Park Improvements project expanded the size of the parking lot, upgraded lighting and the dog park, and added a snow storage area, ADA-accessible pathways, and a rain garden. Construction was completed in 2017, with minor signage added in 2018.

The park is located immediately adjacent to Chester Creek, which is listed as an impaired water body in the MOA/DOT&PF APDES permit. The rain garden was designed to minimize direct stormwater runoff into Chester Creek by capturing runoff from the expanded parking lot and snow storage area, and providing treatment and infiltration. Figure 45 shows a site overview of the northeast portion of the park.

Figure 45: Valley of the Moon Site Overview



7.1. Rain Garden Details

The Valley of the Moon rain garden has a footprint of approximately 0.14 acres, and is located east of the parking lot, between the parking lot and the dog park. The rain garden lies approximately 400 feet from Chester Creek. The rain garden has a depth capacity of approximately three feet and is lined with a variety of grasses, trees, shrubs, and large rock boulders. The rain garden collects runoff from the eastern portion of the parking lot and from most of the adjacent dog park, draining a total of approximately 0.7 acres, approximately 0.1 acre of which is impervious surface from the parking lot. Uniquely, the rain garden is treating or eliminating stormwater contaminants from impervious surfaces in two additional ways. First, construction of the rain garden resolved a drainage issue that was causing ponding on the south side of West 17th Avenue. Stormwater from the adjacent pervious areas would periodically spill onto the roadway surface. Second, in addition to rainfall runoff, the rain garden is also providing treatment for the snow melt runoff. Snow from the parking lot is stored in the rain garden throughout the winter, and the rain garden provides treatment and infiltration of the snow during spring melts. Figure 46 shows the rain garden from the south, looking north towards the eastern edge of the parking lot.

The rain garden is designed to contain small to midsize rainfall events. Large rainfall events would safely overflow the rain garden and discharge to the creek via overland flow.

Figure 46: Valley of the Moon Rain Garden

7.2. Rainfall Events

Performance evaluation of this site was based on rainfall Event 1 (August 21, 2018) and Event 3 (10-year, 24-hour) as presented in Section 4.2.

7.3. Performance Evaluation

The project performance was evaluated through a combination of visual inspection and hydrologic modeling, as discussed below.

7.3.1. Visual Monitoring

The project was observed on August 21, 2018. It was actively raining at the time of the site visit, and approximately six to eight inches of standing water was observed in the rain garden. A 30-foot by 75-foot area of the parking lot was draining to the rain garden. The remaining portion of the parking lot was flowing to the grassy, depressed areas on the southwest side of the parking lot. The dog park appeared to be draining to the rain garden. The pathway areas to the north of the rain garden adjacent to the road were draining into the rain garden. Figure 47 shows the rain garden at the time of the site visit. Figure 48 shows the surrounding areas.

Figure 47: Standing Water in the Rain Garden (left) and Near the Dog Park (right), August 21, 2018

Figure 48: Ponding to the North (left) and Parking Lot (right), August 21, 2018

7.3.2. Hydrograph Development

To demonstrate the impact of the rain garden on runoff volume and peak flows, discharge hydrographs for the two rainfall events were developed using SWMM for two cases.

1. Case 1 is the as-constructed case with the LID rain garden.
2. Case 2 is the hypothetical case of the project constructed without an LID feature. In this case, runoff from the project would flow directly towards Chester Creek via overland flow.

To represent Case 1, the rain garden was modeled as a storage unit using seepage parameters. Contributing runoff was routed to the storage unit and outflow was routed through a weir to an overflow outfall. Model results were compared with actual observations and adjustments to soil parameters were made to calibrate the model to observed ponding depth during the August site visit.

In the Case 2 model representing no LID feature, runoff was routed directly to the overflow outfall, representing discharge to adjacent grassy areas. Model parameters are presented in Appendix F.

7.3.3. Results

Figures 49 and 50 provide discharge hydrographs for Case 1 and Case 2 for each rainfall event. Table 10 provides a summary of peak flows and runoff volumes for both cases for the two rainfall events. The SWMM modeling results show that the rain garden held all stormwater runoff for the two events analyzed.

Figure 49: Event 1 August 20-22, 2018 Discharge Hydrographs – Valley of the Moon

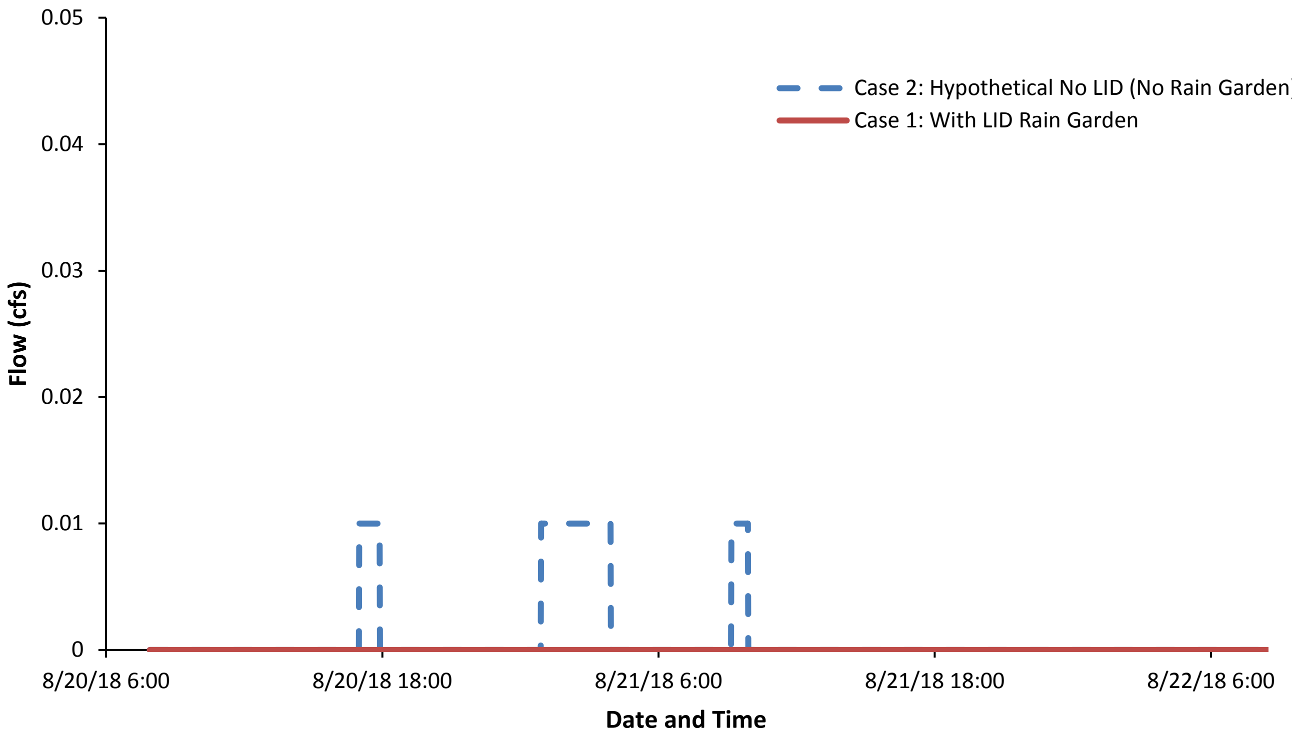


Figure 50: Event 3 10-Year, 24-Hour Discharge Hydrographs – Valley of the Moon

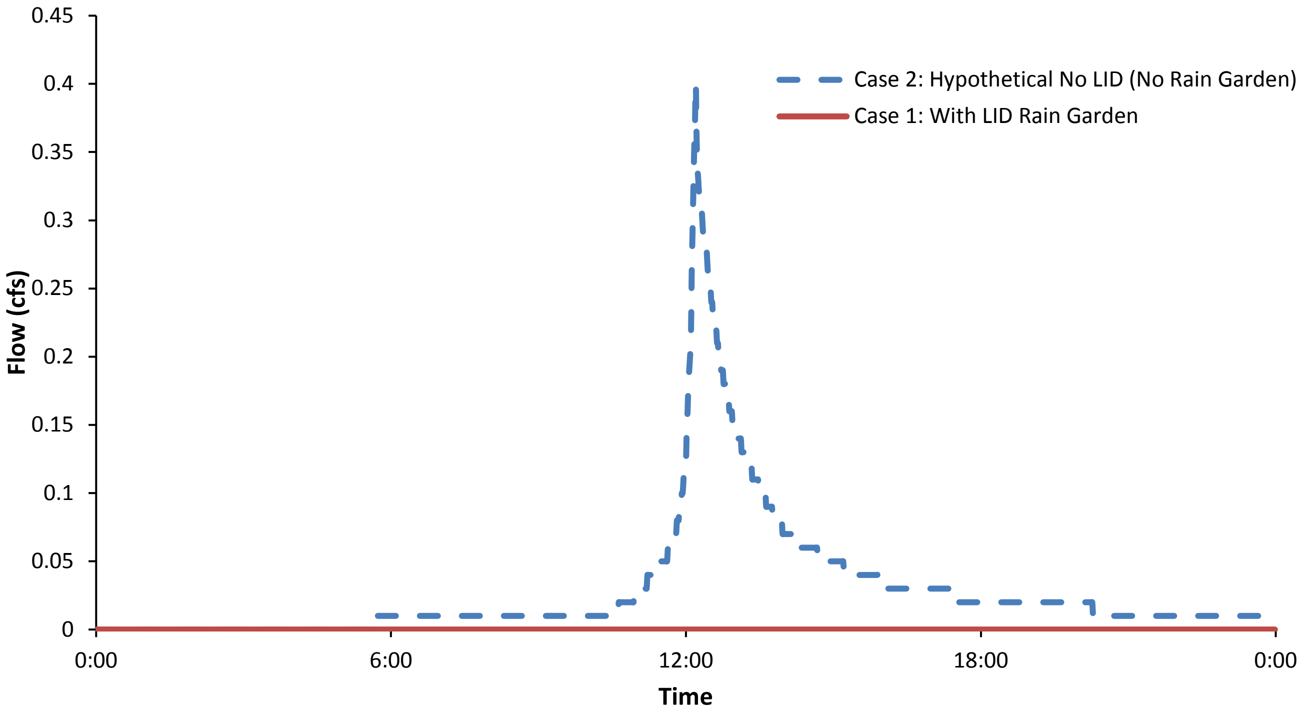


Table 10: Valley of the Moon Rain Garden Performance Summary

Case	August 21, 2018		10-Year, 24-Hour	
	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
Case 1 - With LID Rain Garden	0.00	0	0.00	0
Case 2 - Hypothetical No LID	0.01	267	0.40	2,406
% Decrease	100	100	100	100

7.4. Conclusions and Recommendations for Future Projects

This rain garden is performing very well and is providing stormwater treatment and retention for both small and moderate rain events. The use of the rain garden for snow storage and snow melt treatment is somewhat unique, and ongoing performance monitoring may be useful to determine if sediment collection from the snowmelt becomes an issue over time.

