APPENDIX E

STORM WATER CONTROL PLAN

Stormwater Control Plan for
Salinas Union High School District
High School #5
Salinas, CA

Date: March 2011

Prepared for:

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Prepared by:

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Stormwater Control Plan
for
Salinas Union High School District High School #5

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Stormwater Control Plan
for
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1.0 Purpose

The primary purpose of this report is to identify features that can be incorporated into the site plan for the Salinas Union High School District (UHSD) High School #5 to meet applicable post-construction stormwater requirements. RBF Consulting prepared this report for Kasavan Archtects to support Kasavan Architect's planning of a new high school within the Future Growth Area of the City of Salinas. This report provides baseline hydrologic information for planning and design of drainage features that will be part of the proposed Salinas UHSD High School #5 project.

The primary drainage features for the project will be Low Impact Development (LID) elements that promote infiltration and provide storm water quality treatment, and additional detention and/or retention systems necessary to meet numeric criteria for post-development flow conditions. Some onsite storm drain piping will also be required, but will be detailed as part of final design. The objective of the LID elements is to mitigate for potential increases in runoff to an extent that results in less than significant changes to offsite discharges so that no offsite drainage improvements are required for project implementation. The project also includes a channel along the eastern edge of the project site to convey offsite runoff to replace an existing ditch.

This report identifies Best Management Practices (BMPs) that could be used to satisfy design requirements and provide the required level of mitigation for potential impacts to surface water quality and quantity. BMPs include specific LID design features as required by the City of Salinas ***Stormwater Development Standards*** (SWDS), dated April 2010.

2.0 Setting

The Salinas UHSD is planning to construct a high school complex on approximately 39 acres south of Rogge Road between San Juan Grade and Natividad Road, as shown on Exhibit 1, Project Vicinity Map. The project site is currently in agricultural use with row crops and has one single family residence. Photographs 1 through 7 provided herein were taken on December 21, 2010, and show existing conditions on and around the project site. There is an existing residential neighborhood to the west of the project site; otherwise, the project site is bounded by agricultural land use.

3.0 Drainage Criteria

Storm drainage criteria are contained in the ***City of Salinas Stormwater Development Standards for New and Significant Redevelopment Projects***, (SWDS, 2010) and the ***Final Supplement for the Salinas General Plan Final Program EIR*** (PEIR) (EDAW, 2007).

The SWDS establishes the requirements for new development to use LID principles and includes numeric criteria for stormwater management. Criteria from Section 1.5.3 of the SWDS that are applicable to the High School #5 project include:

> 1. All new development projects shall direct runoff from 100% of the area of new impervious surfaces into BMPs meeting the requirements of these standards. This is equivalent to 0% Effective Impervious Area. Exceptions may be allowed for driveways when grade breaks are located to minimize the area draining to the street. Plans for new development projects not meeting this requirement will only be approved if the applicant demonstrates, to the satisfaction of the City Engineer, that the full achievement of such is impracticable.
>
> 3. The project applicant shall prepare an exhibit showing the entire site divided into discrete drainage areas and demonstrate in submitted site stormwater control plans (SWCPs) that for each discrete drainage area the following numeric criteria are met:
>
> > A. Volume Reduction Requirements: Runoff from impervious areas produced by the 24-hour 85th percentile storm (currently 0.6 inches of rainfall for the City of Salinas) is either (1) retained, or (2) detained and allowed to infiltrate and/or seep away slowly, as occurs in a bioretention facility designed with a minimum 18 inches of soil, a design surface loading rate not exceeding 5 inches/hour, and a total volume (including surface detention, soil interstices, and subsurface storage) equal to the volume of runoff produced by the first 0.6 inches of rainfall on the drainage area tributary to the facility.
> >
> > B. Water Quality Treatment Requirements: All treatment BMPs must be adequately sized to treat runoff from the designated drainage area per the following numeric criteria:
> >
> > > (1) All flow based BMPs shall be sized, at minimum, to the maximum flow rate of runoff from the designated drainage area using the 85th percentile hourly rainfall intensity multiplied by two. For the City of Salinas, this equates to 0.22 inches per hour.
> > >
> > > (2) All volume based BMPs shall be sized, at minimum, for the volume of runoff produced by the drainage area from a 24-hour 85th percentile storm event. For the City of Salinas, this equates to a rainfall depth of 0.6 inches.
> >
> > C. Project applicants must comply with 3, 3.A., and 3.B above by following and applying the BMP design methodologies, guidelines, and considerations in Section 4, Stormwater Design Considerations.
>
> 4. In addition, for all new development and redevelopment projects creating or replacing one acre or more of impervious surfaces, the project applicant shall either:
>
> > A. Demonstrate post-project runoff peaks and durations do not exceed pre-development runoff peaks and durations for storm events up to and including the 10-year 24-hour event with a continuous simulation computer model of runoff in the pre-project and post-project condition using 30 years or more of local hourly rainfall data, or
> >
> > B. Conduct an assessment incorporating sediment transport modeling across the range of channel-forming flows that demonstrates to the City Engineer's satisfaction that the project flows and sediment reductions will not detrimentally affect the receiving water. Channel-forming flows include up to the 10-year event unless the assessment demonstrates otherwise.

From a practical standpoint, meeting numeric criteria 3.A requires the use of volume-based treatment that meets the conditions of 3.B(2). Because the project will create one acre or more of impervious surface, the project must also meet numeric criteria 4.A or 4.B. A procedure for meeting criteria 4.A was developed by RBF Consulting for the City of Salinas and is documented in a report titled “Hourly Precipitation Records and SWDS Compliance,” dated June 1, 2009. A copy of this report is included in Appendix A of this stormwater control plan (SWCP). Because of the methods proposed to meet runoff rate and volume requirements of numeric criteria 4.A, the water quality requirements listed in numeric criteria 3 will also be met.

Section 5 of the SWDS provides storm drain and flood control design criteria that are applicable to the project, such as requiring that the conveyance (open channel or pipe) along the eastern edge of the project site be designed for a 20-year discharge. The SWDS identifies appropriate methodologies and parameters for determining design discharge rates. The criteria and methods are described in Section 9.0 of this report.

The PEIR includes the following requirement:

> The City will implement General Plan Implementation Program LU-17 that requires, as a condition of Project approval, new development to provide adequate storm water and flood management facilities to control direct and indirect erosion and discharges of pollutants and/or sediments so that “no net increase in runoff” occurs as a result of the proposed Project. To determine the facility and Best Management Practices (BMPs) needs, the City will require, when necessary, a hydrological/drainage analysis to be performed by a certified and City-approved engineer, with the cost of said analysis the responsibility of the Project applicant.

The PEIR requirement relative to total runoff from the project site is more restrictive than the SWDS.

4.0 General Drainage Patterns

The project site is bordered by a residential neighborhood to the west, and farmland to the north, east and south. Drainage areas that are significant to site planning are shown on Exhibit 2.

The project site, though relatively flat, is situated on a hydrologic ridge. Runoff directly from the north of the site is intercepted by a drainage ditch on the north side of Rogge Road, which directs runoff to the west. Lands to the northeast of the project drain across Rogge Road though a system of ditches and culverts to an earthen ditch along the eastern edge of the project site. The eastern portion of the project site drains to the southeastern corner of the site into a ditch that conveys flows to a storm drain that connects to a system that ultimately discharges into Markley Swamp. The western portion of the project site drains to the southwestern corner of the site into a ditch that conveys flows into Santa Rita Creek.

The entire project site is within the Reclamation Ditch watershed. Both Markley Swamp and Santa Rita Creek connect to the Reclamation Ditch drainage system downstream from Carr Lake.

It should be noted that more accurate topographic mapping is now available compared to what was available when the ***Zone 9 and Reclamation Ditch Drainage System***

Operation Study (Schaaf & Wheeler, 1999) was prepared for Monterey County Water Resources Agency (MCWRA) and the ***City of Salinas Storm Water Master Plan*** (CDM, 2004) was prepared. Both of the historic studies indicate that the project site is on the drainage divide between Santa Rita Creek and Gabilan Creek (Gabilan Creek drains to Carr Lake). However, from inspection of the City's two-foot contour topographic mapping, field investigation, and the observed flow directions in the ditches between the fields revealed that the eastern portion of the project site actually drains to Markley Swamp, not Carr Lake. These revised watersheds are illustrated in Exhibit 3. There may be significant implications of this more accurate delineation of watersheds from a regional hydrologic perspective, but it does not impact the recommendation and conclusions presented in this report. This study concluded that the actual area tributary to Markley Swamp is 3.8 square miles, whereas the ***Zone 9 and Reclamation Ditch Drainage System Operation Study*** had estimated the Markley Swamp watershed (MS10) are to be only 2.9 square miles.

4.1 Areas Draining to Markley Swamp

Runoff from Offsite Drainage Area (DA) 1 collects on the north side of Rogge Road and is conveyed westward in a drainage ditch for a relatively short distance to culverts that convey flows to the south. There is a depression in the southwest corner of one of the fields that retains some local flow from that field, as shown in Photograph 1. This area retains flows from some frequent rainfall events, with no initial conveyance to the drainage ditch that exists on the north side of Rogge Road. Runoff in excess of the capacity of the local depression discharges west along the roadside ditch on north side of Rogge Road and then turns southward under the road through culverts. Exhibit 4 indicates the locations where included photographs 1 through 7 were taken.

Photograph 1 – Area of Ponding Northeast of Project Site from North Edge of Rogge Road

The majority of the flow from Offsite DA 1 then continues toward the northeast corner of the proposed project site, and gathers at Node 1. The southern half of Rogge Road along the north edge of Onsite DA 1 flows eastward to, and gathers at, Node 1 as well. Photograph 2 shows Node 1 with its piping to the south.


Photograph 2 - Node 1, Looking South from South Edge of Rogge Road

Runoff from Onsite DA 1 drains to the southeast corner of the project site and discharges into the drainage ditch at Node 3, joining flows from Offsite DA 1 and Offsite DA 2.

Runoff from Offsite DA 2 flows toward the southwest corner and discharges into a drainage ditch at Node 2. This ditch conveys the flow southward to Node 3, and is joined by flows from Onsite DA 1 and Offsite DA 1.


Photograph 3 - Node 2, Looking Northwest

Photograph 4 - Node 3, Looking South

The combined flows from Onsite DA 1, Offsite DA 1, and Offsite DA 2 travel generally southward through a series of drainage ditches that convey surface runoff to a storm drain structure at East Boronda Road and McKinnon Street, which connects to a system that ultimately drains to Markley Swamp.

4.2 Areas Draining to Santa Rita Creek

Runoff from Offsite DA 3 is conveyed westward in a roadside ditch along the north side of Rogge Road to a drainage inlet at Node 5. This inlet connects to a drainage system associated with the adjacent development that ultimately discharges into Santa Rita Creek. Offsite DA 3 is included in the analysis because improvements to Rogge Road associated with the construction of the high school may impact the flows in the existing ditch.

Photograph 5 - Node 5, Looking East

Photograph 6 - Node 4, Looking West

The western half of the project site, Onsite DA 2, drains toward the southwestern corner of the site. Runoff from Onsite DA 2 collects in a drainage ditch that directs flows to Node 4, from where it is conveyed by drainage ditches along the southern border of the adjacent residential neighborhood. At approximately one quarter of a mile from the project site, the ditch turns south and ultimately leads to a culvert underneath San Juan Grade Road, which discharges into Santa Rita Creek. Table 1 summarizes the drainage areas that are tributary to each node. Note that Node 2 is upstream from the confluence of the ditch from Offsite DA 1 with the ditch from Offsite DA 2. The 20.8 acres of Onsite DA 1 is included with the tributary areas of Offsite DA 1 and Offsite DA 2 in the total area tributary to Node 3.

Table 1 – Node Tributary Areas

Node	Tributary Area (Acres)	Drainage Areas Flowing to this Node
1	174.6	Offsite DA 1
2	57.2	Offsite DA 2
3	252.6	Offsite DA 1, Offsite DA 2, Onsite DA 1
4	17.9	Onsite DA2
5	57.9	Offsite DA3

Existing Site and Surrounding Area Soil Characteristics

Soil maps and reports of the project site and surrounding area were acquired from the U.S. Department of Agriculture, Natural Resources Conservation Service. The hydrologic soil group classifications are presented in Appendix B. In general, hydrologic soil groups range from high infiltration rates (Group A) to very slow infiltration rates (Group D). The soil groups that are present onsite and on tributary areas offsite include Soil Groups B and D, as shown on Exhibit 5. The site is predominately Soil Group B, with the southeastern portion of the site classified as Soil Group D. Table 2 summarizes the amount of each hydrologic soil on each major offsite and onsite drainage area.

The hydrologic soil group and ground cover factor into how much rainfall becomes runoff. Currently, the site is in agricultural use with row crops running north-south and has one single family residence, as shown in Photograph 7. Much of the western portion of the project site is covered by plastic sheeting. However, because numeric criteria 4.A from the SWDS states, “Demonstrate post-project runoff peaks and durations do not exceed ***pre-development*** runoff peaks and durations…,” and the stated intent of the Central Coast Regional Water Quality Control Board is to base evaluations on pre-development, and not pre-project conditions; pre-development runoff was based on shrub ground cover, not compacted, plastic covered agricultural cover. Therefore, the proposed LID measures are sized to mitigate to pre-development conditions for the project site, and they will actually be expected to reduce runoff when compared to the existing pre-project conditions.

Table 2 - Existing Drainage Area Soil Types

	Soil Group B (Acres)	Soil Group D (Acres)	Total Area (Acres)
Offsite DA 1	138	14	152
Offsite DA 2	50	7	57
Offsite DA 3	58	0	58
Onsite DA 1	14	7	21
Onsite DA 2	18	0	18

Photograph 7 - Northwest corner of the project site looking east toward existing residence.

5.0 Preliminary High School Project Site Plan

The proposed preliminary high school project site plan was provided by the site architect and was evaluated for pervious and impervious areas. This provided the basis for applying LID and stormwater control measures. Table 3 tabulates the proposed coverage types.

Table 3 - Proposed Site Plan Coverage Types

	Impervious (Acres)	Pervious (Acres)	Total Area (Acres)
Onsite DA 1	7.0	14.0	21
Onsite DA 2	10.4	7.6	18

6.0 Low Impact Development Features

LID design approach involves maximizing tree planting, minimizing impervious areas, using pervious pavement, directing runoff from impervious areas into vegetated areas and bioretention systems, directing runoff into infiltration basins, as well as implementing other systems. LID features that could be incorporated into the project site include:

1. Pervious pavement for sidewalks and student parking areas (more information is provided in Appendix C)
2. Depressed landscaping with underdrains near parking lots and other impervious surfaces
3. Self-retaining area including the football stadium
4. Vegetated swales for runoff treatment upstream from underground infiltration chambers under athletic fields, as well as to provide an overland release path
5. A surface infiltration/detention basin at the southwestern corner of the site
6. Shallow bioretention swale with underdrains to treat runoff into the drainage channel on the eastern boundary of the project site.

Exhibit 6 shows the project site divided into Drainage Management Areas (DMA) to evaluate runoff that are tributary to the various BMPs that are proposed to meet the requirements of the SWDS.

The Bay Area Hydrology Model (BAHM) was used with Salinas Hourly Rainfall data developed by RBF Consulting for the City of Salinas to size the BMPs. Pre-development and post-project conditions were input based on the land use and soil types described in this report and shown on the preliminary site plan. The LID features were sized to meet flow-duration criteria described in Section 1.5.3 of the SWDS.

Integrated Management Practices (IMPs), a subset of BMPs, proposed for Salinas UHSD High School #5 include direct and indirect infiltration systems listed as approved IMPs in Section 2.2.1 of the SWDS. Design standards for infiltration IMPs are listed in Table 4-3 of the SWDS. Though not appropriate for final design, RBF Consulting assumed an infiltration rate of 0.6 inches per hour, which is the lowest for Group B soils listed in Table 5-3 of the SWDS. An infiltration reduction factor of 0.9 was used to account for long-term degradation of the infiltration rate. Though this does indicate an infiltration rate for this planning level evaluation as being less than that indicated as a minimum in Table 4-3, final design will be based on dual ring infiltrometer infiltration rate testing. Underdrains and surface connections to an onsite drainage system will be provided as necessary to address surface standing water and geotechnical concerns. It is recommended that at least three dual ring infiltrometer tests be performed to provide a design basis for infiltration at the football field area, the student parking area, and the staff parking area.

7.0 Hydrologic Modeling with BAHM

7.1 Onsite DA 1

Onsite DA 1 was divided into four DMAs. One DMA is defined for each IMP. The BAHM report file for Onsite DA 1 is included in Appendix D.

Drainage Management Area 1 (DMA 1)

DMA 1 includes 3.6 acres of impervious area (basketball and tennis courts), 3.8 acres of pervious area in Soil Group B, and 4.3 acres of pervious area in Soil Group D. Collected runoff is proposed to drain to the area of the football field. A system under the football field will be designed to act as an infiltration basin with 18-inches of gravel below the 8-inches of top soil/turf section to retain and infiltrate runoff. Excess flow from DMA 1 due to large events will flow east from the football field towards the event parking on the eastern edge, and will ultimately be conveyed in the engineered channel to the south.

Drainage Management Area 2 (DMA 2)

DMA 2 includes 4.6 acres of pervious area in Soil Group B and 2.4 acres of pervious area in Soil Group D. Runoff from the softball and baseball fields will sheet flow to the south. The runoff will be collected in a vegetated bioswale on the southern edge of the DMA to treat and convey the water. The runoff collected in the bioswale will be discharged into the ditch along the eastern edge of the project site at Node 3. Because DMA 2 is all pervious in both the pre-development and proposed project conditions, and the swale will not be designed to provide retention, the changes to DMA 2 will not be hydrologically significant and were not modeled (though the area itself was included in the model).

Drainage Management Area 6 (DMA 6)

DMA 6 encompasses the student parking lot and surrounding landscaped areas. All 2.6 acres of its underlying soils are in Soil Group B. It is proposed to have the parking stalls be designed and constructed with a pervious paving section that will receive runoff from adjacent impervious drive aisles. There are 0.7 acres of pervious paving to receive runoff from 1.5 acres of impervious sidewalk and traditional paved areas. The islands will be landscaped and are counted as 0.3 acres of pervious area.

The preliminarily proposed pervious pavement section is 6-inch thick with an 18-inch gravel base for detention. The areas of pervious paving may need to include underdrains that would be detailed in the design stage of the project. DMA 6 is proposed to be connected to the infiltration area underneath the football field. Overland release will be directed toward the football field and onto the southeastern corner of the project site.

Drainage Management Area 7 (DMA 7)

Runoff from the event parking area is proposed to flow to the east and into a 6-foot bioretention swale into the ditch paralleling the parking area.

7.2 Onsite DA 2

The Onsite DA 2 was divided into three DMAs. One DMA is used for each IMP. The BAHM report file for Onsite DA 2 is included in Appendix E.

Drainage Management Area 3 (DMA 3)

DMA 3 includes 5.4 acres of impervious area and 6.5 acres of pervious area in Soil Group B. Runoff from the school buildings, basketball courts, and walk areas flow south and west towards the baseball fields. Bioswales on the southern property boundary collect and convey the runoff to a detention/infiltration pond on the southwest corner, behind the baseball field fence. The bioswales will treat the runoff and allow opportunities for infiltration.

The detention pond will be 1.5 feet deep and spread over approximately 0.4 acres. The pond will allow infiltration through the soil, and overflow will discharge into the ditch to the west and offsite.

The walkways in the quad area between the buildings may optionally be constructed using permeable materials to allow additional infiltration, if it is determined to be both necessary and feasible during the detailed design phase.

Drainage Management Area 4 (DMA 4)

DMA 4 includes 2.5 acres of impervious area and 0.4 acres of pervious area in Soil Group B. Roof drains from the school buildings are routed to flow onto permeable pavement in the staff parking area, covering 0.9 acres on the west side of the project site. The permeable pavement section is preliminarily proposed to be 6-inches thick with an 18-inch gravel base for storage. The permeable pavement area will allow infiltration. Overflow from the permeable pavement will flow into DMA 3 via a swale on the west side of the baseball field. The swale will discharge into the detention/infiltration pond on the southwest corner of the project site.

Drainage Management Area 5 (DMA 5)

DMA 5 includes 1.9 acres of impervious area and 0.4 acres of pervious area in Soil Group B. The parking area is proposed to drain to a bioretention area between the drop-off loop and Rogge Road. The proposed configuration includes a 2-inch diameter underdrain connecting the bioretention area in DMA 5 with the permeable pavement area in DMA 4.

8.0 Flow Duration Results

BAHM results are summarized in Appendices D and E and are presented graphically in Charts 1 and 2, below, demonstrating that the numeric criteria in the SWDS would be met by implementing the proposed system.

These charts show the percent of time that the indicated runoff flow rates are exceeded during the computer simulation of 30 years of hourly rainfall data. The percent of time that post-development flow rates are above each plotted value is less than that for pre-development conditions. Therefore, the proposed LID measures are adequate to meet the requirements of the SWDS. These plots are based on conditions at the southeastern (DA 1) and southwestern (DA 2) corners of the site.

Chart 1: Pre- and Post-Development Flow-Duration Curves for Onsite DA 1

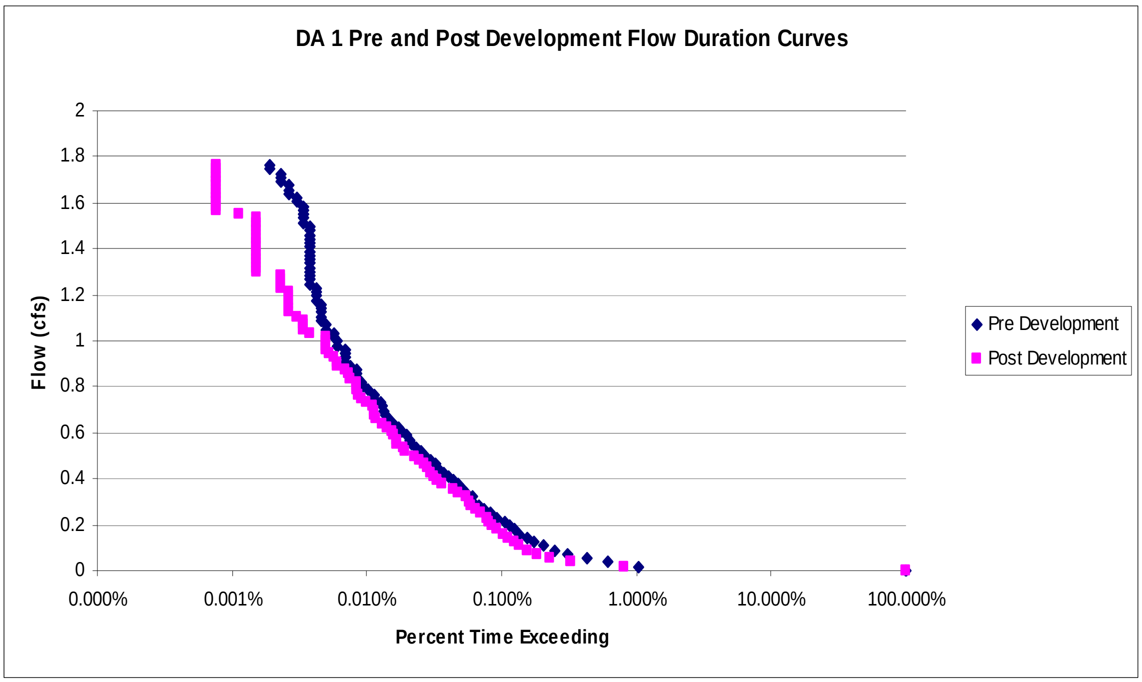
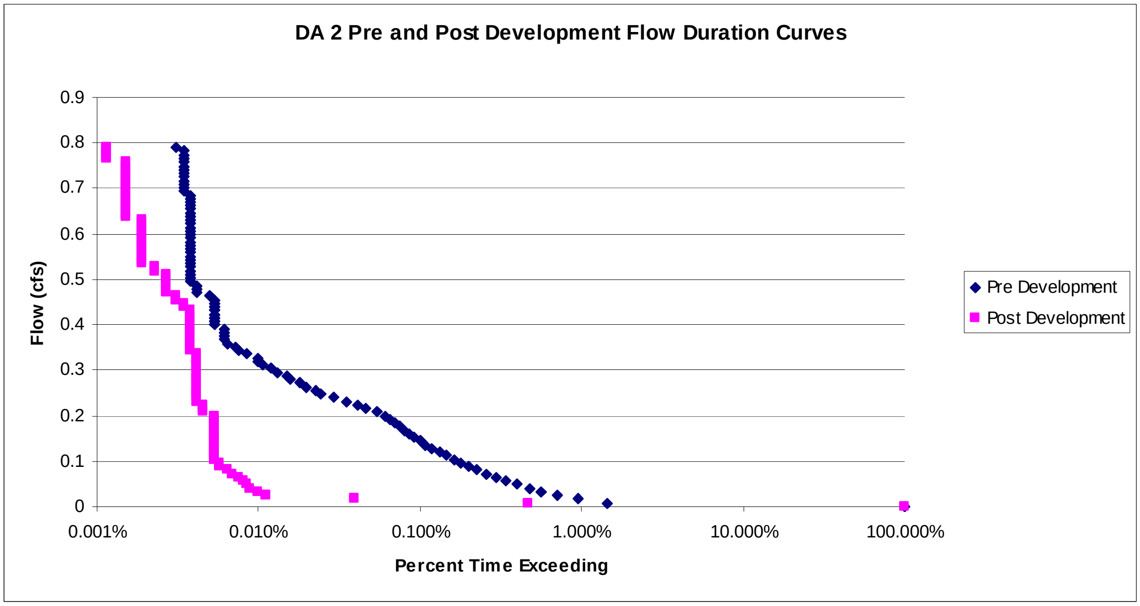


