Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

TO: Thompson Holdings, LLC

COPIES: David Von Rueden P.E./CH2M HILL

FROM: Meabon Burns P.E./CH2M HILL
Erika Powell P.E./CH2M HILL

DATE: October 28, 2008

PROJECT NUMBER: 366335.03

REGISTERED PROFESSIONAL ENGINEER MEABON KYLE BURNS 71053 exp. 6/30/2009 CIVIL STATE OF CALIFORNIA

The purpose of this memorandum is to provide responses to review comments of Technical Memorandums titled Paraiso Springs Resort: Preliminary Hydrology and Hydraulic Analysis and Paraiso Springs Resort: Erosion Control Measures dated July 15, 2005. Comments were provided in a memorandum from Harvey Oslick, MS 1300 to Meryka Blumer, MS 1600 in a memorandum dated January 17, 2008. A copy of this memorandum is included in Attachment 1 for reference.

Additional Analysis to Support Response to Comments

An HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) model was developed to support the response to comments provided in this memorandum. HEC-HMS (version 3.1.0) is a hydrologic model developed and made available by the US Army Corps of Engineers. The key parameters of the analysis methodology are presented below:

- Unit system – U.S Customary
- Loss: – Soil Conservation Service (SCS) Curve Number (CN)
- Transform – Kinematic Wave
- Baseflow – None
- Routing: – Kinematic Wave
- Precipitation – SCS Storm
- Evapotranspiration – None
- Snowmelt – None

Analysis results are presented below within the response to comments.

Response to Comments

Information for Describing Existing Conditions/Setting

Hydrology and Hydraulic Analysis

1. Upon leaving the Project site, stormwater travels first through a natural ravine then through agricultural drainage ditches and culverts under road crossings (see

Attachment 2). The ditches are highly channelized, and are either located along natural drainage paths or adjacent to roads. The banks have been stabilized in some locations by the installation of sandbags. These drainage ditches are man-made, most likely by local property owners, and are characterized by steep, unvegetated side slopes. The level of maintenance for these incised channels is unknown. See Photos 1 through 3 in Attachment 3.

2. Maps showing the subbasin delineation for the Project watershed and Project site are included in Attachment 4. The Project watershed was delineated into nine subbasins. These subbasins were delineated because they either had distinct drainage characteristics or the flows collected at a location where specific project impacts could be identified, such as the potential for landslides or debris flows.

3. The HEC-HMS model facilitates a more rigorous and detailed analysis than the analysis that was conducted for the July 2005 Project evaluation and is appropriate for this application. The 10-year and 100-year event stormwater volumes for the entire watershed, using this more detailed hydrologic methodology as described above, were found to increase from 117.5 ac-ft (123.5 cfs) to 124.0 ac-ft (124.2 cfs) and 261.1 ac-ft (310.9 cfs) to 269.6 ac-ft (315.8 cfs) (see Supporting Data Tables/Figures), respectively. This increase in stormwater runoff of 6.5 ac-ft (0.7 cfs) for the 10-year storm and 8.5 ac-ft (4.9 cfs) for the 100-year storm translates to 5.5 percent and 3.3 percent, respectively, of the total runoff volume and 0.6 percent and 1.6 percent, respectively, of the peak discharge. This result is based on conservative assumptions regarding post-development conditions, such as new impervious area, overland flow roughness, and Soil Conservation Service Curve Numbers (SCS CN).

The approach to minimizing Project impacts due to stormwater runoff, as calculated above, will be to use low impact design (LID) methodologies. Specific LID techniques, often referred to as stormwater best management practices (BMPs), will be determined during the design process. For purposes of this preliminary analysis, the areas of "hardscape" shown on the Land Use Summary Table of the Project Tentative Map were evaluated for appropriate LID construction techniques. Project "hardscape" areas and related potential LID construction techniques are summarized below (CASQA, 2003). Actual BMPs and combinations of BMPs to be used will be evaluated during final design.

- Building footprints (7.22 acres)
  - Roof runoff controls
  - Site design and landscape planning
  - Alternative building materials

- Patios, Paths, and Driveways (5.99 acres)
  - Site design and landscape planning
  - Pervious paving
  - Vegetated swales
  - Vegetated buffer strip
  - Bioretention

- Parking and Roadways (9.98 acres)
  - Pervious paving
  - Vegetated swales
  - Vegetated buffer strip
  - Bioretention

As noted in the July 15, 2005 Memorandum, only 23.19 acres of the 1,160 acre Project watershed will be developed with "hardscape" features. Utilization of the LID techniques, as described above, is anticipated to limit the post-Project runoff from frequent storm events to virtually identical volumes as the pre-Project condition and to result in insignificant increases during the rare, infrequent events (i.e. 100 yr event).

It should also be noted that the Project site is underlain by predominantly sandy soils, as identified in the Project Geologic and Soil Engineering Report, prepared by Landset Engineers, Inc. and dated December 2004. This soil condition should be very compatible with the proposed LID construction techniques.

It should also be noted that the Project stormwater features will be designed to ensure that the pre-project 10-year event flow will continue to reach the drainage channel downstream of the Project site, post-development.

4. A U.S. Geological Survey (USGS) Water-Resources Investigations Report (USGS, 1994), which was used for the previous analysis and is included in Attachment 5, and private, unpublished information indicate that the mean annual precipitation (MAP) is approximately 11 inches east of the Project site. However, the elevation across the entire watershed ranges from 1,000 to approximately 2,400 feet. Therefore, it is likely that the MAP varies, potentially significantly, across the watershed with elevation. Figure 2.3 of the Monterey County Water Resources Agency's (MCWRA) *Water Resources Data Report: Water Year 1994-1995* presents MAP for Monterey County (MCWRA, 2007). The project site location was approximated on this map to find the MAP, see Attachment 6. MAP for the Project site was found to be 23 inches. This MAP was verified by data collected by a rain gage from 1950 to 1982. The Paloma Station is located approximately 9 miles southeast of the Project site (Longitude 121.500 W, Latitude 36.350 N) at an elevation 1,835 feet. The data collected at this station indicates that the MAP is 23.25 inches for the period of record (DWR, 1983).

   Based on available data, the MAP could range from 11 to 23 inches across the entire watershed. To be conservative, a MAP of 23 inches was used for the purpose of this analysis.

   The MAP, 23 inches, was used to calculate precipitation depth for the 10-year and 100-year storms for a duration of 24 hours. Precipitation depth was calculated using the Santa Clara County's Return Period-Duration-Specific (TDS) Regional Equation, which establishes a relationship between precipitation depth and MAP for various storm return periods. This equation was developed based on the three-day December 1995 rainfall event that is still considered to be the storm of record for Northern California. (Santa Clara County, 2007)

5. Detention ponds are not included in the Project, because the LID stormwater mitigation methodologies described above will be implemented. Debris basins, as recommended in

the previously referenced Geologic and Soil Engineering Report, would be implemented and located at the point of concentration for Subbasins N-1 (see Photo 4 in Attachment 3) and N-2, located in Indian Valley along the Northern edge of the Project site, and Subbasins S-1, S-2, and S-3, located along the southern edge of the Project site (see Attachment 4). These debris basins would intercept debris flows/slides from the identified Subbasins, above the developed areas of the Project. They will be located immediately adjacent to Project features and incorporated into the site grading footprint for the overall Project. The debris basins are expected to include a series of two-to-four small soil and rock checkdams, approximately three-feet tall, constructed at the low flow line of the natural drainage feature. Minimal excavation behind the checkdams is planned and no additional trees would be removed for construction. The debris basins would be constructed adjacent to Project roadways, parking lots or maintenance paths to facilitate inspection and maintenance.

Although Subbasin V-1 was identified as a potential site for debris flows, it is not anticipated that a debris basin will be needed at the point of concentration for this basin. The drainage channel was found to be well defined and relatively clear of debris at this location. Rocks that were present were in general no greater than approximately 24 inches in diameter. Debris flowing through the main drainage channel did cause flooding on site during a storm in 1995. However, this was due to the debris blocking flow through an existing culvert located upstream of the hot springs pools (see Photo 8 in Appendix 3). The culverts at this location and the culverts located just upstream of the property line (see Photo 1 in Appendix 3) will be removed as part of the Project to restore the drainage channel capacity. Bridges will be installed to allow vehicular and pedestrian access across the drainage channel. The bridges are expected to be single-span structures, with abutments on each bank of the stream. Stream banks would be reconstructed as part of the bridge construction and lined with rock riprap for scour protection immediately adjacent to the abutments. Small storm drain outfalls would be located within the bridge and rock riprap footprints.

Erosion Control Measures

Because the intention is to implement stormwater BMPs to ensure that post-development stormwater flows in excess of pre-development conditions for a 100-year storm event do not leave the Project site, aggradation of the channel downstream of the project site, is not expected. Based on field observations, most of the sediment that travels from the steeper areas of the watershed to the valley of the watershed during annual rainfall events, is naturally deposited on the flatter areas of the watershed (i.e., within the Project site). Sediment that currently feeds the channel downstream of the Paraiso Springs Resort Project site, during more frequent or annual rainfall events, is contributed by the adjacent floodplain below the Project site through sheetflow. Onsite debris basins will be designed to retain large-particle sediment and other debris, but not suspended sediment. Passage of suspended sediment will also be aided by the removal of existing culverts and the restoration of natural drainage channel conditions as part of the Project. Therefore, it is expected that nutrients that are necessary for the health of the channel, downstream of the project site, will continue to be replenished.

Any points where stormwater flows collect and it is necessary to discharge into the channel will be designed with appropriate and primarily natural erosion protection measures, such as rock slope protection and vegetation.

Regulatory Background Information

Comment noted regarding compliance with the requirements of Monterey County Ordinance Chapter 16.2 Erosion Control and Ordinance Chapter 19.10 Design and Standard Improvements, paragraph 19.10.050, Drainage. Analysis and design efforts for the Project will comply with County policies in place when construction documents are developed. Mitigation measures, such as permeable pavements and vegetated drainage swales, and stormwater collection systems will be designed to ensure that stormwater drainage volume and peak flows do not increase from existing conditions, as a result of the Project.

Comment noted regarding the anticipated new statewide NPDES Construction General Permit. Project construction documents will comply with the most current General Permit.

Analytical Methodology and Significance Thresholds

The proposed project will not alter the course of flow through the main drainage channel, will not significantly alter existing drainage patterns, and will not significantly increase the rate of runoff. Minimal impacts to peak flow discharge and flow volume will be mitigated onsite to ensure that no downstream impacts will result directly from the Project. Downstream capacity will not be exceeded due to the Project, flow in excess of current flows will be allowed to infiltrate on site.

Pre- and post-Project stormwater drainage volumes for 10-year and 100-year storm events are summarized under Supporting Data Tables/Figures below. Stormwater runoff in excess of existing conditions will be allowed to infiltrate on site. Design options that include roof drain catchments, permeable surfaces for roads and pedestrian paths, permeable drainage swales, and other alternatives to typical storm drain facilities will be applied (see Attachment 7). Mitigation and LID improvements are not expected to create any additional environmental impacts and are planned to be located in already disturbed areas as indicated more specifically above.

Project Characteristics and Design Features Description Pertinent to Resource Category

Comment noted, the previous responses provide general information on the proposed design of stormwater features, based upon the LID methodology, and also for the proposed debris basins. Additional information needed for analysis and final design of Project features, such as debris basins and channel stabilization measures would be collected and utilized during the design phase. Resources would include documents such as the *California Stormwater Best Management Practice Handbook: New Development and Redevelopment* developed by the California Stormwater Quality Association (CASQA). These resources would reflect industry accepted, proven BMPs for stormwater management. Additional information and examples from the California Stormwater BMP Handbook is provided in Attachment 7.

Impact Analysis Information

Potential impacts associated with the Project, relative to site drainage and runoff are expected to be mitigated by the proposed LID techniques that would include, but not be limited to, the following design elements (CASQA, 2003), and are highlighted in the responses above.

- Site design and landscape planning
- Roof runoff controls
- Alternative building materials
- Pervious paving
- Vegetated swales
- Vegetated buffer strips
- Bioretention

The existing stream that runs through the Project site will not be modified, except for the removal of existing culverts and bridge construction mentioned previously.

Supporting Data Tables/Figures

Site and watershed photos are presented in Attachment 3.

SCS CN were developed for the HEC-HMS model. The hydrologic soil group (A through D) was identified utilizing an online soils database and mapping system provided by the Natural Resource Conservation Service (NRCS) called Web Soil Survey 2.0. Attachment 8 includes a map of the Project watershed developed using Web Soil Survey 2.0 showing soil type and identifying the hydrologic soil groups appropriate for developing the SCS CN. The basis for SCS CN development is summarized in Table 1; SCS CN used in the HEC-HMS model are summarized in Table 2 by Subbasin.

TABLE 1
Basis for development of Subbasin Soil Conservation Service Curve Numbers
Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

Cover/Land Use [1]	Hydrologic Condition	Curve Numbers for Hydrologic Soil Group			
		A	B	C	D
Forestland – grass or orchards, evergreen or deciduous	Good	32	58	72	79
Residential – average lot size 1/3 acre (average 30% imperious, includes paved streets)	N/A	57	72	81	86

Notes:
1. Taken from Table 8.7.3 (Mays, 2001)

TABLE 2
HEC-HMS Subbasin Soil Conservation Service Curve Numbers
Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

Subbasin	Hydrologic Soil Group [1]	CN: Existing Conditions [2]	CN: Proposed Conditions [3]
V-1	B, C, and D	72	72
V-2			
Plane 1	A, C, and D	72	72
Plane 2	A, B, and D	72	81
N-1	C	72	72
N-2	C	72	72
N-3			
Plane 1	C and D	79	79
Plane 2	B and D	79	86
S-1	B	58	58
S-2	B	58	58
S-3	C	72	72
S-4			
Plane 1	B and C	72	72
Plane 2	B and D	72	81

Notes:
1. When more than one Hydrologic Soil Group was found to be present in a given Subbasin, soil group was determine
2. Assumes cover is Forestland for all Subbasins
3. Assumes cover changes from Forestland to Residential – average lot size 1/3 acre in Subbasins where development is proposed

Based on the current tentative map for the Project, approximately 24 acres of the proposed development could be impervious surfaces post construction if traditional design methods were utilized. However, the goal of the Project is to use LID to minimize the effect of the development to stormwater drainage patterns, to the extent feasible, with the ultimate goal of no net impact. Therefore, the percentage of impervious surface included in the model for post-Project conditions was assumed to be approximately 26 percent of the potential impervious surface area.

Table 3 presents the overall results for the Project watershed, volume and peak discharge, obtained from the HEC-HMS model for pre- and post-project conditions for 10-year and 100-year storm events.

TABLE 3
HEC-HMS Results, Pre- and Post-Project for 10-year and 100-year Storm Events
Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

Parameter	10-year Storm Event		100-year Storm Event	
	Pre-Project	Post Project	Pre-Project	Post Project
Volume (ac-ft)	117.5	124.0	261.1	269.6
Peak Discharge (cfs)	123.5	124.2	310.9	315.8

References

California Department of Water Resources (DWR). 1983. Paloma Gage Station, Station Number D20 6650 00.

California Stormwater Quality Association (CASQA). January 2003. California Stormwater Best Management Practice Handbook: New Development and Redevelopment. <www.cabmphandbooks.com>.

Landset Engineers Inc. December 2004. Geologic and Soil Engineering Feasibility Report for Paraiso Hot Springs Spa Resort, Monterey County, California. Salinas, California.

Mays, Larry W. 2001. *Water Resources Engineering*. John Wiley & Sons, Inc. 1st ed.

Monterey County Water Resources Agency (MCWRA). October 2007. *Water Resources Data Report: Water year 1994-1995*.

Natural Resource Conservation Service (NRCS). 20 June 2007. Web Soil Survey 2.0. <http://websoilsurvey.nrcs.usda.gov/app/>. 5 May 2008.

Santa Clara County. 14 August 2007. *Drainage Manual*.

U.S. Army Corps of Engineers (USACE). March 2000. *Hydrologic modeling System (HEC-HMS): Technical Reference Manual*.

USACE. November 2003. *Hydrologic modeling System (HEC-HMS): Users Manual*. Version 3.1.0.

U.S. Geological Survey (USGS). 1994. *Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites, 1993*. Water Resources Investigations Report 94-4002. Reston, Virginia.

Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

PROFESSIONAL REGISTERED ENGINEER MEABON KYLE BURNS 71053 exp. 6/30/2009 CIVIL STATE OF CALIFORNIA

TO:	Thompson Holdings, LLC
COPIES:	David Von Rueden P.E./CH2M HILL
FROM:	Meabon Burns P.E./CH2M HILL Erika Powell P.E./CH2M HILL
DATE:	October 28, 2008
PROJECT NUMBER:	366335.03

The purpose of this memorandum is to provide responses to review comments of Technical Memorandums titled Paraiso Springs Resort: Preliminary Hydrology and Hydraulic Analysis and Paraiso Springs Resort: Erosion Control Measures dated July 15, 2005. Comments were provided in a memorandum from Harvey Oslick, MS 1300 to Meryka Blumer, MS 1600 in a memorandum dated January 17, 2008. A copy of this memorandum is included in Attachment 1 for reference.

Additional Analysis to Support Response to Comments

An HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) model was developed to support the response to comments provided in this memorandum. HEC-HMS (version 3.1.0) is a hydrologic model developed and made available by the US Army Corps of Engineers. The key parameters of the analysis methodology are presented below:

- Unit system – U.S Customary
- Loss: – Soil Conservation Service (SCS) Curve Number (CN)
- Transform – Kinematic Wave
- Baseflow – None
- Routing: – Kinematic Wave
- Precipitation – SCS Storm
- Evapotranspiration – None
- Snowmelt – None

Analysis results are presented below within the response to comments.

Response to Comments

Information for Describing Existing Conditions/Setting

Hydrology and Hydraulic Analysis

1. Upon leaving the Project site, stormwater travels first through a natural ravine then through agricultural drainage ditches and culverts under road crossings (see

Attachment 2). The ditches are highly channelized, and are either located along natural drainage paths or adjacent to roads. The banks have been stabilized in some locations by the installation of sandbags. These drainage ditches are man-made, most likely by local property owners, and are characterized by steep, unvegetated side slopes. The level of maintenance for these incised channels is unknown. See Photos 1 through 3 in Attachment 3.

2. Maps showing the subbasin delineation for the Project watershed and Project site are included in Attachment 4. The Project watershed was delineated into nine subbasins. These subbasins were delineated because they either had distinct drainage characteristics or the flows collected at a location where specific project impacts could be identified, such as the potential for landslides or debris flows.