Water flows into this rain garden only via surface flow—there are no piped inlets. Inflow across the vegetation provides an opportunity for pretreatment of rainfall runoff prior to entering the facility.

Depending on what treatment media is installed, performance could potentially be enhanced if vegetation were extended to include the facility floor. This would encourage evapotranspiration and help maintain pathways for infiltration via the plant roots.

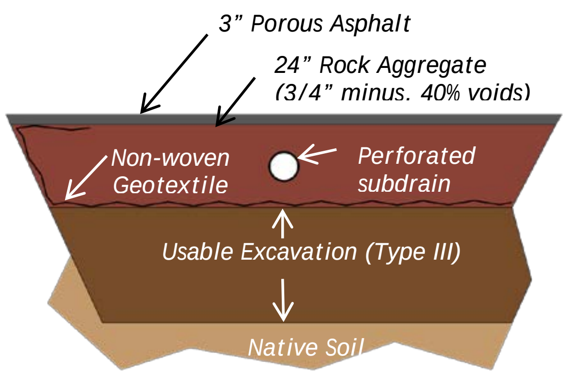
8. Russian Jack Springs Park Porous Asphalt and Infiltration Gallery (MOA)

The Russian Jack Spring Park (RJSP) parking lot has been included in the MOA monitoring program since the project construction in 2012. The parking lot is located at 821 Pine Street in Anchorage, which is south of 6th Avenue, and north of Debarr Road. As a joint effort between the MOA Watershed and Parks departments, the approximately one-acre parking lot was retrofitted to provide improved parking and safer pedestrian facilities for park users. The RJSP parking lot is used in the summer months for access to the softball fields located north and south of the parking lot and the soccer fields to the east. It is also used year-round for access to the park's popular trail system. The parking lot LID features include porous asphalt and an underground infiltration gallery made of chambers. The parking lot layout is shown in Figure 51.

Figure 51: RJSP Parking Lot Layout

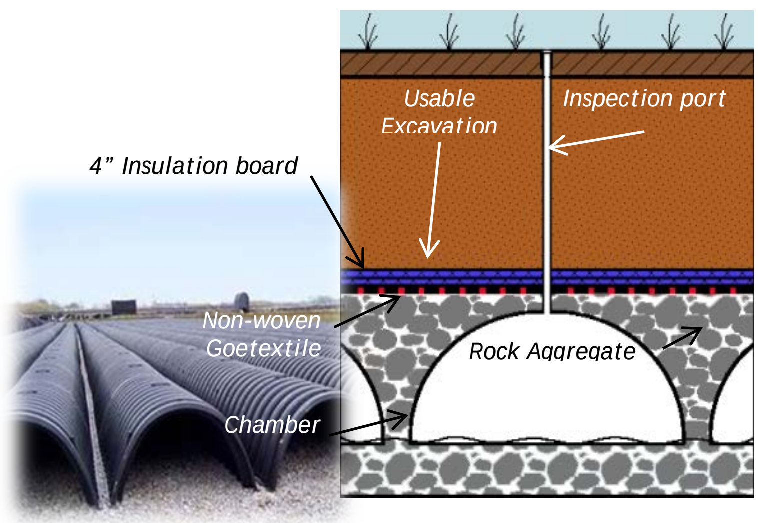
Porous Asphalt. Portions of the RJSP parking lot are constructed with porous asphalt. Rain water that falls on these areas flows through the asphalt into a subsurface rock storage area. Water is stored there and slowly infiltrated as soil capacity becomes available. The porous asphalt was designed to store and infiltrate up to the 10-year, 24-hour rainfall event. Two of the three porous asphalt sections were installed with a perforated subdrain near the top of the asphalt's structural section. In the event that the asphalt's structural section should become filled with water in excess of the design volume, water would be collected in the subdrain pipe and directed away from the asphalt. Figure 52 shows a schematic of a typical porous asphalt section. One section was installed without the subdrain in order to compare the performance of the two types. The subdrain pipes are routed to the subsurface infiltration gallery via an on-site storm drain system.

Figure 52: Typical Porous Asphalt Section



Infiltration Chambers. Water that falls on the traditional asphalt is directed to a subsurface infiltration chamber facility via traditional stormwater conveyance piping. The chambers are designed to store and infiltrate up to the 100-year, 24-hour event. Figure 53 shows a schematic of a chamber system typical section.

Figure 53: Typical Infiltration Gallery Section



8.1. Visual Monitoring

RJSP was visited on August 21 and on October 16 of 2018. Previous monitoring reports (2013 through 2016) have noted good drainage performance of this parking lot despite ongoing maintenance and site use concerns associated with the porous asphalt. The 2018 observations continue this general trend. An overview of the parking lot from the August site visit is provided in Figure 54 below.

Figure 54: RJSP Parking Lot August 21 Site Visit

The August 21 site visit occurred about 5:30 pm. It was actively raining at this time, and the site visit occurred near the end of a storm event that generated 0.72 inches of rain in a 24-hour period and over an inch of rain in a 48-hour period. (This event is described in Section 4.2 of this report.) All three sections of porous asphalt were observed to be draining well. Surface ponding was only noted at the edges of the porous asphalt, where runoff from the traditional asphalt was flowing onto the porous asphalt.

Figure 55: Porous/Traditional Asphalt Interface – August 21 Site Visit

Previous monitoring reports have noted surface raveling of the porous asphalt. This continues to be a concern, but did not appear to be notably worse than previous observations. There did not appear to be signs of new asphalt wear or damage, such as rutting or depressions. Damage mentioned in previous reports, such as rutting on the parking lot's west side, was still present but did not appear to be worsened. Light debris and small rocks from the surface raveling were observed on the asphalt surface.

The monitoring wells in each of the three section of porous asphalt were checked to evaluate the depth of water in the subgrade. In the center section of porous asphalt, water depth was 6 inches, and in the west section of porous asphalt, water depth was 8.5 inches.

The monitoring well in the northern section of porous asphalt was filled with rocks and was no longer accessible. This is unfortunate for ongoing performance monitoring, as the north section was installed without a perforated subdrain for comparison with the other two sections.

The infiltration gallery was also inspected via the surface inspections ports, and there was no standing water in the infiltration gallery. This indicates that water entering the infiltration gallery is infiltrating quickly, and storage capacity in the facility chambers is not being utilized. This is consistent with previous inspections. Note that the inspection port on the far west side of the facility is no longer present. It was apparently cut off and buried.

The October 16 site visit occurred about noon, which was shortly after a rain event that had resulted in 0.52 inches of rain in 24 hour period and 0.82 inches of rain in a 48 hour period. It was not raining at the time of the inspection. Site observations were very similar to observations from the August site visit. The asphalt condition was the same as previously described, except there was notably less surface water at the interface between the porous asphalt and the traditional asphalt. There was no standing water in the infiltration gallery. The water depth was approximately 6.5 inches deep in the center monitoring well and approximately 5 inches deep in the west monitoring well. Leaves and other miscellaneous debris were noted on the porous asphalt surface, particularly on the west side which is close to adjacent trees.

Figure 56: RJSP West Section of Porous Asphalt – October 16 Site Visit

8.2. Performance Summary

Despite the noted surface raveling and ongoing concerns with maintenance, the porous asphalt is still draining well and performing as intended. The surface raveling remains a concern. The small rocks that are loosened from the asphalt surface cause additional surface abrasion as they are driven on, which further compounds the raveling. Frequent sweeping of the parking lot may help reduce this issue, but resources for frequent sweeping are generally not available. The approved maintenance plan for this parking lot calls for two sweeps each year.

The low water levels observed in the monitoring wells indicate that water in the porous asphalt subgrade is successfully infiltrating, and that water is not reaching the elevation of the subdrain.

The subsurface infiltration gallery is performing very well and exceeding design expectations, as the facility storage area is not being utilized. These types of infiltration facilities have become successful in many parts of Anchorage where the groundwater elevation is not close to the surface.

9. Taku Lake Rain Garden (MOA)

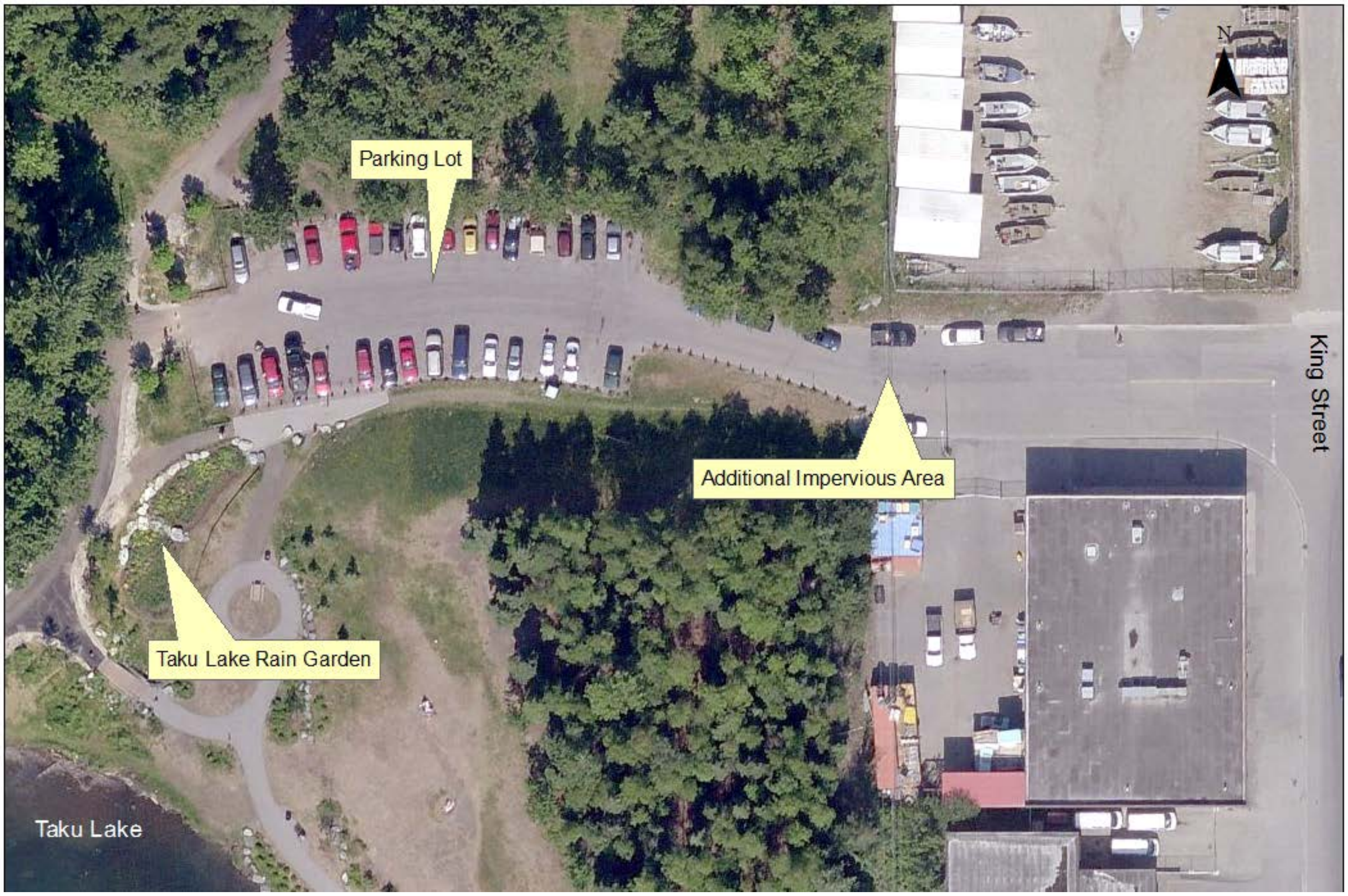
The Taku Lake Rain Garden project was completed by the MOA in 2007 as part of an effort to improve a localized drainage and flooding problem at the Taku Lake parking lot. Taku Lake is located in Anchorage, north of Dimond Boulevard and west of King Street. The Campbell Creek trail is adjacent to the lake, and the area is popular year-round for recreational activities including walking, running, skiing, biking, and remote-control boats. The paved parking lot is approximately 12,150 square feet. The rain garden accepts runoff from the parking lot, a portion of the grassy area around the parking lot, and a portion of the roadway surface that provides access to the park.

