STUDY: EFFECTIVENESS OF EXISTING GREEN INFRASTRUCTURE IN PHOENIX

8426900000-4400000001

PHOENIX, ARIZONA

City of Phoenix Contract No. 143989

December 28, 2018

Prepared for:

City of Phoenix

200 W Washington Street

Phoenix, AZ 85003

Prepared by:

Coe & Van Loo Consultants, Inc.

4550 N. 12th Street

Phoenix, AZ 85014

(602) 264-6831

Registered Professional Engineer (Civil)
CERTIFICATE NO.
37297
JASON K.
KELLEY
Date Signed 12-28-18
ARIZONA, U.S.A.
Expires 3-31-2020

City of Phoenix

CVL CONSULTANTS
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APPENDICES (ON CD)

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1.0 INTRODUCTION

This study evaluates the function of existing green infrastructure (GI) in the City of Phoenix. Over the past several years, GI pilot projects have been implemented throughout the City. Currently, the City is involved in three concurrent efforts to evaluate and expand GI. These efforts (by others) include site favorability study, a cost benefit analysis and a technical standards book. This study provides field test and performance data on selected, existing GI features for the City's ongoing efforts in meeting sustainability goals, improving water quality and quantity outcomes, and providing green spaces for the community.

Three types of existing City GI features were evaluated: (i) bioswales (ii) permeable pavers and (iii) pervious concretes. Eleven sites were selected from the City's GI inventory. The project began with a data collection effort and field testing. Field testing does not include water quality measurements.

2.0 DATA COLLECTION

2.1 EXISTING DOCUMENTS

The City provided CVL with available documentation for each site, including design plans/as-builts (see Appendix A). Plans have been reviewed and compared to site observations and field test data. This report documents a comparison of the original design and existing conditions for each GI. A summary of data collected includes:

- City of Phoenix Street Transportation Department, Record Drawings: *Buckeye Road Intersections and 24th Street Intersections,* AV14000019, 2008.
- As_Built Drawings for *University of Arizona Cancer Center*, Hensel Phelps Construction Co.; ZGF Architects, 2015.
- City of Phoenix, Public Transit Department, *Central Station Refurbishments*, PT0210001, 2010.
- City of Phoenix, Engineering & Architectural Services, As-built drawings: *Civic Space Park Phase 2*, PA75100126, 2011.
- City of Phoenix, Engineering & Architectural Services, Permit set: *Phoenix Fire Training Academy, Driver Training Building*, FD57120006, 2009.
- City of Phoenix Street Transportation Department, Record Drawings: *Hatcher Road Sidewalk Improvements, 19th Avenue to 7th Street*, ST87750001, 2000.
- DRW Engineering Inc., As-Builts: *Manzanita Senior Center*, KIVA 11-1465, 2010.
- City of Phoenix, Engineering & Architectural Services, As-Builts: *Unnamed City Park*, PA75200308, 2009.
- HDR, Sundt et al., *Taylor Street Mall Package,* KIVA 06-4981, 2008.
- HDR, Sundt et al., *Taylor Mall Extension at Cronkite School of Journalism and KAET 8,* KIVA 06-4981, 2008.
- City of Phoenix, *Off-Site Improvements with Drainage Facilities for ASU Downtown Student Housing*, Proj# 07-747, 2008
- City of Phoenix Street Transportation Department, Record Drawings: *Taylor Mall: Taylor Street Improvements*, CD30000010, AR84850012-4, WS85500324, 20070.
- City of Phoenix, Engineering & Architectural Services, As-Builts: *Tovrea Castle Parking Entry Project,* KIVA 05-1006; LPRR#1001609, 2012.

- City of Phoenix, Engineering & Architectural Services, *Employee Parking Lot for Union Hills Service Center,* PW24400002, 2001.

Further documentation regarding maintenance records were unavailable.

2.2 FIELD OBSERVATIONS

The purpose of the visits were to (i) note physical features such as plantings, soil types, irrigation systems, curbs, curb-cuts, drains, weepholes (ii) observe existing feature conditions such as sediment/trash/debris accumulation and pavement/paver conditions (iii) obtain photographs of site and features. Field observations are a key component of the evaluation. Field observation notes and photos for each GI can be found in Appendix B.

3.0 FIELD TESTING

3.1 TEMPERATURE MEASUREMENTS


Temperature measurement at Helen Drake Center

Ground level temperature measurements were obtained using an infrared temperature gun. Measurements were taken in non-wetted conditions for each site. Using field measuring tape, a temperature measurement was obtained every foot to every four feet depending on the size of the GI. Location of measurement at each site was based on transecting differing surface types within the GI feature as well as beyond the GI feature. In some cases due to traffic, existing utilities, or vegetation, the location selected had anomalies such as sporadic shade or plastic electric box covers. These anomalies have been identified, noted and will be considered in the evaluation of each feature. Tests were conducted during sunlight hours in the range of 11am to 4pm. The first set of tests was conducted from July 23rd to 27th, 2018. The second set of tests was conducted from September 26th to 28th, 2018. Times, dates and ambient temperatures are contained in the field notes with the temperature measurement data. Temperature profiles were plotted for each measured feature (see Appendix C). Temperature profiles and review of data trends was used to identify any ground-level heat island/mitigation effects.

3.2 Subsurface Testing

Ninyo & Moore (N&M) was contracted to perform sub-surface testing of pervious concrete, bioswales, bioretention and permeable pavers. Single-ring field infiltration tests were conducted to help evaluate infiltration function of each GI. Boring samples of the soil and/or pavement were collected from each site. Each of the samples collected were measured for unit weight, permeability and compressive strength. Additionally, soil boring samples were examined to determine soils index properties, including gradation and plasticity. N&M's test results and report are included in Appendix D.

Pavement boring at Central Station

4.0 SITE ASSESSMENTS

The components of each GI were observed, sampled and tested to assess general performance, field conditions compared to original design, heat island profile and any maintenance deficiencies. The comparison of field conditions to original design assessment was done by comparing as-built plans (as available) to field conditions observed and tested (see Appendix E). General performance parameters considered for all GI features included runoff reduction, stormwater infiltration, and associated drainage infrastructure such as weepholes, curb cuts, catch basins, etc. Additionally, a stormwater storage parameter was also considered in the general performance assessment of permeable pavement and pervious concrete sites. Stormwater calculations relating to runoff, storage and conveyance can be found in Appendix F. Heat temperature profiles were measured at each GI site as described in Section 3.1. Temperatures measurements were extended through adjacent non-GI infrastructure for comparison. Lastly, observations of field conditions were used to predict maintenance history and recommend maintenance measures. Minimal maintenance information was received throughout this project; records can be obtained by the department responsible for maintenance. Maintenance history logs may become available, but were not obtained at the time of this report.

Sites were rated through a point system then compared to sites that shared like GI features. Scoring summary tables for each of the three GI features (1) bioswales (2) permeable pavers and (3) pervious concrete are provided in Sections 4.1, 4.2 and 4.3, respectively.

4.1 BIOSWALES

The Natural Resources Conservation Service (NCRS) defines bioswales as "storm water runoff conveyance systems that provide an alternative to storm sewers. They can absorb low flows or carry runoff from heavy rains to storm sewer inlets or directly to surface waters. Bioswales improve water quality by infiltrating the first flush of storm water runoff and filtering the large storm flows they convey."[1] City of Phoenix bioswales at Manzanita Park, University of Arizona Cancer Center, Union Hills Service Center and at Taylor Mall were evaluated for this study. Below is a scoring summary table for the four bioswale sites.

BIOSWALE SITE	**SCORE**	**%**
CANCER CENTER	17.5/18	97%
TAYLOR MALL	18/19	95%
UNION HILLS SERVICE CENTER	13/18	72%
MANZANITA PARK	13/19	68%

[1] NRCS (2005) [1]

4.1.1 Manzanita Park

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Collects stormwater	✓			**1**
Infiltrates stormwater	✓			**1**
Reduces runoff	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weephole sweep, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Swale cross-section per plan	✓			**1**
Vegetation per plan	✓			**1**
Irrigation per plan	✓			**1**
Inert material per plan	✓			**1**
VEGETATION				
Vegetation is healthy			✓	**0.5**
Vegetation coverage is dense and evenly spaced		✓		**0**
Plant species are native or have low-water needs		✓		**0**
IRRIGATION				
Irrigation system in place	✓			**1**
Irrigation promotes water efficiency		✓		**0**
Irrigation appears to be in good working order		✓		**0**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure	✓			**1**
MAINTENANCE/CONDITION				
Bottom of basin is clean with minor to no sedimentation			✓	**0.5**
Encourages natural form and function of vegetation		✓		**0**
Basin is clear of garbage and debris	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**13/19**

Site Assessment Summary

- Two weirs allow basins to meter to south channel (capacity of ~1.1 cfs)
- Basin stores over 693k-ft^3 of stormwater runoff.
- Stormwater runoff is reduced by 95 from 48.2-cfs to 2.2-cfs (primarily by attenuation)
- Stormwater runoff is infiltrated at an average rate of 0.91 in/hr.
- Vegetation other than turf has 10%-15% coverage.
- Soil conditions match as-builts.
- Irrigation valve boxes need repair.
- Maintenance may not support the function of the bioretention.