Chart 2: Pre- and Post-Development Flow-Duration Curves for Onsite DA 2



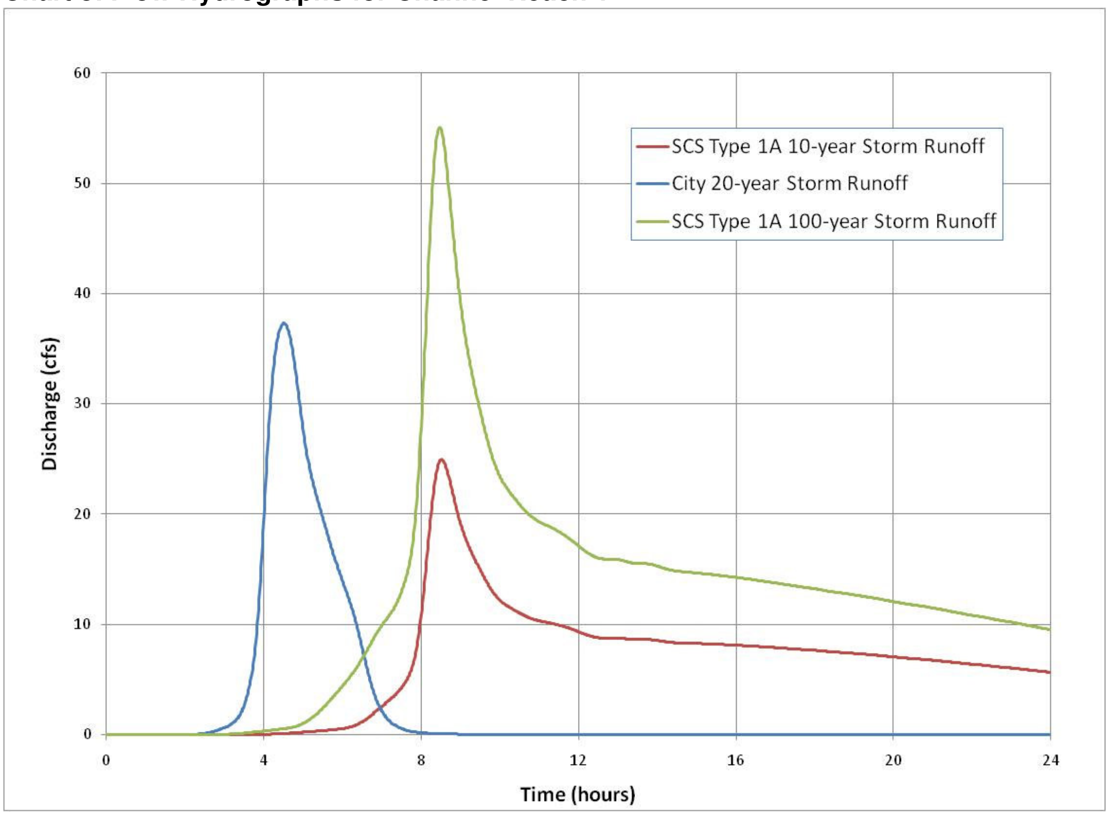
9.0 Channel along Eastern Edge of Project

The proposed project must not obstruct existing conveyance across the property. Therefore, the site plan must provide for a channel along the eastern side of the property where there is an existing ditch that conveys flows from Offsite DA 1 to the southeastern corner of the project site. The existing channel is an earthen ditch that experiences significant bank erosion and does not have adequate capacity to meet the City's design criteria for a manmade open channel. Currently, runoff from Offsite DA 2 combines with runoff from Offsite DA 1 at the southwestern corner of the site. However, it appears that it would be appropriate to modify a section of the ditch leading from Offsite DA 2 to connect straight into the channel that will be improved as part of the HS #5 site, approximately 250 north of the existing confluence. This section provides a basis for the channel top width used in the site plan.

Section 5.5.2 of the SWDS, Open Channel Criteria, states: "A 20-year design storm shall be used to demonstrate adequate freeboard for any manmade open channel (including swales used as part of the conventional storm drain system) incorporated into developments regardless of the tributary area (see Hydraulic Considerations, below)." Section 5.7 of the SWDS, Hydraulic Considerations, states: "Open channels (including swales used to meet conventional storm drainage requirements) shall be designed with a minimum of one (1) foot freeboard for peak design flow." Table 5-4, Roughness Coefficients, indicates that manmade open channels shall be design using a Manning's n-value of 0.03.

Hydrologic calculations for the flows tributary to the channel were computed using the computer program xpsmm with SCS methodology. Times of concentration were calculated using the procedures in the USDA's manual, ***Urban Hydrology for Small Watersheds*** (TR-55). The times of concentration for Offsite DAs 1 and 2 were calculated to be 42 and 44 minutes, respectively. Based on Table 2-2b of TR-55, considering the area to be straight row crops with poor cover, curve numbers of 81 and 91 were assigned for tributary areas of Type B and D soils, respectively. These values are used to determine the portion of rainfall that becomes runoff according to the SCS methodology formula. Runoff rates for the 10-, 20- and 100-year events were computed. The SCS Type 1A rainfall pattern was used with 24-hour precipitation depths of 2.5 and 3.7 inches for the 10- and 100-year storm events. The City's 20-year, 6-hour storm was used to compute the 20-year discharges. Chart 3 illustrates the resultant runoff hydrographs for the upstream portion of the channel along the eastern edge of the project site, channel Reach 1.

Chart 3: Flow Hydrographs for Channel Reach 1



Reach 1 of the proposed channel extends from Rogge Road to the confluence with runoff from Offsite DA 2. Reach 2 of the proposed channel extends from the confluence to the site boundary.

Table 4 lists the computed peak discharges in cubic feet per second (cfs) for the 20- and 100-year storm events.

Table 4: Computed Peak Discharges

Recurrence Interval (years)	Reach 1 (cfs)	Reach 2 (cfs)
20	38	51
100	56	76

The channel improvements are constrained in depth by the depth of the existing channel below surrounding grade at the southwestern corner of the site which would be the terminus of the proposed channel. The maximum channel depth was assumed to be 2.5 feet based on an estimate of the existing channel depth at the point where the proposed improvements would need to conform with existing conditions at the southwestern corner of the project. The slope of the channel was determined to be 0.0056 ft/ft. It was assumed that the channel would have a trapezoidal cross section with side slopes of 3H:1V. It was determined that bottom widths of 10 and 14 feet would be appropriate for Reaches 1 and 2, respectively. Based on these dimensions, the channel top widths would be 25 and 29 feet for Reaches 1 and 2, respectively. Table # lists calculated depth, freeboard and velocity for the both reaches of the channel, for n-values of 0.03 and 0.10. The n-value of 0.03 was used to demonstrate that the configuration would have more than one foot of freeboard in the 20-year event. Channel analysis indicates that the proposed configuration would contain the 100-year discharge even if vegetation causes the n-value to rise to 0.10. Channel velocities between three and four feet per second (fps) are reasonable and are expected to be non-erosive as long as moderate vegetation is established, or an appropriate turf reinforcement mat (TRM) is properly installed.

Though the proposed channel is large enough to permit significant vegetation while still providing adequate capacity, allowing too much vegetation in the ditch could cause flow velocities to be much lower than those under current conditions. Lowering the velocities somewhat would be advantageous because there are currently undesirable erosive conditions. However, if too much vegetation is allowed to develop, sediment delivered to the site from upstream may deposit in the channel which would reduce channel capacity. Therefore, it is recommended that vegetation be permitted in the channel and it should be mowed periodically to prevent the flow velocities from dropping too much.

Table 5 - Channel Depth, Freeboard and Velocity

		Reach 1		Reach 2	
n-value	Recurrence (years)	20	100	20	100
0.03	Depth (ft)	0.95	1.18	0.95	1.19
0.03	Freeboard (ft)	1.55	1.32	1.55	1.31
0.03	Velocity (fps)	3.10	3.50	3.19	3.64
0.10	Depth (ft)	1.83	2.24	1.86	2.31
0.10	Freeboard (ft)	0.67	0.26	0.64	0.19
0.10	Velocity (fps)	1.34	1.49	1.40	1.58

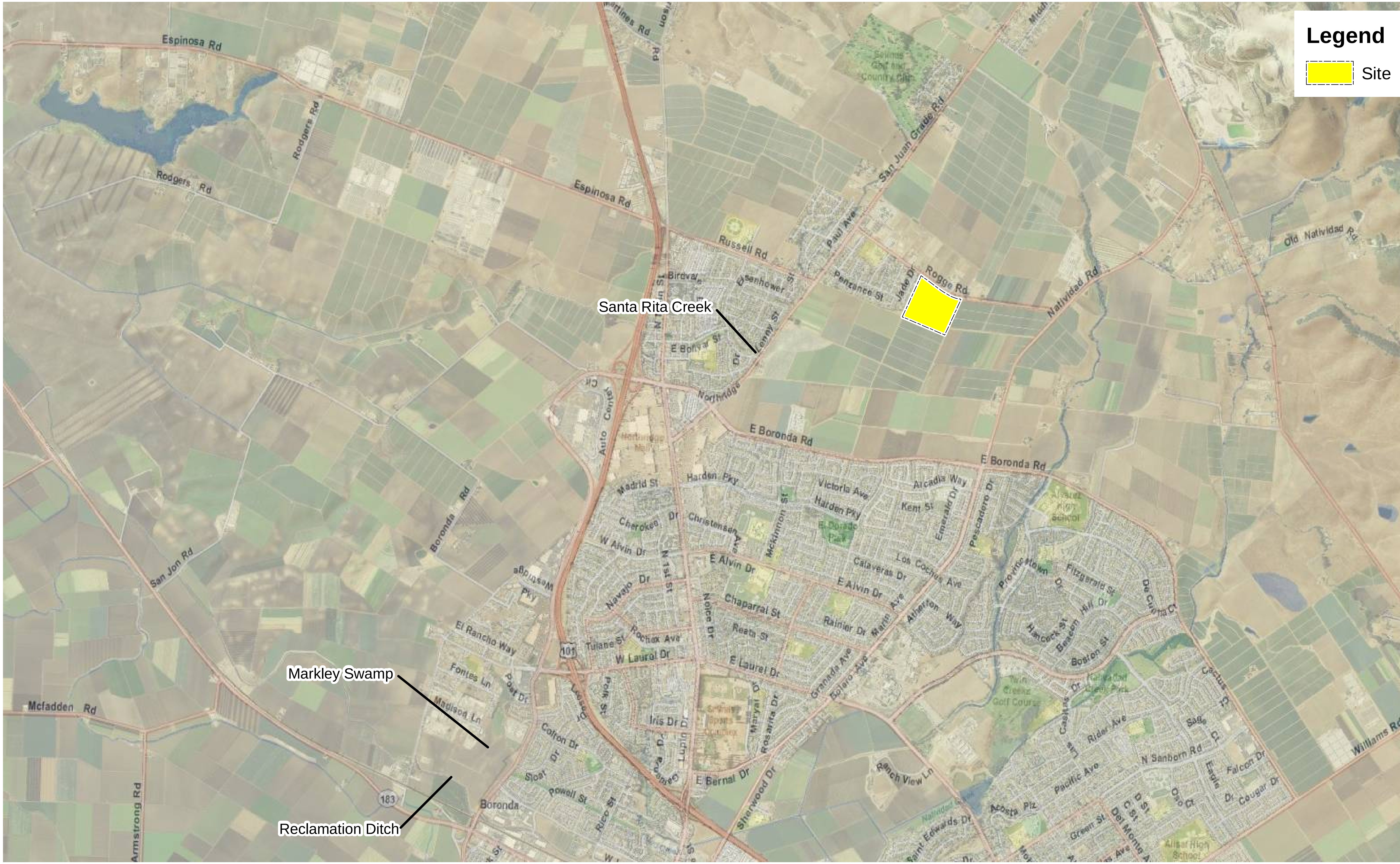
10.0 Conclusion

Through the use of pervious pavement, bioretention, an infiltration underdrain system under the football field, vegetated swales, and a shallow detention basin as described in this report, the proposed Salinas UHSD High School #5 can meet the numeric criteria in the SWDS. By meeting the design standards to match pre-development flow conditions, the proposed development will not significantly impact discharge rates into receiving waters. In fact, because the project mitigates to pre-development conditions, the proposed project is expected to reduce discharge rates from existing conditions. Therefore, no offsite drainage improvements should be required of the project.

The specific IMP configurations presented in this report were developed for planning purposes and not design. Infiltration rate test results and a detailed site grading plan will be required to perform design level analysis. Final design will integrate the IMP features with internal site drainage details.

This report also provides a basis of design for the channel that will need to be constructed along the eastern edge of the project site to accommodate flows from offsite. Final design of the channel will require detailed survey along the project edge to refine the grading to match edge conditions.

Exhibits



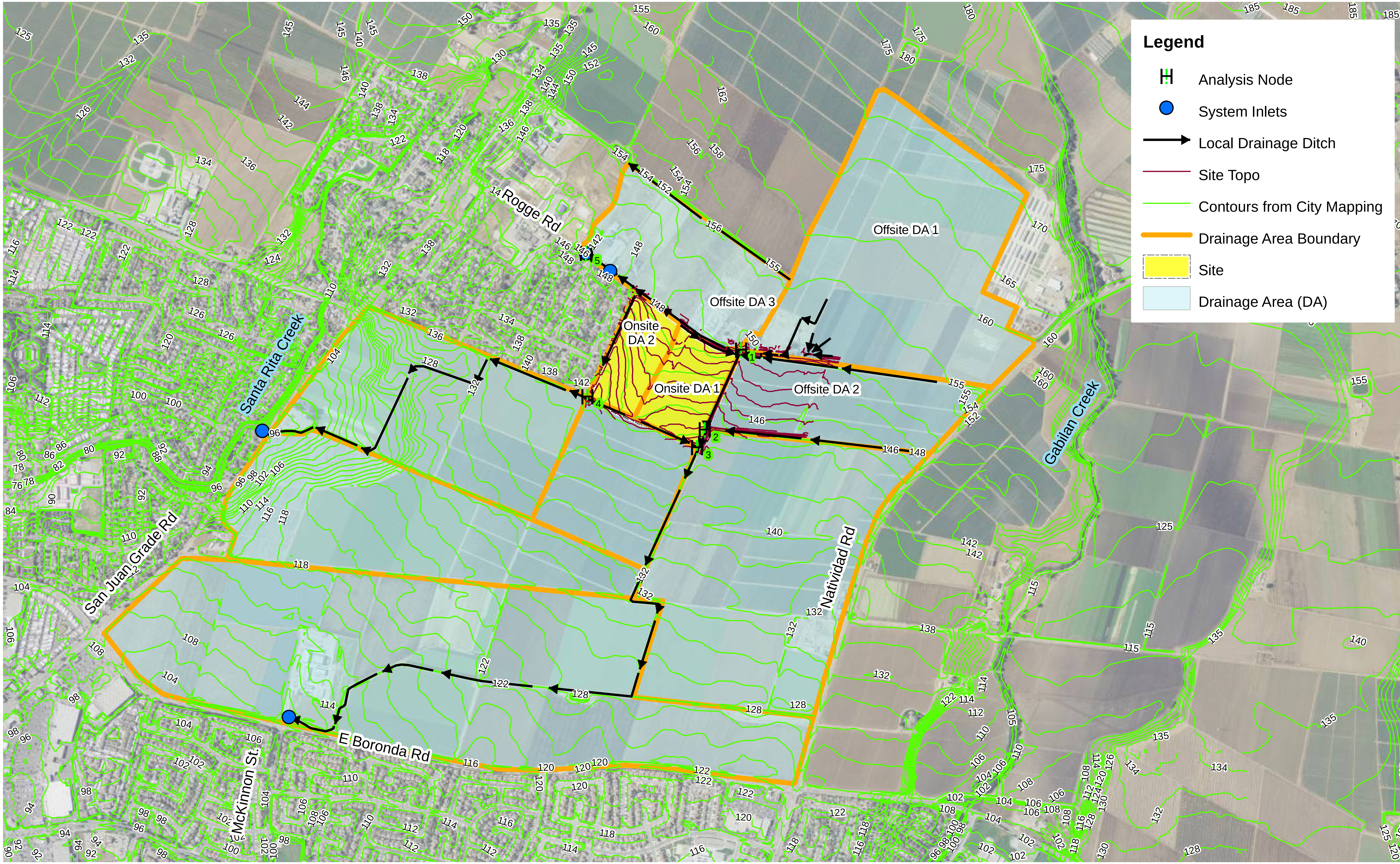
0 0.25 0.5 Miles
1" = 0.5 Miles

Salinas High School #5

Project Vicinity Map

Exhibit 1

2011/03/04 JN60-100766 M:\MDATA\60100766\Plots\0766-EX-001-VicinityMap.mxd P Shopbell
SOURCES: ESRI StreetMap World 2D, Department of Fish and Game



Salinas High School #5

Existing Drainage Areas and Flow Patterns

Exhibit 2

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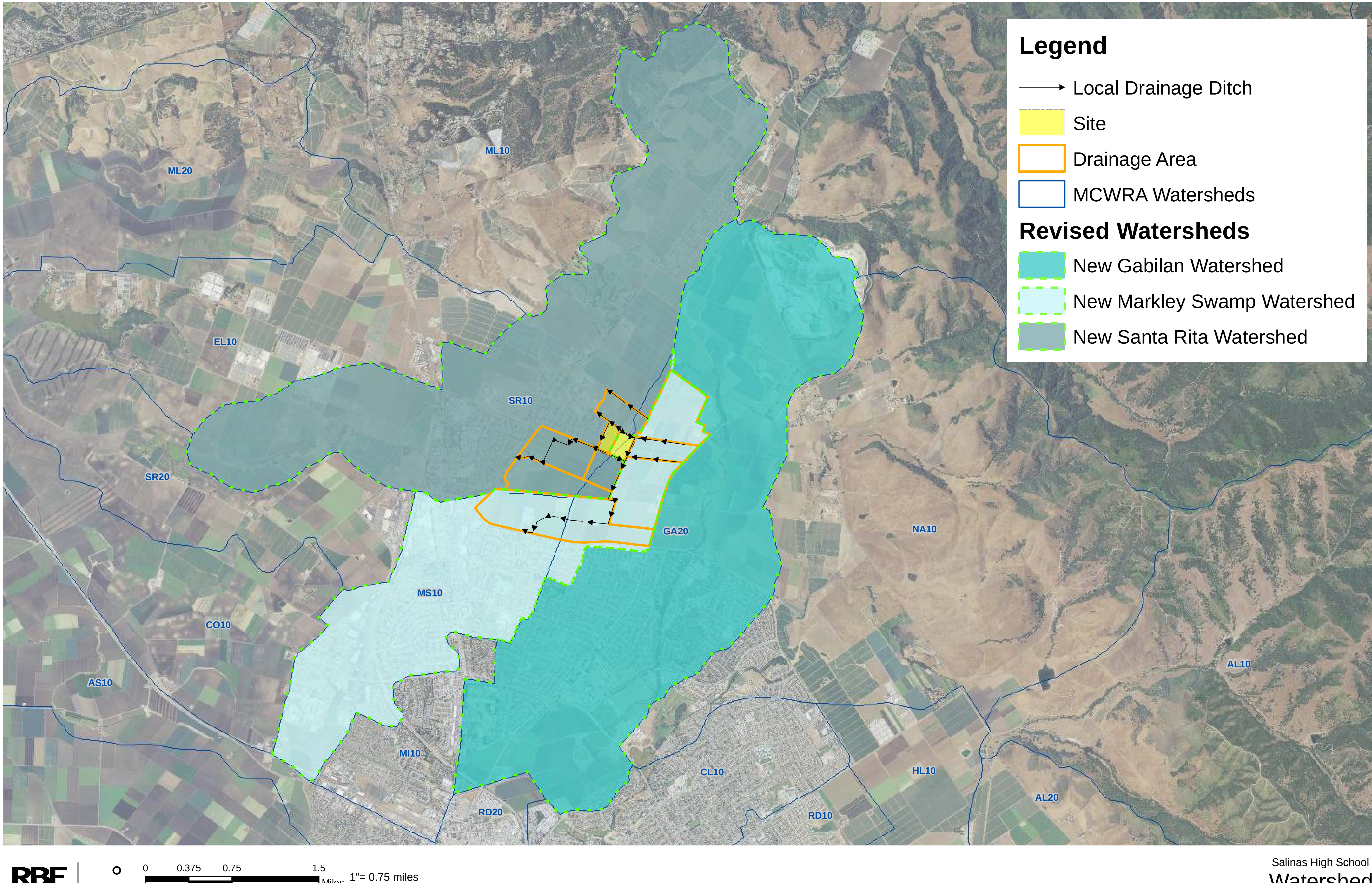
2011/01/03 JN60-100766 M:\MDATA\60100766\Plots\0766-EX-002-DrainageAreas.mxd P Shopbell

SOURCES: NAIP 2009 Imagery, City of Salinas



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Salinas High School #5

Watersheds

Exhibit 3

2011/03/04 JN60-100766 M:\MDATA\60100766\Plots\JN0766_EX_003_Watersheds.mxd L Simmons

SOURCES: NAIP 2009 Imagery, City of Salinas

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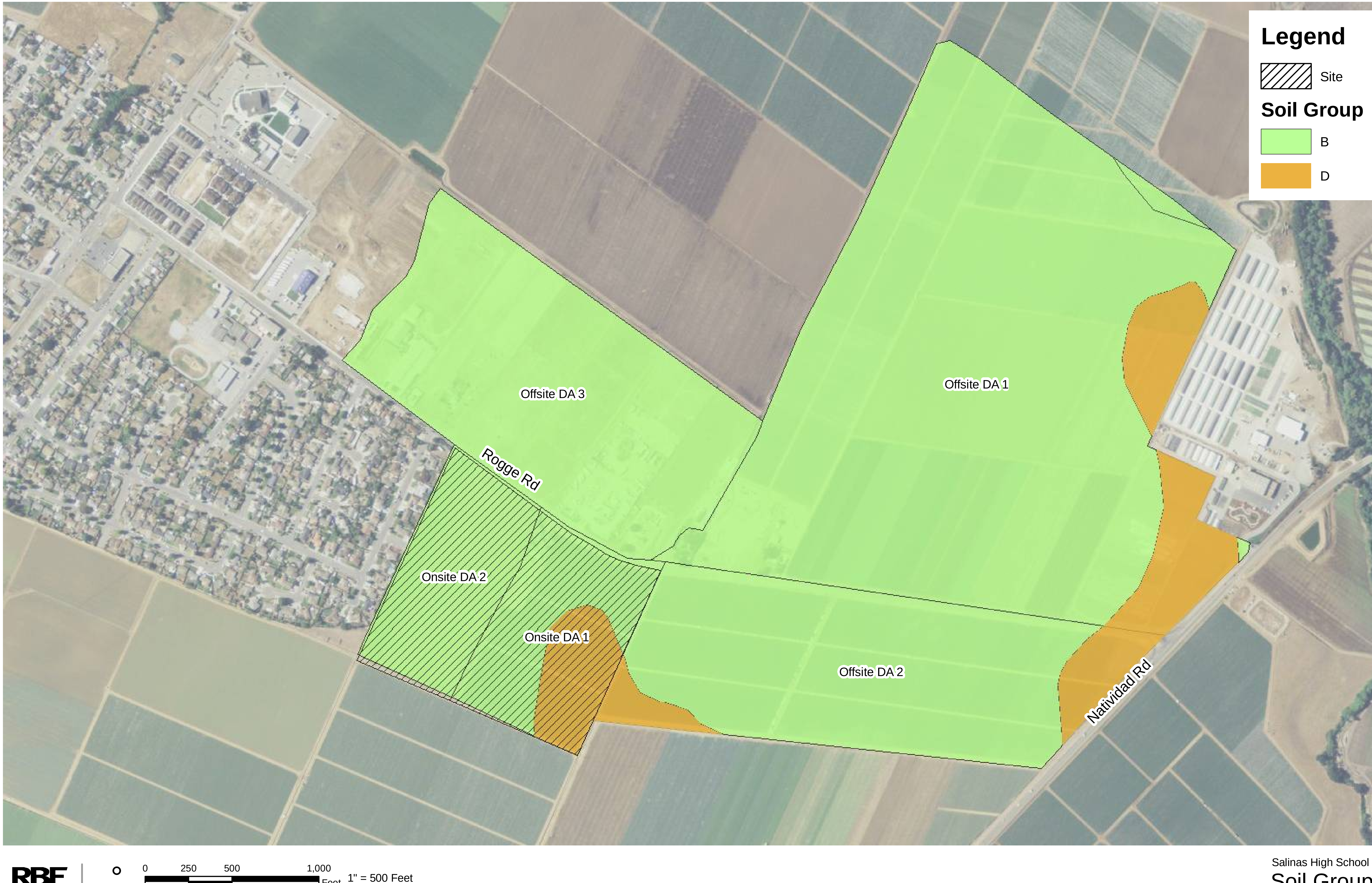
0 250 500 1,000 Feet 1" = 500 Feet