The rain garden is approximately 1,400 square feet, and is located approximately 60 feet from the normal edge of water of Taku Lake. The rain garden consists of approximately 1.3 feet of amended topsoil on top of 2.3 feet of large drain rock. The drain rock is surrounded by geotextile separation fabric. A four-inch diameter perforated drain pipe was installed one foot from the bottom of the rain garden to collect excess water that is not infiltrated into the native subgrade. The perforated drain pipe discharges at the west end of the rain garden near the edge of Taku Lake. The MOA planted a variety of native vegetation in the rain garden including wildflowers, ferns, and grasses.

The rain garden was designed to accept and infiltrate runoff from small, frequent rainfall events. Water beyond the design capacity is either collected in the subdrain or is allowed to overflow from the rain garden and flow into the lake via overland flow. Figure 57 shows the rain garden and its contributing area.

The rain garden was monitored as part of the 2013, 2014, 2015, and 2016 monitoring programs and was found to be performing very well. The rain garden has been consistently infiltrating small, frequent rain events with no flow out the subdrain. For larger rain events, the rain garden provided water quality treatment as well as some attenuation of peak flows by infiltrating water through the rain garden soils prior to discharge. During larger events, excess water was observed to flow out the subdrain to Taku Lake.

Figure 57: Taku Lake Rain Garden Site



9.1. Visual Monitoring

The Taku Lake rain garden was visited on August 21 at about 3:30 pm. It was actively raining at this time, and the visit occurred during the later portion of this storm event which generated 0.72 inches of rain in a 24-hour period and over an inch of rain in a 48-hour period. (This event is described in Section 4.2 of this report.)

Surface runoff from the contributing parking lot and additional impervious areas was flowing into the rain garden near the edge of the parking lot. Vegetation in the rain garden was thick and mature, and there was a large alder growing near the rain garden's main inlet area. There was no standing water observed in the rain garden. The rain garden's perforated subdrain was flowing about half full and discharging water to adjacent Taku Lake.

Figure 58 shows an overview of the rain garden, and Figure 59 shows stormwater flowing into the rain garden and the large alder near the inlet.

Figure 58: Taku Lake Rain Garden – August 21 Site Visit

Figure 59: Parking Lot Flow to Rain Garden – August 21 Site Visit

9.2. Performance Summary

The Taku Lake rain garden has been successfully treating, infiltrating, and detaining stormwater runoff for over 11 years. It is an excellent example of how successful bioretention can be, and it is a low-maintenance facility. Vegetation in this rain garden does not appear to be controlled, as the facility has become dominated by alders. While this is not expected to be negatively influencing the facility performance, the alders may be hindering the growth of other plant species.

10. West Dowling Road Phase I Bioswale (DOT&PF)

Dowling Road is an east-west road in Anchorage, connecting Elmore Road to Minnesota Drive. The West Dowling Road Extension Phase I project was constructed in 2012 and widened the Dowling Road corridor from the Old Seward Highway (OSH) to C Street from a two-lane road to a four-lane road with a center median. The project also constructed new pedestrian facilities and drainage improvements. The project lies in the Campbell Creek Watershed and crosses Campbell Creek via a bridge between Potter Drive and the OSH.

The West Dowling Road Phase I project included several LID/GI features, but the focus of the ongoing performance monitoring is the project's large bioswale located on the north side of the road, east of the OSH. Stormwater runoff from approximately 17.4 acres of residential and industrial areas is directed to the swale via a series of storm drain collection pipes that outfall at various locations along the length of the swale. This bioswale was also included in the MOA's 2013, 2015, and 2016 monitoring programs and was found to be performing well. The primary purpose of the bioswale is to improve water quality before the runoff enters Campbell Creek. Treatment is achieved via infiltration, transpiration, and filtration to remove sediment and associated pollutants. The 2013 monitoring results indicated that the swale is also providing attenuation of peak flows for lower rainfall events, generally less than the 10-year event. An overview of the swale site is presented in Figure 60.

Figure 60: West Dowling Phase I Bioswale Site Overview

10.1. Visual Monitoring

The West Dowling bioswale was visited on August 21 at about 2:35 pm. It was actively raining at this time, as the site visit occurred during a storm event which generated 0.72 inches of rain in a 24-hour period and over an inch of rain in a 48-hour period. (This event is described in Section 4.2 of this report.) Photos of the bioswale during the site visit are provided in Figures 61 and 62.

Water was flowing into the swale from all but one of the 5 storm drain pipes that discharge water into the swale. Water in the swale was moving slowly to the east, toward the swale's outlet into Campbell Creek. The grasses on the swale side slopes had been mowed, but the vegetation in the facility bottom was un-mowed and tall, which helped slow water as it moved through the facility. In previous site visits, vegetation in the facility was primarily noted as grasses, but cattails were also observed at this site visit. Water from the swale was discharging into Campbell Creek via a rock-lined outlet channel at the far east end.

Figure 61: West Dowling Bioswale West End – August 21 Site Visit

Figure 62: West Dowling Bioswale East End – August 21 Site Visit

10.2. Performance Summary

This bioswale continues to provide infiltration, filtration, and detention of large volumes of stormwater prior to discharging stormwater to Campbell Creek. No performance issues were noted. The bioswale performance is expected to be enhanced by the mature vegetation, particularly since the vegetation height exceeds the depth of water in the swale. This provides increased filtration and more opportunity for infiltration.

11. New Seward Highway Improvements from Dowling Rd to Tudor Rd (DOT&PF)

The New Seward Highway (NSH) is located in Anchorage and serves as one of the city's primary north-south highway corridors. The New Seward Highway Improvements – Dowling to Tudor project, constructed from 2013-2014, expanded the existing highway corridor from four lanes to six lanes and reconstructed portions of the frontage roads. The majority of the project lies in the Campbell Creek watershed, and the highway crosses Campbell Creek via a bridge located north of International Airport Drive and south of Tudor Road. A small portion of the Tudor-NSH intersection lies within the Fish Creek watershed. Fish Creek crosses Tudor Road via a piped storm drain near this intersection.

This project incorporated several types of LID/GI treatment, including vegetated swales with check dams and an infiltration basin. The infiltration basin has been the focus of ongoing performance monitoring, and was also included in the 2013, 2015, and 2016 monitoring programs. The infiltration basin is located near the intersection of Brayton Drive and Alpenhorn Avenue, and is collecting stormwater runoff from approximately 9.4 acres, 6.7 of which is impervious surface. The retention basin is approximately 150 feet long and 45 feet wide, with gentle side slopes and an approximate average depth of two feet. The basin is vegetated with grasses, and riprap is present near the inlet and outlet. The basin inlet is a 24-inch diameter culvert on the southwest side of the basin, and the outlet is a small earthen berm on the north side. The outlet berm is overtopped when the inflow exceeds the basin capacity. The infiltration basin was designed to capture and infiltrate the runoff generated from the 90^{th} percentile water quality event. Larger events were designed to overflow from the pond to a vegetated ditch that discharges to Campbell Creek. An overview of the infiltration basin site is shown in Figure 63.

Figure 63: NSH Infiltration Basin Site Overview

11.1. Visual Monitoring

The NSH infiltration pond was visited twice during the monitoring period—once on August 21 and once on October 16. The August 21 site visit occurred about 4:45 pm. It was actively raining at this time, and the visit occurred near the end of a storm event which generated 0.72 inches of rain in a 24-hour period and over an inch of rain in a 48-hour period. (This event is described in Section 4.2 of this report.)

Water was flowing steadily into the pond from the piped storm drain inlet on the pond's south side, and some trash and debris had collected at the inlet. There was standing water in the pond, but the pond's outlet was not flowing.

There was noticeably more mature vegetation around the pond than had been observed in previous years. Alders and tall grasses lined the pond's perimeter. Photos from the August site visit are provided in Figures 64 and 65.

Figure 64: NSH Infiltration Basin – August 21 Site Visit

Figure 65: NSH Infiltration Basin Inlet (left) and Outlet (right) – August 21 Site Visit

The October 16 site visit occurred at about 11:40 am, shortly after a rain event that had resulted in 0.52 inches of rain in 24 hour period and 0.82 inches of rain in a 48 hour period. It was not raining at the time of the site visit. The pond water level was notably lower than it had been in August, and neither the inlet nor the outlet were actively flowing. A photo of the pond from the October site visit is shown in Figure 66.

Figure 66: NSH Infiltration Basin – October 16 Site Visit

11.2. Performance Summary

The NSH infiltration pond is performing very well. It is successfully capturing and infiltrating large volumes of stormwater for small and mid-size rain events, and providing safe bypass for large flows. Prior analyses of this pond have shown that this facility can accept and infiltrate water from events notably lager than the water quality event for which it was designed, and the pond continues to exceed design expectations. The pond appears to fully drain between rain events, as evident by the low water surface elevation in the pond following the October rain event. The increase in pond vegetation should be an overall enhancement of the pond performance, provided the vegetation does not grow to the point that it blocks the inlet.