Key Issues

- No understory or groundcover vegetation in/around swale that conveys water from street to the turf bioretention area. Benefits of slowing, filtering or cleaning stormwater may be reduced.
- Over 50% of trees in as-builts no longer exist.
- Bare spots in turf (assumption is from cars/heavy pedestrian-use) may decrease water infiltration rates.
- Flood irrigation and sprinkler systems may not promote efficient water use.

Notes

Site visit occurred within 24 hours of a rain event.

Manzanita Park Turf Bioretention

Manzanita Park Decomposed Granite Bioretention

4.1.2 Cancer Center

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Collects stormwater	✓			**1**
Infiltrates stormwater	✓			**1**
Reduces runoff	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Swale cross-section per plan	✓			**1**
Vegetation per plan			✓	**0.5**
Irrigation per plan	✓			**1**
Inert material per plan	n/a	n/a	n/a	**n/a**
VEGETATION				
Vegetation is healthy	✓			**1**
Vegetation coverage is dense and evenly spaced	✓			**1**
Plant species are native or have low-water needs	✓			**1**
IRRIGATION				
Irrigation system in place	✓			**1**
Irrigation promotes water efficiency	✓			**1**
Irrigation appears to be in good working order	✓			**1**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure	✓			**1**
MAINTENANCE/CONDITION				
Bottom of basin is clean with minor to no sedimentation	✓			**1**
Encourages natural form and function of vegetation	✓			**1**
Basin is clear of garbage and debris	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**17.5/18**

Site Assessment Summary

- The four scuppers along 7th Street have an interception capacity of 6.2-cfs.
- The bioswale stores up to 1,222-ft^3 of stormwater runoff.
- Stormwater runoff is reduced by 68% from 0.25-cfs to 0.08-cfs.
- Stormwater runoff is infiltrated at an average rate of 0.75 in/hr.
- Vegetation has 75%-80% coverage.
- Majority of vegetation looks healthy and has natural form.
- Soil conditions match as-builts.
- Irrigation is functioning efficiently. Maintenance supports the function of the bioswale.

Key Issues

- Some holes in bioswale appear to have been left from a tree that was damaged or died.

Notes

Site visit occurred within 24 hours of a rain event. As-builts were not available at time of visit, but have since been obtained and reviewed as part of the assessment.

Cancer Center Bioswale

4.1.3 Union Hills Service Center

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Collects stormwater	✓			**1**
Infiltrates stormwater	✓			**1**
Reduces runoff	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Swale cross-section per plan	✓			**1**
Vegetation per plan			✓	**0.5**
Irrigation per plan			✓	**0.5**
Inert material per plan	n/a	n/a	n/a	**n/a**
VEGETATION				
Vegetation is healthy			✓	**0.5**
Vegetation coverage is dense and evenly spaced		✓		**0**
Plant species are native or have low-water needs	✓			**1**
IRRIGATION				
Irrigation system in place	✓			**1**
Irrigation promotes water efficiency			✓	**0.5**
Irrigation appears to be in good working order			✓	**0.5**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure	✓			**1**
MAINTENANCE/CONDITION				
Bottom of basin is clean with minor to no sedimentation			✓	**0.5**
Encourages natural form and function of vegetation		✓		**0**
Basin is clear of garbage and debris	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**13/18**

Site Assessment Summary

- Bioswale stores 5,063-ft^3 of stormwater runoff.
- Bioswale infiltrates stormwater runoff at an average rate of 4 in/hr.
- Bioswale reduced stormwater runoff by 68% from 0.28-cfs to 0.09-cfs.
- Vegetation has 25% coverage. Soil conditions match as-builts.
- Irrigation valve boxes need repairs.
- Maintenance may not support the function of the bioswale due to extreme uplimbing of trees and shearing of shrubs.

Key Issues

- Uplimbing of trees and continuous extreme shearing of shrubs has permanently stunted or killed vegetation.
- Majority of groundcover and mid-story plantings in as-builts were no longer on site.
- Large, open areas in the basin are bare and pedestrians cross through it to get across parking lot, possibly causing soil compaction and hindering filtration.

Notes

Union Hills is one of the oldest designs from the group of bioswale/bioretention test sites. This may have something to do with the condition of its irrigation and plant survival rate. Site visit occurred within 24 hours of a rain event.

Union Hills Service Bioswale

4.1.4 Taylor Mall

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Collects stormwater	✓			**1**
Infiltrates stormwater	✓			**1**
Reduces runoff	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Swale cross-section section per plan	✓			**1**
Vegetation per plan			✓	**0.5**
Irrigation per plan	✓			**1**
Inert material per plan			✓	**0.5**
VEGETATION				
Vegetation is healthy	✓			**1**
Vegetation coverage is dense and evenly spaced	✓			**1**
Plant species are native or have low-water needs	✓			**1**
IRRIGATION				
Irrigation system in place	✓			**1**
Irrigation promotes water efficiency	✓			**1**
Irrigation appears to be in good working order	✓			**1**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure	✓			**1**
MAINTENANCE/CONDITION				
Bottom of basin is clean with minor to no sedimentation	✓			**1**
Encourages natural form and function of vegetation	✓			**1**
Basin is clear of garbage and debris	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**18/19**

Site Assessment Summary

- Bioswales on Taylor Mall store 4,061-ft^3.
- Bioswales reduce stormwater runoff by 68% from 0.29-cfs to 0.09-cfs.
- Bioswales infiltrate stormwater at an average rate of 0.34 in/hr.
- Vegetation has 85%-95% coverage.
- Soil conditions match as-builts with some deposition of sediment at inlets.
- Irrigation is functioning efficiently.
- Maintenance supports the function of the bioswale.

Key Issues

- Erosion at some inlets was amended with large rock not specified in as-built.
- Missing vegetation in basin between 2nd Ave. and 3rd Ave. allows pedestrians to cross through, thus aggravating bare areas and compacting soil, possibly leading to reduced infiltration rates.

Notes

Site visit occurred within 24 hours of a rain event. Adjacent basins not tested had some understory vegetation that appeared to be struggling (chlorotic). This could be from malfunctioning irrigation, too much shade from surrounding buildings, but no cause could be determined from initial site visit.

Taylor Mall Bioswale

4.2 Permeable Pavers

Permeable pavers are a form of a permeable pavement composed of modular concrete blocks. The NRCS defines permeable pavers as "funnel-like openings installed over an infiltration storage bed of uniformly graded limestone."[2] These permeable paver systems allow stormwater to infiltrate to the paver subgrade then infiltrate into the soil below. The City of Phoenix permeable paver systems at Taylor Mall, Fire Training Academy, Central Station and at the intersection of Buckeye Road and 16th Street were evaluated for this study. Below is a scoring summary table for the four permeable paver sites.

PERMEABLE PAVER SITES	**SCORE**	**%**
CENTRAL STATION	7/10	70%
TAYLOR MALL	7.5/11	68%
FIRE TRAINING ACADEMY	5/9	56%
BUCKEYE ROAD & 16TH STREET	3.5/10	35%

[2] NRCS (2009) [2]

4.2.1 Taylor Mall

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater in subgrade	✓			**1**
Infiltrates stormwater	✓			**1**
Reduces runoff		✓		**0**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Permeable pavers constructed per plan	✓			**1**
Subgrade constructed per plan	n/a	n/a	n/a	**n/a**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure			✓	**0.5**
MAINTENANCE/CONDITION				
Clear of garbage and debris			✓	**0.5**
Clear of sediment	✓			**1**
Clear of oil/ grease		✓		**0**
Appears to be regularly maintained			✓	**0.5**
TOTAL SCORE:				**7.5/11**

Site Assessment Summary

- Collectively, the permeable pavement parking bays store 202-ft^3 of stormwater runoff.
- The permeable pavers are infiltrating stormwater at 1 in/hr.
- Stormwater runoff reduction is negligible from 0.09-cfs to 0.08-cfs.
- The temperatures were generally about the same as adjacent non-GI infrastructure.
- The pavers are in need of maintenance as oil and debris have collected.
- Subgrade specifications were not contained in As-built plans.
- Overall, the permeable pavers are in good functioning condition with some need of maintenance.

