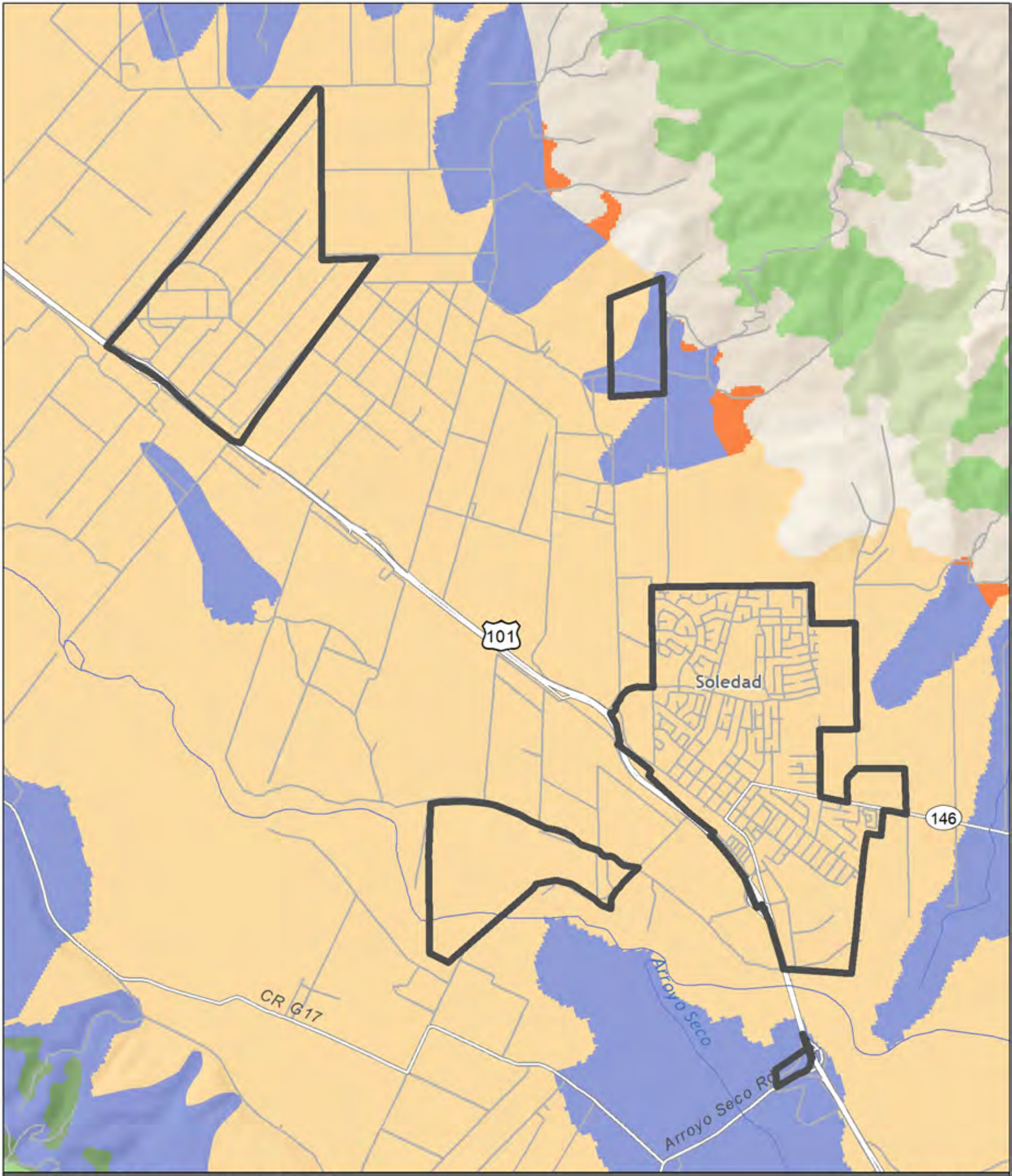

CENTRAL COAST JOINT EFFORT **Soledad, California**

Watershed management zones

1
2
3
4
5
6
7
8
9
10

Urban area boundary

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

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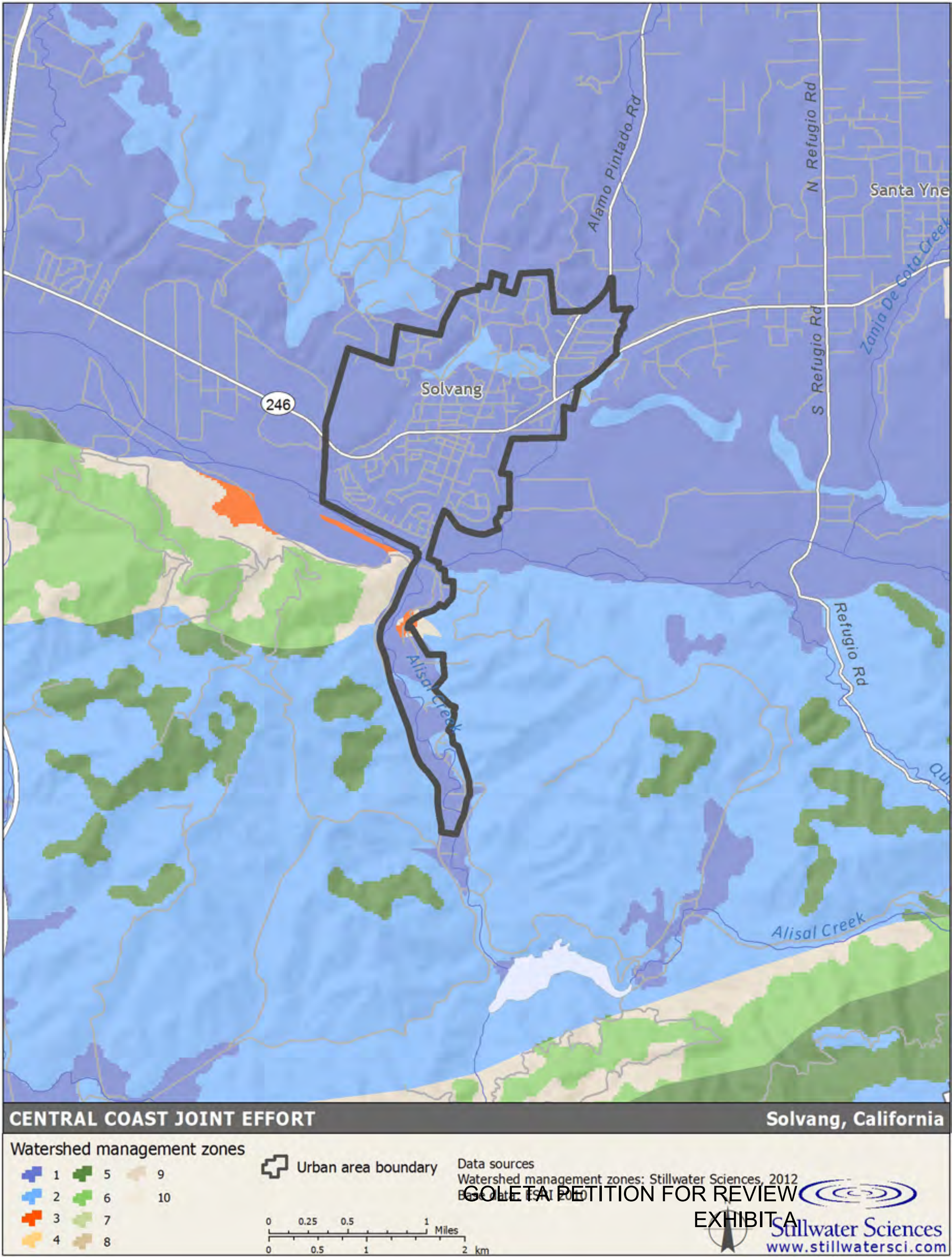
Stillwater Sciences
www.stillwatersci.com



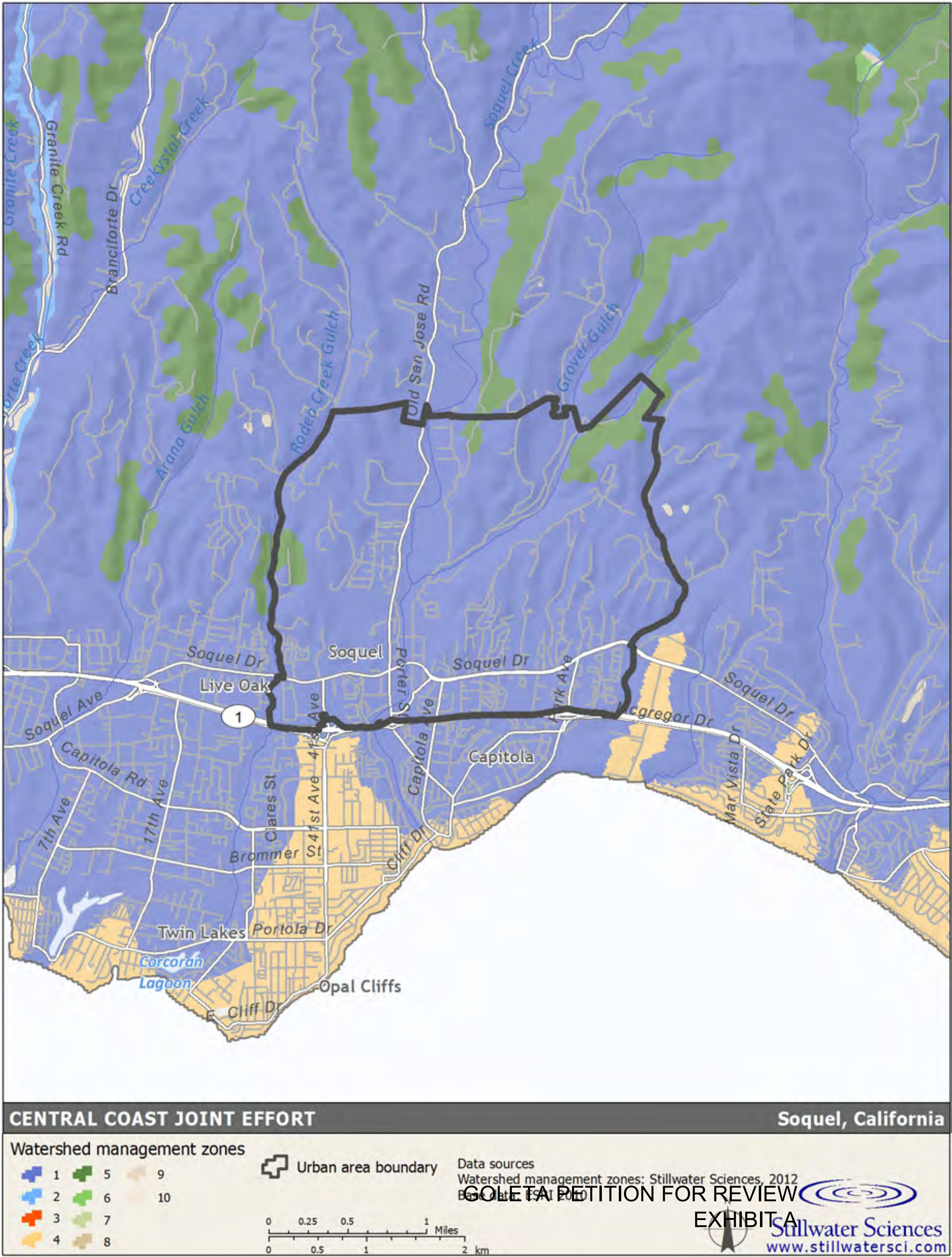
CENTRAL COAST JOINT EFFORT

Solvang, California

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

GOLETA PETITION FOR REVIEW
EXHIBIT A

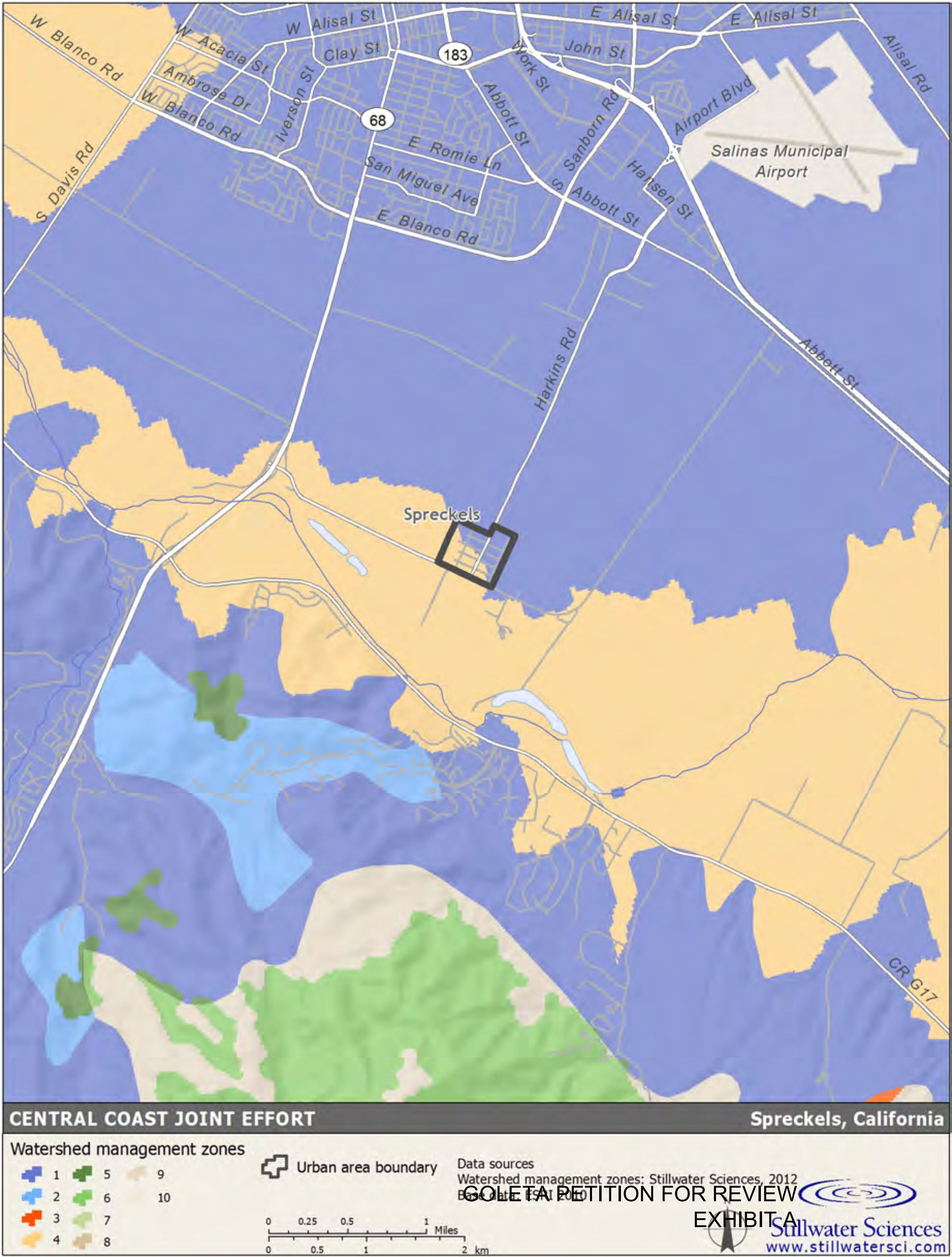
GOLETA PETITION FOR REVIEW
EXHIBIT A



CENTRAL COAST JOINT EFFORT

Soquel, California

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010



CENTRAL COAST JOINT EFFORT

Spreckels, California

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

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CENTRAL COAST JOINT EFFORT **Summerland, California**

Watershed management zones

- ■ 1
- ■ 2
- ■ 3
- ■ 4
- ■ 5
- ■ 6
- ■ 7
- ■ 8
- ■ 9
- 10

Urban area boundary

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

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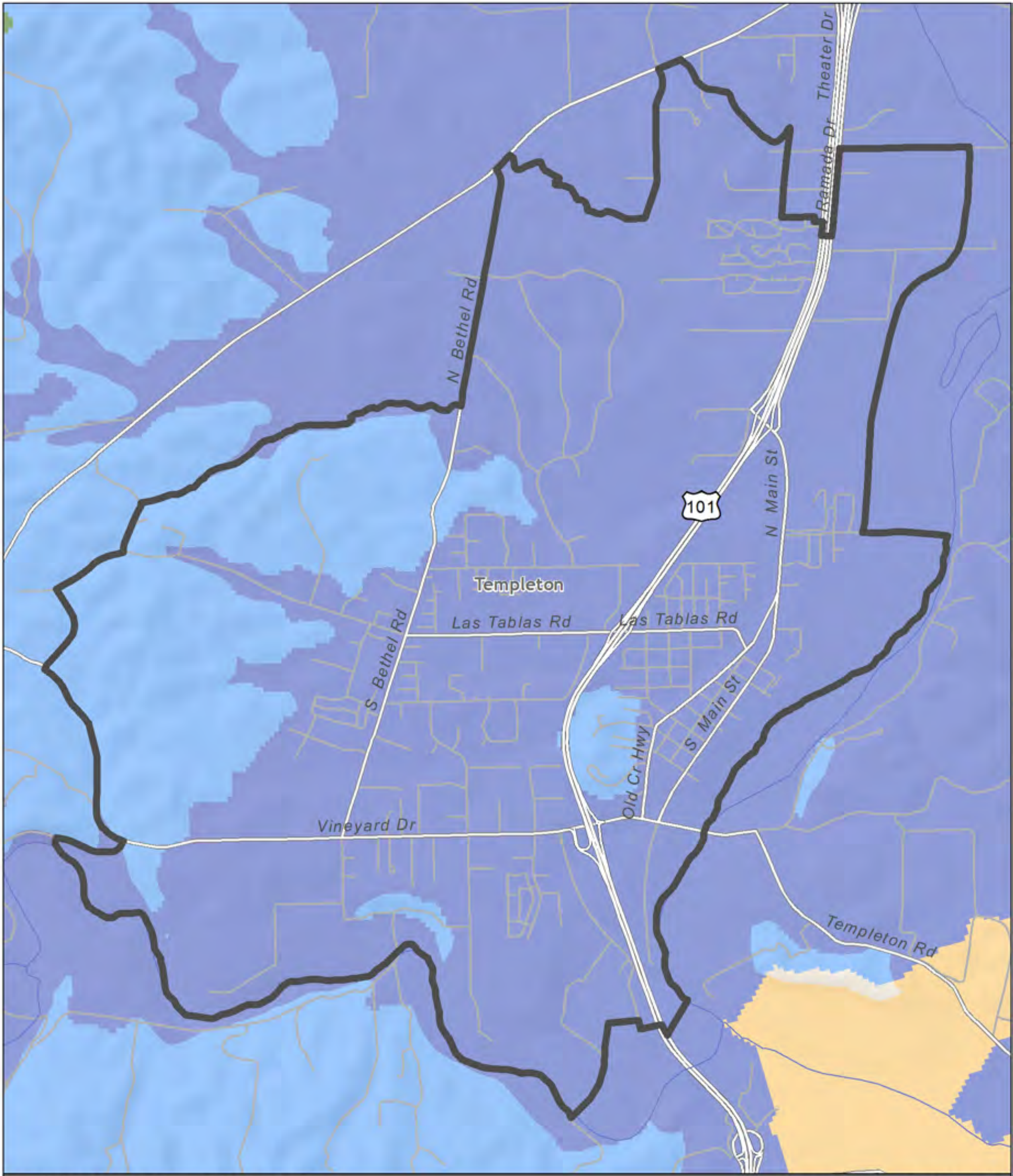

CENTRAL COAST JOINT EFFORT **Templeton, California**

Watershed management zones

🟦 1	🟩 5	⬜ 9
🟦 2	🟩 6	10
🟧 3	🟩 7	
🟧 4	🟫 8	

Urban area boundary

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

0 0.25 0.5 1 Miles
0 0.5 1 2 km

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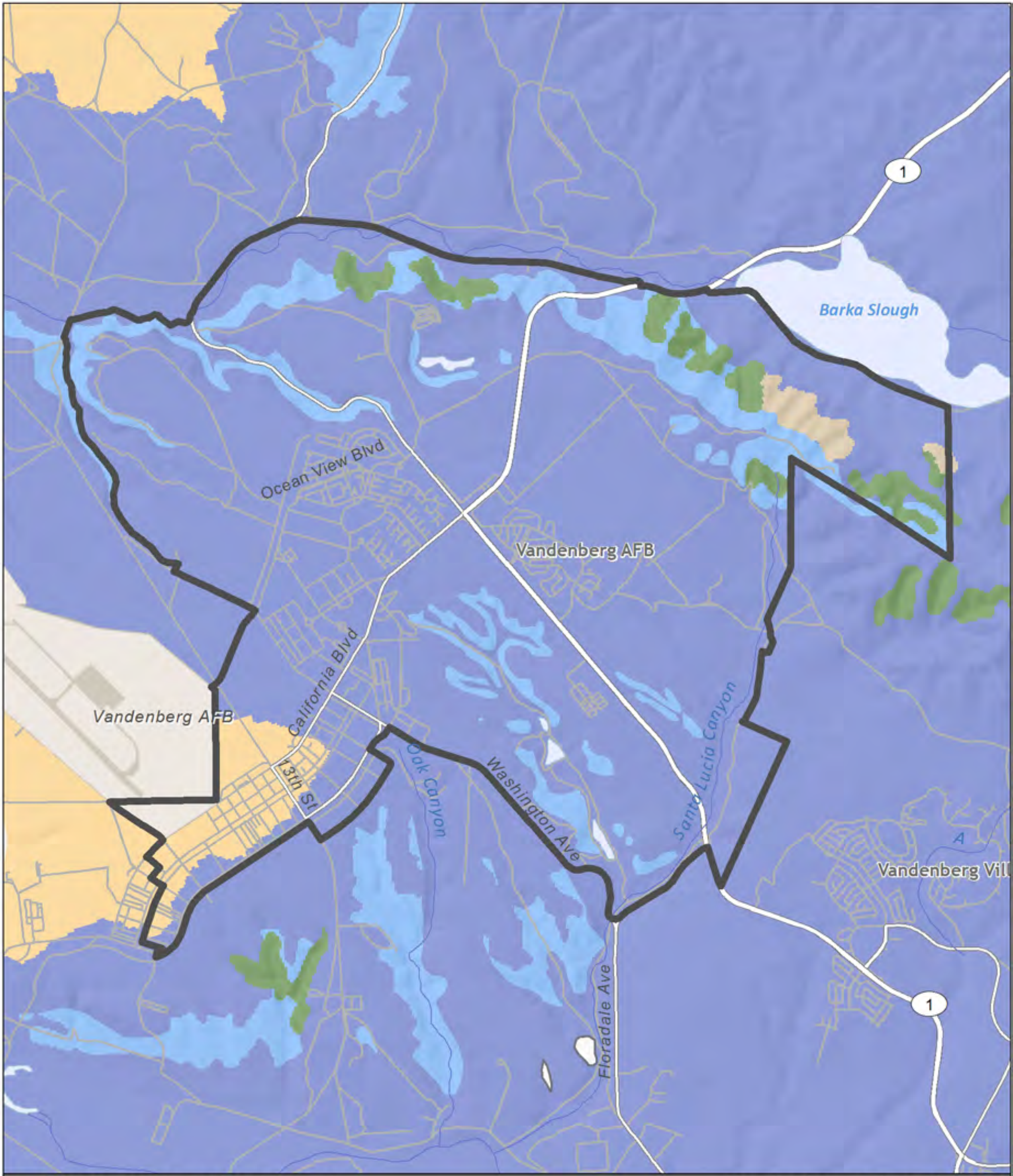

CENTRAL COAST JOINT EFFORT **Vandenberg AFB, California**

Watershed management zones

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

Urban area boundary

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

0 0.25 0.5 1 Miles
0 0.5 1 2 km

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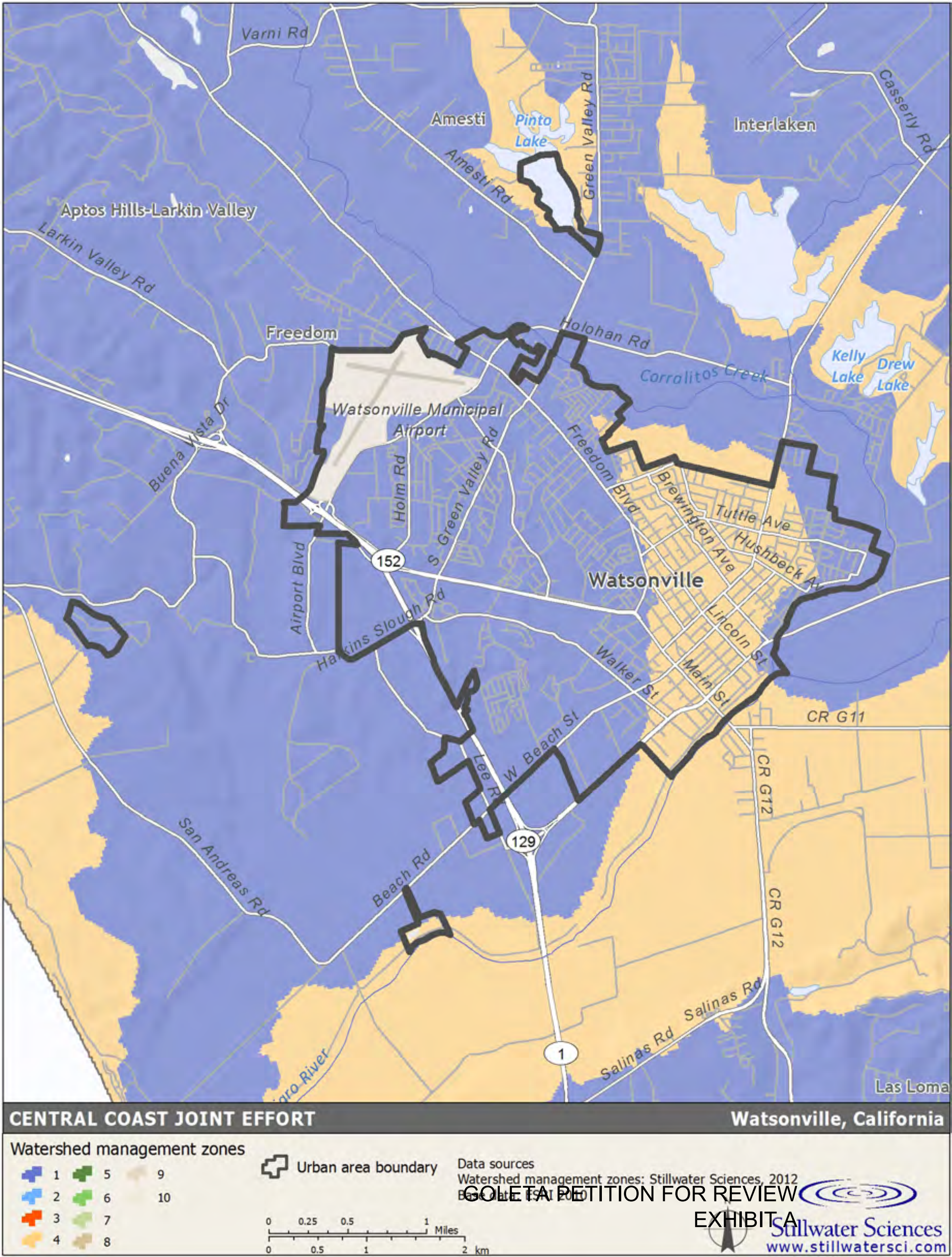

CENTRAL COAST JOINT EFFORT **Watsonville, California**

Watershed management zones

1	5	9
2	6	10
3	7	
4	8	

Urban area boundary

Data sources
Watershed management zones: Stillwater Sciences, 2012
Base data: ESRI 2010

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Stillwater Sciences
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Case Study of the Hydrologic Benefits of On-Site Retention in the Central Coast Region

July 25, 2012

Prepared by Northwest Hydraulic Consultants Inc, Seattle WA

Background:

The Central Coast Water Board is proposing post-construction stormwater requirements for new and redevelopment projects in the Central Coast Region. The proposed performance requirements on all sites creating or replacing ≥22,500 ft^2 are as follows:

1. Retain runoff from all storms up to the 95th Percentile Event - Prevent offsite discharge for all days on which accumulated rainfall does not exceed the 95th percentile 24-hr, precipitation total. This volume must be infiltrated, evaporated/transpired, and/or harvested for later use, and
2. Post-development peak flows shall not exceed pre-project peak flows for the 2- through 100-yr storm events.
3. Continuous simulation modeling is required to evaluate the runoff characteristics and evaluate compliance with the performance requirements.

The first requirement is identical to “Option 1” of the EISA Section 438 (2009) requirements for federal facilities. The second requirement is the current Santa Barbara County peak matching requirement. The Water Board recognizes that peak matching does not address flow duration effectively; specifically, requiring facilities to maintain peaks at pre-project levels does not prevent longer duration flows, below the peaks, that result from additional runoff volumes generated by the project. However, the Water Board is interested in knowing whether the peak matching requirement used in combination with the retention requirement affords protection to receiving waters that is comparable to the protections afforded by a flow duration management requirement. In pursuing this question, the first step is to examine the effects of the proposed requirements (i.e. the combination of retention and peak management) on runoff characteristics

Evaluation of runoff characteristics requires an estimation of the amount of retention (item 1, above) that can be achieved on-site under different development scenarios. The retention estimate will then influence the total amount of runoff that will need to be addressed by a detention facility and finally, the discharge characteristics leaving the project site (e.g., flow volumes and duration). While the impacts of altered flow regimes are ultimately of interest to the Water Board, this analysis is intended to isolate and answer the question of how and to what degree the flow regime is affected, rather than what effect those alterations may have on stream conditions.

Scenarios Modeled

Two development project scenarios were analyzed, each involving the same total project area, one representing single family residential development which was assumed to involve a land use conversion from a pre-developed pasture condition, and the other a commercial redevelopment project. Each project type was assumed to occur on two different soils, NRCS type C soil and NRCS type D soil. Infiltration rates for on-site retention facilities were based on the daily average rates reported in the EISA Section 438 Stormwater guidance document (December, 2009).

Hydrologic Modeling

HSPF continuous hydrologic modeling was used to generate three components of discharge for each scenario (and each sub-scenario) at project area outlets. The three components modeled were surface runoff (rapidly responding runoff with high peak unit area discharge from impervious and saturated pervious areas), interflow (slower responding subsurface runoff with moderate peak unit area discharge from pervious areas that emerges to the surface at slope breaks and road cuts), and groundwater runoff (long-lasting, very low peak unit area discharge to the drainage system which provides base flow). Urban pervious infiltration rates for a D-soil were characterized in HSPF using an HSPF INFILT parameter value typical of disturbed, low-infiltration soil (0.030 iph). Pre-developed pasture conditions were assumed to have an INFILT value midway between an urban disturbed landscape and undisturbed landscape (0.055 iph). Corresponding INFILT values for C-soils (.19 and .33 iph) were estimated from the ratio of 2-hr average infiltration rates for C and D soils specified by EISA Section 438. Detention facilities were modeled as impermeable storages with assumed flexible outlet controls. The total size and volume-discharge relationship (outlet control) for detention facilities were optimized by trial and error based on matching mitigated developed to pre-developed (100% pasture) peak annual flow frequency curves between the 2-yr and 100-hr quantiles.

Assumed Routing of Runoff

For the mitigated scenarios, inflows to on-site retention facilities were assumed to include all impervious area runoff and any surface runoff from the residual pervious site area not devoted to retention facilities. Groundwater runoff from residual pervious areas was assumed to leave the site and enter the downstream drainage system. Onsite retention facilities were assumed to infiltrate at the 24-hr average rate specified by EISA 438 for each soil type. Runoff infiltrated in the bioretention facility was route through a groundwater storage reservoir with sufficient storage capacity to assure low, steady release to the stream, typical of a base flow. Overflows from the bioretention facility were routed to a detention facility which was assumed to be off-site (i.e. it did not take up any site area). Interflow from the site pervious area not devoted to bioretention was also routed to the detention facility. Outflow from the detention facility was combined with the groundwater outflow to estimate the total discharge to the drainage system from the site. Figure 1 provides a schematic view of how flow component pathways are conceptualized in the HSPF model for pre-developed, unmitigated developed, and mitigated developed cases.

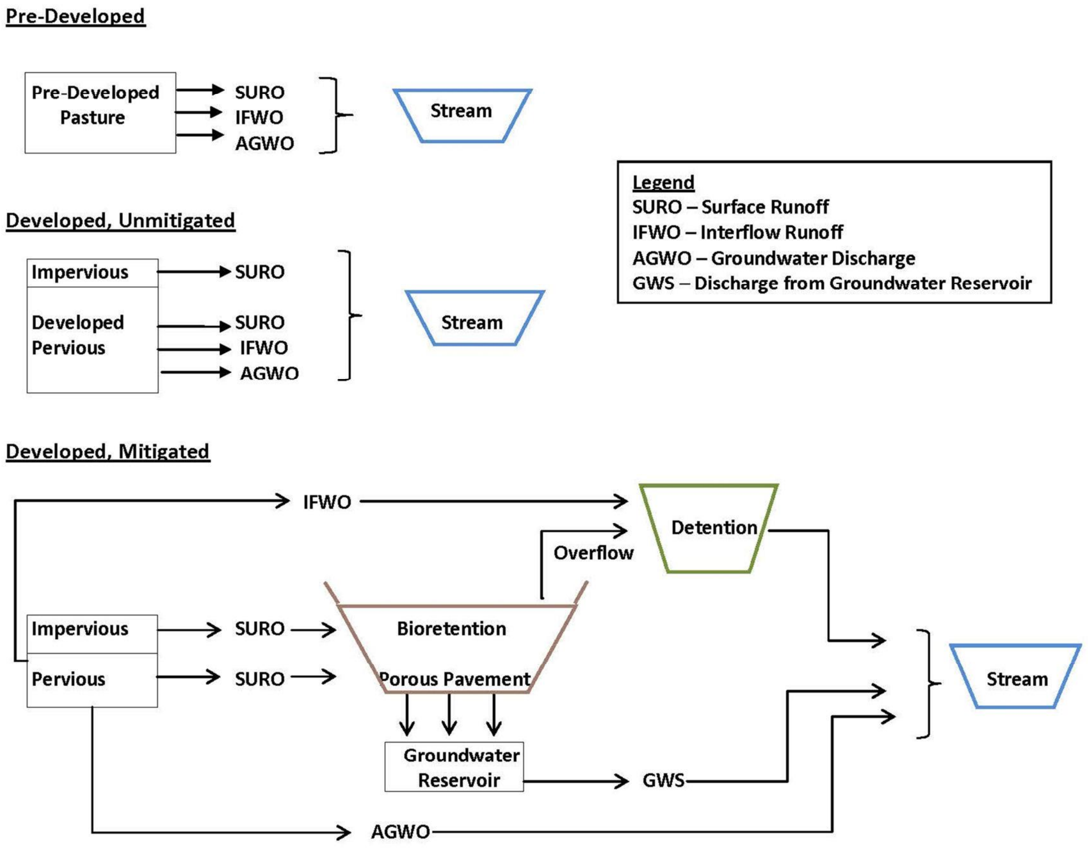


Figure 1. Schematic showing how runoff component pathways are conceptualized in HSPF modeling.

Hydrometeorological Data Inputs

Continuous hydrologic modeling of all scenarios required long term rainfall and potential evapotranspiration data sets. Chad Helmle (Personal Communication, May 23, 2012) provided a synthesized hourly rainfall record for Santa Cruz derived primarily by spatial correlation of available daily rainfall totals at Santa Cruz (NCDC site 047916) with hourly records at nearby sites (Tetra-Tech, 2011). Daily potential evapotranspiration for the 1950-2010 simulation period was estimated using monthly average values of reference evapotranspiration reported by CMIS for Region 3 (CMIS, 2010).

Design Rainfall Amount

The design rainfall amount was based on the 61-water year record for Santa Cruz. It was determined following procedures outlined in EISA 438 as follows. All 24-hr rainfall depths greater than 0.1 inches were ranked in descending order. The depth corresponding to the breakpoint between the lower 95% and upper 5% of was identified as the design depth for retention facilities equal to 1.96 inches for the Santa Cruz record.

Sizing of Bioretention and Detention Facilities

Bioretention facilities were conceptualized as storage "boxes" with surface areas and volumes consistent with a standard that requires retention of runoff from the 95% non-exceedance, 24 hour rainfall event on-site. For the SFR scenario, sizing retention to the standard was based on estimated surface runoff for the entire developed site impervious and pervious areas. For the commercial redevelopment scenario, sizing to the standard was based on runoff from 50% of the total site impervious.

The procedure to determine the area and storage volume necessary to meet the stated retention standard applied a conservative approach that assured retention and infiltration of runoff from the design event regardless of the time distribution of rainfall within the 24-hr period. The approach was based on the following key concepts:

- The facility is assumed to infiltrate at the average 24-hr rate for the soil class specified by EISA 438
- The facility must have storage capacity equal to the runoff volume from the site plus the volume of rain on the facility surface
- If the facility's drainage time of the runoff volume from the 24 hour design storm exceeds 24 hours and the storage area is fixed, then facility volume must be increased commensurate with the runoff volume and rainfall from the 95% non-exceedance storm with a longer duration equal to the drainage time for 24-hour runoff volume.