12. Alaska Commercial Fishing and Agriculture Bank (Private)

The Commercial Fishing and Agriculture Bank (CFAB) rain garden was constructed in 2009 as part of an expansion and remodeling project for the CFAB building. WMS partnered with the CFAB owners and provided a portion of the rain garden funding through the MOA Rain Garden Program. The project is located at the corner of Lakeshore Drive and Wisconsin Avenue, near Spenard Road in Anchorage. The project site is in the Fish Creek watershed. This project was included in the 2013 and 2015 monitoring programs, and was found to be performing well.

The rain garden utilizes the site's landscaping to capture and infiltrate stormwater. It is designed to capture stormwater runoff from the approximately 11,000 square-foot parking lot and from approximately 2,600 square feet of the building roof. Smaller events are generally captured by the rain garden, and larger flows are discharged to an adjacent storm drain via a bee-hive inlet in the center of the garden. Some volume reduction and attenuation of peak flows is also provided for larger rain events.

Figure 67: Alaska Commercial Fishing and Agriculture Bank Site Overview

12.1. Visual Monitoring

A winter inspection of the CFAB rain garden was completed to determine how the rain garden space was being used in the winter months and if the facility was used to store snow. The site visit was completed on January 24, 2019 at about 10:30 am. It was overcast with no precipitation and temperatures were in the mid-20s. The facility was covered in approximately two feet of snow. The snow on the rain garden surface was from natural accumulation and did not appear to be from plowing adjacent parking areas. Taller trees and shrubs were visible above the snow. The facility's beehive inlet was covered with snow, but was located and uncovered for reference.

Figure 68: CFAB Rain Garden – January 2019 Site Visit

Figure 69: CFAB Rain Garden and Beehive Overflow – January 2019 Site Visit

12.2. Performance Summary

The CFAB rain garden is not being used for snow storage or snow melt runoff treatment. This approach is likely helping to keep heavy sediment loading out of the rain garden, as it not known if the facility was designed for snowmelt loading. Snow that falls on the rain garden surface will be treated by the rain garden as it melts, or, if the underlying soil layers are frozen when the snow melts, snow melt will be directed to the beehive in the center of the rain garden.

13. Conclusions

Green Infrastructure and LID facilities are becoming more prevalent for onsite stormwater management in Anchorage, and their use is expected to continue to grow as a result of updated stormwater management requirements. Ongoing performance monitoring provides valuable lessons learned for future designs, as well as a documented record of facility longevity and performance over time. Key lessons learned from the 2018 monitoring program are summarized below.

1. Understanding how a site will be used and how the site use may change over time is critically important for successful selection, design, and construction of LID/GI facilities. Choose LID/GI facilities that are compatible with the current and anticipated future site use.
2. Permeable Pavement Turf Grid is expected to be a good solution for cases where heavy surface loading is not expected such that the subgrade can be safely constructed of porous, open-graded rock.
3. Bioretention is one of the most widely used and successful types of LID/GI tools in Anchorage. Rain gardens, vegetated swales/bioswales, and landscaped areas are all types of bioretention facilities that are working very well in a number sites.
4. Bioretention is most effective when the facility is fully vegetated, especially along the facility floor or flow line. Vegetation can be used to help slow the movement of water through a bioswale, especially when the vegetation is taller than the flow depth of the swale. Vegetation also provides pathways for infiltration, promotes filtration, and utilizes more water via evapotranspiration.
5. Rain gardens and other bioretention areas can be used for wintertime snow storage, though it is not known if the associated sediment loading will decrease facility performance over time. Depending on how the facility is configured and what storage volume it has, this practice may result in some treatment for snowmelt water. In other cases, if the facility does not provide much storage or if the rain garden soils are frozen and unable to infiltrate water, snow melt should be designed to safely overflow to an adjacent receiving system.
6. Various types of stormwater ponds are another prevalent LID/GI in Anchorage. Ponds are used for a combination of stormwater treatment, peak flow detention, and/or permanent retention of large volumes of water. In cases where ponds are not designed to hold runoff from large storms events, safe bypass facilities are important. Bypass channels are usually lined with riprap to prevent erosion during flood bypass.

Appendix A: Rainfall Data

Rainfall Data - FIRE STATION 9 and O'MALLEY ROAD

August 20 - 22, 2018

Date and Time	Hourly Rainfall (inches)
8/20/18 8:00	0.00
8/20/18 9:00	0.00
8/20/18 10:00	0.00
8/20/18 11:00	0.00
8/20/18 12:00	0.00
8/20/18 13:00	0.06
8/20/18 14:00	0.08
8/20/18 15:00	0.03
8/20/18 16:00	0.01
8/20/18 17:00	0.01
8/20/18 18:00	0.00
8/20/18 19:00	0.00
8/20/18 20:00	0.00
8/20/18 21:00	0.00
8/20/18 22:00	0.00
8/20/18 23:00	0.00
8/21/18 0:00	0.07
8/21/18 1:00	0.02
8/21/18 2:00	0.06
8/21/18 3:00	0.06
8/21/18 4:00	0.13
8/21/18 5:00	0.01
8/21/18 6:00	0.00
8/21/18 7:00	0.00
8/21/18 8:00	0.01
8/21/18 9:00	0.03
8/21/18 10:00	0.07
8/21/18 11:00	0.04
8/21/18 12:00	0.04
8/21/18 13:00	0.06
8/21/18 14:00	0.05
8/21/18 15:00	0.09
8/21/18 16:00	0.08
8/21/18 17:00	0.05
8/21/18 18:00	0.02
8/21/18 19:00	0.01
8/21/18 20:00	0.00
8/21/18 21:00	0.00
8/21/18 22:00	0.00
8/21/18 23:00	0.00
8/22/18 0:00	0.00
8/22/18 1:00	0.02
8/22/18 2:00	0.01
8/22/18 3:00	0.02
8/22/18 4:00	0.00
8/22/18 5:00	0.00

8/22/18 6:00	0.00
8/22/18 7:00	0.00
8/22/18 8:00	0.00
Total Rainfall (in)	1.14

Rainfall Data - FIRE STATION 9 and O'MALLEY ROAD
10-Year, 24-Hour

Date	Time	Rainfall Depth (inches)
01/01/2018	0:00	0
	0:06	0.00463239
	0:12	0.00468141
	0:18	0.00473043
	0:24	0.00477945
	0:30	0.00482847
	0:36	0.004902
	0:42	0.00492651
	0:48	0.00497553
	0:54	0.00502455
	1:00	0.00509808
	1:06	0.00512259
	1:12	0.00519612
	1:18	0.00522063
	1:24	0.00529416
	1:30	0.00531867
	1:36	0.0053922
	1:42	0.00544122
	1:48	0.00546573
	1:54	0.00553926
	2:00	0.00558828
	2:06	0.0056373
	2:12	0.00568632
	2:18	0.00573534
	2:24	0.00578436
	2:30	0.00583338
	2:36	0.0058824
	2:42	0.00593142
	2:48	0.00598044
	2:54	0.00602946
	3:00	0.00607848
	3:06	0.00615201
	3:12	0.00617652
	3:18	0.00622554
	3:24	0.00629907
	3:30	0.00632358
	3:36	0.00639711
	3:42	0.00642162
	3:48	0.00649515
	3:54	0.00654417
	4:00	0.00656868
	4:06	0.00664221
	4:12	0.00669123
	4:18	0.00674025
	4:24	0.00676476
	4:30	0.00683829

	4:36	0.00688731
	4:42	0.00693633
	4:48	0.00698535
	4:54	0.00703437
	5:00	0.00708339
	5:06	0.00715692
	5:12	0.00718143
	5:18	0.00723045
	5:24	0.00727947
	5:30	0.007353
	5:36	0.00737751
	5:42	0.00742653
	5:48	0.00750006
	5:54	0.00752457
	6:00	0.0075981
	6:06	0.00762261
	6:12	0.00769614
	6:18	0.00774516
	6:24	0.00776967
	6:30	0.0078432
	6:36	0.00789222
	6:42	0.00794124
	6:48	0.00799026
	6:54	0.00803928
	7:00	0.0080883
	7:06	0.00813732
	7:12	0.00818634
	7:18	0.00823536
	7:24	0.00828438
	7:30	0.0083334
	7:36	0.00838242
	7:42	0.00845595
	7:48	0.00848046
	7:54	0.00852948
	8:00	0.00860301
	8:06	0.00862752
	8:12	0.00870105
	8:18	0.00872556
	8:24	0.00879909
	8:30	0.0088236
	8:36	0.00889713
	8:42	0.00894615
	8:48	0.00899517
	8:54	0.00901968
	9:00	0.00909321
	9:06	0.01075989
	9:12	0.01085793

	9:18	0.01093146
	9:24	0.0110295
	9:30	0.01110303
	9:36	0.01120107
	9:42	0.0112746
	9:48	0.01137264
	9:54	0.01144617
	10:00	0.01154421
	10:06	0.01161774
	10:12	0.01169127
	10:18	0.01181382
	10:24	0.01186284
	10:30	0.01198539
	10:36	0.0142158
	10:42	0.01485306
	10:48	0.0154413
	10:54	0.01605405
	11:00	0.01664229
	11:06	0.01727955
	11:12	0.01786779
	11:18	0.01848054
	11:24	0.01909329
	11:30	0.01968153
	11:36	0.02348058
	11:42	0.02674041
	11:48	0.03598068
	11:54	0.05137296
	12:00	0.0941184
	12:06	0.16661898
	12:12	0.05137296
	12:18	0.03598068
	12:24	0.02674041
	12:30	0.02348058
	12:36	0.01968153
	12:42	0.01909329
	12:48	0.01848054
	12:54	0.01786779
	13:00	0.01727955
	13:06	0.01664229
	13:12	0.01605405
	13:18	0.0154413
	13:24	0.01485306
	13:30	0.0142158
	13:36	0.01198539
	13:42	0.01186284
	13:48	0.01181382
	13:54	0.01169127

	14:00	0.01161774
	14:06	0.01154421
	14:12	0.01144617
	14:18	0.01137264
	14:24	0.0112746
	14:30	0.01120107
	14:36	0.01110303
	14:42	0.0110295
	14:48	0.01093146
	14:54	0.01085793
	15:00	0.01075989
	15:06	0.00909321
	15:12	0.00901968
	15:18	0.00899517
	15:24	0.00894615
	15:30	0.00889713
	15:36	0.0088236
	15:42	0.00879909
	15:48	0.00872556
	15:54	0.00870105
	16:00	0.00862752
	16:06	0.00860301
	16:12	0.00852948
	16:18	0.00848046
	16:24	0.00845595
	16:30	0.00838242
	16:36	0.0083334
	16:42	0.00828438
	16:48	0.00823536
	16:54	0.00818634
	17:00	0.00813732
	17:06	0.0080883
	17:12	0.00803928
	17:18	0.00799026
	17:24	0.00794124
	17:30	0.00789222
	17:36	0.0078432
	17:42	0.00776967
	17:48	0.00774516
	17:54	0.00769614
	18:00	0.00762261
	18:06	0.0075981
	18:12	0.00752457
	18:18	0.00750006
	18:24	0.00742653
	18:30	0.00737751
	18:36	0.007353