Key Issues

- Pavers around mid-section of parking bays are stained with oil drippings (see picture below) which may have seeped into paver joints
- Debris build-up is present in paver joints especially adjacent to trees (see picture on right)

Debris on Pavers

Notes

The two temperature sets were taken at different locations. One location was in complete shade while the other was in direct sunlight. The two sets of measurements had a significant temperature differential overall. Assumption is that the later summer measurement (end of September) and the GI being completely in the shade lowered total heat storage and surface temperature.

Oil on pavers

Oil on pavers

4.2.2 Fire Training Academy

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater in subgrade		✓		**0**
Infiltrates stormwater		✓		**0**
Reduces runoff		✓		**0**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	n/a	n/a	n/a	**n/a**
AS-BUILT COMPARISON				
Permeable pavers constructed per plan	n/a	n/a	n/a	**n/a**
Subgrade constructed per plan	n/a	n/a	n/a	**n/a**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment	✓			**1**
Clear of oil/ grease	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**5/9**

Site Assessment Summary

- The permeable pavers could not be removed for geotechnical subgrade testing.
- The infiltration tests indicate water does not infiltrate through the joints of the pavers and down into the subgrade. Therefore the paver system cannot be considered as permeable.
- Due to the lack of infiltration and inability to remove one of the pavers, it is possible that the pavers were grouted instead of laid upon a sand subgrade.
- The temperatures were higher than adjacent non-GI infrastructure.
- The pavers appear to be regularly maintained.

- Plans specifying pavers and subgrade were not available for review.

Key Issues

- Pavers do not allow water to infiltrate
- Handicap parking symbols were painted onto pavers and may be detrimental to infiltration function in these areas (see picture below)

Notes

- This site experiences less traffic than the other permeable paver sites.

Painted Permeable Pavers

4.2.3 Central Station

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater in subgrade			✓	**0.5**
Infiltrates stormwater			✓	**0.5**
Reduces runoff			✓	**0.5**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	n/a	n/a	n/a	**n/a**
AS-BUILT COMPARISON				
Permeable pavers constructed per plan			✓	**0.5**
Subgrade constructed per plan	✓			**1**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment	✓			**1**
Clear of oil/ grease	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**8/11**

Site Assessment Summary

- Infiltration testing was done at two permeable paver sites at Central Station. One site (CS-1 per Geotechnical Report in Appendix D) indicated no infiltration and the other site (CS-3) indicated infiltration of 17.1 in/hr.
- Collectively, permeable pavers at Central Station have a potential of storing 3,115-ft^3 assuming all permeable pavement sections infiltrate water.
- The permeable pavers reduce onsite stormwater runoff by 8% from 1.3-cfs to 1.2-cfs.
- Pavers were not able to be removed at either location for subgrade testing. Pavers located around the perimeter appeared to be cemented at bottom base.
- As-built comparison demonstrates subgrade parameters were generally met with the exception of a 4-inch Aggregate Base Course installed instead of 3-inch per original plan

design (see Appendix A and E for more detail). No boring samples were able to be extracted for further comparison.

- The temperatures measured on the pavers were higher than adjacent non-GI infrastructure.
- The pavers appear to be regularly maintained.

Key Issues

- One of the two site tested indicated no infiltration
- Permeable pavers could not be removed for subgrade testing due to narrow joints, or grouting of pavers near the perimeter (see picture below)

Grouted pavers around edge (header)

4.2.4 Buckeye Road & 16th Street

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater in subgrade		✓		**0**
Infiltrates stormwater		✓		**0**
Reduces runoff		✓		**0**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	n/a	n/a	n/a	**n/a**
AS-BUILT COMPARISON				
Permeable pavers constructed per plan	n/a	n/a	n/a	**n/a**
Subgrade constructed per plan	n/a	n/a	n/a	**n/a**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure			✓	**0.5**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment		✓		**0**
Clear of oil/ grease		✓		**0**
Appears to be regularly maintained		✓		**0**
TOTAL SCORE:				**3.5/10**

Site Assessment Summary

- Permeable paver subgrade testing at Buckeye and 16th Street was not possible due to potential damage during removal of pavers for geotechnical testing.
- Documentation (i.e. as-built plans, maintenance history logs, original construction plans with paver specifications) was not available at this time.
- Infiltration tests indicate no water is able to infiltrate pavers through the joints and into the subgrade.
- Historical aerials indicate the pavers were installed sometime between December 1986 and June 1991. Older date of installation may indicate the pavers were installed for aesthetic purposes only.
- Stormwater runoff reduction is negligible.

Key Issues

- No infiltration through paver joints and into the subgrade
- Pavers in the intersection are stained with oil that appears to have built-up over the years
- Excavations for underground utility repairs conducted subsequent to installation of pavers have not replaced the pavers leaving areas of the intersection as asphalt (see picture below).
- Pavers located at the northeast and southeast corners are clear of oil and grease but do contain adjacent landscape dust and smaller decomposed granite in the joints
- A white substance has been spilled over an area of pavers located at the southeast corner (see picture below)
- Permeable pavers appear to be grouted and therefore would not allow stormwater to be infiltrated and stored in the subgrade
- Missing pavers in the middle of the intersection (see picture on following page)

Notes

Temperatures of the pavers were slightly lower than concrete in July, but were slightly higher in September (see Appendix C for temperature profiles). Measurements indicate shade is a significant factor.

Paint spill over pavers

Trenching at intersection

Intersection pavers missing and stained with oil and grease

4.3 Pervious Concrete

Similar to permeable pavers, pervious concretes are another form of a permeable pavement accomplishing the same purposes. Through the voids in the pervious concrete, stormwater runoff is able to reach the subgrade and infiltrate. The voids also serve as stormwater storage for ordinary storm events. The City of Phoenix pervious concrete systems at Civic Space Park, Helen Drake Senior Center, Hatcher Road between Central and 3rd Street, Tovrea Castle, Fire Training Academy and Central Station were evaluated for this study. Below is a scoring summary table for the five pervious concrete sites.

PERVIOUS CONCRETE SITES	**SCORE**	**%**
HELEN DRAKE SENIOR CENTER	12/13	92%
TOVREA CASTLE	12/13	92%
HATCHER ROAD	7/11	64%
CENTRAL STATION	7.5/12	63%
CIVIC SPACE PARK	6/12	50%
FIRE TRAINING ACADEMY	4.5/10	45%

4.3.1 Civic Space Park

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater		✓		**0**
Infiltrates stormwater through subgrade		✓		**0**
Reduces runoff		✓		**0**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	n/a	n/a	n/a	**n/a**
AS-BUILT COMPARISON				
Pervious concrete constructed per plan			✓	**0.5**
Subgrade constructed per plan	✓			**1**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment		✓		**0**
Clear of oil/grease	✓			**1**
Free of cracks, holes, pop-outs and/or spalling	✓			**1**
Appears to be regularly maintained			✓	**0.5**
TOTAL SCORE:				**6/12**

Site Assessment Summary

- The pervious concrete appeared to have sediment packed into the concrete and did not appear to be regularly maintained, which may prohibit infiltration and storage of stormwater (see picture on following page). As a result, the pervious concrete may perform like traditional concrete.

Key Issues

- Sediment build-up on pervious concrete throughout the park (see picture on following page)

Pervious concrete full of sediment

4.3.2 Helen Drake Senior Center

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater	✓			**1**
Infiltrates stormwater through subgrade	✓			**1**
Reduces runoff	✓			**1**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Pervious concrete constructed per plan	✓			**1**
Subgrade constructed per plan	✓			**1**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment	✓			**1**
Clear of oil/grease	✓			**1**
Free of cracks, holes, pop-outs and/or spalling	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**12/13**

Site Assessment Summary

- The pervious concrete parking lot, with an average void content of 24% and an average depth of almost 7-inches, captures 5,991-ft^3, nearly 75% of the equivalent 100-yr, 2-hr stormwater retention requirement of the pervious concrete parking lot.
- Stormwater runoff is reduced by 90% from 3.05-cfs to 0.32-cfs.
- Infiltration test results indicate water is being infiltrated at an average rate of 120.9 in/hr.
- Concrete surface is free of oils but does have pockets of debris and sediment (see picture on following page).
- Pervious concrete appears to handle traffic loads.
- Maintenance appears to be up kept regularly. It is recommended to vacuum the pockets of sediment that have infiltrated the voids.

- Overall, the Helen Drake pervious concrete parking lot is performing well.