3. The HEC-HMS model facilitates a more rigorous and detailed analysis than the analysis that was conducted for the July 2005 Project evaluation and is appropriate for this application. The 10-year and 100-year event stormwater volumes for the entire watershed, using this more detailed hydrologic methodology as described above, were found to increase from 117.5 ac-ft (123.5 cfs) to 124.0 ac-ft (124.2 cfs) and 261.1 ac-ft (310.9 cfs) to 269.6 ac-ft (315.8 cfs) (see Supporting Data Tables/Figures), respectively. This increase in stormwater runoff of 6.5 ac-ft (0.7 cfs) for the 10-year storm and 8.5 ac-ft (4.9 cfs) for the 100-year storm translates to 5.5 percent and 3.3 percent, respectively, of the total runoff volume and 0.6 percent and 1.6 percent, respectively, of the peak discharge. This result is based on conservative assumptions regarding post-development conditions, such as new impervious area, overland flow roughness, and Soil Conservation Service Curve Numbers (SCS CN).

The approach to minimizing Project impacts due to stormwater runoff, as calculated above, will be to use low impact design (LID) methodologies. Specific LID techniques, often referred to as stormwater best management practices (BMPs), will be determined during the design process. For purposes of this preliminary analysis, the areas of "hardscape" shown on the Land Use Summary Table of the Project Tentative Map were evaluated for appropriate LID construction techniques. Project "hardscape" areas and related potential LID construction techniques are summarized below (CASQA, 2003). Actual BMPs and combinations of BMPs to be used will be evaluated during final design.

- Building footprints (7.22 acres)
  - Roof runoff controls
  - Site design and landscape planning
  - Alternative building materials

- Patios, Paths, and Driveways (5.99 acres)
  - Site design and landscape planning
  - Pervious paving
  - Vegetated swales
  - Vegetated buffer strip
  - Bioretention

- Parking and Roadways (9.98 acres)
  - Pervious paving
  - Vegetated swales
  - Vegetated buffer strip
  - Bioretention

As noted in the July 15, 2005 Memorandum, only 23.19 acres of the 1,160 acre Project watershed will be developed with "hardscape" features. Utilization of the LID techniques, as described above, is anticipated to limit the post-Project runoff from frequent storm events to virtually identical volumes as the pre-Project condition and to result in insignificant increases during the rare, infrequent events (i.e. 100 yr event).

It should also be noted that the Project site is underlain by predominantly sandy soils, as identified in the Project Geologic and Soil Engineering Report, prepared by Landset Engineers, Inc. and dated December 2004. This soil condition should be very compatible with the proposed LID construction techniques.

It should also be noted that the Project stormwater features will be designed to ensure that the pre-project 10-year event flow will continue to reach the drainage channel downstream of the Project site, post-development.

4. A U.S. Geological Survey (USGS) Water-Resources Investigations Report (USGS, 1994), which was used for the previous analysis and is included in Attachment 5, and private, unpublished information indicate that the mean annual precipitation (MAP) is approximately 11 inches east of the Project site. However, the elevation across the entire watershed ranges from 1,000 to approximately 2,400 feet. Therefore, it is likely that the MAP varies, potentially significantly, across the watershed with elevation. Figure 2.3 of the Monterey County Water Resources Agency's (MCWRA) *Water Resources Data Report: Water Year 1994-1995* presents MAP for Monterey County (MCWRA, 2007). The project site location was approximated on this map to find the MAP, see Attachment 6. MAP for the Project site was found to be 23 inches. This MAP was verified by data collected by a rain gage from 1950 to 1982. The Paloma Station is located approximately 9 miles southeast of the Project site (Longitude 121.500 W, Latitude 36.350 N) at an elevation 1,835 feet. The data collected at this station indicates that the MAP is 23.25 inches for the period of record (DWR, 1983).

   Based on available data, the MAP could range from 11 to 23 inches across the entire watershed. To be conservative, a MAP of 23 inches was used for the purpose of this analysis.

   The MAP, 23 inches, was used to calculate precipitation depth for the 10-year and 100-year storms for a duration of 24 hours. Precipitation depth was calculated using the Santa Clara County's Return Period-Duration-Specific (TDS) Regional Equation, which establishes a relationship between precipitation depth and MAP for various storm return periods. This equation was developed based on the three-day December 1995 rainfall event that is still considered to be the storm of record for Northern California. (Santa Clara County, 2007)

5. Detention ponds are not included in the Project, because the LID stormwater mitigation methodologies described above will be implemented. Debris basins, as recommended in

the previously referenced Geologic and Soil Engineering Report, would be implemented and located at the point of concentration for Subbasins N-1 (see Photo 4 in Attachment 3) and N-2, located in Indian Valley along the Northern edge of the Project site, and Subbasins S-1, S-2, and S-3, located along the southern edge of the Project site (see Attachment 4). These debris basins would intercept debris flows/slides from the identified Subbasins, above the developed areas of the Project. They will be located immediately adjacent to Project features and incorporated into the site grading footprint for the overall Project. The debris basins are expected to include a series of two-to-four small soil and rock checkdams, approximately three-feet tall, constructed at the low flow line of the natural drainage feature. Minimal excavation behind the checkdams is planned and no additional trees would be removed for construction. The debris basins would be constructed adjacent to Project roadways, parking lots or maintenance paths to facilitate inspection and maintenance.

Although Subbasin V-1 was identified as a potential site for debris flows, it is not anticipated that a debris basin will be needed at the point of concentration for this basin. The drainage channel was found to be well defined and relatively clear of debris at this location. Rocks that were present were in general no greater than approximately 24 inches in diameter. Debris flowing through the main drainage channel did cause flooding on site during a storm in 1995. However, this was due to the debris blocking flow through an existing culvert located upstream of the hot springs pools (see Photo 8 in Appendix 3). The culverts at this location and the culverts located just upstream of the property line (see Photo 1 in Appendix 3) will be removed as part of the Project to restore the drainage channel capacity. Bridges will be installed to allow vehicular and pedestrian access across the drainage channel. The bridges are expected to be single-span structures, with abutments on each bank of the stream. Stream banks would be reconstructed as part of the bridge construction and lined with rock riprap for scour protection immediately adjacent to the abutments. Small storm drain outfalls would be located within the bridge and rock riprap footprints.

Erosion Control Measures

Because the intention is to implement stormwater BMPs to ensure that post-development stormwater flows in excess of pre-development conditions for a 100-year storm event do not leave the Project site, aggradation of the channel downstream of the project site, is not expected. Based on field observations, most of the sediment that travels from the steeper areas of the watershed to the valley of the watershed during annual rainfall events, is naturally deposited on the flatter areas of the watershed (i.e., within the Project site). Sediment that currently feeds the channel downstream of the Paraiso Springs Resort Project site, during more frequent or annual rainfall events, is contributed by the adjacent floodplain below the Project site through sheetflow. Onsite debris basins will be designed to retain large-particle sediment and other debris, but not suspended sediment. Passage of suspended sediment will also be aided by the removal of existing culverts and the restoration of natural drainage channel conditions as part of the Project. Therefore, it is expected that nutrients that are necessary for the health of the channel, downstream of the project site, will continue to be replenished.

Any points where stormwater flows collect and it is necessary to discharge into the channel will be designed with appropriate and primarily natural erosion protection measures, such as rock slope protection and vegetation.

Regulatory Background Information

Comment noted regarding compliance with the requirements of Monterey County Ordinance Chapter 16.2 Erosion Control and Ordinance Chapter 19.10 Design and Standard Improvements, paragraph 19.10.050, Drainage. Analysis and design efforts for the Project will comply with County policies in place when construction documents are developed. Mitigation measures, such as permeable pavements and vegetated drainage swales, and stormwater collection systems will be designed to ensure that stormwater drainage volume and peak flows do not increase from existing conditions, as a result of the Project.

Comment noted regarding the anticipated new statewide NPDES Construction General Permit. Project construction documents will comply with the most current General Permit.

Analytical Methodology and Significance Thresholds

The proposed project will not alter the course of flow through the main drainage channel, will not significantly alter existing drainage patterns, and will not significantly increase the rate of runoff. Minimal impacts to peak flow discharge and flow volume will be mitigated onsite to ensure that no downstream impacts will result directly from the Project. Downstream capacity will not be exceeded due to the Project, flow in excess of current flows will be allowed to infiltrate on site.

Pre- and post-Project stormwater drainage volumes for 10-year and 100-year storm events are summarized under Supporting Data Tables/Figures below. Stormwater runoff in excess of existing conditions will be allowed to infiltrate on site. Design options that include roof drain catchments, permeable surfaces for roads and pedestrian paths, permeable drainage swales, and other alternatives to typical storm drain facilities will be applied (see Attachment 7). Mitigation and LID improvements are not expected to create any additional environmental impacts and are planned to be located in already disturbed areas as indicated more specifically above.

Project Characteristics and Design Features Description Pertinent to Resource Category

Comment noted, the previous responses provide general information on the proposed design of stormwater features, based upon the LID methodology, and also for the proposed debris basins. Additional information needed for analysis and final design of Project features, such as debris basins and channel stabilization measures would be collected and utilized during the design phase. Resources would include documents such as the *California Stormwater Best Management Practice Handbook: New Development and Redevelopment* developed by the California Stormwater Quality Association (CASQA). These resources would reflect industry accepted, proven BMPs for stormwater management. Additional information and examples from the California Stormwater BMP Handbook is provided in Attachment 7.

Impact Analysis Information

Potential impacts associated with the Project, relative to site drainage and runoff are expected to be mitigated by the proposed LID techniques that would include, but not be limited to, the following design elements (CASQA, 2003), and are highlighted in the responses above.

- Site design and landscape planning
- Roof runoff controls
- Alternative building materials
- Pervious paving
- Vegetated swales
- Vegetated buffer strips
- Bioretention

The existing stream that runs through the Project site will not be modified, except for the removal of existing culverts and bridge construction mentioned previously.

Supporting Data Tables/Figures

Site and watershed photos are presented in Attachment 3.

SCS CN were developed for the HEC-HMS model. The hydrologic soil group (A through D) was identified utilizing an online soils database and mapping system provided by the Natural Resource Conservation Service (NRCS) called Web Soil Survey 2.0. Attachment 8 includes a map of the Project watershed developed using Web Soil Survey 2.0 showing soil type and identifying the hydrologic soil groups appropriate for developing the SCS CN. The basis for SCS CN development is summarized in Table 1; SCS CN used in the HEC-HMS model are summarized in Table 2 by Subbasin.

TABLE 1
Basis for development of Subbasin Soil Conservation Service Curve Numbers
Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

Cover/Land Use [1]	Hydrologic Condition	Curve Numbers for Hydrologic Soil Group			
		A	B	C	D
Forestland – grass or orchards, evergreen or deciduous	Good	32	58	72	79
Residential – average lot size 1/3 acre (average 30% imperious, includes paved streets)	N/A	57	72	81	86

Notes:
1. Taken from Table 8.7.3 (Mays, 2001)

TABLE 2
HEC-HMS Subbasin Soil Conservation Service Curve Numbers
Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

Subbasin	Hydrologic Soil Group [1]	CN: Existing Conditions [2]	CN: Proposed Conditions [3]
V-1	B, C, and D	72	72
V-2			
Plane 1	A, C, and D	72	72
Plane 2	A, B, and D	72	81
N-1	C	72	72
N-2	C	72	72
N-3			
Plane 1	C and D	79	79
Plane 2	B and D	79	86
S-1	B	58	58
S-2	B	58	58
S-3	C	72	72
S-4			
Plane 1	B and C	72	72
Plane 2	B and D	72	81

Notes:

1. When more than one Hydrologic Soil Group was found to be present in a given Subbasin, soil group was determine
2. Assumes cover is Forestland for all Subbasins
3. Assumes cover changes from Forestland to Residential – average lot size 1/3 acre in Subbasins where development is proposed

Based on the current tentative map for the Project, approximately 24 acres of the proposed development could be impervious surfaces post construction if traditional design methods were utilized. However, the goal of the Project is to use LID to minimize the effect of the development to stormwater drainage patterns, to the extent feasible, with the ultimate goal of no net impact. Therefore, the percentage of impervious surface included in the model for post-Project conditions was assumed to be approximately 26 percent of the potential impervious surface area.

Table 3 presents the overall results for the Project watershed, volume and peak discharge, obtained from the HEC-HMS model for pre- and post-project conditions for 10-year and 100-year storm events.

TABLE 3
HEC-HMS Results, Pre- and Post-Project for 10-year and 100-year Storm Events
Paraiso Springs Resort – Response to Hydrology and Hydraulic Analysis and Erosion Control Measures Review Comments

Parameter	10-year Storm Event		100-year Storm Event	
	Pre-Project	Post Project	Pre-Project	Post Project
Volume (ac-ft)	117.5	124.0	261.1	269.6
Peak Discharge (cfs)	123.5	124.2	310.9	315.8

References

California Department of Water Resources (DWR). 1983. Paloma Gage Station, Station Number D20 6650 00.

California Stormwater Quality Association (CASQA). January 2003. California Stormwater Best Management Practice Handbook: New Development and Redevelopment. <www.cabmphandbooks.com>.

Landset Engineers Inc. December 2004. Geologic and Soil Engineering Feasibility Report for Paraiso Hot Springs Spa Resort, Monterey County, California. Salinas, California.

Mays, Larry W. 2001. *Water Resources Engineering*. John Wiley & Sons, Inc. 1st ed.

Monterey County Water Resources Agency (MCWRA). October 2007. *Water Resources Data Report: Water year 1994-1995*.

Natural Resource Conservation Service (NRCS). 20 June 2007. Web Soil Survey 2.0. <http://websoilsurvey.nrcs.usda.gov/app/>. 5 May 2008.

Santa Clara County. 14 August 2007. *Drainage Manual*.

U.S. Army Corps of Engineers (USACE). March 2000. *Hydrologic modeling System (HEC-HMS): Technical Reference Manual*.

USACE. November 2003. *Hydrologic modeling System (HEC-HMS): Users Manual*. Version 3.1.0.

U.S. Geological Survey (USGS). 1994. *Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites, 1993*. Water Resources Investigations Report 94-4002. Reston, Virginia.

Attachment 1
Review of CH2M HILL Technical Memoranda (Hydrology and Hydraulic Analysis and Erosion Control Measures)

MEMORANDUM

To:	Meryka Blumer, MS 1600	JN 70-100140
From:	Harvey Oslick, MS 1300	
Cc:	Elizabeth Caraker, MS 1600	
Date:	January 17, 2008	
Subject:	Review of CH2MHill Technical Memoranda Paraiso Springs Resort: Preliminary Hydrology and Hydraulic Analysis and Paraiso Springs Resort: Erosion Control Measures (both dated July 15, 2005)	

The purpose of this memorandum is to provide a peer review of the technical memoranda, "Paraiso Springs Resort: Preliminary Hydrology and Hydraulic Analysis" and "Paraiso Springs Resort: Erosion Control Measures," both dated July 15, 2005. The focus of the review was to identify additional information necessary for RBF to complete a CEQA review of the project related to drainage and erosion impacts.

Information for Describing Existing Condition/Setting

The information in the technical memorandum on "Existing Hydrologic and Hydraulic Site Conditions" generally adequately describes existing conditions and setting of the site from a hydrologic standpoint, except as noted:

1. The Watershed Description, "travels northeasterly to the Arroyo Seco Valley floor, where flows are collected and enter the Arroyo Seco River," does not completely describe the condition of the receiving waterways that have the greatest potential to be impacted by the proposed development. The channels downstream from the project are not addressed on the Channel Characteristics section, either. Additional description of the receiving channels that cross the agricultural fields, Arroyo Seco Road and Los Coches Road should be provided.
2. The statement, "Topographic contour patterns show that there are four points within the basin that collect and transfer flows from the higher areas of the basin to the existing stream," is not supported by the exhibit. Additional clarification should be provided.
3. Calculations should be provided to support the statement, "Because this is such a(s) small percentage of the overall drainage basin at 2%, no significant increase on outflow from the basin is anticipated." The impacts of interceptor drainage ditches on hillside, increased impervious area, and channelization on both frequent storm flows should be addressed. Though the proposed project may not significantly alter the 100-year runoff from the site, increased discharges during frequent storm events may significantly impact flows and sediment transport to the agricultural fields downstream from the project. The impacts of the site on flows and sediment transport need to be addressed.
4. No reference is identified as the source of the listed average annual rainfall in the Project area of 11-inches. A value of 11-inches per year may be appropriate for the floor of the Salinas River Valley in the vicinity of the Project, however, it appears low for the

watershed tributary to the project with a centroid elevation of about 1800 feet. A suggested reference is the "Mean Annual Precipitation Map San Francisco & Monterey Bay Region, 1988" prepared by Santa Clara Valley Water District.

5. The report needs to include information regarding location and function of detention pond(s). It is suggested that the developer the Monterey County Water Resources Agency (MCWRA) to identify specific requirements. Typically, MCWRA has required that a subdivision include detention pond(s) with adequate volume to store the difference between the 100-year post-development runoff rate and the 10-year pre-development runoff rate, while limiting the discharge to the 10-year pre-development rate."

The information in the technical memorandum on "Preliminary Erosion Protection Measures" states that the site surface soils are erodible and that the hillside areas are susceptible to landslides and debris flow. The information in the technical memorandum on "Existing Hydrologic and Hydraulic Site Conditions" states that the bankfull capacity of the primary drainage channel far exceeds the 100-year storm flow. The documents should provide a detailed assessment of potential aggradation and degradation of the channels through and downstream from the project.

Regulatory Background Information

The project will need to satisfy the requirements of County Ordinance Chapter 16.12, Erosion Control. Preliminary erosion protection measures should be described in the context of meeting the specific provisions of this ordinance.

The project will need to satisfy the requirements of County Ordinance Chapter 19.10 Design and Standard Improvements, Paragraph 19.10.050, Drainage. Measures to mitigate for impacts to off site properties should be described in the context of meeting the specific provisions of this ordinance.

Note that it is anticipated that a new Statewide NPDES Construction General Permit (http://www.swrcb.ca.gov/stormwtr/constpermits.html) will be in place that will require additional measures to be addressed.

Analytical Methodology and Significance Thresholds

As required under CEQA, the project documents should present analysis related to the potential for the project to:

- Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner, which would result in flooding on- or off-site.
- Create or contribute runoff water, which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff.

