Appendix J

Preliminary Storm Water Control & Treatment Strategy and
Preliminary Drainage Report

Cannon

SAN LUIS RANCH

Preliminary Storm Water Control & Treatment Strategy

Prepared for
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Prepared by
Cannon
1050 Southwood Drive
San Luis Obispo, CA 93401

July 28, 2016

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1. INTRODUCTION

San Luis Ranch is a 131 acre infill site located west of U.S. Highway 101 and East of Madonna Road. Currently in the County of San Luis Obispo the project plans are being processed through the City of San Luis Obispo with the intent of annexation to the city. Portions of the property are subject to flooding from the 100-year storm and through grading of the property and modifications to existing drainage facilities, development will be removed from the flood plain. Remapping of the FIRM through processing of a CLOMR and LOMR are being handled by Wallace Group. That work, along with information related to the widening of Cerro San Luis Channel, and bench widening along a portion of Prefumo Creek is addressed in a separate document.

It is the intent of this document to describe the project strategy to meet requirements for stormwater peak flow management and treatment as required by the governing agency. This project is subject to requirements for stormwater peak flow management as identified in the City Drainage Design Manual, and for runoff reduction and treatment as dictated by Resolution R3-2013-0032 of the California Regional Water Quality Control Board, Central Coast Region.

The project site plan, with stormwater control measures noted, is provided as Exhibit 1.

2. Stormwater Peak Flow Management

It is the goal of the San Luis Ranch project to provide an abundance of workforce housing with open space along the existing creek and channel while maintaining an expanse of the existing agricultural uses. The development of a peak flow management strategy for this project was based on the need to provide detention in a manner which supports those development goals; that is to provide detention in a manner which would combine the required detention with another land use.

The design of storm water detention for the San Luis Ranch project employs the concept of “over-detention” on the upstream side of the property through the construction of a diversion structure at Cerro San Luis Channel which will divert flows to underground storage chambers within the Commercial site. Flows from these chambers will be released through a metered outlet structure to a storm drain which will outfall to Prefumo Creek south of the Froom Ranch Way Bridge. Design of the chambers and the outflow structure are based on City of San Luis Obispo requirements as stated in their Drainage Design Manual, matching post development flows to pre-development for the 2 through 100-year storm events. The detention structure is designed to address increased runoff from the proposed residential properties (large lot and small lot single family and multi- family properties, as well as increased runoff due to development of the project infrastructure roadways). Detention for commercial properties (hotel, office and commercial) is to be incorporated into the designs for those projects.

The basin as designed will hold a maximum of 310,000 cubic feet of water, and release flows at rates varying from approximately 12 cfs (2 year storm) to 67 cfs (100 year storm) through a 48” storm drain main. Details for the basin and diversion structure can be seen in **Exhibit 2**.

Proposed drainage basins are identified in **Exhibit 3** and **Exhibit 4** contains a summary of peak flow rates off of the site for the 2-year through 100-year storms.

3. Stormwater Treatment

Through adoption of Resolution R3-2013-0032 the Central Coast Regional Water Quality Control Board has made findings that Central Coast municipalities must implement the Post Construction requirements in order to comply with the statewide Phase II Municipal General Permit which requires small MS4s to develop and implement Best Management Practices to reduce the discharge of pollutants and protect water quality. Those measures and the manner in which the project will comply are described below.

1. **Runoff Reduction**. Requirements here include limiting disturbance to creeks and drainage features, minimize compaction of permeable soils, limiting the clearing and grading of vegetation, and minimizing impermeable surfaces. The San Luis Ranch project will maintain open space areas along Prefumo Creek and Cerro San Luis Channel thereby limiting disturbance to those areas as well as limiting the clearing and grading of vegetation. Measures to minimize impermeable surfaces will be incorporated into individual site designs for the residential and commercial projects.

2. **Water Quality Treatment.** The strategy for the San Luis Ranch project is to limit the release of "first flush" water from the site by providing onsite retention for those flows. The proposed retention will equal the runoff volume of the 95^{th} percentile 24-hr storm which exceeds the requirement for Water Quality Treatment in order to comply with the requirements for Runoff Retention described below. By addressing some of the retention requirements in localized biofiltration areas the project will achieve treatment beyond that required.

3. **Runoff Retention** – As noted under Stormwater Treatment, the retention designs for San Luis Ranch incorporate the water quality treatment requirements. Runoff from the proposed single family residential development areas is proposed to be retained within underlying rock below biofiltration areas scattered throughout the residential developments and within a below ground retention basin at the proposed public park. Designs for Water Quality Treatment measures for the multi-family and commercial properties will be incorporated into the designs of those properties.

   Exhibit 5 gives a cross section of the bioretention areas. **Exhibit 6** provides information on the underground retention chambers, and **Exhibit 7** indicates proposed treatment areas. **Exhibit 8** indicates required vs provided retention for each of the areas depicted in Exhibit 6. It should be noted that for those areas in which the proposed treatment is less than the required, required treatment is made up in overflow to other areas with capacity.

4. **Peak Management**. Storm Water Detention requirements as dictated by the City Drainage Design Manual noted above exceed the requirements of the Regional Board. Compliance with city requirements dictates compliance here. See above for discussion on proposed measures.

PROPOSED STORM WATER DETENTION

PROPOSED DETENTION OUTFALL

PROPOSED RETENTION

PROPOSED BIOFILTRATION AND RETENTION

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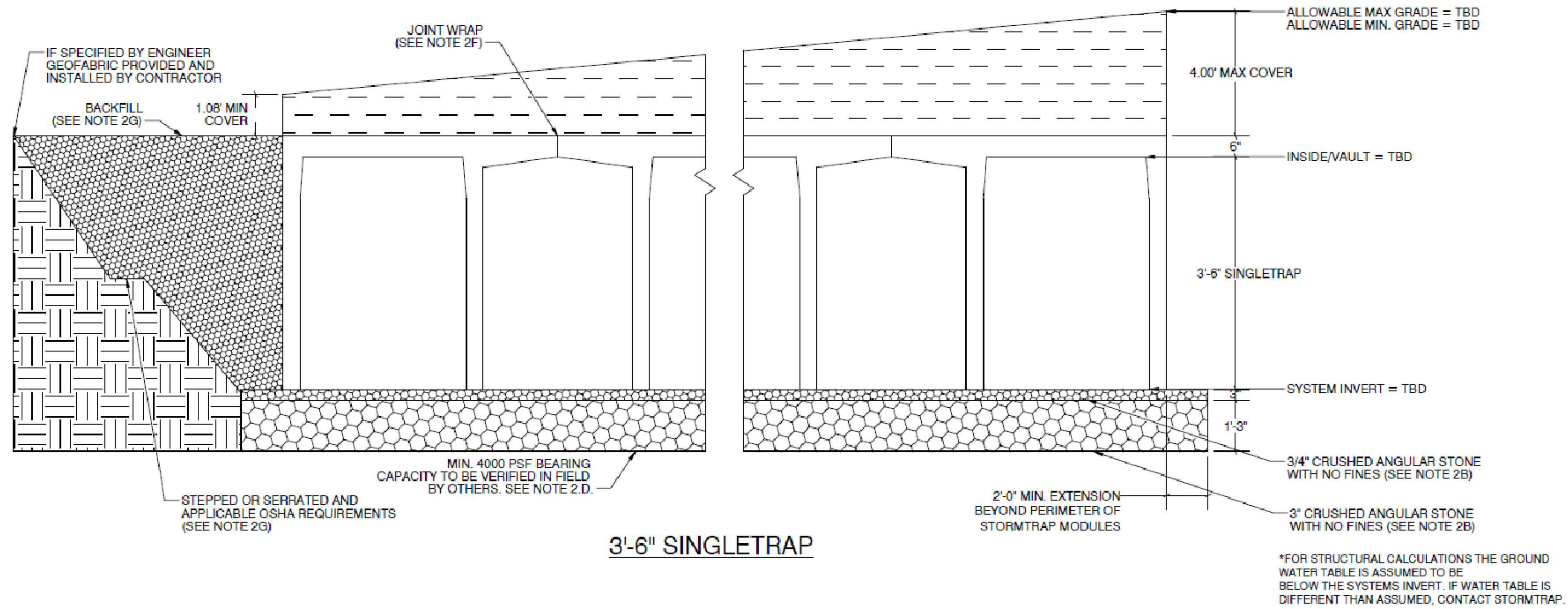
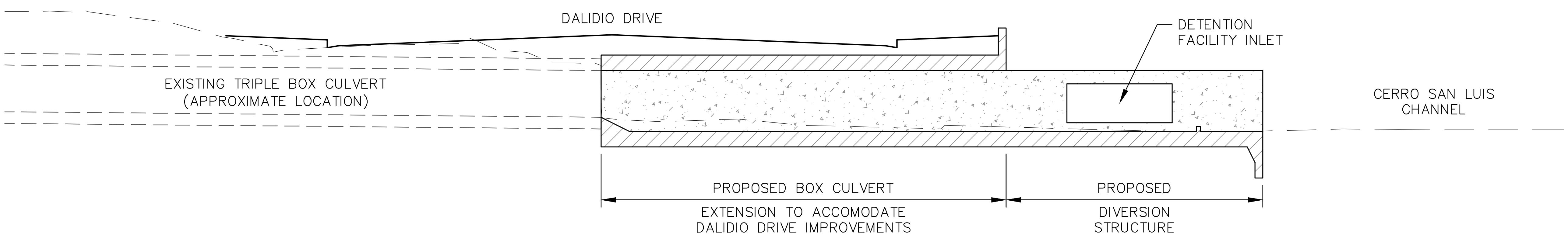
EXHIBIT 1
SITE PLAN
SAN LUIS RANCH
SAN LUIS OBISPO, CA

DRAWN BY JW	DATE 07/26/16	CA JOB NO. 140310
CHECKED BY SR	SCALE 1" = 400'	SHEET 1 OF 1



UNDERGROUND DETENTION FACILITY CROSS-SECTION (X)

TYPICL SECTION



DIVERSION STRUCTURE LONGITUDINAL SECTION (X)

TYPICL SECTION — LOOKING EAST

Cannon
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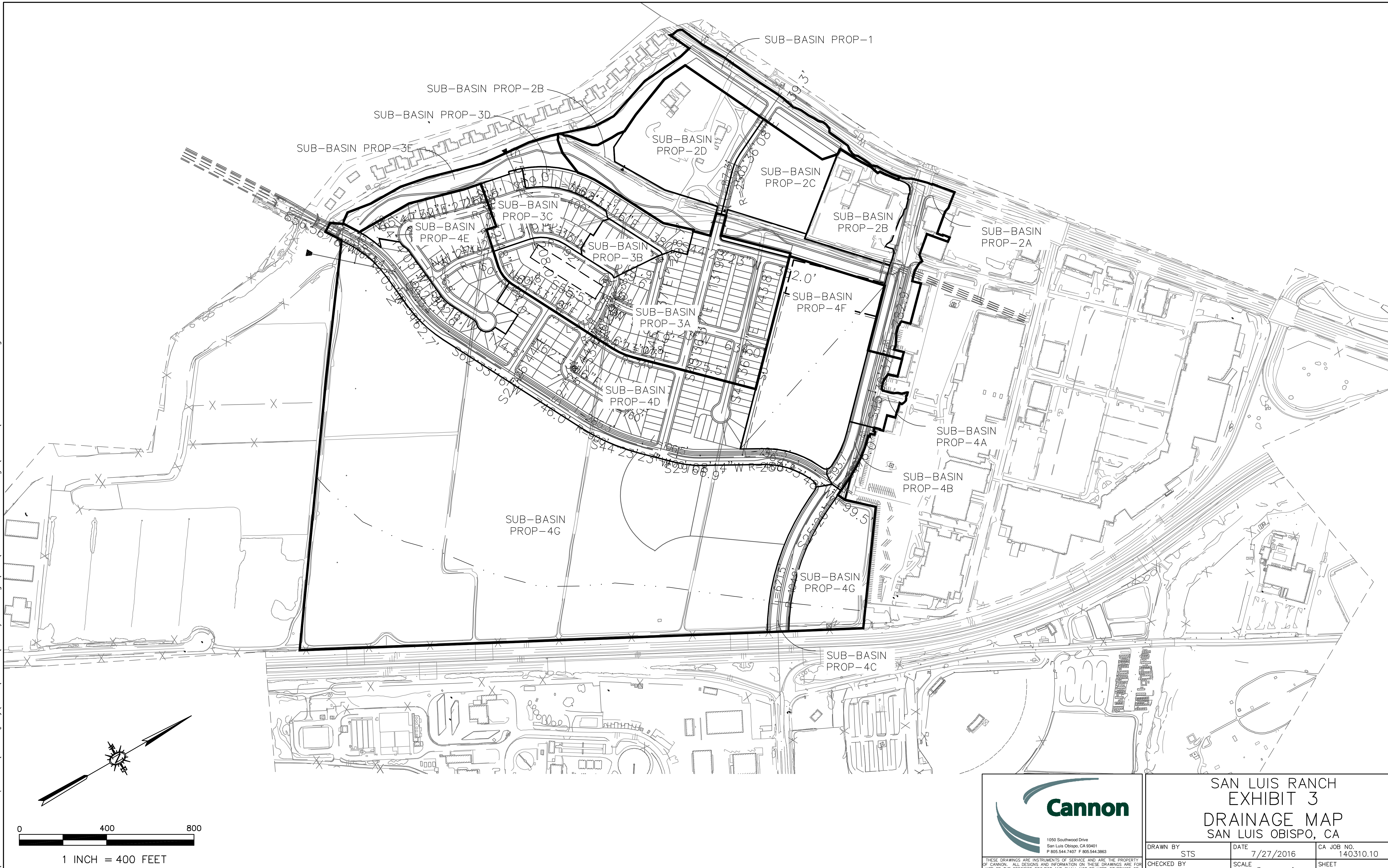
SAN LUIS RANCH
EXHIBIT 2 – STORM WATER DETENTION BASIN
SAN LUIS OBISPO, CA