The steps followed in sizing bioretention for the residential case were:

1. Estimate surface runoff volume (ac-in) to the bioretention facility based on the 95% non-exceedance, 24-hr rainfall amount per EISA 438 direct method (i.e. daily rainfall – interception/depression storage-infiltration depth).
2. Determine the potential 24-hr infiltrated volume per acre for C or D soil based on EISA 438 average daily infiltration depth. (ac-in/ac)
3. Divide result 1 by result 2 to arrive at initial facility area in acres.
4. If the result of 3 is less than 50% of pervious area on-site, then it represents the bioretention area to be modeled with an assumed storage depth (before any surface spill occurs) equal to result 1 divided by result 3. Both area and storage volume to meet criterion are assumed to be met. If this is not the case, then go on to steps 5 - 10
5. If result 3 is greater than 50% of the site pervious area, assume the site is "area-constrained" and set the bioretention area to an area equal to 50% of the site pervious area.
6. Compute the drainage volume in 24 hrs (ac-in) by multiplying the result of 5 by the average daily infiltration rate.
7. Determine the hours to drain the 95% 24-hr runoff volume by dividing 1 by 6 and multiplying by 24. The result will be greater than 24 hours by definition.

8. Perform frequency analysis on hourly rainfall to determine the 95% non-exceedance rainfall amount for the storm duration determined in step 7.
9. Use the result of in lieu of the 24-hr, 95 percent non-exceedance rainfall to estimate runoff volume (ac-in). This is the estimated storage required in the bioretention facility to assure no overflow of the 95%, 24-hr storm runoff from the site.
10. Divide result of step 9 (ac-in) by result of step 5 (ac) to arrive at required storage depth for an area-constrained bio-retention facility.

For the commercial case, the porous pavement and bioretention areas are specified in advance therefore, the steps are as follows:

1. Estimate surface runoff volume (ac-in) to the bioretention facility based on the 95% non-exceedance, 24-hr rainfall amount per EISA 438 direct method and the assumption that 50% of the impervious area must be mitigated. In this calculation, it is assumed that the porous pavement area first removes a portion of that runoff volume consistent with its area and the average daily infiltration rate. It has no storage capacity.
2. Compute the potential bioretention drainage volume in 24 hrs (ac-in) by multiplying the pre-specified area by the average daily infiltration rate.
3. Follow steps 6-10 as described for the residential case to determine the bioretention storage volume and depth.

An example of the bioretention design calculation is provided below for the Single Family Residential, D-Soil case [3.04 ac site, 45% impervious (1.33 ac), 55% pervious (1.71 ac) with assumed maximum limit to bioretention area of 50% of site pervious = 0.86 acres.]

1. Estimate runoff volume to facility (initial abstractions and average daily infiltration rates from EISA 438)
    a. Volume = impervious runoff + pervious runoff
        i. Impervious runoff =(rainfall – initial abstraction)* impervious area
           Impervious runoff = (1.96 in - .10 in) * 1.33 ac = 2.47 ac-in
        ii. Pervious runoff = (rainfall – initial abstraction – infiltration)*pervious area
           Pervious runoff = (1.96 in - .20 in - .77 in) * 1.71 ac = 1.69 ac-in
        iii. Total runoff volume = 2.47 + 1.69 = 4.16 ac-in

2. Determine 24-hr infiltrated volume per acre of bioretention
   24-hr average infiltration depth = 0.77 in (EISA 438, p. 60) = 0.77 ac-in/ac

3. Estimate Initial Facility Size Runoff Volume/(Infiltrated volume/ac)
   4.16/0.77 = 5.4 acres
4. 5.4 ac is much greater than assumed upper limit of bioretention area = 1.71/2 = 0.86 ac
5. Therefore the site is area-constrained and bioretention area = 0.86 acres
6. 24 hour drainage volume for 0.86 ac bioretention = 0.86 ac * 0.77 ac-in/ac = 0.66 ac-in
7. Estimate hours to drain runoff volume = 24*4.16/0.66 = 152 hours
8. Perform frequency analysis to determine 95% non-exceedance rainfall amount for a duration of 152 hours (per EISA 438 procedure except using 152 hour totals instead of 24 hour totals. This amount is approximately 3.0 inches.
9. Compute runoff volume except for 3.0 inches over 152 hours instead of 24 hours
   Volume = impervious runoff + pervious runoff

    i. Impervious runoff =(rainfall – initial abstraction)* impervious area
        Impervious runoff = (3.0 in - .10 in) * 1.33 ac = 3.86 ac-in
    ii. Pervious runoff = (rainfall – initial abstraction – infiltration)*pervious area
        Pervious runoff = (3.0 in - .20 in - .77*152/24 in) * 1.71 ac <0, however, assume storage required for rain on pool = 3 in *.86 ac = 2.58 ac-in
    iii. Storage required in facility = 3.86 ac-in + 2.58 ac-in = 6.44 ac-in or 0.54 ac-ft

10. Required storage depth with 100% void space = 0.54 ac-ft/0.86 ac = 0.62 ft = 7.5 inches

Detention facilities for both SFR and Commercial scenarios were sized to fully mitigate peak flows ranging from the 2-yr to 100-yr for 100% of the developed sites by matching the frequency curve in this range determined for a 100% pasture condition on the site.

Simulation Cases for Each Land Use Scenario

The simulation cases for each land use scenario (Single Family Residential (SFR) Development and Commercial Redevelopment (COMM) are summarized in Tables 1 and 2 respectively. Note that for the residential scenario, there are a total of six cases, three for each soil class: 1) developed with no retention or detention, 2) developed with retention and detention and 3) pre-developed 100% pasture. For each case the volume and area required for retention facilities and the detention volume necessary to meet the 2-100 peak control standard are reported.

For the commercial scenario, 8 cases are shown in Table 2; however, the 2 pre-developed cases (C and D soil with 100% pasture) are identical to cases in the SFR scenario. Therefore, there are really only 6 unique cases; 3 for each soil class. These cases include “no mitigation”, “detention mitigation only” and “combined detention and retention”. The two mitigation scenarios show the marginal amount of detention volume required to meet the standard if retention is not implemented.

Table 1. Single Family Residential Development from Pasture, Land Cover and Mitigation Summary (C-Soil and D-Soil)

Total site area for all cases = 3.04 acres

CASES	*PASTURE (AC)*	*IMPERVIOUS (AC)*	*GRASS (AC)*	*ON-SITE BIORETENTION (AC)*	*ON-SITE BIORETENTION STORAGE VOLUME[1] (AC-FT)*	*DETENTION VOLUME[2] (AC-FT)*
No Mitigation ***C&D- Soil***	-	45%	55%	-	-	-
On-Site Retention and Detention ***C-Soil***	-	45%	31%	24%	*0.21*	*0.85*
On-Site Retention and Detention ***D-Soil***		45%	27.5%	27.5%	*0.54*	*0.38*
Pasture Reference ***C&D-Soil***	*100%*	-	-	-	-	-

Table 2. Commercial Redevelopment, C-Soil and D-Soil Scenarios (total site area = 3.04 acres for all cases)

CASES	PASTURE (AC)	IMPERVIOUS (AC)	GRASS (AC)	POROUS PAVEMENT[3] (AC)	ON-SITE BIORETENTION[4] (AC)	BIORETENTION STORAGE VOLUME[1] (AC-FT)	DETENTION VOLUME[2] (AC-FT)
No Mitigation ***C&D- Soil***	-	87%	13%	-	-	-	-
Detention Only, **C-Soil**	-	87%	13%	-	-	-	1.60
Detention Only, **D-Soil**	-	87%	13%	-	-	-	0.62
On-Site Retention and Detention, **C-Soil**	-	78%	-	9%	13%	0.19	1.25
On-Site Retention And Detention, **D-Soil**	-	78%	-	9%	13%	0.91	0.42
Pasture Reference ***C&D-Soil***	100%	-	-	-	-		

[1] SIZED TO MITIGATE RUNOFF FOR 95%-NON EXCEEDANCE 24-HR EVENT FOR 50% OF REDEVELOPED IMPERVIOUS (SCENARIO ASSUMES FULL REDEVELOPMENT)

[2] SIZED TO MATCH 2-YR TO 100-YR PEAK ANNUAL FLOW QUANTILES FOR PASTURE REFERENCE CONDITION

[3] AREA FIXED AT 10% OF TOTAL SITE IMPERVIOUS

[4] AREA FIXED AT 13% OF TOTAL SITE AREA

Results for Single Family Residential Scenario for C and D Soils

Single Family Residential Development, C-Soil

Flood Frequency Comparison

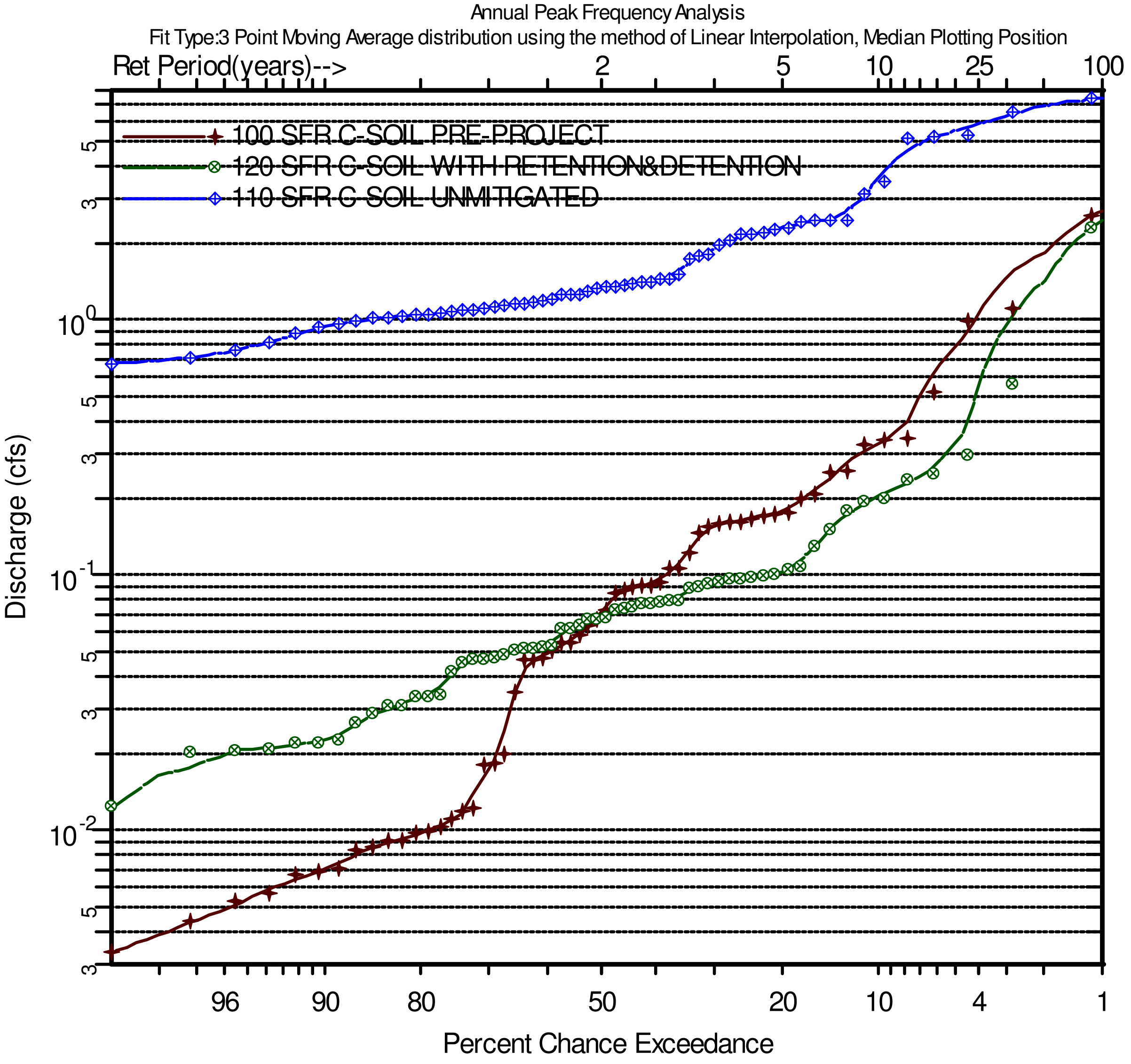
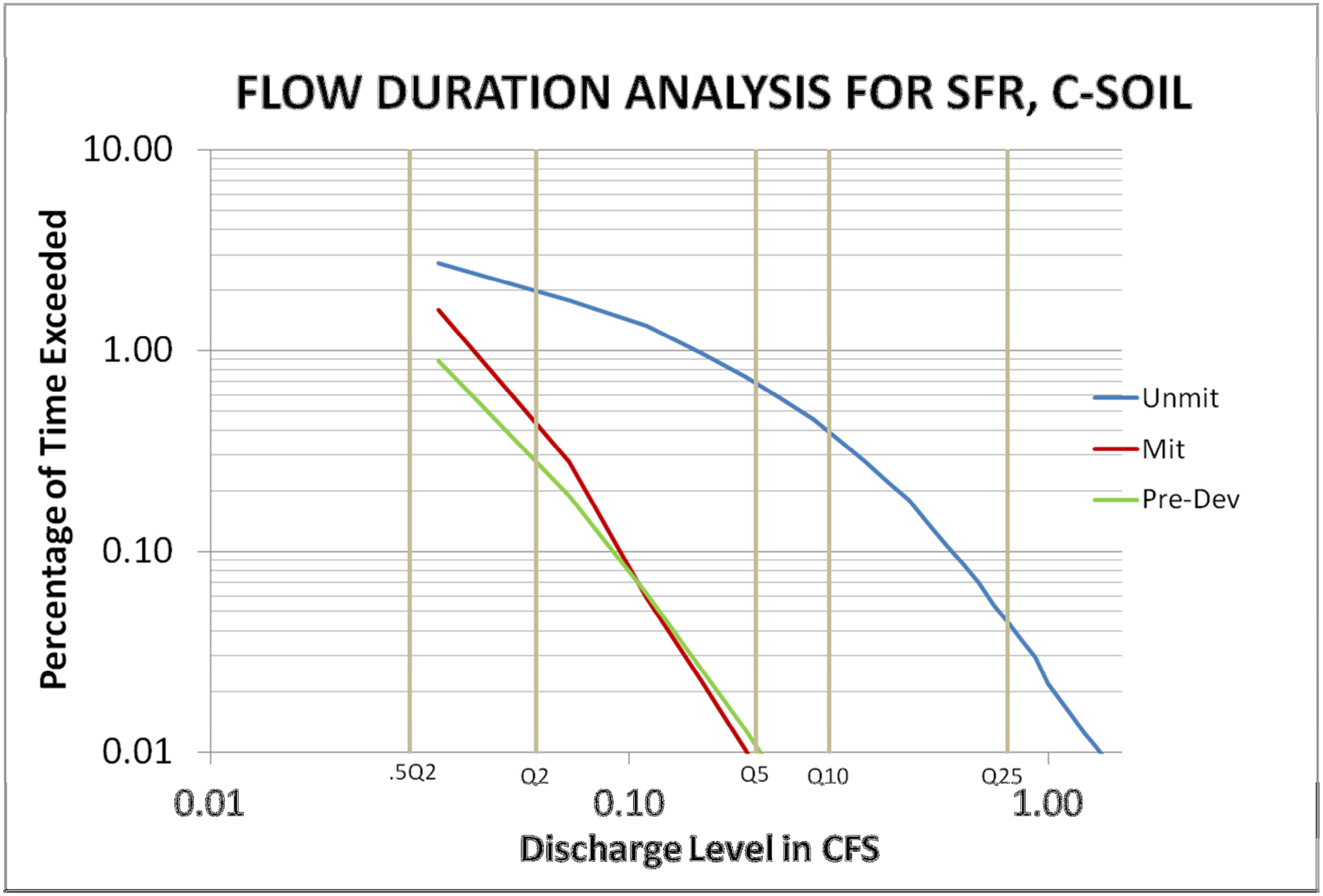


Table 3. Peak Annual Flood Frequency Curve Data for C-Soil, SFR						
Average Recurrence Interval (years)	2	5	10	25	50	100
	Quantiles (cfs)					
Pre-Dev, C-Soil	0.07	0.18	0.33	1.14	1.85	2.70
SFR- no R/D- C-Soil	1.33	2.31	3.74	5.96	6.94	7.45
SFR w R/D, C-Soil[1]	0.07	0.10	0.21	0.63	1.45	2.48

Peak Annual Flow Frequency Discussion, Single Family Residential Development, C-Soil

A total of 1.06 ac-ft of combined bioretention and detention storage is required to meet the 2-100-yr standard for residential development. Note that the detention seems to over-mitigate for some intermediate quantiles; however, in the case of the C-soil, it is difficult to match both the 2-yr and 100-yr peaks without over mitigating for intermediate peak quantiles.

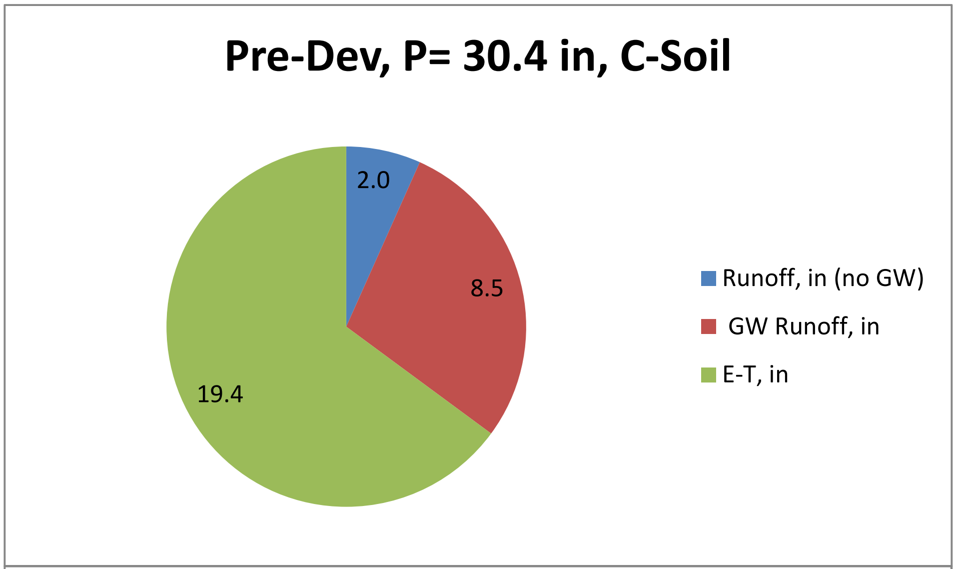
Durational Analysis

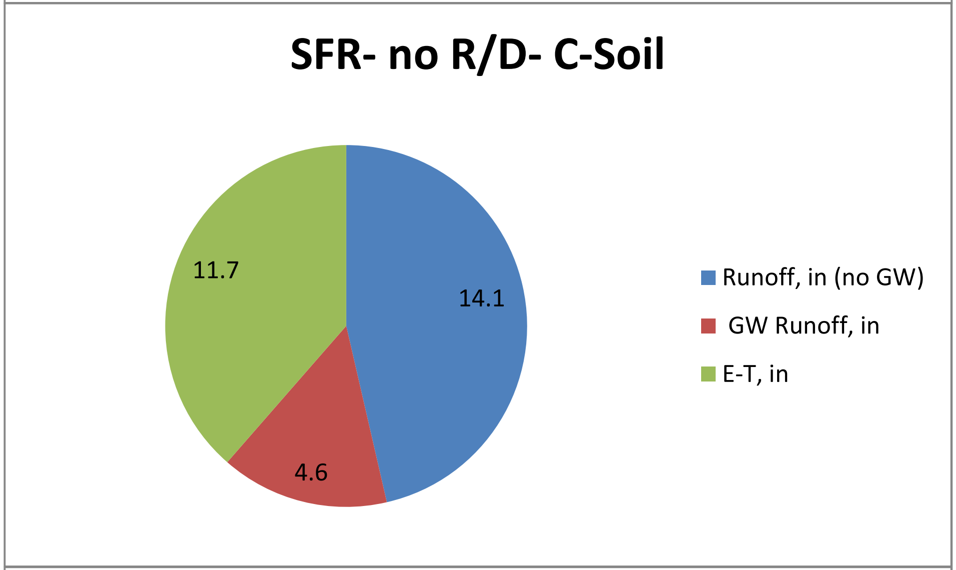


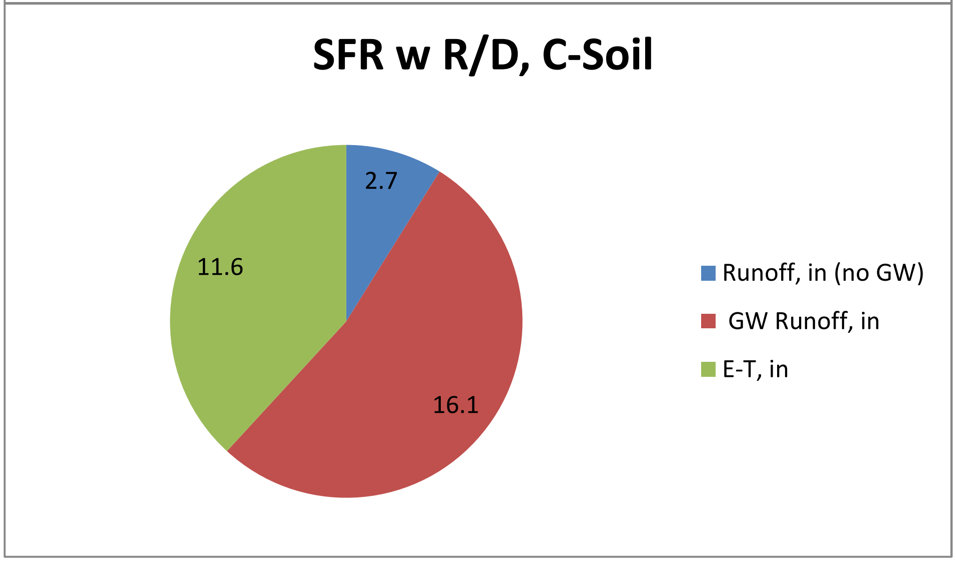
Flow Duration Discussion, Single Family Residential Development, C-Soil

Duration analysis was performed for total runoff (surface and interflow) leaving the site. For cases with detention facilities, the analysis was performed on discharges from these facilities. For flow thresholds between 50% of the pasture 2-yr and the pasture 10-yr peak, the combined facilities mitigate approximately 92% of the increase in high flow durations for the single family residential development on the C-soil.

Water Balance Results- SFR, C-Soil





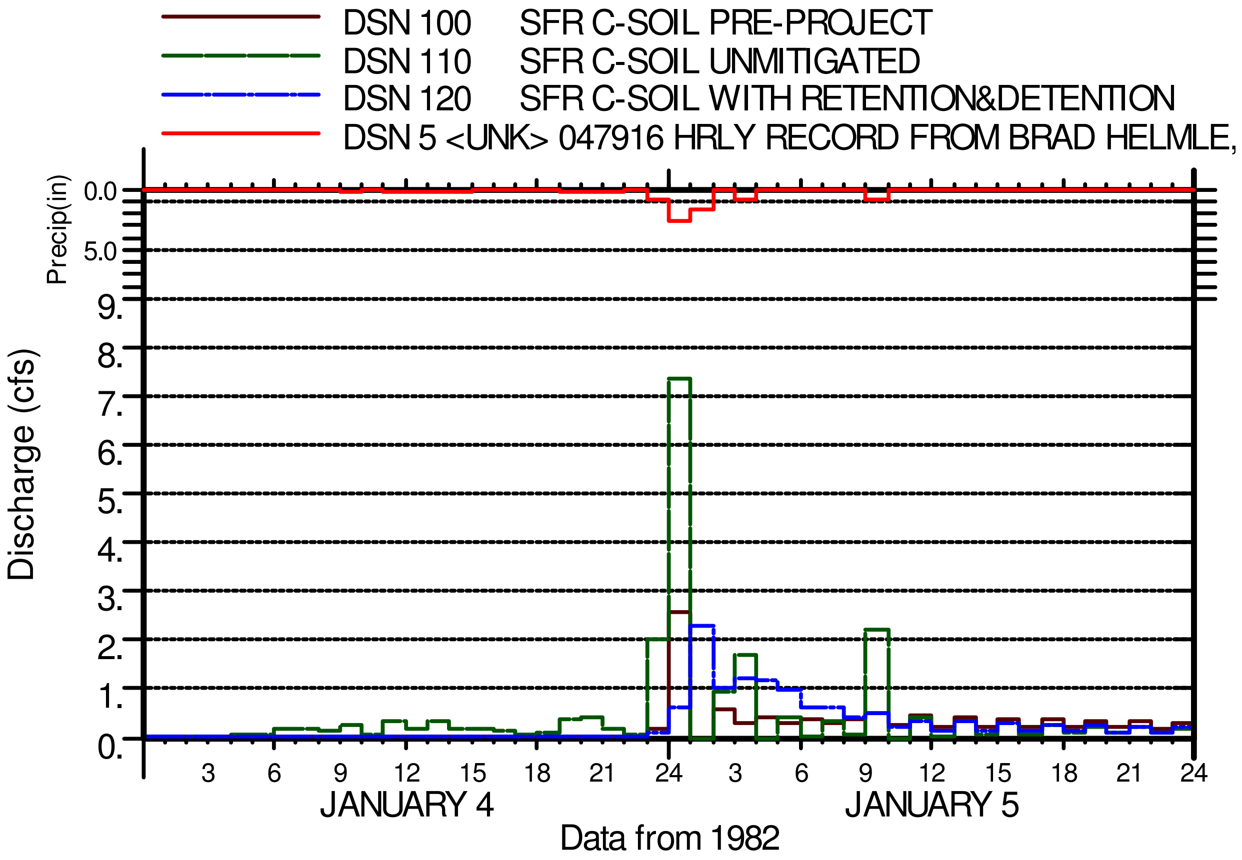


Water Balance Discussion, Single Family Residential Development, C-Soil

A bioretention area (.73 ac) taking up 44% of the pervious portion and 24% of the total site area with a storage depth of 3.5 inches infiltrates (and therefore provides some water quality treatment) 81% of the runoff from impervious and landscaped areas. This percentage is calculated from the difference of the unmitigated and retained runoff amounts (14.1 – 2.7 = 11.5 inches) and dividing by the unmitigated runoff amount (14.1). The average runoff volume (surface runoff and interflow) with retention is moderately higher (35%) than for the pre-developed, pasture runoff volume, but E-T is 40% less than the pre-developed case. Groundwater loading is increased by a factor of 3.4 due to storage and subsequent infiltration in the bioretention facility. The detention facility is assumed to be impermeable, located off-site and not part of the site water balance.

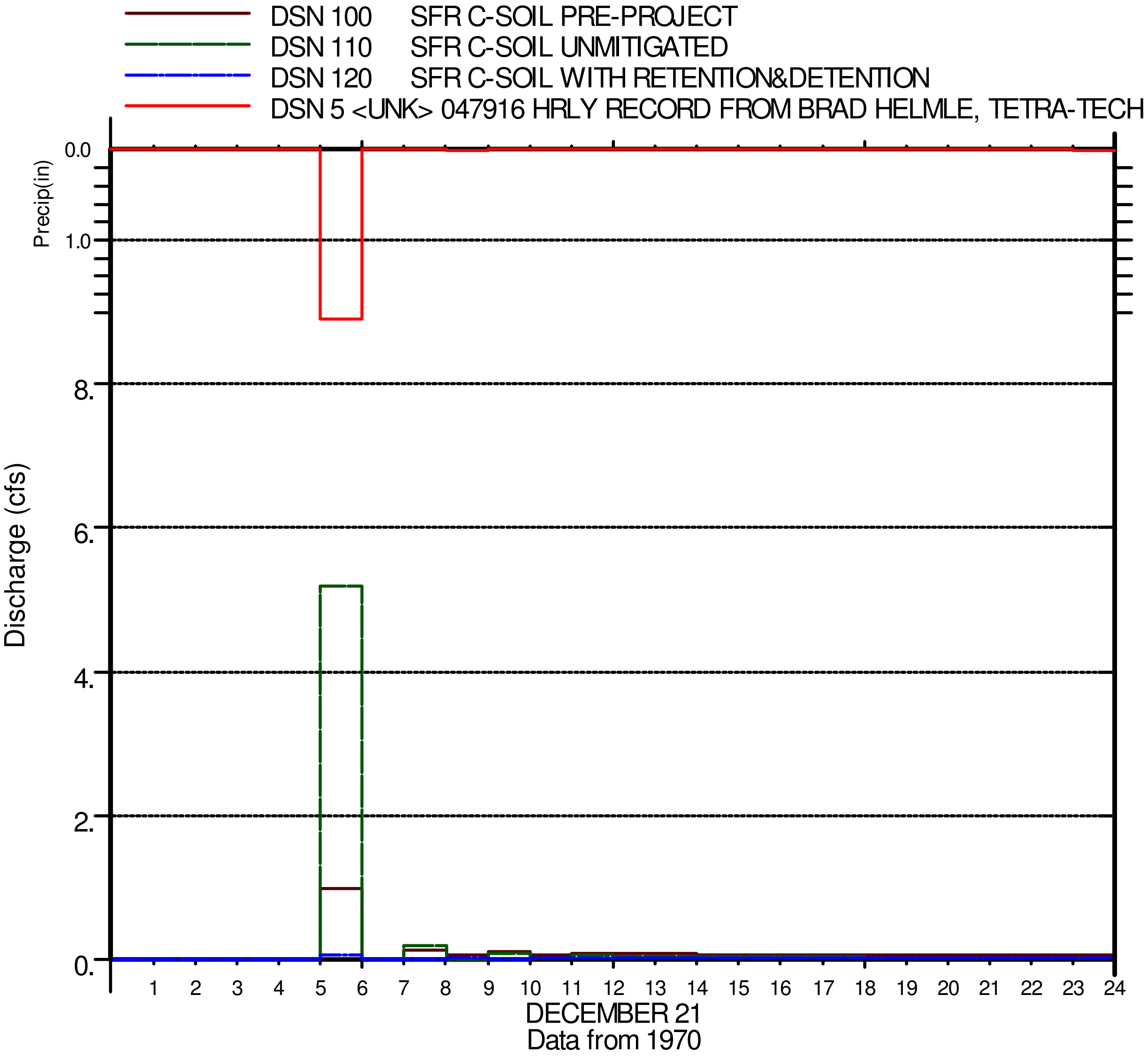
Sample Hydrographs, Single Family Residential Development, C-Soil

Storm of record (60 years), January 5, 1982

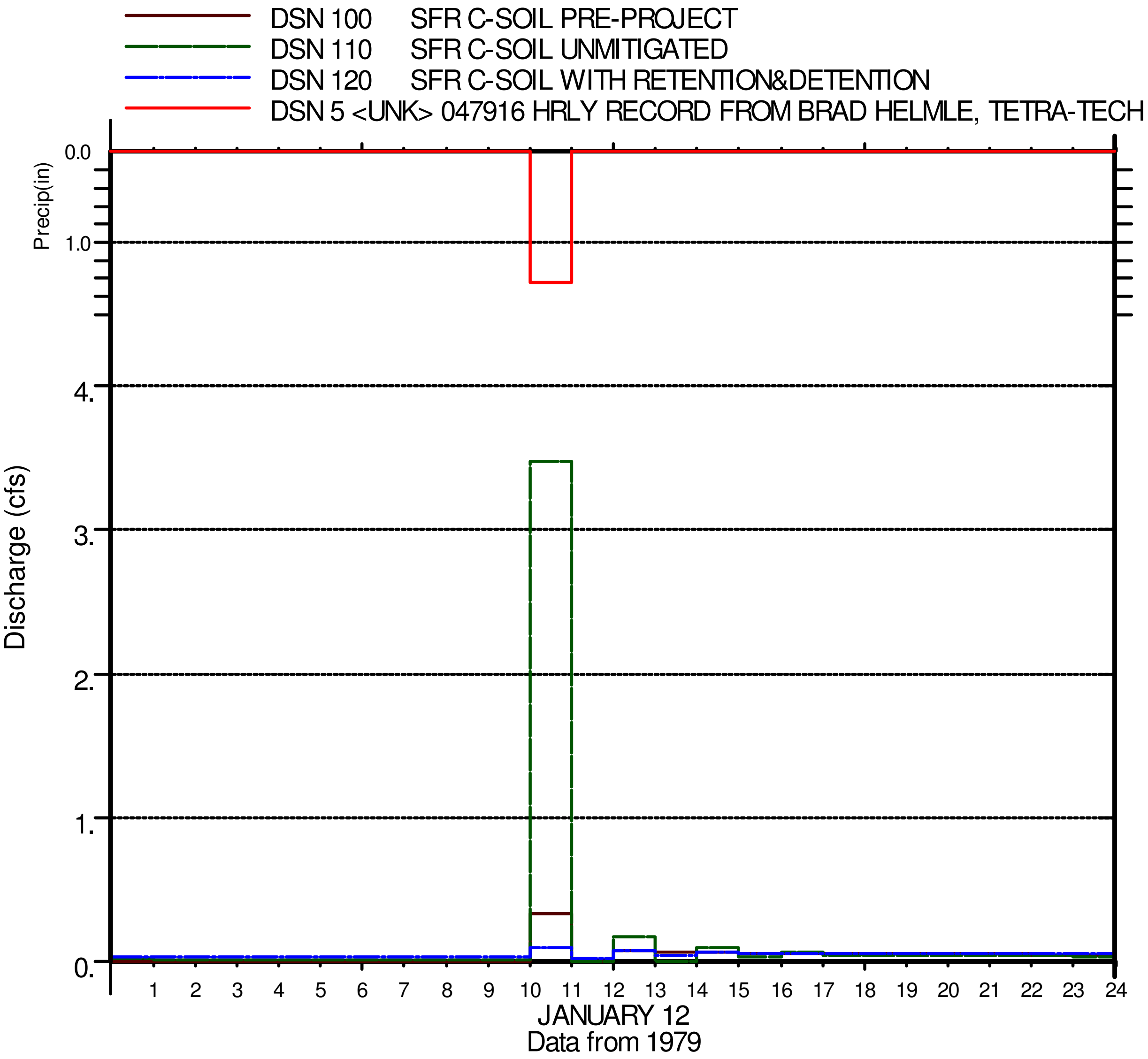


25 yr Peak Annual Flow Event (pre-developed and unmitigated), December 21, 1970.

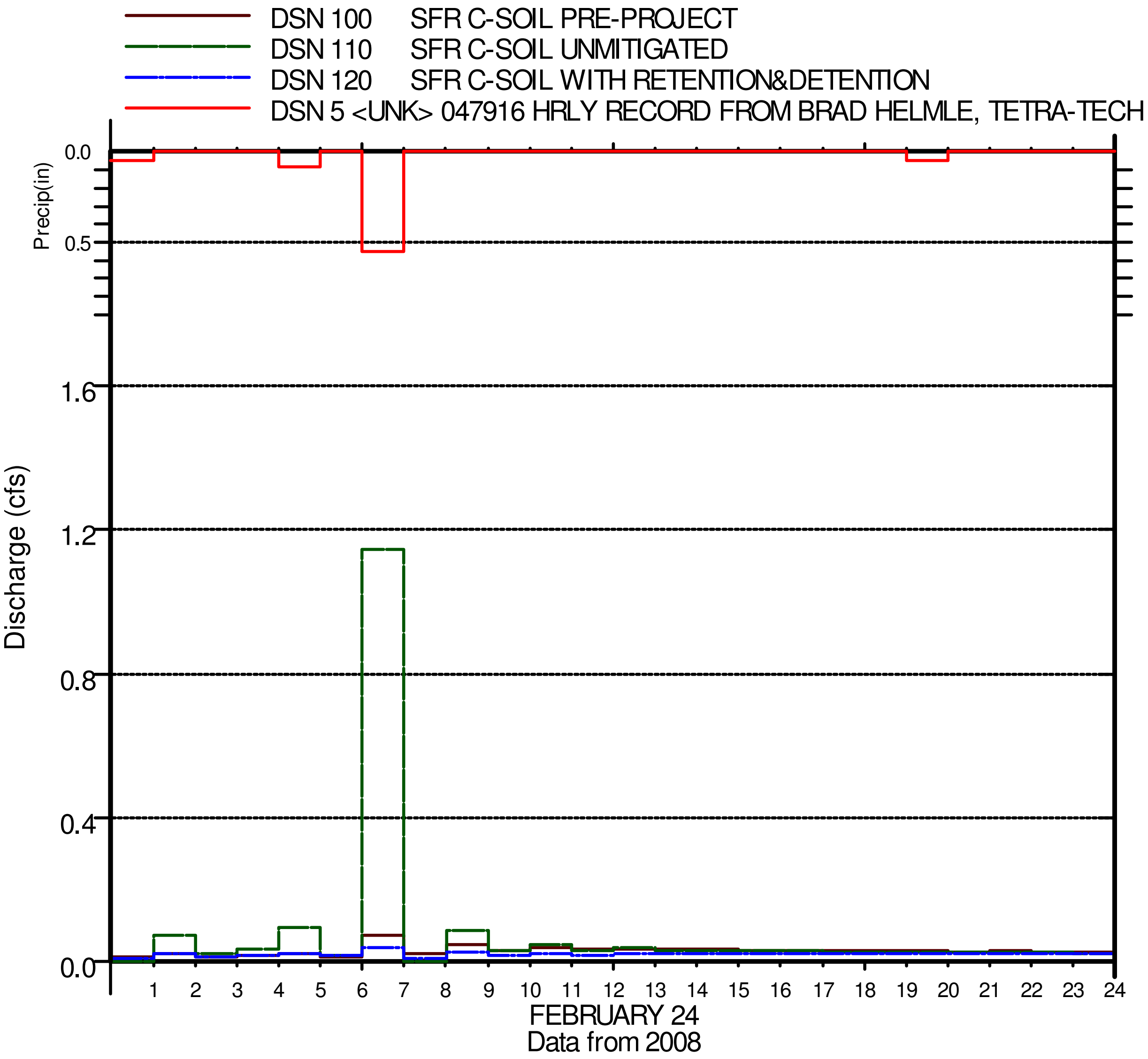
Note that that bioretention is able to absorb this event because there it is a relatively isolate burst of rainfall. Therefore, it does not produce a peak for the mitigated scenario.