Key Issues

- Small areas of sediment and loose leaf debris (see pictures on following page)

Sediment filling surface voids

Loose leaf debris in pervious concrete

4.3.3 Hatcher Road

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater	✓			**1**
Infiltrates stormwater through subgrade			✓	**0.5**
Reduces runoff	✓			**1**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately			✓	**0.5**
AS-BUILT COMPARISON				
Pervious concrete constructed per plan	n/a	n/a	n/a	**n/a**
Subgrade constructed per plan	n/a	n/a	n/a	**n/a**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris			✓	**0.5**
Clear of sediment			✓	**0.5**
Clear of oil/grease	✓			**1**
Free of cracks, holes, pop-outs and/or spalling	✓			**1**
Appears to be regularly maintained		✓		**0**
TOTAL SCORE:				**7/11**

Site Assessment Summary

- Pervious concrete sidewalk sections has an average void content of 28% and average depth of almost 5-inches; enough to store 609-ft^3, equivalent to 60% of the 100-yr, 2-hr stormwater storage requirement.
- Stormwater runoff is reduced by 90% from 0.38-cfs to 0.04-cfs.
- One of the three sites tested for infiltration showed no infiltration occurring. The other two sites averaged an infiltration rate of 32.6 in/hr.
- Concrete surface is free of oils but is full of debris and sediment mostly in the form of dead leaves coming from adjacent trees (see picture on following page).
- Regular maintenance may not have been kept up and is currently needed in order to return pervious concrete performance to peak level.

- As-built plans were not available.

Key Issues

- Small drainage inlets in the pervious concrete mostly on the south side of Hatcher were clogged with debris.
- Voids were partially clogged with debris.
- HR-3 boring site did not infiltrate (see Geotechnical Report in Appendix D)

Notes

There appears to be an under-drain system which was not found in the as-built plans. Pervious concrete sidewalk sections were intermixed with traditional concrete sidewalk sections with under-drain throughout.

Unclogged drain inlet

Pervious conc. partially clogged with debris

Clogged drain inlet

4.3.4 TOVREA CASTLE

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater	✓			**1**
Infiltrates stormwater through subgrade	✓			**1**
Reduces runoff	✓			**1**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	✓			**1**
AS-BUILT COMPARISON				
Pervious concrete constructed per plan	✓			**1**
Subgrade constructed per plan	✓			**1**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment	✓			**1**
Clear of oil/grease	✓			**1**
Free of cracks, holes, pop-outs and/or spalling	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**12/13**

Site Assessment Summary

- Pervious concrete parking lot has an average void content of 15%, an average depth just over 6-inches and is able to store 635-ft^3, equivalent to 47% of the 100-yr-2-hr stormwater storage requirement.
- Stormwater runoff is reduced by 90% from 0.49-cfs to 0.05-cfs.
- Infiltration test results indicate water is being infiltrated at an average rate of 71.4 in/hr.
- One test location (TC-1) has a very slow infiltration rate. Excess cementitious material was noticed in this location potentially sealing the voids of the pavement. This would indicate a mix design issue or an installation issue.
- Concrete surface is free of oils but does have pockets of debris and sediment (see picture on following page).

- Feature appears to be handling traffic loads.
- Maintenance appears to be up kept regularly. It is recommended to vacuum the pockets of sediment that have infiltrated the surface voids.
- Overall, the Tovrea Castle pervious concrete parking lot is performing well.

Key Issues

- Small areas of sediment and loose leaf debris (see pictures on following page)
- Handicap parking symbols painted onto pervious concrete which prohibit infiltration (see picture below)

Debris buildup at sump locations

Sediment buildup at sump locations

Painted handicap symbol

4.3.5 Fire Training Academy

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater		✓		**0**
Infiltrates stormwater through subgrade		✓		**0**
Reduces runoff		✓		**0**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	N/A	N/A	N/A	**N/A**
AS-BUILT COMPARISON				
Pervious concrete constructed per plan	N/A	N/A	N/A	**N/A**
Subgrade constructed per plan	N/A	N/A	N/A	**N/A**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment		✓		**0**
Clear of oil/grease	✓			**1**
Free of cracks, holes, pop-outs and/or spalling	✓			**1**
Appears to be regularly maintained			✓	**0.5**
TOTAL SCORE:				**4.5/10**

Site Assessment Summary

- The pervious concrete appeared to have sediment packed into the voids and did not appear to be regularly maintained, which may prohibit infiltration and storage of stormwater (see picture on following page). As a result, the pervious concrete may perform like traditional concrete. It is recommended to vacuum the pockets of sediment that have infiltrated the surface voids.
- Feature appears to be handling traffic loads.

Key Issues

- Sediment build-up on pervious concrete throughout the pavement (see picture on following page)

Sediment filling surface voids

4.3.6 Central Station

	YES	NO	PARTIALLY	SCORE
GENERAL PERFORMANCE				
Stores stormwater		✓		**0**
Infiltrates stormwater through subgrade		✓		**0**
Reduces runoff		✓		**0**
Able to withstand traffic loads	✓			**1**
Associated drainage infrastructure (i.e. curb-cuts, weepholes, drains, pipes, etc.) is performing adequately	n/a	n/a	n/a	**n/a**
AS-BUILT COMPARISON				
Pervious concrete constructed per plan	✓			**1**
Subgrade constructed per plan			✓	**0.5**
HEAT ISLAND PROFILE				
Lower temperatures than surrounding non-GI infrastructure		✓		**0**
MAINTENANCE/CONDITION				
Clear of garbage and debris	✓			**1**
Clear of sediment	✓			**1**
Clear of oil/grease	✓			**1**
Free of cracks, holes, pop-outs and/or spalling	✓			**1**
Appears to be regularly maintained	✓			**1**
TOTAL SCORE:				**7.5/12**

Site Assessment Summary

- According to the Geotechnical Data Report provided by Ninyo & Moore and observations during testing, it is suspected that the mix design may have contained too much water, which, after hardening, would have sealed it and prohibit it from infiltrating and storing water (see picture). As a result, the pervious concrete performs like traditional concrete and

Pervious concrete at Central Station

would not be considered a GI feature. City maintenance officials state that an integral color was mixed into the concrete.

- No sediment blockages were observed at this specific location.
- Further investigation is recommended to determine a precise cause for the lack of infiltration.

Key Issues

- The pervious concrete is not infiltrating.

5.0 MAINTENANCE MEASURES

5.1 BIOSWALES

Healthy vegetation and well-functioning infrastructure components are key features to address in establishing successful bioswales. Healthy vegetation can take several growing seasons to establish and often requires a temporary or permanent irrigation system to be installed and maintained during this establishment period. While desert-adapted and native plants should be selected for drought-tolerant characteristics in order to survive without supplemental irrigation at maturity, permanent supplemental irrigation may be preferred to maintain desired aesthetic plant qualities (longer, more frequent bloom periods, lusher appearance) in high-visibility public areas. Recommended vegetation maintenance measures include:

- Check and replenish organic or inorganic mulch to maintain adequate depth and coverage, reducing weed growth[3]
- Prune trees and shrubs as appropriate for the plant type to maintain health and meet safe public access and visibility requirements[3]
- Replace any plants lost to maintain adequate and intended vegetation coverage[3]- review plant type and location, replace with a type which ensures the right plant for the right place.
- If irrigation system is in place, check the system is functioning as intended, including inspecting the following: emitters are in correct locations to provide water to plants; controller programming is correct for time of year; valves and valve boxes are damage-free.

While the design of bioswales can vary in terms of the size and depth of the basin and the volume of stormwater to be treated, several general bioswale infrastructure components should be monitored and addressed in a typical maintenance plan. These components include the stormwater inlet (how the water is entering the basin- this could be via a curb cut or graded slope), the intended shape of the basin (slope of basin sides, width across bottom), and the stormwater outlet (does the basin drain out into another area, or is the water intended to infiltrate and/or include a sediment trap). Recommended maintenance measures include:

- Check inlets and clear any debris or waste which may be blocking water from entering basin

[3] MacAdam (2012) [3]

- Clear any accumulated sediment in bottom of basin to allow for infiltration as intended or to maintain outlet access
- Smooth, regrade or refresh erosion control measures (ex. riprap apron) on basin slopes[4]

5.2 PERMEABLE PAVERS

Permeable pavers can become clogged with sediment over time, thereby decreasing the infiltration rate and storage capacity of the system. The rate of sedimentation depends on the amount of traffic and other sources that wash sediment into the joints, base and soil. Permeable paver systems provide 20 to 25 years of service, measured by the extent to which they continue to store runoff, when properly constructed and maintained[5]. Maintenance of permeable pavers consists of removing sediment buildup from the joints periodically. Owners and/or property managers should always follow good housekeeping practices to prevent accumulation of sediment, debris and trash in the joints. These good housekeeping practices include:

- Unpaved areas should generally drain away from permeable pavers
- Unpaved areas that do drain to permeable pavers should be kept seeded and well-maintained to minimize sediment deposition
- Blowing and collecting loose debris and trash from permeable pavers regularly
- Trimming adjacent vegetation regularly
- Keeping drainage infrastructure such as curb inlets and grates free from debris