DRAWN BY	DATE	CA JOB NO.
WGC	2016-07-25	140310
CHECKED BY	SCALE N.T.S.	SHEET 2 OF 6


SUB-BASIN PROP-1
SUB-BASIN PROP-2B
SUB-BASIN PROP-3D
SUB-BASIN PROP-3E
SUB-BASIN PROP-2D
SUB-BASIN PROP-2C
SUB-BASIN PROP-2B
SUB-BASIN PROP-2A
SUB-BASIN PROP-3C
SUB-BASIN PROP-4E
SUB-BASIN PROP-3B
SUB-BASIN PROP-3A
SUB-BASIN PROP-4F
SUB-BASIN PROP-4D
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SUB-BASIN PROP-4B
SUB-BASIN PROP-4G
SUB-BASIN PROP-4G
SUB-BASIN PROP-4C
0 400 800
1 INCH = 400 FEET
Cannon
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San Luis Obispo, CA 93401
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THESE DRAWINGS ARE INSTRUMENTS OF SERVICE AND ARE THE PROPERTY OF CANNON. ALL DESIGNS AND INFORMATION ON THESE DRAWINGS ARE FOR USE OF THE SPECIFIED PROJECT AND SHALL NOT BE USED OTHERWISE OR REPRODUCED WITHOUT THE EXPRESSED WRITTEN PERMISSION OF CANNON.
SAN LUIS RANCH
EXHIBIT 3
DRAINAGE MAP
SAN LUIS OBISPO, CA
DRAWN BY STS
DATE 7/27/2016
CA JOB NO. 140310.10
CHECKED BY
SCALE 1" = 400'
SHEET X OF XX

Combined Peak Discharge from Areas Shown on Drainage Map Proposed Conditions & Cerro San Luis Channel

Date: 7/27/16

EXHIBIT 4

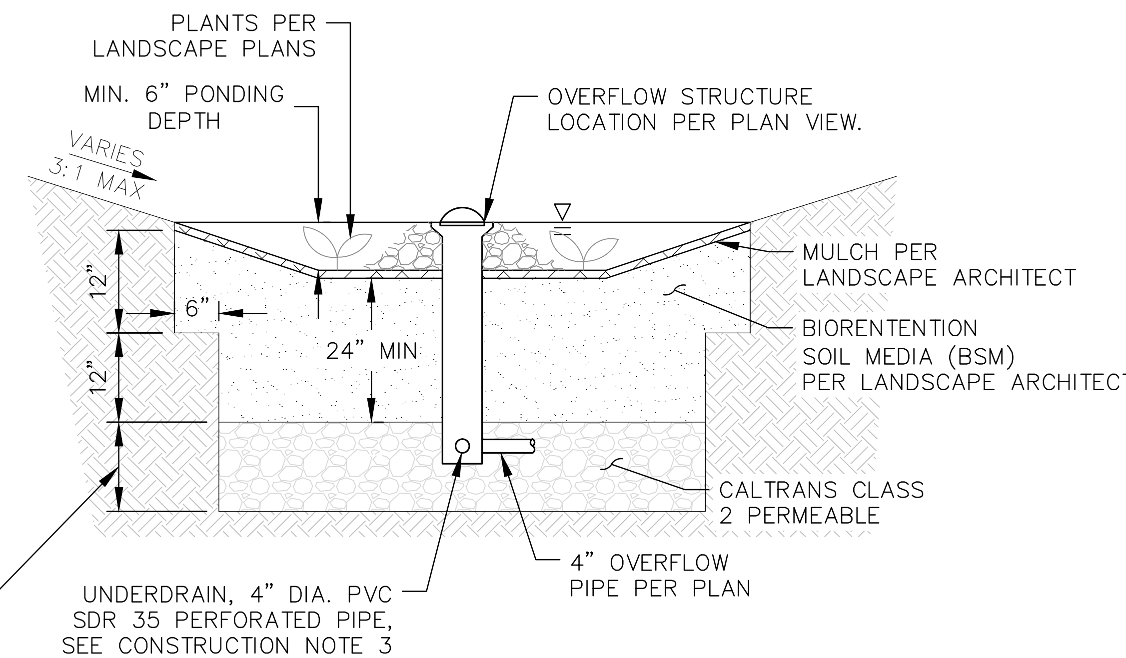
	Peak Flow (cfs)*				
Scenario	**2-year**	**10-year**	**25-year**	**50-year**	**100-year**
Existing Conditions	262.20	505.92	673.51	804.08	906.47
Proposed Conditions	265.39	495.44	646.58	756.81	861.59
Difference	3.20	-10.48	-26.93	-47.27	-44.88
% Change	1.2%**	-2.1%	-4.0%	-5.9%	-5.0%

*Peak flows shown are preliminary and are subject to change as the design develops

**SLO City Drainage Deisgn Manual (Section 3.3) allows up to a 5% increase in peak flows from existing conditions

BIORETENTION CONSTRUCTION NOTES

1. SCARIFY SUBGRADE BEFORE INSTALLING BIORETENTION AREA BSM.
2. FACILITY EXCAVATION TO ALLOW FOR SPECIFIED SOIL AND MULCH DEPTHS TO ACHIEVE FINISHED GRADE ELEVATION ON PLAN.
3. INSTALL UNDERDRAIN WITH HOLES FACING DOWN. UNDERDRAIN DISCHARGE ELEVATION SHALL BE NEAR TOP OF AGGREGATE LAYER. UNDERDRAIN SLOPE MAY BE FLAT.
4. COMPACT EACH 6" LIFT OF BSM WITH LANDSCAPE ROLLER OR BY LIGHTLY WETTING. IF WETTING, ALLOW TO DRY OVERNIGHT BEFORE PLANTING.
5. DO NO WORK WITHIN BIORETENTION ARE DURING RAIN OR UNDER WET CONDITIONS.
6. KEEP HEAVY MACHINERY OUTSIDE BIORETENTION AREA LIMITS.



TYPICAL BIORETENTION FACILITY CROSS-SECTION

TYPICL SECTION

X

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SAN LUIS RANCH
EXHIBIT 5 – TYPICAL BIORETENTION AREA
SAN LUIS OBISPO, CA

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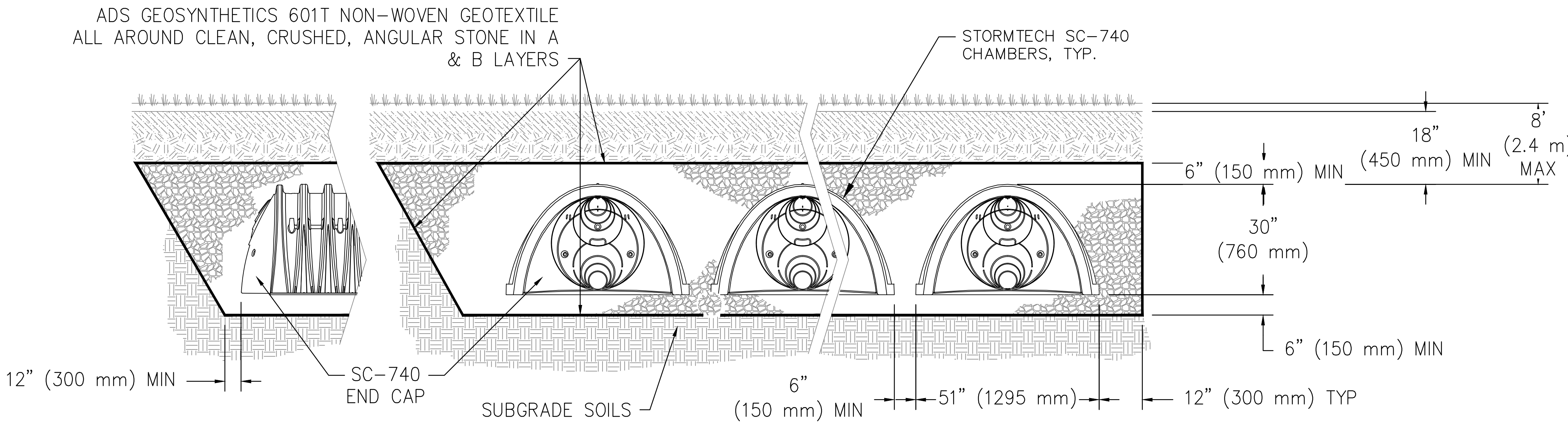

UNDERGROUND STORMWATER RETENTION FACILITY CROSS-SECTION

X

TYPICL SECTION

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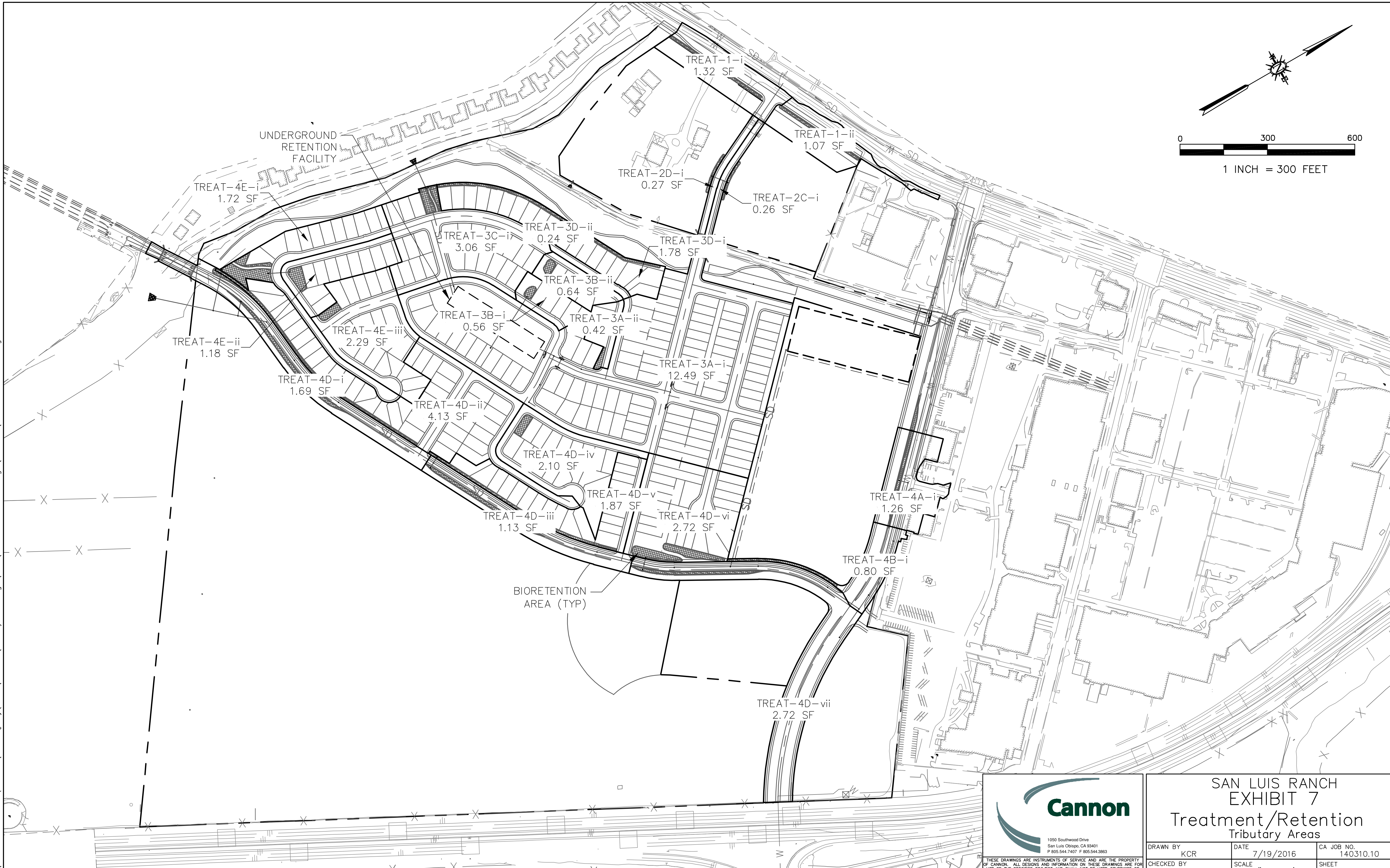
SAN LUIS RANCH
EXHIBIT 6
UNDERGROUND RETENTION
SAN LUIS OBISPO, CA