2011/01/03 JN60-100766 0766-EX-003-PhotoLocation.mxd P Shopbell
SOURCES: NAIP 2009 Imagery, Site Photos

Salinas High School #5

Photograph Locations

Exhibit 4



RBF CONSULTING

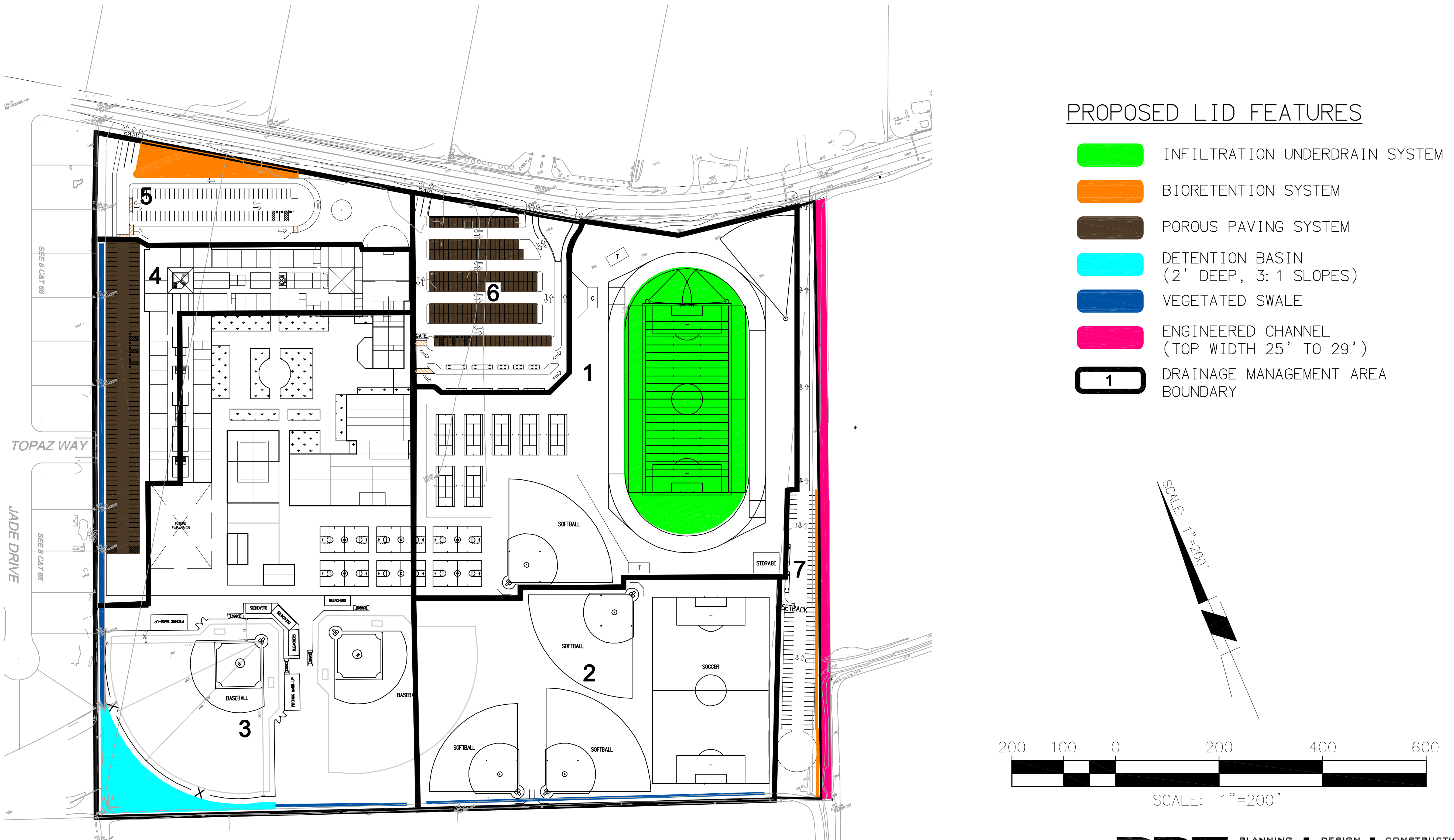
2011/01/03 JN60-100766 0766-EX-003-SoilType.mxd P Shopbell
SOURCE: US Department of Agriculture, Natural Resources Conservation Service , NAIP 2009 Imagery

Salinas High School #5

Soil Groups

Exhibit 5

EXHIBIT 6
SALINAS UNION HIGH SCHOOL DISTRICT HIGH SCHOOL #5
PRELIMINARY LOW IMPACT DEVELOPMENT FEATURES



H:\PDATA\60100766\CADD\STRMWATER\EXHIBITS\0766-EX-006-LID.DWG PSHOPBELL 3/7/11 10:56 am

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SACRAMENTO, CALIFORNIA 95834-2597
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Appendices

Appendix A

RBF CONSULTING

June 1, 2001 JN 60-100253

Mr. Carl Niizawa, P.E. DEE
Deputy City Engineer
City of Salinas
200 Lincoln Street
Salinas, CA 93901

Subject: Hourly Precipitation Records and SWDS Compliance

Dear Mr. Niizawa,

The purpose of this letter report is to document the methods used to prepare an hourly rainfall data set for the City of Salinas. This report also describes how this data may be used to perform long duration simulations for runoff flow-duration analyses. This report does not address the susceptibility of streams to hydromodification which may need to be determined to decide if flow duration controls should be applied at a particular location.

The purpose of the hourly rainfall data set is to provide a common basis for performing long duration hydrologic simulations including those required to comply with the numeric criteria in the City's Stormwater Development Standards (SWDS). In general, long duration simulations, such as those that would be performed with the 30-year data set, are used to evaluate changes in hydrologic conditions that could negatively impact erosion and sedimentation conditions. An additional hypothetical 100-year recurrence interval rainfall year was developed that could be used to evaluate the ability of proposed hydromodification management and additional measures to mitigate for potential impacts on 100-year flood conditions along the Reclamation Ditch.

The relevant criterion in the SWDS states:
"Demonstrate post-project runoff peaks and durations do not exceed pre-development runoff peaks and durations for storm events up to and including the 10 year 24-hour event with a continuous simulation computer model of runoff in the pre-project and post-project condition using 30 years or more of local hourly rainfall data, or…"

(The optional criterion to conduct an assessment incorporating sediment transport modeling is not discussed in this letter.)

The data that is the subject of, and transmitted with, this report provides a 30 year series of hourly rainfall data directly taken or synthesized from available gage data. A review and statistical analysis of the rainfall records indicates that the storm on February 22-23, 2001 can be considered to be a 10 year 24-hour event. Twenty-four hour events in February 1987 and January 2000 were more severe than the 10 year 24-hour event. Though the February 1998 data did not indicate any 24-hour period exceeding the 10 year storm depth, longer durations include depths that significantly exceed 10 year depths. Therefore, the upper threshold of required compliance with the SWDS can be assigned as the peak discharge indicated by the simulation of pre-project conditions on February 22, 2001 of the long duration simulation.

In addition to the high flow threshold, practical application of hydromodification management requires establishment of a low flow threshold below which post-project conditions would be allowed to release for durations longer than occur under pre-project conditions. The criterion in the SWDS that uses the terminology of "up to and including the 10 year 24-hour event" does establish the low flow threshold. Without such a threshold, hydromodification becomes infeasible, except for areas with ample infiltration potential. The establishment of a low flow threshold may be the most significant factor controlling the volume of detention required for mitigation.

The Santa Clara Valley Urban Runoff Pollution Protection Program applies a low flow threshold of 10 percent of the 2-year discharge, below which discharge durations are allowed to be increased. However, this low flow threshold criterion may be inequitable under certain reasonable circumstances, and is not directly linked to the controlling critical discharge in the receiving waters from a sediment transport perspective. An alternative approach to a site-by-site discharge calculation to determine a low flow threshold would be to assign a low flow discharge threshold on a per unit acre basis, dependent on the infiltration potential of the site.

A possible set of low flow thresholds that could be applied are presented in Table 1:

Table 1: Low Flow Thresholds

Hydrologic Soil Group	Discharge (cfs/acre)
A	0.000
B	0.001
C	0.006
D	0.013

These values were tested for practicality and unit storage volumes in the range of 0.17 to 0.19 acre-feet per impervious acre were determined. This range is consistent with typical volumes determined using Contra Costa County and Santa Clara Valley Hydromodification Management Plan procedures, but should provide a more consistent and equitable approach while providing an appropriate degree of stream protection. The indicated volumes are based on some percolation being included. Specifically, it was assumed that one-half of the minimum infiltration rate for the soil group (see Table 3-4 of the City of Salinas Storm Water Master Plan, dated May 2004) could be achieved over 10 percent of the site. Specifically, percolation rates of 1, 0.3, 0.1 and 0.03 inches per hour were assumed to be feasible for soil groups A, B, C and D, respectively. Expected percolation should be considered in the facility design process and can significantly impact volume requirements.

Available Precipitation Data

A review of available local hourly rainfall records concluded that no single continuous record set was available. Table 2 summarizes hourly rainfall data sets that were investigated as part of this process. Within the periods of records, each gage is missing significant amounts of information, and in some cases contained erroneous data, which required review, synthesis and adjustment.

Table 2: Hourly Rainfall Data Sets

Gage Name	Latitude	Longitude	Elevation (feet)	Begin (year)	End (year)	Source
Salina AP	36° 39' 49"	121° 36' 29"	74	2001	2006	NCDC
Salinas South	36° 36' 36"	121° 31' 46"	120	1993	2008	CIMIS
Salinas North	36° 43' 00"	121° 41' 27"	61	1993	2008	CIMIS
USDA Salinas	36° 37' 14"	121° 32' 43"	120	1983	1992	CIMIS
Del Monte	36° 36' 00"	121° 52' 00"	45	1948	2005	NCDC

In addition to the above listed gages, there was a Monterey County Water Resources Agency gage at the Salinas Golf & Country Club that recorded hourly rainfall from at least 1971 through 1981 and had at least a 29 year record of either hourly or daily data. However, this data is not available from MCWRA. Mr. James Goodridge (former state climatologist), the Desert Research Institute and Santa Clara Valley Water District were all contacted in unsuccessful attempts to obtain the missing data.

Also, summary data from the CA Climate CD developed by Mr. James Goodridge (former state climatologist) was also obtained. The data is a summary of the maximum rainfall by duration (from 1-60 days) and includes total water year rainfall depths. However, the data does not include a breakdown of daily or monthly totals. Based on a review of the totals depths included on the CA Climate CD and the total depths indicated by this study, there were at least four years when the totals on the CA Climate CD appear to be missing significant information.

The process of synthesizing a continuous, consistent rainfall data set involves using what appears to be the most reasonable data for each period and normalizing the data to be consistent with the daily rainfall record at the location of interest.

A 30-year continuous rainfall data set from October 1978-September 2008 was synthesized from four primary hourly datasets as show in Table 3.

Table 3: Hourly data sets used to create 30-year continuous rainfall data set

Gage Name	Range
Del Monte	1978-1983
USDA Salinas	1983-1992
Salinas South	1993-2001
Salinas AP	2001-2006
Salinas South	2007-2008

When values were missing from the indicated rainfall record, hourly rainfall depths were duplicated from the most appropriate gage where data was available. Most values were normalized and made consistent with daily rainfall values recorded at the Salinas Airport. When daily rainfall depths were not available from the Salinas Airport, the hourly values were adjusted using normalization values consistent with the other adjustments used for the data set, ranging from 0.9 to 1.1 depending on the original source of the data.

A comparison of the total water year depths for the synthesized hourly rainfall set, the CA Climate CD, and the Salinas Daily rainfall set are shown in Table 4. The rainfall depths with gray cells are known to be missing values that are found in the hourly data set.

Table 4: Summary of water year rainfall depths.

	Synthesized Hourly Rainfall Depth (in)	CA Climate CD Rainfall Depth (in)	Salinas Daily Rainfall Depth (in)
1979	10.62	10.62	10.62
1980	12.33	12.33	12.33
1981	9.39	6.39	6.39
1982	18.86	18.86	18.86
1983	22.84	22.84	22.84
1984	8.00	7.96	8.00
1985	8.98	8.98	8.98
1986	11.24	11.24	11.24
1987	8.82	8.82	8.82
1988	6.73	6.56	6.73
1989	8.96	8.96	8.96
1990	8.16	8.01	8.16
1991	10.06	10.06	10.06
1992	11.55	11.55	11.55
1993	16.23	16.23	16.23
1994	9.28	9.28	9.28
1995	21.27	20.87	20.87
1996	18.14	13.71	0.00
1997	20.94	17.75	0.00
1998	31.22	34.74	20.40
1999	12.69	14.15	12.33
2000	14.01	7.96	7.96
2001	19.81	13.48	16.09
2002	3.59	3.59	3.59
2003	7.11	7.11	7.11
2004	9.30	9.99	8.91
2005	19.42	NA	NA
2006	15.34	NA	NA
2007	6.77	NA	NA
2008	5.76	NA	NA

Because of the missing values, not all water years match the CA Climate CD data or the Salinas daily data. The total water year depths of the hourly synthesized data match the Salinas Daily totals where available and determined to be complete; however, the rainfall depths from the CA Climate CD are equal to or exceeded by the synthesized hourly depths in each water year except for 1998. Four months are missing from the Salinas Daily rainfall for 1998 which account for approximately 11 inches of rain in the hourly data set. To match the CA Climate CD total of 34.74, the 11 inches would need to be increased by about 25%, which seemed to be inappropriately high for adjustment of hourly data. The hourly data set for 1998 was not adjusted to match the CA Climate CD total. The hourly data set is in the file: Salinas_Hourly_Syn-base 30yr.xls.

The mean annual precipitation for the Salinas Airport gage is 13.40 inches according to the CA Climate CD but only 12.91 inches according to the synthesized hourly values. The rainfall dataset should be adjusted proportionally for locations in the City based away from the airport based on a ratio determined from mean annual precipitation mapping such as that available from SCVWD.

Evaporation Data

An average hourly evaporation value data set was created for the same period of record as the precipitation values to be able to perform long duration simulation, because evaporation data is required in the Bay Area Hydrology Model (BAHM) and may be used in SWMM. Daily evaporation values were available from the Salinas South CIMIS gage for 1992-2008. Monthly average evaporation values were calculated from the available data set. The daily and hourly averages were calculated from the monthly averages and are listed in Table 5.

Table 5: Average evaporation values from the Salinas South gage for a 1992-2008.

	Hourly Average (in)	Daily Average (in)	Monthly Average (in)
January	0.0021	0.0498	1.5433
February	0.0029	0.0700	1.9788
March	0.0048	0.1154	3.5775
April	0.0066	0.1580	4.8993
May	0.0077	0.1840	5.7031
June	0.0090	0.2159	6.6915
July	0.0085	0.2037	6.3144
August	0.0078	0.1872	5.8038
September	0.0064	0.1538	4.7667
October	0.0048	0.1141	3.5365
November	0.0028	0.0670	2.0757
December	0.0066	0.1580	4.8993

A 30-year continuous hourly evaporation data set was created using the average hourly values by month.

Hypothetical 100-Year Rainfall Data

A water-year's worth of hypothetical hourly rainfall data was developed for use as a basis for evaluating a systems ability to mitigate for the potential impacts of increased runoff volume flooding on the Reclamation Ditch. This data set was developed to be consistent with the daily rainfall statistics at the Salinas Airport rain gage from the CA Climate CD and the 100-year 3-day rainfall pattern used for the Zone 9 Operations Study, dated May 1999.

The data set matches the following 100-year depths according to the values in Table 6:

Table 6: 100-year rainfall depths used to create hypothetical rainfall data.

Duration (days)	Depth (inches)
1	3.10
2	4.39
3	5.07
4	5.37
5	5.85
6	6.06
8	6.73
10	7.27
15	8.40
20	9.23
30	10.97
60	16.41

Data Uses

Several methods exist for performing long duration hydrologic simulation and evaluating the effects of hydromodification mitigation measures. These include the EPA models HSPF and SWMM. The BAHM was developed by Santa Clara, San Mateo, and Alameda counties using the HSPF model to standardize long-duration simulation and to size hydromodification mitigation measures. The BAHM model can efficiently model numerous conditions, however, it has some limitations. The SWMM model, or any of a number of proprietary packages that use the SWMM engine with enhanced user interfaces, may be used in any situation, including those that require analysis of complex hydraulic systems and systems where tailwater conditions limit discharges.

The enclosed CD includes data sets formatted for use in BAHM and an Excel worksheet with the data in a format that can be pasted into a SWMM model, and would be readily adaptable to any other program.

Using the Data with BAHM

BAHM allows importing alternative precipitation and evaporation data sets to be used in calculations. The 30-year continuous rainfall and evaporation synthesized data sets for the Salinas Airport may be imported into BAHM and used to size hydromodification mitigation measures such as detention basins and bioretention swales.

The accompanying CD contains salinas.wdm which contains the 4 data sets described previously for use in BAHM: 30-year precipitation and evaporation and hypothetical 100-year precipitation and evaporation. To import Salinas rainfall and evaporation into BAHM, the following steps should be taken:

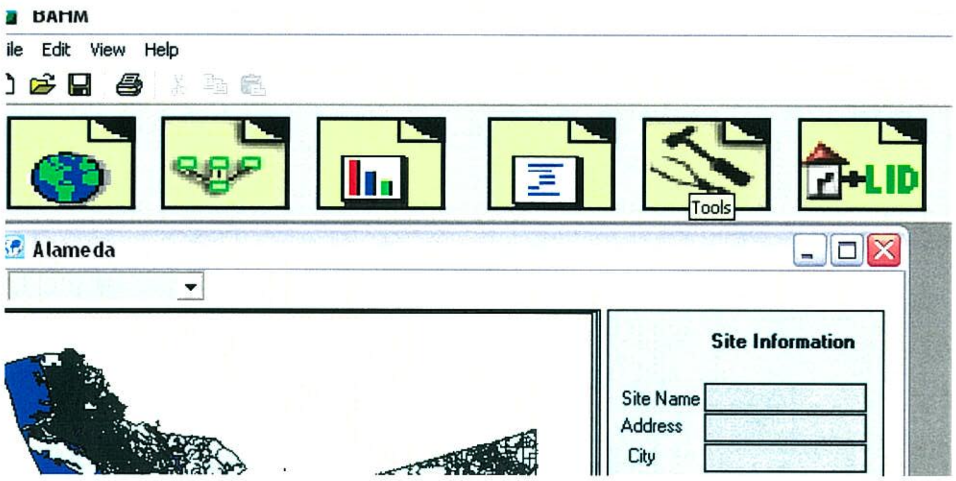
1. Copy the accompanying WDM to your local hard drive.

2. Download the Bay Area Hydrology Model and User Manual from:
http://www.bayareahydrologymodel.org/downloads.html

3. Install the program

4. After installation, open BAHM

5. After opening BAHM, a map will be shown. This is the window to select the location of a project so that BAHM will select and appropriate rain gage and adjustment factor. *Do not* select a location on this map. Instead, click on the tools icon (2nd from the right).



6. Select "ALTERNATE PRECIP"

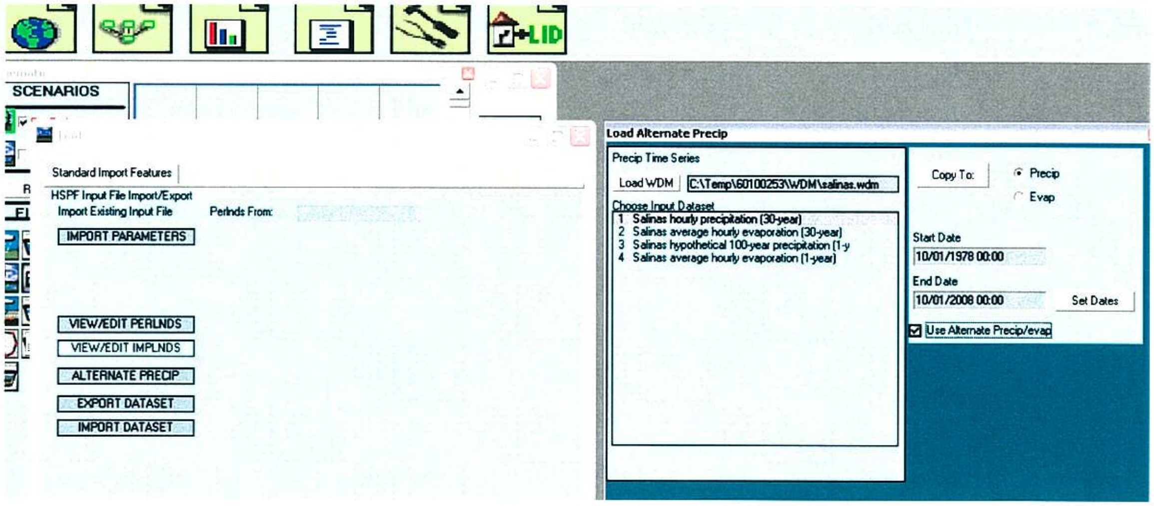
7. Select "Load WDM"

8. Locate the WDM in the explorer and select open.

9. Select the desired precipitation data set from the listed Input Datasets

10. Check the "Use Alternate Precip/evap" checkbox.

11. Select the "Precip" box



12. Modify the "Start Date" from "00:00" to "01:00."

13. Click "Copy To:"

14. Select the desired evaporation data set and change start date

15. Make sure that the "Use Alternate Precip/evap" checkbox is checked.

16. Select the "Evap" box

17. Click "Copy To:"

18. Close the Load Alternate Precip and Tools windows.

19. Save the project.

20. Follow instructions in the BAHM User Manual to create pre-project and mitigated scenarios and view the results. The high and low flow criteria thresholds can be modified by clicking "Options" under the "View" pull down menu. (The high flow threshold can be set by reviewing the pre-project condition hydrology results and entering the peak discharge from February 22, 2001.)

An example simple BAHM project has also been included on the enclosed CD. If you have any questions or comments regarding this data, please call me at (916) 928-5170.

Sincerely,

Harvey R. Oslick, P.E., CFM, CPSWQ
Senior Associate

REGISTERED PROFESSIONAL ENGINEER
HARVEY R. OSLICK
No. C54466
Exp 12/31/09
CIVIL
STATE OF CALIFORNIA

Appendix B


121° 37' 57''
121° 37' 31''
36° 43' 57''
36° 43' 56''
622100
622200
622300
622400
622500
622600
622700
4066000
4065900
4065800
4065700
4065600
4065500
4065400
4065300
Jasper Way
Opal Ct
Rogge Rd
Jade Dr
Topaz Way
Penzance St
Jade Cir
CbA
PnA
36° 43' 28''
36° 43' 28''
121° 37' 58''
121° 37' 32''
Map Scale: 1:4,140 if printed on A size (8.5" x 11") sheet.
N
Meters
0 35 70 140 210
Feet
0 150 300 600 900

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Units

Soil Ratings

A

A/D

B

B/D

C

C/D

D

Not rated or not available

Political Features

Cities

Water Features

Oceans

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

MAP INFORMATION

Map Scale: 1:4,140 if printed on A size (8.5" × 11") sheet.