Hydrology, hydraulic, and sediment transport analysis should be included to quantify the potential of the impacts of the project on drainage patterns, off-site flooding and water quality. The conclusions in the technical memorandum on "Existing Hydrologic and Hydraulic Site Conditions" state that debris basins upstream from the development should be implemented.

The impact that debris basins may have on the degradation of downstream channels as a result of a reduction in bed load should be addressed. Analysis should be provided to: identify locations of limited capacity downstream from the project; estimate the frequency that the capacity of the downstream system would be exceeded based on existing conditions; and estimate the impact the proposed project would have on this frequency.

Project Characteristics and Design Features Description Pertinent to Resource Category

The preliminary documents only discuss features in general terms. Additional information would be required to perform analysis on detention basins, permanent sediment traps, channel stabilization measures, and other design features that may be incorporated to mitigate for project impacts.

Impact Analysis Information

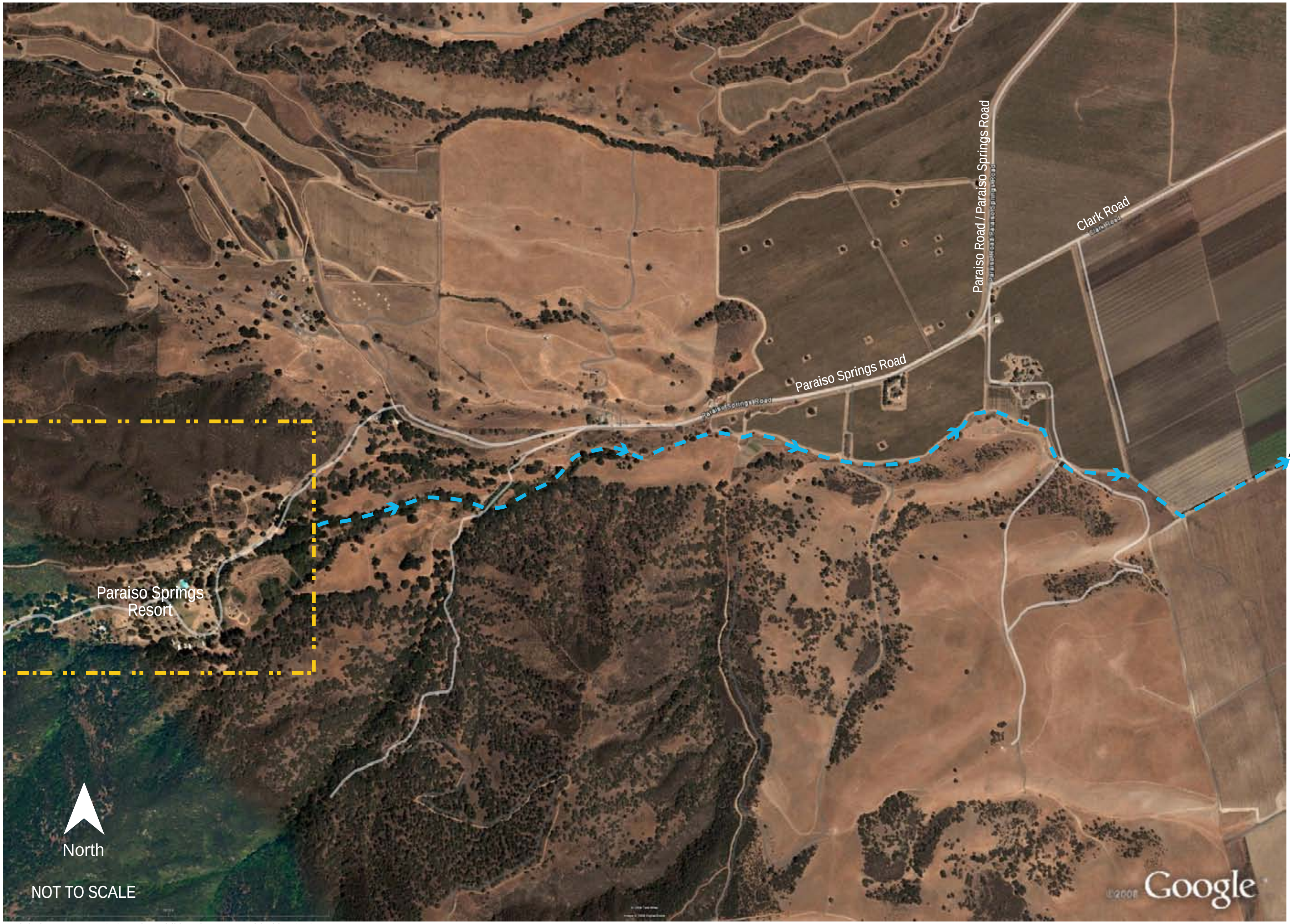
Potential impacts associated with the project as defined by the thresholds above should be clearly identified. Modifications to the project and or proposed mitigation measures should be included.

Supporting Data Tables/Figures

Data tables and figures should include soils maps and SCS curve numbers. Site and watershed photographs should be included to document existing conditions. Pre- and post-project times of concentration and flow rates for a wide range of storm events should be tabulated. Sediment and debris quantities should be addressed to identify preliminary debris basin sizes.

H:\PDATA\70100140\Admin\correspndnc\140HY-MEM01 Drainage Peer Review.doc

Attachment 2
Localized Stormwater Drainage Patterns



Aerial photo source: © Google, additional content added by CH2M HILL

Stormwater Drainage Route

Approximate Property Line

ATTACHMENT 2A

Stormwater Drainage Route Downstream of the Project Site

Localized Stormwater Drainage Patterns

Paraiso Springs Resort Subbasin Delineation

CH2MHILL

See Attachment 2A

Aerial photo source: © Google, additional content added by CH2M HILL

Stormwater Drainage Route

ATTACHMENT 2B
Stormwater Drainage Route Downstream of the Project Site
Localized Stormwater Drainage Patterns
Paraiso Springs Resort Subbasin Delineation

CH2MHILL

Attachment 3
Project Site Photos

Photo 1: Existing culverts on the Project Site above the eastern property line

Photo 2: Drainage channel passing through a vineyard downstream of the Project site

Photo 3: Roadside drainage ditch downstream of the Project site

Photo 4: Approximate point of concentration for Subbasin N-1

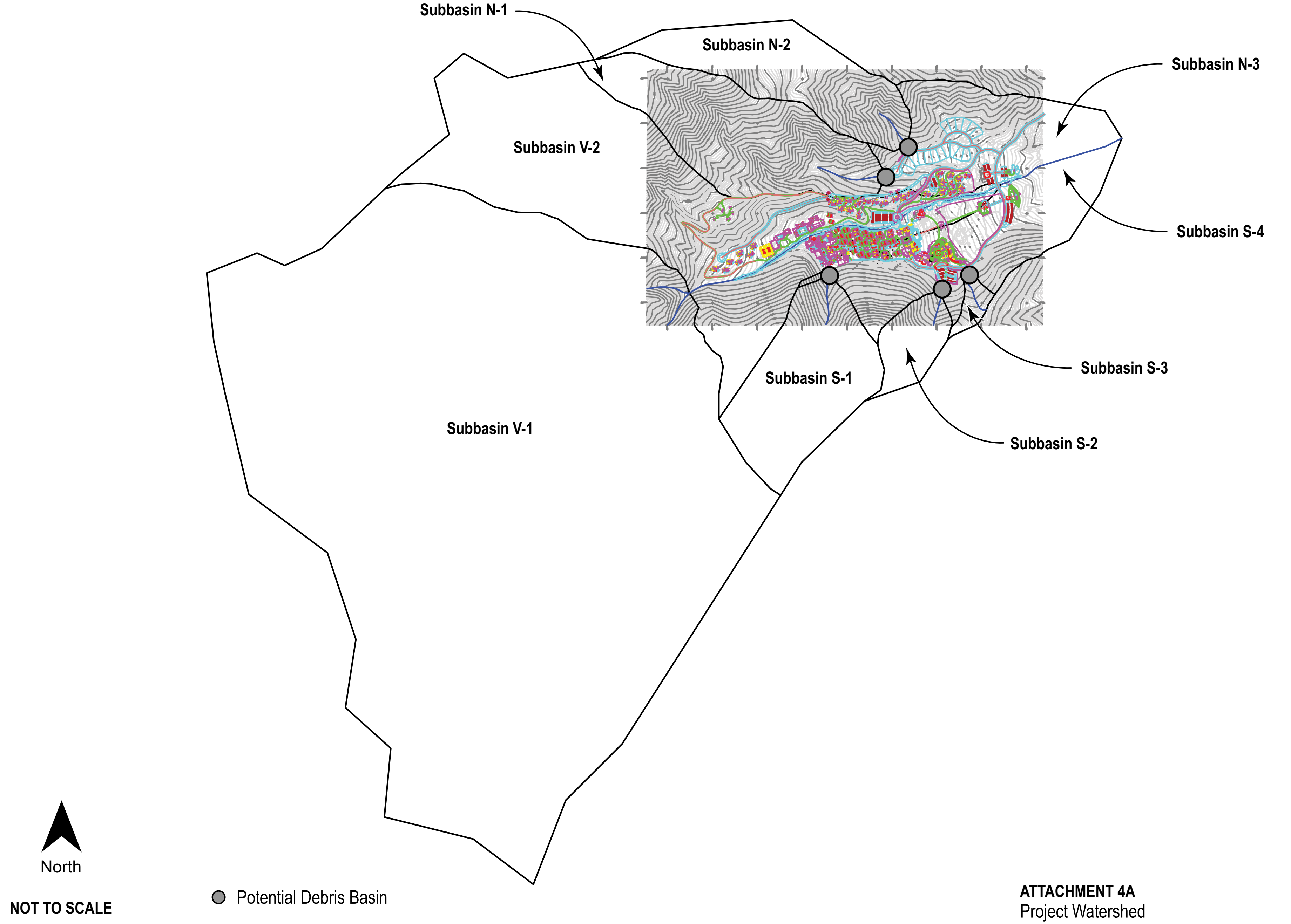
Photo 5: Approximate point of concentration for Subbasin V-1

Photo 6: Main drainage channel looking upstream, downstream of Photo 5 and downstream of Photo 7

Photo 7: Main drainage channel looking upstream, just upstream from Photo 8

Photo 8: Main drainage channel looking downstream; culverts located upstream of the existing hot springs pools

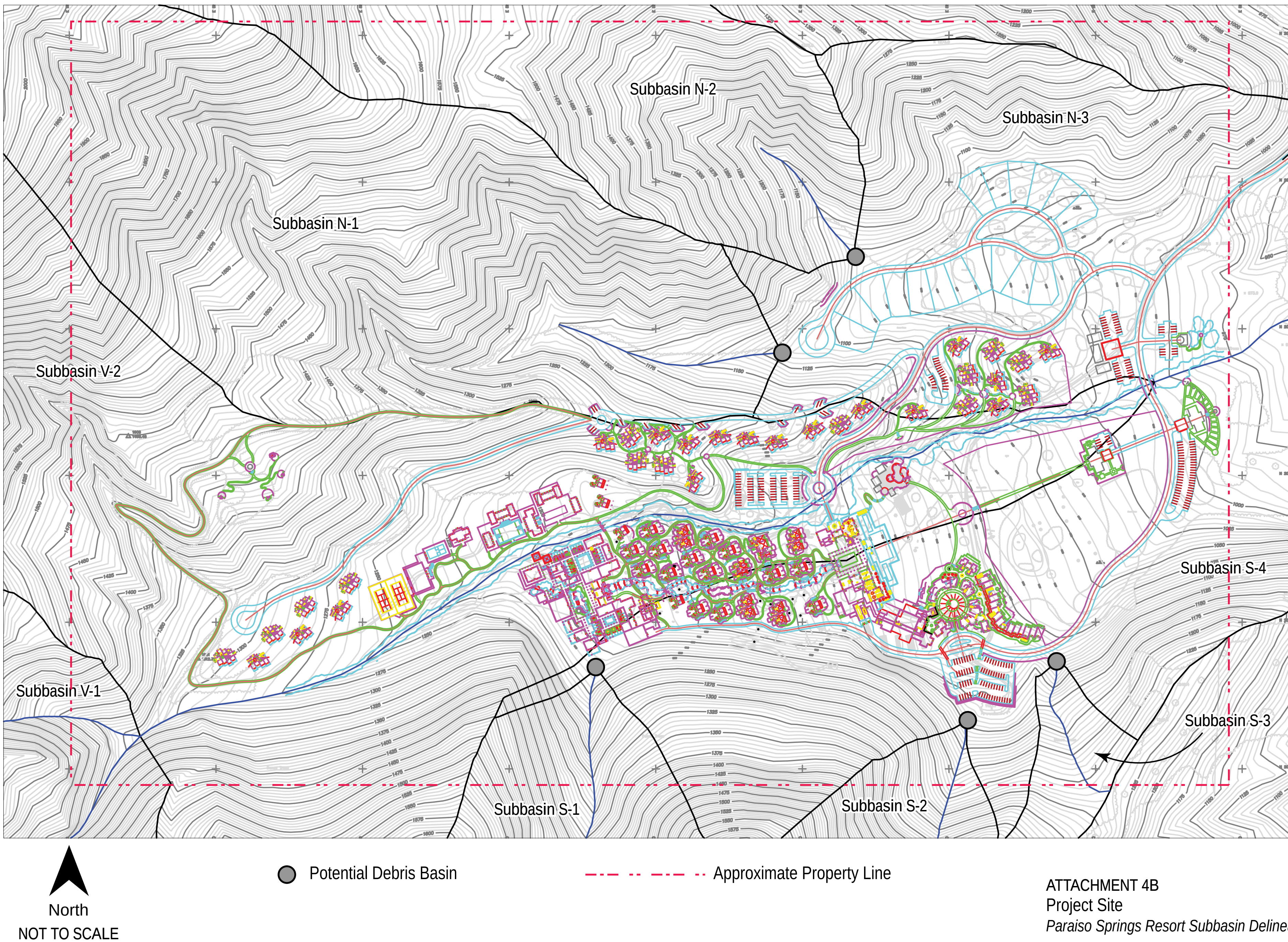
Attachment 4
Subbasin Delineation



ATTACHMENT 4A
Project Watershed
Paraiso Springs Resort Subbasin Delineation

CH2MHILL

WB052008003BAO Attachment_4A_potential_debris_basin 05-15-08 dash



ATTACHMENT 4B
Project Site
Paraiso Springs Resort Subbasin Delineation

CH2MHILL

Attachment 5
U.S. Geological Survey Water Resources Investigations Report 94-4002 Mean Annual Precipitation Analysis

Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites, 1993

Compiled By M.E. Jennings, W.O. Thomas, Jr., and H.C. Riggs

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4002

Prepared in cooperation with the
FEDERAL HIGHWAY ADMINISTRATION
and the
FEDERAL EMERGENCY MANAGEMENT AGENCY

Reston, Virginia
1994

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
8011 Cameron Rd.
Austin, TX 78754-3898

Copies of this report can be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, Mail Stop 517
Denver Federal Center
Denver, CO 80225-0046

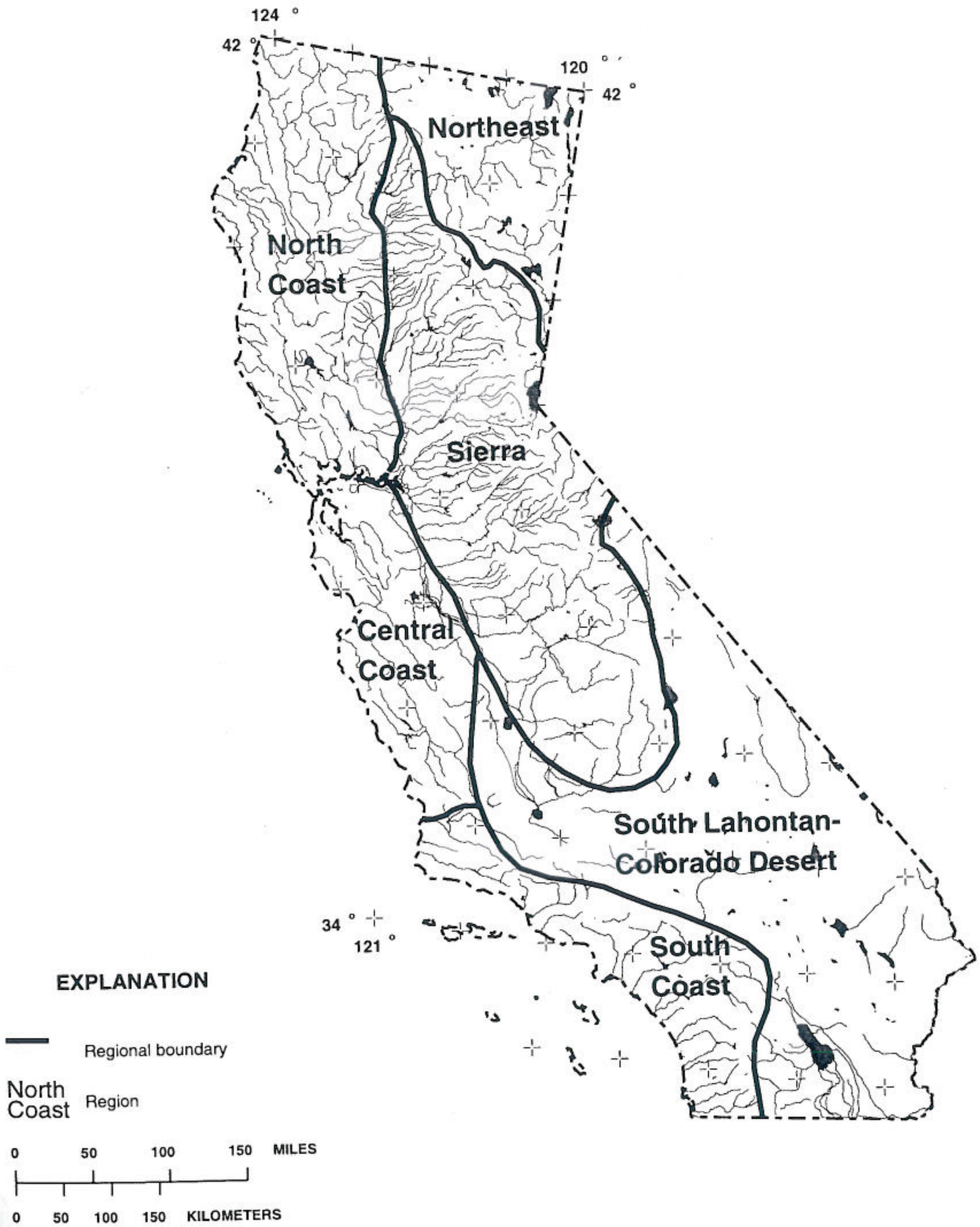


Figure 1. Flood-frequency region map for California.