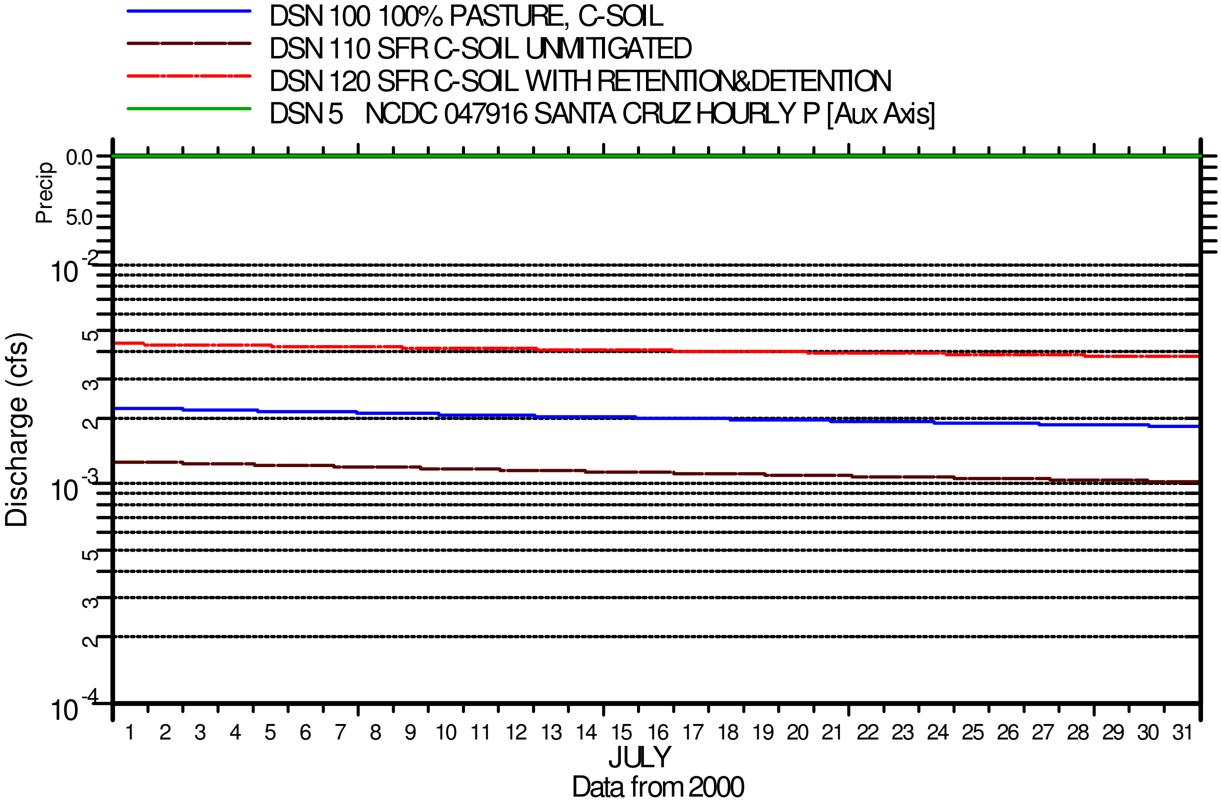
~10 yr Peak Annual Flow Event, January 12, 1979



~2 yr Peak Annual Flow Event, February 24, 2008



Summer Base Flow, July, 2000- a month with zero precipitation



July, 2000 was a month of zero rainfall which was preceded by a month with only .2 inches. Thus, the graph above compares summer base flows under very dry conditions. As shown in the graph above, without on-site retention (brown line), the base flow is approximately cut in half compared to the pre-developed, 100% pasture case (blue line). In contrast, the developed project with bioretention (red line) maintains base flow during dry conditions above the pre-developed level.

Single Family Residential Development, D-Soil

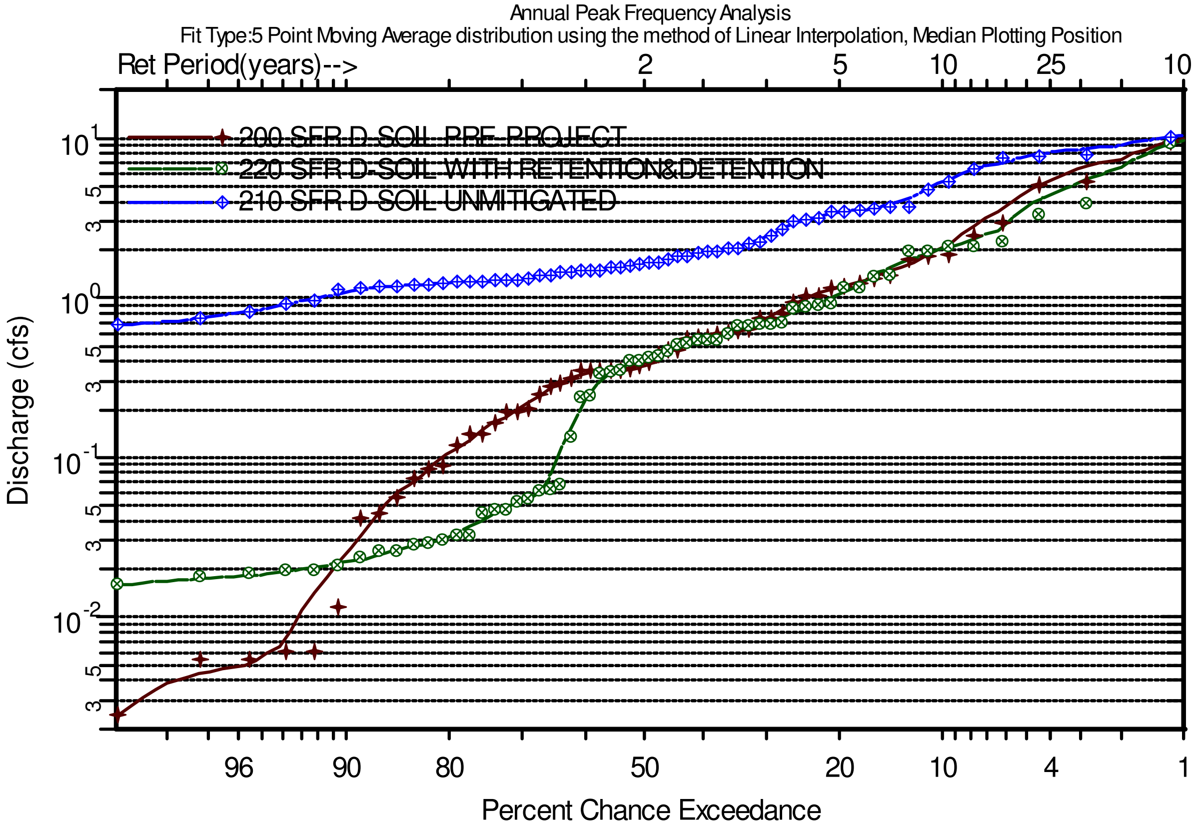


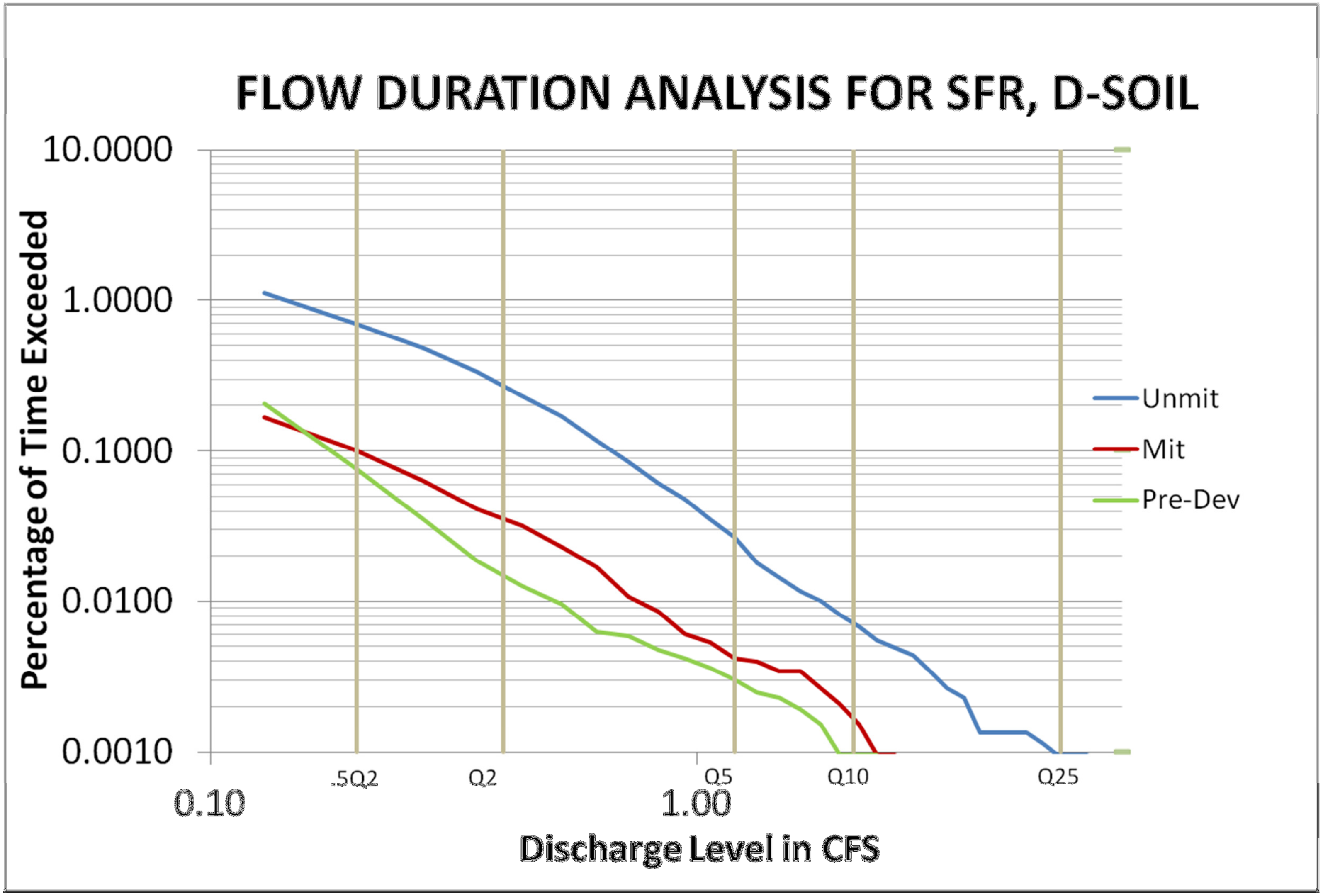
Table 4. Peak Annual Flood Frequency Curve Data for D-Soil, SFR

Average Recurrence Interval (years)	2	5	10	25	50	100
	Quantiles (cfs)					
Pre-Dev, C-Soil	0.4	1.2	2.1	5.6	7.5	10.0
SFR- no R/D- D-Soil	1.6	3.4	5.5	8.3	9.1	10.5
SFR w R/D, D-Soil	0.4	1.1	2.0	4.6	6.6	9.8

Peak Annual Flow Frequency, Single Family Residential Development, D-Soil

A total of .96 ac-ft of combined bioretention and detention storage is required to meet the 2-100-yr standard for residential development on a D-soil. In contrast to the development on the more infiltrative C-soil, the required bioretention volume is greater than the volume required for detention and peak flow control. However, it should be noted that the relatively small size of the detention facility is partly due to the peak and volume reduction action of the upstream bioretention facility.

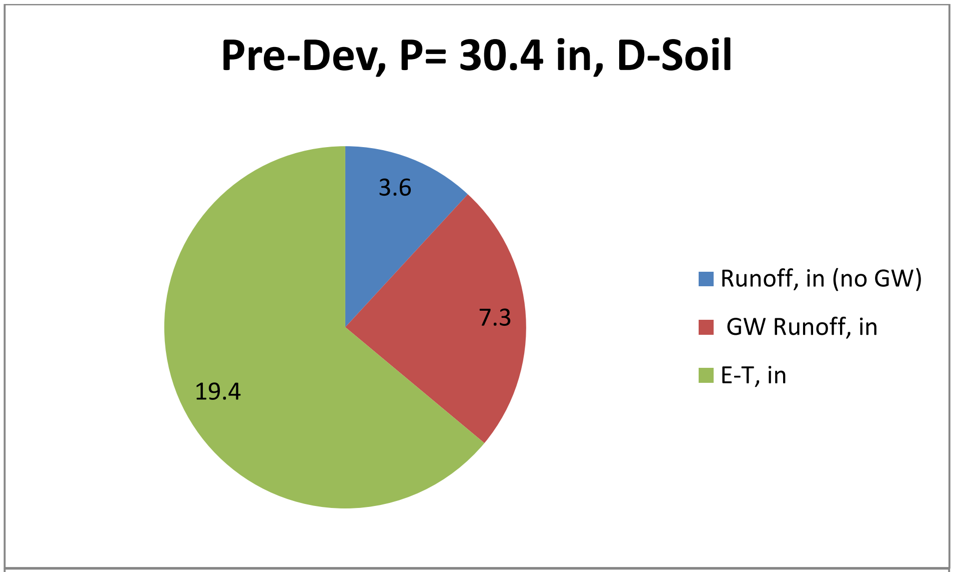
Flow Duration Analysis- SFR, D-Soil

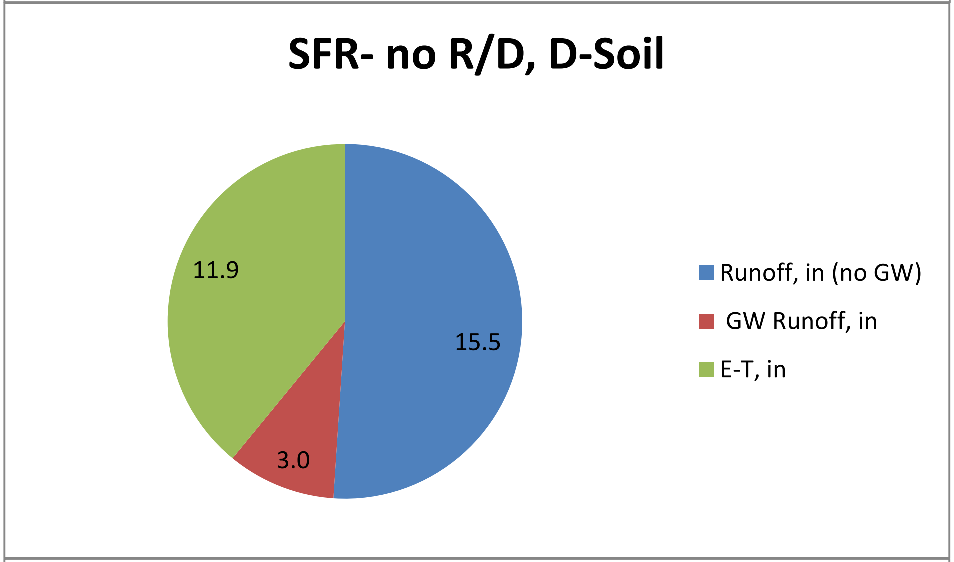


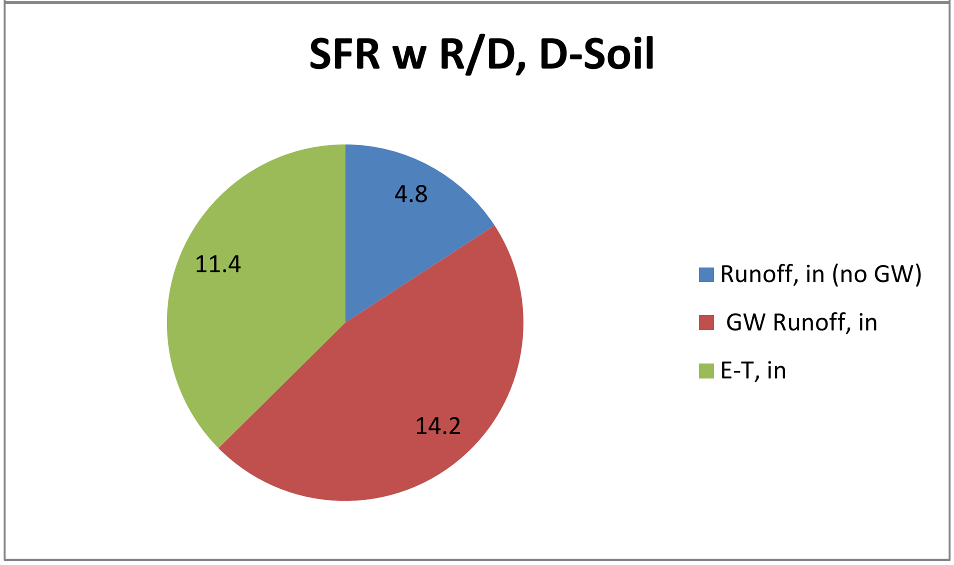
Durational Analysis Discussion, Single Family Residential Development, D-Soil

For the single family residential development on the D-soil, the combination of retention and detention facilities reduced increases in high flow durations ranging from 50% of the pasture 2-yr to the pasture 10-yr peak by 91%.

Water Balance Results- Single Family Residential, D-Soil. As shown, the bioretention


Pre-Dev, P= 30.4 in, D-Soil
3.6
7.3
19.4
Runoff, in (no GW)
GW Runoff, in
E-T, in


SFR- no R/D, D-Soil
11.9
15.5
3.0
Runoff, in (no GW)
GW Runoff, in
E-T, in

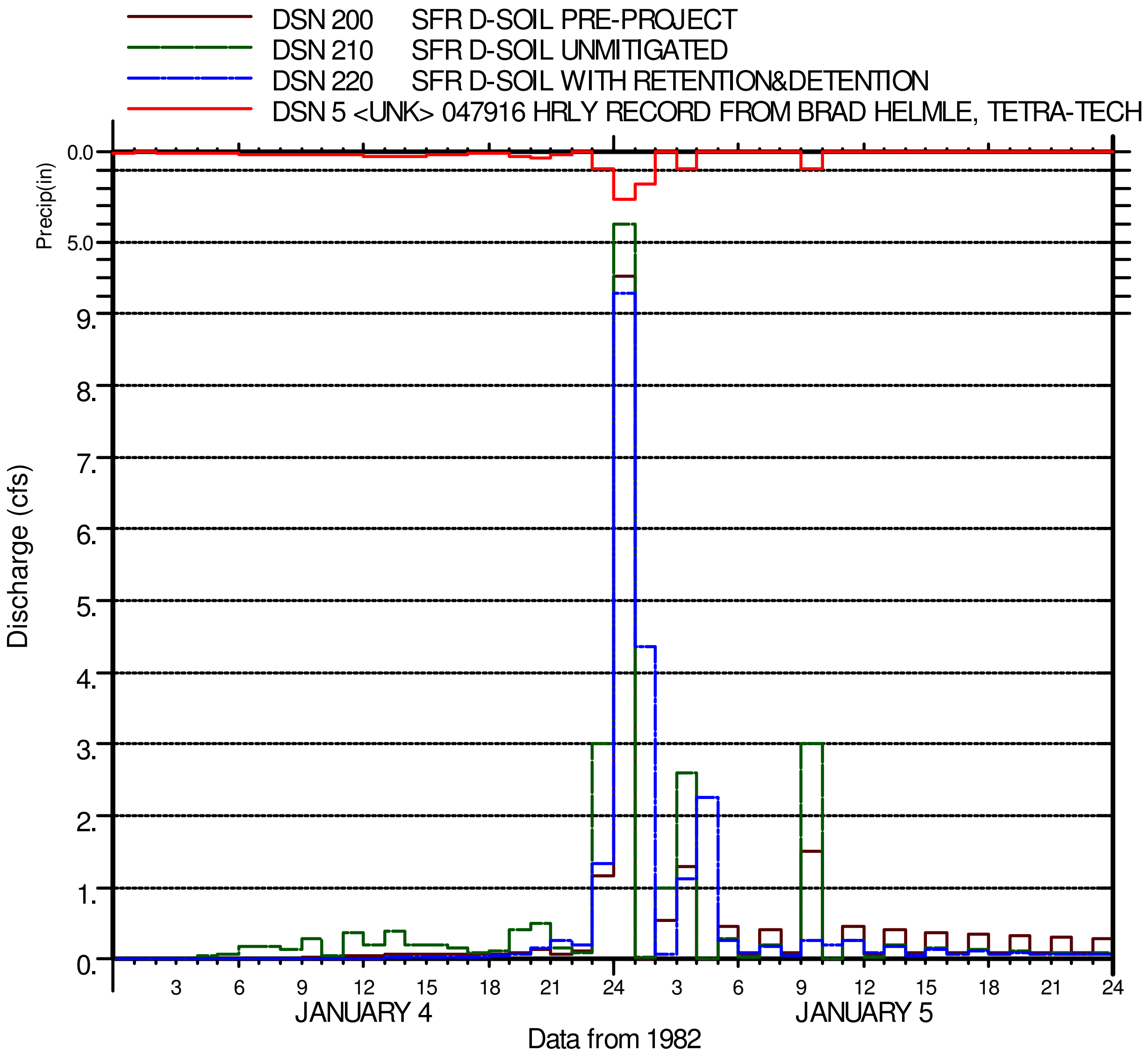

SFR w R/D, D-Soil
4.8
11.4
14.2
Runoff, in (no GW)
GW Runoff, in
E-T, in

Water Balance Discussion, Single Family Residential Development, D-Soil

The bioretention area (.84 ac) takes up 50% of the pervious portion and 27% of the total site area. It has a storage depth of 8 inches. Because the infiltration rate is lower for a D soil than a C soil by more than a factor of four, more storage is required to assure retention of runoff from the 24-hr, 95-percentile rainfall amount. The retention facilities reduce the average runoff volume from 15.5 inches (430% of the pasture value) to 4.8 inches (133% of the pasture value). The bioretention facility accomplishes significant water quality treatment by infiltrating 69% of runoff from the developed site (10.7 inches out of 15.5 inches. The detention facility is assumed to be impermeable and to play no role in infiltrating or treating site runoff.

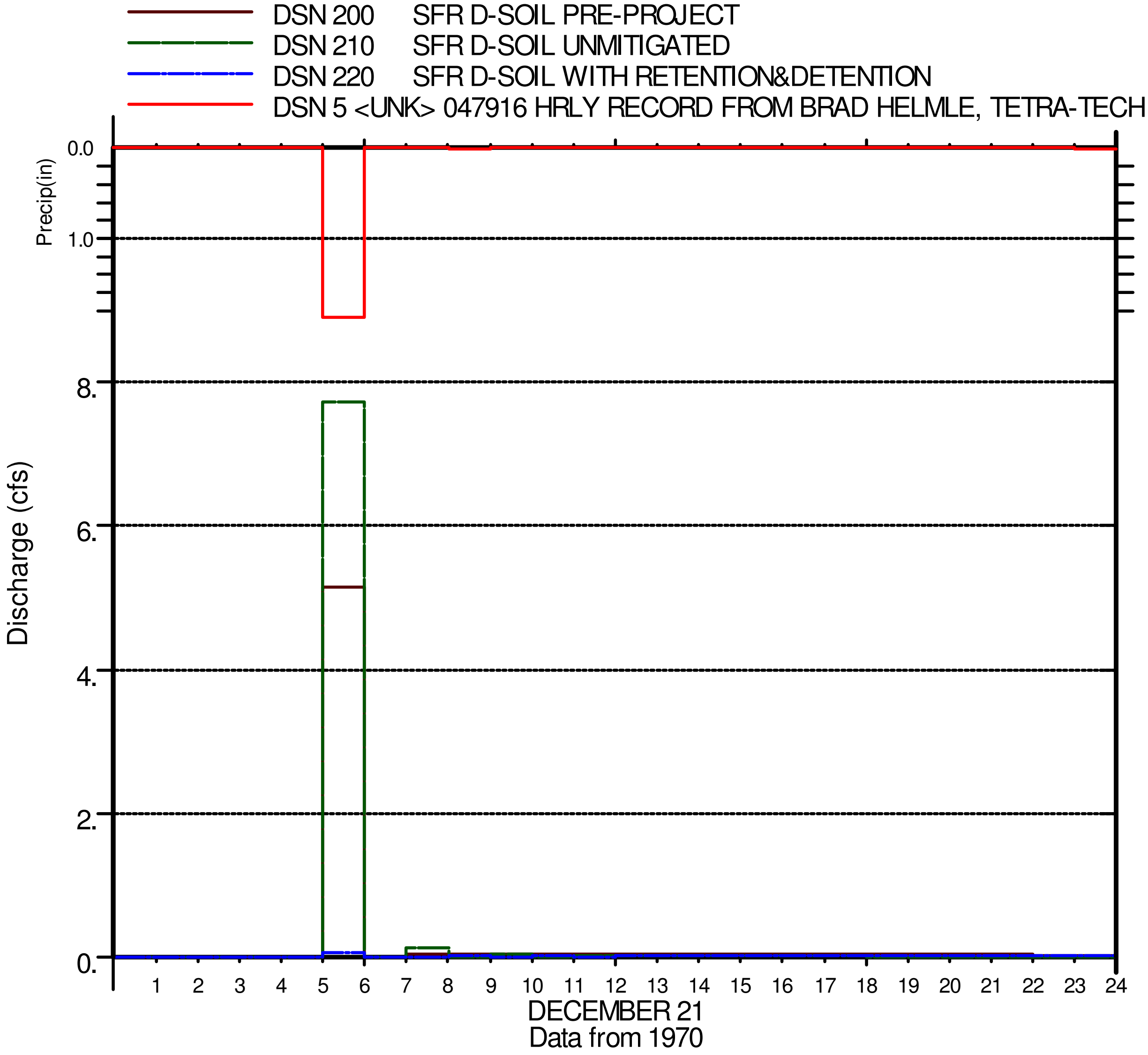
Sample Hydrographs, Single Family Residential, D-Soil

Peak Flow Event of record, 50-100 yr event (all scenarios), January 4-5, 1982

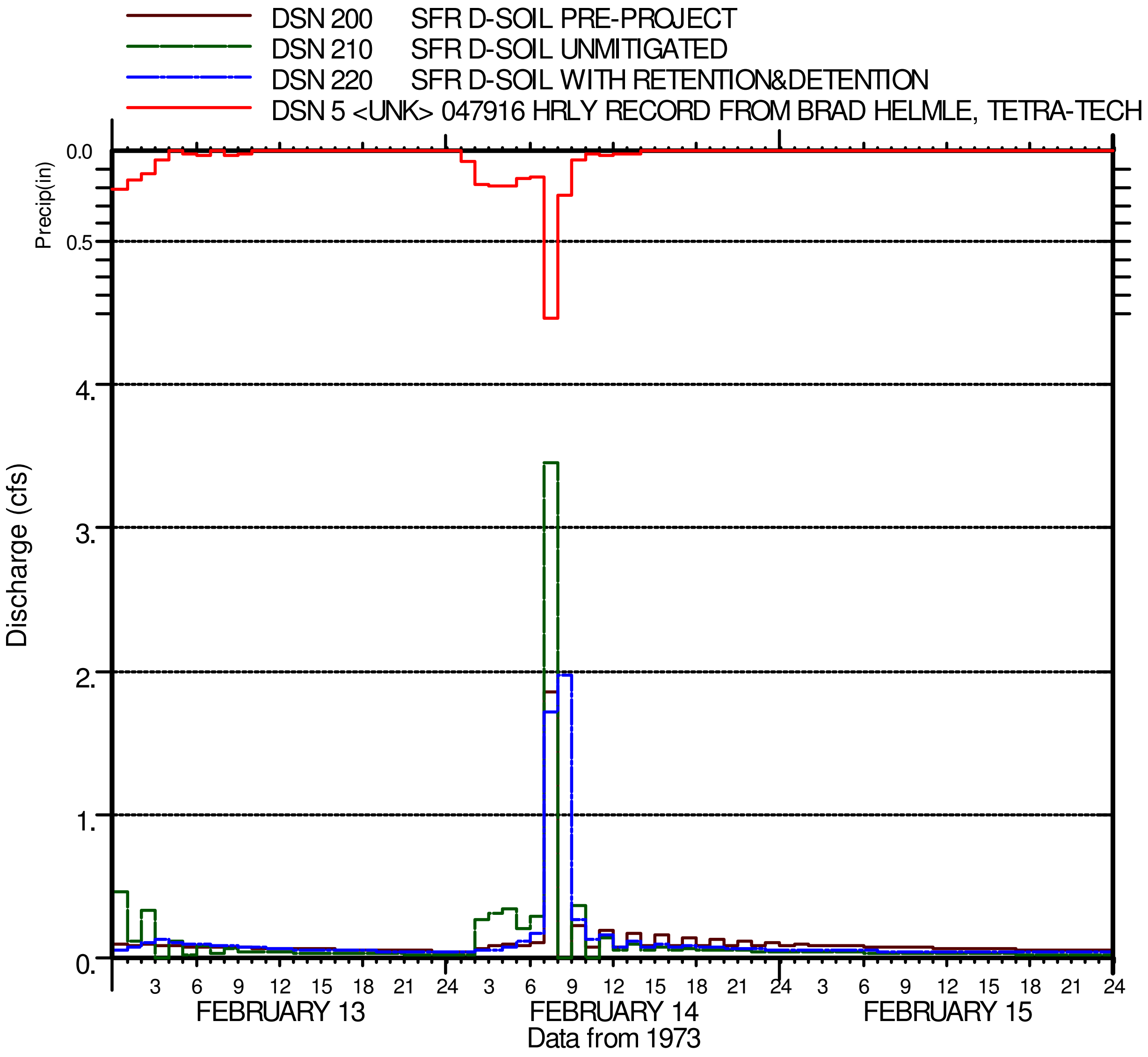


25 yr Peak Annual Flow Event (pre-developed and unmitigated), December 21, 1970.

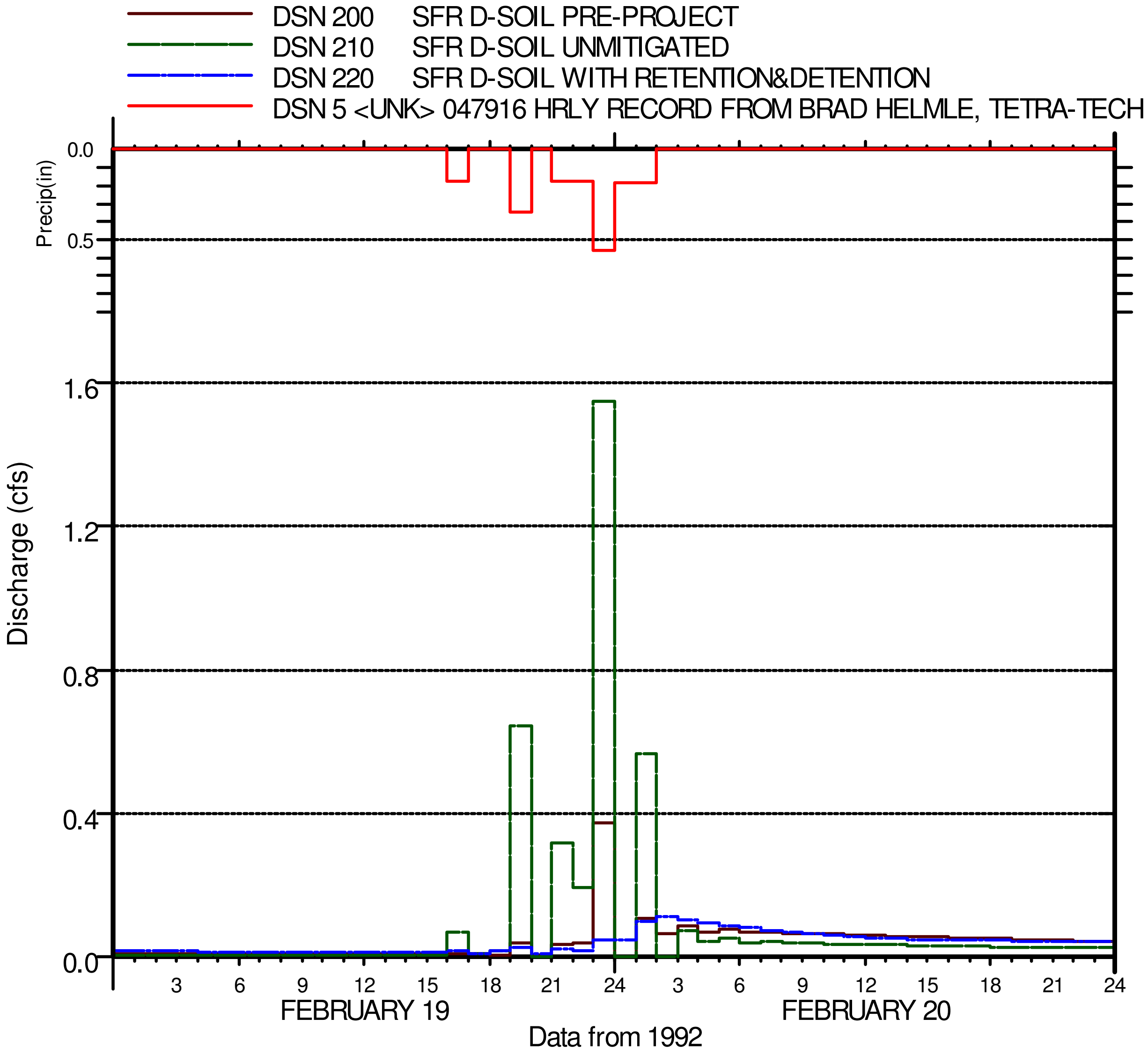
Note that that bioretention is able to absorb this event because there it is a relatively isolate burst of rainfall. Therefore, it does not produce a peak for the mitigated scenario.

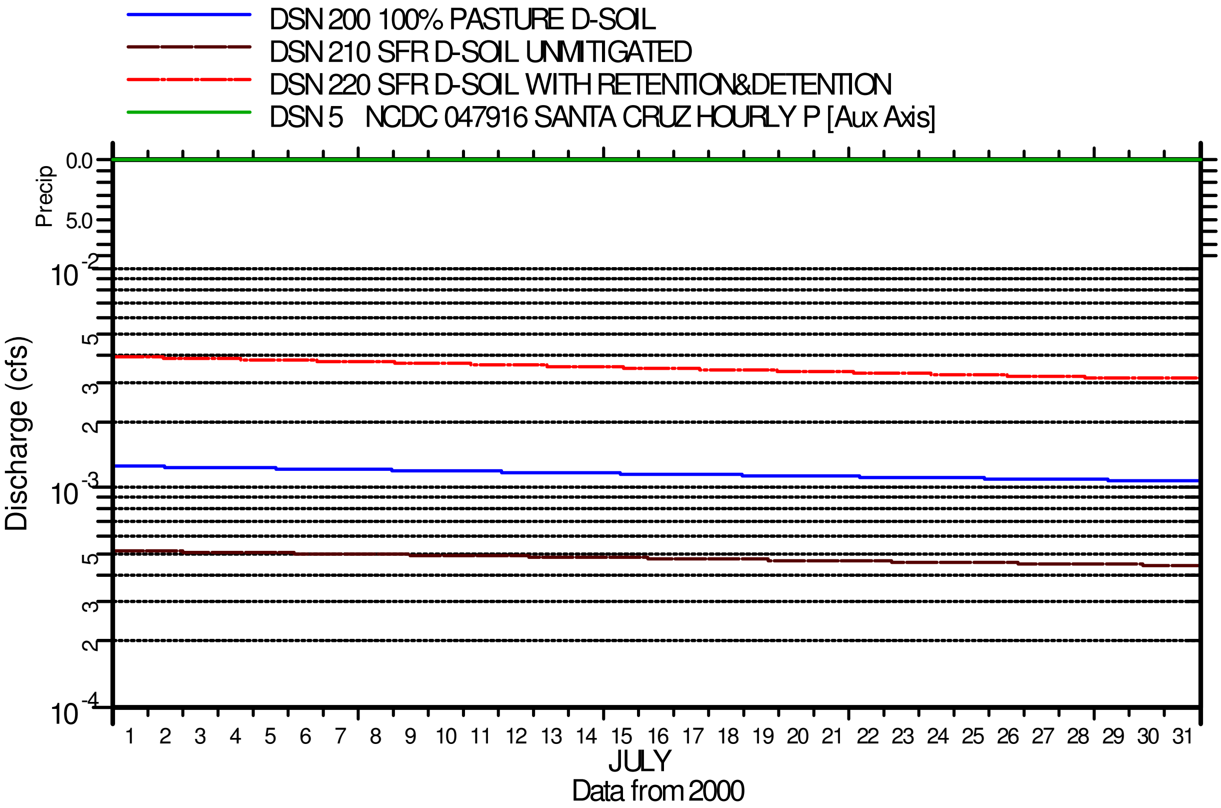


~10 yr Peak Annual Flow Event (pre-developed and mitigated), February 14, 1973



~2 yr Peak Annual Flow Event (pre-developed and unmitigated), February 19-20, 1992





The base flow results for very dry summer conditions for the SFR D-soil are similar to the SFR C-Soil case. The developed site without on-site retention (brown line) exhibits a base flow that is less than 50% of the pre-developed, 100% pasture condition (blue line) while the developed project with bioretention (red line) maintains base flows above the pre-developed level by a substantial margin.