	18:42	0.00727947
	18:48	0.00723045
	18:54	0.00718143
	19:00	0.00715692
	19:06	0.00708339
	19:12	0.00703437
	19:18	0.00698535
	19:24	0.00693633
	19:30	0.00688731
	19:36	0.00683829
	19:42	0.00676476
	19:48	0.00674025
	19:54	0.00669123
	20:00	0.00664221
	20:06	0.00656868
	20:12	0.00654417
	20:18	0.00649515
	20:24	0.00642162
	20:30	0.00639711
	20:36	0.00632358
	20:42	0.00629907
	20:48	0.00622554
	20:54	0.00617652
	21:00	0.00615201
	21:06	0.00607848
	21:12	0.00602946
	21:18	0.00598044
	21:24	0.00593142
	21:30	0.0058824
	21:36	0.00583338
	21:42	0.00578436
	21:48	0.00573534
	21:54	0.00568632
	22:00	0.0056373
	22:06	0.00558828
	22:12	0.00553926
	22:18	0.00546573
	22:24	0.00544122
	22:30	0.0053922
	22:36	0.00531867
	22:42	0.00529416
	22:48	0.00522063
	22:54	0.00519612
	23:00	0.00512259
	23:06	0.00509808
	23:12	0.00502455
	23:18	0.00497553

	23:24	0.00492651
	23:30	0.004902
	23:36	0.00482847
	23:42	0.00477945
	23:48	0.00473043
	23:54	0.00468141
01/02/2018	0:00	0.00463239
Total Rainfall (in)		2.45

Rainfall Data - WEST DOWLING ROAD PHASE II and VALLEY OF THE MOON

August 20 - 22, 2018

Date	Time	Rainfall Depth (inches)
8/20/2018	7:53	0
	8:53	0
	9:53	0
	10:53	0
	11:53	0
	12:53	0.04
	13:53	0.07
	14:53	0.06
	15:53	0.02
	16:53	0.08
	17:53	0
	18:53	0
	19:53	0
	20:53	0
	21:53	0
	22:53	0
	23:53	0.06
8/21/2018	0:53	0.11
	1:53	0.08
	2:53	0.12
	3:53	0.02
	4:53	0.01
	5:53	0.01
	6:53	0
	7:53	0
	8:53	0.07
	9:53	0.02
	10:53	0.01
	11:53	0.03
	12:53	0.06
	13:53	0.05
	14:53	0.06
	15:53	0.05
	16:53	0.01
	17:53	0
	18:53	0
	19:53	0
	20:53	0
	21:53	0
	22:53	0
	23:53	0.01
8/22/2018	0:53	0.02
	1:53	0.01
	2:53	0
	3:53	0
	4:53	0

	5:53	0
	6:53	0
Total Rainfall (in)		1.08

Rainfall Data - WEST DOWLING ROAD PHASE II

October 15 - 16, 2018

Date	Time	Rainfall Depth (inches)
10/15/2018	0:53	0
	1:53	0
	2:53	0
	3:53	0
	4:53	0
	5:53	0
	6:53	0
	7:53	0
	8:53	0
	9:53	0
	10:53	0.02
	11:53	0.01
	12:53	0
	13:53	0
	14:53	0
	15:53	0.01
	16:53	0
	17:53	0.02
	18:53	0.06
	19:53	0.05
	20:53	0.06
	21:53	0.01
	22:53	0.03
	23:53	0.03
10/16/2018	0:53	0.02
	1:53	0.03
	2:53	0.04
	3:53	0.1
	4:53	0.17
	5:53	0.11
	6:53	0.04
	7:53	0
	8:53	0
	9:53	0
	10:53	0
	11:53	0
	12:53	0
	13:53	0
	14:53	0
	15:53	0.01
	16:53	0
	17:53	0
	18:53	0
	19:53	0
	20:53	0
	21:53	0

	22:53	0
	23:53	0
Total Rainfall (in)		0.82

Rainfall Data - WEST DOWLING ROAD PHASE II and VALLEY OF THE MOON
10-Year, 24-Hour

Date	Time	Rainfall Depth (inches)
01/01/2019	0:00	0
	0:06	0.0043092
	0:12	0.0043548
	0:18	0.0044004
	0:24	0.004446
	0:30	0.0044916
	0:36	0.00456
	0:42	0.0045828
	0:48	0.0046284
	0:54	0.004674
	1:00	0.0047424
	1:06	0.0047652
	1:12	0.0048336
	1:18	0.0048564
	1:24	0.0049248
	1:30	0.0049476
	1:36	0.005016
	1:42	0.0050616
	1:48	0.0050844
	1:54	0.0051528
	2:00	0.0051984
	2:06	0.005244
	2:12	0.0052896
	2:18	0.0053352
	2:24	0.0053808
	2:30	0.0054264
	2:36	0.005472
	2:42	0.0055176
	2:48	0.0055632
	2:54	0.0056088
	3:00	0.0056544
	3:06	0.0057228
	3:12	0.0057456
	3:18	0.0057912
	3:24	0.0058596
	3:30	0.0058824
	3:36	0.0059508
	3:42	0.0059736
	3:48	0.006042
	3:54	0.0060876
	4:00	0.0061104
	4:06	0.0061788
	4:12	0.0062244
	4:18	0.00627

	4:24	0.0062928
	4:30	0.0063612
	4:36	0.0064068
	4:42	0.0064524
	4:48	0.006498
	4:54	0.0065436
	5:00	0.0065892
	5:06	0.0066576
	5:12	0.0066804
	5:18	0.006726
	5:24	0.0067716
	5:30	0.00684
	5:36	0.0068628
	5:42	0.0069084
	5:48	0.0069768
	5:54	0.0069996
	6:00	0.007068
	6:06	0.0070908
	6:12	0.0071592
	6:18	0.0072048
	6:24	0.0072276
	6:30	0.007296
	6:36	0.0073416
	6:42	0.0073872
	6:48	0.0074328
	6:54	0.0074784
	7:00	0.007524
	7:06	0.0075696
	7:12	0.0076152
	7:18	0.0076608
	7:24	0.0077064
	7:30	0.007752
	7:36	0.0077976
	7:42	0.007866
	7:48	0.0078888
	7:54	0.0079344
	8:00	0.0080028
	8:06	0.0080256
	8:12	0.008094
	8:18	0.0081168
	8:24	0.0081852
	8:30	0.008208
	8:36	0.0082764
	8:42	0.008322
	8:48	0.0083676
	8:54	0.0083904
	9:00	0.0084588

	9:06	0.0100092
	9:12	0.0101004
	9:18	0.0101688
	9:24	0.01026
	9:30	0.0103284
	9:36	0.0104196
	9:42	0.010488
	9:48	0.0105792
	9:54	0.0106476
	10:00	0.0107388
	10:06	0.0108072
	10:12	0.0108756
	10:18	0.0109896
	10:24	0.0110352
	10:30	0.0111492
	10:36	0.013224
	10:42	0.0138168
	10:48	0.014364
	10:54	0.014934
	11:00	0.0154812
	11:06	0.016074
	11:12	0.0166212
	11:18	0.0171912
	11:24	0.0177612
	11:30	0.0183084
	11:36	0.0218424
	11:42	0.0248748
	11:48	0.0334704
	11:54	0.0477888
	12:00	0.087552
	12:06	0.1549944
	12:12	0.0477888
	12:18	0.0334704
	12:24	0.0248748
	12:30	0.0218424
	12:36	0.0183084
	12:42	0.0177612
	12:48	0.0171912
	12:54	0.0166212
	13:00	0.016074
	13:06	0.0154812
	13:12	0.014934
	13:18	0.014364
	13:24	0.0138168
	13:30	0.013224
	13:36	0.0111492
	13:42	0.0110352

	13:48	0.0109896
	13:54	0.0108756
	14:00	0.0108072
	14:06	0.0107388
	14:12	0.0106476
	14:18	0.0105792
	14:24	0.010488
	14:30	0.0104196
	14:36	0.0103284
	14:42	0.01026
	14:48	0.0101688
	14:54	0.0101004
	15:00	0.0100092
	15:06	0.0084588
	15:12	0.0083904
	15:18	0.0083676
	15:24	0.008322
	15:30	0.0082764
	15:36	0.008208
	15:42	0.0081852
	15:48	0.0081168
	15:54	0.008094
	16:00	0.0080256
	16:06	0.0080028
	16:12	0.0079344
	16:18	0.0078888
	16:24	0.007866
	16:30	0.0077976
	16:36	0.007752
	16:42	0.0077064
	16:48	0.0076608
	16:54	0.0076152
	17:00	0.0075696
	17:06	0.007524
	17:12	0.0074784
	17:18	0.0074328
	17:24	0.0073872
	17:30	0.0073416
	17:36	0.007296
	17:42	0.0072276
	17:48	0.0072048
	17:54	0.0071592
	18:00	0.0070908
	18:06	0.007068
	18:12	0.0069996
	18:18	0.0069768
	18:24	0.0069084

	18:30	0.0068628
	18:36	0.00684
	18:42	0.0067716
	18:48	0.006726
	18:54	0.0066804
	19:00	0.0066576
	19:06	0.0065892
	19:12	0.0065436
	19:18	0.006498
	19:24	0.0064524
	19:30	0.0064068
	19:36	0.0063612
	19:42	0.0062928
	19:48	0.00627
	19:54	0.0062244
	20:00	0.0061788
	20:06	0.0061104
	20:12	0.0060876
	20:18	0.006042
	20:24	0.0059736
	20:30	0.0059508
	20:36	0.0058824
	20:42	0.0058596
	20:48	0.0057912
	20:54	0.0057456
	21:00	0.0057228
	21:06	0.0056544
	21:12	0.0056088
	21:18	0.0055632
	21:24	0.0055176
	21:30	0.005472
	21:36	0.0054264
	21:42	0.0053808
	21:48	0.0053352
	21:54	0.0052896
	22:00	0.005244
	22:06	0.0051984
	22:12	0.0051528
	22:18	0.0050844
	22:24	0.0050616
	22:30	0.005016
	22:36	0.0049476
	22:42	0.0049248
	22:48	0.0048564
	22:54	0.0048336
	23:00	0.0047652
	23:06	0.0047424

	23:12	0.004674
	23:18	0.0046284
	23:24	0.0045828
	23:30	0.00456
	23:36	0.0044916
	23:42	0.004446
	23:48	0.0044004
	23:54	0.0043548
Total Rainfall (in)		2.28