South Lahontan-Colorado Desert Region

$$Q2 = 7.3A^{0.30}$$
$$Q5 = 53A^{0.44}$$
$$Q10 = 150A^{0.53}$$
$$Q25 = 410A^{0.63}$$
$$Q50 = 700A^{0.68}$$
$$Q100 = 1{,}080A^{0.71}$$

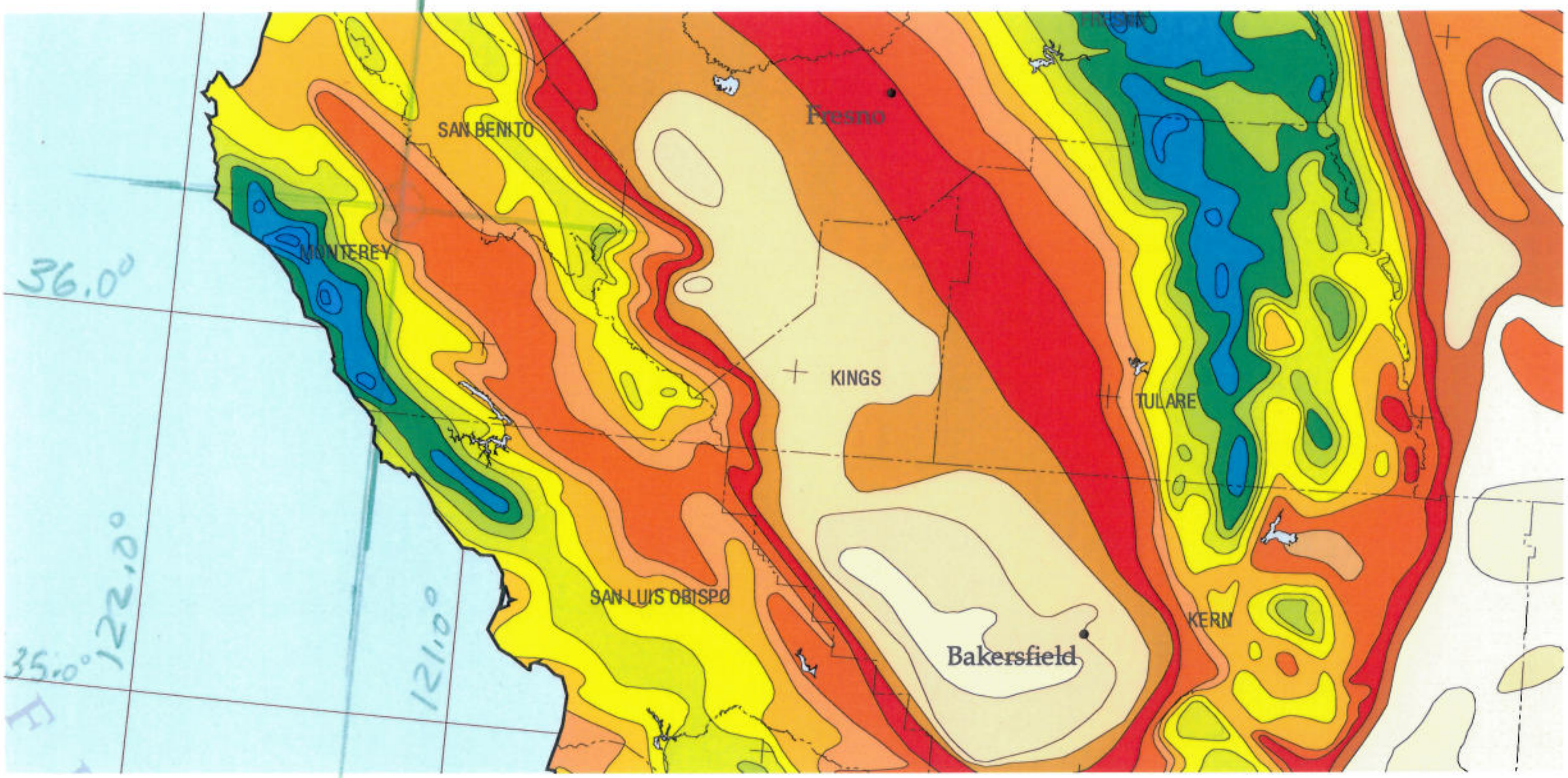
In the North Coast region, use a minimum value of 1.0 for the altitude index (H). Equations are defined only for basins of 25 mi^2 or less in the Northeast and South Lahontan-Colorado Desert regions.

Reference

Waananen, A.O. and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 96 p.

Additional Reference

Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).

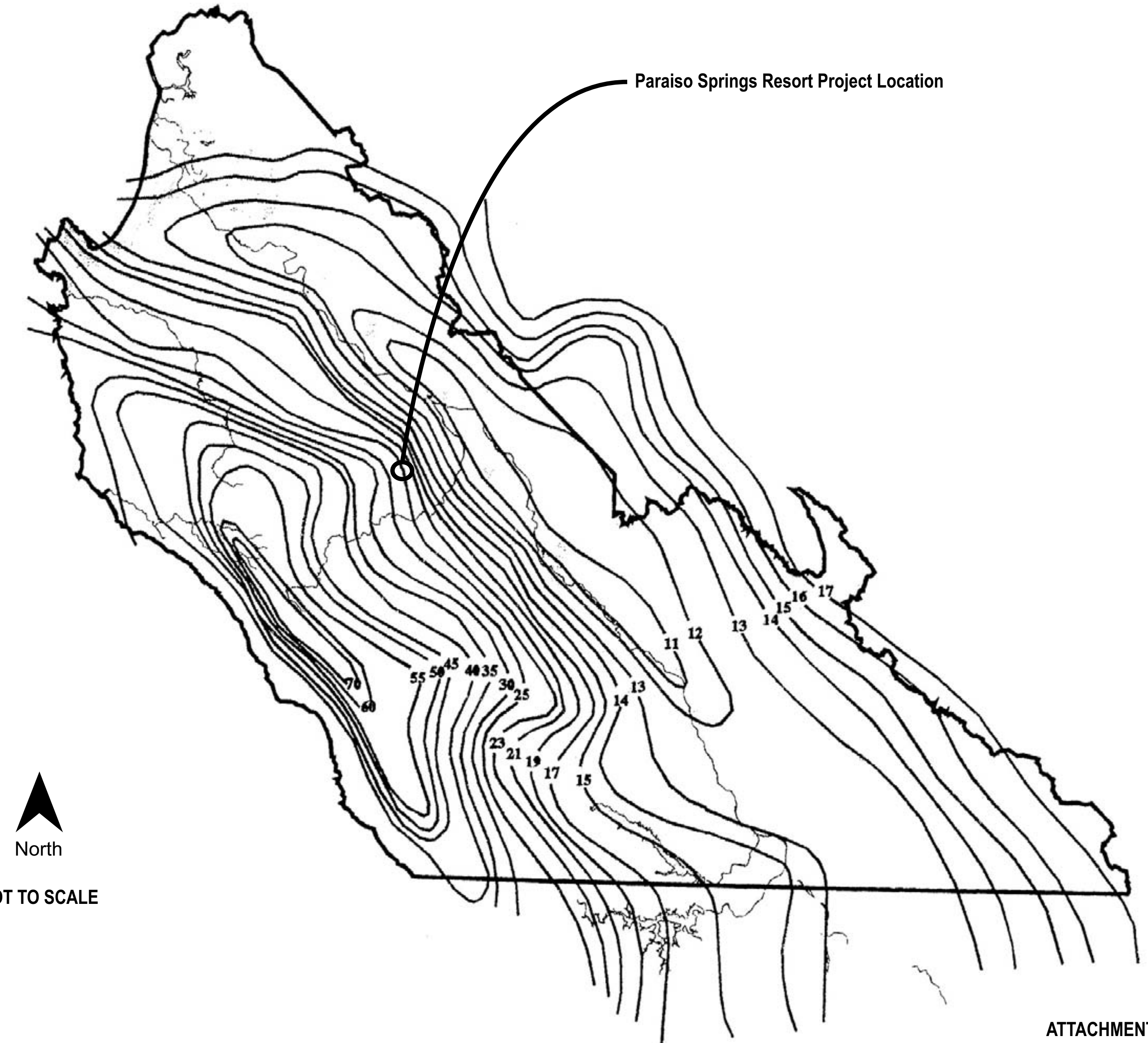

SAN BENITO
Fresno
MONTEREY
36.0°
KINGS
TULARE
122.0°
SAN LUIS OBISPO
KERN
Bakersfield
35.0°
121.0°

PRECIPITATION

2.5	7.5	15.0	30.0	65.0
3.5	8.0	17.0	32.5	75.0
4.5	9.0	17.5	35.0	85.0
5.0	11.0	18.0	37.5	95.0
5.5	12.5	22.5	40.0	105.0
6.5	13.0	25.0	45.0	115.0
7.0	14.0	27.5	55.0	125.0

Annual average precipitation polygons represent areas described by isohyetal lines of precipitation, measured in inches, averaged over the period 1900-1960.

Attachment 6
Monterey County Mean Annual Precipitation Map Used for HEC-HMS Analysis



ATTACHMENT 5
Monterey County Mean Annual Precipitation
Paraiso Springs Resort Subbasin Delineation

SOURCE: MCWRA Annual Report 1995 Water Year (MCWRA, 1997)

Attachment 7
Potential Mitigation Measures

Design Objectives

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

Description

Each project site possesses unique topographic, hydrologic, and vegetative features, some of which are more suitable for development than others. Integrating and incorporating appropriate landscape planning methodologies into the project design is the most effective action that can be done to minimize surface and groundwater contamination from stormwater.

Approach

Landscape planning should couple consideration of land suitability for urban uses with consideration of community goals and projected growth. Project plan designs should conserve natural areas to the extent possible, maximize natural water storage and infiltration opportunities, and protect slopes and channels.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Design requirements for site design and landscapes planning should conform to applicable standards and specifications of agencies with jurisdiction and be consistent with applicable General Plan and Local Area Plan policies.

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

Designing New Installations

Begin the development of a plan for the landscape unit with attention to the following general principles:

- Formulate the plan on the basis of clearly articulated community goals. Carefully identify conflicts and choices between retaining and protecting desired resources and community growth.

- Map and assess land suitability for urban uses. Include the following landscape features in the assessment: wooded land, open unwooded land, steep slopes, erosion-prone soils, foundation suitability, soil suitability for waste disposal, aquifers, aquifer recharge areas, wetlands, floodplains, surface waters, agricultural lands, and various categories of urban land use. When appropriate, the assessment can highlight outstanding local or regional resources that the community determines should be protected (e.g., a scenic area, recreational area, threatened species habitat, farmland, fish run). Mapping and assessment should recognize not only these resources but also additional areas needed for their sustenance.

Project plan designs should conserve natural areas to the extent possible, maximize natural water storage and infiltration opportunities, and protect slopes and channels.

Conserve Natural Areas during Landscape Planning

If applicable, the following items are required and must be implemented in the site layout during the subdivision design and approval process, consistent with applicable General Plan and Local Area Plan policies:

- Cluster development on least-sensitive portions of a site while leaving the remaining land in a natural undisturbed condition.

- Limit clearing and grading of native vegetation at a site to the minimum amount needed to build lots, allow access, and provide fire protection.

- Maximize trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native and/or drought tolerant plants.

- Promote natural vegetation by using parking lot islands and other landscaped areas.

- Preserve riparian areas and wetlands.

Maximize Natural Water Storage and Infiltration Opportunities Within the Landscape Unit

- Promote the conservation of forest cover. Building on land that is already deforested affects basin hydrology to a lesser extent than converting forested land. Loss of forest cover reduces interception storage, detention in the organic forest floor layer, and water losses by evapotranspiration, resulting in large peak runoff increases and either their negative effects or the expense of countering them with structural solutions.

- Maintain natural storage reservoirs and drainage corridors, including depressions, areas of permeable soils, swales, and intermittent streams. Develop and implement policies and regulations to discourage the clearing, filling, and channelization of these features. Utilize them in drainage networks in preference to pipes, culverts, and engineered ditches.

- Evaluating infiltration opportunities by referring to the stormwater management manual for the jurisdiction and pay particular attention to the selection criteria for avoiding groundwater contamination, poor soils, and hydrogeological conditions that cause these facilities to fail. If necessary, locate developments with large amounts of impervious surfaces or a potential to produce relatively contaminated runoff away from groundwater recharge areas.

Protection of Slopes and Channels during Landscape Design

- Convey runoff safely from the tops of slopes.
- Avoid disturbing steep or unstable slopes.
- Avoid disturbing natural channels.
- Stabilize disturbed slopes as quickly as possible.
- Vegetate slopes with native or drought tolerant vegetation.
- Control and treat flows in landscaping and/or other controls prior to reaching existing natural drainage systems.
- Stabilize temporary and permanent channel crossings as quickly as possible, and ensure that increases in run-off velocity and frequency caused by the project do not erode the channel.
- Install energy dissipaters, such as riprap, at the outlets of new storm drains, culverts, conduits, or channels that enter unlined channels in accordance with applicable specifications to minimize erosion. Energy dissipaters shall be installed in such a way as to minimize impacts to receiving waters.
- Line on-site conveyance channels where appropriate, to reduce erosion caused by increased flow velocity due to increases in tributary impervious area. The first choice for linings should be grass or some other vegetative surface, since these materials not only reduce runoff velocities, but also provide water quality benefits from filtration and infiltration. If velocities in the channel are high enough to erode grass or other vegetative linings, riprap, concrete, soil cement, or geo-grid stabilization are other alternatives.
- Consider other design principles that are comparable and equally effective.

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.

Redevelopment may present significant opportunity to add features which had not previously been implemented. Examples include incorporation of depressions, areas of permeable soils, and swales in newly redeveloped areas. While some site constraints may exist due to the status of already existing infrastructure, opportunities should not be missed to maximize infiltration, slow runoff, reduce impervious areas, disconnect directly connected impervious areas.

Other Resources

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Stormwater Management Manual for Western Washington, Washington State Department of Ecology, August 2001.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Roof Runoff Controls SD-11

Rain Garden

Design Objectives

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

Description

Various roof runoff controls are available to address stormwater that drains off rooftops. The objective is to reduce the total volume and rate of runoff from individual lots, and retain the pollutants on site that may be picked up from roofing materials and atmospheric deposition. Roof runoff controls consist of directing the roof runoff away from paved areas and mitigating flow to the storm drain system through one of several general approaches: cisterns or rain barrels; dry wells or infiltration trenches; pop-up emitters, and foundation planting. The first three approaches require the roof runoff to be contained in a gutter and downspout system. Foundation planting provides a vegetated strip under the drip line of the roof.

Approach

Design of individual lots for single-family homes as well as lots for higher density residential and commercial structures should consider site design provisions for containing and infiltrating roof runoff or directing roof runoff to vegetative swales or buffer areas. Retained water can be reused for watering gardens, lawns, and trees. Benefits to the environment include reduced demand for potable water used for irrigation, improved stormwater quality, increased groundwater recharge, decreased runoff volume and peak flows, and decreased flooding potential.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Designing New Installations

Cisterns or Rain Barrels

One method of addressing roof runoff is to direct roof downspouts to cisterns or rain barrels. A cistern is an above ground storage vessel with either a manually operated valve or a permanently open outlet. Roof runoff is temporarily stored and then released for irrigation or infiltration between storms. The number of rain barrels needed is a function of the rooftop area. Some low impact developers recommend that every house have at least 2 rain barrels, with a minimum storage capacity of 1000 liters. Roof barrels serve several purposes including mitigating the first flush from the roof which has a high volume, amount of contaminants, and thermal load. Several types of rain barrels are commercially available. Consideration must be given to selecting rain barrels that are vector proof and childproof. In addition, some barrels are designed with a bypass valve that filters out grit and other contaminants and routes overflow to a soak-away pit or rain garden.

If the cistern has an operable valve, the valve can be closed to store stormwater for irrigation or infiltration between storms. This system requires continual monitoring by the resident or grounds crews, but provides greater flexibility in water storage and metering. If a cistern is provided with an operable valve and water is stored inside for long periods, the cistern must be covered to prevent mosquitoes from breeding.

A cistern system with a permanently open outlet can also provide for metering stormwater runoff. If the cistern outlet is significantly smaller than the size of the downspout inlet (say ¼ to ½ inch diameter), runoff will build up inside the cistern during storms, and will empty out slowly after peak intensities subside. This is a feasible way to mitigate the peak flow increases caused by rooftop impervious land coverage, especially for the frequent, small storms.

Dry wells and Infiltration Trenches

Roof downspouts can be directed to dry wells or infiltration trenches. A dry well is constructed by excavating a hole in the ground and filling it with an open graded aggregate, and allowing the water to fill the dry well and infiltrate after the storm event. An underground connection from the downspout conveys water into the dry well, allowing it to be stored in the voids. To minimize sedimentation from lateral soil movement, the sides and top of the stone storage matrix can be wrapped in a permeable filter fabric, though the bottom may remain open. A perforated observation pipe can be inserted vertically into the dry well to allow for inspection and maintenance.

In practice, dry wells receiving runoff from single roof downspouts have been successful over long periods because they contain very little sediment. They must be sized according to the amount of rooftop runoff received, but are typically 4 to 5 feet square, and 2 to 3 feet deep, with a minimum of 1-foot soil cover over the top (maximum depth of 10 feet).

To protect the foundation, dry wells must be set away from the building at least 10 feet. They must be installed in solids that accommodate infiltration. In poorly drained soils, dry wells have very limited feasibility.

Infiltration trenches function in a similar manner and would be particularly effective for larger roof areas. An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives stormwater runoff. These are described under Treatment Controls.

Pop-up Drainage Emitter

Roof downspouts can be directed to an underground pipe that daylights some distance from the building foundation, releasing the roof runoff through a pop-up emitter. Similar to a pop-up irrigation head, the emitter only opens when there is flow from the roof. The emitter remains flush to the ground during dry periods, for ease of lawn or landscape maintenance.

Foundation Planting

Landscape planting can be provided around the base to allow increased opportunities for stormwater infiltration and protect the soil from erosion caused by concentrated sheet flow coming off the roof. Foundation plantings can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration. These plantings must be sturdy enough to tolerate the heavy runoff sheet flows, and periodic soil saturation.