The most effective way of removing sediment buildup within the joints is by vacuum street cleaning equipment that do not have brooms or water sprays. This type of equipment will loosen and remove sediment from the joints without pushing the sediment deeper into the joint or base. Vacuuming should be done when sediment is completely dry and should be avoided if there is moisture in the joints. Below is a simple checklist for inspection and maintenance operations:

1. Visual inspection of permeable paver system on a monthly basis and after every storm
2. No standing water on the surface after any storm event
3. Vacuum joints during dry conditions as needed; adjust suction of equipment as necessary
4. Replenish joint material (e.g. ASTM D448) as needed after vacuuming
5. Repair ruts or deformations in pavers exceeding ½ inch as required

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[4] MacAdam (2012) [3]
[5] Smith (2006) [4]

5.3 Pervious Concrete

Maintenance of pervious concrete as a stormwater control measure consists of monitoring and removing any surface buildup that would obstruct permeability such as sediment, debris and trash. Owners and/or property managers should follow good housekeeping practices to prevent accumulation of sediment, debris and trash onto pervious concrete surface. These good housekeeping practices include:

- Unpaved areas should generally drain away from pervious concrete
- Unpaved areas that drain onto pervious concrete should be kept stabilized and well-maintained to minimize sediment deposition
- Blowing and collecting loose debris and trash from pervious concrete regularly
- Trimming adjacent vegetation regularly
- Keeping drainage infrastructure such as curb inlets and grates free from debris

A baseline infiltration rate for the permeable paver system should be established using an ASTM C1781: Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Unit Systems. Ideally, this test should be done prior to the pavement being in service. The infiltration rate tested should be documented and considered as the optimal performance for any future testing comparison. Original testing location(s) should also be documented. Ultimately, frequency of maintenance will be determined by future test results compared with the initial baseline test.

Maintenance of pervious concrete/unclogging[6]:

1. Routine Maintenance
    a. Visual inspections to ensure pavement is clean of debris and sediment and that pavement is dewatering between storms
    b. Dry vacuum and/or regenerative air sweeper should be utilized on a monthly basis to keep pavement area clean of sediment and debris and are the best options for long-term function.
    c. Truck sweepers and leaf blowers are less effective methods as they track in debris and redistribute dust and other particles

[6] NRMCA [5]

2. Periodic Maintenance
    a. Visual inspections after every storm should be conducted, especially during the monsoon season when dust storms are more prevalent
    b. Pressure washing and/or regenerative vacuum sweepers should be used once heavy sediment and/or oils and grease are observed on the pavement
    c. Care should be taken to avoid extremely high pressures with a pressure washer, as this can degrade the bonding cement paste and increase raveling of concrete
3. Deep Cleaning/Unclogging
    a. Deep cleaning/unclogging may become necessary, particularly if any of the following items are true:
        i. Routine and periodic maintenance has not been performed
        ii. Surface voids appear clogged
        iii. Infiltration test results indicate 25% or more below baseline infiltration rate
        iv. Infiltration test results indicate rates below 100 inches/hour (if no baseline infiltration data available)[7]
        v. Puddling or ponding after storm has come and gone
    b. Deep cleaning/unclogging best accomplished by simultaneous pressure washing and vacuuming. Several equipment manufacturers have pressure washing/vacuum systems that have been proven to restore pore structure of pervious concrete. Follow manufacturer's recommendations for best results.
    c. Use of chemicals to clean pervious concrete should be done with caution as some chemicals can harm aquifers, biological organisms in subsurface, and/or pervious concrete itself

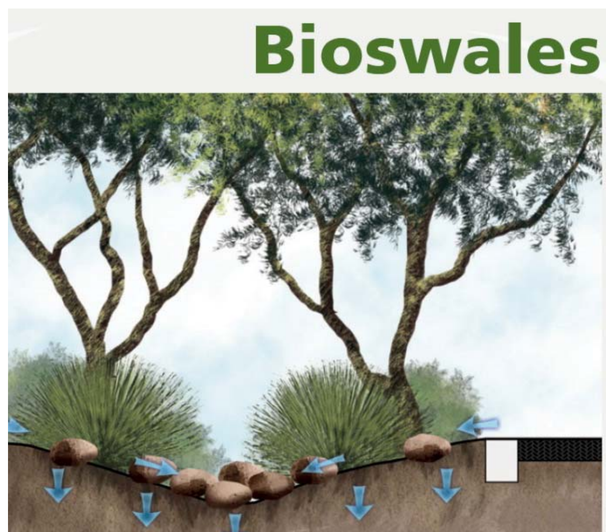
[7] NRMCA 4 [5]

6.0 Conclusions and Recommendations

6.1 General Conclusions

Proper documentation of GI is necessary in order to ensure long-term performance. Notification and disbursement of documentation to key City departments in charge of promoting, implementing and maintaining the GI is crucial to ensure GI performance. Initial documentation should include GI site location, original plans, as-built plans, manufacturer's specifications, suggested maintenance and frequency, baseline infiltration test results, plant inventories and pictures of GI during and after construction is complete. Ongoing documentation of detailed maintenance records should be kept for future reference and comparison. Proper documentation and notification to key departments will ensure optimal GI performance and provide a better return on investment for the City of Phoenix.

6.1.1 Bioswales



Bioswale Infiltration

Bioswales, vegetated swales, and bioretention areas can serve as important green infrastructure features in an arid region. While rainfall is less frequent here than in other areas of the country, arid regions such as metro Phoenix receive higher pollutant and sediment loads in a given storm event with greater impact to groundwater quality and therefore, vegetated drainage features can help to slow, filter and infiltrate this storm water volume.[8] Each of the four bioswale sites assessed in this research functioned effectively for stormwater management. The sites receive year-round supplemental support via permanent irrigation systems, which helps foster the plants' growth through dry seasons. The irrigation assessment was based on a visual inspection of each site, including review of accessible valve boxes and visible emitters and/or poly tubing. As a site feature, swales have been shown to be more cost-effective than pipes and the addition of vegetation, such as landscaping or turf, further

[8] Russ (2009) [6]

reduces the cumulative impact of stormwater flowing downstream to an ultimate outfall point.[9] The heat profile study conducted at each test site indicated bioswale features can serve to reduce the ground-level urban heat island impact on a site scale. Further research into the capacity of bioswales to reduce heat and foster more comfortable microclimates is recommended to better understand design factors such as the size, sun exposure of the swale, vegetation coverage, method of irrigation and shade tree canopy size.

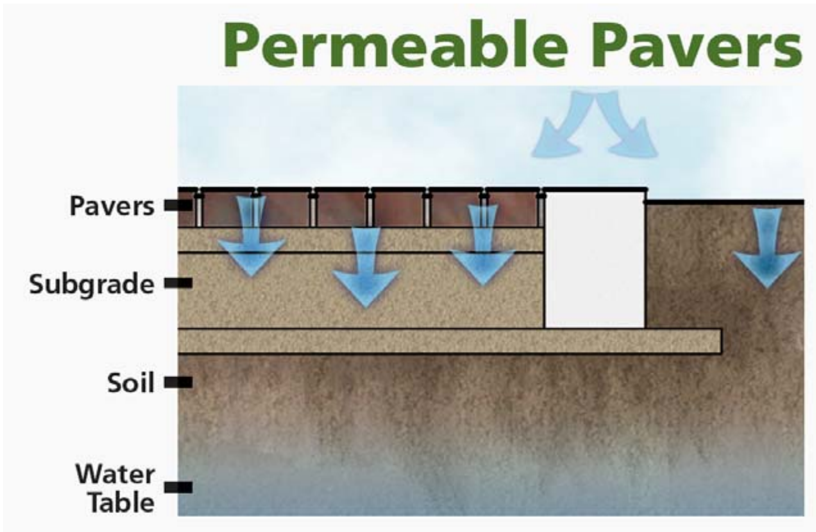
In conducting the four bioswale site visits, each swale had a varying level of vegetative coverage. The Taylor Mall bioswales appeared to be the most successful site in terms of relation to original design intent, integration with other green infrastructure design techniques such as permeable pavers, and successful mature plantings. The scale of the swale features appeared visually proportional to the street size and amount of shade and sun received by the site from adjacent buildings in a dense downtown streetscape. While the plantings were more homogeneous than would be present with a more natural diversity of arid plants, the combination of palo verde trees and ruellia shrubs has been effectively irrigated and the plants have been pruned to a healthy and mature condition. The Cancer Center bioswale was also appropriately sized for the streetscape context and had a greater diversity of native and desert-adapted plants. This bioswale received run-off from a larger street and had well-designed curb cuts with cobble drainage catchments. Located on the east side of the building, this bioswale performed well in the heat profile study. Further testing of a bioswale with western exposure is recommended to better understand the impact of sun exposure when determining an appropriate location for a bioswale in site design. The Manzanita Park bioretention areas included decomposed granite ("DG") and turf surface treatments. The turf bioretention areas performed better in the heat island profile test as compared to the DG surface. The site receives run-off from adjacent streets and while the swales and retention areas function effectively in managing the volume of storm water, the vegetation differed significantly from the original design intent. Few shrubs or understory plantings were present on the site, creating an imbalance in tree-shrub coverage. The Union Hills Service Center site captured storm water from the parking lot, was well-sized for functionality and had a balance of trees and shrubs present. However, the pruning techniques were more severe than recommended for these native and/or desert-adapted shrubs in such an intended naturalized swale setting and this along with evidence of damage to the irrigation system could have some impact on