Rainfall Data - GLENN HIGHWAY
August 20 - 22, 2018

Date and Time	Hourly Rainfall (inches)
8/20/18 7:46	0.01
8/20/18 8:46	0
8/20/18 9:46	0
8/20/18 10:46	0
8/20/18 11:46	0
8/20/18 12:46	0.01
8/20/18 13:46	0
8/20/18 14:46	0.02
8/20/18 15:46	0.04
8/20/18 16:46	0
8/20/18 17:46	0.01
8/20/18 18:46	0.02
8/20/18 19:46	0
8/20/18 20:46	0
8/20/18 21:46	0
8/20/18 22:46	0
8/20/18 23:46	0
8/21/18 0:46	0
8/21/18 1:46	0.02
8/21/18 2:46	0.04
8/21/18 3:46	0.02
8/21/18 4:46	0.05
8/21/18 5:46	0.09
8/21/18 6:46	0.07
8/21/18 7:46	0.01
8/21/18 8:46	0.02
8/21/18 9:46	0.01
8/21/18 10:46	0.06
8/21/18 11:46	0.04
8/21/18 12:46	0
8/21/18 13:46	0.14
8/21/18 14:46	0.07
8/21/18 15:46	0.04
8/21/18 16:46	0.04
8/21/18 17:46	0.04
8/21/18 18:46	0.05
8/21/18 19:46	0
8/21/18 20:46	0
8/21/18 21:46	0
8/21/18 22:46	0
8/21/18 23:46	0.01
8/22/18 0:46	0
8/22/18 1:46	0
8/22/18 2:46	0
8/22/18 3:46	0.03
8/22/18 4:46	0.02

8/22/18 5:46	0.01
8/22/18 6:46	0
Total Rainfall (in)	0.99

Rainfall Data - GLENN HIGHWAY
10-Year, 24-Hour

Date	Time	Rainfall Depth (inches)
01/01/2019	0:00	0
	0:06	0.004395384
	0:12	0.004441896
	0:18	0.004488408
	0:24	0.00453492
	0:30	0.004581432
	0:36	0.0046512
	0:42	0.004674456
	0:48	0.004720968
	0:54	0.00476748
	1:00	0.004837248
	1:06	0.004860504
	1:12	0.004930272
	1:18	0.004953528
	1:24	0.005023296
	1:30	0.005046552
	1:36	0.00511632
	1:42	0.005162832
	1:48	0.005186088
	1:54	0.005255856
	2:00	0.005302368
	2:06	0.00534888
	2:12	0.005395392
	2:18	0.005441904
	2:24	0.005488416
	2:30	0.005534928
	2:36	0.00558144
	2:42	0.005627952
	2:48	0.005674464
	2:54	0.005720976
	3:00	0.005767488
	3:06	0.005837256
	3:12	0.005860512
	3:18	0.005907024
	3:24	0.005976792
	3:30	0.006000048
	3:36	0.006069816
	3:42	0.006093072
	3:48	0.00616284
	3:54	0.006209352
	4:00	0.006232608
	4:06	0.006302376
	4:12	0.006348888
	4:18	0.0063954
	4:24	0.006418656
	4:30	0.006488424

	4:36	0.006534936
	4:42	0.006581448
	4:48	0.00662796
	4:54	0.006674472
	5:00	0.006720984
	5:06	0.006790752
	5:12	0.006814008
	5:18	0.00686052
	5:24	0.006907032
	5:30	0.0069768
	5:36	0.007000056
	5:42	0.007046568
	5:48	0.007116336
	5:54	0.007139592
	6:00	0.00720936
	6:06	0.007232616
	6:12	0.007302384
	6:18	0.007348896
	6:24	0.007372152
	6:30	0.00744192
	6:36	0.007488432
	6:42	0.007534944
	6:48	0.007581456
	6:54	0.007627968
	7:00	0.00767448
	7:06	0.007720992
	7:12	0.007767504
	7:18	0.007814016
	7:24	0.007860528
	7:30	0.00790704
	7:36	0.007953552
	7:42	0.00802332
	7:48	0.008046576
	7:54	0.008093088
	8:00	0.008162856
	8:06	0.008186112
	8:12	0.00825588
	8:18	0.008279136
	8:24	0.008348904
	8:30	0.00837216
	8:36	0.008441928
	8:42	0.00848844
	8:48	0.008534952
	8:54	0.008558208
	9:00	0.008627976
	9:06	0.010209384
	9:12	0.010302408

	9:18	0.010372176
	9:24	0.0104652
	9:30	0.010534968
	9:36	0.010627992
	9:42	0.01069776
	9:48	0.010790784
	9:54	0.010860552
	10:00	0.010953576
	10:06	0.011023344
	10:12	0.011093112
	10:18	0.011209392
	10:24	0.011255904
	10:30	0.011372184
	10:36	0.01348848
	10:42	0.014093136
	10:48	0.01465128
	10:54	0.01523268
	11:00	0.015790824
	11:06	0.01639548
	11:12	0.016953624
	11:18	0.017535024
	11:24	0.018116424
	11:30	0.018674568
	11:36	0.022279248
	11:42	0.025372296
	11:48	0.034139808
	11:54	0.048744576
	12:00	0.08930304
	12:06	0.158094288
	12:12	0.048744576
	12:18	0.034139808
	12:24	0.025372296
	12:30	0.022279248
	12:36	0.018674568
	12:42	0.018116424
	12:48	0.017535024
	12:54	0.016953624
	13:00	0.01639548
	13:06	0.015790824
	13:12	0.01523268
	13:18	0.01465128
	13:24	0.014093136
	13:30	0.01348848
	13:36	0.011372184
	13:42	0.011255904
	13:48	0.011209392
	13:54	0.011093112

	14:00	0.011023344
	14:06	0.010953576
	14:12	0.010860552
	14:18	0.010790784
	14:24	0.01069776
	14:30	0.010627992
	14:36	0.010534968
	14:42	0.0104652
	14:48	0.010372176
	14:54	0.010302408
	15:00	0.010209384
	15:06	0.008627976
	15:12	0.008558208
	15:18	0.008534952
	15:24	0.00848844
	15:30	0.008441928
	15:36	0.00837216
	15:42	0.008348904
	15:48	0.008279136
	15:54	0.00825588
	16:00	0.008186112
	16:06	0.008162856
	16:12	0.008093088
	16:18	0.008046576
	16:24	0.00802332
	16:30	0.007953552
	16:36	0.00790704
	16:42	0.007860528
	16:48	0.007814016
	16:54	0.007767504
	17:00	0.007720992
	17:06	0.00767448
	17:12	0.007627968
	17:18	0.007581456
	17:24	0.007534944
	17:30	0.007488432
	17:36	0.00744192
	17:42	0.007372152
	17:48	0.007348896
	17:54	0.007302384
	18:00	0.007232616
	18:06	0.00720936
	18:12	0.007139592
	18:18	0.007116336
	18:24	0.007046568
	18:30	0.007000056
	18:36	0.0069768

	18:42	0.006907032
	18:48	0.00686052
	18:54	0.006814008
	19:00	0.006790752
	19:06	0.006720984
	19:12	0.006674472
	19:18	0.00662796
	19:24	0.006581448
	19:30	0.006534936
	19:36	0.006488424
	19:42	0.006418656
	19:48	0.0063954
	19:54	0.006348888
	20:00	0.006302376
	20:06	0.006232608
	20:12	0.006209352
	20:18	0.00616284
	20:24	0.006093072
	20:30	0.006069816
	20:36	0.006000048
	20:42	0.005976792
	20:48	0.005907024
	20:54	0.005860512
	21:00	0.005837256
	21:06	0.005767488
	21:12	0.005720976
	21:18	0.005674464
	21:24	0.005627952
	21:30	0.00558144
	21:36	0.005534928
	21:42	0.005488416
	21:48	0.005441904
	21:54	0.005395392
	22:00	0.00534888
	22:06	0.005302368
	22:12	0.005255856
	22:18	0.005186088
	22:24	0.005162832
	22:30	0.00511632
	22:36	0.005046552
	22:42	0.005023296
	22:48	0.004953528
	22:54	0.004930272
	23:00	0.004860504
	23:06	0.004837248
	23:12	0.00476748
	23:18	0.004720968

	23:24	0.004674456
	23:30	0.0046512
	23:36	0.004581432
	23:42	0.00453492
	23:48	0.004488408
	23:54	0.004441896
Total Rainfall (in)		2.32

Appendix B: SWMM Modeling Input – Fire Station 9

```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CFS
INFILTRATION         HORTON
FLOW_ROUTING         DYNWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
ALLOW_PONDING        YES
SKIP_STEADY_STATE    NO

START_DATE           08/20/2018
START_TIME           08:00:00
REPORT_START_DATE    08/20/2018
REPORT_START_TIME    08:00:00
END_DATE             08/24/2018
END_TIME             00:00:00
SWEEP_START          01/01
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          00:01:00
WET_STEP             00:01:00
DRY_STEP             00:01:00
ROUTING_STEP         0:00:10

INERTIAL_DAMPING     PARTIAL
NORMAL_FLOW_LIMITED  BOTH
FORCE_MAIN_EQUATION  H-W
VARIABLE_STEP        0.75
LENGTHENING_STEP     0
MIN_SURFAREA         12.557
MAX_TRIALS           8
HEAD_TOLERANCE       0.005
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5
MINIMUM_STEP         0.5
THREADS              1
```

FireStation9.inp

```
[EVAPORATION]
;;Data Source    Parameters
;;-------------- ----------------
CONSTANT         0.0
DRY_ONLY         NO

[RAINGAGES]
;;Name           Format    Interval SCF      Source
;;-------------- --------- ------ ------ ----------
1                CUMULATIVE 1:00     1.0      TIMESERIES AUG2018

[SUBCATCHMENTS]
;;Name           Rain Gage        Outlet           Area     %Imperv  Width    %Slope   CurbLen  SnowPack
;;-------------- ---------------- ---------------- -------- -------- -------- -------- -------- ----------------
Parking          1                Swale            0.22     82       95       0.5      0
Swale            1                Bioretention     0.03     0        251      1        0
SideYard         1                Swale            0.10     13       220      1        0
Roof             1                Swale            0.16     100      114      13       0
Driveway         1                Bioretention     0.32     99       156      1.5      0
Bioretention     1                OverflowInlet    0.02     0        96       0.1      0
AdjacentLand     1                Bioretention     0.19     11       269      25       0

[SUBAREAS]
;;Subcatchment   N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;-------------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
Parking          0.011      0.24       0.1        0.25       25         OUTLET
Swale            0.012      0.24       0.1        0.25       25         OUTLET
SideYard         0.012      0.24       0.1        0.25       25         OUTLET
Roof             0.011      0.24       0          0.05       25         OUTLET
Driveway         0.011      0.24       0.1        0.25       25         OUTLET
Bioretention     0.012      0.24       0.25       0.25       25         OUTLET
AdjacentLand     0.012      0.24       0          0.05       25         OUTLET

[INFILTRATION]
;;Subcatchment   MaxRate    MinRate    Decay      DryTime    MaxInfil
;;-------------- ---------- ---------- ---------- ---------- ----------
Parking          2          0.15       3          7          0
Swale            2          0.15       3          7          0
SideYard         2          0.15       3          7          0
Roof             2          0.15       3          7          0
Driveway         2          0.15       3          7          0
Bioretention     2          0.15       3          7          0
AdjacentLand     2          0.15       3          7          0
```