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.

Supplemental Information

Examples

- City of Ottawa's Water Links Surface –Water Quality Protection Program
- City of Toronto Downspout Disconnection Program
- City of Boston, MA, Rain Barrel Demonstration Program

Other Resources

Hager, Marty Catherine, Stormwater, "Low-Impact Development", January/February 2003. www.stormh2o.com

Low Impact Urban Design Tools, Low Impact Development Design Center, Beltsville, MD. www.lid-stormwater.net

Start at the Source, Bay Area Stormwater Management Agencies Association, 1999 Edition

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:

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

- 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**

Other Resources

Abbott C.L. and Comino-Mateos L. 2001. *In situ performance monitoring of an infiltration drainage system and field testing of current design procedures*. Journal CIWEM, 15(3), pp.198-202.

Construction Industry Research and Information Association (CIRIA). 2002. *Source Control using Constructed Pervious Surfaces C582*, London, SW1P 3AU.

Construction Industry Research and Information Association (CIRIA). 2000. *Sustainable urban drainage systems - design manual for Scotland and Northern Ireland Report C521*, London, SW1P 3AU.

Construction Industry Research and Information Association (CIRIA). 2000 C522 *Sustainable urban drainage systems - design manual for England and Wales*, London, SW1P 3AU.

Construction Industry Research and Information Association (CIRIA). *RP448 Manual of good practice for the design, construction and maintenance of infiltration drainage systems for stormwater runoff control and disposal*, London, SW1P 3AU.

Dierkes C., Kuhlmann L., Kandasamy J. & Angelis G. Pollution Retention Capability and Maintenance of Permeable Pavements. *Proc 9th International Conference on Urban Drainage, Portland Oregon, September 2002*.

Hart P (2002) Permeable Paving as a Stormwater Source Control System. *Paper presented at Scottish Hydraulics Study Group 14th* Annual seminar, SUDS. 22 March 2002, Glasgow.

Kobayashi M., 1999. Stormwater runoff control in Nagoya City. Proc. 8 th Int. Conf. on

Urban Storm Drainage, Sydney, Australia, pp.825-833.

Landphair, H., McFalls, J., Thompson, D., 2000, Design Methods, Selection, and Cost Effectiveness of Stormwater Quality Structures, Texas Transportation Institute Research Report 1837-1, College Station, Texas.

Legret M, Colandini V, Effects of a porous pavement with reservior strucutre on runoff water:water quality and the fate of heavy metals. Laboratoire Central Des Ponts et Chaussesss

Macdonald K. & Jefferies C. Performance Comparison of Porous Paved and Traditional Car Parks. *Proc. First National Conference on Sustainable Drainage Systems, Coventry June 2001*.

Niemczynowicz J, Hogland W, 1987: Test of porous pavements performed in Lund, Sweden, in Topics in Drainage Hydraulics and Hydrology. BC. Yen (Ed.), pub. Int. Assoc. For Hydraulic Research, pp 19-80.

Pratt C.J. SUSTAINABLE URBAN DRAINAGE – A Review of published material on the performance of various SUDS devices prepared for the UK Environment Agency. Coventry University, UK December 2001.

Pratt C.J., 1995. Infiltration drainage – case studies of UK practice. Project Report

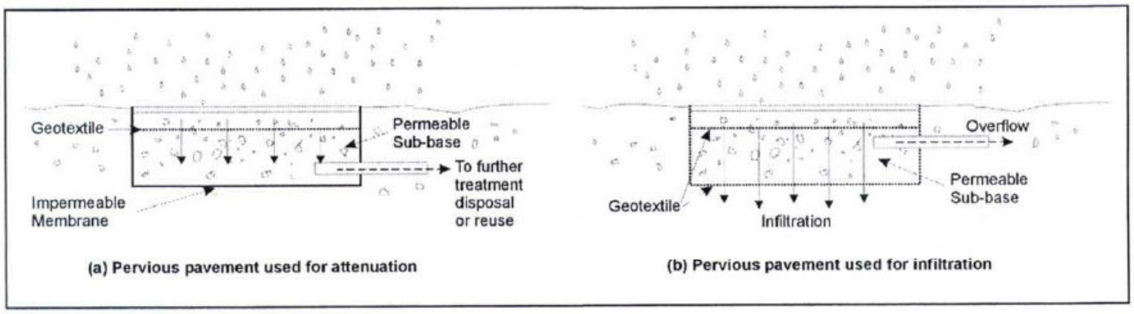
22,Construction Industry Research and Information Association, London, SW1P 3AU; also known as National Rivers Authority R & D Note 485

Pratt. C. J., 1990. Permeable Pavements for Stormwater Quality Enhancement. In: Urban Stormwater Quality Enhancement - Source Control, retrofitting and combined sewer technology, Ed. H.C. Torno, ASCE, ISBN 087262 7594, pp. 131-155

Raimbault G., 1997 French Developments in Reservoir Structures Sustainable water resources I the 21st century. Malmo Sweden

Schlüter W. & Jefferies C. Monitoring the outflow from a *Porous Car Park Proc. First National Conference on Sustainable Drainage Systems, Coventry June 2001*.

Wild, T.C., Jefferies, C., and D'Arcy, B.J. SUDS in Scotland – the Scottish SUDS database Report No SR(02)09 *Scotland and Northern Ireland Forum for Environmental Research, Edinburgh*. In preparation August 2002.



Schematics of a Pervious Pavement System

Alternative Building Materials SD-21

Design Objectives

- ☑ Maximize Infiltration
- ☑ Provide Retention
- ☑ Source Control
- Minimize Impervious Land Coverage
- Prohibit Dumping of Improper Materials
- Contain Pollutant
- Collect and Convey

Description

Alternative building materials are selected instead of conventional materials for new construction and renovation. These materials reduce potential sources of pollutants in stormwater runoff by eliminating compounds that can leach into runoff, reducing the need for pesticide application, reducing the need for painting and other maintenance, or by reducing the volume of runoff.

Approach

Alternative building materials are available for use as lumber for decking, roofing materials, home siding, and paving for driveways, decks, and sidewalks.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Designing New Installations

Decking

One of the most common materials for construction of decks and other outdoor construction has traditionally been pressure treated wood, which is now being phased out. The standard treatment is called CCA, for chromated copper arsenate. The key ingredients are arsenic (which kills termites, carpenter ants and other insects), copper (which kills the fungi that cause wood to rot) and chromium (which reacts with the other ingredients to bind them to the wood). The amount of arsenic is far from trivial. A deck just 8 feet x 10 feet contains more than 1 1/3 pounds of this highly potent poison. Replacement materials include a new type of pressure treated wood, plastic and composite lumber.

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

There are currently over 20 products in the market consisting of plastic or plastic-wood composites. Plastic lumber is made from 100% recycled plastic, # 2 HDPE and polyethylene plastic milk jugs and soap bottles. Plastic-wood composites are a combination of plastic and wood fibers or sawdust. These materials are a long lasting exterior weather, insect, and chemical resistant wood lumber replacement for non structural applications. Use it for decks, docks, raised garden beds and planter boxes, pallets, hand railings, outdoor furniture, animal pens, boat decks, etc.

New pressure treated wood uses a much safer recipe, ACQ, which stands for ammoniacal copper quartenary. It contains no arsenic and no chromium. Yet the American Wood Preservers Association has found it to be just as effective as the standard formula. ACQ is common in Japan and Europe.

Roofing

Several studies have indicated that metal used as roofing material, flashing, or gutters can leach metals into the environment. The leaching occurs because rainfall is slightly acidic and slowly dissolved the exposed metals. Common traditional applications include copper sheathing and galvanized (zinc) gutters.

Coated metal products are available for both roofing and gutter applications. These products eliminate contact of bare metal with rainfall, eliminating one source of metals in runoff. There are also roofing materials made of recycled rubber and plastic that resemble traditional materials.

A less traditional approach is the use of green roofs. These roofs are not just green, they're alive. Planted with grasses and succulents, low- profile green roofs reduce the urban heat island effect, stormwater runoff, and cooling costs, while providing wildlife habitat and a connection to nature for building occupants. These roofs are widely used on industrial facilities in Europe and have been established as experimental installations in several locations in the US, including Portland, Oregon. Their feasibility is questionable in areas of California with prolonged, dry, hot weather.

Paved Areas

Traditionally, concrete is used for construction of patios, sidewalks, and driveways. Although it is non-toxic, these paved areas reduce stormwater infiltration and increase the volume and rate of runoff. This increase in the amount of runoff is the leading cause of stream channel degradation in urban areas.

There are a number of alternative materials that can be used in these applications, including porous concrete and asphalt, modular blocks, and crushed granite. These materials, especially modular paving blocks, are widely available and a well established method to reduce stormwater runoff.

Building Siding

Wood siding is commonly used on the exterior of residential construction. This material weathers fairly rapidly and requires repeated painting to prevent rotting. Alternative “new” products for this application include cement-fiber and vinyl. Cement-fiber siding is a masonry product made from Portland cement, sand, and cellulose and will not burn, cup, swell, or shrink.

Pesticide Reduction
A common use of powerful pesticides is for the control of termites. Chlordane was used for many years for this purpose and is now found in urban streams and lakes nationwide. There are a number of physical barriers that can be installed during construction to help reduce the use of pesticides.

Sand barriers for subterranean termites are a physical deterrent because the termites cannot tunnel through it. Sand barriers can be applied in crawl spaces under pier and beam foundations, under slab foundations, and between the foundation and concrete porches, terraces, patios and steps. Other possible locations include under fence posts, underground electrical cables, water and gas lines, telephone and electrical poles, inside hollow tile cells and against retaining walls.

Metal termite shields are physical barriers to termites which prevent them from building invisible tunnels. In reality, metal shields function as a helpful termite detection device, forcing them to build tunnels on the outside of the shields which are easily seen. Metal termite shields also help prevent dampness from wicking to adjoining wood members which can result in rot, thus making the material more attractive to termites and other pests. Metal flashing and metal plates can also be used as a barrier between piers and beams of structures such as decks, which are particularly vulnerable to termite attack.

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.

Other Resources
There are no good, independent, comprehensive sources of information on alternative building materials for use in minimizing the impacts of stormwater runoff. Most websites or other references to "green" or "alternative" building materials focus on indoor applications, such as formaldehyde free plywood and low VOC paints, carpets, and pads. Some supplemental information on alternative materials is available from the manufacturers.

Fires are a source of concern in many areas of California. Information on the flammability of alternative decking materials is available from the University of California Forest Product Laboratory (UCFPL) website at: http://www.ucfpl.ucop.edu/WDDeckIntro.htm

Design Considerations

- Tributary Area
- Area Required
- Slope
- Water Availability

Description

Vegetated swales are open, shallow channels with vegetation covering the side slopes and bottom that collect and slowly convey runoff flow to downstream discharge points. They are designed to treat runoff through filtering by the vegetation in the channel, filtering through a subsoil matrix, and/or infiltration into the underlying soils. Swales can be natural or manmade. They trap particulate pollutants (suspended solids and trace metals), promote infiltration, and reduce the flow velocity of stormwater runoff. Vegetated swales can serve as part of a stormwater drainage system and can replace curbs, gutters and storm sewer systems.

California Experience

Caltrans constructed and monitored six vegetated swales in southern California. These swales were generally effective in reducing the volume and mass of pollutants in runoff. Even in the areas where the annual rainfall was only about 10 inches/yr, the vegetation did not require additional irrigation. One factor that strongly affected performance was the presence of large numbers of gophers at most of the sites. The gophers created earthen mounds, destroyed vegetation, and generally reduced the effectiveness of the controls for TSS reduction.

Advantages

- If properly designed, vegetated, and operated, swales can serve as an aesthetic, potentially inexpensive urban development or roadway drainage conveyance measure with significant collateral water quality benefits.

Targeted Constituents

☑	Sediment	▲
☑	Nutrients	●
☑	Trash	●
☑	Metals	▲
☑	Bacteria	●
☑	Oil and Grease	▲
☑	Organics	▲

Legend ***(Removal Effectiveness)***

● Low ■ High

▲ Medium

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

- Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible.

Limitations

- Can be difficult to avoid channelization.
- May not be appropriate for industrial sites or locations where spills may occur
- Grassed swales cannot treat a very large drainage area. Large areas may be divided and treated using multiple swales.
- A thick vegetative cover is needed for these practices to function properly.
- They are impractical in areas with steep topography.
- They are not effective and may even erode when flow velocities are high, if the grass cover is not properly maintained.
- In some places, their use is restricted by law: many local municipalities require curb and gutter systems in residential areas.
- Swales are mores susceptible to failure if not properly maintained than other treatment BMPs.

Design and Sizing Guidelines

- Flow rate based design determined by local requirements or sized so that 85% of the annual runoff volume is discharged at less than the design rainfall intensity.
- Swale should be designed so that the water level does not exceed 2/3rds the height of the grass or 4 inches, which ever is less, at the design treatment rate.
- Longitudinal slopes should not exceed 2.5%
- Trapezoidal channels are normally recommended but other configurations, such as parabolic, can also provide substantial water quality improvement and may be easier to mow than designs with sharp breaks in slope.
- Swales constructed in cut are preferred, or in fill areas that are far enough from an adjacent slope to minimize the potential for gopher damage. Do not use side slopes constructed of fill, which are prone to structural damage by gophers and other burrowing animals.
- A diverse selection of low growing, plants that thrive under the specific site, climatic, and watering conditions should be specified. Vegetation whose growing season corresponds to the wet season are preferred. Drought tolerant vegetation should be considered especially for swales that are not part of a regularly irrigated landscaped area.
- The width of the swale should be determined using Manning's Equation using a value of 0.25 for Manning's n.

Construction/Inspection Considerations

- Include directions in the specifications for use of appropriate fertilizer and soil amendments based on soil properties determined through testing and compared to the needs of the vegetation requirements.

- Install swales at the time of the year when there is a reasonable chance of successful establishment without irrigation; however, it is recognized that rainfall in a given year may not be sufficient and temporary irrigation may be used.

- If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the swale or strip.

- Use a roller on the sod to ensure that no air pockets form between the sod and the soil.

- Where seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season.

Performance

The literature suggests that vegetated swales represent a practical and potentially effective technique for controlling urban runoff quality. While limited quantitative performance data exists for vegetated swales, it is known that check dams, slight slopes, permeable soils, dense grass cover, increased contact time, and small storm events all contribute to successful pollutant removal by the swale system. Factors decreasing the effectiveness of swales include compacted soils, short runoff contact time, large storm events, frozen ground, short grass heights, steep slopes, and high runoff velocities and discharge rates.

Conventional vegetated swale designs have achieved mixed results in removing particulate pollutants. A study performed by the Nationwide Urban Runoff Program (NURP) monitored three grass swales in the Washington, D.C., area and found no significant improvement in urban runoff quality for the pollutants analyzed. However, the weak performance of these swales was attributed to the high flow velocities in the swales, soil compaction, steep slopes, and short grass height.

Another project in Durham, NC, monitored the performance of a carefully designed artificial swale that received runoff from a commercial parking lot. The project tracked 11 storms and concluded that particulate concentrations of heavy metals (Cu, Pb, Zn, and Cd) were reduced by approximately 50 percent. However, the swale proved largely ineffective for removing soluble nutrients.

The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 17 meter (50 foot) increments along their length (See Figure 1). These dams maximize the retention time within the swale, decrease flow velocities, and promote particulate settling. Finally, the incorporation of vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale.

Only 9 studies have been conducted on all grassed channels designed for water quality (Table 1). The data suggest relatively high removal rates for some pollutants, but negative removals for some bacteria, and fair performance for phosphorus.

Table 1 Grassed swale pollutant removal efficiency data							
Removal Efficiencies (% Removal)							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Type**
Caltrans 2002	77	8	67	66	83-90	-33	dry swales
Goldberg 1993	67.8	4.5	-	31.4	42–62	-100	grassed channel
Seattle Metro and Washington Department of Ecology 1992	60	45	-	-25	2–16	-25	grassed channel
Seattle Metro and Washington Department of Ecology, 1992	83	29	-	-25	46–73	-25	grassed channel
Wang et al., 1981	80	-	-	-	70–80	-	dry swale
Dorman et al., 1989	98	18	-	45	37–81	-	dry swale
Harper, 1988	87	83	84	80	88–90	-	dry swale
Kercher et al., 1983	99	99	99	99	99	-	dry swale
Harper, 1988.	81	17	40	52	37–69	-	wet swale
Koon, 1995	67	39	-	9	-35 to 6	-	wet swale

While it is difficult to distinguish between different designs based on the small amount of available data, grassed channels generally have poorer removal rates than wet and dry swales, although some swales appear to export soluble phosphorus (Harper, 1988; Koon, 1995). It is not clear why swales export bacteria. One explanation is that bacteria thrive in the warm swale soils.

Siting Criteria

The suitability of a swale at a site will depend on land use, size of the area serviced, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the swale system (Schueler et al., 1992). In general, swales can be used to serve areas of less than 10 acres, with slopes no greater than 5 %. Use of natural topographic lows is encouraged and natural drainage courses should be regarded as significant local resources to be kept in use (Young et al., 1996).

Selection Criteria (NCTCOG, 1993)

- Comparable performance to wet basins
- Limited to treating a few acres
- Availability of water during dry periods to maintain vegetation
- Sufficient available land area

Research in the Austin area indicates that vegetated controls are effective at removing pollutants even when dormant. Therefore, irrigation is not required to maintain growth during dry periods, but may be necessary only to prevent the vegetation from dying.

The topography of the site should permit the design of a channel with appropriate slope and cross-sectional area. Site topography may also dictate a need for additional structural controls. Recommendations for longitudinal slopes range between 2 and 6 percent. Flatter slopes can be used, if sufficient to provide adequate conveyance. Steep slopes increase flow velocity, decrease detention time, and may require energy dissipating and grade check. Steep slopes also can be managed using a series of check dams to terrace the swale and reduce the slope to within acceptable limits. The use of check dams with swales also promotes infiltration.

Additional Design Guidelines

Most of the design guidelines adopted for swale design specify a minimum hydraulic residence time of 9 minutes. This criterion is based on the results of a single study conducted in Seattle, Washington (Seattle Metro and Washington Department of Ecology, 1992), and is not well supported. Analysis of the data collected in that study indicates that pollutant removal at a residence time of 5 minutes was not significantly different, although there is more variability in that data. Therefore, additional research in the design criteria for swales is needed. Substantial pollutant removal has also been observed for vegetated controls designed solely for conveyance (Barrett et al, 1998); consequently, some flexibility in the design is warranted.