[9] Russ (2009) [6]

the plants' health. The varying vegetation coverage present across the four sites raises the question of how much biomaterial is necessary with this type of green infrastructure feature to merit being classified as a 'bioswale' as compared to a drainage swale with some level of landscaping present for aesthetic value. The theory of bioretention expands on the concept of bioretainment, or the benefits of slowing and collecting water on the leaves, bark and branches of a plant, by combining bioretainment with a designed soil to encourage infiltration. Plants with larger leaves, such as broadleaf evergreen trees and shrubs, can provide more bioretainment benefits year-round than compared to cacti and succulents.[10] While more study is recommended to determine a suitable range of plant palette for bioswales in Phoenix, the four bioswales observed in this study indicate that a more standardized, tried-and-tested set of design guidelines specific for bioswale planting palettes would be helpful in ensuring this type of green infrastructure feature is designed, installed and maintained more cohesively across the city's streetscapes.

6.1.2 PERMEABLE PAVERS

Permeable pavers are a system of interlocking concrete blocks where runoff can infiltrate through the joints into a porous bed typically composed of sand for quicker infiltration. Permeable paver systems can offer a plethora of benefits to developers and residents alike such as mitigation of runoff volumes and peak flows, reduction of heat island effect, and enhanced community character. While the four City of Phoenix permeable paver sites studied in this report certainly benefit from an enhanced community character, three of the four sites performed poorly on mitigation of runoff and reduction of heat island effect.



Permeable Pavers Infiltration

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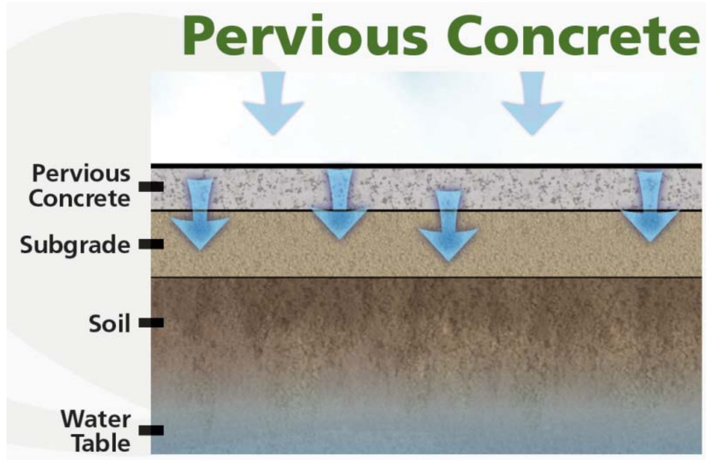
[10] Strom et al. (2013) [7]

Taylor Mall parking bays performed satisfactory in these two categories. However, the heat island effect reduction may have been more of a shade factor from surrounding high-rise buildings and canopy cover than the pavers themselves. Temperature measurements were generally higher than adjacent non-GI infrastructure for the other sites. Permeable pavers at all four sites are generally darker-colored than traditional concrete. Darker colors have a lower solar reflectivity index (SRI) thereby absorbing more sunlight and generating higher temperatures. The lower SRI values of darker-colored pavers compared to higher SRI values of traditional concrete could explain higher temperatures than non-GI counterparts.

Subgrade assessment presented a challenge due to unavailable as-built plans and/or inability to remove permeable pavers without causing damage to pavers for subgrade testing. Permeable pavers at the Fire Training Academy and Central Station could not be removed due to grouting/cementing of pavers which indicate the pavers do not conform to a customary installation practice where a porous material such as compacted sand fills the joints and bed of the system. Infiltration test results for the Fire Training Academy and Central Station support this conclusion as no water was able to infiltrate. Permeable pavers at Buckeye Road and 16th Street also demonstrate no infiltration although pavers were not grouted at this location. Permeable pavers at Buckeye Road were adjoined edge to edge with narrow joints. Review of historical aerials indicates these pavers were installed prior to 1991. Over the years, the joints have been filled with sediment and other fines that may keep storm water from infiltrating. See Appendix D for the infiltration data.

Overall, permeable pavers performed subpar from a stormwater management perspective, did not reduce ground-level heat island effect, and had incorrect installation issues or modifications to original design. Infiltration testing for (the properly constructed) pavers at Taylor Mall indicates infiltration is much slower than pervious concrete.

6.1.3 Pervious Concrete



Pervious Concrete Infiltration

Pervious concrete is a mixture of Portland Cement, coarse aggregate rock and water. Because the mix contains little or no sand, the pore structure has many voids, allowing water and air to pass through allowing water to drain through. Pervious concrete is able to store stormwater in the pavement layer which reduces runoff and in turn can increase land utilization by reducing retention areas. The City of Phoenix pervious concrete sites studied exhibited varying degrees of performance ranging from poor to excellent.

The sites that performed poorly were Civic Space Park, Central Station, Hatcher Road, and Fire Training Academy. Central Station performed poorly either due to sediment or mix design issues (too much cement). Blockage is preventing runoff from infiltrating into the pervious concrete voids. Hatcher Road, Fire Training Academy, and Civic Space Park performed poorly mostly due to sediment and debris filling surface voids. The sites that performed excellent were Tovrea Castle and Helen Drake Senior Center. Both of these sites mostly exhibited high infiltration rates and were well maintained with the exception of a few pockets of sediment and debris occurring mostly at sump locations.

The City of Phoenix requires developers to store onsite runoff for the 100-yr, 2-hr storm event[11]. Using the pervious concrete footprint area for the three sites that demonstrated infiltration, a runoff coefficient of 0.95 for traditional impervious areas, and NOAA Atlas 14 rainfall depths for the corresponding area, the volume requirements were calculated and correlated to the storage capacity of each site. A minimum of two boring samples at each site were tested for void content and depth. The average depth and void content were used to calculate storage capacities in the pervious concrete. Calculations indicate that Helen Drake, Hatcher Road and Tovrea Castle store, respectively, 73%, 60% and 47% of the 100-yr, 2-hr storm (see Appendix F for storage calculations). Depth of pervious concrete remained consistent but void content fluctuated greatly

[11] City of Phoenix (2013) [8]

from site to site (see summary table below and Appendix D). Potential reasons for fluctuations could be due to inconsistencies in mix design, installation issues or clogged voids in need of maintenance. Consistent mix design and installation would yield higher void content. Regular maintenance would sustain maximum void content.

PERVIOUS CONCRETE SITE	BORING NO.	DEPTH (in)	VOID CONTENT (%)	STORAGE CAPACITY (ft^3)	STORAGE REQUIREMENT (ft^3)	STORAGE RQUIREMENT MET
Helen Drake Senior Center	HD-1	7.15	25.5	5,991	8,177	73%
	HD-2	6.40	22.4			
Hatcher Road	HR-1	4.65	35.3	609	1,015	60%
	HR-2	4.64	19.7			
Tovrea Castle	TC-1	6.58	8.3	635	1,339	47%
	TC-2	5.57	22.4			

Temperature measurements at the pervious concrete sites indicated no reduction of ground-level heat island effect. Similar to permeable pavers, temperatures were higher for pervious concrete than adjacent non-GI features. Unlike permeable pavers however, the pervious concrete was not darker-colored than traditional concrete, ruling out solar reflectivity as a potential explanation. Although more research would be needed, the higher temperatures of the pervious concretes could be related to larger air voids and increased surface area. Generally, pervious concrete can lower temperatures through evaporative cooling when it is wet or moist. Under dry conditions, pervious concrete can exhibit increased daytime temperatures via convection in the larger air voids and limited heat transfer to the subsurface layer. Thus, pervious concrete in the City would typically exhibit higher daytime surface temperatures as observed in this study. However, pervious concrete may dissipate stored heat more efficiently at nighttime reducing bulk heat storage.[12] This study conducted summer temperature measurements during midday and would need further study in order to make a determination on how pervious concrete reacts during the nighttime.

Overall, pervious concrete performed well from a stormwater management perspective excluding the sites where it had not been maintained or mix design may have been incorrect. The sites that were shown to infiltrate are capable of storing roughly 50% to 75% of the 100-yr, 2-hr storm storage requirement. Moreover, stormwater runoff was reduced by approximately 90% over using traditional impervious features.