DRAWN BY	DATE	CA JOB NO.
WGC	2016-07-25	140310
CHECKED BY	SCALE N.T.S.	SHEET 5 OF 6

F:\proj\2014\140310\3 Project Design\Civil\Construction Drawings\EIR Coordination\2016-07-28 EIR Grading Summary\Exhibits\CE140310EX0005.dwg 7-28-16 02:13:06 PM JeffreyW



Cannon 1050 Southwood Drive San Luis Obispo, CA 93401 P 805.544.7407 F 805.544.3863	SAN LUIS RANCH EXHIBIT 7 Treatment/Retention Tributary Areas	
DRAWN BY KCR	DATE 7/19/2016	CA JOB NO. 140310.10
CHECKED BY	SCALE 1" = 300'	SHEET X OF XX

Summary of Retetion Volume Calculations
Date: 7/27/16
EXHIBIT 8

Sub-basin	Total Required Retention Volume (cf)	Provided Retention Volume (cf)	Notes
TREAT-1-i	3,281	4,418	
TREAT-1-ii	2,207	4,194	
TREAT-2C-i	1,710	1,847	
TREAT-2D-i	1,740	1,850	
TREAT-3A-i	48,854	50,450	Underground Retention Facility
TREAT-3A-ii	1,743	1,915	
TREAT-3B-i	1,816	1,923	
TREAT-3B-ii	2,266	2,297	
TREAT-3C-i	13,453	14,085	
TREAT-3D-i	5,788	10,657	
TREAT-3D-ii	958	1,028	
TREAT-4A-i	5,168	5,873	
TREAT-4B-i	3,264	5,024	
TREAT-4D-i	7,446	8,518	
TREAT-4D-ii	22,473	24,000	
TREAT-4D-iii	4,928	7,631	
TREAT-4D-iv	9,163	3,455	Accounted for in TREAT-4D-ii
TREAT-4D-v	6,350	9,373	
TREAT-4D-vi	9,254	15,102	
TREAT-4D-vii	12,116	13,837	
TREAT-4E-i	12,833	13,948	
TREAT-4E-ii	11,460	5,287	Accounted for in TREAT-4E-i
TREAT-4E-iii	10,014	3,397	Accounted for in TREAT-4E-ii

*Retention volumes shown are preliminary and are subject to change as the design develops

Preliminary Drainage Report

San Luis Ranch
Tentative Tract Map
Tract 3096

Prepared for
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Pismo Beach, CA 93449

Prepared by
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San Luis Obispo, CA 93401

10/14/2016

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1. Introduction and Background

1.1. Introduction

Coastal Community Builders (CCB) is proposing a new residential development in the City of San Luis Obispo. A drainage study was conducted to be submitted with the Tentative Tract Map application for the proposed project. The intent of that study was to establish the major drainage components that will be included with the proposed project, and to determine their effects on the horizontal and vertical layout of lots, roads, grading, and utilities. This report presents the methods and results generated from that study.

1.2. Project Location and Site Description

The proposed project is located in the City of San Luis Obispo in San Luis Obispo County. The project site is located to the south of the intersection of Madonna Road and Dalidio Drive. The site consists of approximately 131.4 acres of mostly agricultural land, along with wooded land, a few residences and miscellaneous farm structures, and the two channel corridors associated with Prefumo Creek and Cerro San Luis Channel. Prefumo Creek, a seasonal creek, runs along the western portion of the property. The project site is bisected by a seasonal drainage called Cerro San Luis Channel, which conveys flow that discharges from underground culverts and surface flow at Dalidio Drive to lower Prefumo Creek.

1.3. Project Description

The project consists of the construction of a new 302 lot residential development. Single family houses will be constructed on each of the 302 lots. In general, the lots vary in size from about 2,400 sf to 3,200 sf, although there are some larger lots. The project includes a large central park, along with several small parks dispersed around the proposed development. There are also open space areas proposed along the stream corridors. Several streets are proposed within the development to provide access to the lots.

The proposed project includes extensions of and improvements to existing arterial and collector streets, including Froom Ranch Way and Dalidio Drive, to improve regional access. The project also includes mass grading of pads for future development of commercial and multi-family residential lots.

2. Stormwater Regulations and Design Criteria

There are several governing bodies that have regulations and design criteria pertaining to stormwater management for new development. The project is currently located within San Luis Obispo County, but is planned to be annexed into the City of San Luis Obispo. For purposes of this study, it was assumed that the project is located within the City of San Luis Obispo. This project is within the jurisdictions of the following agencies:

- City of San Luis Obispo

- Central Coast Regional Water Quality Control Board (RWQCB)
- California Department of Fish and Wildlife (CDFW)
- Federal Emergency Management Agency (FEMA)
- US Army Corps of Engineers (USACE)

2.1. City of San Luis Obispo

The City of San Luis Obispo has several regulations and standards that pertain to stormwater management, including:

- Municipal Code
- Waterway Management Plan (which includes the Drainage Design Manual)
- Standard Specifications and Engineering Standards

2.2. Municipal Code

There following sections of the Municipal Code pertain to stormwater management.

Creek Setbacks (Municipal Code 17.16.025)

The City's Creek Setback requirement applies to all creeks that are shown on Figure 9 of the Conservation and Open Space Element in the General Plan. Prefumo Creek is shown on that figure as a "perennial creek with good riparian corridor." Per the code, a 35-foot setback is required for Prefumo Creek "from the existing top of bank (or the future top of bank resulting from a creek alteration reflected in a plan approved by the city), or from the edge of the predominant pattern of riparian vegetation, whichever is farther from the creek flow line".

Cerro San Luis Channel is shown on Figure 9 of the Conservation and Open Space Element in the General Plan as an "intermittent creek with good riparian corridor". Per the code, a 20-foot setback is required for Prefumo Creek "from the existing top of bank (or the future top of bank resulting from a creek alteration reflected in a plan approved by the city), or from the edge of the predominant pattern of riparian vegetation, whichever is farther from the creek flow line".

Floodplain Management Regulations (Municipal Code 17.84)

The City's Floodplain Management Regulations apply to areas of special flood hazard as identified by FEMA, which are areas that FEMA has identified as subject to inundation by the 1% annual chance flood (100-year flood). The FEMA Flood Insurance Rate Map Number 06079C1069G, Panel 1068 (Appendix A) shows a large portion the project site to be within Zone A of the 1% annual chance floodplain boundary (100-year floodplain). Zone A includes areas where no base flood elevations have been determined, and floodplains in these areas are typically determined using approximate methodologies and not a detailed hydraulic analysis. Per the code, the following pertain to the proposed project:

- The proposed development is within a special floodplain management zone as defined by the City of San Luis Obispo (see requirements from Waterway Management Plan below), so the requirements in the Drainage Design Manual for those zones must be met
- Base flood elevations for the project site must be determined
- A approved Letter of Map Revision (LOMR) is required prior to issuance of building permits
- All proposed nonresidential structures require certification from a registered civil engineer or architect that they are flood-proofed in accordance with Section 17.84.050(A)(3) of the Municipal Code
- All proposed residential structures require post-construction certification from a registered civil engineer or licensed land surveyor that their lowest floors are one foot above the base flood elevation
- Public utilities and facilities such as sewer, gas, electrical and water systems are to be located and constructed to minimize flood damage

2.3. Waterway Management Plan (which includes the Drainage Design Manual)

The Waterway Management Plan (WMP) is a watershed-based management plan for San Luis Obispo Creek and its tributaries. The Drainage Design Manual (DDM) is Volume 3 of the WMP, and provides design guidance and criteria intended to meet surface water management objectives. The following are some of the sections that pertain to the proposed project:

Off-Site Facility Analysis, Design, and Mitigation (DDM 3.3)

Runoff shall be managed to prevent any significant increase in downstream peak flows, including 2-year, 10-year, 50-year, and 100-year events. Significant generally means an increase of over 5 percent at and immediately downstream of the project site.

Special Floodplain Management Zone Regulations (DDM 3.5.3)

A large portion of the project site is located in Special Floodplain Management Zone #2, as identified by Figure DDM 3-1 (Appendix A) in the DDM. These areas have been determined to have a potentially significant effect on downstream flooding and bank stability, and therefore development of these areas is restricted in the following ways:

- The project shall not cause the 100-year flood elevation to increase more than 2.5 inches
- The project shall not cause stream velocities to increase more than 0.3 ft/s
- The project shall not cause a significant net decrease in floodplain storage volume unless several exceptions are met.

Erosion Control and Stormwater Quality Requirements (DDM 3.7)

The proposed project is over 2.5 hectares in size, so a detailed erosion control plan is required and shall be prepared in accordance with Section 10.0 of the DDM.

Analysis and Design of Bank Stabilization Structures (DDM 6.0)
The proposed bench for Prefumo Creek and widened section of Cerro San Luis Channel shall be designed in accordance with Section 6.0 of the DDM to provide for bank stability and to minimize impacts to aquatic and riparian habitat.

Channel and Conduit Capacity (DDM 7.2.1) and Hydraulic Gradient (7.2.10)
This section requires that conveyance systems shall be designed to convey the peak runoff for the 10-year design storm with the hydraulic gradient a minimum of 6 inches below the elevation of the inlet grates and manhole covers. In addition, an overland conveyance shall be provided for the 100-year event such that the water surface elevation is at least 1 foot below the finish floor of adjacent structures.

Inlets and Catch Basins (DDM 7.2.7)
Inlets shall be spaced so that gutter flow does not exceed a depth of 6 inches at the face of the curb for a 10-year storm and so that a 100-year storm will not cause any damage and can be contained within the right of way.

Outfalls/Open Channel & Pipe Systems (DDM 7.4.5)
Outfalls shall be above the mean low water (2-year flow) level unless the City approves an exception.

2.4. Central Coast Regional Water Quality Control Board (RWQCB)

The RWQCB is responsible for administering and enforcing the National Pollutant Discharge Elimination System (NPDES) permit program, as authorized by the federal Clean Water Act. This program regulates the quality of stormwater that is discharged to surface water bodies. There are two separate permits that this project is required to obtain coverage under, one that applies to stormwater discharges during construction, and one that applies to stormwater discharges after construction is complete.

During Construction – Construction General Permit
Construction projects that disturb one or more acres of soil during construction are required to obtain coverage under the Construction General Permit. This permit requires the development and implementation of a Storm Water Pollution Prevention Plan (SWPPP). The SWPPP must list Best Management Practices (BMPs) the discharger will use to protect stormwater runoff and the placement of those BMPs. Additionally, the SWPPP must contain a visual monitoring program and a chemical monitoring program for "non-visible" pollutants to be implemented if there is a failure of BMPs. Section A of the Construction General Permit describes the elements that must be contained in a SWPPP.