FireStation9.inp

```
[LID_CONTROLS]
;;Name           Type/Layer Parameters
;;-------------- ---------- ----------
Swale            VS
Swale            SURFACE    24         0.1        0.24       1.0        2

Bioretention     BC
Bioretention     SURFACE    21.6       0          0.02       0.1        5
Bioretention     SOIL       12         0.52       0.15       0.08       1          39.3       1.9
Bioretention     STORAGE    14         0.45       0.3        0
Bioretention     DRAIN      1          0          3          6

[LID_USAGE]
;;Subcatchment   LID Process      Number  Area       Width      InitSat    FromImp    ToPerv     RptFile
       DrainTo
;;-------------- ---------------- ------- ---------- ---------- ---------- ---------- ----------
------------------------ ----------------
Swale            Swale            1       1306.80    8          0          0          0
Bioretention     Bioretention     1       871.20     0          20         0          0          "D:\Dropbox (AWR
Engineering, LLC)\Jobs\1200 MOA\03 Hydro Term\01 GI LID Performance Monitoring\Sites\01 Fire Station
9\SWMM\LID_Bioretention.txt" SouthCleanOut

[JUNCTIONS]
;;Name           Elevation  MaxDepth   InitDepth  SurDepth   Aponded
;;-------------- ---------- ---------- ---------- ---------- ----------
SouthCleanOut    205.78     0          0          0          0
DitchInlet       206.68     1.5        0          0          0
OverflowOutlet   209.73     1.5        0          0          0
OverflowInlet    209.8      1          0          0          0
CatchBasin       205.39     0          0          0          0

[OUTFALLS]
;;Name           Elevation  Type       Stage Data       Gated    Route To
;;-------------- ---------- ---------- ---------------- -------- ----------------
SD               205        FREE                        NO

[CONDUITS]
;;Name           From Node        To Node          Length     Roughness  InOffset   OutOffset  InitFlow   MaxFlow

;;-------------- ---------------- ---------------- ---------- ---------- ---------- ---------- ---------- -------
OverflowCulvert  OverflowInlet    OverflowOutlet   14         0.017      0          0          0          0

Ditch            OverflowOutlet   DitchInlet       27         0.03       0          0          0          0
```

FireStation9.inp

```
DitchInlet        DitchInlet        CatchBasin        49          0.024       0           0.47        0           0

BioretentionOutlet SouthCleanOut    CatchBasin        67          0.017       0           0.05        0           0

SD                CatchBasin        SD                400         0.01        0           0           0           0

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels    Culvert
;;-------------- ------------ ---------------- ---------- ---------- ---------- ---------- ----------
OverflowCulvert  CIRCULAR     1                0          0          0          1
Ditch            TRIANGULAR   1.5              6          0          0          1
DitchInlet       CIRCULAR     1.5              0          0          0          1
BioretentionOutlet CIRCULAR   1                0          0          0          1
SD               DUMMY        0                0          0          0          1

[REPORT]
;;Reporting Options
INPUT      NO
CONTROLS   NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL
```

Appendix C: SWMM Modeling Input – West Dowling Road Phase II

```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CFS
INFILTRATION         HORTON
FLOW_ROUTING         DYNWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
ALLOW_PONDING        NO
SKIP_STEADY_STATE    NO

START_DATE           08/20/2018
START_TIME           07:53:00
REPORT_START_DATE    08/20/2018
REPORT_START_TIME    07:53:00
END_DATE             08/22/2018
END_TIME             06:53:00
SWEEP_START          01/01
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          00:01:00
WET_STEP             00:01:00
DRY_STEP             00:01:00
ROUTING_STEP         0:00:10

INERTIAL_DAMPING     PARTIAL
NORMAL_FLOW_LIMITED  BOTH
FORCE_MAIN_EQUATION  H-W
VARIABLE_STEP        0.75
LENGTHENING_STEP     0
MIN_SURFAREA         12.557
MAX_TRIALS           8
HEAD_TOLERANCE       0.005
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5
MINIMUM_STEP         0.5
THREADS              1

[EVAPORATION]
;;Data Source    Parameters
;;-------------- ----------------
CONSTANT         0.0
DRY_ONLY         NO
```

```
[RAINGAGES]
;;Name           Format    Interval SCF      Source
;;-------------- --------- ------ ------ ----------
G-1              VOLUME    1:00     1.0      TIMESERIES 8-21-2018

[SUBCATCHMENTS]
;;Name           Rain Gage        Outlet           Area     %Imperv  Width    %Slope   CurbLen  SnowPack

;;-------------- ---------------- ---------------- -------- -------- -------- -------- --------
----------------
S-BasinB         G-1              O-B              6.16     28.06    1546.84  9.50     0

S-BasinA         G-1              Stor-InfiltrationBasin1 4.83     43.18    990.39   4.01     0


[SUBAREAS]
;;Subcatchment   N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;-------------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
S-BasinB         0.011      .20        0          0.09       100        OUTLET
S-BasinA         0.011      .28        0.06       .32        40         OUTLET

[INFILTRATION]
;;Subcatchment   MaxRate    MinRate    Decay      DryTime    MaxInfil
;;-------------- ---------- ---------- ---------- ---------- ----------
S-BasinB         1.5        .05        4          7          0
S-BasinA         .75        .05        5          7          0

[OUTFALLS]
;;Name           Elevation  Type       Stage Data       Gated    Route To
;;-------------- ---------- ---------- ---------------- -------- ----------------
O-B              91.0       FREE                        NO
O-A              89.4       FREE                        NO

[STORAGE]
;;Name           Elev.    MaxDepth   InitDepth  Shape      Curve Name/Params            N/A      Fevap
Psi      Ksat     IMD
;;-------------- -------- ---------- ---------- ---------- ---------------------------- -------- --------
       -------- --------
Stor-InfiltrationBasin1 89.4     6          0          TABULAR    InfiltrationBasin1           0        0
    4.33     .43      .412

[CONDUITS]
;;Name           From Node        To Node          Length     Roughness  InOffset   OutOffset  InitFlow
MaxFlow
;;-------------- ---------------- ---------------- ---------- ---------- ---------- ---------- ----------
----------
C-1              Stor-InfiltrationBasin1 O-A              12         0.025      5.5        0          0
    0
```

WDowlingPhII.inp

```
[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels    Culvert
;;-------------- ------------ ---------------- ---------- ---------- ---------- ---------- ----------
C-1              TRAPEZOIDAL  1                4          2          2          1

[CURVES]
;;Name           Type       X-Value    Y-Value
;;-------------- ---------- ---------- ----------
InfiltrationBasin1 Storage    0          936.85
InfiltrationBasin1            0.6        1393.24
InfiltrationBasin1            1.6        2292.07
InfiltrationBasin1            2.6        3291.22
InfiltrationBasin1            3.6        4387.98
InfiltrationBasin1            4.6        5582.21
InfiltrationBasin1            5.6        6873.80
InfiltrationBasin1            6          6873.8

[REPORT]
;;Reporting Options
INPUT      NO
CONTROLS   NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL
```

Appendix D: SWMM Modeling Input – Glenn Highway

```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CFS
INFILTRATION         HORTON
FLOW_ROUTING         DYNWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
ALLOW_PONDING        YES
SKIP_STEADY_STATE    NO

START_DATE           08/20/2018
START_TIME           07:46:00
REPORT_START_DATE    08/20/2018
REPORT_START_TIME    07:46:00
END_DATE             08/22/2018
END_TIME             06:46:00
SWEEP_START          01/01
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          00:01:00
WET_STEP             00:01:00
DRY_STEP             00:01:00
ROUTING_STEP         0:00:10

INERTIAL_DAMPING     PARTIAL
NORMAL_FLOW_LIMITED  BOTH
FORCE_MAIN_EQUATION  H-W
VARIABLE_STEP        0.75
LENGTHENING_STEP     0
MIN_SURFAREA         12.557
MAX_TRIALS           8
HEAD_TOLERANCE       0.005
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5
MINIMUM_STEP         0.5
THREADS              1

[EVAPORATION]
;;Data Source    Parameters
;;-------------- ----------------
CONSTANT         0.0
DRY_ONLY         NO
```