Results for Commercial Case with C and D Soils

Commercial Redevelopment, C-Soil

Flood Frequency Comparison

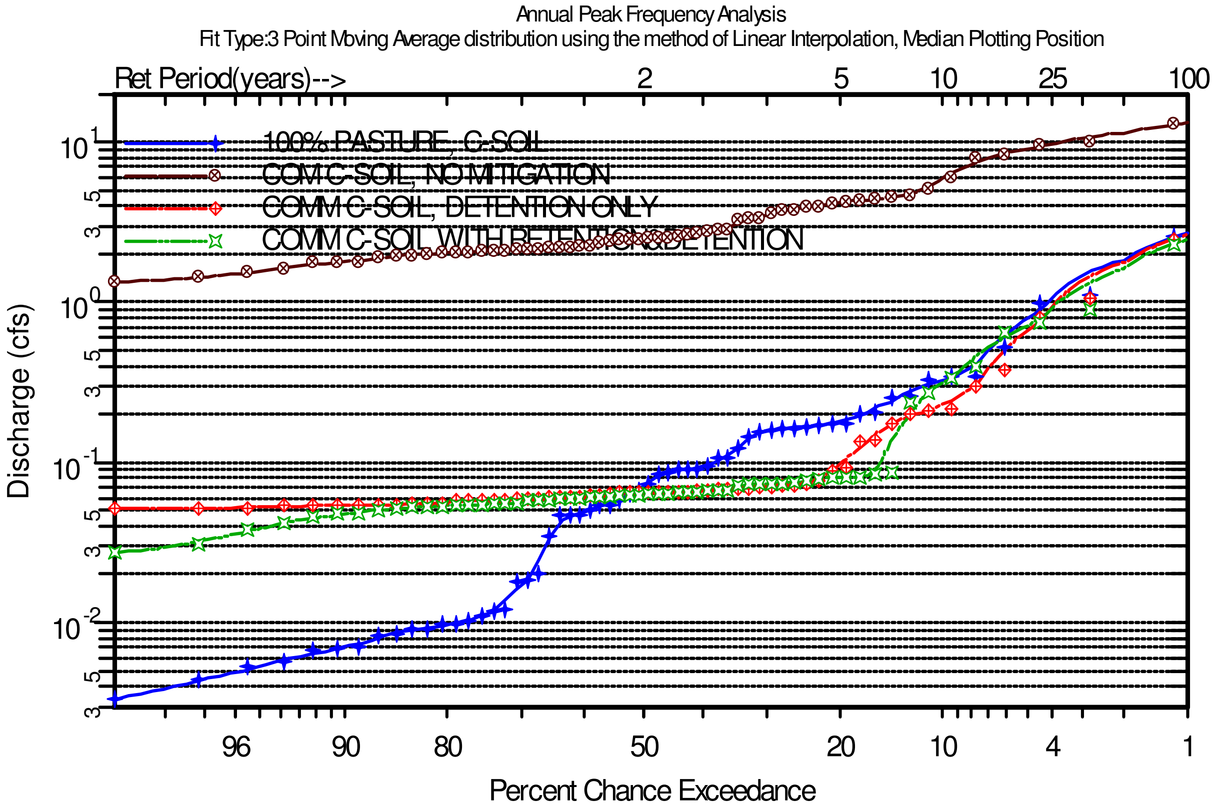
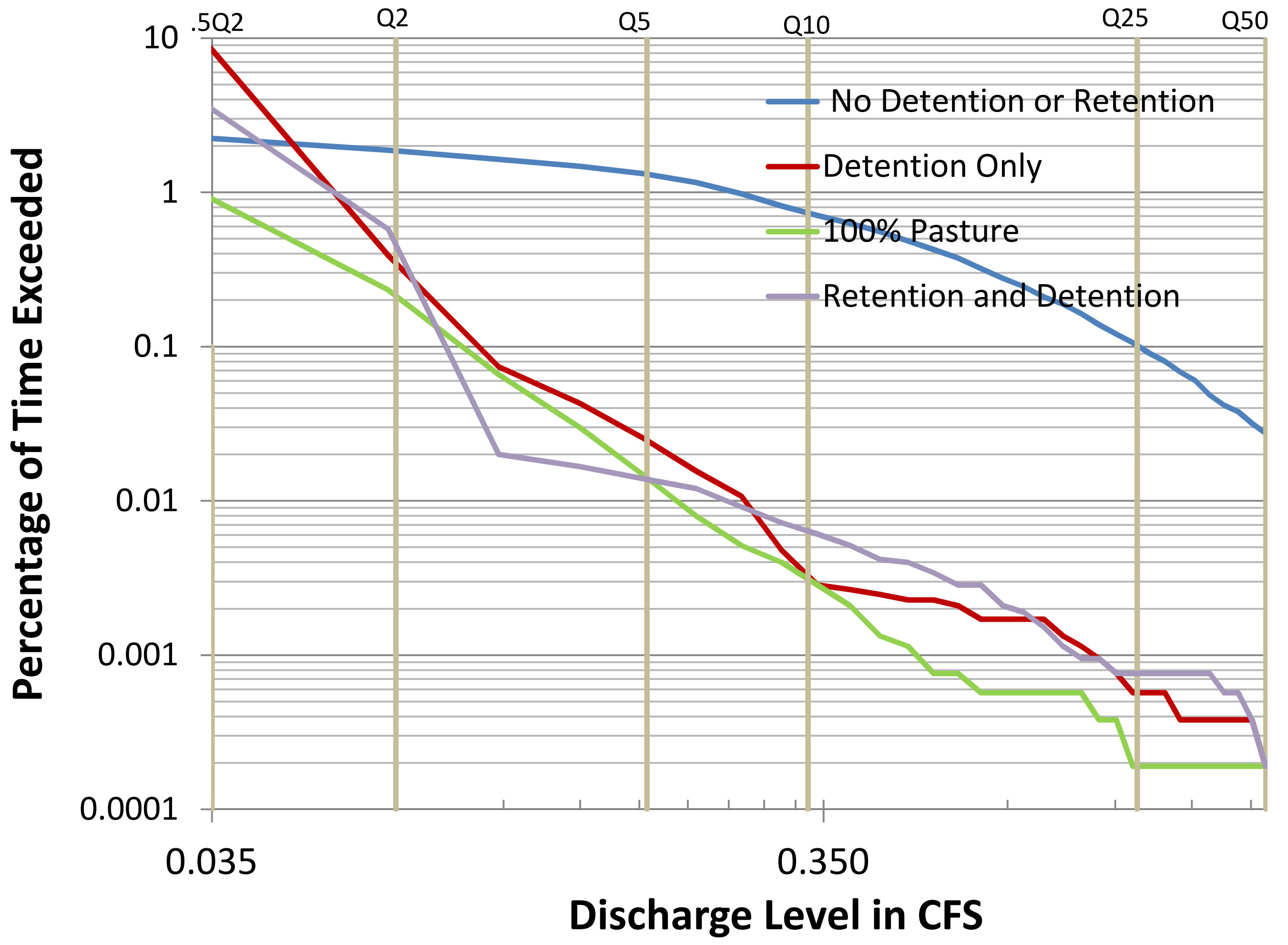


Table 5. Peak Annual Flood Frequency Curve Data for C-Soil, Commercial						
Average Recurrence Interval (years)	2	5	10	25	50	100
	Quantiles (cfs)					
Pre-Dev (Pasture),	0.07	0.18	0.33	1.14	1.85	2.70
Detention Only	0.07	0.10	0.24	1.02	1.78	2.62
On-Site Retention and Detention	0.06	0.08	0.32	0.99	1.62	2.45
NO MITIGATION	2.50	4.19	6.14	9.87	11.43	13.18

Peak Annual Flow Frequency Discussion, Commercial Redevelopment, C-Soil

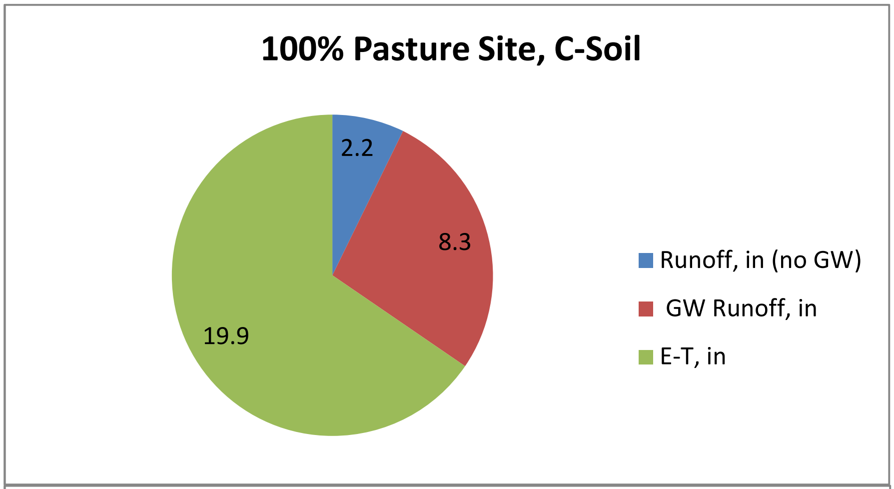
For the commercial development on a C-soil, matching of the pre-developed (100% pasture) frequency curve between the 2-yr and 100-yr quantiles is achieved either with a detention facility with 1.60 ac-ft with no on-site retention, or with a detention facility of 1.25 ac-ft and on-site facilities consisting of 0.26 ac of porous pavement and 0.40 acres of bioretention with 6 inches of available storage.

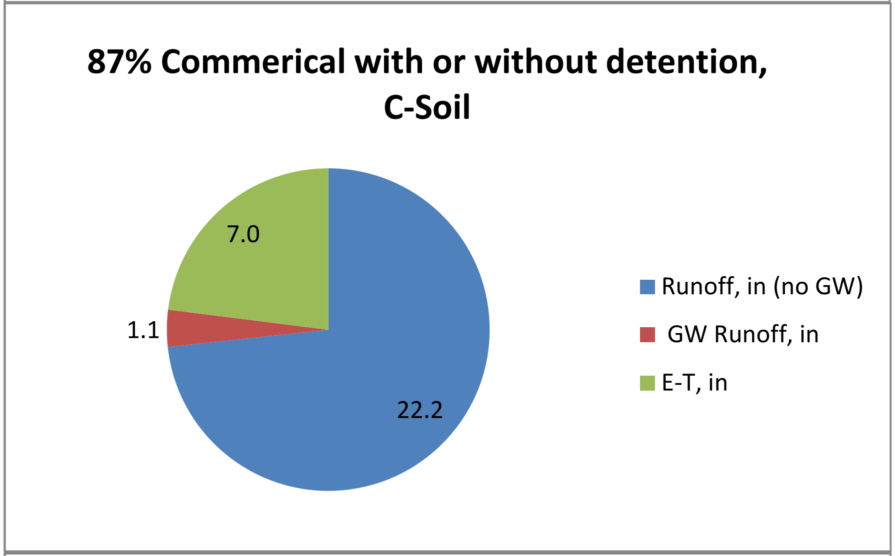
FLOW DURATION ANALYSIS FOR COMMERCIAL REDEVELOPMENT, C-SOIL

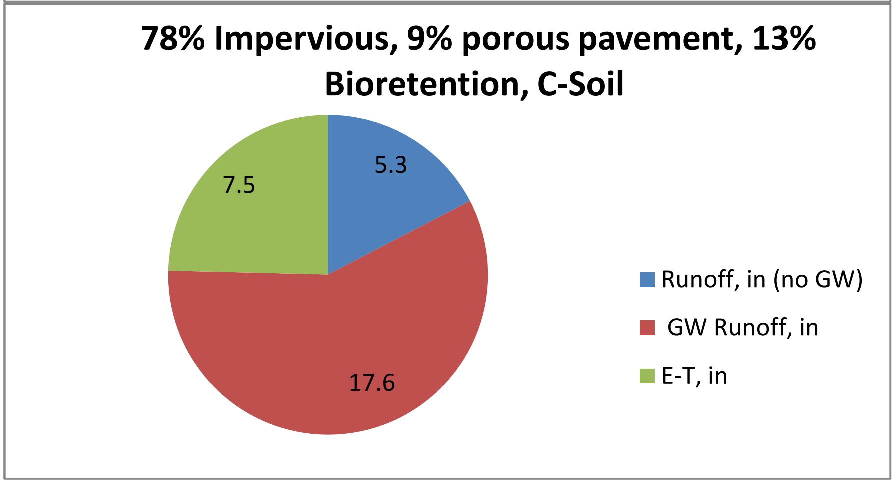


Flow Duration Discussion, Commercial Redevelopment, C-Soil

Over range from 50% of the 2-yr to the 10-yr peak, the average reduction in high flow durations is 79% for the combined retention-detention case, and 35% for the detention-only case. For flows at or above the 2-year flow, average performance for both cases is at the 96% level; however, for the more frequent sub-2-yr peaks, durations are clearly much higher and even exceed the un-mitigated level which drags the average performance down.


100% Pasture Site, C-Soil


87% Commerical with or without detention, C-Soil

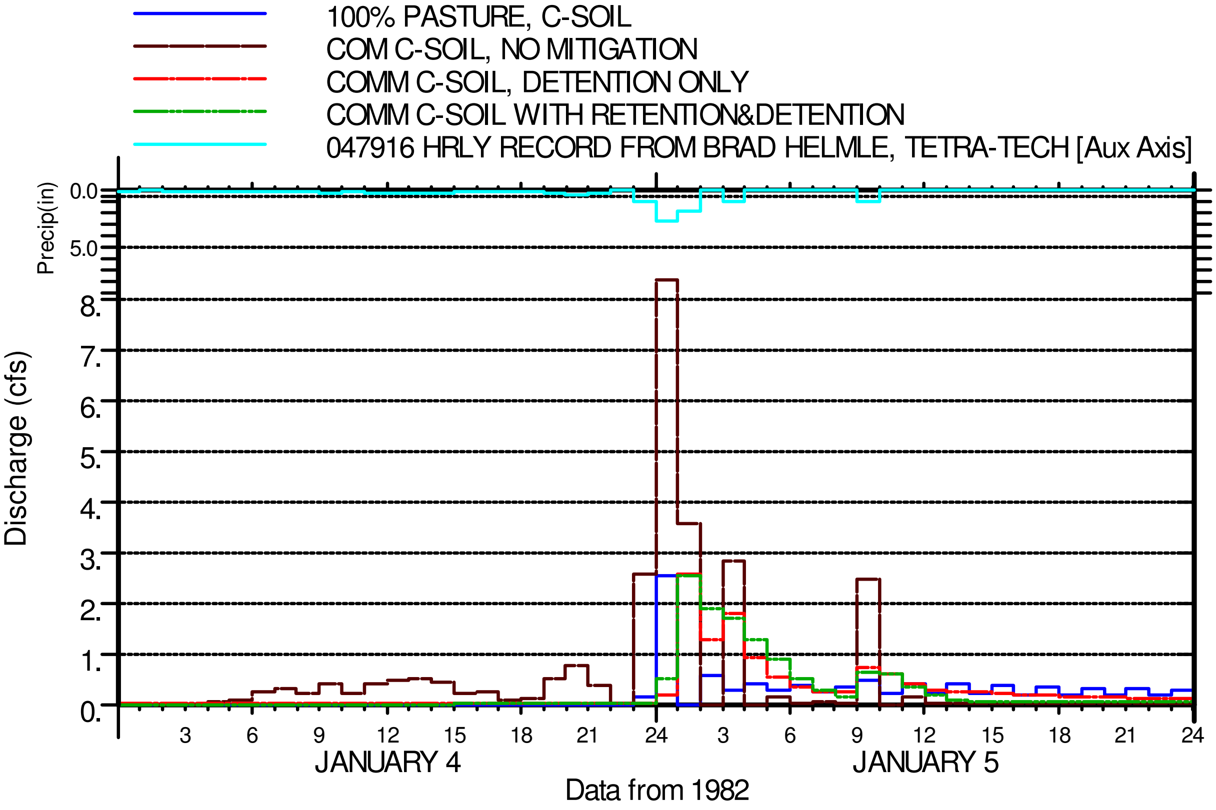

78% Impervious, 9% porous pavement, 13% Bioretention, C-Soil

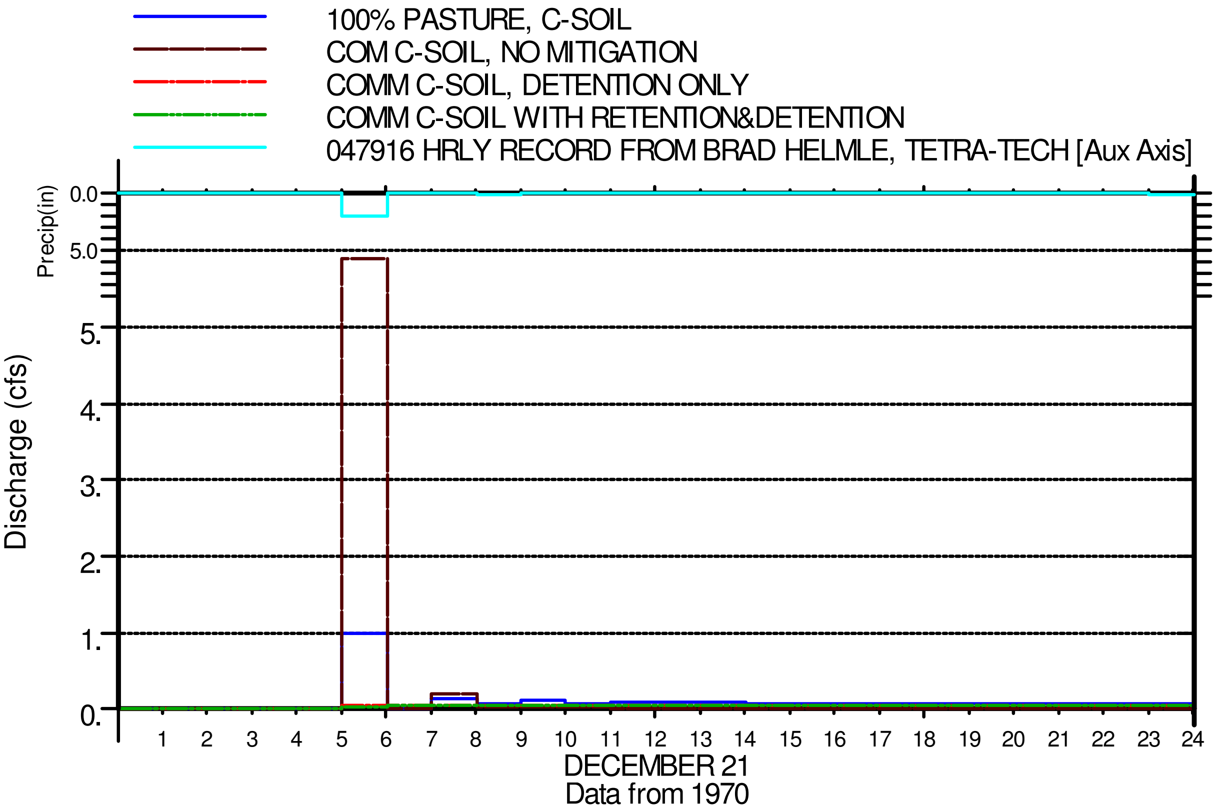
Water Balance Discussion, Commercial Redevelopment, C-Soil

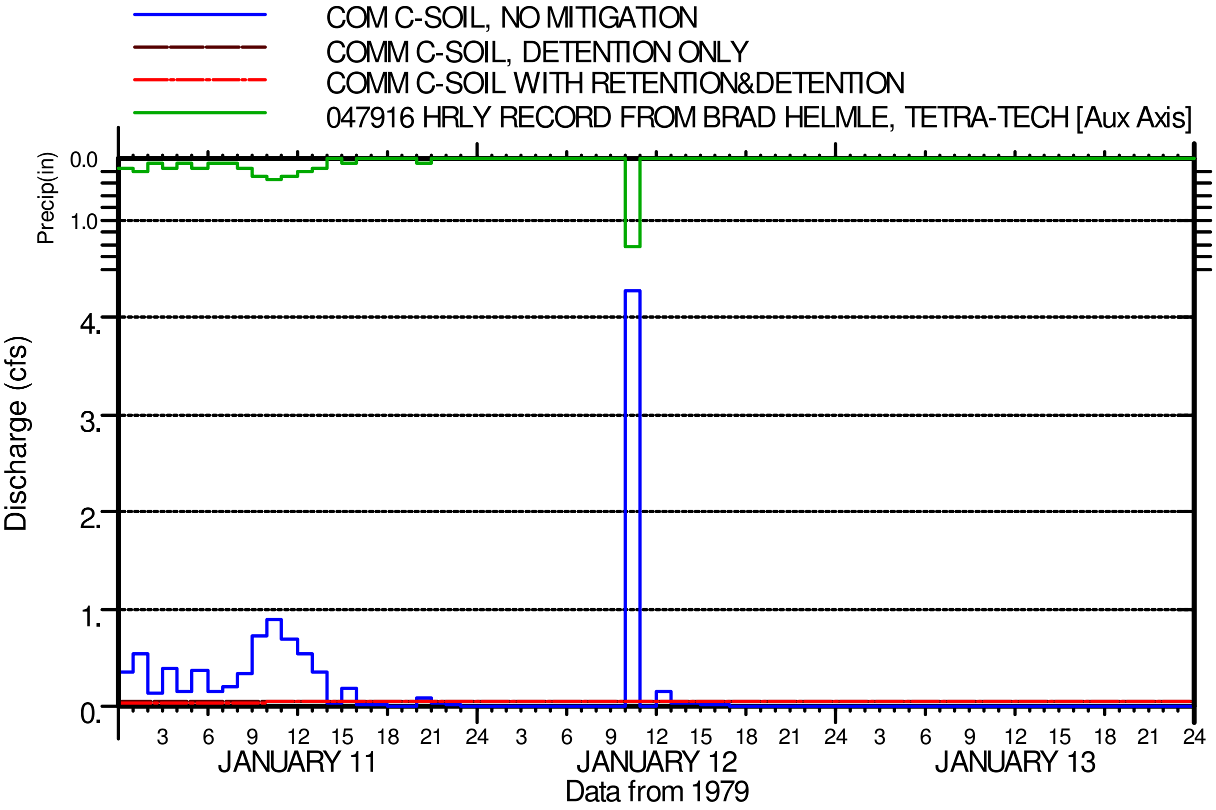
On-site retention facilities consist of 0.26 acres of porous pavement and 0.40 acres of bioretention taking up 10% of the impervious area and 100% of the pervious area on-site. Both facilities are assumed to infiltrate at a constant rate typical of a C-soil. Porous pavement is assumed to have zero storage, while bioretention must have 0.19 acre-ft of volume (5.7 inches in the bioretention facility) in order meet the retention design requirement for 50% of the replaced impervious area.

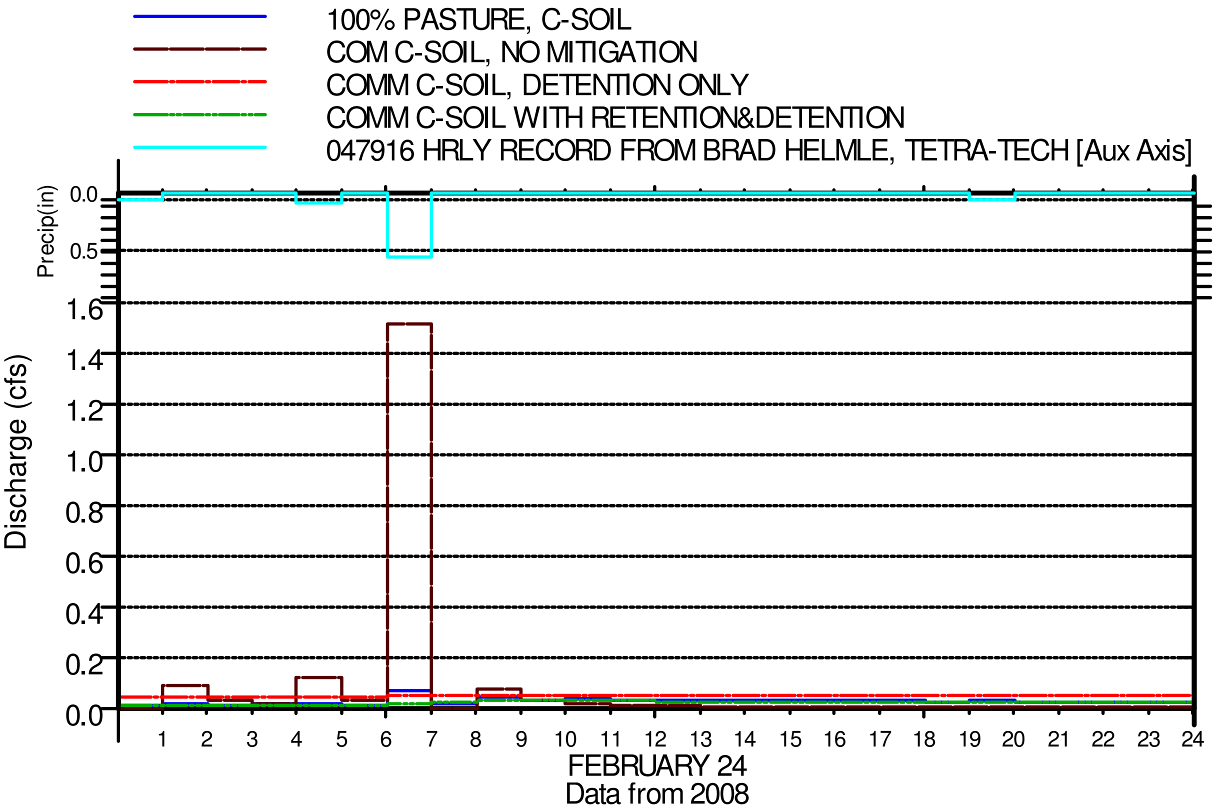
The average runoff volume (surface runoff and interflow) with on-site retention is over double the runoff for pasture conditions; however, the retention facilities treat 76% of the runoff from the site. Groundwater loading is more than doubled compared to pasture conditions and increased by a factor of sixteen compared to developed conditions with no retention facilities. Detention is assumed to play no role in affecting the developed water balance. It is assumed to be off-site with zero infiltration capacity.

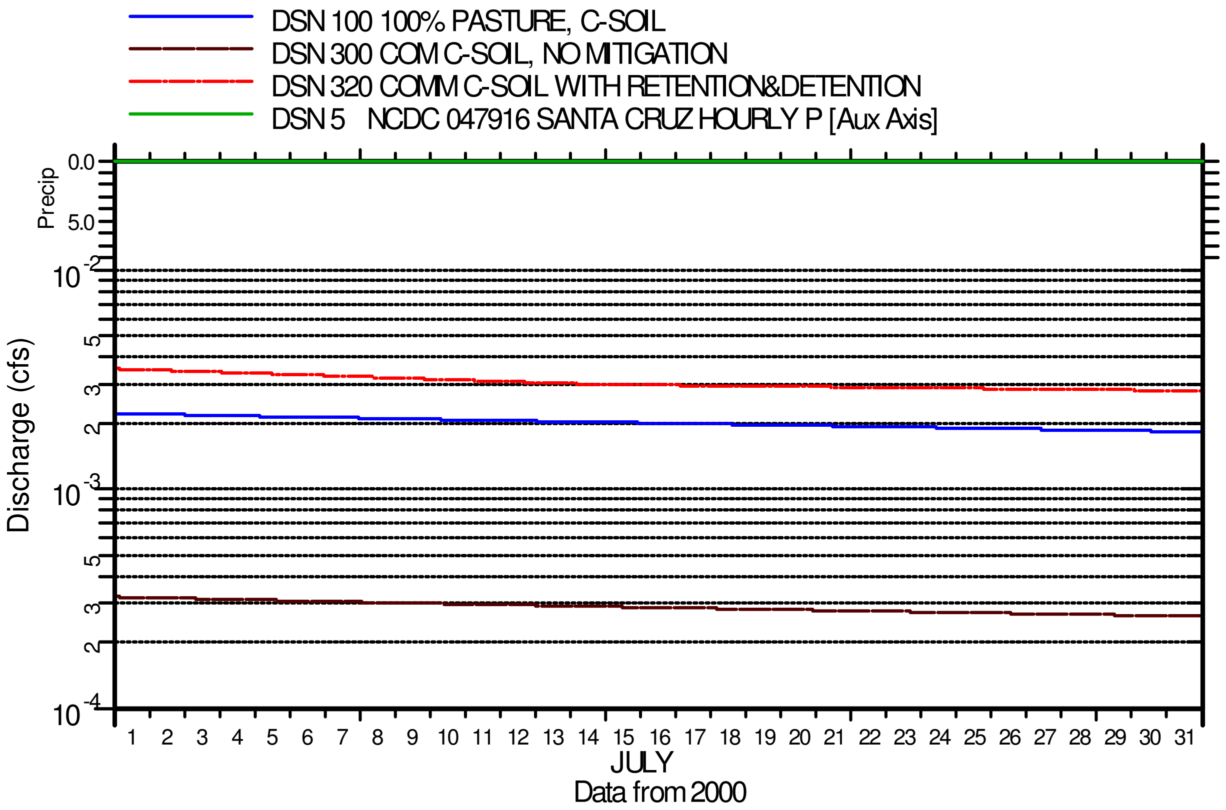
Sample Hydrographs, Commercial Redevelopment, C-Soil




100% PASTURE, C-SOIL
COM C-SOIL, NO MITIGATION
COMM C-SOIL, DETENTION ONLY
COMM C-SOIL WITH RETENTION&DETENTION
047916 HRLY RECORD FROM BRAD HELMLE, TETRA-TECH [Aux Axis]
Precip(in)
0.0
5.0
Discharge (cfs)
5.
4.
3.
2.
1.
0.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
DECEMBER 21
Data from 1970


COM C-SOIL, NO MITIGATION
COMM C-SOIL, DETENTION ONLY
COMM C-SOIL WITH RETENTION&DETENTION
047916 HRLY RECORD FROM BRAD HELMLE, TETRA-TECH [Aux Axis]
Precip(in)
0.0
1.0
Discharge (cfs)
4.
3.
2.
1.
0.
3 6 9 12 15 18 21 24 3 6 9 12 15 18 21 24 3 6 9 12 15 18 21 24
JANUARY 11
JANUARY 12
JANUARY 13
Data from 1979


100% PASTURE, C-SOIL
COM C-SOIL, NO MITIGATION
COMM C-SOIL, DETENTION ONLY
COMM C-SOIL WITH RETENTION&DETENTION
047916 HRLY RECORD FROM BRAD HELMLE, TETRA-TECH [Aux Axis]
Precip(in)
0.0
0.5
Discharge (cfs)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
FEBRUARY 24
Data from 2008



The base flow results for very dry summer conditions for the Commercial C-soil are similar to results for the residential scenario except that the base flow depletion for developed conditions is far more extreme. The developed site without on-site retention (brown line) is roughly seven times lower than the pre-developed, 100% pasture condition (blue line) while the developed project with bioretention (red line) maintains base flows above the pre-developed level.

Commercial Redevelopment, D-Soil

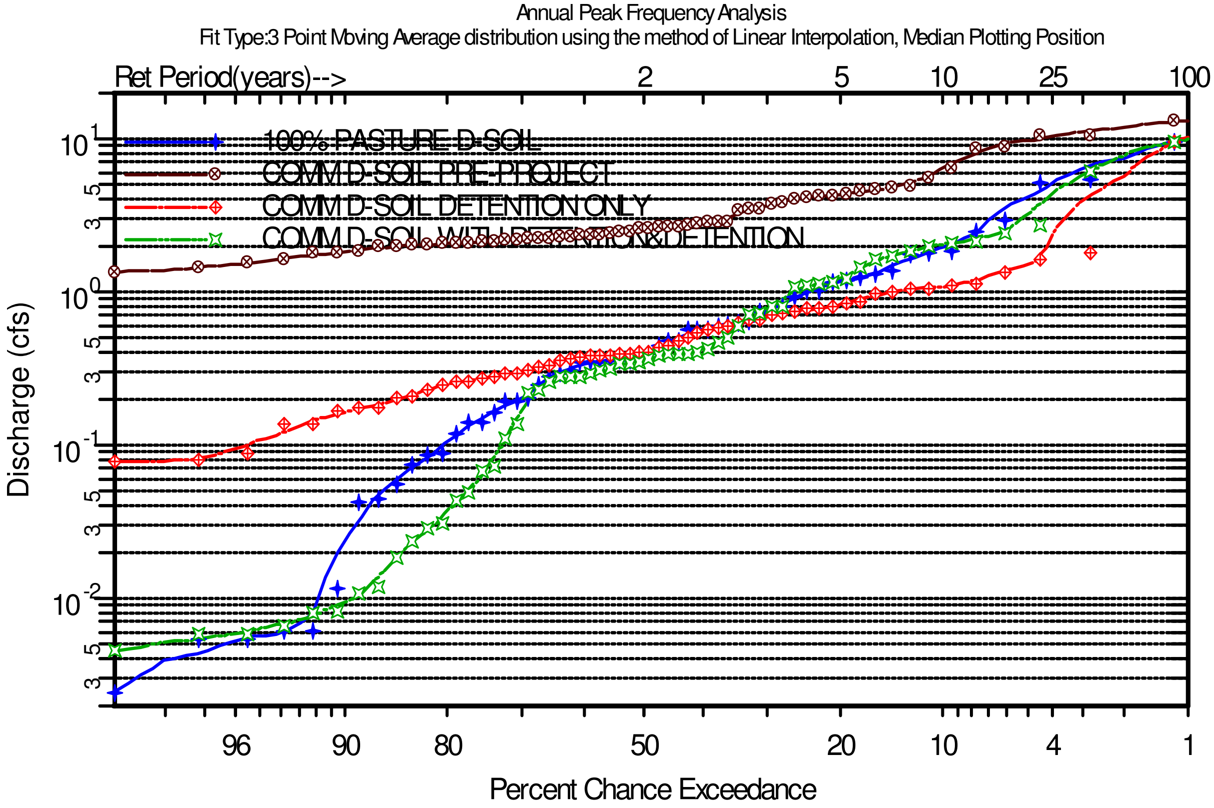
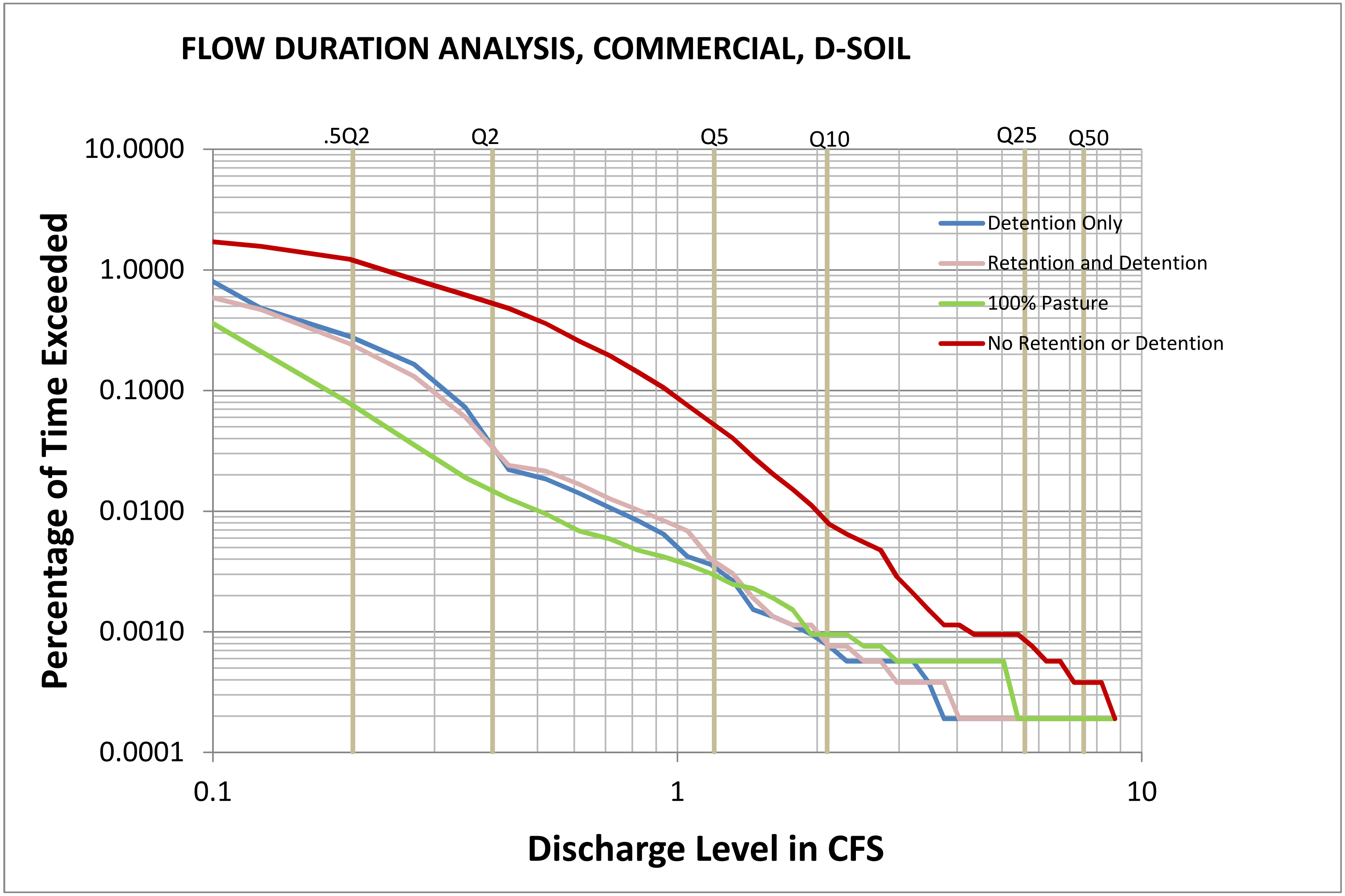


Table 6. Peak Annual Flood Frequency Curve Data for D-Soil, Commercial

Average Recurrence Interval (years)	2	5	10	25	50	100
	Quantiles (cfs)					
Pre-Dev (Pasture),	0.39	1.17	2.00	5.34	7.50	9.95
Detention Only	0.41	0.83	1.09	2.64	5.72	10.26
On-Site Retention and Detention	0.36	1.24	2.05	4.63	7.84	9.93
NO MITIGATION	2.57	4.35	6.62	10.43	11.73	13.11

Peak Annual Flood Frequency, Commercial Redevelopment, D-Soil

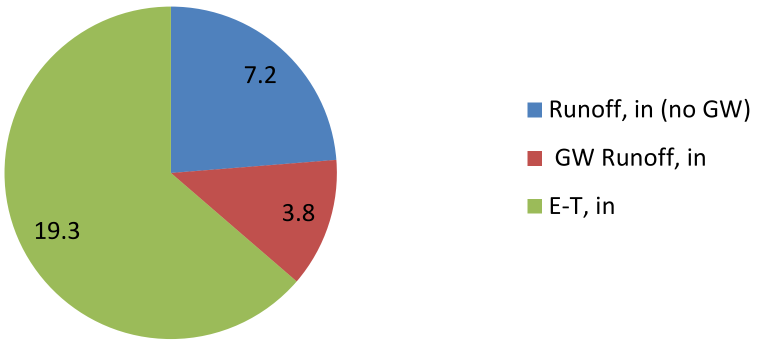
For the commercial development on a D-soil, matching of the pre-developed (100% pasture) frequency curve between the 2-yr and 100-yr quantiles is achieved either with a detention facility with 0.62 ac-ft with no on-site retention, or with a detention facility of 0.42 ac-ft and on-site facilities consisting of 0.26 ac of porous pavement and 0.40 acres of bioretention with 27 inches of available storage.