Many design guidelines recommend that grass be frequently mowed to maintain dense coverage near the ground surface. Recent research (Colwell et al., 2000) has shown mowing frequency or grass height has little or no effect on pollutant removal.

Summary of Design Recommendations

1) The swale should have a length that provides a minimum hydraulic residence time of at least 10 minutes. The maximum bottom width should not exceed 10 feet unless a dividing berm is provided. The depth of flow should not exceed 2/3rds the height of the grass at the peak of the water quality design storm intensity. The channel slope should not exceed 2.5%.

2) A design grass height of 6 inches is recommended.

3) Regardless of the recommended detention time, the swale should be not less than 100 feet in length.

4) The width of the swale should be determined using Manning's Equation, at the peak of the design storm, using a Manning's n of 0.25.

5) The swale can be sized as both a treatment facility for the design storm and as a conveyance system to pass the peak hydraulic flows of the 100-year storm if it is located "on-line." The side slopes should be no steeper than 3:1 (H:V).

6) Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible. If flow is to be introduced through curb cuts, place pavement slightly above the elevation of the vegetated areas. Curb cuts should be at least 12 inches wide to prevent clogging.

7) Swales must be vegetated in order to provide adequate treatment of runoff. It is important to maximize water contact with vegetation and the soil surface. For general purposes, select fine, close-growing, water-resistant grasses. If possible, divert runoff (other than necessary irrigation) during the period of vegetation

establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.

Maintenance

The useful life of a vegetated swale system is directly proportional to its maintenance frequency. If properly designed and regularly maintained, vegetated swales can last indefinitely. The maintenance objectives for vegetated swale systems include keeping up the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover.

Maintenance activities should include periodic mowing (with grass never cut shorter than the design flow depth), weed control, watering during drought conditions, reseeding of bare areas, and clearing of debris and blockages. Cuttings should be removed from the channel and disposed in a local composting facility. Accumulated sediment should also be removed manually to avoid concentrated flows in the swale. The application of fertilizers and pesticides should be minimal.

Another aspect of a good maintenance plan is repairing damaged areas within a channel. For example, if the channel develops ruts or holes, it should be repaired utilizing a suitable soil that is properly tamped and seeded. The grass cover should be thick; if it is not, reseed as necessary. Any standing water removed during the maintenance operation must be disposed to a sanitary sewer at an approved discharge location. Residuals (e.g., silt, grass cuttings) must be disposed in accordance with local or State requirements. Maintenance of grassed swales mostly involves maintenance of the grass or wetland plant cover. Typical maintenance activities are summarized below:

- Inspect swales at least twice annually for erosion, damage to vegetation, and sediment and debris accumulation preferably at the end of the wet season to schedule summer maintenance and before major fall runoff to be sure the swale is ready for winter. However, additional inspection after periods of heavy runoff is desirable. The swale should be checked for debris and litter, and areas of sediment accumulation.

- Grass height and mowing frequency may not have a large impact on pollutant removal. Consequently, mowing may only be necessary once or twice a year for safety or aesthetics or to suppress weeds and woody vegetation.

- Trash tends to accumulate in swale areas, particularly along highways. The need for litter removal is determined through periodic inspection, but litter should always be removed prior to mowing.

- Sediment accumulating near culverts and in channels should be removed when it builds up to 75 mm (3 in.) at any spot, or covers vegetation.

- Regularly inspect swales for pools of standing water. Swales can become a nuisance due to mosquito breeding in standing water if obstructions develop (e.g. debris accumulation, invasive vegetation) and/or if proper drainage slopes are not implemented and maintained.

Cost

Construction Cost

Little data is available to estimate the difference in cost between various swale designs. One study (SWRPC, 1991) estimated the construction cost of grassed channels at approximately $0.25 per ft^2. This price does not include design costs or contingencies. Brown and Schueler (1997) estimate these costs at approximately 32 percent of construction costs for most stormwater management practices. For swales, however, these costs would probably be significantly higher since the construction costs are so low compared with other practices. A more realistic estimate would be a total cost of approximately $0.50 per ft^2, which compares favorably with other stormwater management practices.

Table 2 Swale Cost Estimate (SEWRPC, 1991)

Component	Unit	Extent	Unit Cost			Total Cost		
			Low	Moderate	High	Low	Moderate	High
Mobilization / Demobilization-Light	Swale	1	$107	$274	$441	$107	$274	$441
Site Preparation								
Clearing[b]...............	Acre	0.5	$2,200	$3,800	$5,400	$1,100	$1,900	$2,700
Grubbing[c].............	Acre	0.25	$3,800	$5,200	$6,600	$950	$1,300	$1,650
General Excavation[d]...........	Yd^3	372	$2.10	$3.70	$5.30	$781	$1,376	$1,972
Level and Till[e]........	Yd^2	1,210	$0.20	$0.35	$0.50	$242	$424	$605
Sites Development								
Salvaged Topsoil Seed, and Mulch[f]..	Yd^2	1,210	$0.40	$1.00	$1.60	$484	$1,210	$1,936
Sod[g].....................	Yd^2	1,210	$1.20	$2.40	$3.60	$1,452	$2,904	$4,356
Subtotal	--	--	--	--	--	$5,116	$9,388	$13,660
Contingencies	Swale	1	25%	25%	25%	$1,279	$2,347	$3,415
Total	--	--	--	--	--	$6,395	$11,735	$17,075

Source: (SEWRPC, 1991)

Note: Mobilization/demobilization refers to the organization and planning involved in establishing a vegetative swale.

[a] Swale has a bottom width of 1.0 foot, a top width of 10 feet with 1:3 side slopes, and a 1,000-foot length.

[b] Area cleared = (top width + 10 feet) x swale length.

[c] Area grubbed = (top width x swale length).

[d] Volume excavated = (0.67 x top width x swale depth) x swale length (parabolic cross-section).

[e] Area tilled = $\left(\text{top width} + \frac{8(\text{swale depth}^2)}{3(\text{top width})}\right)$ x swale length (parabolic cross-section).

[f] Area seeded = area cleared x 0.5.

[g] Area sodded = area cleared x 0.5.

Table 3 Estimated Maintenance Costs (SEWRPC, 1991)

Component	Unit Cost	Swale Size (Depth and Top Width)		Comment
		1.5 Foot Depth, One-Foot Bottom Width, 10-Foot Top Width	3-Foot Depth, 3-Foot Bottom Width, 21-Foot Top Width	
Lawn Mowing	$0.85 / 1,000 ft^2/ mowing	$0.14 / linear foot	$0.21 / linear foot	Lawn maintenance area=(top width + 10 feet) x length. Mow eight times per year
General Lawn Care	$9.00 / 1,000 ft^2/ year	$0.18 / linear foot	$0.28 / linear foot	Lawn maintenance area = (top width + 10 feet) x length
Swale Debris and Litter Removal	$0.10 / linear foot / year	$0.10 / linear foot	$0.10 / linear foot	–
Grass Reseeding with Mulch and Fertilizer	$0.30 / yd^2	$0.01 / linear foot	$0.01 / linear foot	Area revegetated equals 1% of lawn maintenance area per year
Program Administration and Swale Inspection	$0.15 / linear foot / year, plus $25 / inspection	$0.15 / linear foot	$0.15 / linear foot	Inspect four times per year
Total	--	**$0.58 / linear foot**	**$ 0.75 / linear foot**	--

Maintenance Cost
Caltrans (2002) estimated the expected annual maintenance cost for a swale with a tributary area of approximately 2 ha at approximately $2,700. Since almost all maintenance consists of mowing, the cost is fundamentally a function of the mowing frequency. Unit costs developed by SEWRPC are shown in Table 3. In many cases vegetated channels would be used to convey runoff and would require periodic mowing as well, so there may be little additional cost for the water quality component. Since essentially all the activities are related to vegetation management, no special training is required for maintenance personnel.

References and Sources of Additional Information

Barrett, Michael E., Walsh, Patrick M., Malina, Joseph F., Jr., Charbeneau, Randall J, 1998, "Performance of vegetative controls for treating highway runoff," *ASCE Journal of Environmental Engineering*, Vol. 124, No. 11, pp. 1121-1128.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems*. Prepared for the Chesapeake Research Consortium, Solomons, MD, and USEPA Region V, Chicago, IL, by the Center for Watershed Protection, Ellicott City, MD.

Colwell, Shanti R., Horner, Richard R., and Booth, Derek B., 2000. *Characterization of Performance Predictors and Evaluation of Mowing Practices in Biofiltration Swales*. Report to King County Land And Water Resources Division and others by Center for Urban Water Resources Management, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA

Dorman, M.E., J. Hartigan, R.F. Steg, and T. Quasebarth. 1989. *Retention, Detention and Overland Flow for Pollutant Removal From Highway Stormwater Runoff. Vol. 1*. FHWA/RD 89/202. Federal Highway Administration, Washington, DC.

Goldberg. 1993. *Dayton Avenue Swale Biofiltration Study*. Seattle Engineering Department, Seattle, WA.

Harper, H. 1988. *Effects of Stormwater Management Systems on Groundwater Quality*. Prepared for Florida Department of Environmental Regulation, Tallahassee, FL, by Environmental Research and Design, Inc., Orlando, FL.

Kercher, W.C., J.C. Landon, and R. Massarelli. 1983. Grassy swales prove cost-effective for water pollution control. *Public Works*, 16: 53–55.

Koon, J. 1995. *Evaluation of Water Quality Ponds and Swales in the Issaquah/East Lake Sammamish Basins*. King County Surface Water Management, Seattle, WA, and Washington Department of Ecology, Olympia, WA.

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The Dark Side Of Stormwater Runoff Management: Disease Vectors Associated With Structural BMPs. Stormwater 3(2): 24-39.Oakland, P.H. 1983. An evaluation of stormwater pollutant removal through grassed swale treatment. In *Proceedings of the International Symposium of Urban Hydrology, Hydraulics and Sediment Control, Lexington, KY*. pp. 173–182.

Occoquan Watershed Monitoring Laboratory. 1983. Final Report: *Metropolitan Washington Urban Runoff Project*. Prepared for the Metropolitan Washington Council of Governments, Washington, DC, by the Occoquan Watershed Monitoring Laboratory, Manassas, VA.

Pitt, R., and J. McLean. 1986. *Toronto Area Watershed Management Strategy Study: Humber River Pilot Watershed Project*. Ontario Ministry of Environment, Toronto, ON.

Schueler, T. 1997. Comparative Pollutant Removal Capability of Urban BMPs: A reanalysis. *Watershed Protection Techniques* 2(2):379–383.

Seattle Metro and Washington Department of Ecology. 1992. *Biofiltration Swale Performance: Recommendations and Design Considerations*. Publication No. 657. Water Pollution Control Department, Seattle, WA.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

U.S. EPA, 1999, Stormwater Fact Sheet: Vegetated Swales, Report # 832-F-99-006 http://www.epa.gov/owm/mtb/vegswale.pdf, Office of Water, Washington DC.

Wang, T., D. Spyridakis, B. Mar, and R. Horner. 1981. *Transport, Deposition and Control of Heavy Metals in Highway Runoff*. FHWA-WA-RD-39-10. University of Washington, Department of Civil Engineering, Seattle, WA.

Washington State Department of Transportation, 1995, *Highway Runoff Manual*, Washington State Department of Transportation, Olympia, Washington.

Welborn, C., and J. Veenhuis. 1987. *Effects of Runoff Controls on the Quantity and Quality of Urban Runoff in Two Locations in Austin, TX*. USGS Water Resources Investigations Report No. 87-4004. U.S. Geological Survey, Reston, VA.

Yousef, Y., M. Wanielista, H. Harper, D. Pearce, and R. Tolbert. 1985. *Best Management Practices: Removal of Highway Contaminants By Roadside Swales*. University of Central Florida and Florida Department of Transportation, Orlando, FL.

Yu, S., S. Barnes, and V. Gerde. 1993. *Testing of Best Management Practices for Controlling Highway Runoff*. FHWA/VA-93-R16. Virginia Transportation Research Council, Charlottesville, VA.

Information Resources

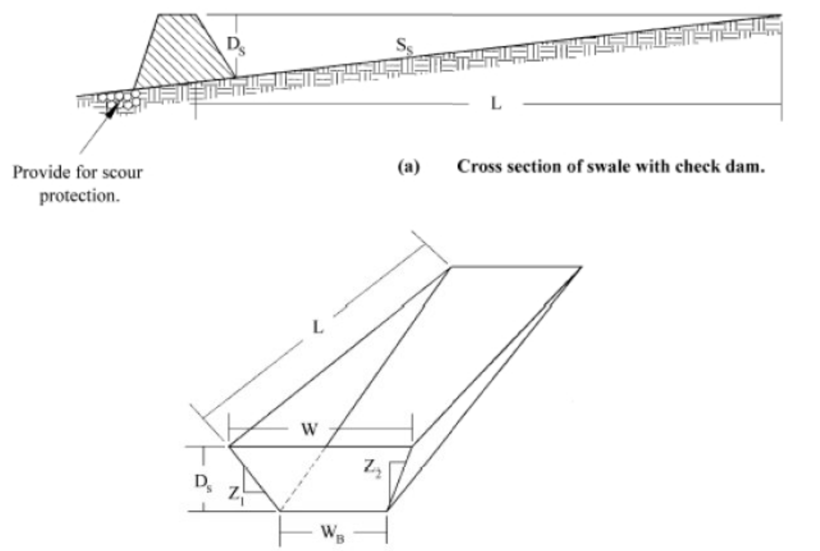
Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. www.mde.state.md.us/environment/wma/stormwatermanual. Accessed May 22, 2001.

Reeves, E. 1994. Performance and Condition of Biofilters in the Pacific Northwest. *Watershed Protection Techniques* 1(3):117–119.

Seattle Metro and Washington Department of Ecology. 1992. *Biofiltration Swale Performance*. Recommendations and Design Considerations. Publication No. 657. Seattle Metro and Washington Department of Ecology, Olympia, WA.

USEPA 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water. Washington, DC.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water. Washington, DC, by the Watershed Management Institute, Ingleside, MD.



(a) Cross section of swale with check dam.

(b) Dimensional view of swale impoundment area.

Notation:
L = Length of swale impoundment area per check dam (ft)
D_S = Depth of check dam (ft)
S_S = Bottom slpe of swale (ft/ft)
W = Top width of check dam (ft)
W_B = Bottom width of check dam (ft)
$Z_{1\&2}$ = Ratio of horizontal to vertical change in swale side slope (ft/ft)

Design Considerations

- Tributary Area
- Slope
- Water Availability
- Aesthetics

Targeted Constituents

☑	Sediment	■
☑	Nutrients	●
☑	Trash	▲
☑	Metals	■
☑	Bacteria	●
☑	Oil and Grease	■
☑	Organics	▲

Legend ***(Removal Effectiveness)***

● Low ■ High

▲ Medium

Description

Grassed buffer strips (vegetated filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by slowing runoff velocities and allowing sediment and other pollutants to settle and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. In addition, the public views them as landscaped amenities and not as stormwater infrastructure. Consequently, there is little resistance to their use.

California Experience

Caltrans constructed and monitored three vegetated buffer strips in southern California and is currently evaluating their performance at eight additional sites statewide. These strips were generally effective in reducing the volume and mass of pollutants in runoff. Even in the areas where the annual rainfall was only about 10 inches/yr, the vegetation did not require additional irrigation. One factor that strongly affected performance was the presence of large numbers of gophers at most of the southern California sites. The gophers created earthen mounds, destroyed vegetation, and generally reduced the effectiveness of the controls for TSS reduction.

Advantages

- Buffers require minimal maintenance activity (generally just erosion prevention and mowing).
- If properly designed, vegetated, and operated, buffer strips can provide reliable water quality benefits in conjunction with high aesthetic appeal.

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

- Flow characteristics and vegetation type and density can be closely controlled to maximize BMP effectiveness.

- Roadside shoulders act as effective buffer strips when slope and length meet criteria described below.

Limitations

- May not be appropriate for industrial sites or locations where spills may occur.

- Buffer strips cannot treat a very large drainage area.

- A thick vegetative cover is needed for these practices to function properly.

- Buffer or vegetative filter length must be adequate and flow characteristics acceptable or water quality performance can be severely limited.

- Vegetative buffers may not provide treatment for dissolved constituents except to the extent that flows across the vegetated surface are infiltrated into the soil profile.

- This technology does not provide significant attenuation of the increased volume and flow rate of runoff during intense rain events.

Design and Sizing Guidelines

- Maximum length (in the direction of flow towards the buffer) of the tributary area should be 60 feet.

- Slopes should not exceed 15%.

- Minimum length (in direction of flow) is 15 feet.

- Width should be the same as the tributary area.

- Either grass or a diverse selection of other low growing, drought tolerant, native vegetation should be specified. Vegetation whose growing season corresponds to the wet season is preferred.

Construction/Inspection Considerations

- Include directions in the specifications for use of appropriate fertilizer and soil amendments based on soil properties determined through testing and compared to the needs of the vegetation requirements.

- Install strips at the time of the year when there is a reasonable chance of successful establishment without irrigation; however, it is recognized that rainfall in a given year may not be sufficient and temporary irrigation may be required.

- If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the strip.

- Use a roller on the sod to ensure that no air pockets form between the sod and the soil.

- Where seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season.