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for accurate map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 10N NAD83

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Monterey County, California
Survey Area Data: Version 9, Apr 14, 2009

Date(s) aerial images were photographed: 6/13/2005

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Hydrologic Soil Group

Hydrologic Soil Group— Summary by Map Unit — Monterey County, California				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
CbA	Chualar loam, 0 to 2 percent slopes	B	31.9	82.5%
PnA	Placentia sandy loam, 0 to 2 percent slopes	D	6.8	17.5%
Totals for Area of Interest			**38.6**	**100.0%**

Description

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Rating Options

Aggregation Method: Dominant Condition

Component Percent Cutoff: *None Specified*

Tie-break Rule: Lower

Appendix C

Bay Area Hydrology Model
PROJECT REPORT

Project Name: DA1
Site Address:
City :
Report Date : 3/3/2011
Gage :
Data Start : 1978/10/01 00:00
Data End : 2008/09/30
Precip Scale: 0.80
BAHM Version:

PREDEVELOPED LAND USE

Name : DMA6
Bypass: No

GroundWater: No

Pervious Land Use	Acres
B,Grass,Flat(0-5%)	**.3**

Impervious Land Use	Acres
Roads,Flat(0-5%)	**1.5**

Element Flows To:

Surface	Interflow	Groundwater
Gravel Trench Bed 2,	Gravel Trench Bed 2,	

Name : Gravel Trench Bed 2
Bottom Length: 170ft.
Bottom Width : 180ft.
Trench bottom slope 1: 0.005 To 1
Trench Left side slope 0: 0.5 To 1
Trench right side slope 2: 0.5 To 1
Material thickness of first layer : 0.5
Pour Space of material for first layer : 0.25
Material thickness of second layer : 1.5
Pour Space of material for second layer : 0.25
Material thickness of third layer : 0
Pour Space of material for third layer : 0
Infiltration On
Infiltration rate : 0.6
Infiltration saftey factor : 0.9
Discharge Structure
Riser Height: 0.5 ft.
Riser Diameter: 12 in.

Element Flows To:

Outlet 1 **Outlet 2**

Gravel Trench Bed Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.000	0.702	0.000	0.000	0.000
0.022	0.703	0.004	0.000	0.383
0.044	0.703	0.008	0.000	0.383
0.067	0.703	0.012	0.000	0.383
0.089	0.703	0.016	0.000	0.383
0.111	0.703	0.020	0.000	0.383
0.133	0.703	0.023	0.000	0.383
0.156	0.703	0.027	0.000	0.383
0.178	0.703	0.031	0.000	0.383
0.200	0.703	0.035	0.000	0.383
0.222	0.703	0.039	0.000	0.383
0.244	0.703	0.043	0.000	0.383
0.267	0.704	0.047	0.000	0.383
0.289	0.704	0.051	0.000	0.383
0.311	0.704	0.055	0.000	0.383
0.333	0.704	0.059	0.000	0.383
0.356	0.704	0.063	0.000	0.383
0.378	0.704	0.066	0.000	0.383
0.400	0.704	0.070	0.000	0.383
0.422	0.704	0.074	0.000	0.383
0.444	0.704	0.078	0.000	0.383
0.467	0.704	0.082	0.000	0.383
0.489	0.704	0.086	0.000	0.383
0.511	0.704	0.090	0.011	0.383
0.533	0.705	0.094	0.059	0.383
0.556	0.705	0.098	0.128	0.383
0.578	0.705	0.102	0.211	0.383
0.600	0.705	0.106	0.308	0.383
0.622	0.705	0.109	0.416	0.383
0.644	0.705	0.113	0.535	0.383
0.667	0.705	0.117	0.663	0.383
0.689	0.705	0.121	0.800	0.383
0.711	0.705	0.125	0.945	0.383
0.733	0.705	0.129	1.098	0.383
0.756	0.705	0.133	1.258	0.383
0.778	0.706	0.137	1.426	0.383
0.800	0.706	0.141	1.600	0.383
0.822	0.706	0.145	1.781	0.383
0.844	0.706	0.149	1.969	0.383
0.867	0.706	0.153	2.162	0.383
0.889	0.706	0.156	2.362	0.383
0.911	0.706	0.160	2.567	0.383
0.933	0.706	0.164	2.778	0.383
0.956	0.706	0.168	2.995	0.383
0.978	0.706	0.172	3.216	0.383
1.000	0.706	0.176	3.443	0.383
1.022	0.707	0.180	3.675	0.383
1.044	0.707	0.184	3.912	0.383
1.067	0.707	0.188	4.154	0.383
1.089	0.707	0.192	4.401	0.383

1.111	0.707	0.196	4.653	0.383
1.133	0.707	0.200	4.909	0.383
1.156	0.707	0.204	5.169	0.383
1.178	0.707	0.208	5.434	0.383
1.200	0.707	0.211	5.704	0.383
1.222	0.707	0.215	5.978	0.383
1.244	0.707	0.219	6.256	0.383
1.267	0.707	0.223	6.538	0.383
1.289	0.708	0.227	6.824	0.383
1.311	0.708	0.231	7.114	0.383
1.333	0.708	0.235	7.409	0.383
1.356	0.708	0.239	7.707	0.383
1.378	0.708	0.243	8.009	0.383
1.400	0.708	0.247	8.315	0.383
1.422	0.708	0.251	8.625	0.383
1.444	0.708	0.255	8.939	0.383
1.467	0.708	0.259	9.256	0.383
1.489	0.708	0.263	9.577	0.383
1.511	0.708	0.267	9.902	0.383
1.533	0.709	0.270	10.23	0.383
1.556	0.709	0.274	10.56	0.383
1.578	0.709	0.278	10.90	0.383
1.600	0.709	0.282	11.24	0.383
1.622	0.709	0.286	11.58	0.383
1.644	0.709	0.290	11.92	0.383
1.667	0.709	0.294	12.27	0.383
1.689	0.709	0.298	12.62	0.383
1.711	0.709	0.302	12.98	0.383
1.733	0.709	0.306	13.34	0.383
1.756	0.709	0.310	13.70	0.383
1.778	0.709	0.314	14.07	0.383
1.800	0.710	0.318	14.44	0.383
1.822	0.710	0.322	14.81	0.383
1.844	0.710	0.326	15.18	0.383
1.867	0.710	0.330	15.56	0.383
1.889	0.710	0.333	15.94	0.383
1.911	0.710	0.337	16.33	0.383
1.933	0.710	0.341	16.71	0.383
1.956	0.710	0.345	17.10	0.383
1.978	0.710	0.349	17.50	0.383
2.000	0.710	0.353	17.89	0.383

Name : DMA1
Bypass: No

GroundWater: No

Pervious Land Use	Acres
B,Grass,Flat(0-5%)	**4.6**
C D,Shrub,Flat(0-5%)	**.8**

Impervious Land Use	Acres
Roads,Flat(0-5%)	**2.4**

Element Flows To:

Surface	**Interflow**	**Groundwater**
Gravel Trench Bed 1,	Gravel Trench Bed 1,	

Name : Gravel Trench Bed 1
Bottom Length: 400ft.
Bottom Width : 200ft.
Trench bottom slope 1: 0.005 To 1
Trench Left side slope 0: 0 To 1
Trench right side slope 2: 0 To 1
Material thickness of first layer : 0.67
Pour Space of material for first layer : 0.4
Material thickness of second layer : 1.5
Pour Space of material for second layer : 0.25
Material thickness of third layer : 0
Pour Space of material for third layer : 0
Infiltration On
Infiltration rate : 0.6
Infiltration saftey factor : 0.9
<u>Discharge Structure</u>
Riser Height: 1 ft.
Riser Diameter: 6 in.
Orifice 1 Diameter: 1.5 in. **Elevation:** 0.1 ft.

Element Flows To:

Outlet 1	**Outlet 2**

Gravel Trench Bed Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.000	1.837	0.000	0.000	0.000
0.041	1.837	0.030	0.000	1.000
0.082	1.837	0.060	0.000	1.000
0.123	1.837	0.091	0.009	1.000
0.164	1.837	0.121	0.015	1.000
0.206	1.837	0.151	0.019	1.000
0.247	1.837	0.181	0.023	1.000
0.288	1.837	0.211	0.026	1.000
0.329	1.837	0.242	0.028	1.000
0.370	1.837	0.272	0.031	1.000
0.411	1.837	0.302	0.033	1.000
0.452	1.837	0.332	0.035	1.000
0.493	1.837	0.362	0.037	1.000
0.534	1.837	0.393	0.039	1.000
0.576	1.837	0.423	0.041	1.000
0.617	1.837	0.453	0.042	1.000
0.658	1.837	0.483	0.044	1.000
0.699	1.837	0.502	0.046	1.000
0.740	1.837	0.521	0.047	1.000
0.781	1.837	0.540	0.049	1.000
0.822	1.837	0.559	0.050	1.000
0.863	1.837	0.578	0.052	1.000

0.904	1.837	0.596	0.053	1.000
0.946	1.837	0.615	0.054	1.000
0.987	1.837	0.634	0.056	1.000
1.028	1.837	0.653	0.079	1.000
1.069	1.837	0.672	0.146	1.000
1.110	1.837	0.691	0.237	1.000
1.151	1.837	0.710	0.347	1.000
1.192	1.837	0.729	0.472	1.000
1.233	1.837	0.747	0.612	1.000
1.274	1.837	0.766	0.764	1.000
1.316	1.837	0.785	0.928	1.000
1.357	1.837	0.804	1.103	1.000
1.398	1.837	0.823	1.289	1.000
1.439	1.837	0.842	1.484	1.000
1.480	1.837	0.861	1.689	1.000
1.521	1.837	0.880	1.902	1.000
1.562	1.837	0.898	2.124	1.000
1.603	1.837	0.917	2.354	1.000
1.644	1.837	0.936	2.593	1.000
1.686	1.837	0.955	2.838	1.000
1.727	1.837	0.974	3.092	1.000
1.768	1.837	0.993	3.352	1.000
1.809	1.837	1.012	3.620	1.000
1.850	1.837	1.031	3.894	1.000
1.891	1.837	1.050	4.175	1.000
1.932	1.837	1.068	4.463	1.000
1.973	1.837	1.087	4.757	1.000
2.014	1.837	1.106	5.057	1.000
2.056	1.837	1.125	5.364	1.000
2.097	1.837	1.144	5.676	1.000
2.138	1.837	1.163	5.994	1.000
2.179	1.837	1.238	6.318	1.000
2.220	1.837	1.314	6.648	1.000
2.261	1.837	1.389	6.983	1.000
2.302	1.837	1.465	7.324	1.000
2.343	1.837	1.540	7.670	1.000
2.384	1.837	1.616	8.022	1.000
2.426	1.837	1.691	8.378	1.000
2.467	1.837	1.767	8.740	1.000
2.508	1.837	1.842	9.107	1.000
2.549	1.837	1.918	9.479	1.000
2.590	1.837	1.993	9.856	1.000
2.631	1.837	2.069	10.24	1.000
2.672	1.837	2.144	10.62	1.000
2.713	1.837	2.220	11.02	1.000
2.754	1.837	2.295	11.41	1.000
2.796	1.837	2.371	11.81	1.000
2.837	1.837	2.446	12.22	1.000
2.878	1.837	2.522	12.63	1.000
2.919	1.837	2.597	13.04	1.000
2.960	1.837	2.673	13.46	1.000
3.001	1.837	2.748	13.89	1.000
3.042	1.837	2.824	14.31	1.000
3.083	1.837	2.899	14.74	1.000
3.124	1.837	2.975	15.18	1.000
3.166	1.837	3.050	15.62	1.000
3.207	1.837	3.126	16.07	1.000

3.248	1.837	3.201	16.52	1.000
3.289	1.837	3.277	16.97	1.000
3.330	1.837	3.352	17.43	1.000
3.371	1.837	3.428	17.89	1.000
3.412	1.837	3.504	18.35	1.000
3.453	1.837	3.579	18.82	1.000
3.494	1.837	3.655	19.29	1.000
3.536	1.837	3.730	19.77	1.000
3.577	1.837	3.806	20.25	1.000
3.618	1.837	3.881	20.74	1.000
3.659	1.837	3.957	21.22	1.000

Name : DMA2
Bypass: No

GroundWater: No

Pervious Land Use	**Acres**
C D,Shrub,Flat(0-5%)	**6.8**

Impervious Land Use	**Acres**

Element Flows To:

Surface	**Interflow**	**Groundwater**

Name : DA1
Bypass: No

GroundWater: No

Pervious Land Use	**Acres**
C D,Shrub,Flat(0-5%)	**6.5**
B,Shrub,Flat(0-5%)	**14**

Impervious Land Use	**Acres**

Element Flows To:

Surface	**Interflow**	**Groundwater**

Name : Bioretention Swale 1

Element Flows To:

Outlet 1	**Outlet 2**

Name : Bioretenti Surface 1

Element Flows To:

Outlet 1	**Outlet 2**
Bioretention Swale 1,	

Name : Basin 4
Bypass: No

GroundWater: No

Pervious Land Use	Acres

Impervious Land Use	Acres
Roads,Flat(0-5%)	**1.1**

Element Flows To:

Surface	**Interflow**	**Groundwater**
Bioretenti Surface 1,	Bioretenti Surface 1,	

MITIGATED LAND USE

ANALYSIS RESULTS

Flow Frequency Return Periods for Predeveloped. POC #1

Return Period	Flow(cfs)
2 year	0.003504
5 year	0.699858
10 year	1.763115
25 year	3.224064

Flow Frequency Return Periods for Mitigated. POC #1

Return Period	Flow(cfs)
2 year	0.144759
5 year	0.649705
10 year	1.174826
25 year	1.874091

Yearly Peaks for Predeveloped and Mitigated. POC #1

Year	Predeveloped	Mitigated
1980	0.003	0.202
1981	0.004	0.105
1982	0.003	0.205
1983	0.263	0.266
1984	0.908	0.886
1985	0.003	0.073
1986	0.001	0.015

1987	0.018	0.133
1988	0.059	0.606
1989	0.001	0.011
1990	0.004	0.158
1991	0.002	0.087
1992	0.016	0.035
1993	0.066	0.236
1994	0.458	0.484
1995	0.003	0.092
1996	1.842	1.556
1997	0.544	0.514
1998	3.901	2.075
1999	2.152	1.212
2000	0.003	0.017
2001	0.745	0.663
2002	1.233	0.923
2003	0.001	0.012
2004	0.003	0.015
2005	0.003	0.359
2006	0.503	0.506
2007	0.003	0.030
2008	0.001	0.099
2009	0.001	0.012

Ranked Yearly Peaks for Predeveloped and Mitigated. POC #1

Rank	**Predeveloped**	**Mitigated**
1	3.9014	2.0750
2	2.1516	1.5560
3	1.8417	1.2122
4	1.2325	0.9229
5	0.9080	0.8863
6	0.7454	0.6626
7	0.5438	0.6055
8	0.5029	0.5143
9	0.4577	0.5063
10	0.2627	0.4845
11	0.0663	0.3588
12	0.0586	0.2658
13	0.0176	0.2363
14	0.0160	0.2054
15	0.0041	0.2019
16	0.0036	0.1576
17	0.0034	0.1328
18	0.0033	0.1053
19	0.0032	0.0990
20	0.0031	0.0924
21	0.0030	0.0871
22	0.0029	0.0732
23	0.0027	0.0352
24	0.0026	0.0295
25	0.0022	0.0168
26	0.0012	0.0154
27	0.0011	0.0145
28	0.0010	0.0121
29	0.0008	0.0119
30	0.0007	0.0114

POC #1
The Facility PASSED

The Facility PASSED.

Flow(CFS)	Predev	Dev	Percentage	Pass/Fail
0.0004	262992	262992	100	Pass
0.0182	2740	2107	76	Pass
0.0360	1633	849	51	Pass
0.0538	1122	593	52	Pass
0.0716	811	479	59	Pass
0.0894	653	405	62	Pass
0.1072	532	358	67	Pass
0.1250	459	325	70	Pass
0.1428	403	295	73	Pass
0.1606	360	269	74	Pass
0.1784	330	241	73	Pass
0.1962	303	226	74	Pass
0.2140	277	210	75	Pass
0.2318	243	204	83	Pass
0.2496	216	185	85	Pass
0.2674	195	170	87	Pass
0.2852	177	155	87	Pass
0.3030	162	152	93	Pass
0.3209	159	143	89	Pass
0.3387	144	126	87	Pass
0.3565	136	116	85	Pass
0.3743	125	95	76	Pass
0.3921	115	88	76	Pass
0.4099	107	82	76	Pass
0.4277	97	79	81	Pass
0.4455	88	74	84	Pass
0.4633	84	70	83	Pass
0.4811	78	65	83	Pass
0.4989	73	59	80	Pass
0.5167	67	51	76	Pass
0.5345	61	49	80	Pass
0.5523	57	44	77	Pass
0.5701	55	44	80	Pass
0.5879	52	42	80	Pass
0.6057	48	40	83	Pass
0.6236	45	37	82	Pass
0.6414	42	34	80	Pass
0.6592	38	31	81	Pass
0.6770	36	30	83	Pass
0.6948	35	30	85	Pass
0.7126	34	29	85	Pass
0.7304	33	26	78	Pass
0.7482	30	24	80	Pass
0.7660	30	23	76	Pass
0.7838	27	22	81	Pass
0.8016	25	22	88	Pass
0.8194	24	22	91	Pass
0.8372	23	20	86	Pass
0.8550	22	19	86	Pass

0.8728	22	18	81	Pass
0.8906	20	16	80	Pass
0.9084	18	16	88	Pass
0.9262	18	15	83	Pass
0.9441	18	14	77	Pass
0.9619	18	13	72	Pass
0.9797	16	13	81	Pass
0.9975	16	13	81	Pass
1.0153	15	13	86	Pass
1.0331	15	10	66	Pass
1.0509	13	9	69	Pass
1.0687	13	9	69	Pass
1.0865	12	9	75	Pass
1.1043	12	8	66	Pass
1.1221	12	7	58	Pass
1.1399	12	7	58	Pass
1.1577	12	7	58	Pass
1.1755	11	7	63	Pass
1.1933	11	7	63	Pass
1.2111	11	7	63	Pass
1.2289	11	6	54	Pass
1.2467	10	6	60	Pass
1.2646	10	6	60	Pass
1.2824	10	6	60	Pass
1.3002	10	4	40	Pass
1.3180	10	4	40	Pass
1.3358	10	4	40	Pass
1.3536	10	4	40	Pass
1.3714	10	4	40	Pass
1.3892	10	4	40	Pass
1.4070	10	4	40	Pass
1.4248	10	4	40	Pass
1.4426	10	4	40	Pass
1.4604	10	4	40	Pass
1.4782	10	4	40	Pass
1.4960	10	4	40	Pass
1.5138	9	4	44	Pass
1.5316	9	4	44	Pass
1.5494	9	3	33	Pass
1.5673	9	2	22	Pass
1.5851	9	2	22	Pass
1.6029	8	2	25	Pass
1.6207	8	2	25	Pass
1.6385	7	2	28	Pass
1.6563	7	2	28	Pass
1.6741	7	2	28	Pass
1.6919	6	2	33	Pass
1.7097	6	2	33	Pass
1.7275	6	2	33	Pass
1.7453	5	2	40	Pass
1.7631	5	2	40	Pass

Perlnd and Implnd Changes

Total of 263 changes have been made.
Perlnd changes.

Name	Property	Original	Changed
C/D,Grass,Flat(0-5%)	.pnum	0	50
C/D,Grass,Flat(0-5%)	.name		NBLKS
C/D,Grass,Flat(0-5%)	NBLKS	0	1
C/D,Grass,Flat(0-5%)	.name		USER
C/D,Grass,Flat(0-5%)	USER	0	1
C/D,Grass,Flat(0-5%)	.name		IN
C/D,Grass,Flat(0-5%)	IN	0	1
C/D,Grass,Flat(0-5%)	.name		OUT
C/D,Grass,Flat(0-5%)	OUT	0	1
C/D,Grass,Flat(0-5%)	.name		ENGL
C/D,Grass,Flat(0-5%)	ENGL	0	27
C/D,Grass,Flat(0-5%)	.name		METER
C/D,Grass,Flat(0-5%)	.name		ATMP
C/D,Grass,Flat(0-5%)	.name		SNOW
C/D,Grass,Flat(0-5%)	.name		PWAT
C/D,Grass,Flat(0-5%)	PWAT	0	1
C/D,Grass,Flat(0-5%)	.name		SED
C/D,Grass,Flat(0-5%)	.name		PST
C/D,Grass,Flat(0-5%)	.name		PWG
C/D,Grass,Flat(0-5%)	.name		PQAL
C/D,Grass,Flat(0-5%)	.name		MSTL
C/D,Grass,Flat(0-5%)	.name		PEST
C/D,Grass,Flat(0-5%)	.name		NITR
C/D,Grass,Flat(0-5%)	.name		PHOS
C/D,Grass,Flat(0-5%)	.name		TRAC
C/D,Grass,Flat(0-5%)	.name		ATMP2
C/D,Grass,Flat(0-5%)	.name		SNOW2
C/D,Grass,Flat(0-5%)	.name		PWAT2
C/D,Grass,Flat(0-5%)	PWAT2	0	4
C/D,Grass,Flat(0-5%)	.name		SED2
C/D,Grass,Flat(0-5%)	.name		PST2
C/D,Grass,Flat(0-5%)	.name		PWG2
C/D,Grass,Flat(0-5%)	.name		PQAL2
C/D,Grass,Flat(0-5%)	.name		MSTL2
C/D,Grass,Flat(0-5%)	.name		PEST2
C/D,Grass,Flat(0-5%)	.name		NITR2
C/D,Grass,Flat(0-5%)	.name		PHOS2
C/D,Grass,Flat(0-5%)	.name		TRAC2
C/D,Grass,Flat(0-5%)	.name		PVIL
C/D,Grass,Flat(0-5%)	PVIL	0	1
C/D,Grass,Flat(0-5%)	.name		PYR
C/D,Grass,Flat(0-5%)	PYR	0	9
C/D,Grass,Flat(0-5%)	.name		CSNO
C/D,Grass,Flat(0-5%)	.name		RTOP
C/D,Grass,Flat(0-5%)	.name		UZFG
C/D,Grass,Flat(0-5%)	.name		VCS
C/D,Grass,Flat(0-5%)	VCS	0	1
C/D,Grass,Flat(0-5%)	.name		VUZ
C/D,Grass,Flat(0-5%)	.name		VNN
C/D,Grass,Flat(0-5%)	.name		VIFW
C/D,Grass,Flat(0-5%)	.name		VIRC
C/D,Grass,Flat(0-5%)	.name		VLE
C/D,Grass,Flat(0-5%)	VLE	0	1
C/D,Grass,Flat(0-5%)	.name		INFC

C/D,Grass,Flat(0-5%).name		HWT
C/D,Grass,Flat(0-5%).name		FOREST
C/D,Grass,Flat(0-5%).name		LZSN
C/D,Grass,Flat(0-5%)LZSN	0	4
C/D,Grass,Flat(0-5%).name		INFILT
C/D,Grass,Flat(0-5%)INFILT	0	0.04
C/D,Grass,Flat(0-5%).name		LSUR
C/D,Grass,Flat(0-5%)LSUR	0	400
C/D,Grass,Flat(0-5%).name		SLSUR
C/D,Grass,Flat(0-5%)SLSUR	0	0.05
C/D,Grass,Flat(0-5%).name		KVARY
C/D,Grass,Flat(0-5%)KVARY	0	2
C/D,Grass,Flat(0-5%).name		AGWRC
C/D,Grass,Flat(0-5%)AGWRC	0	0.95
C/D,Grass,Flat(0-5%).name		PETMAX
C/D,Grass,Flat(0-5%)PETMAX	0	40
C/D,Grass,Flat(0-5%).name		PETMIN
C/D,Grass,Flat(0-5%)PETMIN	0	35
C/D,Grass,Flat(0-5%).name		INFEXP
C/D,Grass,Flat(0-5%)INFEXP	0	3
C/D,Grass,Flat(0-5%).name		INFILD
C/D,Grass,Flat(0-5%)INFILD	0	2
C/D,Grass,Flat(0-5%).name		DEEPFR
C/D,Grass,Flat(0-5%)DEEPFR	0	0.15
C/D,Grass,Flat(0-5%).name		BASETP
C/D,Grass,Flat(0-5%)BASETP	0	0.15
C/D,Grass,Flat(0-5%).name		AGWETP
C/D,Grass,Flat(0-5%).name		CEPSC
C/D,Grass,Flat(0-5%).name		UZSN
C/D,Grass,Flat(0-5%)UZSN	0	0.3
C/D,Grass,Flat(0-5%).name		NSUR
C/D,Grass,Flat(0-5%)NSUR	0	0.25
C/D,Grass,Flat(0-5%).name		INTFW
C/D,Grass,Flat(0-5%)INTFW	0	0.7
C/D,Grass,Flat(0-5%).name		IRC
C/D,Grass,Flat(0-5%)IRC	0	0.5
C/D,Grass,Flat(0-5%).name		LZETP
C/D,Grass,Flat(0-5%).name		MELEV
C/D,Grass,Flat(0-5%)MELEV	0	400
C/D,Grass,Flat(0-5%).name		BELV
C/D,Grass,Flat(0-5%).name		GWDATM
C/D,Grass,Flat(0-5%).name		PCW
C/D,Grass,Flat(0-5%)PCW	0	0.15
C/D,Grass,Flat(0-5%).name		PGW
C/D,Grass,Flat(0-5%)PGW	0	0.17
C/D,Grass,Flat(0-5%).name		UPGW
C/D,Grass,Flat(0-5%)UPGW	0	0.2
C/D,Grass,Flat(0-5%).name		STABNO
C/D,Grass,Flat(0-5%)STABNO	0	1
C/D,Grass,Flat(0-5%).name		SRRC
C/D,Grass,Flat(0-5%)SRRC	0	0.1
C/D,Grass,Flat(0-5%).name		SREXP
C/D,Grass,Flat(0-5%).name		IFWSC
C/D,Grass,Flat(0-5%)IFWSC	0	4
C/D,Grass,Flat(0-5%).name		DELTA
C/D,Grass,Flat(0-5%)DELTA	0	0.2
C/D,Grass,Flat(0-5%).name		UELFAC