FLOW DURATION ANALYSIS, COMMERCIAL, D-SOIL

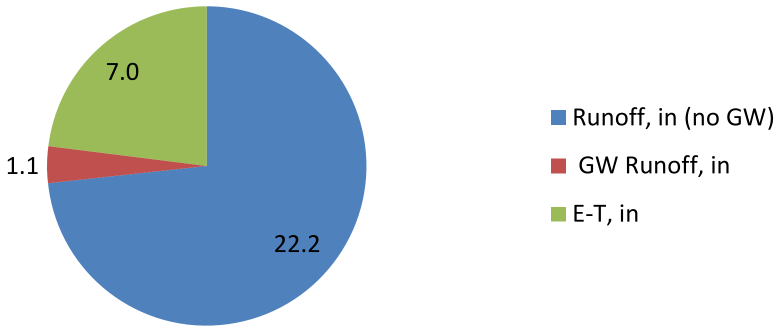
Flow Duration Discussion, Commercial Redevelopment, D-Soil

Both mitigation scenarios (commercial with 2-100 yr detention and commercial with detention plus retention designed for 50% of the impervious area runoff) reduce increases in high flow durations resulting from the unmitigated case by 96%. With no on-site retention facilities, the detention necessary to meet the peak flow standard is 0.62 ac-ft compared to 0.42 ac-ft for the case of a retention facility with 0.91 ac-ft of storage. These results indicate that on a less infiltrative D-soil, is not as effective as detention for controlling high runoff durations.

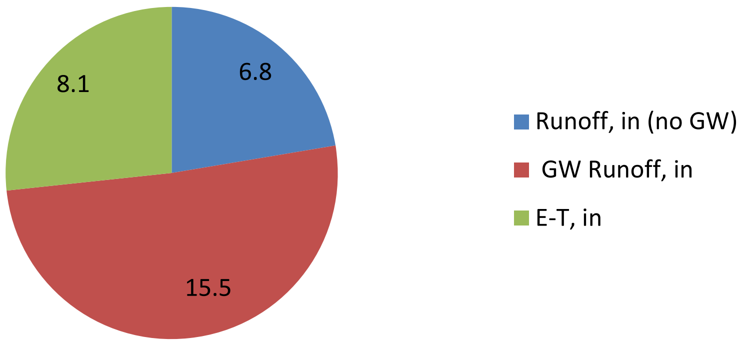
100% Pasture, D-Soil



87% Impervious, with or without detention/ no onsite retention



78% Impervious, 9% porous pavement, 13% Bioretention, D-Soil

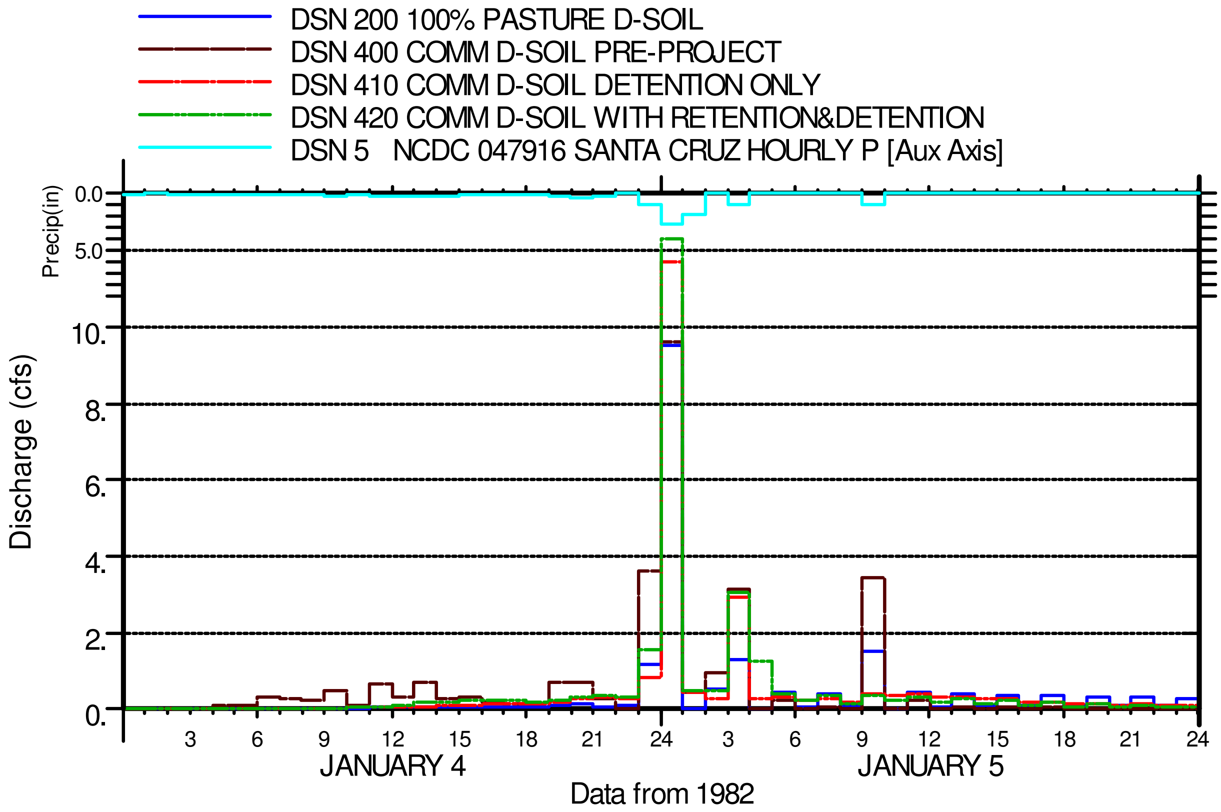


Water Balance Discussion, Commercial Redevelopment, D-Soil

On-site retention facilities takes up the same areas as for the commercial redevelopment on the C-soil, i.e. 0.26 acres of porous pavement and 0.40 acres of bioretention taking up 10% of the impervious area and 100% of the pervious area on-site respectively. Both facilities are assumed to infiltrate at a constant rate typical of a D-soil. Porous pavement is assumed to have zero storage, while bioretention must have 0.91 acre-ft of volume (27.3 inches in the bioretention facility) in order meet the retention design requirement for 50% of the replaced impervious area. Such a large storage depth may be infeasible.

The average runoff volume (surface runoff and interflow) with on-site retention is slightly less than for pasture conditions. Retention infiltrates and provides quality treatment to approximately 70% of runoff from developed site surfaces. Groundwater loading is increased by a factor of four compared to pasture conditions and by a factor of fourteen compared to developed conditions with no retention facilities. Detention is assumed to play no role in affecting the developed water balance. It is assumed to be off-site with zero infiltration capacity.

Sample Hydrographs, Commercial Redevelopment, D-Soil


DSN 200 100% PASTURE D-SOIL
DSN 400 COMM D-SOIL PRE-PROJECT
DSN 410 COMM D-SOIL DETENTION ONLY
DSN 420 COMM D-SOIL WITH RETENTION&DETENTION
DSN 5 NCDC 047916 SANTA CRUZ HOURLY P [Aux Axis]
Precip(in)
0.0
5.0
Discharge (cfs)
10.
8.
6.
4.
2.
0.
3
6
9
12
15
18
21
24
3
6
9
12
15
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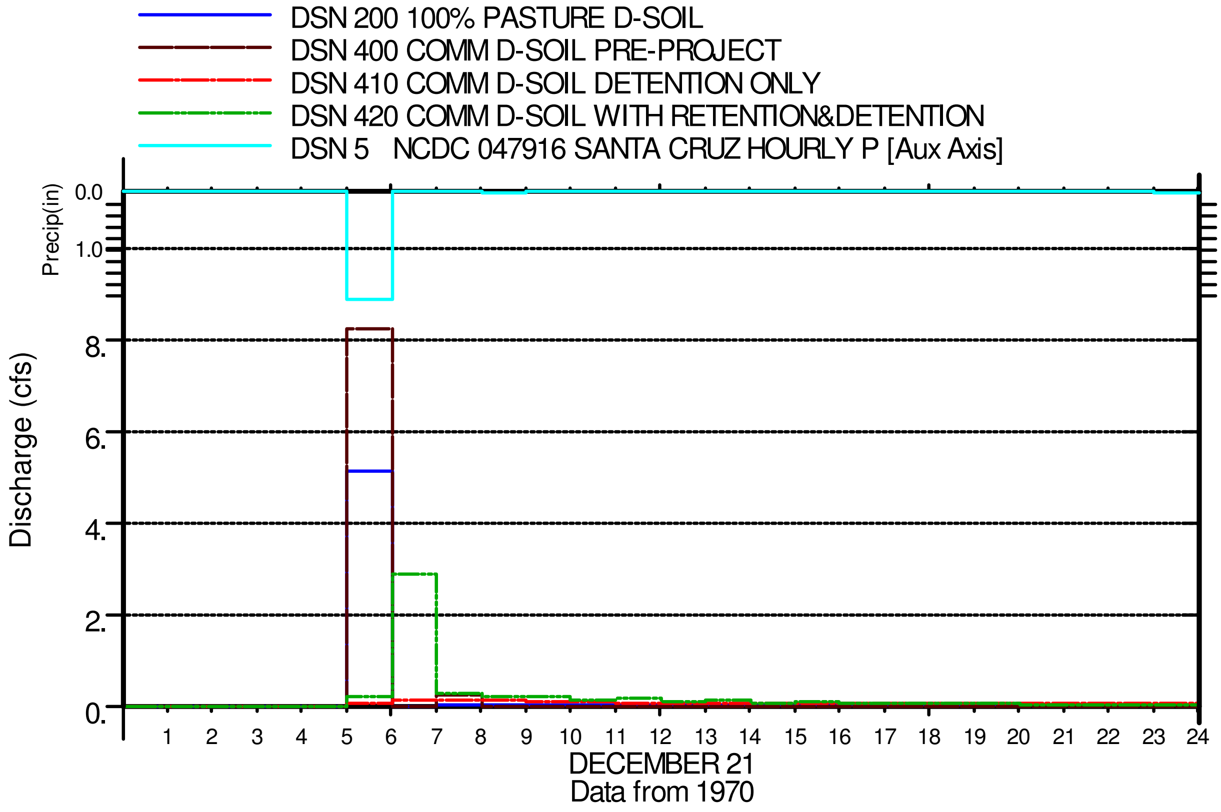
21
24
JANUARY 4
JANUARY 5
Data from 1982


DSN 200 100% PASTURE D-SOIL
DSN 400 COMM D-SOIL PRE-PROJECT
DSN 410 COMM D-SOIL DETENTION ONLY
DSN 420 COMM D-SOIL WITH RETENTION&DETENTION
DSN 5 NCDC 047916 SANTA CRUZ HOURLY P [Aux Axis]
Precip(in)
0.0
1.0
Discharge (cfs)
8.
6.
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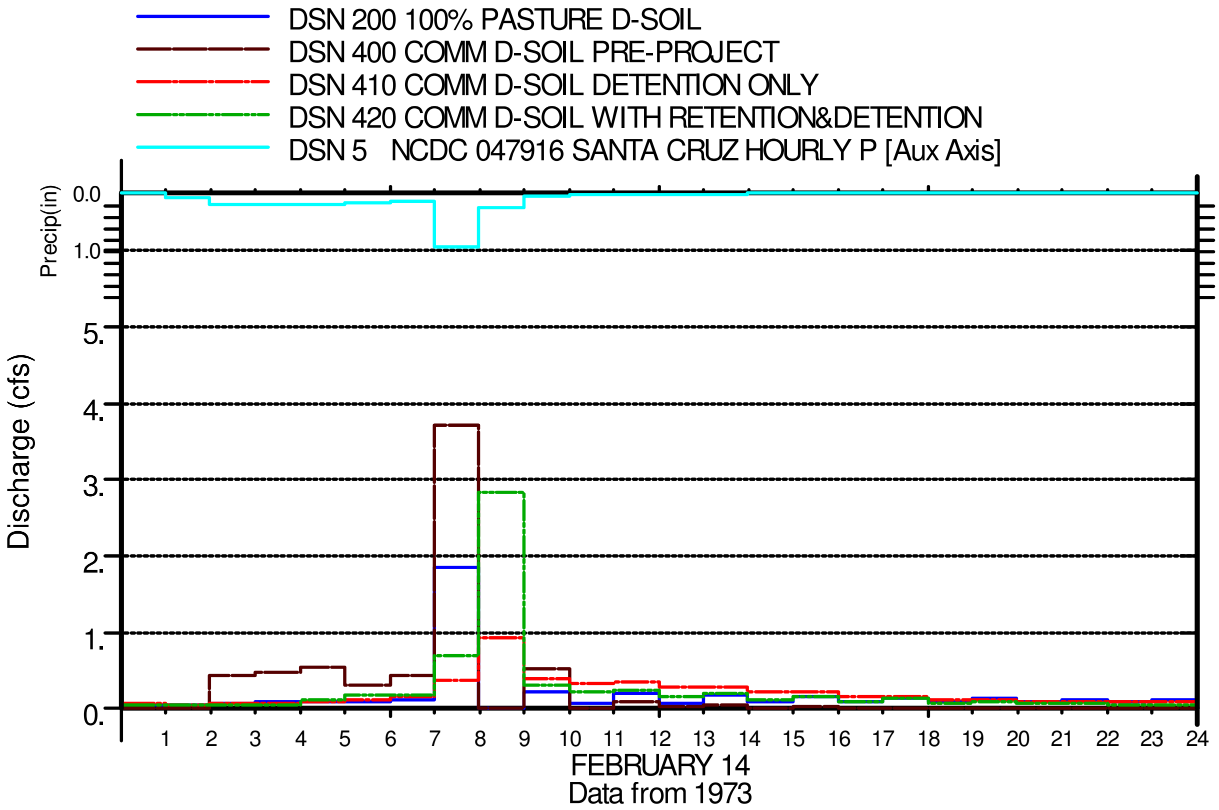
DECEMBER 21
Data from 1970


DSN 200 100% PASTURE D-SOIL
DSN 400 COMM D-SOIL PRE-PROJECT
DSN 410 COMM D-SOIL DETENTION ONLY
DSN 420 COMM D-SOIL WITH RETENTION&DETENTION
DSN 5 NCDC 047916 SANTA CRUZ HOURLY P [Aux Axis]
Precip(in)
0.0
1.0
Discharge (cfs)
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4.
3.
2.
1.
0.
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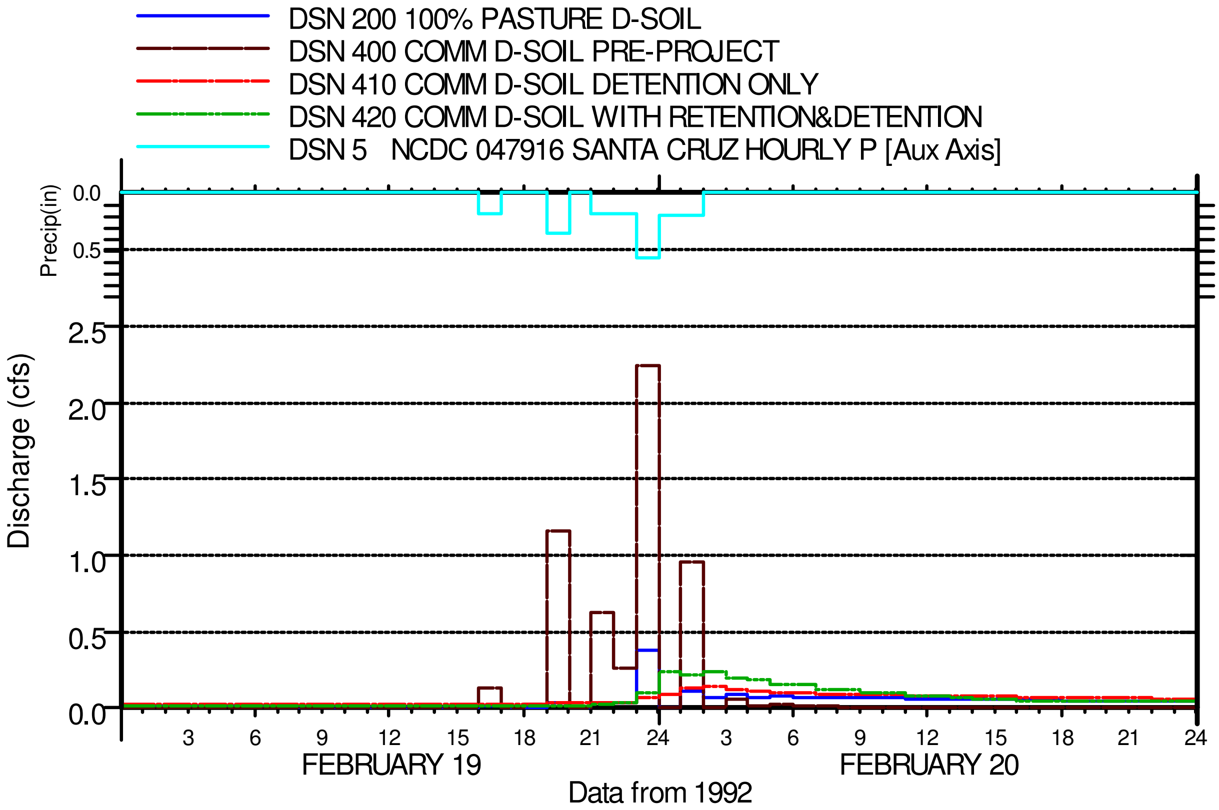
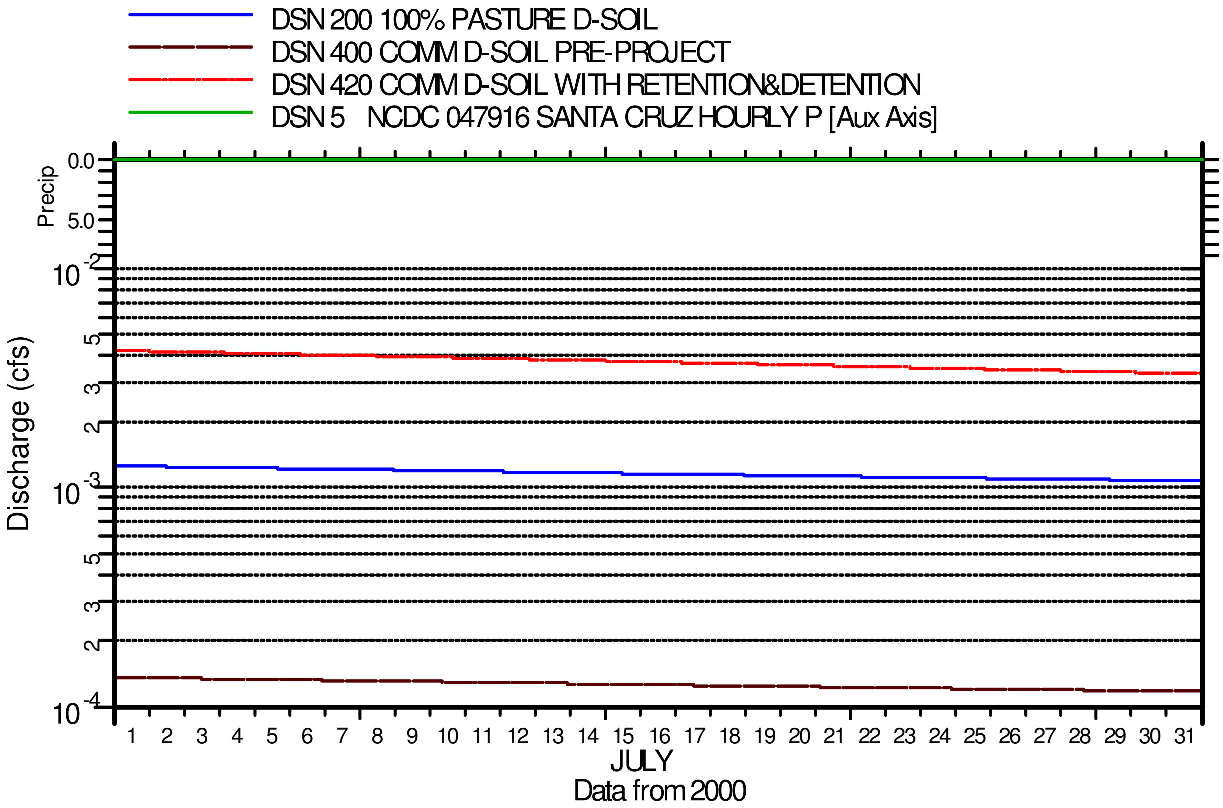
FEBRUARY 14
Data from 1973


DSN 200 100% PASTURE D-SOIL
DSN 400 COMM D-SOIL PRE-PROJECT
DSN 410 COMM D-SOIL DETENTION ONLY
DSN 420 COMM D-SOIL WITH RETENTION&DETENTION
DSN 5 NCDC 047916 SANTA CRUZ HOURLY P [Aux Axis]
Precip(in)
0.0
0.5
Discharge (cfs)
2.5
2.0
1.5
1.0
0.5
0.0
3 6 9 12 15 18 21 24 3 6 9 12 15 18 21 24
FEBRUARY 19
FEBRUARY 20
Data from 1992



The base flow results for very dry summer conditions for the Commercial D-soil are similar to results for the Commercial C-Soil case. The developed site without on-site retention (brown line) is roughly four times lower than the pre-developed, 100% pasture condition (blue line) while the developed project with bioretention (red line) maintains base flows above the pre-developed level.

Summary of Results

Peak Flows

Unmitigated Cases

For unmitigated development (no retention or detention facilities), factors of increase in peak flow above the baseline of 100% pasture ranged from about 3 to 19 times. These factors were computed by averaging quantile values for 2-, 5-, 10-, 25-, 50- and 100-yr peak annual flows and taking the ratio of each unmitigated value to baseline value for 100% pasture.

As shown in Table 7, factors of increase in peak flows were greater on the C-soil which exhibits very little surface runoff under pasture conditions. In contrast D-soils are more prone to surface runoff, therefore ratios of increase are less pronounced but still very significant. Differences in the peak flow ratios between residential and commercial for a given soil, are not as great as the differences between the two soils for the same development scenario.

Table 7. Average Factor of Increase in 100% Pasture Peak Annual Flows with No Retention or Detention		
	C-Soil	D-Soil
SFR Development	11.3	2.8
Commercial Development	18.6	3.3

Mitigated and Partially Mitigated Cases

For all scenarios that included a detention facility, peak annual flow frequency quantiles were match to the 100% pasture conditions quantiles over the range of 2-yr to 100-yr peaks. The only difference in these scenarios was in the total amount of retention and detention storage required to match the pasture condition frequency curve. A summary of the required storage amounts is shown in Table 8.

Table 8. Total Volume of Facilities Required to Match 100% Pasture Condition Peak Annual Flow Quantiles		
	Total Storage Required* C-Soil (ac-ft)	Total Storage Required* D-Soil (ac-ft)
Residential with Retention & Detention	1.06	0.94
Commercial with Detention Only	1.66	0.75
Commercial with Retention & Detention	1.54	1.51

*Detention volume plus any additional volume from bioretention

The total active storage volume within both retention and detention facilities is similar for C- and D-Soil cases in both the development scenarios. This is a result of the higher volume required for retention facilities on D-soils than on C-soils. As evidenced by the commercial case in which only detention is applied with no retention, if matching peak flows to pre-developed, pasture conditions is the only concern, it requires less detention storage on a D-soil than on a C-soil because the baseline or target condition on a lower infiltration soil is hydrologically closer to the developed condition. In the case of retention sizing, the standard requiring prevention of runoff from 95% non-exceedance, 24 hour rainfall does not account for differences in pre-developed runoff frequency that might be expected from soils with different infiltration characteristics.

High Flow Durations

The flow duration performance of the fully mitigated and partially mitigated simulation is characterized by an average reduction in high flow durations at four pasture condition peak flow quantile values, 50% of the 2-yr, 2-yr, 5-yr and 10-yr. For each of these flow levels a percent reduction was calculate as follows:

$$(T_u - T_i) / (T_u - T_p) \times 100\%$$

in which T is the flow duration, and the subscripts u, i, and p correspond to unmitigated, the current simulation case being evaluated, and pasture respectively. This calculation is made for each of the four quantiles and resulting percentages were averaged to represent the approximate duration mitigation performance of the simulation case over the range of flows listed above. Results this calculation for the six cases with different combinations of soil and facilities are shown in Table 9.

Table 9. Average Percentage Reduction in High Flow Durations from 50% of the 2-yr to the 10-yr Peak Annual

Development Scenario	C-Soil	D-Soil
Residential with Retention & Detention	92%	91%
Commercial with Detention Only	9%	96%
Commercial with Retention & Detention	71%	96%

For the lower infiltration D-soil, high flow durations are suppressed to the same degree by detention alone or in combination with retention for both the residential and commercial scenarios.

In contrast, for the Commercial scenario on a C-Soil with no retention, there is a large drop in performance to 9% compared to the same land use-soil combination that includes retention (71%). The relatively poor performance of the detention-only case is caused solely by extremely poor performance at the extreme low end of the range (i.e. -700% at half the 2-yr level). For flows ranging from the 2-yr the 10-yr, performance is consistently above 90%. If the lower limit of the threshold of concern were raise to the 2-yr peak flow, there would be minimal difference between the C-Soil and D-Soil performance under either development scenario.

Results of the commercial simulations and analysis suggest that on-site retention facilities are not necessarily superior to detention facilities in controlling high flow durations on tight (D) soils; however, on C soils the additional infiltration greatly assists in lower durations of flows smaller than the 2-yr peak annual flow.

Reduction and Treatment of Surface Runoff Volume

Surface runoff entering on-site retention facilities from developed impervious surfaces infiltrates and on occasion overflows and runs off the site during larger storms and wetter seasons. Under the retention standard and sizing approach discussed earlier, model simulations indicate that between 70% and 81% of surface runoff is infiltrated for all cases where retention is applied. Table 10, below, provides a summary of these results for the two different development scenarios and soil types. The relatively consistent performance of retention facilities constructed on high infiltration and low infiltration soils is made possible by the additional storage volume specified for D-soil facilities which compensates for their slower infiltration rate.

Table 10. Average Percentage of Surface Runoff Infiltrated and Treated by On-site Retention Facilities

Scenario	C-Soil	D-Soil
Residential with Bioretention	81%	69%
Commercial with Porous Pavement and Bioretention	76%	70%

Base Flows

Under dry, summer conditions exemplified by project outflow hydrographs during July, 2000, base flows are depleted by factors ranging from 2 to 7 if no on-site retention is provided. The depletion factor is directly related to the intensity of development as indicated by the percentage of impervious surface. However, with on-site retention facilities, base flows are actually augmented over the baseline case with 100% pasture condition for both development and soil scenarios. This "over mitigation" may be restorative to varying degrees in stream basins where summer base flows may have been depleted by previous development that did not implement on-site retention.

References

EPA Office of Water, 2009. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act, EPA 841-B-09-001, (http://www.epa.gov/owow/NPS/lid/section438/), 60 pp.

Methods and Findings of the Joint Effort for Hydromodification Control in the Central Coast Region of California

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1 INTRODUCTION

The Central Coast Joint Effort for Hydromodification Control (the "Joint Effort") is a collaborative, region-wide approach municipalities are using to implement low impact development and hydromodification control. The goal of the Joint Effort is to protect or restore key watershed processes that otherwise would be, or that already have been, adversely affected by human activity. The approach taken by the Joint Effort to reach this goal is to use a foundation of landscape characterization to identify the hydromodification control strategies for new urban development and redevelopment that will be most effective at achieving the protection and restoration of aquatic resources. The interim products of the Joint Effort have included literature and data summaries (Task 1); a preliminary, GIS-based characterization of the landscape and watersheds of the Central Coast Region (Task 2); the data- and field-supported identification of landscape attributes, watershed processes, receiving-water conditions, and primary disturbances present on that landscape (Task 3); and a GIS-based analysis of a final set of "Physical Landscape Zones" (PLZ's) and a systematic description of the primary landscape attributes and the dominant watershed processes associated with each one (Task 4).

The specific purpose of this report is to document the entire Joint Effort methodology and findings, including the determination of Watershed Management Zones and the identification of associated hydromodification management strategies. This report describes how each of the following steps were undertaken, and the results of each step:

1. Definition and mapping of Physical Landscape Zones;
2. Association of key watershed processes with each PLZ;
3. Definition of the interrelationships between landscape disturbance, PLZ's, watershed processes, and receiving waters;
4. Definition and mapping of Watershed Management Zones;
5. Identification of hydromodification management strategies associated with each WMZ; and
6. Incorporation of local-scale and/or site-specific data to inform final stormwater management controls and their numeric criteria.

2 STEPS IN THE JOINT EFFORT METHODOLOGY

2.1 Defining and mapping Watershed Processes and Physical Landscape Zones

2.1.1 Watershed Processes

"Watershed processes" is the term adopted by the Joint Effort to encompass the storage, movement, and delivery of water, chemical constituents, and/or sediment to receiving waters. Watershed processes across the landscape of the Central Coast region were anticipated to be similar to those found throughout temperate latitudes throughout the world, and so characterizations and discussions in the scientific literature formed the basis for initial definition of those processes, and subsequently for making and interpreting field observations. Most commonly, that literature subdivides the set of watershed processes into those relating to the movement of *water* and to the movement of *sediment*. Although obviously interrelated, that subdivision is maintained here.

The delivery, movement, storage, and loss of water within a watershed is one set of watershed processes, most commonly represented by the hydrologic cycle. Components of the hydrologic cycle constitute the fundamental ***hydrological processes*** that are active in any watershed: precipitation, surface runoff, infiltration, groundwater flow, return flow, surface-water storage, groundwater storage, evaporation and transpiration (e.g., Beighley et al. 2005). Although present virtually everywhere across a watershed, these individual processes vary greatly in their importance to watershed "health" and functions

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of its physical, chemical, and biological processes. Recognizing their magnitude and spatial distribution has been a long-standing effort of landscape studies, of which the Joint Effort is merely the latest (e.g., England and Holtan 1969).

Hillslope processes are a second set of watershed processes that strongly influence watershed health and function. They broadly refer to the movement or deposition of sediment, driven largely but not exclusively by the movement of water, that affect the land surface. In the Central Coast region, these processes are primarily erosion, landsliding and other mass wasting, and sediment transport and deposition in stream channels and other receiving waters. Their magnitude and distribution across different landscapes has also been the focus of much scientific study, albeit for not nearly as long as for their hydrological counterparts (local examples include Warrick and Mertes 2009, Stillwater Sciences 2010).

Less precisely defined or constrained are a third set of watershed processes, namely those physical, chemical, and biological actions that occur within receiving waters themselves. These have no uniformly used name in the scientific literature; we here refer to them as ***within-waterbody processes*** to distinguish them from the hydrologic and hillslope processes that are active across the landscape as a whole.

Our prior literature review of approaches to hydromodification control, including prior assessments of watershed processes (Task 1, *Literature Review*), includes a number of references that list the "typical" watershed processes for temperate-region parts of the planet. Additional text references (e.g., Reid and Dunne 1996, Ritter et al. 2011) modestly augmented these sources. Field review and common knowledge of the region then guided the condensation of the original list down to those watershed processes that we judge to be important in some or all of the Central Coast Region. Table 1 summarizes the outcome of this (largely literature-based) assessment of potential key watershed processes:

Table 2-1. Summary of literature-derived watershed processes likely to be important in the Central Coast Region. More detailed descriptions of the key processes are provided in Section 2.2.

Predominantly *hydrologic* processes (i.e., "water")	**Predominantly *hillslope* processes (i.e., "sediment")**
Evapotranspiration	Creep
Overland flow	Sheetwash
Surface infiltration	Rilling and gullying
Shallow, lateral subsurface flow ("interflow")	Other mass failures ("landsliding")
Deep infiltration to groundwater ("groundwater recharge")	Tributary bank erosion
Transport of organic matter	Chemical, biological reactions in soil
Within-waterbody processes	
Fluvial transport and deposition; mainstem bank erosion	
Biological interactions (nutrient dynamics, trophic interactions)	
Chemical and biological reactions of sediment- and water-borne constituents	

Note that most of the hydrologic processes (left-hand column) can only be inferred, given the limitations of one-time observation in non-rainy conditions. However, some of these processes are virtually certain to occur to *some* extent in every part of the landscape (e.g., evapotranspiration and surface infiltration); subsequent analyses, however, might be necessary to quantify their relative or absolute magnitude if this proves to be an important parameter.

In contrast, most of the "hillslope" processes (we recognize that runoff also occurs on hillslopes but use this term to identify those processes responsible for sediment movement and delivery) typically have direct field expression even if the process is not active at the time of observation. Gullies are one such example; mass failures are another. Creep is generally inferred by the absence of other expression, but it is known to be ubiquitous across nearly all landscapes and can be the dominant sediment-delivery process where other modes of sediment movement are not active.

2.1.2 Physical Landscape Zones

Although the conditions that affect the delivery of water, chemical constituents, and/or sediment to the receiving water vary greatly over time, different parts of the landscape can be readily identified as to their *relative* production and delivery potential, and the dominant process(es) by which this happens. The primary determinants of watershed processes have been cataloged by many prior studies. Commonly recognized attributes include the material being eroded (i.e,. lithology), a measure of topographic gradient (hillslopes, basin slope), climate (mean annual temperature, mean annual precipitation, climate zone, latitude), land cover (vegetation, constructed cover and imperviousness), and episodic disturbance (e.g., fire, large storms).