Performance

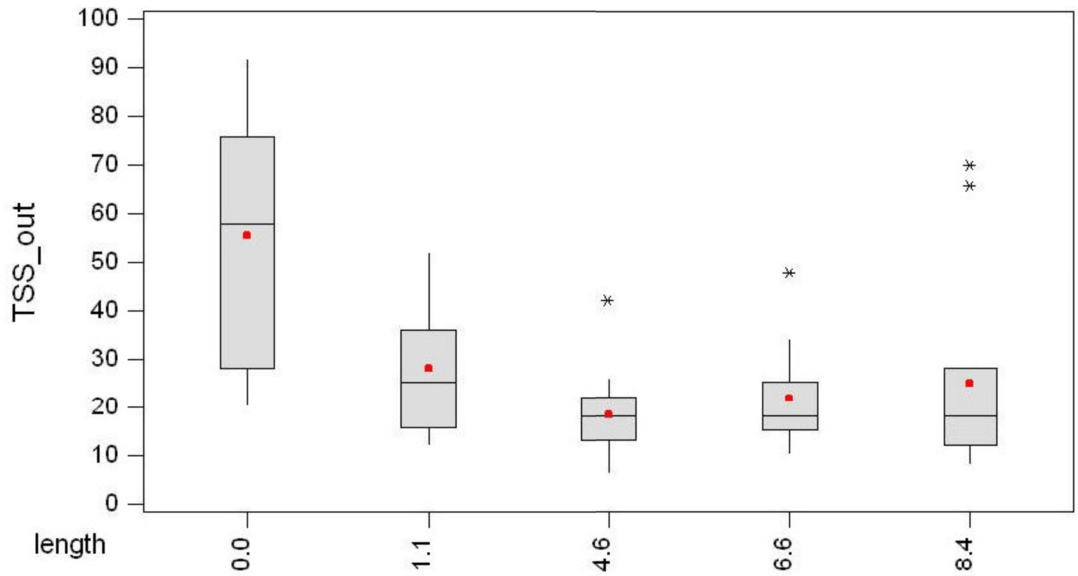
Vegetated buffer strips tend to provide somewhat better treatment of stormwater runoff than swales and have fewer tendencies for channelization or erosion. Table 1 documents the pollutant removal observed in a recent study by Caltrans (2002) based on three sites in southern California. The column labeled "Significance" is the probability that the mean influent and effluent EMCs are not significantly different based on an analysis of variance.

The removal of sediment and dissolved metals was comparable to that observed in much more complex controls. Reduction in nitrogen was not significant and all of the sites exported phosphorus for the entire study period. This may have been the result of using salt grass, a warm weather species that is dormant during the wet season, and which leaches phosphorus when dormant.

Another Caltrans study (unpublished) of vegetated highway shoulders as buffer strips also found substantial reductions often within a very short distance of the edge of pavement. Figure 1 presents a box and whisker plot of the concentrations of TSS in highway runoff after traveling various distances (shown in meters) through a vegetated filter strip with a slope of about 10%. One can see that the TSS median concentration reaches an irreducible minimum concentration of about 20 mg/L within 5 meters of the pavement edge.

Table 1 Pollutant Reduction in a Vegetated Buffer Strip

Constituent	Mean EMC		Removal %	Significance
	Influent (mg/L)	Effluent (mg/L)		P
TSS	119	31	74	<0.000
NO_3-N	0.67	0.58	13	0.367
TKN-N	2.50	2.10	16	0.542
Total N[a]	3.17	2.68	15	-
Dissolved P	0.15	0.46	-206	0.047
Total P	0.42	0.62	-52	0.035
Total Cu	0.058	0.009	84	<0.000
Total Pb	0.046	0.006	88	<0.000
Total Zn	0.245	0.055	78	<0.000
Dissolved Cu	0.029	0.007	77	0.004
Dissolved Pb	0.004	0.002	66	0.006
Dissolved Zn	0.099	0.035	65	<0.000



Filter strips also exhibit good removal of litter and other floatables because the water depth in these systems is well below the vegetation height and consequently these materials are not easily transported through them. Unfortunately little attenuation of peak runoff rates and volumes (particularly for larger events) is normally observed, depending on the soil properties. Therefore it may be prudent to follow the strips with another practice than can reduce flooding and channel erosion downstream.

Siting Criteria

The use of buffer strips is limited to gently sloping areas where the vegetative cover is robust and diffuse, and where shallow flow characteristics are possible. The practical water quality benefits can be effectively eliminated with the occurrence of significant erosion or when flow concentration occurs across the vegetated surface. Slopes should not exceed 15 percent or be less than 1 percent. The vegetative surface should extend across the full width of the area being drained. The upstream boundary of the filter should be located contiguous to the developed area. Use of a level spreading device (vegetated berm, sawtooth concrete border, rock trench, etc) to facilitate overland sheet flow is not normally recommended because of maintenance considerations and the potential for standing water.

Filter strips are applicable in most regions, but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer or as pretreatment to a structural practice. In arid areas, however, the cost of irrigating the grass on the practice will most likely outweigh its water quality benefits, although aesthetic considerations may be sufficient to overcome this constraint. Filter strips are generally impractical in ultra-urban areas where little pervious surface exists.

Some cold water species, such as trout, are sensitive to changes in temperature. While some treatment practices, such as wet ponds, can warm stormwater substantially, filter strips do not are not expected to increase stormwater temperatures. Thus, these practices are good for protection of cold-water streams.

Filter strips should be separated from the ground water by between 2 and 4 ft to prevent contamination and to ensure that the filter strip does not remain wet between storms.

Additional Design Guidelines

Filter strips appear to be a minimal design practice because they are basically no more than a grassed slope. In general the slope of the strip should not exceed 15fc% and the strip should be at least 15 feet long to provide water quality treatment. Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion. The top of the strip should be installed 2-5 inches below the adjacent pavement, so that vegetation and sediment accumulation at the edge of the strip does not prevent runoff from entering.

A major question that remains unresolved is how large the drainage area to a strip can be. Research has conclusively demonstrated that these are effective on roadside shoulders, where the contributing area is about twice the buffer area. They have also been installed on the perimeter of large parking lots where they performed fairly effectively; however much lower slopes may be needed to provide adequate water quality treatment.

The filter area should be densely vegetated with a mix of erosion-resistant plant species that effectively bind the soil. Native or adapted grasses, shrubs, and trees are preferred because they generally require less fertilizer and are more drought resistant than exotic plants. Runoff flow velocities should not exceed about 1 fps across the vegetated surface.

For engineered vegetative strips, the facility surface should be graded flat prior to placement of vegetation. Initial establishment of vegetation requires attentive care including appropriate watering, fertilization, and prevention of excessive flow across the facility until vegetation completely covers the area and is well established. Use of a permanent irrigation system may help provide maximal water quality performance.

In cold climates, filter strips provide a convenient area for snow storage and treatment. If used for this purpose, vegetation in the filter strip should be salt-tolerant (e.g., creeping bentgrass), and a maintenance schedule should include the removal of sand built up at the bottom of the slope. In arid or semi-arid climates, designers should specify drought-tolerant grasses to minimize irrigation requirements.

Maintenance

Filter strips require mainly vegetation management; therefore little special training is needed for maintenance crews. Typical maintenance activities and frequencies include:

- Inspect strips at least twice annually for erosion or damage to vegetation, preferably at the end of the wet season to schedule summer maintenance and before major fall run-off to be sure the strip is ready for winter. However, additional inspection after periods of heavy run-off is most desirable. The strip should be checked for debris and litter and areas of sediment accumulation.

- Recent research on biofiltration swales, but likely applicable to strips (Colwell et al., 2000), indicates that grass height and mowing frequency have little impact on pollutant removal;

consequently, mowing may only be necessary once or twice a year for safety and aesthetics or to suppress weeds and woody vegetation.

- Trash tends to accumulate in strip areas, particularly along highways. The need for litter removal should be determined through periodic inspection but litter should always be removed prior to mowing.

- Regularly inspect vegetated buffer strips for pools of standing water. Vegetated buffer strips can become a nuisance due to mosquito breeding in level spreaders (unless designed to dewater completely in 48-72 hours), in pools of standing water if obstructions develop (e.g. debris accumulation, invasive vegetation), and/or if proper drainage slopes are not implemented and maintained.

Cost

Construction Cost

Little data is available on the actual construction costs of filter strips. One rough estimate can be the cost of seed or sod, which is approximately 30¢ per ft^2 for seed or 70¢ per ft^2 for sod. This amounts to between $13,000 and $30,000 per acre of filter strip. This cost is relatively high compared with other treatment practices. However, the grassed area used as a filter strip may have been seeded or sodded even if it were not used for treatment. In these cases, the only additional cost is the design. Typical maintenance costs are about $350/acre/year (adapted from SWRPC, 1991). This cost is relatively inexpensive and, again, might overlap with regular landscape maintenance costs.

The true cost of filter strips is the land they consume. In some situations this land is available as wasted space beyond back yards or adjacent to roadsides, but this practice is cost-prohibitive when land prices are high and land could be used for other purposes.

Maintenance Cost

Maintenance of vegetated buffer strips consists mainly of vegetation management (mowing, irrigation if needed, weeding) and litter removal. Consequently the costs are quite variable depending on the frequency of these activities and the local labor rate.

References and Sources of Additional Information

Caltrans, 2002, BMP Retrofit Pilot Program Proposed Final Report, Rpt. CTSW-RT-01-050, California Dept. of Transportation, Sacramento, CA.

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems*. Prepared for Chesapeake Research Consortium, Solomons, MD, and EPA Region V, Chicago, IL.

Desbonette, A., P. Pogue, V. Lee, and N. Wolff. 1994. *Vegetated Buffers in the Coastal Zone: A Summary Review and Bibliography*. Coastal Resources Center. University of Rhode Island, Kingston, RI.

Magette, W., R. Brinsfield, R. Palmer and J. Wood. 1989. Nutrient and Sediment Removal by Vegetated Filter Strips. *Transactions of the American Society of Agricultural Engineers* 32(2): 663–667.

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The Dark Side Of Stormwater Runoff Management: Disease Vectors Associated With Structural BMPs. Stormwater 3(2): 24-39.

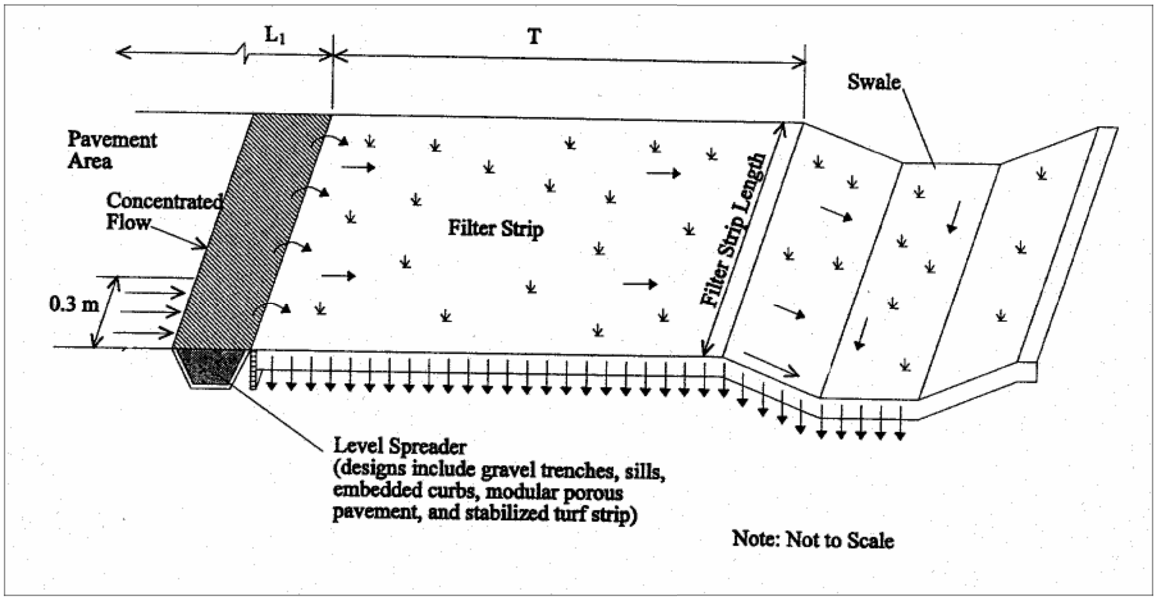
Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Yu, S., S. Barnes and V. Gerde. 1993. *Testing of Best Management Practices for Controlling Highway Runoff*. FHWA/VA 93-R16. Virginia Transportation Research Council, Charlottesville, VA.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency Office of Wetlands, Oceans and Watersheds. Washington, DC.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. http://www.mde.state.md.us/environment/wma/stormwatermanual. Accessed May 22, 2001.


L1
T
Swale
Pavement Area
Concentrated Flow
Filter Strip
Filter Strip Length
0.3 m
Level Spreader
(designs include gravel trenches, sills, embedded curbs, modular porous pavement, and stabilized turf strip)
Note: Not to Scale

Design Considerations

- Soil for Infiltration
- Tributary Area
- Slope
- Aesthetics
- Environmental Side-effects

Targeted Constituents

☑	Sediment	■
☑	Nutrients	▲
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend ***(Removal Effectiveness)***

● Low ■ High

▲ Medium

Description

The bioretention best management practice (BMP) functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. These facilities normally consist of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. The runoff's velocity is reduced by passing over or through buffer strip and subsequently distributed evenly along a ponding area. Exfiltration of the stored water in the bioretention area planting soil into the underlying soils occurs over a period of days.

California Experience

None documented. Bioretention has been used as a stormwater BMP since 1992. In addition to Prince George's County, MD and Alexandria, VA, bioretention has been used successfully at urban and suburban areas in Montgomery County, MD; Baltimore County, MD; Chesterfield County, VA; Prince William County, VA; Smith Mountain Lake State Park, VA; and Cary, NC.

Advantages

- Bioretention provides stormwater treatment that enhances the quality of downstream water bodies by temporarily storing runoff in the BMP and releasing it over a period of four days to the receiving water (EPA, 1999).

- The vegetation provides shade and wind breaks, absorbs noise, and improves an area's landscape.

Limitations

- The bioretention BMP is not recommended for areas with slopes greater than 20% or where mature tree removal would

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

be required since clogging may result, particularly if the BMP receives runoff with high sediment loads (EPA, 1999).

- Bioretention is not a suitable BMP at locations where the water table is within 6 feet of the ground surface and where the surrounding soil stratum is unstable.
- By design, bioretention BMPs have the potential to create very attractive habitats for mosquitoes and other vectors because of highly organic, often heavily vegetated areas mixed with shallow water.
- In cold climates the soil may freeze, preventing runoff from infiltrating into the planting soil.

Design and Sizing Guidelines

- The bioretention area should be sized to capture the design storm runoff.
- In areas where the native soil permeability is less than 0.5 in/hr an underdrain should be provided.
- Recommended minimum dimensions are 15 feet by 40 feet, although the preferred width is 25 feet. Excavated depth should be 4 feet.
- Area should drain completely within 72 hours.
- Approximately 1 tree or shrub per 50 ft^2 of bioretention area should be included.
- Cover area with about 3 inches of mulch.

Construction/Inspection Considerations

Bioretention area should not be established until contributing watershed is stabilized.

Performance

Bioretention removes stormwater pollutants through physical and biological processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization (EPA, 1999). Adsorption is the process whereby particulate pollutants attach to soil (e.g., clay) or vegetation surfaces. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Thus, the infiltration rate of the soils must not exceed those specified in the design criteria or pollutant removal may decrease. Pollutants removed by adsorption include metals, phosphorus, and hydrocarbons. Filtration occurs as runoff passes through the bioretention area media, such as the sand bed, ground cover, and planting soil.

Common particulates removed from stormwater include particulate organic matter, phosphorus, and suspended solids. Biological processes that occur in wetlands result in pollutant uptake by plants and microorganisms in the soil. Plant growth is sustained by the uptake of nutrients from the soils, with woody plants locking up these nutrients through the seasons. Microbial activity within the soil also contributes to the removal of nitrogen and organic matter. Nitrogen is removed by nitrifying and denitrifying bacteria, while aerobic bacteria are responsible for the decomposition of the organic matter. Microbial processes require oxygen and can result in depleted oxygen levels if the bioretention area is not adequately aerated. Sedimentation occurs in the swale or ponding area as the velocity slows and solids fall out of suspension.

The removal effectiveness of bioretention has been studied during field and laboratory studies conducted by the University of Maryland (Davis et al, 1998). During these experiments, synthetic stormwater runoff was pumped through several laboratory and field bioretention areas to simulate typical storm events in Prince George's County, MD. Removal rates for heavy metals and nutrients are shown in Table 1.

Table 1 Laboratory and Estimated Bioretention Davis et al. (1998); PGDER (1993)

Pollutant	Removal Rate
Total Phosphorus	70-83%
Metals (Cu, Zn, Pb)	93-98%
TKN	68-80%
Total Suspended Solids	90%
Organics	90%
Bacteria	90%

Results for both the laboratory and field experiments were similar for each of the pollutants analyzed. Doubling or halving the influent pollutant levels had little effect on the effluent pollutants concentrations (Davis et al, 1998).

The microbial activity and plant uptake occurring in the bioretention area will likely result in higher removal rates than those determined for infiltration BMPs.

Siting Criteria

Bioretention BMPs are generally used to treat stormwater from impervious surfaces at commercial, residential, and industrial areas (EPA, 1999). Implementation of bioretention for stormwater management is ideal for median strips, parking lot islands, and swales. Moreover, the runoff in these areas can be designed to either divert directly into the bioretention area or convey into the bioretention area by a curb and gutter collection system.

The best location for bioretention areas is upland from inlets that receive sheet flow from graded areas and at areas that will be excavated (EPA, 1999). In order to maximize treatment effectiveness, the site must be graded in such a way that minimizes erosive conditions as sheet flow is conveyed to the treatment area. Locations where a bioretention area can be readily incorporated into the site plan without further environmental damage are preferred. Furthermore, to effectively minimize sediment loading in the treatment area, bioretention only should be used in stabilized drainage areas.

Additional Design Guidelines

The layout of the bioretention area is determined after site constraints such as location of utilities, underlying soils, existing vegetation, and drainage are considered (EPA, 1999). Sites with loamy sand soils are especially appropriate for bioretention because the excavated soil can be backfilled and used as the planting soil, thus eliminating the cost of importing planting soil.

The use of bioretention may not be feasible given an unstable surrounding soil stratum, soils with clay content greater than 25 percent, a site with slopes greater than 20 percent, and/or a site with mature trees that would be removed during construction of the BMP.

Bioretention can be designed to be off-line or on-line of the existing drainage system (EPA, 1999). The drainage area for a bioretention area should be between 0.1 and 0.4 hectares (0.25 and 1.0 acres). Larger drainage areas may require multiple bioretention areas. Furthermore, the maximum drainage area for a bioretention area is determined by the expected rainfall intensity and runoff rate. Stabilized areas may erode when velocities are greater than 5 feet per second (1.5 meter per second). The designer should determine the potential for erosive conditions at the site.

The size of the bioretention area, which is a function of the drainage area and the runoff generated from the area is sized to capture the water quality volume.

The recommended minimum dimensions of the bioretention area are 15 feet (4.6 meters) wide by 40 feet (12.2 meters) long, where the minimum width allows enough space for a dense, randomly-distributed area of trees and shrubs to become established. Thus replicating a natural forest and creating a microclimate, thereby enabling the bioretention area to tolerate the effects of heat stress, acid rain, runoff pollutants, and insect and disease infestations which landscaped areas in urban settings typically are unable to tolerate. The preferred width is 25 feet (7.6 meters), with a length of twice the width. Essentially, any facilities wider than 20 feet (6.1 meters) should be twice as long as they are wide, which promotes the distribution of flow and decreases the chances of concentrated flow.