C/D,Grass,Flat(0-5%)UELFAC	0	4
C/D,Grass,Flat(0-5%).name		LELFAC
C/D,Grass,Flat(0-5%)LELFAC	0	2.5
C/D,Grass,Flat(0-5%).name		CEPS
C/D,Grass,Flat(0-5%).name		SURS
C/D,Grass,Flat(0-5%).name		UZS
C/D,Grass,Flat(0-5%)UZS	0	0.01
C/D,Grass,Flat(0-5%).name		IFWS
C/D,Grass,Flat(0-5%).name		LZS
C/D,Grass,Flat(0-5%)LZS	0	0.5
C/D,Grass,Flat(0-5%).name		AGWS
C/D,Grass,Flat(0-5%)AGWS	0	0.3
C/D,Grass,Flat(0-5%).name		GWVS
C/D,Grass,Flat(0-5%)GWVS	0	0.01
C/D,Grass,Flat(0-5%).name		JAN
C/D,Grass,Flat(0-5%)JAN	0	0.4
C/D,Grass,Flat(0-5%).name		FEB
C/D,Grass,Flat(0-5%)FEB	0	0.4
C/D,Grass,Flat(0-5%).name		MAR
C/D,Grass,Flat(0-5%)MAR	0	0.4
C/D,Grass,Flat(0-5%).name		APR
C/D,Grass,Flat(0-5%)APR	0	0.45
C/D,Grass,Flat(0-5%).name		MAY
C/D,Grass,Flat(0-5%)MAY	0	0.5
C/D,Grass,Flat(0-5%).name		JUNE
C/D,Grass,Flat(0-5%)JUNE	0	0.55
C/D,Grass,Flat(0-5%).name		JULY
C/D,Grass,Flat(0-5%)JULY	0	0.55
C/D,Grass,Flat(0-5%).name		AUG
C/D,Grass,Flat(0-5%)AUG	0	0.55
C/D,Grass,Flat(0-5%).name		SEPT
C/D,Grass,Flat(0-5%)SEPT	0	0.55
C/D,Grass,Flat(0-5%).name		OCT
C/D,Grass,Flat(0-5%)OCT	0	0.55
C/D,Grass,Flat(0-5%).name		NOV
C/D,Grass,Flat(0-5%)NOV	0	0.45
C/D,Grass,Flat(0-5%).name		DEC
C/D,Grass,Flat(0-5%)DEC	0	0.4
C/D,Grass,Flat(0-5%).name		JAN
C/D,Grass,Flat(0-5%)JAN	0	0.12
C/D,Grass,Flat(0-5%).name		FEB
C/D,Grass,Flat(0-5%)FEB	0	0.12
C/D,Grass,Flat(0-5%).name		MAR
C/D,Grass,Flat(0-5%)MAR	0	0.12
C/D,Grass,Flat(0-5%).name		APR
C/D,Grass,Flat(0-5%)APR	0	0.11
C/D,Grass,Flat(0-5%).name		MAY
C/D,Grass,Flat(0-5%)MAY	0	0.1
C/D,Grass,Flat(0-5%).name		JUNE
C/D,Grass,Flat(0-5%)JUNE	0	0.1
C/D,Grass,Flat(0-5%).name		JULY
C/D,Grass,Flat(0-5%)JULY	0	0.1
C/D,Grass,Flat(0-5%).name		AUG
C/D,Grass,Flat(0-5%)AUG	0	0.1
C/D,Grass,Flat(0-5%).name		SEPT
C/D,Grass,Flat(0-5%)SEPT	0	0.1
C/D,Grass,Flat(0-5%).name		OCT

C/D,Grass,Flat(0-5%)OCT		0	0.1
C/D,Grass,Flat(0-5%).name			NOV
C/D,Grass,Flat(0-5%)NOV		0	0.11
C/D,Grass,Flat(0-5%).name			DEC
C/D,Grass,Flat(0-5%)DEC		0	0.12

Implnd changes.

Name	Property	Original	Changed
Roads,Flat(0-5%)	LAT.pnum	0	18
Roads,Flat(0-5%)	LAT.Name		USER
Roads,Flat(0-5%)	LATUSER	0	1
Roads,Flat(0-5%)	LAT.Name		IN
Roads,Flat(0-5%)	LATIN	0	1
Roads,Flat(0-5%)	LAT.Name		OUT
Roads,Flat(0-5%)	LATOUT	0	1
Roads,Flat(0-5%)	LAT.Name		ENGL
Roads,Flat(0-5%)	LATENGL	0	27
Roads,Flat(0-5%)	LAT.Name		METER
Roads,Flat(0-5%)	LAT.Name		ATMP
Roads,Flat(0-5%)	LAT.Name		SNOW
Roads,Flat(0-5%)	LAT.Name		IWAT
Roads,Flat(0-5%)	LATIWAT	0	1
Roads,Flat(0-5%)	LAT.Name		SLD
Roads,Flat(0-5%)	LAT.Name		IWG
Roads,Flat(0-5%)	LAT.Name		IQAL
Roads,Flat(0-5%)	LAT.Name		ATMP2
Roads,Flat(0-5%)	LAT.Name		SNOW2
Roads,Flat(0-5%)	LAT.Name		IWAT2
Roads,Flat(0-5%)	LATIWAT2	0	4
Roads,Flat(0-5%)	LAT.Name		SLD2
Roads,Flat(0-5%)	LAT.Name		IWG2
Roads,Flat(0-5%)	LAT.Name		IQAL2
Roads,Flat(0-5%)	LAT.Name		PVIL
Roads,Flat(0-5%)	LATPVIL	0	1
Roads,Flat(0-5%)	LAT.Name		PYR
Roads,Flat(0-5%)	LATPYR	0	9
Roads,Flat(0-5%)	LAT.Name		CSNO
Roads,Flat(0-5%)	LAT.Name		RTOP
Roads,Flat(0-5%)	LAT.Name		VRS
Roads,Flat(0-5%)	LAT.Name		VNN
Roads,Flat(0-5%)	LAT.Name		RTLI
Roads,Flat(0-5%)	LAT.Name		LSUR
Roads,Flat(0-5%)	LATLSUR	0	100
Roads,Flat(0-5%)	LAT.Name		SLSUR
Roads,Flat(0-5%)	LATSLSUR	0	0.05
Roads,Flat(0-5%)	LAT.Name		NSUR
Roads,Flat(0-5%)	LATNSUR	0	0.1
Roads,Flat(0-5%)	LAT.Name		RETSC
Roads,Flat(0-5%)	LATRETSC	0	0.1
Roads,Flat(0-5%)	LAT.Name		PETMAX
Roads,Flat(0-5%)	LAT.Name		PETMIN
Roads,Flat(0-5%)	LAT.Name		RETS
Roads,Flat(0-5%)	LAT.Name		SURS
Roads,Flat(0-5%)	LAT.pnum	0	19
Roads,Flat(0-5%)	LAT.Name		USER
Roads,Flat(0-5%)	LATUSER	0	1
Roads,Flat(0-5%)	LAT.Name		IN

Roads,Flat(0-5%)	LATIN	0	1
Roads,Flat(0-5%)	LAT.Name		OUT
Roads,Flat(0-5%)	LATOUT	0	1
Roads,Flat(0-5%)	LAT.Name		ENGL
Roads,Flat(0-5%)	LATENGL	0	27
Roads,Flat(0-5%)	LAT.Name		METER
Roads,Flat(0-5%)	LAT.Name		ATMP
Roads,Flat(0-5%)	LAT.Name		SNOW
Roads,Flat(0-5%)	LAT.Name		IWAT
Roads,Flat(0-5%)	LATIWAT	0	1
Roads,Flat(0-5%)	LAT.Name		SLD
Roads,Flat(0-5%)	LAT.Name		IWG
Roads,Flat(0-5%)	LAT.Name		IQAL
Roads,Flat(0-5%)	LAT.Name		ATMP2
Roads,Flat(0-5%)	LAT.Name		SNOW2
Roads,Flat(0-5%)	LAT.Name		IWAT2
Roads,Flat(0-5%)	LATIWAT2	0	4
Roads,Flat(0-5%)	LAT.Name		SLD2
Roads,Flat(0-5%)	LAT.Name		IWG2
Roads,Flat(0-5%)	LAT.Name		IQAL2
Roads,Flat(0-5%)	LAT.Name		PVIL
Roads,Flat(0-5%)	LATPVIL	0	1
Roads,Flat(0-5%)	LAT.Name		PYR
Roads,Flat(0-5%)	LATPYR	0	9
Roads,Flat(0-5%)	LAT.Name		CSNO
Roads,Flat(0-5%)	LAT.Name		RTOP
Roads,Flat(0-5%)	LAT.Name		VRS
Roads,Flat(0-5%)	LAT.Name		VNN
Roads,Flat(0-5%)	LAT.Name		RTLI
Roads,Flat(0-5%)	LAT.Name		LSUR
Roads,Flat(0-5%)	LATLSUR	0	100
Roads,Flat(0-5%)	LAT.Name		SLSUR
Roads,Flat(0-5%)	LATSLSUR	0	0.05
Roads,Flat(0-5%)	LAT.Name		NSUR
Roads,Flat(0-5%)	LATNSUR	0	0.1
Roads,Flat(0-5%)	LAT.Name		RETSC
Roads,Flat(0-5%)	LATRETSC	0	0.1
Roads,Flat(0-5%)	LAT.Name		PETMAX
Roads,Flat(0-5%)	LAT.Name		PETMIN
Roads,Flat(0-5%)	LAT.Name		RETS
Roads,Flat(0-5%)	LAT.Name		SURS

Appendix D

Bay Area Hydrology Model
PROJECT REPORT

Project Name: DA2
Site Address:
City :
Report Date : 3/1/2011
Gage :
Data Start : 10/01/1978 01:00
Data End : 2008/09/30
Precip Scale: 0.80
BAHM Version:

PREDEVELOPED LAND USE

Name : Basin 1
Bypass: No

GroundWater: No

Pervious Land Use	Acres
B,Shrub,Flat(0-5%)	18

Impervious Land Use	Acres

Element Flows To:

Surface	Interflow	Groundwater

Name : DMA3
Bypass: No

GroundWater: No

Pervious Land Use	Acres
B,Shrub,Flat(0-5%)	6.5

Impervious Land Use	Acres
Driveways,Flat(0-5%)	5.4

Element Flows To:

Surface	Interflow	Groundwater
Trapezoidal Pond 1,	Trapezoidal Pond 1,	

Name : Trapezoidal Pond 1
Bottom Length: 200ft.

Bottom Width: 100ft.
Depth : 2ft.
Volume at riser head : 0.7257ft.
Infiltration On
Infiltration rate : 0.6
Infiltration saftey factor : 0.9
Side slope 1: 2 To 1
Side slope 2: 2 To 1
Side slope 3: 2 To 1
Side slope 4: 2 To 1
Discharge Structure
Riser Height: 1.5 ft.
Riser Diameter: 6 in.
Orifice 1 Diameter: 0.75 in. **Elevation:** 0.1 ft.

Element Flows To:
Outlet 1 **Outlet 2**

Pond Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.000	0.459	0.000	0.000	0.000
0.022	0.460	0.010	0.000	0.250
0.044	0.460	0.020	0.000	0.250
0.067	0.461	0.031	0.000	0.250
0.089	0.462	0.041	0.000	0.250
0.111	0.462	0.051	0.002	0.250
0.133	0.463	0.061	0.003	0.250
0.156	0.463	0.072	0.003	0.250
0.178	0.464	0.082	0.004	0.250
0.200	0.465	0.092	0.005	0.250
0.222	0.465	0.103	0.005	0.250
0.244	0.466	0.113	0.006	0.250
0.267	0.467	0.123	0.006	0.250
0.289	0.467	0.134	0.006	0.250
0.311	0.468	0.144	0.007	0.250
0.333	0.468	0.155	0.007	0.250
0.356	0.469	0.165	0.007	0.250
0.378	0.470	0.175	0.008	0.250
0.400	0.470	0.186	0.008	0.250
0.422	0.471	0.196	0.008	0.250
0.444	0.471	0.207	0.009	0.250
0.467	0.472	0.217	0.009	0.250
0.489	0.473	0.228	0.009	0.250
0.511	0.473	0.238	0.009	0.250
0.533	0.474	0.249	0.010	0.250
0.556	0.475	0.259	0.010	0.250
0.578	0.475	0.270	0.010	0.250
0.600	0.476	0.280	0.010	0.250
0.622	0.476	0.291	0.011	0.250
0.644	0.477	0.302	0.011	0.250
0.667	0.478	0.312	0.011	0.250
0.689	0.478	0.323	0.011	0.250
0.711	0.479	0.334	0.012	0.250
0.733	0.480	0.344	0.012	0.250

0.756	0.480	0.355	0.012	0.250
0.778	0.481	0.365	0.012	0.250
0.800	0.481	0.376	0.012	0.250
0.822	0.482	0.387	0.013	0.250
0.844	0.483	0.398	0.013	0.250
0.867	0.483	0.408	0.013	0.250
0.889	0.484	0.419	0.013	0.250
0.911	0.485	0.430	0.013	0.250
0.933	0.485	0.441	0.013	0.250
0.956	0.486	0.451	0.014	0.250
0.978	0.486	0.462	0.014	0.250
1.000	0.487	0.473	0.014	0.250
1.022	0.488	0.484	0.014	0.250
1.044	0.488	0.495	0.014	0.250
1.067	0.489	0.506	0.015	0.250
1.089	0.490	0.516	0.015	0.250
1.111	0.490	0.527	0.015	0.250
1.133	0.491	0.538	0.015	0.250
1.156	0.491	0.549	0.015	0.250
1.178	0.492	0.560	0.015	0.250
1.200	0.493	0.571	0.015	0.250
1.222	0.493	0.582	0.016	0.250
1.244	0.494	0.593	0.016	0.250
1.267	0.495	0.604	0.016	0.250
1.289	0.495	0.615	0.016	0.250
1.311	0.496	0.626	0.016	0.250
1.333	0.497	0.637	0.016	0.250
1.356	0.497	0.648	0.017	0.250
1.378	0.498	0.659	0.017	0.250
1.400	0.498	0.670	0.017	0.250
1.422	0.499	0.681	0.017	0.250
1.444	0.500	0.692	0.017	0.250
1.467	0.500	0.703	0.017	0.250
1.489	0.501	0.715	0.017	0.250
1.511	0.502	0.726	0.023	0.250
1.533	0.502	0.737	0.047	0.250
1.556	0.503	0.748	0.082	0.250
1.578	0.504	0.759	0.124	0.250
1.600	0.504	0.770	0.172	0.250
1.622	0.505	0.782	0.226	0.250
1.644	0.505	0.793	0.286	0.250
1.667	0.506	0.804	0.350	0.250
1.689	0.507	0.815	0.418	0.250
1.711	0.507	0.827	0.491	0.250
1.733	0.508	0.838	0.568	0.250
1.756	0.509	0.849	0.648	0.250
1.778	0.509	0.860	0.732	0.250
1.800	0.510	0.872	0.819	0.250
1.822	0.511	0.883	0.910	0.250
1.844	0.511	0.894	1.004	0.250
1.867	0.512	0.906	1.101	0.250
1.889	0.512	0.917	1.201	0.250
1.911	0.513	0.929	1.303	0.250
1.933	0.514	0.940	1.409	0.250
1.956	0.514	0.951	1.517	0.250
1.978	0.515	0.963	1.628	0.250
2.000	0.516	0.974	1.742	0.250

2.022	0.516	0.986	1.858	0.250

Name : Gravel Trench Bed 1
Bottom Length: 730ft.
Bottom Width : 65ft.
Trench bottom slope 1: 0.005 To 1
Trench Left side slope 0: 0.5 To 1
Trench right side slope 2: 0.5 To 1
Material thickness of first layer : 0.5
Pour Space of material for first layer : 0.25
Material thickness of second layer : 1.5
Pour Space of material for second layer : 0.25
Material thickness of third layer : 0
Pour Space of material for third layer : 0
Infiltration On
Infiltration rate : 0.6
Infiltration saftey factor : 0.9
Discharge Structure
Riser Height: 0.5 ft.
Riser Diameter: 12 in.

Element Flows To:
Outlet 1 **Outlet 2**
Trapezoidal Pond 1,

Gravel Trench Bed Hydraulic Table

Stage(ft)	Area(acr)	Volume(acr-ft)	Dschrg(cfs)	Infilt(cfs)
0.000	1.089	0.000	0.000	0.000
0.022	1.090	0.006	0.000	0.593
0.044	1.090	0.012	0.000	0.593
0.067	1.090	0.018	0.000	0.593
0.089	1.091	0.024	0.000	0.593
0.111	1.091	0.030	0.000	0.593
0.133	1.092	0.036	0.000	0.593
0.156	1.092	0.042	0.000	0.593
0.178	1.092	0.048	0.000	0.593
0.200	1.093	0.055	0.000	0.593
0.222	1.093	0.061	0.000	0.593
0.244	1.093	0.067	0.000	0.593
0.267	1.094	0.073	0.000	0.593
0.289	1.094	0.079	0.000	0.593
0.311	1.095	0.085	0.000	0.593
0.333	1.095	0.091	0.000	0.593
0.356	1.095	0.097	0.000	0.593
0.378	1.096	0.103	0.000	0.593
0.400	1.096	0.109	0.000	0.593
0.422	1.096	0.115	0.000	0.593
0.444	1.097	0.121	0.000	0.593
0.467	1.097	0.128	0.000	0.593
0.489	1.098	0.134	0.000	0.593
0.511	1.098	0.140	0.011	0.593
0.533	1.098	0.146	0.059	0.593
0.556	1.099	0.152	0.128	0.593

0.578	1.099	0.158	0.211	0.593
0.600	1.099	0.164	0.308	0.593
0.622	1.100	0.170	0.416	0.593
0.644	1.100	0.176	0.535	0.593
0.667	1.100	0.182	0.663	0.593
0.689	1.101	0.189	0.800	0.593
0.711	1.101	0.195	0.945	0.593
0.733	1.102	0.201	1.098	0.593
0.756	1.102	0.207	1.258	0.593
0.778	1.102	0.213	1.426	0.593
0.800	1.103	0.219	1.600	0.593
0.822	1.103	0.225	1.781	0.593
0.844	1.103	0.231	1.969	0.593
0.867	1.104	0.238	2.162	0.593
0.889	1.104	0.244	2.362	0.593
0.911	1.105	0.250	2.567	0.593
0.933	1.105	0.256	2.778	0.593
0.956	1.105	0.262	2.995	0.593
0.978	1.106	0.268	3.216	0.593
1.000	1.106	0.274	3.443	0.593
1.022	1.106	0.281	3.675	0.593
1.044	1.107	0.287	3.912	0.593
1.067	1.107	0.293	4.154	0.593
1.089	1.108	0.299	4.401	0.593
1.111	1.108	0.305	4.653	0.593
1.133	1.108	0.311	4.909	0.593
1.156	1.109	0.317	5.169	0.593
1.178	1.109	0.324	5.434	0.593
1.200	1.109	0.330	5.704	0.593
1.222	1.110	0.336	5.978	0.593
1.244	1.110	0.342	6.256	0.593
1.267	1.111	0.348	6.538	0.593
1.289	1.111	0.354	6.824	0.593
1.311	1.111	0.361	7.114	0.593
1.333	1.112	0.367	7.409	0.593
1.356	1.112	0.373	7.707	0.593
1.378	1.112	0.379	8.009	0.593
1.400	1.113	0.385	8.315	0.593
1.422	1.113	0.392	8.625	0.593
1.444	1.114	0.398	8.939	0.593
1.467	1.114	0.404	9.256	0.593
1.489	1.114	0.410	9.577	0.593
1.511	1.115	0.416	9.902	0.593
1.533	1.115	0.422	10.23	0.593
1.556	1.115	0.429	10.56	0.593
1.578	1.116	0.435	10.90	0.593
1.600	1.116	0.441	11.24	0.593
1.622	1.117	0.447	11.58	0.593
1.644	1.117	0.453	11.92	0.593
1.667	1.117	0.460	12.27	0.593
1.689	1.118	0.466	12.62	0.593
1.711	1.118	0.472	12.98	0.593
1.733	1.118	0.478	13.34	0.593
1.756	1.119	0.485	13.70	0.593
1.778	1.119	0.491	14.07	0.593
1.800	1.119	0.497	14.44	0.593
1.822	1.120	0.503	14.81	0.593

1.844	1.120	0.509	15.18	0.593
1.867	1.121	0.516	15.56	0.593
1.889	1.121	0.522	15.94	0.593
1.911	1.121	0.528	16.33	0.593
1.933	1.122	0.534	16.71	0.593
1.956	1.122	0.541	17.10	0.593
1.978	1.122	0.547	17.50	0.593
2.000	1.123	0.553	17.89	0.593

Name : DMA4
Bypass: No

GroundWater: No

Pervious Land Use	**Acres**

Impervious Land Use	**Acres**
Driveways,Flat(0-5%)	**3.7**

Element Flows To:

Surface	**Interflow**	**Groundwater**
Gravel Trench Bed 1,	Gravel Trench Bed 1,	

Name : DMA5
Bypass: No

GroundWater: No

Pervious Land Use	**Acres**
B,Shrub,Flat(0-5%)	**.7**

Impervious Land Use	**Acres**
Driveways,Flat(0-5%)	**1.9**

Element Flows To:

Surface	**Interflow**	**Groundwater**
Bioretenti Surface 1,	Bioretenti Surface 1,	

Name : Bioretention Swale 1

Element Flows To:

Outlet 1	**Outlet 2**
Gravel Trench Bed 1,	

Name : Bioretenti Surface 1

Element Flows To:

Outlet 1	**Outlet 2**
Gravel Trench Bed 1,	Bioretention Swale 1,

MITIGATED LAND USE

ANALYSIS RESULTS

Flow Frequency Return Periods for Predeveloped. POC #1

Return Period	Flow(cfs)
2 year	0.003907
5 year	0.150395
10 year	0.789226
25 year	2.188691

Flow Frequency Return Periods for Mitigated. POC #1

Return Period	Flow(cfs)
2 year	0.011192
5 year	0.016381
10 year	0.080584
25 year	0.973333

Yearly Peaks for Predeveloped and Mitigated. POC #1

Year	Predeveloped	Mitigated
1980	0.003	0.014
1981	0.005	0.010
1982	0.004	0.014
1983	0.037	0.013
1984	0.298	0.015
1985	0.002	0.010
1986	0.001	0.008
1987	0.004	0.011
1988	0.006	1.083
1989	0.001	0.006
1990	0.003	0.011
1991	0.002	0.012
1992	0.004	0.009
1993	0.007	0.013
1994	0.111	0.012
1995	0.003	0.011
1996	0.837	0.017
1997	0.086	0.013
1998	2.749	0.074
1999	1.302	0.082
2000	0.004	0.009
2001	0.162	0.799
2002	0.470	0.017
2003	0.001	0.006
2004	0.002	0.008
2005	0.004	0.015

2006	0.052	0.011
2007	0.003	0.007
2008	0.001	0.010
2009	0.001	0.007

Ranked Yearly Peaks for Predeveloped and Mitigated. POC #1

Rank	**Predeveloped**	**Mitigated**
1	2.7490	1.0835
2	1.3016	0.7989
3	0.8365	0.0815
4	0.4698	0.0744
5	0.2975	0.0171
6	0.1619	0.0168
7	0.1108	0.0151
8	0.0864	0.0146
9	0.0520	0.0137
10	0.0368	0.0136
11	0.0071	0.0134
12	0.0059	0.0129
13	0.0049	0.0125
14	0.0042	0.0121
15	0.0040	0.0116
16	0.0040	0.0113
17	0.0038	0.0110
18	0.0038	0.0107
19	0.0035	0.0105
20	0.0031	0.0104
21	0.0031	0.0096
22	0.0028	0.0096
23	0.0023	0.0090
24	0.0021	0.0090
25	0.0020	0.0081
26	0.0009	0.0076
27	0.0008	0.0068
28	0.0007	0.0065
29	0.0007	0.0064
30	0.0007	0.0058

POC #1
The Facility PASSED

The Facility PASSED.