Individual studies have tended to focus on a subset of these factors, reflecting both the importance any given set of factors relative to others and their range of variability within a circumscribed region. Montgomery (1999) suggested that four factors— regional climate, geology, vegetation, and topography—determine the geomorphic processes over a given landscape. Reid and Dunne (1996) noted that every study area requires simplification and stratification, with topography and geology as the primary determinants. In their framework, land cover is recognized as a potentially significant influence on watershed processes but is considered a "treatment" variable within each topography–geology class, rather than an intrinsic property of the landscape itself. Note that these scientific studies identify *geology*, rather than *soils*, as a key factor—this reflects the physical attribute that most fundamentally determines the landscape- and watershed-scale response to precipitation. Site-specific soils are also important, but primarily in determining the feasibility of particular stormwater controls to protect those responses.

The purpose of defining landscape groups at this step was to characterize watershed processes in their natural, undisturbed state. Thus, lithology and hillslope gradient (but *not* land cover) were the landscape attributes characterized for this step. Data were compiled in a GIS format for the entire watershed at a resolution determined by the coarsest dataset. Rock types were derived from the geologic map of the State of California, originally produced by Jennings et al. (1997) and available electronically at 1:750,000 scale. Mapped units were grouped into seven categories, largely discriminating based on material competency and degree of consolidation.

The relative proportions of the geology categories are summarized in Table 2.2.

Table 2. Geology categories, generalized from Jennings et al. (1977) and as applied across the Central Coast Region.

Geology category	% of area
Quaternary sedimentary deposits	30%
Tertiary sedimentary rocks	37%
Mesozoic metasedimentary rocks	12%
Tertiary volcanic rocks	11%
Granitic rocks	
Mesozoic and Paleozoic metamorphic rocks	
Franciscan mélange	11%

Hillslope gradients were generated directly from the digital elevation model (DEM), which in turn was based on a USGS 10-m DEM. Based on the distribution of slopes and on observed ranges of relative erosion and slope instability seen in previous studies within and adjacent to the Region (e.g., Stillwater Sciences 2010), the continuous range of hillslope gradients was categorized into three groups: 0–10%, 10–40%, and steeper than 40%. The discrete categories defined for these two factors (geology and slope) can overlap into 21 possible combinations—that is, areas that each has a unique combination of these factors that are judged to be the major determinants of watershed processes. This overlap was done in a Geographic Information System (GIS).

However, the resulting data were much too "grainy" to be directly useful for a regional application. In particular, the original topographic data source (USGS/NED, 1-arc second) required "smoothing" in order to be useful, even after grouping into the three slope classes (0–10%, 10–40%, and >40%).

To create the final set of areas based on the combination of geology+slope, both datasets were first projected into NAD 1983 California Teale Albers. Slope-zone geoprocessing was carried out in ESRI ArcGIS 10 Platform and based on Spatial Analyst and ArcInfo supported toolboxes, supported by custom Python scripts. The following steps were then followed:

1. Class boundary filtering: used for cleaning ragged edges between slope classes, based on 'expand and shrink' method on the slope raster data.
2. Neighboring cell filtering: replacing cells in the slope raster based on the majority of their contiguous neighboring cells. This filtering process was based on eight neighboring cells (a 3-by-3 window) using a 'majority' replacement threshold (three out of four or five out of eight connected cells must have the same value before replacement occurs), and was applied sequentially 50 times.
3. Raster-to-vector conversion: the filtered slope raster was converted into polygons without polygon generalization.
4. Sliver polygon filtering: eliminating "small" polygons by merging them with the neighboring polygons with the largest area or the longest shared border. For our purposes, areas smaller than 12 hectares (0.12 square kilometers, equivalent to a square 345 m on a side) were flagged as 'sliver polygons' and so eliminated. This threshold was chosen on the basis of positional accuracy of the data (±125 m), the likely scale of the final map products (presumed 1:250,000), and judgment about the overall appearance and usability of alternative results using different thresholds.

Once the final set of smoothed slope polygons were defined, they were overlaid with the geology polygons to define twenty-one unique "topographic–lithologic" units (i.e., 3 slope classes and 7 geology units) plus open water.

Following this exclusively GIS-based characterization, Task 3 of the Joint Effort (Booth et al. 2011a) comprised a comprehensive field-based and largely qualitative assessment of the varied landscapes and receiving waters across the entire Central Coast Region. It emphasized (relatively) undisturbed, "intact" watersheds to best characterize the natural hydrologic and sediment processes that are most responsible for the movement of water and sediment from hillslopes to receiving waters. Watershed processes in different parts of the landscape were inferred from scientific understanding, with an initial framework that was either confirmed or modified wherever observations so indicated. Receiving waters, primarily streams, were evaluated less comprehensively in the field but their characterization was supplemented by extensive biological data and some stream gage data, which were incorporated into an overall picture of their condition as well.

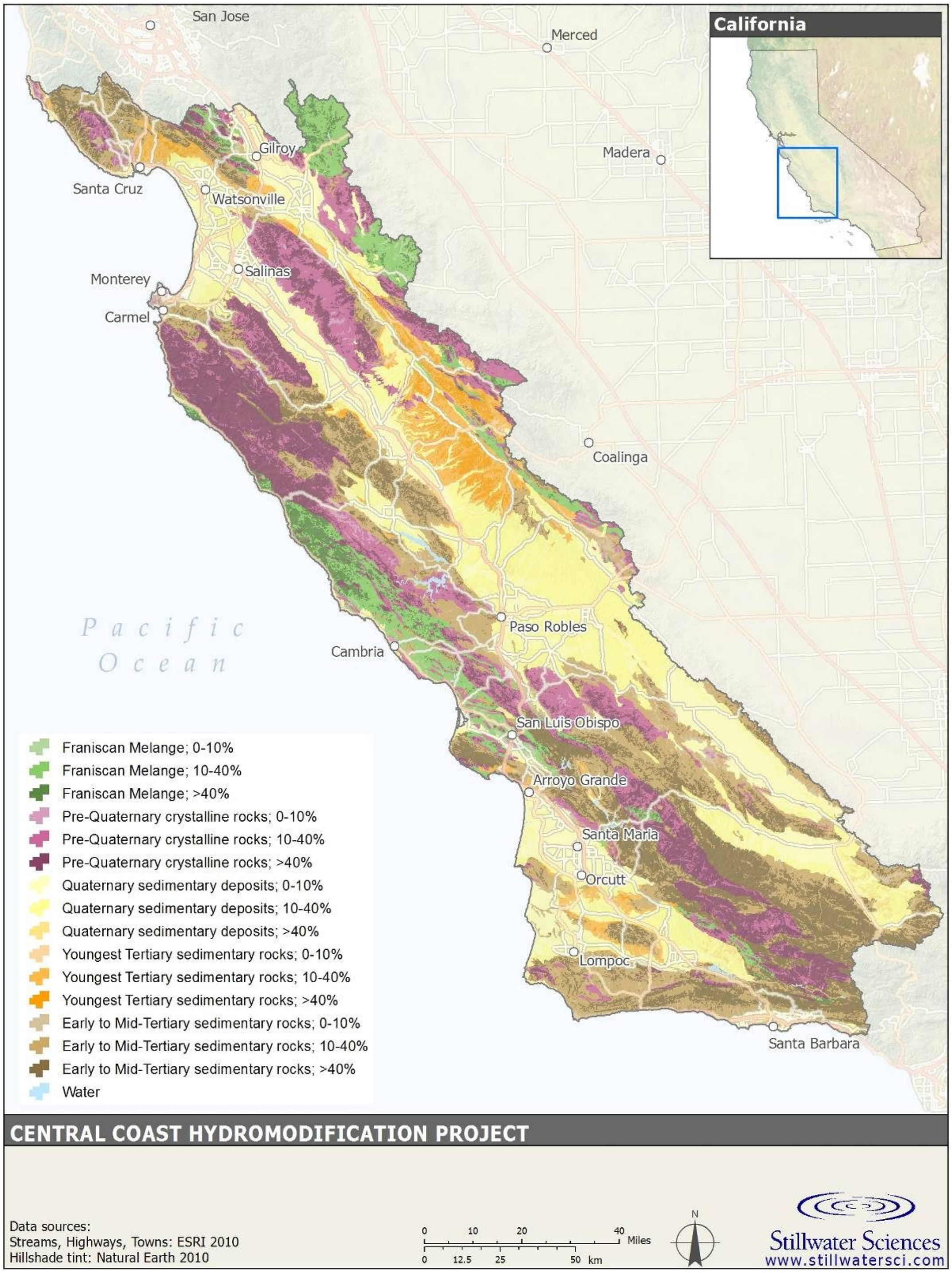
As a result of the field observations, the original seven lithologic groups were redefined. Those mapped separately as Tertiary volcanic rocks, granitic rocks, and Mesozoic and Paleozoic metamorphic rocks were combined into a single category, because no systematic differences in watershed processes could be observed in the field; and one group (Tertiary sedimentary rocks) was subdivided into "Late" and "Early-Mid" Tertiary sedimentary rocks, because these two categories were distinguishable on the map of Jennings et al. (1997) and displayed markedly different field attributes. Thus, fifteen final landscape categories (plus "open water") were defined (Table 3 and Figure 1):

1. Franciscan mélange, a heterogeneous collection of resistant rocks within a matrix of weaker material that has filled the spaces between the resistant clasts (exposed over 8% of the land area of the Region).
2. Pre–Quaternary crystalline rocks, a group of geologically old and generally quite resistant rocks (23% of the Region).
3. Early to Mid–Tertiary sedimentary rocks, primarily resistant sandstones but also some weaker shales and siltstones (30% of the Region).
4. Late Tertiary sediments, weakly cemented sedimentary rocks of relatively young geologic age (6% of the Region).
5. Quaternary sedimentary deposits, weakly cemented or entirely uncemented silt, sand, and gravel that has been deposited in geologically recent time (i.e., the last 2.5 million years; 33% of the Region).

These five lithologic categories were each subdivided by hillslope gradient, which can be considered "flat" (i.e., <10% gradient), "steep" (>40% gradient), and in between (10–40% gradient). Thus, 15 "Physical Landscape Zones" (PLZ's) can be identified across the Central Coast Region, each with a set of properties that are well-correlated with their key watershed processes in an undisturbed landscape. Other factors of potential relevance, particularly the spatial variability of precipitation and the influence of different vegetation types in undisturbed watersheds (e.g., trees vs. shrubs vs. grasslands) were explored but were found to have at most a secondary influence on the dominance of particular watershed processes across the Region as a whole.

Table 2-3. PLZ areas as a proportion of the Central Coast Region.

Symbol	Physical Landscape Zone (based on lithology [geologic material] and hillslope gradient [% slope])	% of total area	
F1	Franciscan mélange; 0–10%	0.5%	8%
F2	Franciscan mélange; 10–40%	5%	
F3	Franciscan mélange; >40%	2%	
pQ1	Pre–Quaternary crystalline rocks; 0–10%	1%	23%
pQ2	Pre–Quaternary crystalline rocks; 10–40%	11%	
pQ3	Pre–Quaternary crystalline rocks; >40%	11%	
ET1	Early to Mid–Tertiary sedimentary; 0–10%	2%	30%
ET2	Early to Mid–Tertiary sedimentary; 10–40%	16%	
ET3	Early to Mid–Tertiary sedimentary; >40%	12%	
LT1	Late Tertiary sediments; 0–10%	1%	6%
LT2	Late Tertiary sediments; 10–40%	4%	
LT3	Late Tertiary sediments; >40%	2%	
Q1	Quaternary sedimentary deposits; 0–10%	18%	33%
Q2	Quaternary sedimentary deposits; 10–40%	14%	
Q3	Quaternary sedimentary deposits; >40%	1%	
	Open water	0.4%	0.4%



Data sources:
Streams, Highways, Towns: ESRI 2010
Hillshade tint: Natural Earth 2010

Figure 1. Final map of the Physical Landscape Zones.

2.2 Associating key watershed processes with each PLZ

2.2.1 Non-urbanized landscapes

Observations of hillslope conditions and processes, emphasizing non-urbanized and (relatively) undisturbed landscape settings, were conducted across the entire geographic extent of the Central Coast Region, with two (and sometimes more) professional geomorphologists accessing every part of the Region accessible by automobile (and some more remote but unique areas by foot). Over a thousand georeferenced photographs, accompanied by field notes, confirmed an overall consistency of the conditions and processes expressed by the intact watersheds throughout the Region with prior assessments of watershed processes. Only a few differences, systematic and readily recognized, distinguished different suites of processes in different PLZ's. Broadly, all but the steepest mountain ridges and the driest hillslopes are well-vegetated, whether by chaparral, coastal scrub, grasslands, oak woodlands, or evergreen forest; most hillslopes are relatively ungullied, expressing a predominance of the hydrologic processes of infiltration and subsurface movement of water after precipitation first falls on the ground surface.

These hydrologic processes, in turn, largely control the movement of sediment and plant detrital material. Sediment movement is driven by gravity and so is negligible on flat ground regardless of the geologic material. On slopes, surface erosion (rilling, gullying) occurs only in the presence of surface flow, and its expression is rare (in undisturbed areas) except in a few very weak rock types. Landslides (and other forms of mass wasting) are more dependent on rock strength, for which the Region has excellent examples at both the weak (Franciscan mélange) and strong (crystalline rocks) ends of the spectrum. Our observations and inferences of watershed processes and the Physical Landscape Zones in which they occur, from Task 3 of the Joint Effort (Booth et al. 2011a), are summarized in Table 4.

Several of the listed processes are particularly relevant to the watershed changes imposed by urbanization, and they are described in greater detail here:

- **<u>Overland flow</u>:** This process can be thought of as the inverse of infiltration; precipitation reaching the ground surface that does not immediately soak in must run over the land surface (thus, "overland" flow). It reflects the relative rates of rainfall intensity and the soil's infiltration capacity: wherever and whenever the rainfall intensity exceeds the soil's infiltration capacity, some overland flow will occur. Most uncompacted, vegetated soils have infiltration capacities of one to several inches per hour at the ground surface, which exceeds the rainfall intensity of even unusually intense storms of the Central Coast and so confirms the field observations of little to no overland flow (Booth et al. 2011a). In contrast, pavement and hard surfaces reduce the effective infiltration capacity of the ground surface to zero, ensuring overland flow regardless of the meteorological attributes of a storm, together with a much faster rate of runoff relative to vegetated surfaces.

- **<u>Infiltration and groundwater recharge</u>:** These closely linked hydrologic processes are dominant across most intact landscapes of the Central Coast Region. Their widespread occurrence is expressed by the common absence of surface-water channels on even steep (undisturbed) hillslopes. Thus, on virtually any geologic material on all but the steepest slopes (or bare rock), infiltration of rainfall into the soil is inferred to be widespread, if not ubiquitous. With urbanization, changes to the process of infiltration are also quite simple to characterize: some (typically large) fraction of that once-infiltrating water is now converted to overland flow.

- **<u>Interflow</u>:** Interflow takes place following storm events as shallow subsurface flow (usually within 3 to 6 feet of the surface) occurring in a more permeable soil layer above a less permeable substrate. In the storm response of a stream, interflow provides a transition between the rapid response from surface runoff and much slower stream discharge from deeper groundwater. In some geologic settings, the distinction between "interflow" and "deep groundwater" is artificial and largely meaningless; in others, however, there is a strong physical discrimination between "shallow" and "deep" groundwater movement. Development reduces infiltration and thus interflow as discussed previously, as well as reducing the footprint of the area supporting interflow volume.

- **Rilling and gullying:** These hillslope processes are the geomorphological expression of the hydrologic process of overland flow, and so the pattern of these two sets of processes are similar. However, they can diverge in several, fairly common settings. First, overland flow across flat surfaces will generate little or no erosion simply because the energy of the water is too low to transport sediment. Second, areas of likely overland flow where the substrate is strong (e.g., bare rock outcrops) will not produce corresponding gullying; conversely, a weak substrate may show evidence of significant surface erosion with only modest levels of overland flow (as long as slopes are sufficiently steep).

Table 2-4. Tabular summary of the observed (and observationally inferred) watershed processes in undisturbed settings, as discriminated by Physical Landscape Zones. The assigned ratings (for "Low," "Medium," and "High") are relative and apply only to a particular column; so, for example, a "H" (high) rate of creep processes will not necessarily produce as much sediment as a high rating for rilling and gullying (indeed, the opposite will be true); but an "H" for creep will produce more sediment than an "L" for creep in a different zone. Compare to Table 5, which evaluates the effects of disturbance on these processes.

Slope class	Geologic unit	WATERSHED PROCESS						
		Overland flow (incl. sheetwash)	**Infiltration**	**Interflow**	**Groundwater recharge**	**Creep**	**Rilling and gullying**	**Landsliding**
0–10%	Franciscan mélange	L	L	L	L	L	L	L
	Pre-Quaternary crystalline	L	L	L	L	L	L	L
	Early to Mid-Tertiary sed.	L	H	M	H	L	L	L
	Late Tertiary sediments	L	H	M	H	L	L	L
	Quaternary deposits	L	H	M	H	L	L	L
10–40%	Franciscan mélange	L	L	L	L	M	M	M
	Pre-Quaternary crystalline	M	L	L	L	L	L	L
	Early to Mid-Tertiary sed.	L	M	M	M	L	L	L
	Late Tertiary sediments	L	H	M	H	M	M	L
	Quaternary deposits	L	H	M	H	M	H	M
>40%	Franciscan mélange	M	L	L	L	H	M	H
	Pre-Quaternary crystalline	M	L	L	L	L	M	L
	Early to Mid-Tertiary sed.	M	M	M	M	L	M	L
	Late Tertiary sediments	M	M	M	M	M	H	H
	Quaternary deposits	M	M	M	M	M	H	H

In addition to these watershed processes, whose activity and influence were observed or inferred from observation, four other processes long-recognized from prior watershed studies were included in the subsequent application of this analysis to the determination of effective stormwater-management strategies:

- **Evapotranspiration:** In undisturbed humid-region watersheds, the process of returning water to the atmosphere by direct evaporation from soil and vegetation surfaces, and by the active transpiration by plants, can account for nearly one-half of the total annual water balance; in more arid regions, this fraction can be even higher. However, there is little reason to anticipate that this fraction will materially change in different PLZ's, and so this process is presumed to have a "M" rating for all areas.

- **Delivery of sediment to receiving waters:** Sediment delivery into the channel network is a critical process for the maintenance of various habitat features in fluvial systems (although *excessive* sediment loading from watershed disturbance can also be a significant source of degradation). Quantifying this rate can be difficult and discriminating the relative contribution from different geologic materials even more so; however, the overriding determinism of hillslope gradient is widely documented. Thus, relative rates of this process are presumed to scale directly (and only) with slope class. Thus, "L" = all PLZ's with slope 0–10%, "M" = 10–40%, and "H" = >40%.

- **Delivery of organics to receiving waters:** Unlike sediment, organic delivery is most critically dependent on the presence, width, and composition of the vegetative riparian zone. This has no systematic relationship with PLZ, and so (as with evapotranspiration) this is presumed to have a "M" rating for all areas.

- **Chemical and biological transformations:** This encompasses the suite of watershed processes that alter the chemical composition of water as it passes through the soil column on its path to (and after entry into) a receiving water. The conversion of subsurface flow to overland flow in a developed landscape eliminates much of the opportunity for such transformations, and this loss is commonly expressed through degraded water quality. The dependency of these processes on watershed conditions is almost unimaginably complex in detail, but in general a greater residence time in the soil should be correlated with greater activity for this group of processes. Since residence time is inversely proportional to the rate of movement, the relative importance of this process is anticipated to be inversely proportional to slope; thus, "H" = all PLZ's with slope 0–10%, "M" = 10–40%, and "L" = >40%.

2.2.2 The effects of urbanization

For the subsequent application of this table to the impacts of urban development and the application of stormwater management strategies, additional refinements were added. Most importantly, the anticipated changes in watershed processes as a result of urbanization were assigned. They were inferred primarily on the basis of more than half a century of study of urban watersheds (e.g., Leopold 1968, Booth 1991, Paul and Meyer 2001, Walsh et al. 2005), which has developed what we have called the "Classical Model" of watersheds and urbanization, and which we embrace as a general principal with widespread applicability to the Central Coast Region. Specific elements of the Classical Model include the following:

- Intact watersheds emphasize subsurface flow paths for the delivery of precipitation from hillslopes to stream channels; disturbed (and, in particular, urbanized watersheds) create large areas of overland flow. This is the **fundamental** change that accompanies urbanization, although it is commonly accompanied by other changes, both *abiotic* (e.g., bank armoring) and *biotic* (e.g., riparian and upland vegetation clearing and replacement).
- Watershed urbanization simplifies watershed and receiving-water structure and processes, reducing or eliminating altogether heterogeneity and diversity (both physical and biological).

- Urban streams share many common attributes with each other, best summarized as “flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced biotic richness, with increased dominance of tolerant species” (Walsh et al. 2005). Instream conditions tend to reflect the combined influence(s) of both the whole contributing watershed and the local/riparian zone.

The Classical Model can be usefully framed in “watershed process” terms:

- Urbanization results in less infiltration and more overland flow;
- Urbanization results in faster delivery of surface runoff from the upland to the receiving water
- Urbanization results in less upland sediment delivery from stabilized hillslopes;
- Urbanization results in reduced biotic activity and biological processes, such as delivery of coarse organic debris to streams or biological uptake/breakdown of nutrients or pollutants in soil or waterbodies; and
- Urbanization results in greater in-channel erosion, independent of any (additional) direct channel modification.

For most processes, urbanization decreases the magnitude of the process, but there are two exceptions. For “overland flow,” the change imposed by urbanization is an increase, rather than a decrease, in this process. Similarly, impairment to “delivery of sediment” is presumed to result in less sediment input to the receiving water. This is counterintuitive to typical concerns of “construction erosion control,” where the goal is to minimize sediment releases. In the post-construction period, however, maintenance of sediment delivery is essential to the health of certain receiving-water types (as is organic delivery), and it is this (long-term) process that is being addressed here.

Other changes to the initial representation of PLZ’s and watershed processes (Table 4) include the following:

- The processes of overland flow and rilling & gullying were combined, since the latter is simply the most visible expression of the former and because the latter (erosive) process requires the former (hydrologic) one. The inverse, however, is NOT true—overland flow on a flat slope will not result in rills, and so their combination is not strictly accurate. However, management practices to minimize creation of overland flow are not anticipated to materially differ on flat slopes because of an absence of rilling—and so the simplification here is judged reasonable and non-consequential to management. Note that “rilling and gullying” (a hillslope process) is not the same as “stream-channel erosion” (a reflection of increase release of rapid runoff to a stream). The latter is symptomatic of a change in watershed process(es) but is not considered an altered process itself.
- Infiltration and groundwater recharge were combined into the same category, because the assessment of their relative importance and susceptibility to disturbance differs only for two uncommon PLZ’s (pQ0 and pQ10) (and even there only modestly), and they are otherwise so closely linked that management strategies identified for this process set are not anticipated to be affected by their combination in either of the two affected PLZ’s.
- Creep and landsliding are not included, because they are generally not directly influenced by stormwater-management strategies.

Applying these considerations leads to the summary representation of PLZ’s, watershed processes, and the effects of urban disturbance shown in Table 5.

Table 5. Final table showing the association of watershed processes with PLZ's, based on Booth et al. (2011b) and subsequent review of data. The table highlighting the qualitative magnitude of anticipated change for each process as a result of urbanization. Red-shaded cells indicate the greatest anticipated change (e.g., a "Low" importance for overland flow in many PLZ's is anticipated to become "High" in an urban watershed).

PLZ's	**Watershed Processes**						
	Overland flow, rilling & gullying (OF)	**Infiltration and groundwater recharge (GW)**	**Interflow (i.e., shallow groundwater mvmt. (IF)**	**Evapotranspiration (ET)**	**Delivery of sediment to waterbody (DS)**	**Delivery of organic matter to waterbody (DO)**	**Chemical/biological transformations (CBT)**
Franciscan mélange 0-10%	L	L	L	M	L	M	H
Pre-Quaternary crystalline 0-10%	L	L	L	M	L	M	H
Early to Mid-Tertiary sed. 0-10%	L	H	M	M	L	M	H
Late Tertiary sediments 0-10%	L	H	M	M	L	M	H
Quaternary deposits 0-10%	L	H	M	M	L	M	H
Franciscan mélange 10-40%	M	L	L	M	M	M	M
Pre-Quaternary crystalline 10-40%	M	L	L	M	M	M	M
Early to Mid-Tertiary sed. 10-40%	L	M	M	M	M	M	M
Late Tertiary sediments 10-40%	L	H	M	M	M	M	M
Quaternary deposits 10-40%	L	H	M	M	M	M	M
Franciscan mélange >40%	M	L	L	M	H	M	L
Pre-Quaternary crystalline >40%	M	L	L	M	H	M	L
Early to Mid-Tertiary sed. >40%	M	M	M	M	H	M	L
Late Tertiary sediments >40%	M	M	M	M	H	M	L
Quaternary deposits >40%	M	M	M	M	H	M	L

2.3 Relating landscape disturbance, PLZ's, watershed processes, and receiving waters

Two broad categories of watersheds, which lie along a continuum of human disturbance, were examined. The first we term "intact," describing landscapes that maintain a predominance of native vegetation with limited grazing or row agriculture, scattered (or absent altogether) rural residences, and minimal intrusion of roads into the stream corridor. Observations in these watersheds provided the basis for the relationships between watershed processes and PLZ's described in the previous section.

The second category of watershed, "disturbed," has one or (more commonly) more land-use impacts occurring over a substantial fraction of its watershed area. For purposes of the Joint Effort we have not endeavored to quantify any thresholds between these two broad categories, although such criteria are readily available in the literature (as a local example, see the quantitative definition of "reference sites" in

Ode et al. 2005). Instead, we recognize that the Region's urban receiving waters (as commonly recognized) will all express the consequences of watershed disturbance, albeit each in their own way(s); and that to find good representatives of truly "intact" watersheds we need to look into some of the most remote parts of the Region.

Receiving waters of the Central Coast are diverse, comprising streams, rivers, lakes, wetlands, marine nearshore, and groundwater aquifers. The analyses for the Joint Effort has emphasized streams and stream channels (as commonly defined, namely freshwater channels that flow at least episodically), because of their widespread distribution, readily expressed responses to disturbance, and availability of preexisting data. We recognize that the findings relating the condition of streams to watershed processes, and to their response to watershed disturbance, are relevant but not entirely transferrable to other types of receiving waters. We also recognize that the division between certain categories is gradational and somewhat arbitrary. In particular; for purposes of the subsequent analyses a "stream" is presumed to be highly sensitive to changes in hydrologic regime as a consequence of upstream urbanization, whereas a "river" is largely unaffected.

2.3.1 Assessing the condition of receiving waters

The purpose of assessing the condition of receiving waters was not to assess their health *per se*, but rather to confirm that disturbance to key watershed processes is indeed significant, and detrimental, to the condition of those receiving waters. To guide this assessment, we used reports from the scientific literature, regional assessments and empirical observation. In any region, and especially in one as varied as varied as the Central Coast, no single metric can appropriately be used to characterize receiving water conditions. There is not even a single discipline-specific perspective over what should reflect the "quality" or the "health" (or, conversely, the magnitude of degradation) of a waterbody. The Clean Water Act calls out "physical, chemical, and biological integrity," suggesting at minimum that no single metric, and no single discipline, should be used to make such an assessment.

In streams, the scientific literature for more than a decade has shown that biological metrics are typically the most sensitive to the earliest impacts of urbanization (Booth and Jackson 1997, Karr and Yoder 2004, King et al. 2011), with multimetric indices based on benthic macroinvertebrates being the most common quantification of instream biological health. Hydrologic changes in urbanizing streams have been recognized for even longer (e.g., Hollis, 1975), but there is less agreement on the appropriate hydrologic metric(s) to discern the "signal" of urbanization in the contributing watershed. In other types of receiving waters, neither biological metrics nor (particularly) hydrologic metrics are nearly as useful because of the fundamental nature of these waterbodies (e.g., gage data are irrelevant for a lake or the marine nearshore).

Based on inspection of the receiving-water data acquired from local municipalities during Task 1 and the overall goals of the Joint Effort, the framework of "*selected* receiving waters" (and their associated sub-watersheds) was embraced with the intention that they can provide broad representation of conditions across the Region, and that they could demonstrate whether impacts to key watershed processes result in receiving-water degradation. An initial list of sites was identified based on available hydrologic and (or) biological data for the analysis of receiving water trends. The distribution and patterns of sites and receiving waters were evaluated to further refine the selection- The geographic distribution of sites north-to-south and dry-to-wet was reviewed on a map, with any gaps filled in as possible. Finally, we reviewed the data provided by the Regional Board and local jurisdictions to determine if any other receiving water(s) held the promise of being so well characterized by available data that their inclusion in this review would likely provide additional insight to the goals of the Joint Effort.

We compiled available chemical data on selected lakes, marine nearshore areas, and groundwater bodies of the region because these other types of receiving waters are of equal concern to streams under the protective goals of the Joint Effort. To date, however, these data are much more limited than those pertaining to streams, and they do not characterize the conditions of these other receiving waters to the same degree of quantification.

2.3.1.1 Hydrologic metrics

A total of 183 USGS gaging stations in the Central Coast Region were initially evaluated to begin an investigation of hydrologic measures of receiving-water condition, specifically limited to streams. The entire period of record was evaluated at each gage, with the objective of selecting stations with relatively low impairment and long temporal records, because stations of this nature will have a greater chance of capturing hydrologic changes for flow duration trend analysis.

A statistical test was performed to determine whether rainfall over two periods (1981–1990 and 2001–2010) could be considered sufficiently "similar" to exclude climatological variations from any changes that were subsequently recognized. Similarly, the variability and the average of annual runoff values were summarized from the online data for each of the USGS gages selected. Annual runoff means in the two periods (1981–1990 and 2001–2010) were also compared to each other and to rainfall totals from the two periods to determine whether meaningful relationships between watershed conditions (particularly those associated with hydromodification) and streamflow could be drawn to support future analyses under the Joint Effort.

Of the entire population of 183 USGS gage stations, 36 had ample coverage of good-quality data for the period of interest (1951–2010). Average annual rainfall totals in the watershed upstream of each gage (based on the PRISM dataset) were evaluated for the entire period of record and the two decadal periods coinciding with the selected land-use profiles (1981–1990 and 2001–2010). Because the period of time for the decadal comparison is relatively short (10 years, versus 61 years for the entire period of interest), the 95% confidence intervals are relatively wide. A statistical test suggests that no individual station has a significantly different annual average rainfall totals between the two decadal periods, because the confidence intervals overlap at every station.

For streamflow, the data across the two decadal periods also showed too much variability to draw meaningful conclusions. There was not a consistent relationship between streamflow and observed precipitation, for various possible reasons. For example, there may be other unfactored conditions or activities upstream of each gage, such as inter-basin transfers, reservoirs, or other hydraulic modifications. The results of this analysis were therefore inconclusive.

2.3.1.2 Benthic macroinvertebrate data

Our objective in this element of the Joint Effort was not to create a comprehensive catalog of biological data across the Region, but instead to seek patterns in the existing data that could inform the broader goals of the project. We therefore narrowed our focus to a homogenous data set, namely BMI analyses that could be converted into a single, recognized "score" of biological quality. For this application the Southern California Index of Biotic Integrity ("SCIBI"; Ode et al. 2005) was judged to be the best such indicator, insofar as the Central Coast Region was almost entirely covered by the set of streams used to develop the index (Ode et al's Figure 1). We created a spreadsheet tool to convert raw BMI data from the various sources across the Central Coast into a SCIBI score where not already provided by the original study authors.

The most comprehensive collection of biological data in the Central Coast Region is compiled and maintained by staff of the Regional Board. It includes data collected as part of the state's Surface Water

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Ambient Monitoring Program (SWAMP) and other data developed by the Regional Board (in total more than 600 unique sites). Because of its geographic extent, we used other criteria (availability of flow data, geographic "holes" in the coverage) to identify sites from this compendium for use in the characterization of receiving-water condition. Detailed, high-quality benthic macroinvertebrate data are also available from the City of Santa Barbara and compiled into annual reports (most recently Ecology Consultants 2010, 2011; available at http://www.sbprojectcleanwater.org/waterquality.aspx?id=66#bioassess; accessed August 7, 2011). We took advantage of several paired sites with multiple years' biological data showing consistent trends, strategic placement up- and downstream of urban development, fully interpreted results, and (in several cases) correspondence with flow data.

Based on data availability and watershed size, a preliminary set of streams were selected, based first on the size of the drainage area contributing to a USGS gage site with high-quality, long term records. Additional sites were added to capture otherwise underrepresented watershed types found in the Region, namely those typified by flat groundwater basins, and the dry eastern side of the coastal and inland mountains. Abundant biological data also led us to include three other channel systems (Aptos, Chorro, and Santa Rosa) in the final list. In total, the receiving waters evaluated for this Task of the Joint Effort were as follows (Table 6).

Table 6. Final set of selected receiving-water sites.

Stream name	Drainage area (mi^2)	USGS gaging station*
Maria Ygnacio Ck (Goleta)	6	11119940
San Jose Ck (Goleta)	6	11120500
Mission Creek	8	11119750
Aptos Creek	25	(11159690, 11159700)
Carpinteria Creek	13	11119500
Atascadero Creek	19	11120000
Orcutt Creek	19	(11141050)
Lopez Ck (Arroyo Grande)	21	11141280
San Simeon Creek	26	(11142300)
Corralitos Creek	28	11159200
Alamo Pintado Ck (Solvang)	29	11128250
Zaca Creek (Buellton)	33	11129800
Gabilan Creek (Salinas)	37	11152600
Soquel Creek	40	11160000
Chorro Creek	45	-
Big Sur River	46	11143000
Salsipuedes Creek	47	11132500
Santa Rosa Creek	47	-
Santa Cruz Ck (Santa Ynez)	74	11124500
San Luis Obispo Creek	84	-
Upper Cuyama River	90	(11136500, 11136600)
San Lorenzo River (Santa Cruz)	106	11160500
Nacimiento River	162	11148900
Carmel River	193	11143200
San Antonio River	217	11149900
San Lorenzo Creek (King City)	233	11151300
Arroyo Seco	244	11152000

* USGS gage numbers in parentheses were not part of the hydrologic analysis by virtue of insufficient length and/or quality of record.

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The results of this inventory and metric calculation are presented in Figure 2. Overwhelmingly, these data show "typical" patterns of biological response to urbanization, namely high-quality conditions upstream of urban development that progressively degrade through and downstream of developed areas. This condition needs little exposition in this report, insofar as its recognition and characterization has been the subject of scientific literature for many decades (for some recent summaries, see Paul and Meyer 2001, or Center for Watershed Protection 2003); the pattern of downstream decline in biological quality through a progressively more urban watershed is clearly as ubiquitous here in this region as it is across the rest of the planet.

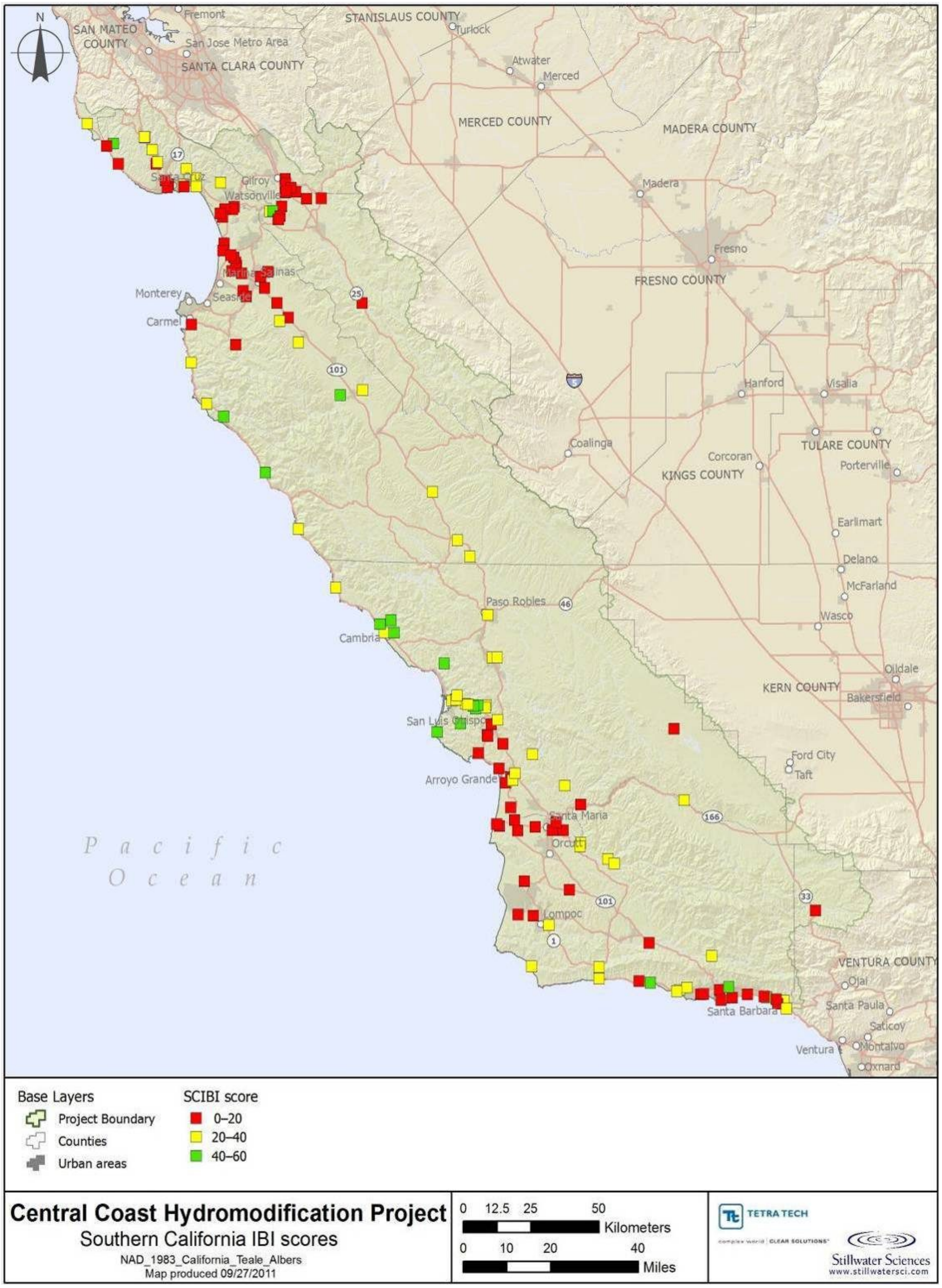

Figure 2-2. Calculated Southern California Index of Biotic Integrity (SCIBI; Ode et al. 2005) scores from BMI data in the Central Coast Region. 149 unique sampling locations are displayed here, of which most represent the average score from two to six annual sampling events. SCIBI scores can range from 0 to 100, but no site in the Central Coast region had a multi-year average greater than 60. In the lexicon of the SCIBI, 0-20 = “very poor”, 20-40 = “poor”, and 40-60 = “fair” (in addition, 60-80 = “good” and 80-100 = “very good”).