[12] U.S. EPA (2008) [9]

6.2 Site Specific Recommendations

6.2.1 Manzanita Park

Manzanita Park has turf basins at the northern end and DG basins at the southern end. It is recommended that the intent and functionality of the basins, particularly the DG basins, to determine if use as a bioretention feature was intended. If so, recommend restoring understory plantings and or revegetation hydroseed mix to help establish initial cover. Additional shade trees would help foster understory growth and reduce the effect of radiant heat from the DG inert material surfacing covering.

- DG basins have little to no vegetation and require very low maintenance. If restoration of understory is implemented at DG basins, ongoing maintenance should be done with much more frequency. This ongoing maintenance would consist of pruning for plant health only, ensuring irrigation system is always functional, removing trash and debris that would be trapped in the denser understory. Maintenance would be required a minimum of every six months and following any storm event.
- Maintenance of the turf basins is to be done every six months and after any storm event. Maintenance is to implement:
  - Checking irrigation system is functional and restoring any malfunctioning elements
  - Clearing any trash, debris and/or sediment for drainage paths to the basins such as scuppers, stormdrain pipes and swales
  - Reseeding patches of dead grass as was observed adjacent to sidewalks

6.2.2 Cancer Center

Overall, the vegetation at the Cancer Center was in good condition. There were a few instances where uprooted shrubs were observed and where holes were left open from a removed tree likely due to wind damage. It is recommended these sites be reviewed and that like-kind vegetation be replaced where these plants once stood. Further investigation of heat island profile is also recommended with data taken seasonally and during daily temperature extremes to better understand the visible oscillation in heat temperature results taken from two days in afternoon shade.

- Maintenance of bioswale should be continued in the existing manner and frequency as plant health is good and bioswale is clean and functional. Maintenance of bioswale should always incorporate:
  - Clearing bioswale and curb-cut inlets of any trash and debris (small amounts of trash were observed at the curb-cut inlets off of 7th Street)
  - Pruning vegetation for plant health only
  - Replanting uprooted or dead vegetation (uprooted and dead vegetation was observed at the Cancer Center)
  - Restoring irrigation elements so that system is fully functional
  - Inspect areas of bioswale where foot traffic is prominent for trash, damaged vegetation, broken irrigation elements, etc.

6.2.3 Union Hills Service Center

Uplimbing of trees and continuous extreme shearing of shrubs has permanently stunted or killed vegetation. It is recommended that maintenance practices and recommended best practices for sustainable landscaping be reviewed and implemented in order to allow existing vegetation to regain natural, fuller form and prune for plant health only. Reparation of faulty irrigation valve boxes along with a check of the irrigation to ensure fully functioning system is also highly recommended. Lastly, review areas where pedestrian foot traffic may be cutting across swale and consider measures to reduce traffic, such as boulders or cobble placement.

- Perform maintenance of bioswale every six months and inspect after any storm event. This ongoing maintenance includes:
  - Clearing bioswale and curb-cut inlets of any trash and debris
  - Pruning and shearing vegetation for plant health only (current conditions demonstrate extreme shearing of shrubs has stunted or killed vegetation)
  - Replanting uprooted or dead vegetation
  - Restoring irrigation elements so that system is fully functional (faulty irrigation valve boxes were observed)
  - Inspect areas of bioswale where foot traffic is prominent for trash, damaged vegetation, broken irrigation elements, etc.

6.2.4 Taylor Mall

The bioswales at Taylor Mall were in good condition with only small patches of missing vegetation observed. It is recommended that certain measures be considered to reduce foot traffic cutting through and compacting soil. Measures may include either adding additional planting to this area or other means of blocking traffic, such as boulders.

The permeable pavers used in the parking bays along Taylor Mall were stained with oil and also contained pockets of debris particularly when adjacent to vegetation. Pressure washing pavers is not recommended, as this can drive residue into the setting bed and base below.[13] Street sweeping with a conventional broom sweeper is recommended to remove the loose leaf debris found at Taylor Mall. Removal of oil and grease stains would require application of specialty cleaners designed to lift and absorb stains.

- Perform maintenance of Taylor Mall bioswales every six months and inspect after any storm event. This ongoing maintenance includes:
  - Clearing bioswale and curb-cut inlets of any trash and debris
  - Pruning and shearing vegetation for plant health only
  - Replanting uprooted or dead vegetation
  - Restoring irrigation elements so that system is fully functional
  - Inspect areas of bioswale where foot traffic is prominent for trash, damaged vegetation, broken irrigation elements, etc. (current conditions demonstrate narrow strips through bioswale where pedestrians have stepped on vegetation)
- Perform maintenance of Taylor Mall permeable pavers every six months and inspect after any storm event. This ongoing maintenance includes:
  - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
  - Cleaning surrounding open spaces in order to reduce sediment flowing onto pavers
  - Removing oil and grease stains using specialty cleaners designed to lift and absorb stains (never use power washers at permeable pavers as this can cause sand in the joints to wash away and be replaced by sediment and residue). Taylor Mall parking bays all had some degree of oil and grease stains. Oil and grease stains must be

[13] UNI-Group U.S.A. (2014) [10]

removed promptly in order to prevent future storms from disseminating those pollutants into the joints and potentially into the subgrade.
    - Removing sediment and debris using a conventional broom sweeper
- An infiltration test using ASTM C1781/C1781M should be performed every two to four years to check infiltration rates of permeable pavers are still at or above the minimum accepted infiltration rate as determined by the engineer of record.

6.2.5 Fire Training Academy

The Fire Training Academy has two GI-features, permeable pavers and pervious concrete. The pavers appeared well-maintained and as such in no need of maintenance for the time being. The key issue with the permeable pavers at the Fire Training Academy is that they did not permeate water. The pavers were not able to be removed for subgrade testing which could be indicative of grouted pavers. It is recommended that a small area of pavers be removed and inspected to see how they were constructed and to test the subgrade in order to determine there is a lack of infiltration. Current conditions of the pervious concrete at the Fire Training Academy indicate heavy sediment has filled surface voids and the concrete no longer functions as pervious. The pervious concrete needs to be vacuumed using a regenerative air vacuum that can remove the sediment then re-tested for infiltration.

- Perform maintenance every six months and inspect after any storm event. This ongoing maintenance includes:
    - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
    - Cleaning surrounding open spaces in order to reduce sediment flowing onto pavers
    - Removing oil and grease stains using specialty cleaners designed to lift and absorb stains (never use power washers at permeable pavers as this can cause sand in the joints to wash away and be replaced by sediment and residue)
    - Removing sediment and debris using a conventional broom sweeper. Regenerative air vacuum sweepers should be used when pavers are severely clogged. Restore sand between the joints as needed when using a regenerative air vacuum sweeper.
- An infiltration test using ASTM C1781/C1781M should be performed every two to four years to check infiltration rates of permeable pavers are still at or above the minimum accepted infiltration rate as determined by the engineer of record.

    - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, remove pavers, relay base, place pavers and fill joints with new sand per manufacturer's specifications.
- Once pervious concrete has been restored and infiltrating, perform maintenance at least every six months due to heavily trafficked area and inspected after any major storm event. The ongoing maintenance includes:
    - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
    - Cleaning surrounding open spaces in order to reduce sediment flowing onto pervious concrete
    - Removing sediment and debris using a conventional broom sweeper
    - Using regenerative air vacuum sweepers when voids are severely clogged
- An infiltration test using ASTM C1701/C1701M should be performed every two to four years to check infiltration rates of pervious concrete are still at or above the minimum accepted infiltration rate as determined by the engineer of record.
    - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, subgrade could potentially be packed with sediment and residue. It is recommendable to extract subgrade boring sample(s) in order to evaluate subgrade content and density.

6.2.6 BUCKEYE ROAD & 16TH STREET

The pavers at the intersection of Buckeye and 16th Street were not infiltrating water. Review of historical aerials revealed pavers were installed prior to 1991. The joints in this paver system appear to be full of sediment and oil which has been compacted by traffic over the years such that no water is able to infiltrate. Regenerative air vacuum sweepers are the most effective form for permeable paver maintenance for severely clogged systems as they have demonstrated the ability to remove up to 3-inches or more of aggregate from openings and even restore systems to original infiltration rates.[14] It is recommended that a small designated area of clogged pavers be treated by a regenerative air vacuum sweeper then retested for infiltration.