Flow(CFS)	**Predev**	**Dev**	**Percentage**	**Pass/Fail**
0.0004	262992	262992	100	Pass
0.0084	3771	1217	32	Pass
0.0163	2483	104	4	Pass
0.0243	1872	29	1	Pass
0.0323	1477	26	1	Pass
0.0402	1246	23	1	Pass
0.0482	1044	22	2	Pass
0.0562	888	21	2	Pass
0.0641	773	20	2	Pass
0.0721	674	18	2	Pass
0.0801	592	17	2	Pass

0.0880	522	15	2	Pass
0.0960	465	15	3	Pass
0.1040	424	14	3	Pass
0.1119	383	14	3	Pass
0.1199	345	14	4	Pass
0.1279	313	14	4	Pass
0.1358	284	14	4	Pass
0.1438	263	14	5	Pass
0.1518	242	14	5	Pass
0.1598	226	14	6	Pass
0.1677	208	14	6	Pass
0.1757	196	14	7	Pass
0.1837	184	14	7	Pass
0.1916	172	14	8	Pass
0.1996	159	14	8	Pass
0.2076	141	12	8	Pass
0.2155	121	12	9	Pass
0.2235	108	12	11	Pass
0.2315	92	11	11	Pass
0.2394	76	11	14	Pass
0.2474	64	11	17	Pass
0.2554	59	11	18	Pass
0.2633	52	11	21	Pass
0.2713	47	11	23	Pass
0.2793	41	11	26	Pass
0.2872	39	11	28	Pass
0.2952	34	11	32	Pass
0.3032	31	11	35	Pass
0.3111	28	11	39	Pass
0.3191	26	11	42	Pass
0.3271	26	11	42	Pass
0.3350	22	11	50	Pass
0.3430	20	10	50	Pass
0.3510	19	10	52	Pass
0.3590	17	10	58	Pass
0.3669	16	10	62	Pass
0.3749	16	10	62	Pass
0.3829	16	10	62	Pass
0.3908	16	10	62	Pass
0.3988	14	10	71	Pass
0.4068	14	10	71	Pass
0.4147	14	10	71	Pass
0.4227	14	10	71	Pass
0.4307	14	10	71	Pass
0.4386	14	9	64	Pass
0.4466	14	9	64	Pass
0.4546	14	8	57	Pass
0.4625	13	8	61	Pass
0.4705	11	7	63	Pass
0.4785	11	7	63	Pass
0.4864	11	7	63	Pass
0.4944	10	7	70	Pass
0.5024	10	7	70	Pass
0.5103	10	7	70	Pass
0.5183	10	6	60	Pass
0.5263	10	6	60	Pass
0.5342	10	5	50	Pass

0.5422	10	5	50	Pass
0.5502	10	5	50	Pass
0.5582	10	5	50	Pass
0.5661	10	5	50	Pass
0.5741	10	5	50	Pass
0.5821	10	5	50	Pass
0.5900	10	5	50	Pass
0.5980	10	5	50	Pass
0.6060	10	5	50	Pass
0.6139	10	5	50	Pass
0.6219	10	5	50	Pass
0.6299	10	5	50	Pass
0.6378	10	4	40	Pass
0.6458	10	4	40	Pass
0.6538	10	4	40	Pass
0.6617	10	4	40	Pass
0.6697	10	4	40	Pass
0.6777	10	4	40	Pass
0.6856	10	4	40	Pass
0.6936	9	4	44	Pass
0.7016	9	4	44	Pass
0.7095	9	4	44	Pass
0.7175	9	4	44	Pass
0.7255	9	4	44	Pass
0.7334	9	4	44	Pass
0.7414	9	4	44	Pass
0.7494	9	4	44	Pass
0.7574	9	4	44	Pass
0.7653	9	3	33	Pass
0.7733	9	3	33	Pass
0.7813	9	3	33	Pass
0.7892	8	3	37	Pass

Perlnd and Implnd Changes

No changes have been made.

Appendix E

Pervious Pavements SD-20

Design Objectives

- ✓ Maximize Infiltration
- ✓ Provide Retention
- ✓ Slow Runoff
- ✓ Minimize Impervious Land Coverage
- Prohibit Dumping of Improper Materials
- Contain Pollutants
- Collect and Convey

Description

Pervious paving is used for light vehicle loading in parking areas. The term describes a system comprising a load-bearing, durable surface together with an underlying layered structure that temporarily stores water prior to infiltration or drainage to a controlled outlet. The surface can itself be porous such that water infiltrates across the entire surface of the material (e.g., grass and gravel surfaces, porous concrete and porous asphalt), or can be built up of impermeable blocks separated by spaces and joints, through which the water can drain. This latter system is termed 'permeable' paving. Advantages of pervious pavements is that they reduce runoff volume while providing treatment, and are unobtrusive resulting in a high level of acceptability.

Approach

Attenuation of flow is provided by the storage within the underlying structure or sub base, together with appropriate flow controls. An underlying geotextile may permit groundwater recharge, thus contributing to the restoration of the natural water cycle. Alternatively, where infiltration is inappropriate (e.g., if the groundwater vulnerability is high, or the soil type is unsuitable), the surface can be constructed above an impermeable membrane. The system offers a valuable solution for drainage of spatially constrained urban areas.

Significant attenuation and improvement in water quality can be achieved by permeable pavements, whichever method is used. The surface and subsurface infrastructure can remove both the soluble and fine particulate pollutants that occur within urban runoff. Roof water can be piped into the storage area directly, adding areas from which the flow can be attenuated. Also, within lined systems, there is the opportunity for stored runoff to be piped out for reuse.

Suitable Applications

Residential, commercial and industrial applications are possible. The use of permeable pavement may be restricted in cold regions, arid regions or regions with high wind erosion. There are some specific disadvantages associated with permeable pavement, which are as follows:

- Permeable pavement can become clogged if improperly installed or maintained. However, this is countered by the ease with which small areas of paving can be cleaned or replaced when blocked or damaged.

- Their application should be limited to highways with low traffic volumes, axle loads and speeds (less than 30 mph limit), car parking areas and other lightly trafficked or non-trafficked areas. Permeable surfaces are currently not considered suitable for adoptable roads due to the risks associated with failure on high speed roads, the safety implications of ponding, and disruption arising from reconstruction.

- When using un-lined, infiltration systems, there is some risk of contaminating groundwater, depending on soil conditions and aquifer susceptibility. However, this risk is likely to be small because the areas drained tend to have inherently low pollutant loadings.

- The use of permeable pavement is restricted to gentle slopes.

- Porous block paving has a higher risk of abrasion and damage than solid blocks.

Design Considerations

Designing New Installations

If the grades, subsoils, drainage characteristics, and groundwater conditions are suitable, permeable paving may be substituted for conventional pavement on parking areas, cul de sacs and other areas with light traffic. Slopes should be flat or very gentle. Scottish experience has shown that permeable paving systems can be installed in a wide range of ground conditions, and the flow attenuation performance is excellent even when the systems are lined.

The suitability of a pervious system at a particular pavement site will, however, depend on the loading criteria required of the pavement.

Where the system is to be used for infiltrating drainage waters into the ground, the vulnerability of local groundwater sources to pollution from the site should be low, and the seasonal high water table should be at least 4 feet below the surface.

Ideally, the pervious surface should be horizontal in order to intercept local rainfall at source. On sloping sites, pervious surfaces may be terraced to accommodate differences in levels.

Design Guidelines

The design of each layer of the pavement must be determined by the likely traffic loadings and their required operational life. To provide satisfactory performance, the following criteria should be considered:

- The subgrade should be able to sustain traffic loading without excessive deformation.

- The granular capping and sub-base layers should give sufficient load-bearing to provide an adequate construction platform and base for the overlying pavement layers.

- The pavement materials should not crack of suffer excessive rutting under the influence of traffic. This is controlled by the horizontal tensile stress at the base of these layers.

There is no current structural design method specifically for pervious pavements. Allowances should be considered the following factors in the design and specification of materials:

- Pervious pavements use materials with high permeability and void space. All the current UK pavement design methods are based on the use of conventional materials that are dense and relatively impermeable. The stiffness of the materials must therefore be assessed.

- Water is present within the construction and can soften and weaken materials, and this must be allowed for.

- Existing design methods assume full friction between layers. Any geotextiles or geomembranes must be carefully specified to minimize loss of friction between layers.

- Porous asphalt loses adhesion and becomes brittle as air passes through the voids. Its durability is therefore lower than conventional materials.

The single sized grading of materials used means that care should be taken to ensure that loss of finer particles between unbound layers does not occur.

Positioning a geotextile near the surface of the pervious construction should enable pollutants to be trapped and retained close to the surface of the construction. This has both advantages and disadvantages. The main disadvantage is that the filtering of sediments and their associated pollutants at this level may hamper percolation of waters and can eventually lead to surface ponding. One advantage is that even if eventual maintenance is required to reinstate infiltration, only a limited amount of the construction needs to be disturbed, since the sub-base below the geotextile is protected. In addition, the pollutant concentration at a high level in the structure allows for its release over time. It is slowly transported in the stormwater to lower levels where chemical and biological processes may be operating to retain or degrade pollutants.

The design should ensure that sufficient void space exists for the storage of sediments to limit the period between remedial works.

- Pervious pavements require a single size grading to give open voids. The choice of materials is therefore a compromise between stiffness, permeability and storage capacity.

- Because the sub-base and capping will be in contact with water for a large part of the time, the strength and durability of the aggregate particles when saturated and subjected to wetting and drying should be assessed.

- A uniformly graded single size material cannot be compacted and is liable to move when construction traffic passes over it. This effect can be reduced by the use of angular crushed rock material with a high surface friction.

In pollution control terms, these layers represent the site of long term chemical and biological pollutant retention and degradation processes. The construction materials should be selected, in addition to their structural strength properties, for their ability to sustain such processes. In general, this means that materials should create neutral or slightly alkaline conditions and they should provide favorable sites for colonization by microbial populations.

Construction/Inspection Considerations

- Permeable surfaces can be laid without cross-falls or longitudinal gradients.

- The blocks should be lain level

- They should not be used for storage of site materials, unless the surface is well protected from deposition of silt and other spillages.
- The pavement should be constructed in a single operation, as one of the last items to be built, on a development site. Landscape development should be completed before pavement construction to avoid contamination by silt or soil from this source.
- Surfaces draining to the pavement should be stabilized before construction of the pavement.
- Inappropriate construction equipment should be kept away from the pavement to prevent damage to the surface, sub-base or sub-grade.

Maintenance Requirements

The maintenance requirements of a pervious surface should be reviewed at the time of design and should be clearly specified. Maintenance is required to prevent clogging of the pervious surface. The factors to be considered when defining maintenance requirements must include:

- Type of use
- Ownership
- Level of trafficking
- The local environment and any contributing catchments

Studies in the UK have shown satisfactory operation of porous pavement systems without maintenance for over 10 years and recent work by Imbe et al. at 9th ICUD, Portland, 2002 describes systems operating for over 20 years without maintenance. However, performance under such regimes could not be guaranteed, Table 1 shows typical recommended maintenance regimes:

Table 1 Typical Recommended Maintenance Regimes	
Activity	**Schedule**
■ Minimize use of salt or grit for de-icing ■ Keep landscaped areas well maintained ■ Prevent soil being washed onto pavement	Ongoing
■ Vacuum clean surface using commercially available sweeping machines at the following times: - End of winter (April) - Mid-summer (July / August) - After Autumn leaf-fall (November)	2/3 x per year
■ Inspect outlets	Annual
■ If routine cleaning does not restore infiltration rates, then reconstruction of part of the whole of a pervious surface may be required. ■ The surface area affected by hydraulic failure should be lifted for inspection of the internal materials to identify the location and extent of the blockage. ■ Surface materials should be lifted and replaced after brush cleaning. Geotextiles may need complete replacement. ■ Sub-surface layers may need cleaning and replacing. ■ Removed silts may need to be disposed of as controlled waste.	As needed (infrequent) Maximum 15-20 years

Permeable pavements are up to 25 % cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account. (Accepting that the porous asphalt itself is a more expensive surfacing, the extra cost of which is offset by the savings in underground pipework etc.) (Niemczynowicz, et al., 1987)

Table 1 gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000)

Redeveloping Existing Installations

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define “redevelopment” in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. The definition of “ redevelopment” must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under “designing new installations” above should be followed.

Additional Information

Cost Considerations

Permeable pavements are up to 25 % cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account. (Accepting that the porous asphalt itself is a more expensive surfacing, the extra cost of which is offset by the savings in underground pipework etc.) (Niemczynowicz, et al., 1987)

Table 2 gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000)

Table 2 Engineer's Estimate for Porous Pavement

Porous Pavement														
Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Grading	SY	$2.00		604	$1,208	1209	$2,418	1812	$3,624	2419	$4,838	3020	$6,040
Paving	SY	$19.00		212	$4,028	424	$8,056	636	$12,084	848	$16,112	1060	$20,140
Excavation	CY	$3.60		201	$724	403	$1,451	604	$2,174	806	$2,902	1008	$3,629
Filter Fabric	SY	$1.15		700	$805	1400	$1,610	2000	$2,300	2800	$3,220	3600	$4,140
Stone Fill	CY	$16.00		201	$3,216	403	$6,448	604	$9,664	806	$12,896	1008	$16,128
Sand	CY	$7.00		100	$700	200	$1,400	300	$2,100	400	$2,800	500	$3,500
Sight Well	EA	$300.00		2	$600	3	$900	4	$1,200	7	$2,100	7	$2,100
Seeding	LF	$0.05		644	$32	1288	$64	1932	$97	2576	$129	3220	$161
Check Dam	CY	$35.00		0	$0	0	$0	0	$0	0	$0	0	$0
Total Construction Costs					**$10,105**		**$19,929**		**$29,619**		**$40,158**		**$49,798**
Construction Costs Amortized for 20 Years					**$505**		**$996**		**$1,481**		**$2,008**		**$2,490**
Annual Maintenance Expense													
Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Sweeping	AC	$250.00	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Washing	AC	$250.00	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Inspection	MH	$20.00	5	5	$100	5	$100	5	$100	5	$100	5	$100
Deep Clean	AC	$450.00	0.5	1	$225	2	$450	3	$675	3.9	$878	5	$1,125
Total Annual Maintenance Expense					**$3,960**		**$7,792**		**$11,651**		**$15,483**		**$19,370**

Supplemental Information

-

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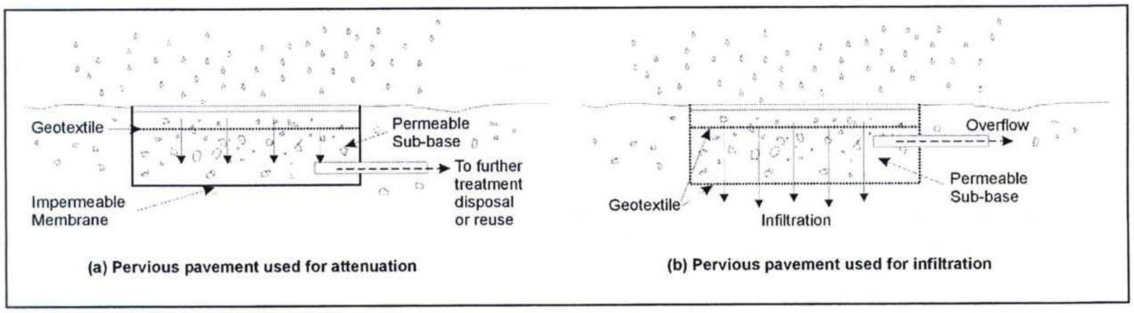

Schematics of a Pervious Pavement System

Pervious Concrete Pavements

Paul D. Tennis

Michael Leming

David J. Akers

Concrete Thinking for a sustainable world

PCA Portland Cement Association

National Ready Mixed Concrete Association

Pervious Concrete Pavements

by Paul D. Tennis, Michael L. Leming, and David J. Akers

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Abstract: Pervious concrete as a paving material has seen renewed interest due to its ability to allow water to flow through itself to recharge groundwater and minimize stormwater runoff. This introduction to pervious concrete pavements reviews its applications and engineering properties, including environmental benefits, structural properties, and durability. Both hydraulic and structural design of pervious concrete pavements are discussed, as well as construction techniques.

Keywords: Applications, construction techniques, hydraulic design, inspection, pervious concrete, properties, structural design

Reference: Tennis, Paul, D.; Leming, Michael, L.; and Akers, David, J., *Pervious Concrete Pavements,* EB302.02, Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland, USA, 2004, 36 pages.

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WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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Table of Contents

Introduction

Pervious concrete pavement is a unique and effective means to meet growing environmental demands. By capturing rainwater and allowing it to seep into the ground, pervious concrete is instrumental in recharging groundwater, reducing stormwater runoff, and meeting U.S. Environmental Protection Agency (EPA) stormwater regulations. In fact, the use of pervious concrete is among the Best Management Practices (BMP) recommended by the EPA—and by other agencies and geotechnical engineers across the country—for the management of stormwater runoff on a regional and local basis. This pavement technology creates more efficient land use by eliminating the need for retention ponds, swales, and other stormwater management devices. In doing so, pervious concrete has the ability to lower overall project costs on a first-cost basis.

In pervious concrete, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. A pervious concrete mixture contains little or no sand, creating a substantial void content. Using sufficient paste to coat and bind the aggregate particles together creates a system of highly permeable, interconnected voids that drains quickly. Typically, between 15% and 25% voids are achieved in the hardened concrete, and flow rates for water through pervious concrete typically are around 480 in./hr (0.34 cm/s, which is 5 gal/ft^2/ min or 200 L/m^2/min), although they can be much higher. Both the low mortar content and high porosity also reduce strength compared to conventional concrete mixtures, but sufficient strength for many applications is readily achieved.

While pervious concrete can be used for a surprising number of applications, its primary use is in pavement. This report will focus on the pavement applications of the material, which also has been referred to as porous concrete, permeable concrete, no-fines concrete, gap-graded concrete, and enhanced-porosity concrete.

Figure 1. Pervious concrete's key characteristic is its open pore structure that allows high rates of water transmission. Trail in Athens Regional Park in Athens, TN, (A. Sparkman). [IMG15880]

Applications

Although not a new technology (it was first used in 1852 (Ghafoori and Dutta 1995b), pervious concrete is receiving renewed interest, partly because of federal clean water legislation. The high flow rate of water through a pervious concrete pavement allows rainfall to be captured and to percolate into the ground, reducing stormwater runoff, recharging groundwater, supporting sustainable construction, providing a solution for construction that is sensitive to environmental concerns, and helping owners comply with EPA stormwater regulations. This unique ability of pervious concrete offers advantages to the environment, public agencies, and building owners by controlling rainwater on-site and addressing stormwater runoff issues. This can be of particular interest in urban areas or where land is very expensive. Depending on local regulations and environment, a pervious concrete pavement and its subbase may provide enough water storage capacity to eliminate the need for retention ponds, swales, and other precipitation runoff containment strategies. This provides for more efficient land use and is one factor that has led to a renewed interest in pervious concrete. Other applications that take advantage of the high flow rate through pervious concrete include drainage media for hydraulic structures, parking lots, tennis courts, greenhouses, and pervious base layers under heavy-duty pavements. Its high porosity also gives it other useful characteristics: it is thermally insulating (for example, in walls of buildings) and has good acoustical properties (for sound barrier walls).

Although pavements are the dominant application for pervious concrete in the U.S., it also has been used as a structural material for many years in Europe (Malhotra 1976). Applications include walls for two-story houses, load-bearing walls for high-rise buildings (up to 10 stories), infill panels for high-rise buildings, sea groins, roads, and parking lots. Table 1 lists examples of applications for which pervious concrete has been used successfully, and Figure 2 shows several examples.

All of these applications take advantage of the benefits of pervious concrete's characteristics. However, to achieve these results, mix design and construction details must be planned and executed with care.

Table 1. Applications for Pervious Concrete

Low-volume pavements
Residential roads, alleys, and driveways
Sidewalks and pathways
Parking lots
Low water crossings
Tennis courts
Subbase for conventional concrete pavements
Patios
Artificial reefs
Slope stabilization
Well linings
Tree grates in sidewalks
Foundations/floors for greenhouses, fish hatcheries, aquatic amusement centers, and zoos
Hydraulic structures
Swimming pool decks
Pavement edge drains
Groins and seawalls
Noise barriers
Walls (including load-bearing)

Figure 2 continued on next page.

Figure 2. Example applications of pervious concrete.
(a) Oregon zoo sidewalk, Portland, OR (P. Davis) [IMG15881]; (b) Miller Park in Fair Oaks, CA, (A. Youngs) [IMG15882]; (c) Finley Stadium parking lot, Chattanooga, TN (L. Tiefenthaler) [IMG15883]; (d) Imperial Beach Sports Park, CA (D. Akers) [IMG15884]; (e) Storage facility lot, Mt. Angel, OR (R. Banka) [IMG15885]; (f) Colored pervious concrete walkway, Bainbridge Island, WA (G. McKinnon) [IMG15886]; (g) Large concrete parking lot, Buford, GA (L. Tiefenthaler) [IMG15887]

Performance

After placement, pervious concrete has a textured surface which many find aesthetically pleasing and which has been compared to a Rice Krispies® treat. Its low mortar content and little (or no) fine aggregate content yield a mixture with a very low slump, with a stiffer consistency than most conventional concrete mixtures. In spite of the high voids content, properly placed pervious concrete pavements can achieve strengths in excess of 3000 psi (20.5 MPa) and flexural strengths of more than 500 psi (3.5 MPa). This strength is more than adequate for most low-volume pavement applications, including high axle loads for garbage truck and emergency vehicles such as fire trucks. More demanding applications require special mix designs, structural designs, and placement techniques.

Pervious concrete is not difficult to place, but it is different from conventional concrete, and appropriate construction techniques are necessary to ensure its performance. It has a relatively stiff consistency, which dictates its handling and placement requirements. The use of a vibrating screed is important for optimum density and strength. After screeding, the material usually is compacted with a steel pipe roller. There are no bullfloats, darbies, trowels, etc. used in finishing pervious concrete, as those tools tend to seal the surface. Joints, if used, may be formed soon after consolidation, or installed using conventional sawing equipment. (However, sawing can induce raveling at the joints.) Some pervious concrete pavements are placed without joints. Curing with plastic sheeting must start immediately after placement and should continue for at least seven days. Careful engineering is required to ensure structural adequacy, hydraulic performance, and minimum clogging potential. More detail on these topics is provided in subsequent sections.

Environmental Benefits

As mentioned earlier, pervious concrete pavement systems provide a valuable stormwater management tool under the requirements of the EPA Storm Water Phase II Final Rule (EPA 2000). Phase II regulations provide programs and practices to help control the amount of contaminants in our waterways. Impervious pavements—particularly parking lots—collect oil, anti-freeze, and other automobile fluids that can be washed into streams, lakes, and oceans when it rains.

EPA Storm Water regulations set limits on the levels of pollution in our streams and lakes. To meet these regulations, local officials have considered two basic approaches: 1) reduce the overall runoff from an area, and 2) reduce the level of pollution contained in runoff. Efforts to reduce runoff include zoning ordinances and regulations that reduce the amount of impervious surfaces in

Table 2. Effectiveness of Porous Pavement Pollutant Removal, % by mass*

Study location	Total suspended solids (TSS)	Total phosphorus (TP)	Total nitrogen (TN)	Chemical oxygen demand (COD)	Metals
Prince William, VA	82	65	80	—	—
Rockville, MD	95	65	85	82	98–99

*Schueler, 1987, as quoted in EPA, 2004. This data was not collected on pervious concrete systems, but on another porous pavement material.

new developments (including parking and roof areas), increased green space requirements, and implementation of "stormwater utility districts" that levy an impact fee on a property owner based on the amount of impervious area. Efforts to reduce the level of pollution from stormwater include requirements for developers to provide systems that collect the "first flush" of rainfall, usually about 1 in. (25 mm), and "treat" the pollution prior to release. Pervious concrete pavement reduces or eliminates runoff and permits "treatment" of pollution: two studies conducted on the long-term pollutant removal in porous pavements suggest high pollutant removal rates. The results of the studies are presented in Table 2.

By capturing the first flush of rainfall and allowing it to percolate into the ground, soil chemistry and biology are allowed to "treat" the polluted water naturally. Thus, stormwater retention areas may be reduced or eliminated, allowing increased land use. Furthermore, by collecting rainfall and allowing it to infiltrate, groundwater and aquifer recharge is increased, peak water flow through drainage channels is reduced and flooding is minimized. In fact, the EPA named pervious pavements as a BMP for stormwater pollution prevention (EPA 1999) because they allow fluids to percolate into the soil.

Another important factor leading to renewed interest in pervious concrete is an increasing emphasis on sustainable construction. Because of its benefits in controlling stormwater runoff and pollution prevention, pervious concrete has the potential to help earn a credit point in the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) Green Building Rating System (Sustainable Sites Credit 6.1) (PCA 2003 and USGBC 2003), increasing the chance to obtain LEED project certification. This credit is in addition to other LEED credits that may be earned through the use of concrete for its other environmental benefits, such as reducing heat island effects (Sustainable Site Credit 7.1), recycled content (Materials and Resources Credit 4), and regional materials (Materials and Resources Credit 5).