ERPonds.inp

```
[RAINGAGES]
;;Name           Format    Interval SCF      Source
;;-------------- --------- ------ ------ ----------
G-1              VOLUME    1:00     1.0      TIMESERIES 8-21-2018ER_Rainfall

[SUBCATCHMENTS]
;;Name                 Rain Gage        Outlet           Area     %Imperv  Width    %Slope   CurbLen
SnowPack
;;--------------       ---------------- ---------------- -------- -------- -------- -------- --------
----------------
S-NorthBasin           G-1              Stor-NorthPond   6.42     57.02    3749.38  2.76     0

S-SouthBasin1          G-1              Stor-SouthPond   29.73    19.17    5138.53  5.35     0

S-SouthBasin2Forested  G-1              Stor-SouthPond   8.27     0        719.94   4.29     0


[SUBAREAS]
;;Subcatchment         N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;--------------       ---------- ---------- ---------- ---------- ---------- ---------- ----------
S-NorthBasin           .011       .15        .06        .15        100        OUTLET
S-SouthBasin1          .011       .15        .06        .15        100        OUTLET
S-SouthBasin2Forested  .011       0.8        0.06       0.15       100        OUTLET

[INFILTRATION]
;;Subcatchment         MaxRate    MinRate    Decay      DryTime    MaxInfil
;;--------------       ---------- ---------- ---------- ---------- ----------
S-NorthBasin           2          .15        3          7          0
S-SouthBasin1          3.5        .3         2          7          0
S-SouthBasin2Forested  4.5        0.3        2          7          0

[OUTFALLS]
;;Name           Elevation  Type       Stage Data       Gated    Route To
;;-------------- ---------- ---------- ---------------- -------- ----------------
O-North          208        FREE                        NO
O-South          208        FREE                        NO

[STORAGE]
;;Name           Elev.    MaxDepth   InitDepth  Shape      Curve Name/Params            N/A      Fevap
Psi      Ksat     IMD
;;-------------- -------- ---------- ----------- ---------- ---------------------------- -------- --------
       -------- --------
Stor-NorthPond   233      6          3          TABULAR    ERNorthPond                  0        0
Stor-SouthPond   214      13         .25        TABULAR    ERSouthPond                  0        0
```

```
[WEIRS]
;;Name           From Node        To Node          Type         CrestHt    Qcoeff     Gated    EndCon
EndCoeff   Surcharge  RoadWidth  RoadSurf
;;-------------- ---------------- ---------------- ------------ ---------- ---------- -------- --------
---------- ---------- ---------- ----------
;Berm between south pond and river
C-South          Stor-SouthPond   O-South          TRAPEZOIDAL  12         3          NO       0        0
      NO
C-North          Stor-NorthPond   O-North          TRAPEZOIDAL  5          3          NO       0        0
      NO

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels    Culvert
;;-------------- ------------ ---------------- ---------- ---------- ---------- ---------- ----------
C-South          TRAPEZOIDAL  1                10         4          4
C-North          TRAPEZOIDAL  1                10         4          4

[CURVES]
;;Name           Type       X-Value    Y-Value
;;-------------- ---------- ---------- ----------
ERSouthPond      Storage    0          385.17
ERSouthPond                 1          814.51
ERSouthPond                 2          1296.92
ERSouthPond                 3          1843.45
ERSouthPond                 4          2486.09
ERSouthPond                 5          3219.28
ERSouthPond                 6          4070.32
ERSouthPond                 7          5597.55
ERSouthPond                 8          6988.86
ERSouthPond                 9          8431.36
ERSouthPond                 10         9937.57
ERSouthPond                 11         11454.67
ERSouthPond                 12         12985.94
ERSouthPond                 13         14000
;
ERNorthPond      Storage    0          1803.11
ERNorthPond                 1          2392.78
ERNorthPond                 2          3052.91
ERNorthPond                 3          3775.50
ERNorthPond                 4          4560.68
ERNorthPond                 5          5408.41
ERNorthPond                 6          6000

[REPORT]
;;Reporting Options
INPUT      YES
CONTROLS   NO
SUBCATCHMENTS ALL
```

```
NODES ALL
LINKS ALL
```

Appendix E: SWMM Modeling Input – O’Malley Road

Omalley.inp

```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CFS
INFILTRATION         HORTON
FLOW_ROUTING         DYNWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
ALLOW_PONDING        YES
SKIP_STEADY_STATE    NO

START_DATE           01/01/2018
START_TIME           00:00:00
REPORT_START_DATE    01/01/2018
REPORT_START_TIME    00:00:00
END_DATE             01/03/2018
END_TIME             00:00:00
SWEEP_START          01/01
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          00:01:00
WET_STEP             00:01:00
DRY_STEP             00:01:00
ROUTING_STEP         0:00:10

INERTIAL_DAMPING     PARTIAL
NORMAL_FLOW_LIMITED  BOTH
FORCE_MAIN_EQUATION  H-W
VARIABLE_STEP        0.75
LENGTHENING_STEP     0
MIN_SURFAREA         12.557
MAX_TRIALS           8
HEAD_TOLERANCE       0.005
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5
MINIMUM_STEP         0.5
THREADS              1

[EVAPORATION]
;;Data Source    Parameters
;;-------------- ----------------
CONSTANT         0.0
DRY_ONLY         NO
```

Omalley.inp

```
[RAINGAGES]
;;Name           Format    Interval SCF      Source    
;;-------------- --------- ------ ------ ----------
1                CUMULATIVE 0:06     1.0      TIMESERIES 10-year

[SUBCATCHMENTS]
;;Name           Rain Gage        Outlet                Area     %Imperv  Width    %Slope   CurbLen  
SnowPack        
;;-------------- ---------------- ----------------      -------- -------- -------- -------- -------- 
----------------
Omalley          1                Swale                 11.7178  36       681      4.5      0

Frontage         1                Swale                 36.7688  26       1714     4.6      0

Swale            1                OfframpCulvertInlet   0.13051  0        55       1        0


[SUBAREAS]
;;Subcatchment   N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted 
;;-------------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
Omalley          0.011      0.4        0.1        0.7        25         PERVIOUS   42
Frontage         0.011      0.4        0.1        0.7        25         OUTLET    
Swale            0.011      0.075      0.1        0.25       25         OUTLET    

[INFILTRATION]
;;Subcatchment   MaxRate    MinRate    Decay      DryTime    MaxInfil  
;;-------------- ---------- ---------- ---------- ---------- ----------
Omalley          1.5        0.23       3.5        7          0
Frontage         1.5        0.23       3.5        7          0
Swale            1.5        0.23       3.5        7          0

[LID_CONTROLS]
;;Name           Type/Layer Parameters
;;-------------- ---------- ----------
Swale            VS
Swale            SURFACE    48         0.05       0.075      1.0        4

[LID_USAGE]
;;Subcatchment   LID Process      Number  Area       Width      InitSat    FromImp    ToPerv     RptFile
             DrainTo         
;;-------------- ---------------- ------- ---------- ---------- ---------- ---------- ---------- 
------------------------ ----------------
Swale            Swale            1       5685.02    55         0          0          0          "D:\Dropbox 
(AWR Engineering, LLC)\Jobs\1200 MOA\03 Hydro Term\01 GI LID Performance Monitoring\Sites\04 
O'Malley\SWMM\LID.txt"
```

```
[JUNCTIONS]
;;Name           Elevation  MaxDepth   InitDepth  SurDepth   Aponded
;;-------------- ---------- ---------- ---------- ---------- ----------
OfframpCulvertInlet 166.89     0          0          0          0

[OUTFALLS]
;;Name           Elevation  Type       Stage Data       Gated    Route To
;;-------------- ---------- ---------- ---------------- -------- ----------------
OfframpCulvertOutlet 165        FREE                        NO

[CONDUITS]
;;Name           From Node        To Node          Length     Roughness  InOffset   OutOffset  InitFlow
MaxFlow
;;-------------- ---------------- ---------------- ---------- ---------- ---------- ---------- ----------
----------
1                OfframpCulvertInlet OfframpCulvertOutlet 80         0.024      0          0          0
    0

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels    Culvert
;;-------------- ------------ ---------------- ---------- ---------- ---------- ---------- ----------
1                CIRCULAR     2                0          0          0          1

[REPORT]
;;Reporting Options
INPUT      NO
CONTROLS   NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL
```

Appendix F: SWMM Modeling Input – Valley of the Moon

ValleyMoon.inp

```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CFS
INFILTRATION         HORTON
FLOW_ROUTING         DYNWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0
ALLOW_PONDING        YES
SKIP_STEADY_STATE    NO

START_DATE           01/01/2018
START_TIME           00:00:00
REPORT_START_DATE    01/01/2018
REPORT_START_TIME    00:00:00
END_DATE             01/03/2018
END_TIME             00:00:00
SWEEP_START          01/01
SWEEP_END            12/31
DRY_DAYS             0
REPORT_STEP          00:01:00
WET_STEP             00:01:00
DRY_STEP             00:01:00
ROUTING_STEP         0:00:10

INERTIAL_DAMPING     PARTIAL
NORMAL_FLOW_LIMITED  BOTH
FORCE_MAIN_EQUATION  H-W
VARIABLE_STEP        0.75
LENGTHENING_STEP     0
MIN_SURFAREA         12.557
MAX_TRIALS           8
HEAD_TOLERANCE       0.005
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5
MINIMUM_STEP         0.5
THREADS              1
```

ValleyMoon.inp

```
[EVAPORATION]
;;Data Source    Parameters
;;-------------- ----------------
CONSTANT         0.0
DRY_ONLY         NO

[RAINGAGES]
;;Name           Format    Interval SCF      Source
;;-------------- --------- ------ ------ ----------
1                VOLUME    0:06     1.0      TIMESERIES 10-year

[SUBCATCHMENTS]
;;Name                  Rain Gage        Outlet           Area     %Imperv  Width    %Slope   CurbLen  SnowPack

;;--------------        ---------------- ---------------- -------- -------- -------- -------- --------
----------------
NewParkingArea&DogPark  1                RainGarden       0.657    11       104      1        0


[SUBAREAS]
;;Subcatchment          N-Imperv   N-Perv     S-Imperv   S-Perv     PctZero    RouteTo    PctRouted
;;--------------        ---------- ---------- ---------- ---------- ---------- ---------- ----------
NewParkingArea&DogPark  0.011      0.15       0.1        0.15       25         OUTLET

[INFILTRATION]
;;Subcatchment          MaxRate    MinRate    Decay      DryTime    MaxInfil
;;--------------        ---------- ---------- ---------- ---------- ----------
NewParkingArea&DogPark  1          0.05       4.5        7          0

[LID_CONTROLS]
;;Name           Type/Layer Parameters
;;-------------- ---------- ----------
RainGarden       BC
RainGarden       SURFACE    36         0.2        0.24       1.0        5
RainGarden       SOIL       36         0.52       0.15       0.08       1          39.3       1.9
RainGarden       STORAGE    12         0.4        0.05       0
RainGarden       DRAIN      0          0          6          6

[LID_USAGE]
;;Subcatchment   LID Process      Number  Area       Width      InitSat    FromImp    ToPerv     RptFile
       DrainTo
;;-------------- ---------------- ------- ---------- ---------- ---------- ---------- ----------
------------------------ ----------------
```

ValleyMoon.inp

```
[OUTFALLS]
;;Name           Elevation  Type       Stage Data       Gated    Route To
;;-------------- ---------- ---------- ---------------- -------- ----------------
Overflow         34         FREE                        NO

[STORAGE]
;;Name           Elev.    MaxDepth   InitDepth  Shape      Curve Name/Params            N/A      Fevap    Psi
Ksat     IMD
;;-------------- -------- ---------- ----------- ---------- ---------------------------- -------- --------
 -------- --------
RainGarden       31       4          0          TABULAR    RainGarden                   0        0        8.27
.04      0.277

[WEIRS]
;;Name           From Node        To Node          Type         CrestHt    Qcoeff     Gated    EndCon   EndCoeff
Surcharge  RoadWidth  RoadSurf
;;-------------- ---------------- ---------------- ------------ ---------- ---------- -------- -------- ----------
---------- --------- ----------
1                RainGarden       Overflow         TRAPEZOIDAL  0          3.33       NO       0        0
YES

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels    Culvert
;;-------------- ------------ ---------------- ---------- ---------- ---------- ---------- ----------
1                TRAPEZOIDAL  1                45         10         10

[CURVES]
;;Name           Type       X-Value    Y-Value
;;-------------- ---------- ---------- ----------
RainGarden       Storage    0          0
RainGarden                  1          2114.307027
RainGarden                  2          3399.463519
RainGarden                  3          4785.147773
RainGarden                  4          6241.53816

[REPORT]
;;Reporting Options
INPUT      NO
CONTROLS   NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL
```