Post-Construction – Phase II Municipal General Permit
The Phase II Municipal General Permit applies to stormwater discharges from small Municipal Separate Storm Sewer Systems (MS4s). To comply with the requirements of the Phase II Municipal General Permit, the RWQCB approved Post-Construction Stormwater Management Requirements for Development Projects in the Central Coast

Region (Post-Construction Requirements) through adoption of Resolution R3-2013-0032. A summary of the post-construction requirements is as follows:

- *Performance Requirement No. 1: Site Design and Runoff Reduction*
  This requirement is intended to limit the disturbance creeks and natural drainage features, minimize compaction of highly permeable soils, limit clearing and grading of native vegetation, minimize impervious surfaces, and minimizing stormwater runoff by collecting it for reuse and by infiltrating it onsite.
- *Performance Requirement No. 2: Water Quality Treatment*
  This requirement is intended to provide onsite retention or treatment (physical, biological, or chemical) of stormwater runoff from developed areas to reduce the discharge of pollutants from the site.
- *Performance Requirement No. 3: Runoff Retention*
  The requirement is intended to maintain the pre-developed hydrology with respect to volume, flow rate, and duration for the site by reducing overland flow and promoting groundwater recharge. The project site is located in Watershed Management Zone 1 per the map included in Resolution R3-2013-0032, which are areas subject to Performance Requirement No. 3.
- *Performance Requirement No. 4: Peak Management*
  The requirement is intended to maintain the pre-developed hydrology with respect to peak discharge from the site. This requirement states that the post-development peak flows discharged from the site shall not exceed the pre-project peak flows for the 2-though 10-year storm events.

2.5. California Department of Fish and Wildlife (CDFW)

A biological study was conducted to define the limits of jurisdiction for the California Department of Fish and Wildlife (CDFW), which includes portions along Prefumo Creek and Cerro San Luis Channel. Any work that is within CDFW jurisdiction will require permitting through CDFW.

2.6. Federal Emergency Management Agency (FEMA)

The Federal Emergency Management Agency (FEMA) has established flood insurance zones throughout the City of San Luis Obispo. Development within these zones must be in compliance with both the City and FEMA regulations.

The FEMA Flood Insurance Rate Map Number 06079C1331G (Appendix A) shows a large portion of the project site within the Zone A of the 1% annual chance floodplain boundary (100-year floodplain). Zone A includes areas where no base flood elevations have been determined, and floodplains in these areas are typically determined using approximate methodologies and not a detailed hydraulic analysis.

The Conditional Letter of Map Revision (CLOMR) and Letter of Map Revision (LOMR) processes will be required to modify flood insurance zones on project property and, if necessary, in the adjacent areas affected by the proposed project.

2.7. US Army Corps of Engineers (USACE)

A biological study was conducted to define the limits of jurisdiction for the US Army Corps of Engineers (USACE), which includes Federal Wetlands and Other Waters of the United States as defined by Section 404 of the Clean Water Act. Both types of waterbodies were defined along portions of Prefumo Creek and Cerro San Luis Channel. Any work that is within USACE jurisdiction will require permitting through USACE.

3. Existing Drainage Conditions

3.1. Description of Existing Offsite Flows that Discharge onto Project

Prefumo Creek, a seasonal creek, runs along the western portion of the project site and flows north to south. The reach of Prefumo Creek that passes through the site is immediately downstream of Laguna Lake and upstream of the confluence with San Luis Creek and is referred to as lower Prefumo Creek. Flow in lower Prefumo Creek is attenuated by Laguna Lake, which has an outlet control structure and functions as a detention pond (SLO WMP, Vol. 1).

The project site is bisected by a seasonal drainage called Cerro San Luis Channel. This channel conveys flow that discharges from underground culverts and surface flow at Dalidio Drive to lower Prefumo Creek. The underground culverts extend from the north corner of the intersection of Madonna Road and the Madonna Inn entrance through the Madonna Plaza and SLO Promenade commercial centers and discharge into Cerro San Luis Channel at Dalidio Drive near the east corner of the US Post Office. Areas that contribute flow to the culverts include a portion of Cerro San Luis, the Madonna Inn, Madonna Road, and the Madonna Plaza and SLO Promenade commercial centers. The culverts consist of three approximately 3-ft high by 7-ft wide box culverts from Madonna Road to El Mercado, where they transition to three approximately 3-ft high by 9-ft wide box culverts from El Mercado to Dalidio Drive ("As-Built" Drawings for San Luis Obispo Mall Project prepared by Contract Survey and Design, Inc., 10/3/87).

In addition to the two channels described above, a significant amount of offsite flow enters the project site at the north-east corner of the property adjacent to Hwy. 101 and the Embassy Suites parking lot (Wallace Group, 2014). There is an existing structure along the Embassy Suites parking lot that consists of a flat gutter and curb. It appears that the intent of this structure was that it would function as a weir and discharge flow evenly across its length. However, due to grading along the flow spreader structure and portions of it being modified, it appears that discharge would be concentrated along the Hwy. 101 side of the structure and onto the eastern side of the project site. In addition to the flow from the commercial center, during a 100-yr flood event, flow from San Luis Creek overtops Hwy. 101 and enters the project site from the east (Wallace Group, 2014).

3.2. Description of Existing Onsite Drainage Conditions

The site consists of approximately 131.4 acres of mostly agricultural land, along with wooded land, a few residences and miscellaneous farm structures, and the two channel corridors associated with Prefumo Creek and Cerro San Luis Channel. The area considered for this study is shown on Figure 2. The study area for the existing conditions was divided into four sub-basins based on the reach of the channel to which they contribute.

Sub-basin Exist-1 includes the area that drains to the reach of Prefumo Creek between Madonna Road and the confluence with Cerro San Luis Channel, referred to in this study as Reach 1. This area includes wooded land, residences and miscellaneous farm structures, and a portion of Madonna Road.

Sub-basin Exist-2 includes the area the drains to Cerro San Luis Channel, referred to in this study as Reach 2. This area includes agricultural land, wooded land, residences and miscellaneous farm structures, the US Post Office and a portion of Dalidio Drive.

Sub-basin Exist-3 includes the area that drains to the reach of Prefumo Creek between the confluence with Cerro San Luis Channel and the proposed Froom Ranch Way bridge, referred to in this study as Reach 3. This area includes agricultural and wooded land.

Sub-basin Exist-4 includes the area that drains to the reach of Prefumo Creek downstream of the proposed Froom Ranch Way bridge, referred to in this study as Reach 4. This area includes the majority of the agricultural area, which generally sheet flows from north to south and enters Prefumo Creek downstream of the project site.

3.3. Hydrologic Analyses of Existing Conditions

Hydrologic Analysis of Study Area

Hydrologic analyses were performed as part of this study to estimate the magnitudes of the stormwater runoff from the project study area considering the existing condition of the site. The project study area is shown on Figure 2. The US Army Corps of Engineers' HEC-HMS (Version 4.1) model was used to perform the hydrologic analyses and is based on the following methodology:

- Watershed Model
    - Loss Method: SCS Curve Number (CN)
    - Hydrograph Transformation Method: SCS Unit Hydrograph lag time
    - Baseflow Method: None
- Flow Routing: None
- Precipitation Model: Specified Hyetograph – 24-hour Storm A hyetographs from City of San Luis Obispo HEC-HMS Model (rainfall depths from Table C-3 SLO WMP, Vol. 1)
    - 2-year rainfall depth: 3.3 inches
    - 10-year rainfall depth: 4.6 inches

- 25-year rainfall depth: 5.7 inches
- 50-year rainfall depth: 6.5 inches
- 100-year rainfall depth: 6.7 inches
- Time Interval: 5 minutes

Composite curve numbers and lag times were calculated for each sub-basin, and those calculations are included in Appendix B. These parameters, along with the sub-basin areas, were input into the HEC-HMS model for each sub-basin and runoff hydrographs for several design storms were generated. The combined hydrographs for all sub-basins in the study area are included in Appendix B and a summary of the peak flows is shown in Table 1.

Table 1 - Summary of peak flows for discharge from study area for existing conditions

Storm Event	Peak Flow (cfs)				
	Sub-basin Exist-1	Sub-basin Exist-2	Sub-basin Exist-3	Sub-basin Exist-4	Total Combined
2-year	3.73	16.3	5.4	41.2	54.2
10-year	6.58	28.6	9.7	74.2	96.7
25-year	8.21	35.6	12.3	93.6	122
50-year	9.52	41.2	14.2	108	140
100-year	10.7	46.0	16.0	122	158

Hydrologic Analysis of Study Area and Cerro San Luis Channel

The proposed approach to peak flow management for this project involves diverting flow out of the upstream end of Cerro San Luis Channel, detaining it, and then reintroducing it into the system at a lower flow, resulting in an overall reduction in peak flow for the system. Therefore, the “existing condition” for peak flow management includes the combined flows from the study area in its existing condition and the inflow into Cerro San Luis Channel. For that reason, the flows from offsite that are discharged into Cerro San Luis Channel had to be estimated as part of this study.

Wallace Group has studied the hydrology for Cerro San Luis Channel and they provided the basis for the estimation of flows that are discharged into the upstream end of the channel. They used the City of San Luis Obispo’s HEC-HMS model as a starting point for the analysis. The sub-basins within the City’s model that contribute flow to Cerro San Luis Channel include the Madonna Inn and Lower Prefumo sub-basins. The Madonna Inn sub-basin is the area that contributes flow to the upstream end of the triple box culvert at Madonna Road. Wallace extracted from the Lower Prefumo sub-basin the area upstream of the San Luis Ranch project and designated it the Madonna Plaza sub-basin. Only a portion of the flow from the Madonna Plaza sub-basin contributes to Cerro San Luis Channel, as the remainder enters the project site at the north-east corner near Embassy Suites. Wallace estimated that 72% of the runoff from the Madonna Plaza sub-basin discharges into Cerro San Luis Channel.

Wallace provided hydrographs for the Madonna Inn and Madonna Plaza sub-basins. Hydrographs for the flow into the upstream end of Cerro San Luis Channel were developed by combing the hydrograph from the Madonna Inn sub-basin and 72% of the hydrograph from the Madonna Plaza sub-basin. The resulting hydrographs for inflow into Cerro San Luis Channel for all of the design storms are shown in Appendix B.

For purposes of this analysis, it was assumed that all flow that enters Cerro San Luis Channel stays within the channel. Hydraulic modeling performed by Wallace shows that at high flows the channel is overtopped and the flow that leaves the channel flows across the agricultural area and enters Prefumo Creek downstream of the confluence of the two channels. Based on that, the assumption stated above is violated when flows within Cerro San Luis Channel are high. However, the peak flow in Prefumo Creek is mostly due to the outflow from Laguna Lake which occurs after the peak in Cerro San Luis Channel. When the peak flow in Prefumo Creek occurs, the flow in Cerro San Luis Channel is contained within the channel, so the assumption when considering flows in Prefumo Creek.

The hydrographs developed for the inflow to Cerro San Luis Channel were combined with the hydrographs developed for the study area to develop peak flows for each stream reach. The hydrographs developed for Reach 4 is included in Appendix B and the peak flows for all reaches are shown in Table 2. These are the peak flows for the "existing conditions" that were used to design the stormwater detention system for peak flow management.

Table 2 - Summary of peak flows for combined discharge from study area and Cerro San Luis Channel for existing conditions

Storm Event	Peak Flow (cfs)			
	Reach 1	Reach 2	Reach 3	Reach 4
2-year	3.73	236	243	266
10-year	6.58	459	471	512
25-year	8.21	604	620	674
50-year	9.52	726	743	804
100-year	10.7	819	839	906

Hydrologic Analysis of Study Area, Cerro San Luis Channel, and Laguna Lake Outflow

While the peak flows given in Table 2 were used for the basis of design of the detention system, they do not account for the flows out of Laguna Lake. The actual flows in Prefumo Creek will be much higher than the flows presented in Table 2 as a result of the flow out of Laguna Lake. To provide a more thorough analysis of the effect of the proposed project on the flows in Prefumo Creek, the flows out of Laguna Lake were considered.

The flows out of Laguna Lake were estimated using the City of San Luis Obispo's HEC-HMS model (Version 3.0.0) and the following parameters:

- Precipitation Model: Specified Hyetograph – 24-hour Storm A hyetographs from City of San Luis Obispo HEC-HMS Model (rainfall depths from Table C-3 SLO WMP, Vol. 1)
- Beginning Lake Elevation:

  - 2-yr: 36.65 m
  - 10-yr: 38.39 m
  - 25-yr: 38.97 m
  - 50-yr: 39.15 m
  - 100-yr: 39.47 m
- Elevation-Area Function: Laguna Lake (Prefumo Creek)
- Elevation-Discharge Function: Laguna Lake (Prefumo Creek)

The resulting hydrographs for flow out of Laguna Lake for all of the design storms are shown in Appendix B and the resulting peak flows are shown in Table 3.