The light color of concrete pavements absorbs less heat from solar radiation than darker pavements, and the relatively open pore structure of pervious concrete stores less heat, helping to lower heat island effects in urban areas.

Trees planted in parking lots and city sidewalks offer shade and produce a cooling effect in the area, further reducing heat island effects. Pervious concrete pavement is ideal for protecting trees in a paved environment. (Many plants have difficulty growing in areas covered by impervious pavements, sidewalks and landscaping, because air and water have difficulty getting to the roots.) Pervious concrete pavements or sidewalks allow adjacent trees to receive more air and water and still permit full use of the pavement (see Figure 2 (b)). Pervious concrete provides a solution for landscapers and architects who wish to use greenery in parking lots and paved urban areas.

Although high-traffic pavements are not a typical use for pervious concrete, concrete surfaces also can improve safety during rainstorms by eliminating ponding (and glare at night), spraying, and risk of hydroplaning.

Engineering Properties

Fresh Properties

The plastic pervious concrete mixture is stiff compared to traditional concrete. Slumps, when measured, are generally less than ¾ in. (20 mm), although slumps as high as 2 in. (50 mm) have been used. When placed and compacted, the aggregates are tightly adhered to one another and exhibit the characteristic open matrix.

For quality control or quality assurance, unit weight or bulk density is the preferred measurement because some fresh concrete properties, such as slump, are not meaningful for pervious concrete. Conventional cast cylinder strength tests also are of little value, because the field consolidation of pervious concrete is difficult to reproduce in cylindrical test specimens, and strengths are heavily dependent on the void content. Unit weights of pervious concrete mixtures are approximately 70% of traditional concrete mixtures.

Concrete working time typically is reduced for pervious concrete mixtures. Usually one hour between mixing and placing is all that is recommended. However, this can be controlled using retarders and hydration stabilizers that extend the working time by as much as 1.5 hours, depending on the dosage.

Hardened Properties

Density and porosity. The density of pervious concrete depends on the properties and proportions of the materials used, and on the compaction procedures used in placement. In-place densities on the order of 100 lb/ft^3 to 125 lb/ft^3 (1600 kg/m^3 to 2000 kg/m^3) are common, which is in the upper range of lightweight concretes. A pavement 5 in. (125 mm) thick with 20% voids will be able to store 1 in. (25 mm) of a sustained rainstorm in its voids, which covers the vast majority of rainfall events in the U.S. When placed on a 6-in. (150-mm) thick layer of open-graded gravel or crushed rock subbase, the storage capacity increases to as much as 3 in. (75 mm) of precipitation (see Figure 3 and discussion on Hydrological Design Considerations).

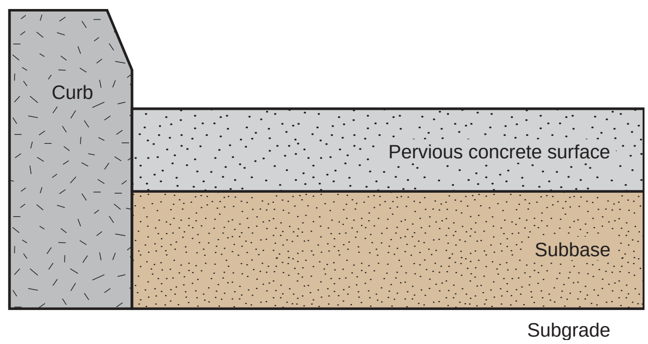

Figure 3. Typical cross section of pervious concrete pavement. On level subgrades, stormwater storage is provided in the pervious concrete surface layer (15% to 25% voids), the subbase (20% to 40% voids), and above the surface to the height of the curb (100% voids). Adapted from Paine 1990.

Permeability. The flow rate through pervious concrete depends on the materials and placing operations. Typical flow rates for water through pervious concrete are 3gal/ft^2/min (288 in./hr, 120 L/m^2/min, or 0.2 cm/s) to 8 gal/ft^2/min (770 in./hr, 320 L/m^2/min, or 0.54 cm/s), with rates up to 17 gal/ft^2/min (1650 in./hr, 700 L/m^2/min, 1.2 cm/s) and higher having been measured in the laboratory (Crouch 2004).

Compressive strength. Pervious concrete mixtures can develop compressive strengths in the range of 500 psi to 4000 psi (3.5 MPa to 28 MPa), which is suitable for a wide range of applications. Typical values are about 2500 psi (17 MPa). As with any concrete, the properties and combinations of specific materials, as well as placement techniques and environmental conditions, will dictate the actual in-place strength. Drilled cores are the best measure of in-place strengths, as compaction differences make cast cylinders less representative of field concrete.

Flexural strength. Flexural strength in pervious concretes generally ranges between about 150 psi (1 MPa) and 550 psi (3.8 MPa). Many factors influence the flexural strength, particularly degree of compaction, porosity, and the aggregate:cement (A/C) ratio. However, the typical application constructed with pervious concrete does not require the measurement of flexural strength for design.

Shrinkage. Drying shrinkage of pervious concrete develops sooner, but is much less than conventional concrete. Specific values will depend on the mixtures and materials used, but values on the order of 200×10^{-6} have been reported (Malhotra 1976), roughly half that of conventional concrete mixtures. The material's low paste and mortar content is a possible explanation. Roughly 50% to 80% of shrinkage occurs in the first 10 days, compared to 20% to 30% in the same period for conventional concrete. Because of this lower shrinkage and the surface texture, many pervious concretes are made without control joints and allowed to crack randomly.

Durability

Freeze-thaw resistance. Freeze-thaw resistance of pervious concrete in the field appears to depend on the saturation level of the voids in the concrete at the time of freezing. In the field, it appears that the rapid draining characteristics of pervious concrete prevent saturation from occurring. Anecdotal evidence also suggests that snow-covered pervious concrete clears quicker, possibly because its voids allow the snow to thaw more quickly than it would on conventional pavements. In fact, several pervious concrete placements in North Carolina and Tennessee have been in service for more than 10 years.

Note that the porosity of pervious concrete from the large voids is distinctly different from the microscopic air voids that provide protection to the paste in conventional concrete in a freeze-thaw environment. When the large open voids are saturated, complete freezing can cause severe damage in only a few cycles. Standardized testing by ASTM C 666 may not represent field conditions fairly, as the large open voids are kept saturated in the test, and because the rate of freezing and thawing is rapid. Neithalath (2003) found that even after 80 cycles of slow freezing and thawing (one cycle/day), pervious concrete mixtures maintained more than 95% of their relative dynamic modulus, while the same mixtures showed less than 50% when tested at a more rapid rate (five to six cycles/day). It was noted that better performance also could be expected in the field because of the rapid draining characteristics of pervious concrete.

Research indicates that entrained air in the paste dramatically improves freeze-thaw protection for pervious concrete (Neithalath 2003; Malhotra 1976). In addition to the use of air-entraining agents in the cement paste, placing the pervious concrete on a minimum of 6 in. (150 mm) (often up to 12 in. (300 mm) or even 18 in. (450 mm)) of a drainable rock base, such as 1-in. (25-mm) crushed stone, is normally recommended in freeze-thaw environments where any substantial moisture will be encountered during freezing conditions (NRMCA 2004a).

Sulfate resistance. Aggressive chemicals in soils or water, such as acids and sulfates, are a concern to conventional concrete and pervious concrete alike, and the mechanisms for attack are similar. However, the open structure of pervious concrete may make it more susceptible to attack over a larger area. Pervious concretes can be used in areas of high-sulfate soils and groundwaters if isolated from them. Placing the pervious concrete over a 6-in. (150-mm) layer of 1-in. (25-mm) maximum top size aggregate provides a pavement base, stormwater storage, and isolation for the pervious concrete. Unless these precautions are taken, in aggressive environments, recommendations of ACI 201 on water:cement ratio, and material types and proportions should be followed strictly.

Abrasion resistance. Because of the rougher surface texture and open structure of pervious concrete, abrasion and raveling of aggregate particles can be a problem, particularly where snowplows are used to clear pavements. This is one reason why applications such as highways generally are not suitable for pervious concretes. However, anecdotal evidence indicates that pervious concrete pavements allow snow to melt faster, requiring less plowing.

Most pervious concrete pavements will have a few loose aggregates on the surface in the early weeks after opening to traffic. These rocks were loosely bound to the surface initially, and popped out because of traffic loading. After the first few weeks, the rate of surface raveling is reduced considerably and the pavement surface becomes much more stable. Proper compaction and curing techniques will reduce the occurrence of surface raveling.

Mixture Proportioning

Materials

Pervious concrete uses the same materials as conventional concrete, with the exceptions that the fine aggregate typically is eliminated entirely, and the size distribution (grading) of the coarse aggregate is kept narrow, allowing for relatively little particle packing. This provides the useful hardened properties, but also results in a mix that requires different considerations in mixing, placing, compaction, and curing. The mixture proportions are somewhat less forgiving than conventional concrete mixtures—tight controls on batching of all of the ingredients are necessary to provide the desired results. Often, local concrete producers will be able to best determine the mix proportions for locally available materials based on trial batching and experience. Table 3 provides typical ranges of materials proportions in pervious concrete, and ACI 211.3 provides a procedure for producing pervious concrete mixture proportions.

Table 3. Typical Ranges of Materials Proportions in Pervious Concrete***

	Proportions, lb/yd³	Proportions, kg/m³
Cementitious materials	450 to 700	270 to 415
Aggregate	2000 to 2500	1190 to 1480
Water:cement ratio*** (by mass)	0.27 to 0.34	
Aggregate:cement ratio*** (by mass)	4 to 4.5:1	
Fine:coarse aggregate ratio**** (by mass)	0 to 1:1	

* These proportions are given for information only. Successful mixture design will depend on properties of the particular materials used and must be tested in trial batches to establish proper proportions and determine expected behavior. Concrete producers may have mixture proportions for pervious concrete optimized for performance with local materials. In such instances those proportions are preferable.

** Chemical admixtures, particularly retarders and hydration stabilizers, are also used commonly, at dosages recommended by the manufacturer. Use of supplementary cementitious materials, such as fly ash and slag, is common as well.

*** Higher ratios have been used, but significant reductions in strength and durability may result.

**** Addition of fine aggregate will decrease the void content and increase strength.

Cementitious materials. As in traditional concreting, portland cements (ASTM C 150, C 1157) and blended cements (ASTM C 595, C 1157) may be used in pervious concrete. In addition, supplementary cementitious materials (SCMs), such as fly ash and pozzolans (ASTM C 618) and ground-granulated blast furnace slag (ASTM C 989), may be used. Testing materials beforehand through trial batching is strongly recommended so that properties that can be important to performance (setting time, rate of strength development, porosity, and permeability, among others) can be determined.

Aggregate. Fine aggregate content is limited in pervious concrete and coarse aggregate is kept to a narrow gradation. Commonly used gradations of coarse aggregate include ASTM C 33 No. 67 (¾ in. to No. 4), No. 8 (⅜ in. to No. 16), or No. 89 (⅜ in. to No. 50) sieves [in metric units: No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), or No. 89 (9.5 to 1.18 mm), respectively]. Single-sized aggregate up to 1 in. (25 mm) also has been used. ASTM D 448 also may be used for defining gradings. A narrow grading is the important characteristic. Larger aggregates provide a rougher surface. Recent uses for pervious concrete have focused on parking lots, low-traffic pavements, and pedestrian walkways. For these applications, the smallest sized aggregate feasible is used for aesthetic reasons. Coarse aggregate size 89 (⅜-in. or 9.5-mm top size) has been used extensively for parking lot

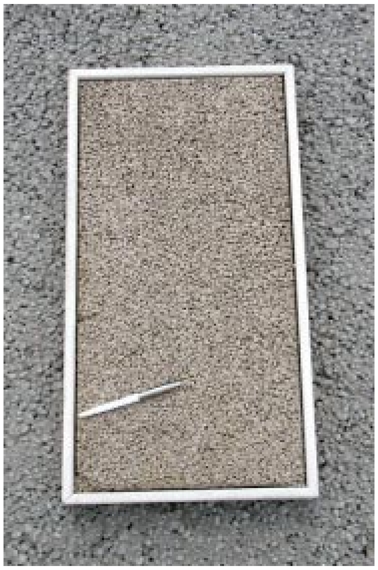

Figure 4. Pervious concrete is made with a narrow aggregate gradation, but different surface textures can be obtained through the use of different maximum sizes. The concrete in the box contained a 1/4-in. (6.5-mm) top size, while that below used a larger top size, 3/4 in. (20 mm) (J. Arroyo). [IMG15888]

and pedestrian applications, dating back 20 years or more in Florida. Figure 4 shows two different aggregate sizes used in pervious concretes to create different surface textures.

Generally, A/C ratios are in the range of 4.0 to 4.5 by mass. These A/C ratios lead to aggregate contents of between about 2200 lb/yd^3 and 3000 lb/yd^3 (1300 kg/m^3 to 1800 kg/m^3). Higher A/C ratios have been used in laboratory studies (Malhotra 1976), but significant reductions in strength result.

Both rounded aggregate (gravel) and angular aggregate (crushed stone) have been used to produce pervious concrete. Typically, higher strengths are achieved with rounded aggregates, although angular aggregates generally are suitable. Aggregates for pavements should conform to ASTM D 448, while ASTM C 33 covers aggregates for use in general concrete construction. As in conventional concrete, pervious concrete requires aggregates to be close to a saturated, surface-dry condition or close monitoring of the moisture condition of aggregates should allow for accounting for the free moisture on aggregates. It should be noted that control of water is important in pervious concrete mixtures. Water absorbed from the mixture by aggregates that are too dry can lead to dry mixtures that do not place or compact well. However, extra water in aggregates contributes to the mixing water and increases the water to cement ratio of the concrete.

Water. Water to cementitious materials ratios between 0.27 to 0.30 are used routinely with proper inclusion of chemical admixtures, and those as high as 0.34 and 0.40 have been used successfully. The relation between strength and water to cementitious materials ratio is not clear for pervious concrete because unlike conventional concrete, the total paste content is less than the voids content between the aggregates. Therefore, making the paste stronger may not always lead to increased overall strength. Water content should be tightly controlled. The correct water content has been described as giving the mixture a sheen, without flowing off of the aggregate. A handful of pervious concrete formed into a ball will not crumble or lose its void structure as the paste flows into the spaces between the aggregates. See Figure 5.

Figure 5. Samples of pervious concrete with different water contents, formed into a ball: (a) too little water, (b) proper amount of water, and (c) too much water. [IMG15595, IMG15596, IMG15597]

Water quality is discussed in ACI 301. As a general rule, water that is drinkable is suitable for use in concrete. Recycled water from concrete production operations may be used as well, if it meets provisions of ASTM C 94 or AASHTO M 157. If there is a question as to the suitability of a water source, trial batching with job materials is recommended.

Admixtures. Chemical admixtures are used in pervious concrete to obtain special properties, as in conventional concrete. Because of the rapid setting time associated with pervious concrete, retarders or hydration-stabilizing admixtures are used commonly. Use of chemical admixtures should closely follow manufacturer's recommendations. Air-entraining admixtures can reduce freeze-thaw damage in pervious concrete and are used where freeze-thaw is a concern. ASTM C 494 governs chemical admixtures, and ASTM C 260 governs air-entraining admixtures. Proprietary admixture products that facilitate placement and protection of pervious pavements are also used.

Design

Basis for Design

Two factors determine the design thickness of pervious pavements: the hydraulic properties, such as permeability and volume of voids, and the mechanical properties, such as strength and stiffness. Pervious concrete used in pavement systems must be designed to support the intended traffic load and contribute positively to the site-specific stormwater management strategy. The designer selects the appropriate material properties, the appropriate pavement thickness, and other characteristics needed to meet the hydrological requirements and anticipated traffic loads simultaneously. Separate analyses are required for both the hydraulic and the structural requirements, and the larger of the two values for pavement thickness will determine the final design thickness.

This section presents an overview of considerations for both hydraulic and structural aspects of designing pervious concrete pavements.

Hydrological Design Considerations

The design of a pervious concrete pavement must consider many factors. The three primary considerations are the amount of rainfall expected, pavement characteristics, and underlying soil properties. However, the controlling hydrological factor in designing a pervious concrete system is the intensity of surface runoff that can be tolerated. The amount of runoff is less than the total rainfall because a portion of the rain is captured in small depressions in the ground (depression storage), some infiltrates into the soil, and some is intercepted by the ground cover. Runoff also is a function of the soil properties, particularly the rate of infiltration: sandy, dry soils will take in water rapidly, while tight clays may absorb virtually no water during the time of interest for mitigating storm runoff. Runoff also is affected by the nature of the storm itself; different sizes of storms will result in different amounts of runoff, so the selection of an appropriate design storm is important. This section will briefly discuss these topics. For more detail, see Leming (in press).

In many situations, pervious concrete simply replaces an impervious surface. In other cases, the pervious concrete pavement system must be designed to handle much more rainfall than will fall on the pavement itself. These two applications may be termed “passive” and “active” runoff mitigation, respectively. A passive mitigation system can capture much, if not all, of the “first flush,” but is not intended to offset excess runoff from adjacent impervious surfaces. An active mitigation system is designed to maintain runoff at a site at specific levels. Pervious concrete used in an active mitigation system must treat runoff from other features on-site as well, including buildings, areas paved with conventional impervious concrete, and buffer zones, which may or may not be planted. When using an active mitigation system, curb, gutter, site drainage, and ground cover should ensure that flow of water into a pervious pavement system does not bring in sediment and soil that might result in clogging the system. One feasibility study found that by using pervious concrete for a parking lot roughly the size of a football field, approximately 9 acres (3.6 hectares) of an urbanized area would act hydrologically as if it were grass (Malcolm, 2002).

Rainfall

An appropriate rainfall event must be used to design pervious concrete elements. Two important considerations are the rainfall amount for a given duration and the distribution of that rainfall over the time period specified. Estimates for these values may be found in TR-55 (USDA 1986) and NOAA Atlas 2 or Atlas 14 maps (NOAA 1973; Bonnin et al. 2004). (See Figure 6.) For example, in one location in the mid-Atlantic region, 3.6 in. (9 cm) of rain is expected to fall in a 24-hour period, once every two years, on average. At

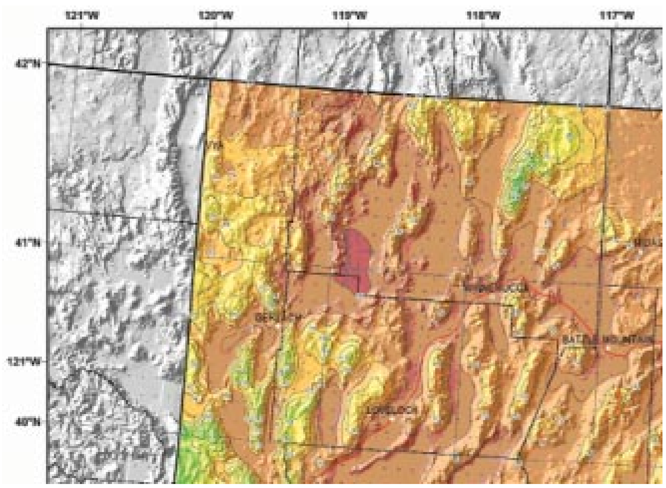

Figure 6. Isopluvials of 2-year, 24-hour precipitation in tenths of an inch, for a portion of Nevada. Maps such as these are useful in determining hydrological design requirements for pervious concrete based on the amount of precipitation expected. Map available at: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_data.html. [IMG15889]

that same location, the maximum rainfall anticipated in a two-hour duration every two years is under 2 in. (5 cm).

Selection of the appropriate return period is important because that establishes the quantity of rainfall which must be considered in the design. The term "two-year" storm means that a storm of that size is anticipated to occur only once in two years. The two-year storm is sometimes used for design of pervious concrete paving structures, although local design requirements may differ.

Pavement Hydrological Design

When designing pervious concrete stormwater management systems, two conditions must be considered: permeability and storage capacity. Excess surface runoff—caused by either excessively low permeability or inadequate storage capacity—must be prevented.

Permeability. In general, the concrete permeability limitation is not a critical design criteria. Consider a passive pervious concrete pavement system overlying a well-draining soil. Designers should ensure that permeability is sufficient to accommodate all rain falling on the surface of the pervious concrete. For example, with a permeability of 3.5 gal/ft^2/min (140 L/m^2/min), a rainfall in excess of 340 in./hr (0.24 cm/s) would be required before permeability becomes a limiting factor. The permeability of pervious concretes is not a practical controlling factor in design. However, the flow rate through the subgrade may be more restrictive (see discussion under "Subbase and Subgrade Soils").

Storage capacity. Storage capacity of a pervious concrete system typically is designed for specific rainfall events, which are dictated by local requirements. The total volume of rain is important, but the infiltration rate of the soil also must be considered. Details may be found in Leming (in press).

The total storage capacity of the pervious concrete system includes the capacity of the pervious concrete pavement, the capacity of any subbase used, and the amount of water which leaves the system by infiltration into the underlying soil. The theoretical storage capacity of the pervious concrete is its effective porosity: that portion of the pervious concrete which can be filled with rain in service. If the pervious concrete has 15% effective porosity, then every 1 in. (25 mm) of pavement depth can hold 0.15 in. (4 mm) of rain. For example, a 4-in. (100-mm) thick pavement with 15% effective porosity on top of an impervious clay could hold up to 0.6 in. (15 mm) of rain before contributing to excess rainfall runoff.

Another important source of storage is the subbase. Compacted clean stone (#67 stone, for example) used as a subbase has a design porosity of 40%; a conventional aggregate subbase, with a higher fines content, will have a lower porosity (about 20%). From the example above, if 4 in. (100 mm) of pervious concrete with 15% porosity was placed on 6 in. (150 mm) of clean stone, the nominal storage capacity would be 3.0 in. (75 mm) of rain:

(15%) 4 in. + (40%) 6 in. = 3.0 in.

The effect of the subbase on the storage capacity of the pervious concrete pavement system can be significant.

A critical assumption in this calculation is that the entire system is level. If the top of the slab is not level, and the infiltration rate of the subgrade has been exceeded, higher portions of the slab will not fill and additional rainfall may run to the lowest part of the slab. Once it is filled, the rain will run out of the pavement, limiting the beneficial effects of the pervious concrete. For example, if a 6-in. (150-mm) thick pavement has a 1% slope and is 100 ft (30 m) long, there is a 1-ft (300-mm) difference in elevation from the front to the back and only 25% of the volume can be used to capture rainfall once the infiltration rate of the subgrade is exceeded. (See Figure 7.)

These losses in useable volume because of slopes can be significant, and indicate the sensitivity of the design to slope. When the surface is not level, the depth of the pavement and subbase must be designed to meet the desired runoff goals, or more complex options for handling water flow may

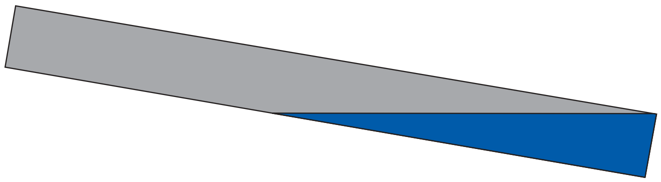

Figure 7. For sloped pavements, storage capacity calculations must consider the angle of the slope, if the infiltration rate of the subgrade is exceeded.

be used. Pervious concrete pavements have been placed successfully on slopes up to 16%. In these cases, trenches have been dug across the slope, lined with 6-mil visqueen, and filled with rock (CCPC 2003). (See Figures 8 and 9.) Pipes extending from the trenches carry water traveling down the paved slope out to the adjacent hillside.

The high flow rates that can result from water flowing downslope also may wash out subgrade materials, weakening the pavement. Use of soil filter fabric is recommended in these cases.

Figure 8. Preparation for a sloped installation. Crushed rock drains at intervals down the slope direct water away from the pavement and prevent water from flowing out of the pervious concrete (See also Figures 9 and 10). (S. Gallego) [IMG15890]

Subbase and Subgrade Soils

Infiltration into subgrade is important for both passive and active systems. Estimating the infiltration rate for design purposes is imprecise, and the actual process of soil infiltration is complex. A simple model is generally acceptable for these applications and initial estimates for preliminary designs can be made with satisfactory accuracy using conservative estimates for infiltration rates. Guidance on the selection of an appropriate infiltration rate to use in design can be found in texts and Soil Surveys published by the Natural Resources Conservation Service (http://soils.usda.gov). TR-55 (USDA 1986) gives approximate values.

As a general rule, soils with a percolation rate of ½ in./hr (12 mm/hr) are suitable for subgrade under pervious pavements. A double-ring infiltrometer (ASTM D 3385) provides one means of determining the percolation rate. Clay soils and other impervious layers can hinder the performance of pervious pavements and may need to be modified to allow proper retention and percolation of precipitation. In some cases, the impermeable layers may need to be excavated and replaced. If the soils are impermeable, a greater thickness of porous subbase must be placed above them. The actual depth must provide the additional retention volume required for each particular project site. Open-graded stone or gravel, open-graded portland cement subbase (ACPA 1994), and sand have provided suitable subgrades to retain and store surface water runoff, reduce the effects of rapid storm runoffs, and reduce compressibility. For existing soils that are predominantly sandy and permeable, an open-graded subbase generally is not required, unless it facilitates placing equipment. A sand and gravel subgrade is suitable for pervious concrete placement.