- Perform maintenance every six months and inspect after any storm event. This ongoing maintenance should consist of:

[14] UNI-Group U.S.A. (2014) [10]

  - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
  - Cleaning surrounding open spaces in order to reduce sediment flowing onto pavers
  - Removing oil and grease stains using specialty cleaners designed to lift and absorb stains (never use power washers at permeable pavers as this can cause sand in the joints to wash away and be replaced by sediment and residue)
  - Removing sediment and debris using a conventional broom sweeper. Regenerative air vacuum sweepers should be used when pavers are severely clogged as is the suspected current condition of the pavers. Restore sand between the joints as needed when using a regenerative air vacuum sweeper.
- An infiltration test using ASTM C1781/C1781M should be performed every two to four years to check infiltration rates of permeable pavers are still at or above the minimum accepted infiltration rate as determined by the engineer of record.
  - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, remove pavers, relay base, place pavers and fill joints with new sand per manufacturer's specifications.

6.2.7 Central Station

Central Station has two GI features, permeable pavers and pervious concrete. Two permeable paver locations were tested for infiltration of which only one demonstrated infiltration. Pavers were not able to be removed at either location. It is recommended that pavers be removed at the location where no infiltration occurred in order to investigate cause. The pervious concrete at Central Station is not functioning. Maintenance will have to be performed in order to function as intended. If maintenance does not alleviate the issue, then replacement may be necessary.

- Perform maintenance every six months and inspect after any storm event. This ongoing maintenance includes:
  - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
  - Cleaning surrounding open spaces in order to reduce sediment flowing onto pavers and pervious concrete
  - Removing oil and grease stains using specialty cleaners designed to lift and absorb stains (never use power washers at permeable pavers as this can cause sand in the joints to wash away and be replaced by sediment and residue)
  - Removing sediment and debris using a conventional broom sweeper

  - Using regenerative air vacuum sweepers when pavers and pervious concretes are severely clogged
- An infiltration test using ASTM C1781/C1781M and ASTM C1701/C1701M for permeable pavers and pervious concrete, respectively, should be performed every two to four years to check infiltration rates are still at or above the minimum accepted infiltration rate as determined by the engineer of record.
  - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again.
  - If permeable paver infiltration rates are still deficient, remove pavers, relay base, place pavers and fill joints with new sand per manufacturer's specifications.
  - If pervious concrete infiltration rates are still deficient, subgrade could potentially be packed with sediment and residue. It is recommendable to extract subgrade boring sample(s) in order to evaluate subgrade content and density.

6.2.8 Civic Space Park

Current conditions of the pervious concrete at Civic Space Park indicate heavy sediment has filled surface voids and the concrete no longer functions as pervious.

- Once pervious concrete has been restored and is infiltrating, maintain at least every six months due to heavily trafficked area and inspect after any major storm event. The ongoing maintenance includes:
  - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
  - Mowing adjacent lawns
  - Cleaning surrounding open spaces in order to reduce sediment flowing onto pervious concrete
  - Removing oil and grease stains using specialty cleaners designed to lift and absorb stains
  - Removing sediment and debris using a conventional broom sweeper.
  - Using regenerative air vacuum when pervious concrete is severely clogged.
- An infiltration test using ASTM C1701/C1701M should be performed every two to four years to check infiltration rates of pervious concrete are still at or above the minimum accepted infiltration rate as determined by the engineer of record.

    - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, subgrade could potentially be packed with sediment and residue. It is recommendable to extract subgrade boring sample(s) in order to evaluate subgrade content and density.

6.2.9 Helen Drake Senior Center

Helen Drake is in good condition. The only recommended measure would be to conduct routine maintenance efforts in sump areas and areas adjacent to vegetation in order to remove sediment and debris build-up that is more prominent in these areas. Furthermore, ongoing maintenance to be performed as outlined below.

- The ongoing maintenance is to be done at least once per year and inspected after any storm to determine if unscheduled maintenance is required. The maintenance items include:
    - Inspecting associated drainage infrastructure such as grated catch basins and curb inlets for trash and debris that could inhibit proper function
    - Pruning and shearing surrounding vegetation in order to reduce loose leaf debris
    - Cleaning surrounding open spaces in order to reduce sediment flowing onto pervious concrete
    - Removing sediment and debris using a conventional broom sweeper
    - Using regenerative air vacuum sweepers when concrete is severely clogged
- An infiltration test using ASTM C1701/C1701M should be performed every two to four years to check infiltration rates of pervious concrete are still at or above the minimum accepted infiltration rate as determined by the engineer of record.
    - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, subgrade could potentially be packed with sediment and residue. It is recommendable to extract subgrade boring sample(s) in order to evaluate subgrade content and density.

6.2.10 Hatcher Road

Hatcher Road's pervious concrete sidewalk sections were laden with sediment and debris. The sidewalk is surrounded by trees and landscape tracts that wash out onto the pervious concrete clogging surface voids and under-drain system. It is recommended that the sidewalk be vacuumed thoroughly and be maintained with more regularity, especially before and after the monsoon season.

- The ongoing maintenance is to be done at least twice per year and inspected after any storm to determine if unscheduled maintenance is required. The maintenance items include:
  - Inspecting the small grated inlets for trash and debris that would inhibit proper function
  - Pruning and shearing surrounding vegetation in adjacent landscape tracts in order to reduce loose leaf debris, particularly on the south side of Hatcher Road
  - Cleaning the surrounding open spaces in order to reduce sediment flowing onto pervious concrete
  - Removing sediment and debris using a conventional broom sweeper
  - Using a regenerative air vacuum sweepers when concrete is severely clogged
- An infiltration test using ASTM C1701/C1701M should be performed every two to four years to check infiltration rates of pervious concrete are still at or above the minimum accepted infiltration rate as determined by the engineer of record.
  - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, subgrade could potentially be packed with sediment and residue. It is recommendable to extract subgrade boring sample(s) in order to evaluate subgrade content and density.

6.2.11 Tovrea Castle

Tovrea Castle is in a well-maintained condition. This is possibly due to less traffic as entry gates providing access are open for special events and tours only. One recommended measure would be to focus routine maintenance efforts in sump areas and areas adjacent to vegetation in order to remove sediment and debris build-up that is more prominent in these areas.

Geotechnical boring samples indicate a significant difference in void content in the two locations sampled. It is likely this difference is due to inconsistent concrete mix design or lack of quality control during construction. It is recommended that a well-defined quality control protocol be implemented for future pervious concrete designs to ensure maximum performance.

- The ongoing maintenance is to be done at least once per year and inspected after any storm to determine if unscheduled maintenance is required. The maintenance items include:

- Inspecting the curb-cut inlets for sediment, trash and debris that would inhibit positive drainage towards the open space tracts
- Pruning and shearing surrounding vegetation in adjacent landscape tracts in order to reduce loose leaf debris, particularly at the sump area located just east of the west entrance
- Cleaning the surrounding open spaces in order to reduce sediment flowing onto pervious concrete
- Removing sediment and debris using a conventional broom sweeper
- Using a regenerative air vacuum sweepers when concrete is severely clogged

- An infiltration test using ASTM C1701/C1701M should be performed every two to four years to check infiltration rates of pervious concrete are still at or above the minimum accepted infiltration rate as determined by the engineer of record.
  - If infiltration rates are determined to be deficient, use a regenerative air vacuum sweeper then test again. If infiltration rates are still deficient, subgrade could potentially be packed with sediment and residue. It is recommendable to extract subgrade boring sample(s) in order to evaluate subgrade content and density.

6.3 Further Recommendations

Several of the permeable paver systems did not allow infiltration. Testing of more paver systems is recommended to obtain additional performance data.

Temperature profiles were taken in summer during midday. Studying temperatures of the GI features in the evening, nighttime and/or early morning is recommended to evaluate heat storage and dissipation. Studying temperatures of other non-GI land uses (such as natural desert) is recommended to provide further data for comparison.

It is recommended that arid region BMP details/specifications for design and construction be evaluated and prioritized. Suggested key elements for this evaluation include: (a) Review of field test data for local GI types; (b) Review of details and specifications by others; (c) Review of costs and (d) Determination of applicability of GI types to specific users and environments.

It is recommended that an approach to water and soil quality sampling at bioswale features be evaluated. Soil samples at curb-cut inlets (where oil, grease has accumulated) and grab samples or first-flush samples would provide further functionality data.

There has been continued interest by developers on increasing GI features within new residential and commercial sites. In turn, there is a desire to satisfy stormwater storage and first flush requirements by use of these features. To provide a basis for supplementing City policy in this regard, certain elements would need to defined. These elements need to be measurable and demonstrate continuous functionality. Elements would become the foundation for design and maintenance documents. It is recommended that further brainstorming be conducted to evaluate the basis for evaluating City policy to manage the implementation of GI. Some of these elements should include: (a) Field-testing based functionality data for existing, local GI features; (b) Applicability of GI types for private and public uses; (c) Quantification of stormwater quality and quantity mitigation by GI type; (d) Evaluation of life-cycle costs; (e) Development of a management program to handle policy changes (review, compliance).

7.0 REFERENCES

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