Table 3 - Summary peak flows from Laguna Lake outflow

Storm Event	Peak Flow (cfs)
2-year	418
10-year	987
25-year	1,421
50-year	1,699
100-year	2,036

The hydrographs developed for the outflows from Laguna Lake were combined with the hydrographs developed for the study area and Cerro San Luis Channel to develop peak flow for each stream reach. Channel routing was not accounted for as the reach lengths are relatively short. The hydrographs developed for Reach 4 is included in Appendix B and the peak flows for all reaches are shown in Table 4.

Table 4 - Summary peak flows for combined discharge from study area, Cerro San Luis Channel, and Laguna Lake outflow for existing conditions

Storm Event	Peak Flow (cfs)			
	Reach 1	Reach 2	Reach 3	Reach 4
2-year	418	236	445	451
10-year	988	459	1,045	1,062
25-year	1,093	604	1,502	1,526
50-year	1,700	726	1,796	1,820
100-year	2,037	819	2,142	2,172

4. Proposed Drainage Conditions

4.1. <u>Description of Proposed Drainage Conditions</u>

The project consists of the construction of a new 302 lot residential development. Single family houses will be constructed on each of the 302 lots. In general, the lots vary in size from about 2,400 sf to 3,200 sf, although there are some larger lots. The other major surface improvements are new streets and sidewalks. The major proposed drainage features are shown on Figure 4 and include a culvert extension/diversion structure at the upstream end of Cerro San Luis Channel, an underground detention system adjacent to the Cerro San Luis Channel on a future commercial lot, an underground retention facility beneath the proposed park, two storm drain outfalls in Prefumo Creek, and two storm drain outfalls in Cerro San Luis Channel. Per the recommendations in *San Luis Ranch Preliminary Drainage Report* (Wallace 2014), the proposed drainage improvements also include widening Cerro San Luis Channel by approximately 30-feet to provide capacity for the 100-year peak flow, and constructing a bench (approximately 19-feet wide by 3-feet deep) on the east bank of Prefumo Creek between the confluence with Cerro San Luis Channel and the proposed Froom Ranch Way bridge to provide additional capacity to reduce the risk of flooding the existing homes adjacent to the creek in that area. There are also proposed bridges where Froom Ranch Way crosses Prefumo Creek and where “A” Street crosses Cerro San Luis Channel.

Most of the proposed lots will drain to the streets, although several along the exterior of the development will drain directly to bioretention areas. Runoff that collects in the sidewalks and streets is proposed to be conveyed by surface flow in the gutters and streets to curb inlets or bioretention facilities with inlets. The inlets will be connected to underground pipes that will ultimately convey the runoff to one of the outfalls. There are three emergency overland flow routes proposed for the single family residential area, and one for the Froom Ranch Way bridge, and those are shown on Figure 4.

The area considered for this study is shown on Figure 3. The study area for the proposed conditions was divided into four major sub-basins based on the reach of the channel to which they contribute. Major sub-basins Prop-2, -3, and -4 were divided into minor sub-basins, for example, sub-basin Prop-3C is a minor sub-basin to the major sub-basin Prop-3.

Sub-basin Prop-1 includes the area that drains to the reach of Prefumo Creek between Madonna Road and the confluence with Cerro San Luis Channel, referred to in this study as Reach 1. This area includes wooded land, future landscape areas, and a portion of Madonna Road.

Sub-basin Prop-2 includes the area the drains to Cerro San Luis Channel, referred to in this study as Reach 2. This area includes wooded land, future multi-family residential areas, the US Post Office and a portion of Dalidio Drive.

Sub-basin Prop-3 includes the area that drains to the reach of Prefumo Creek between the confluence with Cerro San Luis Channel and the proposed Froom Ranch Way bridge, referred to in this study as Reach 3. This area includes wooded land and single family residential development.

Sub-basin Prop-4 includes the area that drains to the reach of Prefumo Creek downstream of the proposed Froom Ranch Way bridge, referred to in this study as Reach 4. This area includes agricultural area, proposed single family residential areas and rough graded pads for future commercial development.

The proposed approach to peak flow management for this project involves diverting flow out of the upstream end of Cerro San Luis Channel, detaining it in an underground detention facility, and then reintroducing it into Prefumo Creek at a lower flow, resulting in an overall reduction in peak flow for the system. The proposed facility was designed to account for the increase in peak flow associated with the proposed single family residential development and streets shown on Figure 3, and also for future multi-family development to occur at sub-basins Prop-2C and Prop-2D. The areas of the site planned for future commercial development were considered to be undeveloped as part of this study, so those properties will need their own detention facilities as part of their development.

4.2. Hydrologic Analysis of Proposed Conditions

Hydrologic Analysis of Study Area

Hydrologic analyses were performed as part of this study to estimate the magnitudes of the stormwater runoff from the project study area considering the proposed condition of the site. The US Army Corps of Engineers' HEC-HMS model was used to perform the hydrologic analyses and is based on the methodology described in Section 3.3.

Composite curve numbers and lag times were calculated for each sub-basin, and those calculations are included in Appendix C. These parameters, along with the sub-basin areas, were input into the HEC-HMS model for each sub-basin and runoff hydrographs for several design storms were generated. The combined hydrographs for all sub-basins in the study area are included in Appendix C and a summary of the peak flows is shown in Table 5.

Table 5 - Summary of peak flows for discharge from study area for proposed conditions

Storm Event	Peak Flow (cfs)				
	Sub-basin Prop-1	Sub-basin Prop-2	Sub-basin Prop-3	Sub-basin Prop-4	Total Combined
2-year	3.68	23.5	23.4	38.0	88.6
10-year	6.48	39.7	40.2	67.0	153
25-year	8.10	48.6	49.7	85.4	192
50-year	9.38	55.8	57.3	97.9	220
100-year	10.4	61.9	63.6	109	244

Hydrologic Analysis of Study Area and Cerro San Luis Channel

As described above, the proposed approach to peak flow management for this project involves diverting flow out of the upstream end of Cerro San Luis Channel, detaining it, and then reintroducing it into the system at a lower flow, resulting in an overall reduction in peak flow for the system. Therefore the "proposed condition" for peak flow management includes the combined flows from the study area in its proposed condition, the flows in Cerro San Luis Channel downstream of the proposed diversion structure, and the discharge from the proposed detention facility.

A model was developed to estimate the effect of the proposed diversion structure and underground detention facility on the inflows to Cerro San Luis Channel. The development of the hydrographs for the inflow to Cerro San Luis Channel is described in Section 3.3, and these hydrographs were input into the model. The model takes the input hydrographs for the flow into the diversion structure and estimates hydrographs for flow that remains in Cerro San Luis Channel and flow out of the detention facility. See Appendix E for more information on the model that was developed for the diversion structure and detention facility.

The hydrographs developed for the flow that remains in Cerro San Luis Channel and flow out of the detention facility were combined with the hydrographs developed for the study area to develop peak flows for each stream reach. The flow out of the detention facility is proposed to be discharged into Reach 4 (Prefumo Creek downstream of the proposed Froom Ranch Way bridge) to distribute flow in a manner more consistent with the existing drainage conditions. The hydrographs developed for Reach 4 is included in Appendix C and the peak flows for all reaches are shown in Table 6 through Table 9. These are the peak flows for the "proposed conditions" that were used to design the stormwater detention system for peak flow management. The flows for the "existing conditions" are also shown in Table 6 through Table 9. The estimated peak flows for all reaches for all design storms are lower in the proposed condition than the existing condition.

Table 6 - Summary of peak flows for combined discharge from study area and Cerro San Luis Channel for Reach 1

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	3.73	6.58	8.21	9.52	10.7
Proposed Conditions	3.68	6.48	8.10	9.38	10.4
Difference	-0.06	-0.10	-0.11	-0.14	-0.22
% Change	-1.5%	-1.5%	-1.4%	-1.4%	-2.0%

Table 7 - Summary of peak flows for combined discharge from study area and Cerro San Luis Channel for Reach 2

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	236	459	604	726	819
Proposed Conditions	203	364	469	548	623
Difference	-32.5	-94.6	-135	-178	-196
% Change	-13.8%	-20.6%	-22.4%	-24.6%	-24.0%

Table 8 - Summary of peak flows for combined discharge from study area and Cerro San Luis Channel for Reach 3

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	243	471	620	743	839
Proposed Conditions	226	403	517	603	684
Difference	-16.7	-67.7	-103	-141	-155
% Change	-6.9%	-14.4%	-16.6%	-18.9%	-18.4%

Table 9 - Summary of peak flows for combined discharge from study area and Cerro San Luis Channel for Reach 4

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	266	512	674	804	906
Proposed Conditions	265	483	624	731	830
Difference	-0.6	-29.3	-49.2	-73.0	-76.2
% Change	-0.2%	-5.7%	-7.3%	-9.1%	-8.4%

Hydrologic Analysis of Study Area, Cerro San Luis Channel, and Laguna Lake Outflow

While the peak flows given in Table 6 through Table 9 were used for the basis of design of the detention system, they do not account for the flows out of Laguna Lake. The actual flows in Prefumo Creek will be much higher than the flows presented in Table 6 through Table 9 as a result of the flow out of Laguna Lake. To provide a more thorough analysis of the effect of the proposed project on the flows in Prefumo Creek, the flows out of Laguna Lake were considered.

The hydrographs developed for the outflows from Laguna Lake (described in Section 3.3) were combined with the hydrographs developed for the study area and Cerro San Luis Channel to develop peak flow for each stream reach. Channel routing was not accounted for as the reach lengths are relatively short. The hydrographs developed for Reach 4 is included in Appendix C and the peak flows for all reaches are shown in Table 10 through Table 13.

Table 10 - Summary of peak flows for combined discharge from study area, Cerro San Luis Channel, and Laguna Lake outflow for Reach 1

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	418	988	1,422	1,700	2,037
Proposed Conditions	418	988	1,421	1,700	2,037
Difference	-0.02	-0.23	-0.25	-0.28	-0.39
% Change	0.0%	0.0%	0.0%	0.0%	0.0%

Table 11 - Summary of peak flows for combined discharge from study area, Cerro San Luis Channel, and Laguna Lake outflow for Reach 2

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	236	459	604	726	819
Proposed Conditions	203	364	469	548	623
Difference	-32.5	-94.6	-135	-178	-196
% Change	-13.8%	-20.6%	-22.4%	-24.6%	-24.0%

Table 12 - Summary of peak flows for combined discharge from study area, Cerro San Luis Channel, and Laguna Lake outflow for Reach 3

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	445	1,045	1,502	1,796	2,142
Proposed Conditions	446	1,047	1,501	1,793	2,138
Difference	1.0	1.6	-0.8	-2.7	-4.1
% Change	0.2%	0.2%	-0.1%	-0.1%	-0.2%

Table 13 - Summary of peak flows for combined discharge from study area, Cerro San Luis Channel, and Laguna Lake outflow for Reach 4

Scenario	Peak Flow (cfs)				
	2-year	10-year	25-year	50-year	100-year
Existing Conditions	451	1,062	1,526	1,820	2,172
Proposed Conditions	452	1,063	1,530	1,824	2,179
Difference	0.8	1.0	3.8	4.1	7.5
% Change	0.2%	0.1%	0.2%	0.2%	0.3%

Table 12 and Table 13 show slight increases in the flows in the reaches of Prefumo Creek that are downstream of the confluence with Cerro San Luis Channel. These increases are minor, not exceeding 0.3% for any of the design storms.

4.3. Major Drainage Features

Cerro San Luis Channel Culvert Extension & Diversion Structure

The proposed improvements include widening Dalidio Drive where the existing triple box culvert discharges into the upstream of Cerro San Luis Channel. The culverts need to be extended to account for the road widening. The proposed improvements also include widening Cerro San Luis Channel by 30-feet, so the culverts need to transition to a wider footprint to match the channel width. It is also anticipated that a substantial amount of surface flow from the SLO Promenade and Dalidio Drive will be collected by the proposed inlets on the south side of Dalidio Drive and discharged into the culverts, so the culvert widening will provide additional capacity for the additional flow added to them.