We also looked for atypical patterns in biological response. Two types of divergence from the Classical Model were identified in limited areas. The first such type is poor biological conditions in streams draining nonurban watersheds, which in part reflects the impacts of nonurban land disturbance (e.g., grazing or agriculture) and in part demonstrates that a reference-based biological scoring method (such as the SCIBI) is limited by the original population of reference sites—if the sampled location is simply too “different,” it will score poorly regardless of the underlying level of disturbance.

The second type of atypical response, namely “high” (or at least not declining) conditions in and below urban areas, is simply very, very rare—we have identified only two locales with even a suggestion of such uncharacteristic patterns within the entire Central Coast Region (Aptos Creek and Santa Rosa Creek, discussed in detail in Booth et al. 2011b). Regrettably, such a limited population suggests that, at best, we have not yet implemented successful strategies for restoration or mitigation of the effects of urbanization on downstream receiving waters.

2.3.1.3 Field investigations

During the five weeks’ field work for the observation and evaluation of landscape zones, disturbance, and watershed processes, we had ample opportunity to visit the full range of receiving waters present in the Central Coast Region (except groundwater; streams, rivers, wetlands, lakes, and marine nearshore areas were all included). Reflecting the focus of the other data sources, the visited sites were overwhelmingly streams. Observations were made of the general geomorphic character, specifically the substrate size and embeddedness, general channel morphology, and the presence or absence of bank erosion. Significant macrophyte (algae) growth was noted, and in many cases the presence or absence of benthic macroinvertebrates was noted, albeit not under any systematic sampling protocol. The goal was not to specify the “condition” of the stream (a single dry-weather observation at a single location along a channel can never achieve this) but rather to characterize the very general quality of the channel (particularly significant physical degradation, which is generally easy to recognize where present) and to complement any other available data of a more quantitative nature.

In summary, the condition of receiving waters were evaluated through a combination of field observations, data on receiving-water conditions previously collected and compiled by others, and reference to an extensive scientific literature that we termed the “Classical Model”—the general characterization of how urbanization affects watersheds, watershed processes, and receiving waters developed over the past 50 years of scientific study. The Classical Model provides a variety of predictions for how receiving waters will respond to disturbance, which were found to be largely supported by data from the Central Coast Region (and throughout the world), to wit:

- Flows are flashier, and with bigger peaks, in urbanized watersheds.
- Aquifer recharge from precipitation sources is decrease due in response to decreased infiltration.
- Physical stream habitat loses complexity in human-disturbed streams as a consequence of changes in runoff and sediment processes in the contributing watershed and/or loss of near-stream riparian vegetation.
- Water quality declines in receiving waters draining urban and/or agricultural watersheds with the introduction of nutrients, pesticides, and toxics not present in the natural environment.
- Receiving waters lose detrital material due to loss of upland and riparian vegetation.
- Instream biota diverge from reference conditions, in response to changes in biotic and abiotic processes in both the contributing watershed and the near-stream riparian zone.

This phase of the Joint Effort relied heavily on the predictions and expectations of the Classical Model, because the scope and timeline of the work did not admit to a systematic evaluation of this framework in the Region. Such an evaluation was also judged unnecessary, since the various elements of the Classical Model have already been explored and almost universally validated in literally hundreds of scientific studies over the past decades. These findings were no less supported by the observations and data analysis performed here as well.

2.3.2 The Linkage Analysis

In the terminology of the Joint Effort, the "Linkage Analysis" was the characterization of the relationships between disturbance, dominant watershed processes, and receiving-water conditions, following the conceptual framework of Figure 2..

IN AN UNDISTURBED ("INTACT") LANDSCAPE:

WMZ →
Watershed Processes →
Receiving Water Conditions

IN A DISTURBED (SPECIFICALLY, URBANIZED) LANDSCAPE:

WMZ →
Disturbance →
Disturbed Watershed Processes →
Disturbed Receiving Water Conditions

Figure 2.3: Conceptual framework of the Linkage Analysis, tracing the physical attributes of a Watershed Management Zone (WMZ) to the watershed processes that control the movement and storage of water, sediment, and organic matter; and finally to the resulting conditions of downstream (or, for aquifers, downgradient) receiving waters. Disturbance to those WMZ's can result in a new set of controlling watershed processes (red text), which in turn result in alterations to the conditions of receiving waters.

This framework implies two primary "linkages"—the first, the association of specific PLZ's with their associated key watershed processes; and the second, the relationship between those watershed processes and downstream receiving-water conditions. It also recognizes the importance of disturbance in those associations, which for the Joint Effort specifically focuses on areas and conditions affected by urbanization; and, subsequent to that understanding, the consequences for receiving-water conditions.

The dominant patterns, and the rare exceptions, of linkages were explored between PLZ's and key watershed processes, and between watershed processes and the resulting conditions in downstream (or downgradient) receiving waters. As described above, the first such association (between PLZ's and their key watershed processes) were evaluated observationally, using the presence or absence of surface-water channels and other signs of overland flow and surface erosion in a wide range of locales throughout the region. The second such association (between watershed processes and receiving-water condition) was evaluated largely by calculating IBI scores (using the protocol of the Southern California Index of Biotic Integrity; Ode et al. 2005) from the widely distributed benthic macroinvertebrate data set compiled by the Regional Board staff, and evaluating the spatial distribution of high and low values to specific PLZ's in the contributing watershed and to land-use disturbance, particularly urbanization (and, to a lesser extent, to grazing and agriculture).

Patterns expressed by the data from the Central Coast confirmed the key tenets of the Classical Model almost uniformly. Although the focus of this analysis was on finding potentially instructive exceptions to the anticipated replacement of infiltration with overland flow from urbanization, and an associated degradation of biological health, no compelling or instructive examples of such exceptions were identified.

2.4 Defining and mapping of Watershed Management Zones

Although prior steps of the Joint Effort identified Physical Landscape Zones, the key watershed processes associated with each of them, and the likely response of those processes to watershed urbanization, this information alone is insufficient to guide stormwater management strategies. This is because the nature of the receiving water is essential to determining whether any particular watershed process, which may be impaired as a result of urbanization, is actually critical to the health of that receiving water.

Receiving waters of the Central Coast are diverse. The Task 4 report emphasized *streams* and *stream channels* (as commonly defined, namely freshwater channels that flow at least episodically), because of their widespread distribution, readily expressed responses to disturbance, and availability of preexisting data. However, the findings relating the condition of streams to watershed processes, and to their response to watershed disturbance, are relevant but not entirely transferrable to other types of receiving waters.

The consequences of urbanization on receiving waters other than streams typically must be inferred, either by studies from other parts of the country or by extrapolation from stream-specific data. The management of these systems will differ, and as a result the actual *management* of particular locations on the landscape will depend not only on the key watershed processes associated with the PLZ but also on the nature of the receiving water. Thus the Joint Effort recognizes “Watershed Management Zones” (WMZ’s), which reflect the combination of PLZ’s and the variety of receiving waters that they drain to, as the key indicators of appropriate stormwater management strategies.

Six types of surface-water features (streams, rivers, lakes, wetlands, marine nearshore, and groundwater aquifers) were identified across the urban and urbanizing areas of the Region. Primary data sources were the “NHD High” data layer from the US Geological Survey (which shows all streams represented on a 1:24,000 topographic map) and the US Fish and Wildlife Service’s national wetland inventory—those areas not draining to streams, rivers, lakes or wetlands identified by these two data layers were adjacent to the coastline and presumed to directly flow to the ocean. “Large” rivers were defined as those features on the NHD High coverage with a cumulative drainage area of at least 200 square miles; lakes had a minimum surface area of 2 acres. Areas with potential recharge to groundwater were presumed to overly the mapped groundwater basins of the Central Coast Region, using a GIS coverage of groundwater basins supplied by the Regional Board; these areas therefore have two such “receiving waters,” namely the groundwater aquifer and the surface-water feature previously identified. Catchment boundaries were taken from the NHD High coverage for simplicity, although they do not always correspond precisely to the drainage divide as expressed by the highest resolution Digital Elevation Model (10-m) available for the region (and typically do not reflect any surface-water diversions resulting from constructed drainage infrastructure at all). The watershed areas associated with each particular type of receiving water thus represent a set of polygons that are shown in Figures 4 and 5: the former cover the five “surface” receiving waters, whereas the latter shows the boundaries of the subsurface groundwater aquifer basins, as mapped by the Central Coast Regional Board.

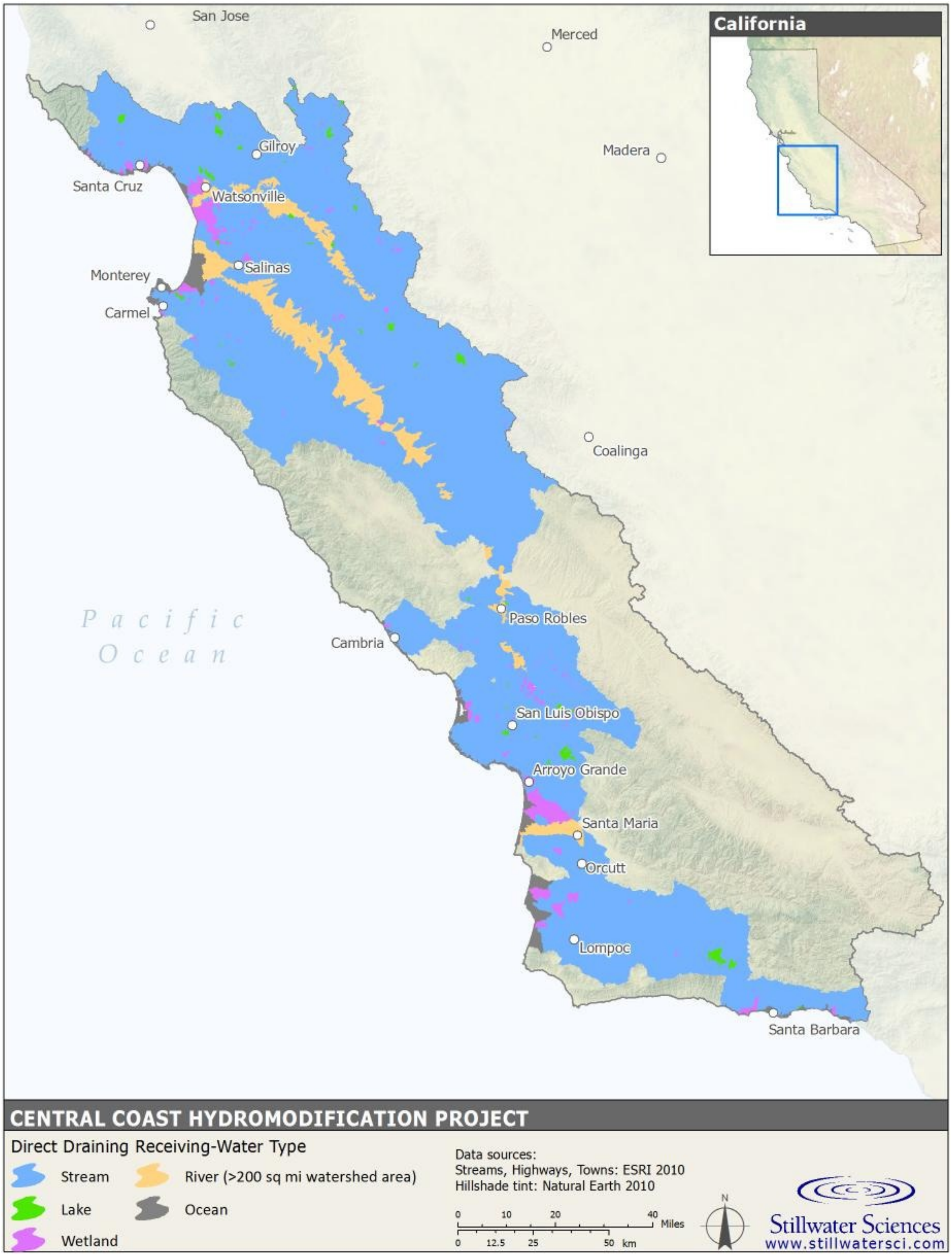

Figure 4. Map of the contributing watershed areas for the five "surface" receiving-water types across all urban areas in the Central Coast Region.

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Figure 5. Mapped groundwater basins of the Central Coast Region, showing the urban areas (outlined).

These two maps of contributing areas to receiving waters can be intersected with that of the PLZ's (Figure 1), resulting in the first-order definition of "Watershed Management Zones": namely, the amalgam of landscape areas having specific combinations of lithology and hillslope gradient (the PLZ's) with the type of receiving water to which they drain. Although the number of WMZ's is theoretically large (i.e., 15 PLZ's times 6 receiving-water types = 90 combinations), many of the unique WMZ's were found to have the same suite of stormwater management strategies associated with them, resulting in a much simpler set of final "management zones." Their definition constitutes the next step of the methodology.

2.5 WMZ's, key watershed processes, and management strategies

Identifying the management strategies that will be most protective of the watershed processes in any given Watershed Management Zone required two steps— (1) filtering the key watershed processes within the underlying PLZ to the (potentially) shorter list whose disturbance can impair the actual downstream receiving water, and (2) the association of effective management strategies with each of the uniquely defined WMZ's.

2.5.1 Watershed processes and receiving waters

Not every watershed process within a given PLZ influences the condition of every downstream receiving-water type equally. A simplified, binary division into those that are "significant" and "not significant" was based on the assessment of watershed processes and their influence of the variety of receiving waters, using either the observational results from Task 3 or the scientific foundation from the published literature (Table 2.7).

Table 2.7. Significance of key watershed processes on the different types of receiving waters (marked with an "X"). Note that the interrelated processes of overland flow, interflow, infiltration, and ET, which in combination determine surface-water flow rates and volumes, are collectively of concern only for streams and wetlands.

	Watershed Processes						
RECEIVING WATER TYPE	Overland flow, rilling & gullying (OF)	Infiltration and groundwater recharge (GW)	Interflow (shallow groundwater mvmt.) (IF)	Evapotranspiration (ET)	Delivery of sediment to streams (DS)	Delivery of organic matter to waterbody (DO)	Chemical/biological transformations (CBT)
Streams	X	X	X	X	X	X	X
Wetland	X	X	X	X		X	X
Lake						X	X
Large rivers					X		X
Marine nearshore					X		X
Groundwater basins		X					X

A few patterns are evident:

(1) Streams are commonly affected by alterations to any of the watershed processes—as noted in the Task 4 report, streams are well-recognized to respond to disturbances in their contributing watersheds, and they are particularly efficient at passing the effects of disturbance farther downstream. For these reasons, they are a useful surrogate for the full range of receiving waters, but their sensitivity to changes in the delivery of water, sediment, and organics is not fully shared by every other receiving-water type.

(2) Natural rates of sediment delivery are presumed important (and beneficial) for streams, large rivers, and the marine nearshore environment, because they sustain in-stream habitat and maintain beaches. Conversely, sediment delivery is not a beneficial process to maintain for lakes and wetlands (indeed, processes that indirectly increase rates of sediment delivery, particularly overland flow, are detrimental) and is irrelevant for groundwater recharge.

(3) All receiving waters are influenced by changes to CBT (i.e., all are water-quality sensitive).

(4) The interrelated processes of overland flow, interflow, infiltration, and ET, which in combination determine surface-water flow rates and volumes, are only of concern for streams and wetlands—lakes and large rivers are defined on the basis of their anticipated insensitivity to typical urban-induced changes in these discharge parameters (and thus management strategies do not target these processes for these receiving waters).

(5) Groundwater aquifers obviously depend on infiltration, but its management will have very different criteria (and perhaps different strategies as well) than for managing discharge to streams.

The commonality of watershed processes amongst the various PLZ’s, and the similarity of “process sensitivity” for large rivers and the marine nearshore (i.e., both are insensitive to flow rates and volumes, but are dependent on a natural rate of sediment delivery and chemical/biological transformations), permits condensation of the original 15 PLZ’s and 6 receiving-water types into a final list of 9 PLZ’s (for all three slope classes, Franciscan mélange was combined with pre-Quaternary crystalline rocks, and Late Tertiary sediments was combined with Quaternary deposits) and four surface receiving-water types. Consideration of groundwater recharge above recognized aquifers is added for those surface receiving-water types (lakes, large rivers, and the marine nearshore) that might otherwise be insensitive to changes in infiltration.

2.5.2 Defining the Watershed Management Zones

With these associations, a final tabulation of 54 unique combinations of PLZ’s and receiving-water types was made. The associated watershed processes that require protection in the face of urbanization, however, form an even fewer number of unique combinations, since more than one receiving water–PLZ combination can share the same group of potentially impaired processes. The processes identified for each Watershed Management Zones (WMZ) are taken directly from the evaluation of importance and magnitude of urban-induced change summarized in Table 5 for their associated PLZ; its relevance to the receiving water is summarized in Table 7.Table 2.8 displays the final compilation of these factors, which results in the definition of 10 unique Watershed Management Zones. These are mapped in Figure 2.6.

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Table 8. Watershed Management Zones associated with each unique PLZ–receiving water combination. Same-colored cells are anticipated to require the same set of stormwater management strategies, and so they are placed in the same WMZ. Asterisks indicate those WMZ's for which management strategies will differ given the presence (*) or absence of an underlying groundwater basin. For the others, strategies will be the same regardless.

	DIRECT RECEIVING WATER					
PHYSICAL LANDSCAPE ZONE	**Stream**	**Wetland**	**Lake**	**Lake, w/GW basin**	**Large rivers & marine nearshore**	**Rivers & marine, w/GW basin**
Franciscan mélange 0-10%	3	3	4	4	4	4
Franciscan mélange 10-40%	9	9	10	10	10	10
Franciscan mélange >40%	6	9	10	10	7	7
Pre-Quaternary crystalline 0-10%	3	3	4	4	4	4
Pre-Quaternary crystalline 10-40%	9	9	10	10	10	10
Pre-Quaternary crystalline >40%	6	9	10	10	7	7
Quaternary deposits 0-10%	1	1	4	4*	4	4*
Quaternary deposits 10-40%	1	1	4	4*	4	4*
Quaternary deposits >40%	5	8	10	10*	7	7*
Late Tertiary sediments 0-10%	1	1	4	4*	4	4*
Late Tertiary sediments 10-40%	1	1	4	4*	4	4*
Late Tertiary sediments >40%	5	8	10	10*	7	7*
Early to Mid-Tertiary sed. 0-10%	1	1	4	4*	4	4*
Early to Mid-Tertiary sed. 10-40%	2	2	10	10*	10	10*
Early to Mid-Tertiary sed. >40%	5	8	10	10*	7	7*

KEY:

1. OF, GW /IF, ET	**1**
2. OF / GW, IF, ET	**2**
3. CBT / OF, ET	**3**
4. CBT (*)/	**4**
5. DS / GW, IF, ET	**5**
6. DS / OF, ET	**6**
7. DS / (*)	**7**
8. / GW, IF, ET	**8**
9. / OF, ET	**9**
10. / (*)	**10**

Abbreviations:

OF = apply strategies to protect OVERLAND FLOW (avoidance)
GW = apply strategies to protect GROUNDWATER RECHARGE
IF = apply strategies to protect INTERFLOW
ET = apply strategies to protect EVAPOTRANSPIRATION
CBT = apply strategies to protect CHEMICAL AND BIOLOGICAL TRANSFORMATIONS
DS = apply strategies to protect DELIVERY OF SEDIMENT
DO = apply strategies to protect DELIVERY OF ORGANICS
(*) = apply strategies to protect GROUNDWATER RECHARGE, but only where underlain by mapped groundwater basin

- Processes listed before the "/" = key watershed processes; of primary concern for protection; should be subject to most stringent numerical criteria (red cells of Table 5).
- Processes listed after the "/" = watershed processes of less critical importance; could be subject to less stringent numerical criteria (yellow cells of Table 5).

Three of the WMZ's (4, 7, and 10) are further subdivided by the presence/absence of a mapped groundwater basin, because these WMZ's do not require protection of the process of groundwater recharge *unless* a groundwater basin is explicitly recognized to underlie them.

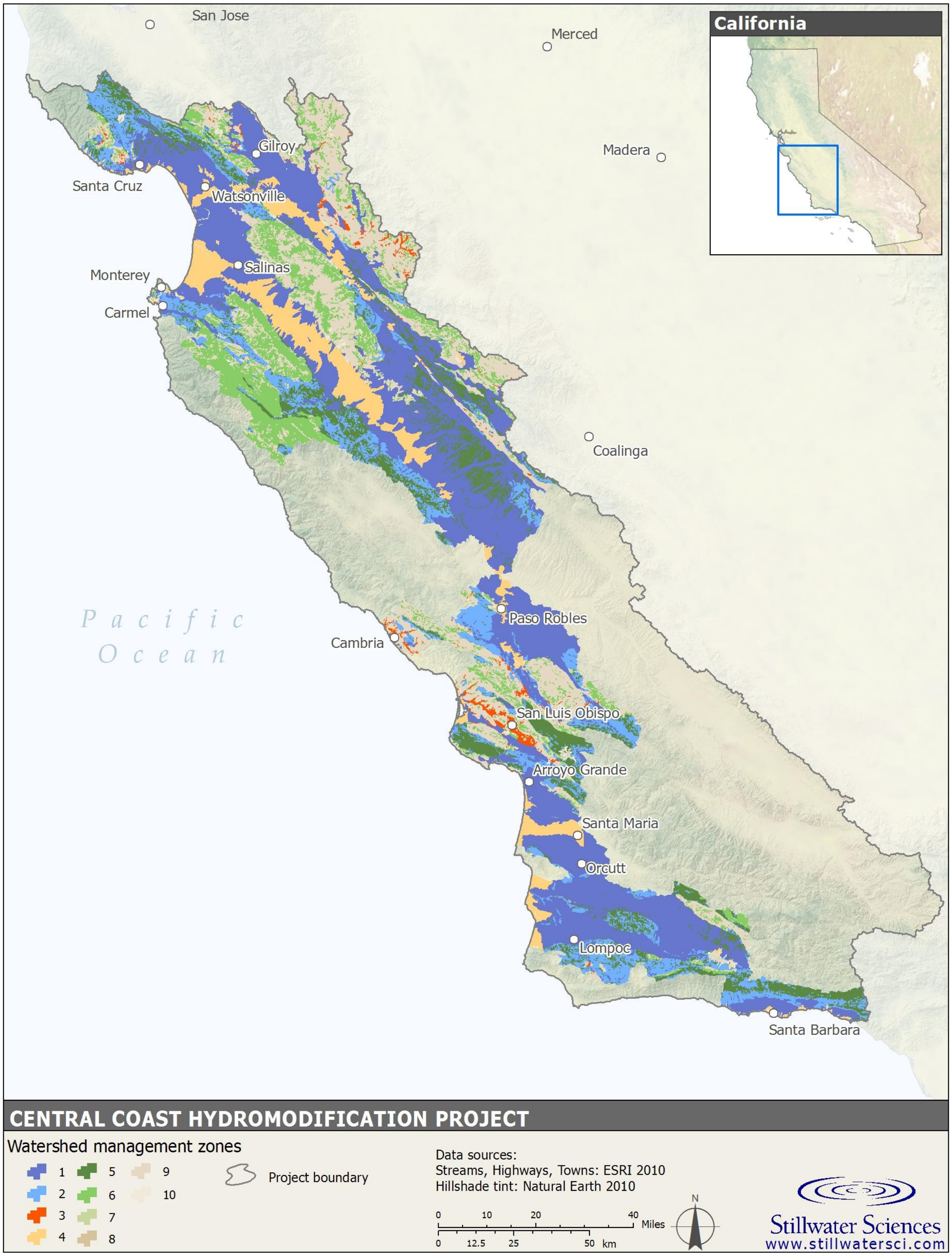

Figure 2.6. The Watershed Management Zones, as mapped across the Central Coast Region to cover all identified urban areas. More detailed maps are available for each individual urban area as pdf's HERE. GIS coverages are available from the links provided HERE.

Summary Characteristics of the Watershed Management Zones

1. **Characteristics: drains to stream or to wetland; underlain by Quaternary and Late Tertiary deposits 0-40%, and Early to Mid-Tertiary sed. 0-10%**
   Attributes and Management Approach: This single WMZ includes almost two-thirds of the urban area of the Region; it is defined by low-gradient deposits (Quaternary and Tertiary in age) together with the moderately sloped areas of these younger deposits that drain to a stream or wetland. The dominant watershed processes in this setting are infiltration into shallow and deeper soil layers; conversely, overland flow is localized and rare. Management strategies should minimize overland flow and promote infiltration, particularly into deeper aquifers if overlying a groundwater basin in its recharge area.

2. **Characteristics: drains to stream or to wetland; underlain by Early to Mid-Tertiary sed. 10-40%**
   Attributes and Management Approach: This WMZ is similar to #1 in both materials and watershed processes, but groundwater recharge is anticipated to be a less critical watershed process in most areas (only 1% of the urban areas of the Region in this WMZ overlie a groundwater basin); thus, whereas management strategies need to minimize overland flow as with WMZ#1, they need not emphasize groundwater recharge as the chosen approach to the same degree.

3. **Characteristics: drains to stream or to wetland; underlain by Franciscan mélange and Pre-Quaternary crystalline 0-10%**
   Attributes and Management Approach: This WMZ includes those few flat areas of the Region underlain by old, generally impervious rocks with minimal deep infiltration (and intersecting with no mapped groundwater basins). Overland flow is still uncommon over the surface soil; chemical and biological remediation of runoff, reflecting the slow movement of infiltrated water within the flat soil layer, are the dominant watershed processes. Management strategies should promote treatment of runoff through infiltration, filtration, and by minimizing overland flow.

4. **Characteristics: drains to lake, large river, or marine nearshore; underlain by all types 0–10%, and Quaternary and Late Tertiary deposits 10-40%**
   Attributes and Management Approach: This WMZ covers those areas geologically equivalent to WMZ's 1 and 3 but draining to one of the receiving-water types that are not sensitive to changes in flow rates. The dominant watershed processes in this low-gradient terrain are those providing chemical and biological remediation of runoff, but a specific focus on infiltrative management strategies is only necessary for those parts of this WMZ that overlie a groundwater basin (which, for this WMZ, constitute in total about 10% of the Region's urban areas).

5. **Characteristics: drains to stream; underlain by Quaternary deposits, Late Tertiary deposits, and Early to Mid-Tertiary sed. >40%**
   Attributes and Management Approach: These steep, geologically young, and generally infiltrative deposits are critical to the natural delivery of sediment into the drainage system; management strategies should also maintain the relatively high degree of shallow (and locally deeper) infiltration that reflects the relatively permeable nature of these deposits. Because this WMZ only covers steeply sloping areas, however, it is relatively uncommon in urban areas

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(<3%).

6. **<u>Characteristics</u>: drains to stream; underlain by Franciscan mélange and Pre-Quaternary crystalline rocks >40%**
   <u>Attributes and Management Approach</u>: The steeply sloping geologic deposits not in WMZ 5 are included here; they are similarly important to the natural delivery of sediment into the drainage system but have little opportunity for deep infiltration, owing to the physical properties of the underlying rock. Management strategies should maintain natural rates of sediment delivery into natural watercourses but avoid any increase in overland flow beyond natural rates, which are low where undisturbed even in this steep terrain.

7. **<u>Characteristics</u>: drains to large river or marine nearshore; underlain by all types >40%**
   <u>Attributes and Management Approach</u>: This WMZ is very rare in the urban parts of the region (0.1% total) because such terrain provides little space or opportunity for urban development. The receiving waters that characterize this WMZ are insensitive to changes in runoff rates but still depend on natural sediment-delivery processes for their continued health; thus, management strategies need to focus on maintaining this process in the few areas that the WMZ is found.

8. **<u>Characteristics</u>: drains to wetland; underlain by Quaternary deposits, Late Tertiary deposits, and Early to Mid-Tertiary sed. >40%**
   <u>Attributes and Management Approach</u>: Equivalent to WMZ 5 but with a different receiving-water type, these steep and generally infiltrative deposits should be managed to maintain the relatively high degree of shallow (and locally deeper) infiltration that reflects the relatively permeable nature of these deposits. Delivery of sediment, however, is unlikely to be important to downstream receiving-water (i.e., wetland) health. Even more so than with the other steep WMZs, this type is extremely uncommon in the Region's urban areas (<0.1%).

9. **<u>Characteristics</u>: drains to wetland; underlain by Franciscan mélange and Pre-Quaternary crystalline rocks >10%; *or* drains to stream or wetland; underlain by Franciscan mélange and Pre-Quaternary crystalline rocks 10–40%**
   <u>Attributes and Management Approach</u>: These moderately sloping, older rocks that drain to either a stream or wetland are neither extremely sensitive to changes in infiltrative processes (because the underlying rock types are typically impervious) nor key sources of sediment delivery (because slopes are only moderate in gradient). Overland flow is still uncommon over the surface soil, and so management strategies should apply reasonable care to avoid gross changes in the distribution of runoff between surface and subsurface flow paths. About 6% of the urban parts of the region are found on this WMZ; none include an underlying groundwater basin, emphasizing the relative unimportance of maintaining deep infiltration.

10. **<u>Characteristics</u>: drains to lake and underlain by all types >40%**; **drains to lake, large river, or marine nearshore and underlain by Early to Mid-Tertiary sed., Franciscan mélange, or Pre-Quaternary crystalline rocks 10-40%**
    <u>Attributes and Management Approach</u>: Underlying less than 1% of the urban areas of the Region, this WMZ drains into those receiving waters insensitive to changes in runoff rates. It includes the moderately sloped areas that are anticipated not to be key sediment-delivery sources (by virtue of hillslope gradient) or that drain into lakes (which generally do not require natural rates of sediment delivery for their continued health). Across the entire urbanized part

of the Region, less than 1 square kilometer of this WMZ also overlies a mapped groundwater basin, suggesting that a broad management focus on deep infiltration is unwarranted.

2.5.3 Associating key watershed processes and stormwater management strategies

In focusing on the protection of key watershed processes, the Joint Effort abandoned the historic, symptomatic approach to stormwater management and hydromodification control. Instead of identifying a problematic outcome of urban development (e.g., "eroding stream channels") and requiring a targeted 'fix' to the 'problem' (e.g., "armor the bank"), it identified the root causes of changes to receiving waters—namely, disruption of the watershed processes that sustain the health and function of these waterbodies. Management strategies, therefore, must similarly focus on these processes.

This approach embodies a key assumption: protecting watershed processes will protect receiving waters. Most current hydromodification control plans are antithetical to this approach, typically with an exclusive focus on metering out surface runoff at a rate designed to minimize in-stream erosion but with no recognition of whether overland flow ever existed in that location, or whether the myriad of other watershed conditions and functions are also being protected by such a narrow focus.

To support this chosen mitigation framework, it proved instructive to identify broad sets of "management strategies" that are appropriate to the protection of watershed processes in various settings, and for which numeric performance criteria can be assigned. Although there is no formally accepted "list" of such strategies, the following set was found to be a useful organizational framework:

- FC: Flow control (either "volume" or "rate")
- PSO: Preserve delivery of sediment and organics (typically, via riparian or other waterbody buffers)
- MSV: Maintain soil and vegetation regime (fostering the movement of water through native vegetation and soil layers)
- PR: Land preservation (both riparian and upland; is an effective subset of MSV but also embraces PSO when implemented adjacent to receiving waters)
- WQ: Water-quality treatment

Flow Control encompasses a broad range of stormwater criteria for addressing hydraulic and hydrologic goals. This includes regulations that typically mandate that (1) post-development peak flows are less than or equal to pre-development peak flows for a series of intermediate and/or large design storm events (i.e., "storm event peak flow" control); (2) runoff from flows with the highest risk potential for channel erosion, and by extension damage to aquatic habitat, are not increased in duration ("flow-duration control"); and (3) runoff is infiltrated or retained onsite, without specific reference to the range of stream-channel flows that are affected, to maintain groundwater flow or reduce overall runoff volume ("retain volume").

Preserve Delivery of Sediment and Organics into the channel network is critical for the maintenance of various habitat features and aquatic ecosystems in the fluvial setting. While preservation of these functions is not a goal found in most stormwater regulations, it is often discussed qualitatively as a goal in establishing or justifying riparian buffer requirements.

Maintain Soil and Vegetation Regime is a valuable and highly effective alternative to water-quality treatment, because much impairment is due to the isolation of soil and vegetation from the path of urban stormwater runoff, which in turn eliminates the processes of filtration, adsorbtion, biological uptake, oxidation, and microbial breakdown (collectively termed the watershed process of "chemical and

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biological transformations" by the Joint Effort). Note that this management strategy overlaps with several others: not only can it accomplish water-quality treatment, but also it can constitute stormwater volume-based flow control; if adjacent to water bodies, it preserves the delivery of sediment and organics to waterbodies; and it is a (typically intentional) byproduct of any application of land-preservation strategies as well.

Land Preservation includes open space requirements and the minimizing of effective impervious area. Both have the goal of avoiding or directing runoff from impervious surfaces to pervious areas, rather than routing it directly to the storm drainage system.

Water Quality Treatment includes a suite of stormwater control measures (SCM's) that address the major link between urbanization and water quality impairment, which is caused by the increased runoff from impervious surfaces and soil compaction of pervious areas, and the delivery of urban sources of pollutants such as nutrients from fertilizer, metals from brake pads, and sediment from exposed soil surfaces.

Within each broad category of management strategies, multiple "stormwater control measures" (SCM's) are available for direct application to meet performance criteria. Similarly, a single SCM may reflect multiple management strategies and address more than one watershed process, which provides the reminder that well-chosen stormwater control measures can accomplish multiple objectives within a relatively simple mitigation approach. This great variety of available measures means that any proscriptive approach to the implementation of stormwater management on a site is ill-advised and likely infeasible, and so there was no attempt within the Joint Effort to mandate specific SCM's, only to provide relevant examples.

Table 9 lists a broad range of SCM's that are commonly implemented in stormwater management and hydromodification control plans, and that directly address one or more watershed processes. They are grouped by watershed process, and so many SCM's appear more than once. Within each process they are grouped by their type and note (in parentheses) the management strategy(s) for which they can be applied effectively.

Table 9. Typical associations of watershed processes, stormwater control measures, and management strategies.