In very tight, poorly draining soils, lower infiltration rates can be used for design. But designs in soils with a substantial silt and clay content—or a high water table—should be approached with some caution. It is important to recall that natural runoff is relatively high in areas with silty or clayey soils, even with natural ground cover, and properly designed and constructed pervious concrete can provide a positive benefit in almost all situations. For design purposes, the total drawdown time (the time until 100% of the storage capacity has been recovered) should be as short as possible, and generally should not exceed five days (Malcolm 2003).

Another option in areas with poorly draining soils is to install wells or drainage channels through the subgrade to more permeable layers or to traditional retention areas. These are filled with narrowly graded rock to create channels to allow stormwater to recharge groundwater. (See Figure 9.) In this case, more consideration needs to be given to water quality issues, such as water-borne contaminants.

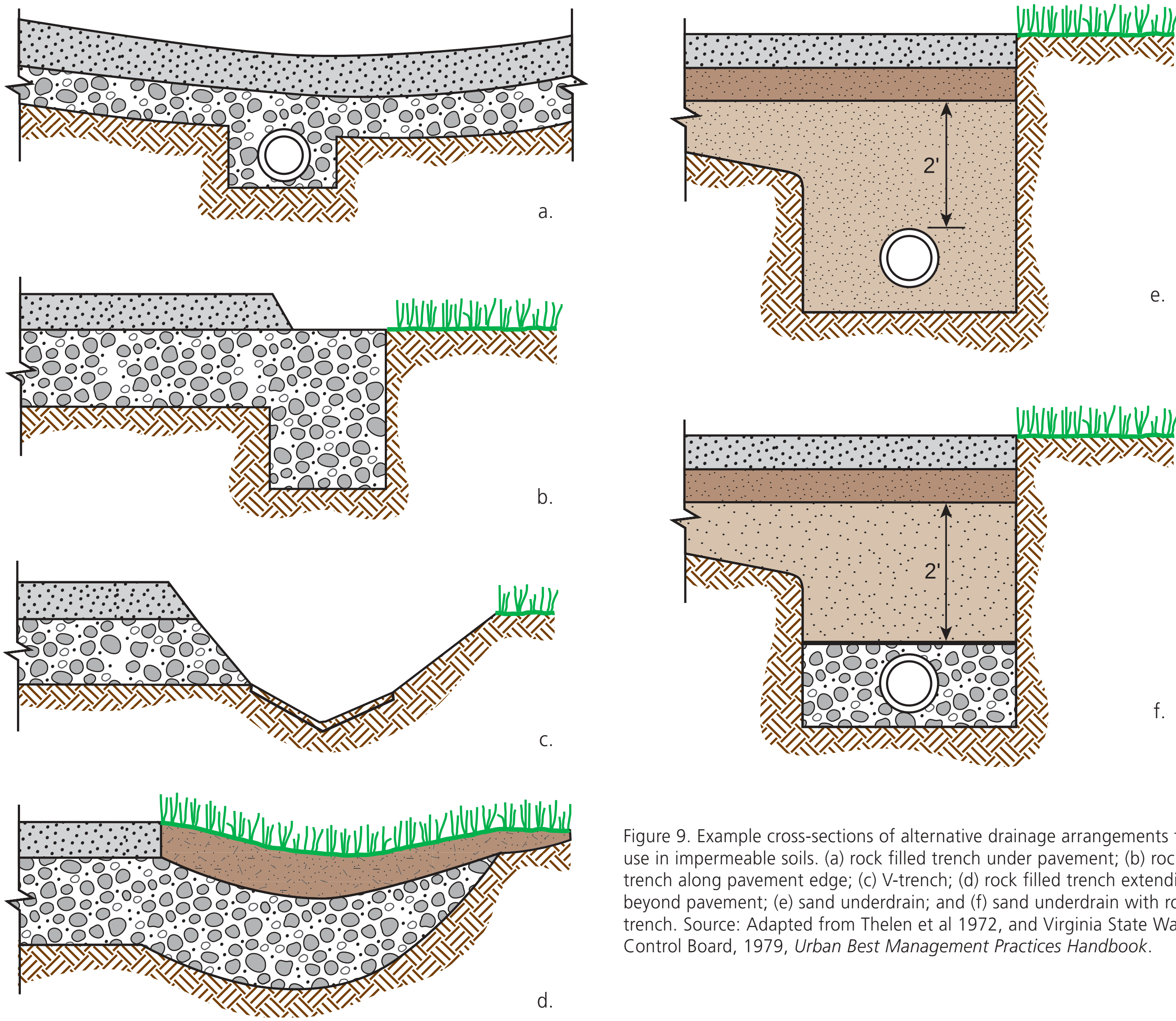

Figure 9. Example cross-sections of alternative drainage arrangements for use in impermeable soils. (a) rock filled trench under pavement; (b) rock trench along pavement edge; (c) V-trench; (d) rock filled trench extending beyond pavement; (e) sand underdrain; and (f) sand underdrain with rock trench. Source: Adapted from Thelen et al 1972, and Virginia State Water Control Board, 1979, *Urban Best Management Practices Handbook*.

Example

As an example, Leming (in press) shows sample calculations for a 3.6 in. (9 cm) (24-hr, two-year) design storm for a site with an active mitigation system composed of an automobile parking area 200 ft by 200 ft (61 m by 61 m) of 6-in. (150-mm) thick pervious concrete with 12% effective porosity and 6 in. (150 mm) of clean stone (40% porosity) overlying a silty soil with an infiltration rate estimated to be 0.1 in./hr (2.5 mm/hr). The pervious concrete system is intended to capture the runoff from an adjacent building (24,000 ft^2 (2300 m^2), impervious) and contiguous park-like, grassed areas (50,000 ft^2 (4600 m^2)), caused by slope, sidewalks, and areas worn from use. In this example, the total runoff was estimated to be about ¾ in. (20 mm) over the entire site for a two-year, 24-hr storm. Without a pervious concrete stormwater management system in place the pre-development runoff would be expected to be 1.2 in. (30 mm) for this storm—about 50% more.

Structural Design Considerations

This section provides guidelines for the structural design of pervious concrete pavements. Procedures described provide a rational basis for analysis of known data and offer methods to determine the structural thickness of pervious concrete pavements.

Pervious concrete is a unique material that has a matrix and behavior characteristics unlike conventional portland cement concrete or other pavement materials. Although these characteristics differ from conventional concretes, they are predictable and measurable. Projects with good to excellent performance over service lives of 20 to 30 years provide a great deal of empirical evidence related to material properties, acceptable subgrades, and construction procedures. Laboratory research in these areas has only recently begun.

Pavement Structural Design

Pervious concrete pavements can be designed using either a standard pavement procedure (AASHTO, WinPAS, PCAPAV, ACI 325.9R, or ACI 330R) or using structural numbers derived from a flexible pavement design procedure. Regardless of the procedure used, guidelines for roadbed (subgrade) soil properties, pervious concrete materials characteristics, and traffic loads should be considered.

Subbase and Subgrade Soils

The design of a pervious pavement base should normally provide a 6- to 12-in. (150- to 300-mm) layer of permeable subbase. The permeable subbase can either be 1 in. (25 mm) maximum size aggregate or a natural subgrade soil that is predominantly sandy with moderate amounts of silts, clays, and poorly graded soil, unless precautions are taken as described in "Clays and Highly Expansive Soils" (later in this section). Either type of material offers good support values as defined in terms of the Westergaard modulus of subgrade reaction (*k*). It is suggested that k not exceed 200 lb/in.^{3} (54 MPa/m), and values of 150 to 175 lb/in.^{3} (40 to 48 MPa/m) generally are suitable for design purposes (FCPA, 2002). Table 4 lists soil characteristics and their approximate *k* values.

The composite modulus of subgrade reaction is defined using a theoretical relationship between *k* values from plate bearing tests (ASTM D 1196 and AASHTO T 222) or estimated from the elastic modulus of subgrade soil (M_R, AASHTO T 292), as:

(Eq. 1) $k\ (pci) = M_R/19.4$, (M_R in units of psi), or

(Eq. 1a) $k\ (MPa/m) = 2.03\ M_R$, (M_R in units of MPa).

where M_R is the roadbed soil resilient modulus (psi). Depending on local practices, the California Bearing Ratio (CBR), R-Value and other tests may be used to determine the support provided by the subgrade. Empirical correlations between *k* and other tests, CBR (ASTM D 1883 and AASHTO T 193), or R-Value test (ASTM D 2844 and AASHTO T 190), are shown in Table 4.

Determining the subgrade's in-situ modulus in its intended saturated service condition can increase the design reliability. If the subgrade is not saturated when the in-situ test is performed, laboratory tests can develop a saturation correction factor. Two samples (one in the "as field test moisture condition" and another in a saturated condition) are subjected to a short-term 10 psi consolidation test. The saturated modulus of subgrade reaction is the ratio of the "field test moisture" to the saturated sample multiplied by the original in-situ modulus.

Table 4. Subgrade Soil Types and Range of Approximate k Values

Type of Soil	Support	*k* Values psi/in^3 (MPa/m)	CBR	R-Value
Fine-grained soils in which silt and clay-size particles predominate	Low	75 to 120 (20 to 34)	2.5 to 3.5	10 to 22
Sands and sand-gravel mixtures with moderate amounts of sand and clay	Medium	130 to 170 (35 to 49)	4.5 to 7.5	29 to 41
Sands and sand-gravel mixtures relatively free of plastic fines	High	180 to 220 (50 to 60)	8.5 to 12	45 to 52

Clays and Highly Expansive Soils

Special design provisions should be considered in the design of pervious concrete pavement for areas with roadbed soils containing significant amounts of clay and silts of high compressibility, muck, and expansive soils. It is recommended that highly organic materials be excavated and replaced with soils containing high amounts of coarser fill material. Also, the design may include filter reservoirs of sand, open-graded stone, and gravel to provide adequate containment and increase the support values. Another design alternative is a sand subbase material placed over a pavement drainage fabric to contain fine particles. In lieu of the sandy soil, a pervious pavement of larger open-graded coarse aggregate (1½ in. or 38 mm) may provide a subbase for a surface course of a pervious mixture containing ⅜-in. (9.5-mm) aggregate. Figure 9 shows several options as examples.

Traffic Loads

The anticipated traffic carried by the pervious pavement can be characterized as equivalent 18,000-lb single axle loads (ESALs), average daily traffic (ADT), or average daily truck traffic (ADTT). Since truck traffic impacts pavements to a greater extent than cars, the estimate of trucks using the pervious pavement is critical to designing a long-life pavement.

Other Design Factors

Depending on the pavement design program used, design factors other than traffic and concrete strength may be incorporated. For example, if the AASHTO design procedure is used, items such as terminal serviceability, load transfer at joints, and edge support are important considerations. The terminal serviceability factor for pervious concrete is consistent with conventional paving. At joints, designers should take credit for load transfer by aggregate interlock. If curbs, sidewalks, and concrete aprons are used at the pavement edges, using the factors for pavement having edge support is recommended.

Pervious concrete should be jointed unless cracking is acceptable. Since the pervious concrete has a minimal amount of water, the cracking potential is decreased and owners generally do not object to the surface cracks.

Materials Properties Related to Pavement Design

The flexural strength of concrete in a rigid pavement is very important to its design. Rigid pavement design is based on the strength of the pavement, which distributes loads uniformly to the subgrade. However, testing to determine the flexural strength of pervious concrete may be subject to high variability; therefore, it is common to measure compressive strengths and to use an empirical relationship to estimate flexural strengths for use in design. Since the strength determines the performance level of the pavement and its service life, the properties of the pervious concrete should be evaluated carefully.

A mix design for a pervious pavement application will yield a wide range of strengths and permeability values, depending on the degree of compaction. Pre-construction testing should determine the relationship between compressive or splitting tensile and flexural strength, as well as the unit weight and/or voids content for the materials proposed for use. The strength so determined can be used in standard pavement design programs such as AASHTO, WinPAS, PCAPAV, ACI 325.9R, or ACI 330R, to name a few.

Specification Guidance

Recommendations and specifications for pervious concrete have been prepared by the National Ready Mixed Concrete Association (NRMCA 2004b), the Florida Concrete and Products Association (FCPA 2001), the Georgia Concrete and Products Association (GCPA 1997), and the Pacific Southwest Concrete Alliance (PSCA 2004). ACI Committee 522 is actively preparing a comprehensive document on the use of pervious concrete.

Construction

Subgrade and Subbase Preparation

Uniformity of subgrade support is a key criterion for placing pervious pavement. As in other types of pavements, truck ruts and other irregularities must be smoothed and compacted prior to placement. Since subgrade and subbase preparation are critical components of pervious concrete pavement performance, refer to "Hydrological Design Considerations" and "Structural Design Considerations" elsewhere in this document for more information. Compaction to a minimum density of 90% to 95% of theoretical density per AASHTO T 180 often is recommended for consistent subgrade support; however, increasing the subgrade density decreases its permeability. Local geotechnical engineers may be the best source of knowledge regarding the properties of subgrade soils.

Since pervious pavements contain minimal water and high porosity, care must be taken to ensure that the pavement does not dry out prematurely. The subgrade must be moist (without free-standing water) prior to placement to prevent water from being removed from the lower portion of the pavement too soon. This is recommended practice for conventional concrete pavement placement if conditions for high evaporation rates are present, but is even more important in pervious concrete placement because the high voids can allow more rapid drying, with subsequent decrease in strength and durability, under less extreme conditions.

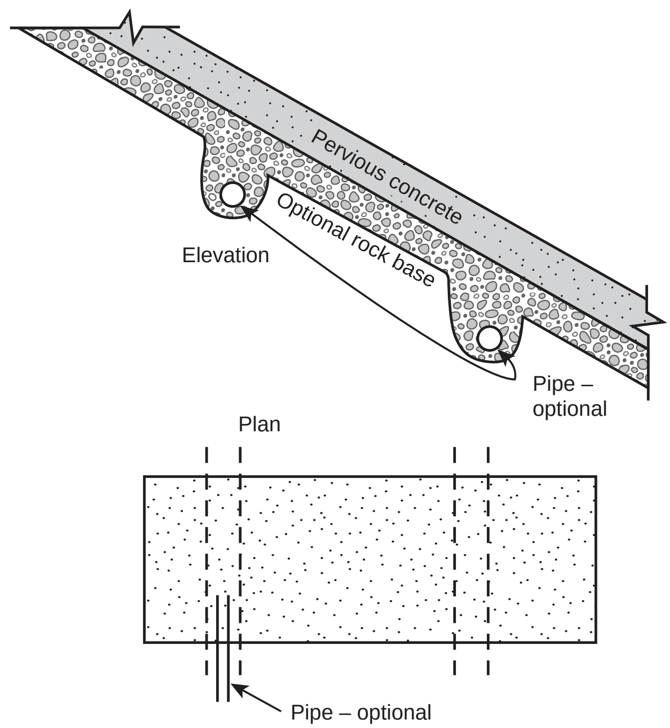

Figure 10. Elevation and plan view drawings of sloped installation.

Batching and Mixing

The special properties of pervious concrete require tighter control of mixture proportioning. In particular, the water content of pervious concrete is limited to a narrow range to provide adequate strength and permeability, and prevent the paste from flowing off the aggregates and closing of the open structure. A limited paste content means that added water will have more drastic impact than that experienced in conventional concrete applications. Aggregate moisture level should be monitored carefully and accounted for, as both water absorbed by the aggregate and excess moisture supplied with the aggregate can be detrimental. Contractors and producers must work together to ensure a proper mixture prior to delivery at the job site. On some occasions, slight adjustments to the water content may be necessary at the job site to achieve proper consistency; however, this should be done with care because jobsite additions of water can be difficult to control. The correct water content will provide a mix with a sheen. A unit weight test is necessary to provide assurance of consistent mixture proportions. Unit weights between 100 lb/ft^3 and 125 lb/ft^3 (1600 kg/m^3 and 2000 kg/m^3) are typical, and on-site measured values typically are required to be within 5% of the design unit weight.

Aggregate and cement proportions will be established by testing and experience with locally available materials, as variations in materials characteristics (for example, cement setting times, strength development rates, aggregate shape, gradation, and density) will limit the usefulness of "cook book" or prescriptive mix designs.

Almost certainly, the mixtures will be stiff. Conventional concrete mixing equipment is used, although mixing times may be extended compared to conventional concrete.

Transportation

Because pervious concrete has a low water content, special attention is required during transportation and placement. Its very low slumps may make discharge from transit mixers slower than for conventional concrete; transit mixers with large discharge openings or paving mixers tend to provide a faster unloading time. A pervious pavement mixture should be discharged completely within one hour after initial mixing. The use of retarding chemical admixtures or hydration-stabilizing admixtures may extend discharge times to 1½ hours or more. High ambient temperatures and windy conditions will have more pronounced effects relative to conventional pavements and should be taken into account.

Placement and Consolidation

A variety of placement techniques can be used for constructing pervious concrete pavements; as with conventional concrete, placement techniques are developed to fit the specific jobsite conditions. It should be noted that pervious concrete mixtures cannot be pumped, making site access an important planning consideration. Prior to placement, the subbase preparation and forms should be double-checked. Any irregularities, rutting, or misalignment should be corrected.

Each load of concrete should be inspected visually for consistency and aggregate coating. The stiff consistency of pervious concrete means that slump testing is not a useful method of quality control. Unit weight tests provide the best routine test for monitoring quality and are recommended for each load of pervious concrete.

Placement should be continuous, and spreading and strikeoff should be rapid. (See Figure 11.) Conventional formwork is used. Mechanical (vibrating) and manual screeds are used commonly, although manual screeds can cause tears in the surface if the mixture is too stiff. Other devices, such as laser screeds, could also be used. For pavements, it is recommended to strike off about ½ to ¾ in. (15 to 20 mm) above the forms to allow for compaction. One technique for accomplishing this (Paine 1992) is to attach a temporary wood strip above the top form to bring it to the desired height. After strikeoff, the strips are removed and the concrete is consolidated to the height of the form. Special height-adjusting vibrating screeds also have been used to provide the extra height. With vibrating screeds, care should be taken that the frequency of vibration is reduced to avoid over-compaction or closing off the surface, resulting in blocked voids. Edges near forms are compacted using a 1 ft by 1 ft (300 mm by 300 mm) steel tamp (like those used in decorative stamped concrete), a float, or other similar device to prevent raveling of the edges.

Figure 11. Pervious concrete is usually placed and then struck off with a vibratory screed. (R. Banka) [IMG15891]

Consolidation generally is accomplished by rolling over the concrete with a steel roller (see Figures 12 and 13), compacting the concrete to the height of the forms. Because of rapid hardening and high evaporation rates, delays in consolidation can cause problems; generally, it is recommended that consolidation be completed within 15 minutes of placement.

Figure 12. Pervious concrete after screeding (left) and after compaction (right). Note the joint aligned with previously placed slab to avoid reflective cracking. Roller used for compaction is visible on the far right. (R. Banka) [IMG15892]

Figure 13. Compaction of pervious concrete with a steel roller. (R. Banka) [IMG15893]

Finishing

Typically, pervious concrete pavements are not finished in the same way as conventional concrete pavements. Normal floating and troweling operations tend to close up the top surface of the voids, which defeats the purpose (for most applications) of pervious concrete. For the majority of pervious pavements, the "finishing" step is the compaction. This leaves a rougher surface, but can improve traction.

Joint Placement

Control joints should be placed if prevention of random cracking of the pavement is desired, although the joint spacing is usually larger than for conventional concrete pavements because pervious concretes tend to shrink much less. Recommended joint spacings of 20 ft (6 m) (GCPA 1997) have been suggested, although some installations have had joint spacings of 45 ft (13.5 m) or more without uncontrolled cracking (Paine 1992). Prevention of uncontrolled reflective cracking is accomplished by installing joints at the same location as in the adjoining pavements. (See Figure 12.) As for conventional pavements, joints one-fourth of the slab thickness provide good control of cracking.

Because setting time and shrinkage are accelerated in pervious concrete construction, joint installation should be soon after consolidation, with a rolling joint tool (see Figure 14). Another technique, suitable for small sections, is to drive a steel straightedge to the required depth with a hammer.

Saw cutting joints also is possible, but is not preferred because slurry from sawing operations may block some of the voids, and excessive raveling of the joints often results. Removing covers to allow sawing also slows curing, and it is recommended that the surfaces be re-wet before the covering is replaced.

As noted previously, some pervious concrete pavements are not jointed, as random cracking is not viewed as a significant deficit in the aesthetic of the pavement (considering its texture), and has no significant affect on the structural integrity of the pavement.

Figure 14. Joint roller, commonly referred to as a "pizza cutter." (R. Banka) [IMG15894]

Curing and Protection

The open structure and relatively rough surface of pervious concrete exposes more surface area of the cement paste to evaporation, making curing even more essential than in conventional concreting. Water is needed for the chemical reactions of the cement and it is critical for pervious concrete to be cured promptly. In some regions, it is common to apply an evaporation retarder *before* compaction to minimize any potential for surface water loss.

Because pervious concrete pavements do not bleed, they can have a high propensity for plastic shrinkage cracking. In fact, "curing" for pervious slabs and pavements begins before the concrete is placed: the subgrade must be moistened to prevent it from absorbing moisture from the concrete. After placement, fog misting followed by plastic sheeting is the recommended curing procedure, and sheeting should remain in place for at least seven days. Using sand or dirt to hold plastic sheeting in place is not recommended because clogging of the voids could result from spillage on removal. Instead, securing plastic sheeting with lumber, rebar, stakes, or other methods is recommended.

Curing should be started as soon as practical after placing, compacting, and jointing. Best practice calls for curing to begin within a maximum of 20 minutes after these procedures. High ambient temperatures and windy conditions will have more pronounced effects relative to conventional pavements and should be taken into account.

Figure 15. Plastic sheeting should be used to cover the pervious concrete and be installed within a few minutes of consolidation to prevent moisture loss. (R. Banka) [IMG15898]

Opening to Traffic

For pavement applications that will see traffic in service, it is generally recommended that the pavements not be opened to construction or public traffic for seven days. Continuous curing is recommended until the pavement is opened.

Inspection and Maintenance

Construction Inspection and Testing

As noted previously, normal construction inspection practices that base acceptance on slump and cylinder strengths are not meaningful for pervious concrete. Strength is a function of the degree of compaction, and compaction of pervious concrete is difficult to reproduce in cylinders. Instead, a unit weight test usually is used for quality assurance, with acceptable values dependent on the mix design, but generally between 100 lb/ft^3 and 125 lb/ft^3 (1600 kg/m^3 and 2000 kg/m^3). ASTM C 29 generally is preferred over ASTM C 138 because of the consistency of pervious concrete, although ASTM C 138 is used in some areas. Testing frequencies of once per day, or when visual inspection indicates a change in the concrete, are common. Acceptance criteria typically are plus or minus 5 lb/ft^3 (80 kg/m^3) of the target value for the mix design.

Post-Construction Inspection and Testing

After seven days, core samples can be taken (per ASTM C 42) and measured for thickness and unit weight as quality assurance and acceptance tests. A typical testing rate is three cores for each 100 yd^3 (75 m^3). Compression testing for strength is not recommended, because of the dependence of compressive strength on compaction. Unit weights, in accordance with ASTM C 140, provide an acceptance measurement; typical requirements dictate that average unit weights be within 5 lb/ft^3 (80 kg/m^3) of the design unit weight. The common criterion for acceptance of thickness is that no core shall be under the design thickness by more than ½ in. (13 mm). It should be noted that pervious concrete pavements may have a higher variability in pavement thicknesses when placed on an open-graded subgrade, compared with conventional concrete pavements.

Maintenance

The majority of pervious concrete pavements function well with little or no maintenance. Maintenance of pervious concrete pavement consists primarily of prevention of clogging of the void structure. In preparing the site prior to construction, drainage of surrounding landscaping should be designed to prevent flow of materials onto pavement surfaces. Soil, rock, leaves, and other debris may infiltrate the voids and hinder the flow of water, decreasing the utility of the pavement. Landscaping materials such as mulch, sand, and topsoil should not be loaded on pervious concrete, even temporarily.

Vacuuming annually or more often may be necessary to remove debris from the surface of the pavements. Other cleaning options may include power blowing and pressure washing. Pressure washing of a clogged pervious concrete pavement has restored 80% to 90% of the permeability in some cases (MCIA 2002). It also should be noted that maintenance practices for pervious concrete pavements are still being developed.

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ACI 301, Specifications for Structural Concrete

ACI 325.9, Guide for Construction of Concrete Pavements and Concrete Bases

ACI 330, Guide for Design & Construction of Concrete Parking Lots

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ASTM C 33, Specification for Concrete Aggregates

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