It is proposed that a diversion structure be included with the culvert extension. The diversion structure will divert water out of Cerro San Luis Channel and into the underground detention facility where it will be temporarily stored, then discharged at a lower rate into Prefumo Creek. Flow will enter the detention facility through a large opening (13.50' wide by 2.50' high) in the eastern wall of the diversion structure. The opening will function as weir until fully submerged, at which point it will function as an orifice. A numerical model was developed as part of this study to estimate the distribution of flow between the detention facility and Cerro San Luis Cannel for flow that enters the diversion structure. A description of that model is included in Appendix E.

Water that leaves the diversion structure though the detention facility inlet will be conveyed by the detention intake channel to the detention facility. The intake channel has been sized to reduce headloss for flow passing through it so that it has an insignificant impact on the function of the inlet. The channel was modeled using the gradually varied flow equation, which is included in Appendix D.

Detention Facility

The proposed detention facility is shown in Figure 4 and will temporarily store water diverted out of Cerro San Luis Channel and then reintroducing it into Prefumo Creek downstream of the proposed Froom Ranch Way bridge at a lower flow rate. The reason for discharging the flow into Prefumo Creek rather than back into Cerro San Luis Channel is to better match the existing distribution of flows among the stream reaches, and to reduce the risk of flooding for the existing residences along Prefumo Creek.

The proposed detention facility is composed of open-bottom concrete chambers underlain by rock. This facility will promote infiltration and will provide for some stormwater retention as the proposed outlet pipe is above the bottom of the rock. Flow out of the detention system will be controlled by a flow control structure that contains orifices or weirs, or both. As part of this study, the outlet structure was modeled as a Cipoletti weir with a bottom width of 2-feet. A numerical model was developed as part of this study to estimate the flow into, flow out of, and water surface elevation within the proposed detention structure. Graphs showing those variables for each design storm are included in Appendix C. A description of the model that was developed for the detention system routing is included in Appendix E.

Outfalls to Channels

There are four proposed storm drain outfalls for this project, and they are shown on Figure 4. Two outfalls are proposed into Cerro San Luis Channel for the runoff from north side of the channel, which includes the future multi-family residential development planned for that area. The third outfall is proposed in Prefumo Creek between the confluence with Cerro San Luis Channel and the Froom Ranch Way bridge which will discharge runoff from a large portion of the single family residential development. The fourth outfall is proposed in Prefumo Creek downstream of the Froom Ranch Way bridge which will discharge the outflow from the detention system, and also the runoff from a large portion of the single family residential development, Froom Ranch Way, and Dalidio Drive.

The proposed outfalls consist of pipes that discharge through a headwall onto riprap aprons. Preliminary sizing of the pipes and riprap aprons has been performed as part of this study and those calculations are included in Appendix D.

Retention Facilities

Retention facilities are proposed as part of this project to comply with the requirements of the RWQCB, and they include several vegetated bioretention facilities and a large underground facility. The bioretention facilities will provide retention volume in surface depressions, porosity in the topsoil, and porosity in sub-surface rock beneath the facilities. The underground facility will provide retention in plastic arch chambers and porosity in rock beneath and around the chambers. The sizing of these facilities is included in the *Stormwater Control Plan for Post-construction Requirements* prepared by Cannon under separate cover.

Bridges

There are two bridges proposed as part of this project; one where Froom Ranch Way crosses Prefumo Creek, and one where Street "A" crosses Cerro San Luis Channel. The proposed bridges are planned to span the 100-yr floodplain and provide 12-inches of freeboard from the bottom of the bridges to the 100-yr water surface elevation.

Emergency Overland Flow Routes

There are three emergency overland flow routes for the single family residential portion of the project. The routes correspond with localized low points in the site and are intended to provide a route for stormwater to drain from the site without damaging residences in the event that the storm drain infrastructure were to fail.

There is also a proposed emergency overland flow route for the Froom Ranch Way bridge in the event that debris were to block a portion of the flow path under the bridge. A low point has been designed into Froom Ranch Way east of the bridge to be below the finished floor elevations of the existing residences along Prefumo Creek to help reduce the risk of flooding those structures.

4.4. Post-construction Phase II Municipal General Permit Requirements

The post-construction requirements associated with the Phase II Municipal General Permit are summarized in Section 2.4. Compliance with these requirements is intended to be achieved by implementing strategies that include maintaining creek setbacks and constructing retention and detention facilities. A *Stormwater Control Plan for Post-*

construction Requirements was prepared for the project by Cannon under separate cover.

4.5. Floodplain Analysis

The FEMA Flood Insurance Rate Map Number 06079C1331G (Appendix A) shows a large portion of the project site within the Zone A of the 1% annual chance floodplain boundary (100-year floodplain). In addition, Figure DDM 3-2c (Appendix A) from the Drainage Design Manual shows a large portion of the project site within the 100-year floodplain.

The proposed improvements incorporate significant modifications within the existing floodplain, including placing fill within the floodplain to remove the proposed development from the floodplain, widening Cerro San Luis Channel to increase its capacity, and adding a bench to Prefumo Creek to increase its capacity.

Wallace Group is conducting the floodplain analysis for this study under separate cover. They have developed a hydraulic model for the project area and have established base flood elevations for the project in its existing and proposed conditions. Those elevations were used as the basis of design for the proposed grading and drainage design. Wallace Group is also preparing the Conditional Letter of Map Revision (CLOMR) associated with this project for processing through the City of San Luis Obispo and FEMA.

References

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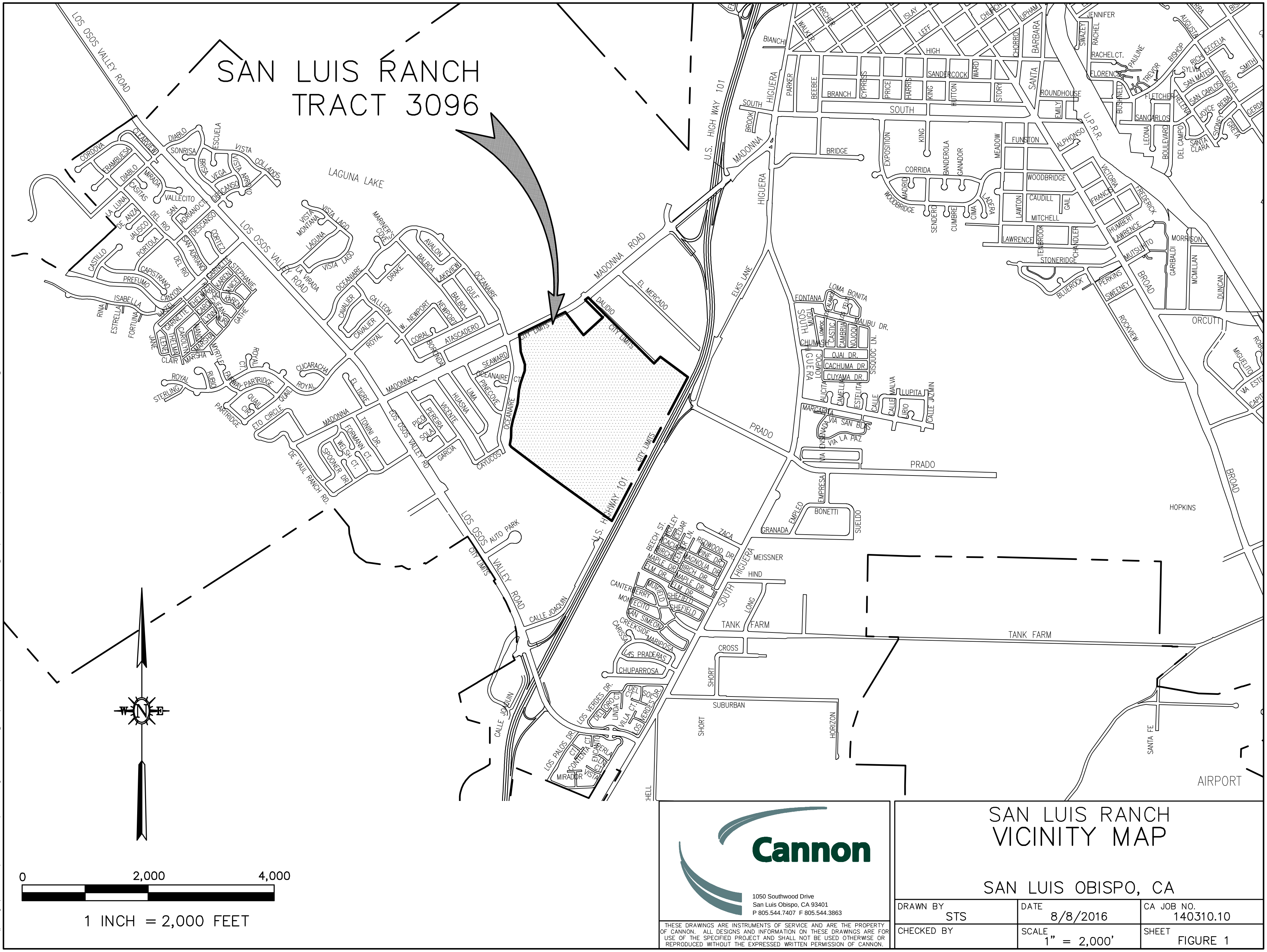

![Cannon]

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SAN LUIS RANCH VICINITY MAP

SAN LUIS OBISPO, CA

DRAWN BY	DATE	CA JOB NO.
STS	8/8/2016	140310.10
CHECKED BY	SCALE 1" = 2,000'	SHEET FIGURE 1

0 400 800

1 INCH = 400 FEET

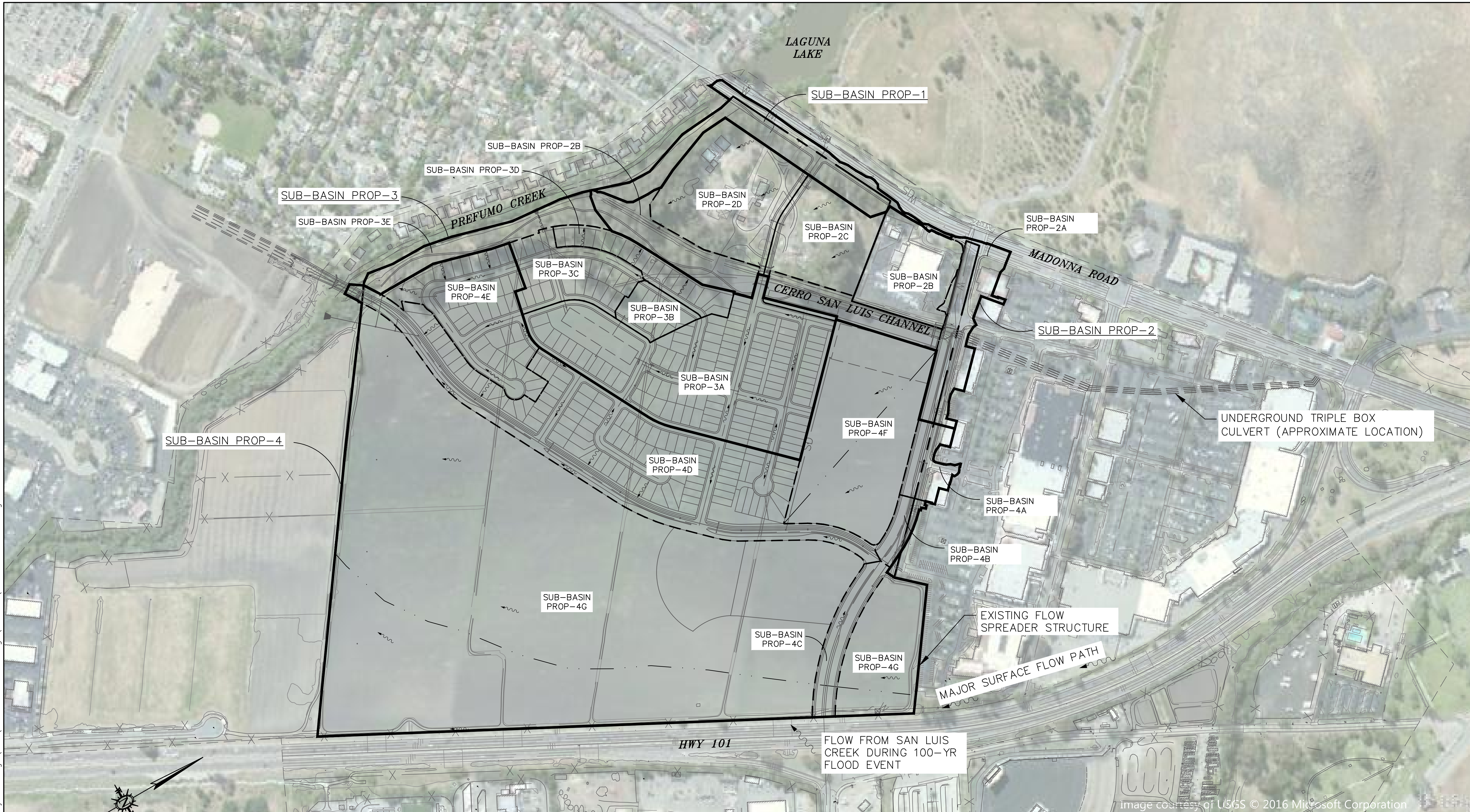
LEGEND

- STUDY AREA BOUNDARY
- SUB–BASIN BOUNDARY
- ROUTE USED FOR TIME OF CONCENTRATION CALCULATION
- SURFACE RUNOFF FLOW DIRECTION