In order to provide adequate storage and prevent water from standing for excessive periods of time the ponding depth of the bioretention area should not exceed 6 inches (15 centimeters). Water should not be left to stand for more than 72 hours. A restriction on the type of plants that can be used may be necessary due to some plants' water intolerance. Furthermore, if water is left standing for longer than 72 hours mosquitoes and other insects may start to breed.

The appropriate planting soil should be backfilled into the excavated bioretention area. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25 percent.

Generally the soil should have infiltration rates greater than 0.5 inches (1.25 centimeters) per hour, which is typical of sandy loams, loamy sands, or loams. The pH of the soil should range between 5.5 and 6.5, where pollutants such as organic nitrogen and phosphorus can be adsorbed by the soil and microbial activity can flourish. Additional requirements for the planting soil include a 1.5 to 3 percent organic content and a maximum 500 ppm concentration of soluble salts.

Soil tests should be performed for every 500 cubic yards (382 cubic meters) of planting soil, with the exception of pH and organic content tests, which are required only once per bioretention area (EPA, 1999). Planting soil should be 4 inches (10.1 centimeters) deeper than the bottom of the largest root ball and 4 feet (1.2 meters) altogether. This depth will provide adequate soil for the plants' root systems to become established, prevent plant damage due to severe wind, and provide adequate moisture capacity. Most sites will require excavation in order to obtain the recommended depth.

Planting soil depths of greater than 4 feet (1.2 meters) may require additional construction practices such as shoring measures (EPA, 1999). Planting soil should be placed in 18 inches or greater lifts and lightly compacted until the desired depth is reached. Since high canopy trees may be destroyed during maintenance the bioretention area should be vegetated to resemble a terrestrial forest community ecosystem that is dominated by understory trees. Three species each of both trees and shrubs are recommended to be planted at a rate of 2500 trees and shrubs per hectare (1000 per acre). For instance, a 15 foot (4.6 meter) by 40 foot (12.2 meter) bioretention area (600 square feet or 55.75 square meters) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1.

Trees and shrubs should be planted when conditions are favorable. Vegetation should be watered at the end of each day for fourteen days following its planting. Plant species tolerant of pollutant loads and varying wet and dry conditions should be used in the bioretention area.

The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures, such as providing a soil breach to eliminate the threat of these species invading the bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities. The designers should evaluate the best placement of vegetation within the bioretention area. Plants should be placed at irregular intervals to replicate a natural forest. Trees should be placed on the perimeter of the area to provide shade and shelter from the wind. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. In cold climates, species that are more tolerant to cold winds, such as evergreens, should be placed in windier areas of the site.

Following placement of the trees and shrubs, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted at the beginning of the growing season. Mulch should be placed immediately after trees and shrubs are planted. Two to 3 inches (5 to 7.6 cm) of commercially-available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion.

Maintenance

The primary maintenance requirement for bioretention areas is that of inspection and repair or replacement of the treatment area's components. Generally, this involves nothing more than the routine periodic maintenance that is required of any landscaped area. Plants that are appropriate for the site, climatic, and watering conditions should be selected for use in the bioretention cell. Appropriately selected plants will aide in reducing fertilizer, pesticide, water, and overall maintenance requirements. Bioretention system components should blend over time through plant and root growth, organic decomposition, and the development of a natural soil horizon. These biologic and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance.

Routine maintenance should include a biannual health evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (EPA, 1999). Diseased vegetation should be treated as needed using preventative and low-toxic measures to the extent possible. BMPs have the potential to create very attractive habitats for mosquitoes and other vectors because of highly organic, often heavily vegetated areas mixed with shallow water. Routine inspections for areas of standing water within the BMP and corrective measures to restore proper infiltration rates are necessary to prevent creating mosquito and other vector habitat. In addition, bioretention BMPs are susceptible to invasion by aggressive plant species such as cattails, which increase the chances of water standing and subsequent vector production if not routinely maintained.

In order to maintain the treatment area's appearance it may be necessary to prune and weed. Furthermore, mulch replacement is suggested when erosion is evident or when the site begins to look unattractive. Specifically, the entire area may require mulch replacement every two to three years, although spot mulching may be sufficient when there are random void areas. Mulch replacement should be done prior to the start of the wet season.

New Jersey's Department of Environmental Protection states in their bioretention systems standards that accumulated sediment and debris removal (especially at the inflow point) will normally be the primary maintenance function. Other potential tasks include replacement of dead vegetation, soil pH regulation, erosion repair at inflow points, mulch replenishment, unclogging the underdrain, and repairing overflow structures. There is also the possibility that the cation exchange capacity of the soils in the cell will be significantly reduced over time. Depending on pollutant loads, soils may need to be replaced within 5-10 years of construction (LID, 2000).

Cost

Construction Cost

Construction cost estimates for a bioretention area are slightly greater than those for the required landscaping for a new development (EPA, 1999). A general rule of thumb (Coffman, 1999) is that residential bioretention areas average about $3 to $4 per square foot, depending on soil conditions and the density and types of plants used. Commercial, industrial and institutional site costs can range between $10 to $40 per square foot, based on the need for control structures, curbing, storm drains and underdrains.

Retrofitting a site typically costs more, averaging $6,500 per bioretention area. The higher costs are attributed to the demolition of existing concrete, asphalt, and existing structures and the replacement of fill material with planting soil. The costs of retrofitting a commercial site in Maryland, Kettering Development, with 15 bioretention areas were estimated at $111,600.

In any bioretention area design, the cost of plants varies substantially and can account for a significant portion of the expenditures. While these cost estimates are slightly greater than those of typical landscaping treatment (due to the increased number of plantings, additional soil excavation, backfill material, use of underdrains etc.), those landscaping expenses that would be required regardless of the bioretention installation should be subtracted when determining the net cost.

Perhaps of most importance, however, the cost savings compared to the use of traditional structural stormwater conveyance systems makes bioretention areas quite attractive financially. For example, the use of bioretention can decrease the cost required for constructing stormwater conveyance systems at a site. A medical office building in Maryland was able to reduce the amount of storm drain pipe that was needed from 800 to 230 feet - a cost savings of $24,000 (PGDER, 1993). And a new residential development spent a total of approximately $100,000 using bioretention cells on each lot instead of nearly $400,000 for the traditional stormwater ponds that were originally planned (Rappahanock,). Also, in residential areas, stormwater management controls become a part of each property owner's landscape, reducing the public burden to maintain large centralized facilities.

Maintenance Cost

The operation and maintenance costs for a bioretention facility will be comparable to those of typical landscaping required for a site. Costs beyond the normal landscaping fees will include the cost for testing the soils and may include costs for a sand bed and planting soil.

References and Sources of Additional Information

Coffman, L.S., R. Goo and R. Frederick, 1999: Low impact development: an innovative alternative approach to stormwater management. Proceedings of the 26th Annual Water Resources Planning and Management Conference ASCE, June 6-9, Tempe, Arizona.

Davis, A.P., Shokouhian, M., Sharma, H. and Minami, C., "Laboratory Study of Biological Retention (Bioretention) for Urban Stormwater Management," *Water Environ. Res.*, 73(1), 5-14 (2001).

Davis, A.P., Shokouhian, M., Sharma, H., Minami, C., and Winogradoff, D. "Water Quality Improvement through Bioretention: Lead, Copper, and Zinc," *Water Environ. Res.*, accepted for publication, August 2002.

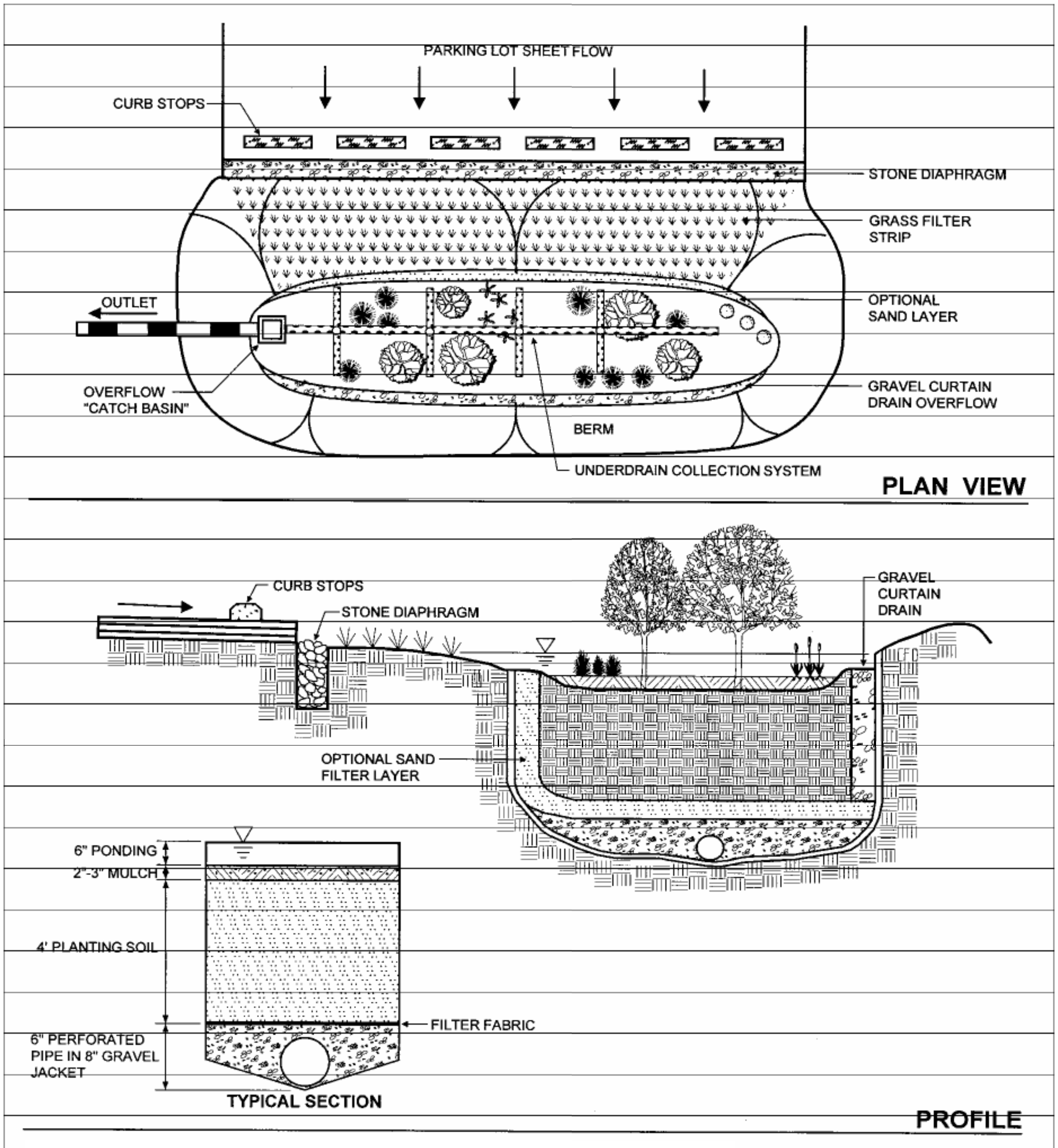
Kim, H., Seagren, E.A., and Davis, A.P., "Engineered Bioretention for Removal of Nitrate from Stormwater Runoff," *WEFTEC 2000 Conference Proceedings on CDROM Research Symposium, Nitrogen Removal*, Session 19, Anaheim CA, October 2000.

Hsieh, C.-h. and Davis, A.P. "Engineering Bioretention for Treatment of Urban Stormwater Runoff," *Watersheds 2002, Proceedings on CDROM Research Symposium*, Session 15, Ft. Lauderdale, FL, Feb. 2002.

Prince George's County Department of Environmental Resources (PGDER), 1993. Design Manual for Use of *Bioretention in Stormwater Management*. Division of Environmental Management, Watershed Protection Branch. Landover, MD.

U.S. EPA Office of Water, 1999. Stormwater Technology Fact Sheet: Bioretention. EPA 832-F-99-012.

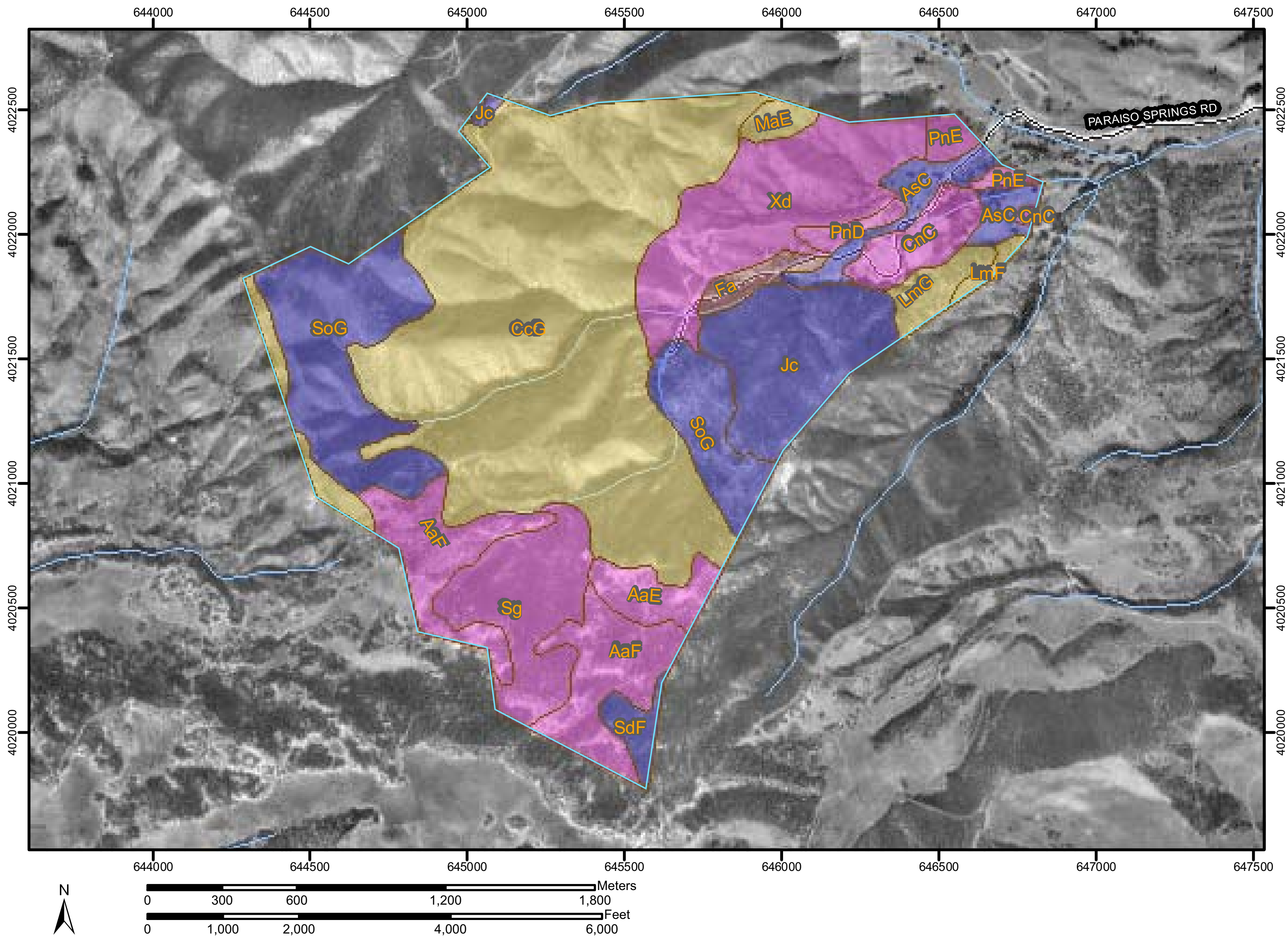
Weinstein, N. Davis, A.P. and Veeramachaneni, R. "Low Impact Development (LID) Stormwater Management Approach for the Control of Diffuse Pollution from Urban Roadways," *5th International Conference Diffuse/Nonpoint Pollution and Watershed Management Proceedings*, C.S. Melching and Emre Alp, Eds. 2001 International Water Association



Schematic of a Bioretention Facility (MDE, 2000)

Attachment 8
Web Soil Survey 2.0 Output for the Project Site

Hydrologic Soil Group–Monterey County, California



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

Municipalities
- Cities
- Urban Areas

Water Features
- Oceans
- Streams and Canals

Transportation
- Rails

Roads
- Interstate Highways
- US Routes
- State Highways
- Local Roads
- Other Roads

MAP INFORMATION

Original soil survey map sheets were prepared at publication scale. Viewing scale and printing scale, however, may vary from the original. Please rely on the bar scale on each map sheet for proper map measurements.

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

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 7, Dec 10, 2007

Date(s) aerial images were photographed: 5/13/1994

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
AaE	Alo silty clay, 15 to 30 percent slopes	D	23.2	2.0%
AaF	Alo silty clay, 30 to 50 percent slopes	D	102.2	8.8%
AsC	Arroyo Seco gravelly sandy loam, 5 to 9 percent slopes	B	36.7	3.1%
CcG	Cieneba fine gravelly sandy loam, 30 to 75 percent slopes	C	467.3	40.0%
CnC	Cropley silty clay, 2 to 9 percent slopes	D	29.5	2.5%
Fa	Fluvents, stony	A	12.1	1.0%
Jc	Junipero-Sur complex	B	89.5	7.7%
LmF	Los Osos clay loam, 30 to 50 percent slopes	C	5.3	0.5%
LmG	Los Osos clay loam, 50 to 75 percent slopes	C	17.2	1.5%
MaE	McCoy clay loam, 15 to 30 percent slopes	C	9.0	0.8%
PnD	Placentia sandy loam, 9 to 15 percent slopes	D	8.0	0.7%
PnE	Placentia sandy loam, 15 to 30 percent slopes	D	11.5	1.0%
SdF	San Benito clay loam, 30 to 50 percent slopes	B	12.6	1.1%
Sg	Santa Lucia-Reliz association	D	73.7	6.3%
SoG	Sheridan coarse sandy loam, 30 to 75 percent slopes	B	150.2	12.9%
Xd	Xerorthents, dissected	D	119.3	10.2%
Totals for Area of Interest (AOI)			1,167.4	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