KEY to type of SCM's:
Key watershed process
Parcel-Scale Site Design
Parcel-Scale Post-Construction SCM's
Other Strategies

1. Overland flow, rilling & gullying (avoidance)
Vegetation + soil preservation (PSO, MSV, PR, WQ)
Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
Impervious surface disconnection (FC)
Bioretention, biofiltration, native vegetation restoration (FC, PSO, MSV, WQ)
Permeable pavement (FC, WQ)
Vegetated roofs (FC, MSV, WQ)
Cisterns, rainwater harvesting (exits watershed) (FC, WQ)
Cisterns, rainwater harvesting (remains in watershed) (FC, WQ)

Retention ponds, infiltration basins (FC, WQ)
Detention ponds/vaults (FC, WQ)
Riparian restoration
Regional by-pass
2. Infiltration and groundwater recharge
Vegetation + soil preservation (PSO, MSV, PR, WQ)
Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
Permeable pavement; other impervious surface disconnection (FC, WQ)
Bioretention (FC, MSV, WQ)
Native vegetation restoration (PSV, MSV)
Soil amendments (FC, MSV, WQ)
Cisterns, rainwater harvesting (remains in watershed) (FC, WQ)
Retention ponds, infiltration basins (FC, WQ)
3. Interflow (shallow groundwater movement)
Vegetation + soil preservation (PSO, MSV, PR, WQ)
Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
Permeable pavement; other impervious surface disconnection (FC, WQ)
Bioretention (FC, MSV, WQ)
Native vegetation restoration (PSV, MSV)
Soil Amendments (FC, MSV, WQ)
Retention ponds, infiltration basins (FC, WQ)
4. Evapotranspiration
Vegetation + soil preservation (PSO, MSV, PR, WQ)
Receiving water preservation and setbacks (PSO, MSV, PR, WQ)
Impervious surface reduction (FC, PR)
Impervious surface disconnection (FC)
Bioretention, biofiltration, native vegetation restoration (FC, PSO, MSV, WQ)
Vegetated roofs (FC, MSV, WQ)
Cisterns, rainwater harvesting (remains in watershed) (FC, WQ)
Retention ponds, infiltration basins (FC, WQ)
Riparian restoration
5. Delivery of sediment to streams
Soil preservation (type and structure) (PSO, MSV, PR)
Receiving water preservation and setbacks (PSO, MSV, PR, WQ)
Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
6. Delivery of organic matter to waterbody
Vegetation preservation (PSO, MSV, PR, WQ)

Receiving water preservation and setbacks (PSO, MSV, PR, WQ)
Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
Bioretention, biofiltration, native vegetation restoration (FC, PSO, MSV, WQ)
Riparian restoration
7. Chemical/biological transformations
Vegetation + soil preservation (PSO, MSV, PR, WQ)
Receiving water preservation and setbacks (PSO, MSV, PR, WQ)
Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
Permeable pavement; other impervious surface disconnection (FC, WQ)
Bioretention, biofiltration, native vegetation restoration (FC, PSO, MSV, WQ)
Bioswales (filter strips), proprietary WQ treatment devices, detention ponds/vaults (WQ)
Source Control
Illicit discharge detection
Riparian restoration

As noted above, hydromodification control plans are assumed to always include a basic level of water-quality treatment and buffers around receiving waters. The SCM's that can address these goals (and their associated management strategies) are as follows, from those at the top of the list that emphasize preservation (and a broad suite of protected processes) to those at the bottom with a more limited, but potentially better targeted, strategic approach:

- Receiving water preservation and setbacks (PSO, MSV, PR, WQ)
- Vegetation + soil preservation (PSO, MSV, PR, WQ)
- Native vegetation restoration (FC, PSO, MSV, WQ)
- Grading limits, building/road placement, impervious surface reduction (FC, PSO,MSV, PR)
- Bioretention and biofiltration (FC, PSO, MSV, WQ)
- Permeable pavement; other impervious surface disconnection (FC, WQ)
- Bioswales (filter strips), proprietary WQ treatment devices, detention ponds/vaults (WQ)

2.5.4 Associating Stormwater Management Strategies with each WMZ

One of the foundational principles of the Joint Effort is that not every location on the landscape requires the same set of stormwater mitigation measures, because of intrinsic differences in the key watershed processes at each locale and the sensitivity to those processes of the downstream receiving water(s). These differences are captured in the map of Watershed Management Zones (Figure 4). Based on the effectiveness of the various stormwater management strategies (and some examples of their associated SCM's) at protecting or replacing the key watershed processes, the following table (Table 10) display those management approaches that are most likely to provide successful mitigation as needed for each WMZ. In the tables that follow, the red-highlighted columns are those requiring the most effective measures, because those are the watershed processes that are most strongly (and, given the downstream receiving water, the most critically) affected by urbanization. Yellow-highlighted columns denote less-strongly or less-critically affected processes, thereby suggesting that a somewhat less stringent criteria may be appropriate. Purple-highlighted columns apply only for those WMZ's (#'s 4, 7, and 10) for which the presence of an underlying groundwater basin will impose additional concerns for the protection of watershed processes.

The entries for Table 10 reflect a qualitative assessment of the degree of effectiveness of each listed SCM for the protection or replacement of the indicated watershed process. Only those that have moderate (3/4 circle) or high (full circle) effectiveness are included for the highlighted watershed processes. In combination, they suggest a possible range of strategies that, in total, can be effective at addressing the suite of key watershed processes. Note, however, that they do not specify any singular approach for a specific site—that lies beyond the ability of any generalized framework to provide.

Table 10. Key watershed processes (highlighted) for each of the 10 watershed management zones, together with the stormwater management strategies and some example criteria that are likely to be effective in their protection.

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #1 **(OF, GW; also IF, ET)** **Management Strategy**	**Example Criteria**	**Watershed Processes**							**Stream Stability**
		Overland flow	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**	
Flow Control	San Diego County – Hydromodification Plan	○	◕	◕	◑	○	○	◕	◕
	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔
	State of Delaware – Final Draft Stormwater Regulations to Minimize Effective Impervious Area	◕	◕	◕	◕	○	○	◕	◑

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #2 **(OF; also GW, IF, ET)** **Management Strategy**	**Example Criteria**	**Watershed Processes**							
		Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Flow Control	San Diego County – Hydromodification Plan	○	◕	◕	◑	○	○	◕	◕
	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔
	State of Delaware – Final Draft Stormwater Regulations to Minimize Effective Impervious Area	◕	◕	◕	◕	○	○	◕	◑

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Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #3 **(CBT; also OF, ET)** **Management Strategy**	**Example Criteria**	**Watershed Processes**							**Stream Stability**
		Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	
Flow Control	San Diego County – Hydromodification Plan	○	◕	◕	◑	○	○	◕	◕
	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔
	State of Delaware – Final Draft Stormwater Regulations to Minimize Effective Impervious Area	◕	◕	◕	◕	○	○	◕	◑

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #4 (CBT*/) **Management Strategy**	**Example Criteria**	**Watershed Processes**							
		Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Flow Control	San Diego County – Hydromodification Plan	○	◕	◕	◑	○	○	◕	◕
	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔
	State of Delaware – Final Draft Stormwater Regulations to Minimize Effective Impervious Area	◕	◕	◕	◕	○	○	◕	◑

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #5 (DS / GW, IF, ET)		**Watershed Processes**							
Management Strategy	**Example Criteria**	Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Flow Control	San Diego County – Hydromodification Plan	○	◕	◕	◑	○	○	◕	◕
	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Preserve Delivery of Sediment and Organics	Santa Cruz – City-wide Creeks and Wetlands Management Plan (Variable Width)	◔	◑	◔	◔	◕	◕	◔	◔
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔
	State of Delaware – Final Draft Stormwater Regulations to Minimize Effective Impervious Area	◕	◕	◕	◕	○	○	◕	◑

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #6 **(DS / OF, ET)** **Management Strategy**	**Example Criteria**	**Watershed Processes**							**Stream Stability**
		Overland flow	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**	
Flow Control	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Preserve Delivery of Sediment and Organics	Santa Cruz – City-wide Creeks and Wetlands Management Plan (Variable Width)	◔	◑	◔	◔	◕	◕	◔	◔
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔
	State of Delaware – Final Draft Stormwater Regulations to Minimize Effective Impervious Area	◕	◕	◕	◕	○	○	◕	◑

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Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #7 **(DS / *)** **Management Strategy**	**Example Criteria**	**Watershed Processes**							**Stream Stability**
		Overland flow	**Infiltration and groundwater recharge**	**Interflow**	**Evapotranspiration**	**Delivery of sediment to waterbodies**	**Delivery of organic matter to waterbodies**	**Chemical/biological transformations**	
Flow Control	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Preserve Delivery of Sediment and Organics	Santa Cruz – City-wide Creeks and Wetlands Management Plan (Variable Width)	◔	◑	◔	◔	◕	◕	◔	◔
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #8 **(/ GW, IF, ET)** **Management Strategy**	**Example Criteria**	**Watershed Processes** Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	**Stream Stability**
Flow Control	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #9 **(/ OF, ET)** **Management Strategy**	**Example Criteria**	**Watershed Processes** Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	**Stream Stability**
Flow Control	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔

Preserve/maintain ● ◕ ◑ ◔ ○ **No benefit**

WMZ #10 (/ *)		**Watershed Processes**							
Management Strategy	**Example Criteria**	Overland flow	Infiltration and groundwater recharge	Interflow	Evapotranspiration	Delivery of sediment to waterbodies	Delivery of organic matter to waterbodies	Chemical/biological transformations	Stream Stability
Flow Control	San Diego County – Hydromodification Plan	○	◕	◕	◑	○	○	◕	◕
	Section 438 of EISA – Retain 95th Percentile Event	◕	◕	◕	◕	○	○	◕	◑
	State of New Jersey – Groundwater Recharge	◑	●	●	◑	○	○	◑	◔
Water Quality Treatment	City of Santa Monica – Urban Runoff Mitigation Plan	◑	◕	◕	◕	○	○	◕	◑
Land Preservation	King County, Washington – Requirements for Sensitive Watersheds	◕	◕	◕	◕	◕	◕	◑	◔

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2.6 Implementing process-based stormwater management strategies

The preceding analysis accomplished several key objectives of the Joint Effort:

- Identifying and mapping distinctive landscape types requiring tailored stormwater-management approaches (the Watershed Management Zones);
- Associating the key watershed processes needing protection or mitigation in each WMZ;
- Identifying particular stormwater management strategies that have proven effective in other jurisdictions for protecting those watershed processes.

The task that remains is to define specific, measureable standards that will allow developer, designer, and regulator alike to determine the performance of any given stormwater control strategy, as implemented on-site through one or more specific stormwater control measures (SCM's). Numeric performance criteria for each of the identified stormwater management strategies were identified by review of existing hydromodification control plans (and other types of stormwater-management programs) in California and nationwide, and evaluating the effectiveness of the standards adopted by those plans with respect to the protection of watershed processes.

The basis for the numeric performance criteria is a combination of science-based findings and practical considerations borne of long experience. For example, there is excellent scientific basis to focus on the creation of impervious area to address damaging changes to watershed processes. There is no scientific basis to "ignore" or "exempt" projects below a certain minimum size, because it is their additive effect over the watershed as a whole that results in impacts. From the perspective of implementation feasibility, however, providing a simplified list of actions for small projects (and exempting very small projects altogether) is justified. The choice of project-size thresholds is beyond the scope of this document, because they were determined on the basis of general assumptions of "feasibility" and "practicality"; the basis for the chosen numerical performance criteria, however, are discussed below.

- **Performance Requirement No. 1: Site Design and Runoff Reduction.** Minimizing the amount of "connected" or "effective" impervious area (EIA) is a key element of stormwater mitigation (Walsh et al. 2009), reflecting the widely documented correlation of imperviousness with waterbody degradation (e.g., CWP 2003). The listed SCM's are broadly recognized for their simplicity and suitability in a wide range of sites (e.g., PSAT 2005); the benefits they provide, although not quantifiable given the standards of performance under this requirement, are likely significant.

- **Performance Requirement No. 2: Water Quality Treatment.** The key element of this requirement is the need to retain stormwater runoff equal to the volume of runoff generated by the 85th percentile 24-hour storm event, based on local rainfall data. The use of the 85th percentile storm is deeply embedded in the practice of stormwater management over the past decade; many jurisdictions cite ASCE (1998) as the source of this guidance, and the same approach is used here.

- **Performance Requirement No. 3: Runoff Retention.** For projects >15,000 ft^2 of impervious area, this requirement triggers the greatest diversity of WMZ-specific measures. It combines two, related elements: the quantity of runoff that must be retained and the hydrologic processes that must be used to achieve that magnitude of retention. Those WMZ's for which urbanization is recognized to have the greatest effect on the processes of overland flow and infiltration are required to retain the full volume from the 95th percentile storm—in other words, eliminating surface-water release of any runoff from all but the largest storm events. This is consistent with the observations of undisturbed Central Coast landscapes in most of the WMZ's across the Region (#'s 1 and 2, and those portions of WMZ's 4, 7, and 10 that overlie designated Groundwater Basins). The choice of the 95th percentile storm is based on the requirements of federal stormwater control standards promulgated by the Energy Independence and Security Act of 2007 (EISA) and applied throughout the United States (USEPA 2009). The EISA standard includes a 95th percentile retention requirement for federal facilities creating or replacing > 5,000 square feet.

For those WMZ's where a lesser degree of impact to these watershed processes was identified in Booth et al. (2011b; #'s 5, 6, 8, and 9), a less restrictive requirement, that of retaining the 85th percentile storm, has been applied. The choice of this standard is based on the historic rationale akin to that for Performance Requirement No. 2—it reflects a long-established standard-of-practice that has been shown to achieve significant benefits. Its application to runoff volumes for purposes of flow control, however, has a less well-defined history.

- **Performance Requirement No. 4: Peak Management.** This requirement is applied only to projects that create and/or replace >22,500 square feet of impervious surface. The criterion itself (i.e., post-development peak flows shall not exceed pre-project peak flows for the through 100-yr storm events) has precedent in the Central Coast Region as the Santa Barbara County flood control requirement. It is required only where streams are potentially impacted by hydromodification effects resulting from alterations to runoff duration, rate, and volume (WMZ's 1, 2, 3, 6, and 9).

  Water Board staff recognizes that peak management alone is not sufficient to protect downstream receiving waters due to the extended flow durations that can still cause adverse impacts. However, Water Board staff anticipates that the Peak Management criterion, when used in combination with the Runoff Retention requirement, will achieve a broad spectrum of watershed process protection while also protecting stream channels from hydromodification impacts. Water Board staff's judgment is based on the fact that the retention requirement is expected to avoid gross changes in the distribution of runoff between surface and subsurface flow paths for smaller events, and that peak management is expected to provide critical stream protection from the larger events, starting conservatively at the year storm event.

2.7 Identifying local, site-specific data to inform final stormwater management controls and their numeric criteria

Throughout the implementation of the Joint Effort, the limitations imposed by the scale of Region-wide data (primarily GIS-based) and the constraints imposed by the project's schedule and resources have been emphasized. Thus, the types of actions anticipated as necessary to protect key watershed processes are evaluated and displayed by the products of the Joint Effort throughout the urban and urbanizing areas of the Region, but they cannot incorporate every local constraint that may influence the final design of a development project and its stormwater mitigation. Two such categories of "local information" were recognized in the course of developing the Joint Effort methodology, with the caveat that their application to the design and permitting process is still not fully determined, and so the "methodology" of how they should be incorporated into site-specific implementation of feasible and effective stormwater management is acknowledged to be incomplete at present.

2.7.1 Local information that imposes physical constraints on the choice of SMC's

Different parts of the landscape have different properties—this is the underlying principle behind the Joint Effort, and those differences should result in different watershed responses to urbanization and thus differing approaches to stormwater mitigation. However, not all of those landscape differences can be resolved with the data incorporated into the products of the Joint Effort. We recognized three primary limitations of this type:

1. **Near-surface variability in geologic materials.** Geologic materials are a primary determinant of PLZ's and thus of WMZ's, but on a Region-wide basis they have been discriminated only at a coarse scale (1:750,000). Lateral variability beyond that resolved at this scale is likely (indeed, one such example was provided in the Task 3 report). In addition, *vertical* variability is also common—the soil overlying any given geologic deposit commonly, but not uniformly, shares a predictable relationship to the underlying material. Thus, a geologic deposit (and thus the identified PLZ) is likely to give rise to a corresponding soil type sharing similar physical properties, but this is not uniformly true. Soils maps can help resolve such uncertainty and identify potential conflicts between "assumed" and "actual" site conditions, but even these maps are scale-limited. Thus, many jurisdictions already require site-specific field investigations where soil properties are critical to mitigation or structural design.

   Although soil limitations are commonly invoked as a basis for eschewing infiltrative and other LID stormwater-management techniques, Horner and Gretz (2011) found that projects on hydrologic soil groups (HSG) B and C soils were projected to meet the 95th percentile retention standard in all but 12 of 125 of the evaluations they considered using LID methods (type "A" soils, being even more infiltrative, were not assessed in detail). On HSG D soils, all hypothetical projects were able to retain greater than 50 percent of the runoff volume associated with the 85th percentile, 24-hour precipitation event and the authors noted that opportunities to use practices or site design principles not modeled in their analysis could potentially further increase the runoff retention volume. Based on the mapped distribution of soils in the urban areas of the Region (Table 11), this constraint is likely to be significant in only a modest subset of cases.

   Table 11. Hydrologic Soil Groups within the urban areas of the Central Coast

Hydrologic Soil Group	Percentage in Urban Areas
A	13%
B	37%
C	19%
D	27%

2. **Uncertainties in receiving-water type.** The NHD High data layer, from which the downslope receiving water for every point on the landscape has been identified, was compiled from 1:24,000-scale topographic maps and has inescapable inaccuracies related to its scale, particularly in very flat areas. Field knowledge of drainage directions

and drainage pathways is essential in such areas; the existing mapping provides good but not infallible guidance. Modifications to the direction of water flow, and thus to the receiving water, may alter the identification of WMZ in some cases and can only be resolved with certainty by detailed topographic mapping or on-the-ground assessment.

3. **Groundwater conditions.** Although the identification of groundwater basins and generally infiltrative geologic deposits are strong indicators of the importance of subsurface flow, they cannot unequivocally discriminate those areas where groundwater is deep and flow directions are generally "down" (i.e., recharge areas, for which infiltration is both feasible and typically advisable) from those areas where groundwater is shallow and the flow is "up" (i.e., areas of groundwater discharge or where groundwater levels are shallow, rendering infiltration at least seasonally difficult). The Joint Effort identified no Region-wide data set that could reliably discriminate these two conditions, commonly occurring in different parts of the same WMZ, and so the task of evaluating the site-specific feasibility of those SCM's that emphasize infiltration requires local-scale assessment.

2.7.2 Local information that informs policy judgments on mitigation

The Joint Effort provides an approach to watershed process-based mitigation of stormwater impacts from urbanization, using a broad-scale characterization of the physical landscape attributes to guide such efforts. Its focus is therefore evaluating the *physical* importance, effectiveness, and feasibility of potential stormwater management strategies and their associated control measures. However, not every such measure is likely to be judged "appropriate" in every physical setting in which it could be applied. Some of the considerations that might lead a policy-setting body to reduce performance or design standards, waive selected requirements altogether, or require mitigation that differs from guidance based on a physical landscape analysis alone include the following:

- Previously constructed constraints (e.g., concrete or otherwise hardened drainage channels, preexisting buffer-encroaching buildings or other structures)
- Documented receiving-water degradation (e.g., known chemical contamination, measured biological condition, filled and/or paved-over wetland)
- Inferred receiving-water degradation (e.g., highly urbanized contributing watershed, intensive upstream agricultural practices)
- Existing infrastructure for water supply, or other critical uses
- Physical constraints (Section 2.7.1) whose limitations would result in very high cost for alternatives to achieve intended levels of mitigation.

These conditions are discussed in greater detail under "Performance Requirement No. 5: Special Circumstances" in the draft *Post-Construction Stormwater Management Requirements for Development Projects in the Central Coast Region*.

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Date: March 7, 2013

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Subject: Alternatives to 1.963 Multiplier for Sizing Retention Volume

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Enclosed please find the results of our analysis of alternatives to using the 1.963 multiplier used in Attachment D of the PCRs.

This analysis was prepared by Valerie Huff and reviewed and approved by the JERT-D over a period of many weeks.

There are essentially two alternatives shown in this work. Both are recommended.

The first (Simple Sizing) follows the first step shown in Attachment D sizing for calculating runoff volume (Runoff Volume = C * 95th Rainfall Depth * Tributary Area), but stops there, without applying the multiplier. The required retention volume (design volume) is the actual runoff produced from the design storm. The facility is sized as if it behaved like a bathtub, with all runoff entering and no outflow (discharge) from the design storm.

The second (Hydrograph Analysis) follows the same first step in calculating runoff volume, but routes that volume through the structure, accounting for the infiltration that will occur[1]. This provides an even

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[1] One example of a computer model that performs the hydrograph analysis is HydroCad, a proprietary program that is commonly used for design of stormwater infrastructure. HydroCad is based on USDA's (Natural Resources Conservation Service) widely-used *TR-55 - Urban Hydrology for Small Watersheds*, developed in the 1980s. HydroCad is commonly specified by municipalities and is available for about $250. The important thing in the use of such analysis are the specified variables.

smaller sized facility, because the facility is assumed to behave like a reservoir, with inflow (runoff) and outflow (infiltration) being analyzed as they change over time.

In situations where the soil would not drain the design volume in 48 hours, the Hydrograph Analysis approach suggests a multiplier of 1.2 for the stormwater control measure storage capacity. This is different from the multiplier of 1.963 currently used in Attachment D, which is applied to the entire retention volume. Even with a volume multiplier of 1.2, the facility would still be smaller than the Simple Sizing method, and much smaller than what's currently used in Attachment D.

In order to be certain of these recommendations, we used actual rainfall data to verify that these sizing methods could accommodate back-to-back storms. We found that 1) the hydrograph method would accommodate multiple rainfall events, where soils infiltrated within 48 hours, 2) the hydrograph method with multiplier would accommodate multiple rainfall events where soils did not infiltrate in 48 hours, and 3) the Simple Sizing method would more than accommodate back-to-back, multiple-day events because the volume is larger than with the hydrograph method.

The JERT-D members would like to emphasize that this work focused only alternatives to the 1.963 multiplier. This analysis does not review the appropriateness nor justify the retention of a particular storm event. Some members of the JERT Attachment D Subcommittee believe that retention of the 95th percentile event could lead to reduced stormwater runoff compared to predevelopment conditions. Therefore, we encourage continued exploration of the best measures to protect and restore watershed processes.

Stormwater Control Measure Sizing:
Evaluation of Attachment D
to the Central Coast
Post Construction Requirements
(Resolution No. R3-2012-0025)

Prepared By:

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April 8, 2013

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5. SCM Sizing Calculations for Goleta, Paso Robles, and San Luis Obispo

CERTIFICATION

In accordance with the provisions of Section 6735 of the Business and Professions Code of the State of California, this report was prepared by or under the direction of the following Civil Engineer, licensed in the State of California:

ENGINEER IN RESPONSIBLE CHARGE:

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PURPOSE

The purpose of this report is to document our work in reviewing the Central Coast Post-Construction Requirements (PCRs) Attachment D. Specifically, we have evaluated the stormwater control measure (SCM) sizing criteria in Attachment D of the PCRs, and identified retention SCM sizing methodologies that could be used in lieu of the criteria currently required in Attachment D (Resolution No. R3-2012-0025).

In response to stakeholder concerns, the Central Coast Water Board has acknowledged that the volume multiplier as currently presented in Attachment D requires revision. Also, Board Staff have expressed an intention to approve alternative sizing methodologies for SCMs, so long as the alternative methodologies meet the objectives of the PCRs.

We are currently participants in the Regional Board's reconvened Joint Effort Review Team (JERT), including the JERT Attachment D Subcommittee. This Subcommittee was formed to evaluate alternatives to the Attachment D multiplier, along with other reviewing other components of Attachment D.

Our focus of work to-date has been analyzing methods for calculating SCM storage capacity. For the purpose of this analysis, retention volume was calculated based on the WEF/ASCE formula presented in Attachment D, without the 1.963 multiplier. A review of methods for calculating retention volume may be undertaken by the Subcommittee at a later date.

This analysis does not review the appropriateness nor justify the retention of a particular storm event. Some members of the JERT Attachment D Subcommittee believe that retention of the 95th percentile event will in many cases lead to reduced stormwater runoff compared to predevelopment conditions.

RECOMMENDATIONS – EXECUTIVE SUMMARY

Based on our review of rainfall statistics for the Central Coast, post-construction criteria developed for other areas of California, and SCM sizing analysis using the Central Coast PCRs, we have the following recommendations for modifying the sizing criteria presented in Attachment D:

1. Eliminate the retention volume multiplier for projects using the simple sizing method (where storage capacity = retention volume)
2. Explicitly recognize hydrograph routing as an acceptable means for sizing retention based SCMs
3. Require a volume multiplier for facilities sized by a routing method that cannot drain within 48-hours. The recommended multiplier is 1.20.

Eliminate the volume multiplier for projects using the simple sizing method

For the purpose of this document, simple sizing refers to a design where SCM storage capacity is equal to the required retention volume. We have evaluated the PCRs based on simple sizing methodology, and results show that when the multiplier is included this method requires significant surface area or storage depth that would not be feasible on the majority of development sites. For comparison, we have also developed SCM capacity calculations using a hydrograph based routing analysis and found that a simple sizing approach with no multiplier results in SCMs that would capture back-to-back storms and still have room to spare. In other words, this simplified approach results in an oversized facility.

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Also, when compared to post-construction criteria in other regions of California, a simple sizing approach based on the PCRs results in overly conservative volumes. For example, the Contra Costa C.3 guidebook includes minimum unit volumes for facilities that must provide water quality treatment AND 10-year peak flow control. With simple sizing and the 1.963 multiplier, the PCRs result in unit volumes 2 to 3 times that required to control a 10-year storm in Contra Costa.

The simple sizing approach may be reasonable for some projects, dependent on project size, complexity, rainfall, soil conditions, and other site specific factors. We recommend that the simple sizing approach is allowed as one sizing alternative, with no multiplier required for retention volume regardless of drawdown time.

Explicitly recognize hydrograph routing as an acceptable means for sizing retention and detention based SCMs

A hydrograph analysis has an advantage over a simple sizing analysis as it takes into account both rate of flow into a facility, and infiltration from a facility during the storm event. There can be two components to a hydrograph analysis: rainfall-runoff and storage routing. The rainfall-runoff portion of the analysis determines the site runoff over time, based on rainfall patterns and the site characteristics, including the infiltration capacity of the pervious surfaces. From this is derived the total runoff volume. For the purposes of the analyses presented in this report, the infiltration factors (CN values) are adjusted so that the runoff volume matches that calculated for the site based on the Attachment D method (WEF/ASCE formula). This produces a time based distribution of the Attachment D runoff volume. The hydrograph storage routing analysis considers the time-based runoff flowing into an SCM, along with the SCM infiltration capability, to determine the net storage over time. From this is derived the total storage capacity needed in the SCM.

We prepared SCM sizing calculations for three 95th percentile rainfall depths, evaluating required SCM capacity based on varying SCM infiltration rates. This analysis demonstrates that SCM capacities calculated by a routing method are more consistent with other criteria in California than results of simple sizing. For example, unit volumes developed by a hydrograph routing of the PCR criteria are generally equivalent to Contra Costa C.3 unit volumes required for water quality and peak flow control up to the 10-year storm event.

Hydrograph analysis for SCM sizing is referenced in the City of Santa Barbara LID BMP Manual. The City of Santa Barbara's program was recently approved by the Central Coast Water Board as an acceptable alternative to the PCRs. In addition, the City's LID Manual is referenced in Attachment D as a resource for design guidance. Also, the EPA guidance manual for federal hydromodification criteria (retention of the 95th percentile event) includes 9 case studies where SCMs were sized using a hydrograph analysis. Therefore, we conclude that hydrograph analysis is acceptable to the Central Coast Water Board for sizing calculations. However, we request that this method is explicitly stated to be acceptable in the PCRs, so there is no question of acceptability when hydrograph calculations are submitted to governing agencies.

Table 1 provides a summary of our recommendations for the variables that are included in a routing method sizing analysis. These recommendations and the relative effect these variables are expected to have on calculation results are discussed in more detail in subsequent sections of this Report.

Table 1. Summary of Recommended Routing Method Variables

Variable	Recommendation
SCM Infiltration	Onsite testing per standardized procedure being developed by Earth Systems Pacific
Rainfall Distribution	NRCS Type I or based on local rainfall data
Time of Concentration	Agency's current drainage and flood control standard
Hydrograph Method	Either NRCS or SBUH
Time Increment	0.10 hour, unless otherwise justified to be more correct based on rainfall distribution
Storage (SCM) Routing Method	Storage-indication, unless otherwise justified to be more correct based on site and storage conditions.

Require a volume multiplier for facilities sized by a routing method that cannot drain within 48-hours. The recommended multiplier is 1.20.

The PCRs currently include a retention volume multiplier, described by Water Board Staff as a means to account for additional storage that may be required to capture runoff from back to back storms, for those facilities that do not drain within 24 hours. We evaluated the need for a multiplier by compiling and analyzing the following:

- Rainfall records for the Central Coast
- NOAA Atlas 14 rainfall frequency estimates
- Multipliers derived from the ASCE/WEF Manual of Practice referenced in the PCRs
- Continuous simulation data available through the program Basin Sizer
- Preparing SCM sizing calculations using hydrograph routing to identify storage capacity required to meet the PCR volume criteria, with varying facility drawdown times and back-to-back storms.

Based on our sizing calculations, facilities that are sized to manage the 95th percentile event can accommodate back-to-back storms with no increase in storage capacity, so long as the facility drains within 48 hours. Facilities that could not drain within 48-hours did require an increase in capacity to capture back-to-back storms. Therefore, we recommend a multiplier is applied only to those facilities that cannot drain within 48-hours. Regarding the value of the multiplier, we identified the following values based on our analysis and review of guidance documents:

Table 2. Summary of Volume Multipliers

Method	Volume Multiplier
ASCE/WEF Manual of Practice	1.19
Analysis of continuous rainfall records	1.10
Basin Sizer	1.30
SCM Sizing Calculations	1.02 – 1.12*

*Multiplier value for 2-day (back-to-back) storm event. Multiplier may increase for 3-day or longer storm event (continuous simulation) compared to our results.

Based on the multiplier values listed above, we recommend a multiplier of 1.20 is applied to facilities that cannot drain within 48-hours, in absence of project specific continuous simulation. This multiplier would be applied to the storage capacity calculated to manage a single 95th percentile event.

EXAMPLE CALCULATIONS

This section provides example calculations comparing results of a simple sizing and hydrograph routing approach, to design a bioretention area for a one-acre commercial development.

Project Details

- 1-acre Commercial Site
- 85% impervious
- Required to infiltrate the 95th percentile storm (2-inches)

Step 1: Calculate Required Retention Volume, Using Attachment D

- Fraction impervious, i = 0.85
- C = 0.66
- A = 43,560 sf
- Rainfall depth = 2 inches (.167 ft)
- Retention Volume = 4,801 cubic feet

Step 2: Calculate Required Storage Capacity, Either Simple Sizing or Routing Method

Simple Sizing: Size Bioretention Capacity Equal to the Retention Volume

- Assume surface area = 10% of impervious
- Bioretention surface area = 3,703 sf
- Required water depth = retention volume ÷ surface area = 1.29 feet
- Surface ponding depth = 0.5 feet, therefore subsurface depth required = 1.29 – 0.5 = 0.79 feet (9.5 inches) of water holding capacity
- Soil depth = 24 inches, with 25% porosity. Soil holds 6 inches.
- Gravel required to store remaining water. Water depth in gravel = 9.5 – 6 = 3.5 inches.
- Gravel porosity of 35%. Total required gravel depth = 3.5 inches ÷ 0.35 = 10 inches.

Results Summary:

- Ponding depth = 6 inches
- Soil depth = 24 inches
- Gravel depth = 10 inches

Routing Method Sizing: Determine Required Storage Capacity to Retain and Infiltrate the Retention Volume

- Set the subcatchment area to the project area (1 acre)
- Assign runoff method (NRCS or SBUH)
- Set the curve number (CN) value such that the volume of runoff from the subcatchment is equal to that calculated in Step 1 (CN = 93 for this example)
- Assign time of concentration (10 minutes used for this example)
- Route subcatchment to a retention pond
- For this example the ponding, soil, and gravel depth was matched to the dimensions found through simple sizing.
- The pond outlet is through soil infiltration. Set infiltration rate based on tested soil conditions (or, in this example case, based on average for HSG soil type). Set infiltration to occur from surface area only (lateral infiltration assumed to be negligible).
- Determine storage capacity needed to manage runoff volume (no overflow).

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Results of the routing method example calculations are summarized in Table 3.

Table 3. Routing Method Results for Example Project

Soil Type	SCM Infiltration Rate (in/hr)	Required Storage Capacity (cubic feet)	Required Surface Area (square feet)	SCM Size as Percent of Retention Volume	Drawdown Time
A	5.0	800	1,600	17%	24 hours
B	1.0	2,394	1,850	50%	32 hours
B/C	0.6	2,912	2,250	61%	48 hours
C	0.23	3,818	2,950	80%	94 hours
D	0.06	4,529	3,500	95%	12 days

Results – Comparison of Simple Sizing to Routing Method

The comparison of simple sizing to the routing method shows that the needed storage capacity for a retention based SCM is significantly less than the retention volume, for an SCM with soils that infiltrate well. As SCM infiltration rate decreases, the needed storage capacity increases. The Type D soil modeled illustrates that because the infiltration rate is very low, the needed storage capacity is nearly the full retention volume. The resulting drawdown time for this type of soil also illustrates the need for a subsurface drain to avoid creating a perched water condition, where water is stored subsurface for long periods of time before infiltrating.

TECHNICAL DETAILS: DATA REVIEW AND SIZING ANALYSIS

The following is a more in depth summary of the data we have reviewed and the calculations developed for this analysis.

EPA Stormwater Guidance

The EPA developed technical guidance for implementing the stormwater runoff requirements for federal projects (Section 438 EISA). The guidance manual includes nine case studies for applying the requirements to project sites. A method called "direct determination" was used in the guidance manual, to evaluate the case studies for runoff volume and SCM sizing. The direct determination method assumes a constant rainfall and SCM infiltration rate for a 24-hour storm duration. SCM storage capacities were calculated based on the physical storage in the SCM, in addition to the SCM infiltration that would occur over a 24-hour period. This is basically a simplified version of a hydrograph analysis, where the rainfall distribution would be constant over time with a relatively low intensity. This method has the potential to under-size a facility, as more storage is typically needed for a shorter more intense storm event. Also, the SCM infiltration volume could be overestimated, because if inflow to the facility is occurring at a rate lower than the soil's infiltrative capacity (which is likely prior to the peak of the storm), it is physically impossible to infiltrate the maximum possible volume over the storm duration. Regardless, the important take-away from the guidance is that the EPA recognized the necessity of including the infiltrative capacity of soil for both the determination of runoff volume and SCM outflow, and a simplified hydrograph analysis was used for SCM sizing.

ASCE/WEF Manual of Practice Volume Multiplier

We reviewed the ASCE/WEF Manual of Practice "Design of Urban Stormwater Controls" to evaluate the drawdown multiplier, as this manual is referenced in the PCRs for the use of the

1.963 multiplier. The intended use of the 1.963 multiplier is to calculate water quality volume based on mean annual precipitation, not to provide buffer storage as is done in the PCRs. However, the ASCE/WEF Manual can be used to ascertain volume multipliers, by comparing the water quality volume calculated for a 24-hour drawdown period to that calculated for a 48-hour drawdown period. Based on the Manual, a **volume multiplier of 1.19** is calculated for event based sizing, for a 48-hour drawdown period.

Rain Gauge Statistics

As the purpose of the Attachment D retention volume multiplier is to provide capacity for back-to-back storms, we prepared an analysis of the frequency of multiple day storms on the Central Coast, and the potential affect on retention feasibility. We reviewed in detail daily rainfall records for a CIMIS rain gauge in San Luis Obispo and a NOAA NCDC rain gauge in Paso Robles. For both gauges, we found that an SCM sized for the 95th percentile storm (with no volume multiplier) would capture at least 98% of one day storms, 80% of two day storms, and nearly 50% of all 3-day storms. This is based on total storm depth compared to the 95th percentile, and actual capture would likely be much higher due to infiltration occurring over the course of the multi-day storms (and therefore the ability to capture depths greater than the 95th).

Table 3. Summary of Storm Totals Compared to the 95th Percentile Event

Storm Duration (Days)	Paso Robles Rain Gauge		San Luis Obispo Rain Gauge	
	Percent of Rain Days	Percent of Storm Totals Less Than the 95th Percentile	Percent of Rain Days	Percent of Storm Totals Less Than the 95th Percentile
1	36%	98%	35%	98%
2	30%	81%	28%	84%
3	15%	43%	18%	45%
4	8%	19%	9%	6%
5+	11%	0%	10%	0%

Rain Gauge Statistics: Analysis for Volume Multiplier

We also used the rain gauge data we compiled for San Luis Obispo and Paso Robles to evaluate the need for increased SCM volume to capture back-to-back storms. We used continuous rainfall records, 26-years for San Luis Obispo and 59-years for Paso Robles, and compared daily rainfall depths to the 95th percentile storm depth. We determined the difference in SCM storage required for capture of the 95th percentile storm depth, comparing a 24-hour drawdown time to 48-hour drawdown time. This approximate analysis demonstrates that a **volume multiplier of 1.10**, for facilities with a 48-hour drawdown, would result in an equivalent volume capture compared to facilities with a 24-hour (or shorter) drawdown time.

This analysis was simple in approach, and was meant to provide a “reality check” in lieu of full continuous simulation modeling. The analysis was performed in a spreadsheet using the continuous rainfall records for each rain gauge. For the analysis we assumed a retention-based SCM was sized to retain the 95th percentile event, with either a 24-hour or 48-hour drawdown period. We further assumed that with a 48-hour drawdown, half of the SCM capacity would be infiltrated prior to the subsequent day of rain (or the storm total would infiltrate, whichever is less). For example, if the 95th percentile event is 2.0 inches, and the first day of rain was 1.6 inches, we assumed that 1.0 inch (half of the 95th percentile) would infiltrate prior to the 2nd day of rain. Or, if the first day of rain was 0.7 inches, we assumed the full 0.7 inches would infiltrate

GOLETA PETITION FOR REVIEW
EXHIBIT A