Cannon
1050 Southwood Drive
San Luis Obispo, CA 93401
P 805.544.7407 F 805.544.3863

SAN LUIS RANCH
DRAINAGE MAP
EXISTING CONDITIONS
SAN LUIS OBISPO, CA

DRAWN BY	DATE	CA JOB NO.
STS	8/5/2016	140310.10
CHECKED BY	SCALE	SHEET
	1" = 400'	FIGURE 2



0 400 800

1 INCH = 400 FEET

LEGEND

MAJOR SUB-BASIN BOUNDARY

MINOR SUB-BASIN BOUNDARY

ROUTE USED FOR TIME OF CONCENTRATION CALCULATION

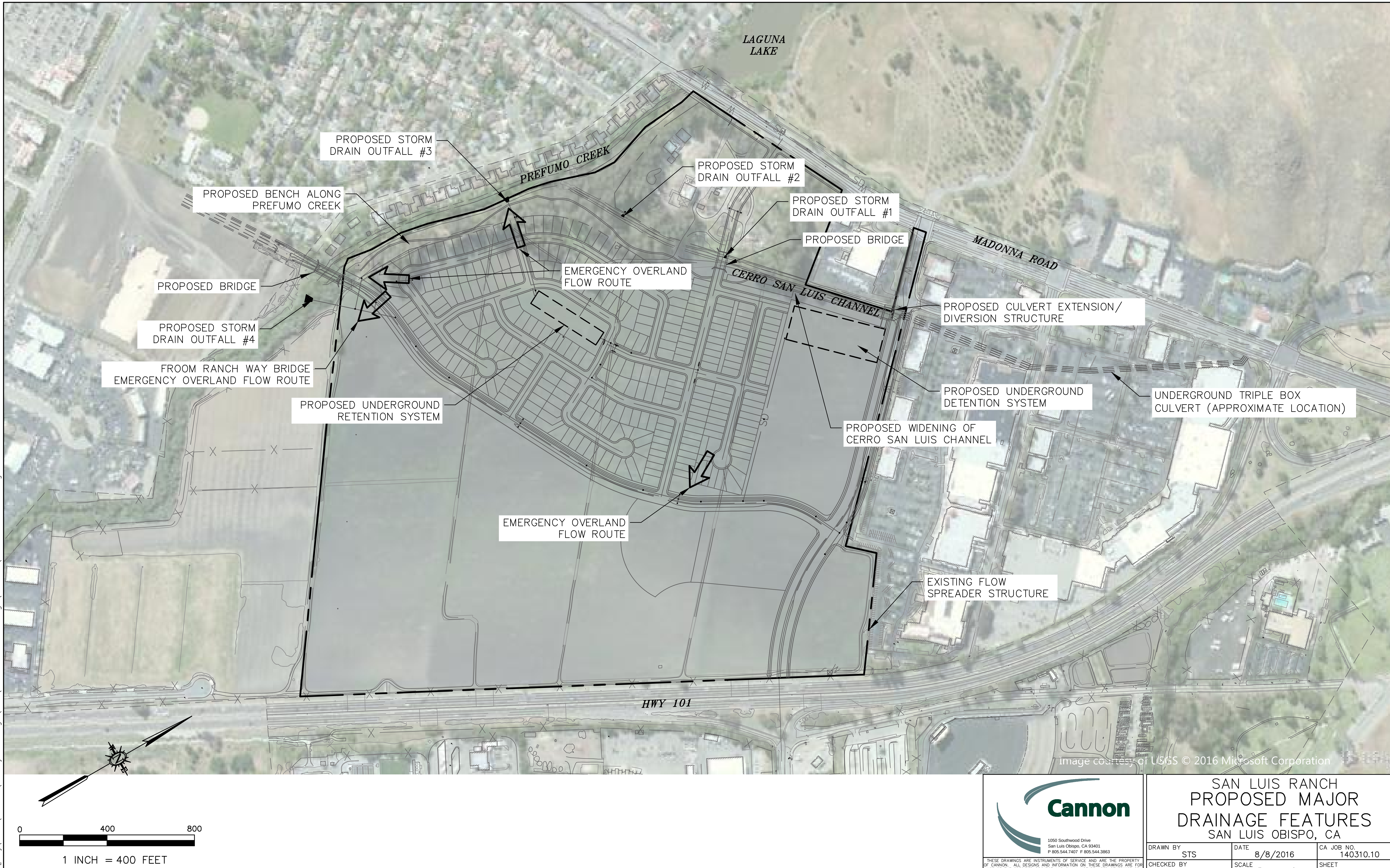
SURFACE RUNOFF FLOW DIRECTION

Cannon

1050 Southwood Drive
San Luis Obispo, CA 93401
P 805.544.7407 F 805.544.3863

SAN LUIS RANCH
DRAINAGE MAP
PROPOSED CONDITIONS
SAN LUIS OBISPO, CA

DRAWN BY	DATE	CA JOB NO.
STS	8/5/2016	140310.10
CHECKED BY	SCALE 1" = 400'	SHEET FIGURE 3



Cannon
1050 Southwood Drive
San Luis Obispo, CA 93401
P 805.544.7407 F 805.544.3863

SAN LUIS RANCH
PROPOSED MAJOR DRAINAGE FEATURES
SAN LUIS OBISPO, CA

DRAWN BY	DATE	CA JOB NO.
STS	8/8/2016	140310.10
CHECKED BY	SCALE	SHEET
	1" = 400'	FIGURE 4

Appendix A

Site Data

ance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

0 250 500 750 1,000 FEET

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 1068G

FIRM

FLOOD INSURANCE RATE MAP

SAN LUIS OBISPO COUNTY, CALIFORNIA

AND INCORPORATED AREAS

PANEL 1068 OF 2050

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SAN LUIS OBISPO COUNTY	060304	1068	G
SAN LUIS OBISPO, CITY OF	060310	1068	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

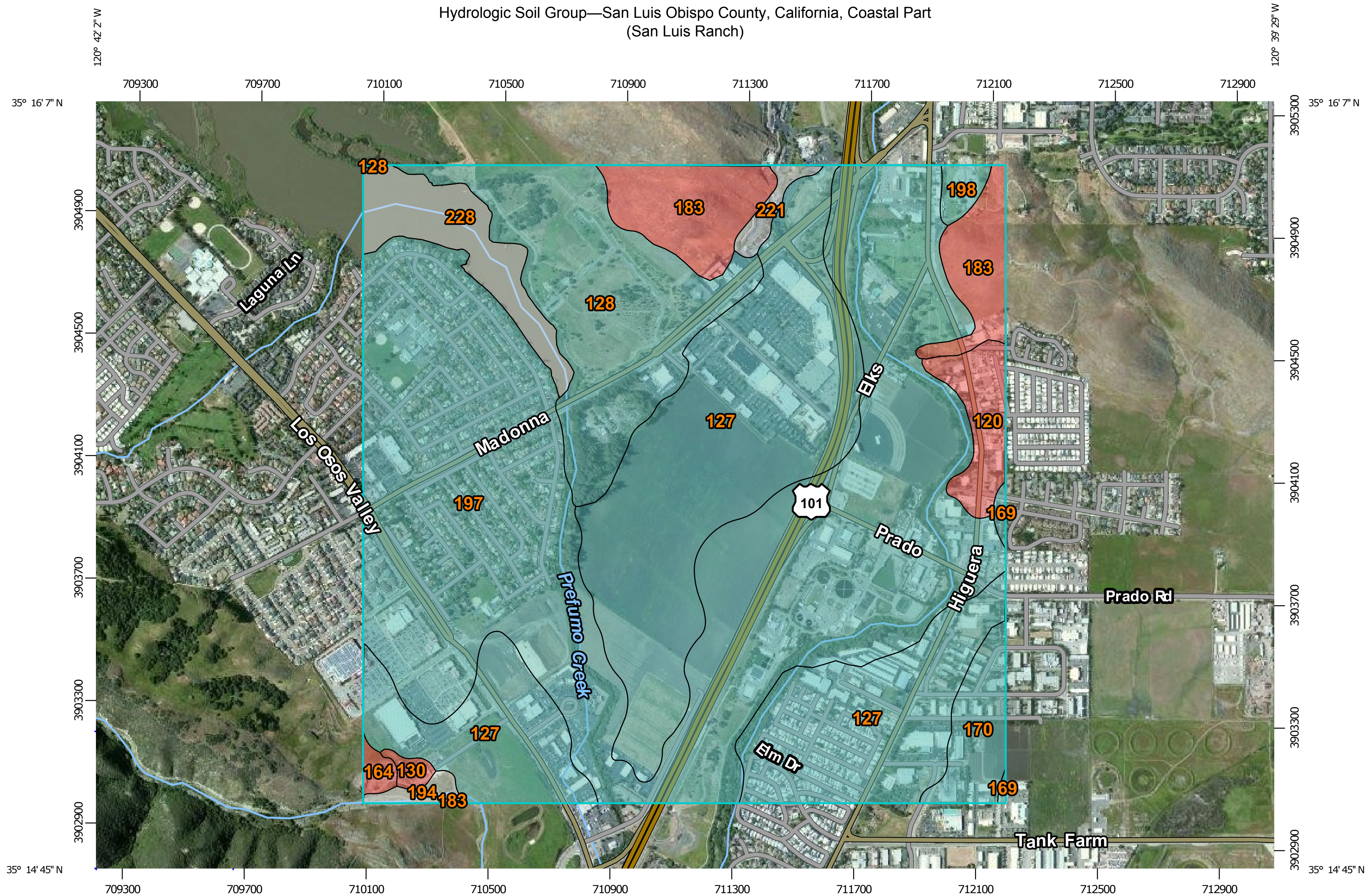
MAP NUMBER
06079C1068G

MAP REVISED
NOVEMBER 16, 2012

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

Hydrologic Soil Group—San Luis Obispo County, California, Coastal Part
(San Luis Ranch)



Map Scale: 1:17,700 if printed on A landscape (11" x 8.5") sheet.

Meters: 0, 250, 500, 1000, 1500

Feet: 0, 500, 1000, 2000, 3000

N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Lines

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Points

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

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

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

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

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

Soil Survey Area: San Luis Obispo County, California, Coastal Part
Survey Area Data: Version 6, Sep 26, 2014

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: May 8, 2010—May 21, 2010

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

Hydrologic Soil Group

Hydrologic Soil Group— Summary by Map Unit — San Luis Obispo County, California, Coastal Part (CA664)				
Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
120	Concepcion loam, 2 to 5 percent slopes	D	21.0	1.9%
127	Cropley clay, 0 to 2 percent slopes	C	328.8	30.2%
128	Cropley clay, 2 to 9 percent slopes	C	114.4	10.5%
130	Diablo and Cibo clays, 9 to 15 percent slopes	D	3.1	0.3%
164	Los Osos-Diablo complex, 15 to 30 percent slopes	D	3.6	0.3%
169	Marimel sandy clay loam, occasionally flooded	C	2.0	0.2%
170	Marimel silty clay loam, drained	C	23.1	2.1%
183	Obispo-Rock outcrop complex, 15 to 75 percent slopes	D	57.8	5.3%
194	Riverwash		4.5	0.4%
197	Salinas silty clay loam, 0 to 2 percent slopes	C	484.0	44.4%
198	Salinas silty clay loam, 2 to 9 percent slopes	C	5.7	0.5%
221	Xererts-Xerolls-Urban land complex, 0 to 15 percent slopes		5.9	0.5%
228	Water		36.1	3.3%
Totals for Area of Interest			**1,089.9**	**100.0%**

Description

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

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

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

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

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

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

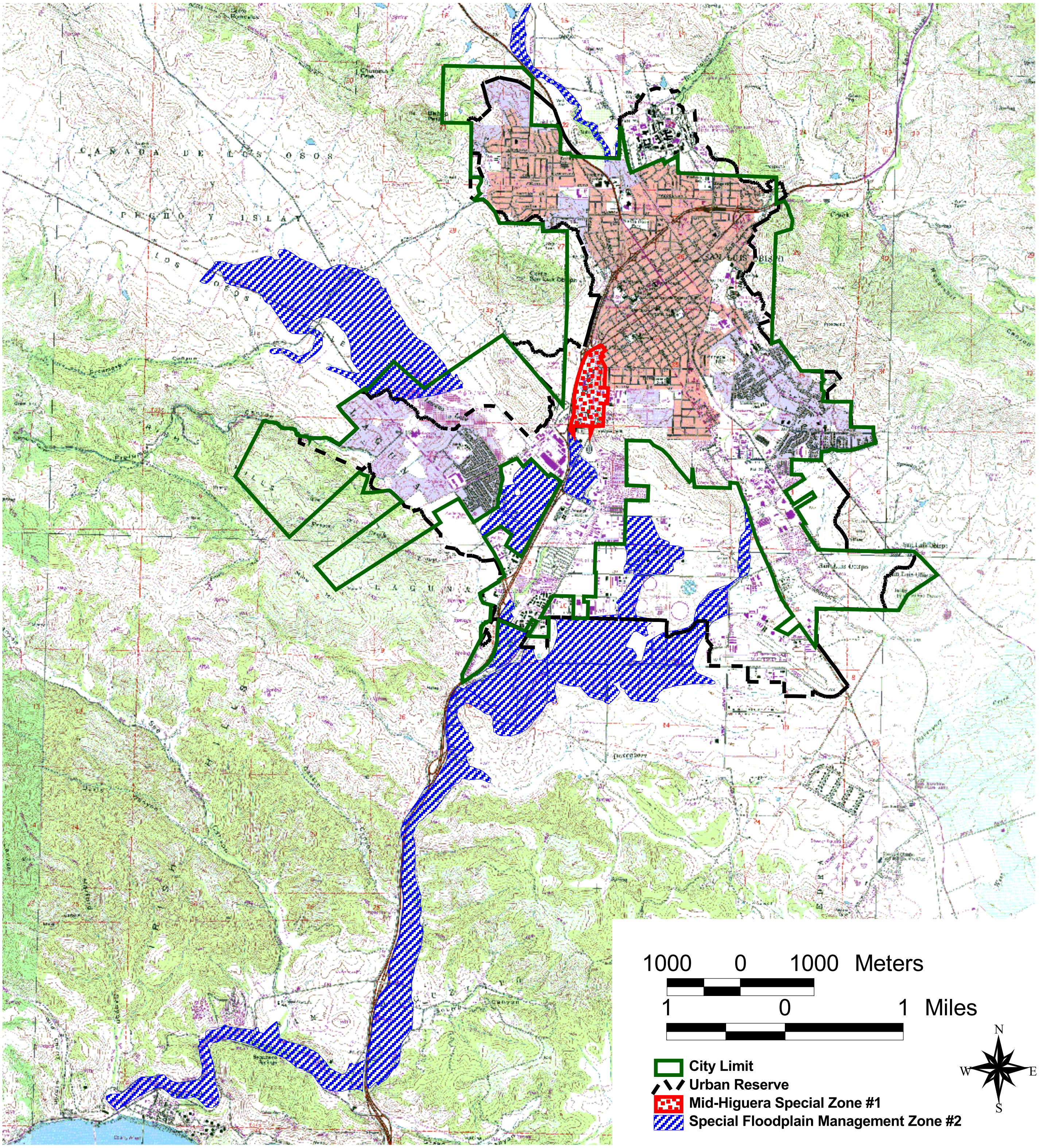
If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Rating Options

Aggregation Method: Dominant Condition

Component Percent Cutoff: *None Specified*

Tie-break Rule: Higher



city of san luis obispo

PUBLIC WORKS DEPARTMENT

Special Floodplain Management Zones

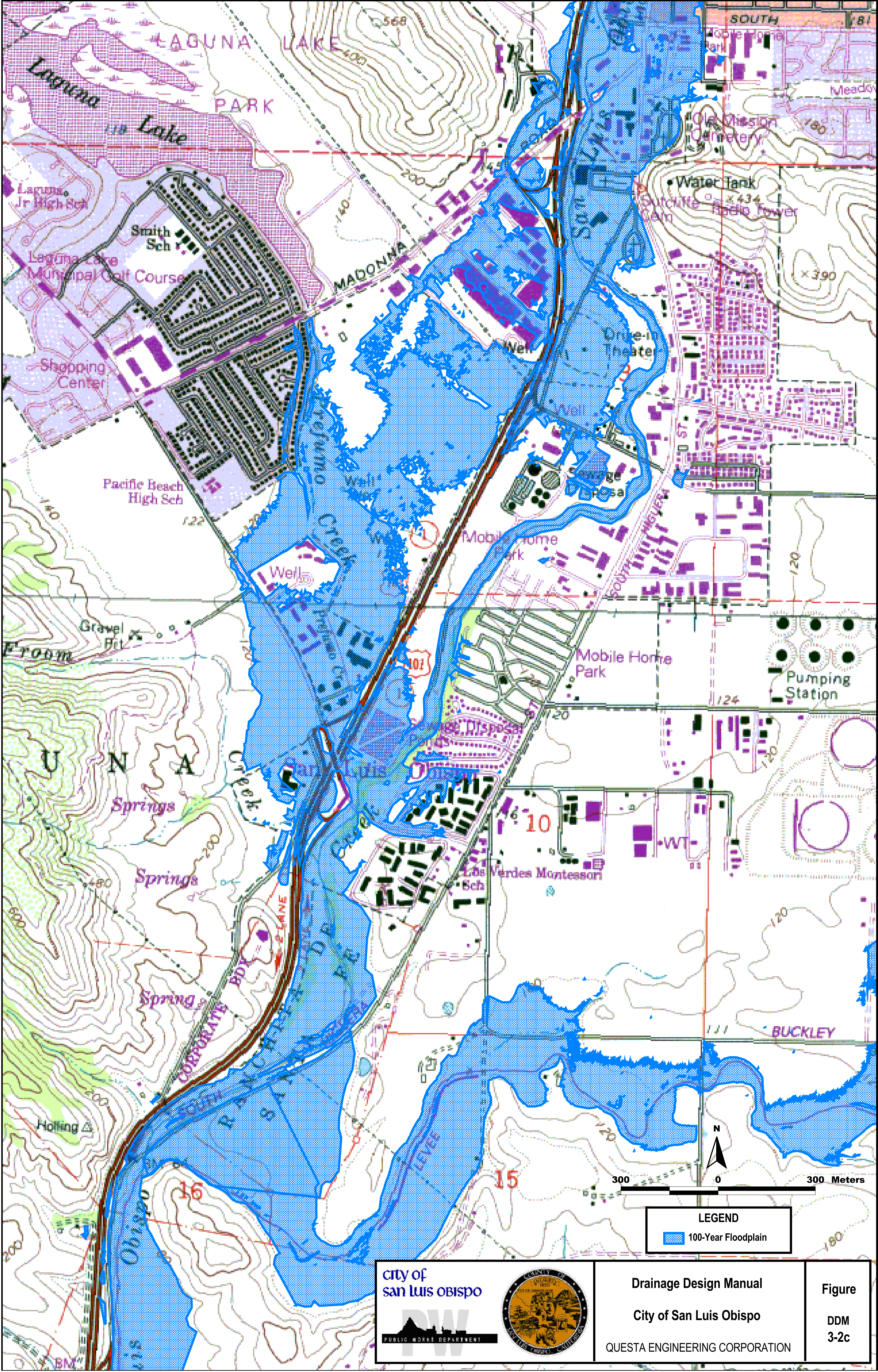
Drainage Design Manual
City of San Luis Obispo

QUESTA ENGINEERING CORPORATION

Figure

DDM 3-1

FILE REFERENCE: c:\arcview projects\98202 slo phase ii\98202_floodplain_management.apr
LAYOUT: 8.5x11
DATE: Nov 26, 2001 4:32 PM



City of San Luis Obispo

PUBLIC WORKS DEPARTMENT

Drainage Design Manual

City of San Luis Obispo

QUESTA ENGINEERING CORPORATION

Figure DDM 3-2c

Appendix B

Hydrologic Analyses of Existing Conditions

Composite Runoff Coefficient and Curve Number Calculations - Existing Conditions

Project: San Luis Ranch - Tentative Map
Updated: 6/7/2016

Runoff Coefficients (from Table 4-1 SLO DDM) and Curve Numbers (from Table 2-2a TR-55)

Type of Development	Hydrologic Soil Goup	Runoff Coefficient, *C*	Curve Number, *CN*	Description
Moderate Vegetation (s < 2%)	C	0.25	82	SLO DDM: Moderate Vegetation; TR-55: Woods-grass Combination (poor hydrologic condition)
Moderate Vegetation (s < 2%)	D	0.25	86	
Moderate Vegetation (s = 2-10%)	C	0.30	82	
Moderate Vegetation (s = 2-10%)	D	0.35	86	
Moderate Vegetation (s > 10%)	C	0.35	82	
Moderate Vegetation (s > 10%)	D	0.45	86	
Agricultural (s < 2%)	C	0.15	82	SLO DDM: Agriculture; TR-55: Row Crops, Straight Rows, Crop Residue Cover (good hydrologic condition)
Agricultural (s < 2%)	D	0.20	85	
Agricultural (s = 2-10%)	C	0.15	82	
Agricultural (s = 2-10%)	D	0.20	85	
Agricultural (s > 10%)	C	0.20	82	
Agricultural (s > 10%)	D	0.25	85	
Impervious (s < 2%)	C	0.80	98	Impervious Surfaces
Impervious (s <2%)	D	0.85	98	
Impervious (s = 2-10%)	C	0.85	98	
Impervious (s = 2-10%)	D	0.87	98	
Impervious (s > 10%)	C	0.90	98	
Impervious (s > 10%)	D	0.90	98	
Parks (s < 2%)	C	0.10	74	SLO DDM: Unimproved Vacant Lots; TR-55: Moderate Vegetation (good hydrologic condition)
Parks (s < 2%)	D	0.15	80	
Parks (s = 2-10%)	C	0.15	74	
Parks (s = 2-10%)	D	0.20	80	
Parks (s > 10%)	C	0.20	74	
Parks (s > 10%)	D	0.30	80	

Calculation Description

Composite runoff coefficients and curve numbers are calculated by using the Area Weighted Average method as follows:

$$Composite\ C = \frac{\sum(C_1A_1 + C_2A_2 + \ldots + C_nA_n)}{\sum(A_1 + A_2 + \ldots + A_n)}$$

Composite Runoff Coefficient and Curve Number Calculation

Sub-basin	Total Area (sf)	Total Area, *A* (ac)	Hydrologic Soil Group	Moderate Vegetation Area (sf)			Agricultural Area (sf)			Impervious Area(sf)			Park Area (sf)			Composite Runoff Coefficient, *C*	Composite Curve Number, *CN*
				s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%		
EXIST-1	219,952	5.05	C	0	172,181	0	0	0	0	47,771	0	0	0	0	0	0.41	85
			D	0	0	0	0	0	0	0	0	0	0	0	0		
EXIST-2	878,271	20.16	C	263,340	263,340	0	118,409	0	0	233,183	0	0	0	0	0	0.40	86
			D	0	0	0	0	0	0	0	0	0	0	0	0		
EXIST-3	554,752	12.74	C	225,139	0	0	329,613	0	0	0	0	0	0	0	0	0.19	82
			D	0	0	0	0	0	0	0	0	0	0	0	0		
EXIST-4	4,391,148	100.81	C	0	0	0	4,391,148	0	0	0	0	0	0	0	0	0.15	82
			D	0	0	0	0	0	0	0	0	0	0	0	0		
Total:	**6,044,123**	**138.75**		**488,479**	**435,521**	**0**	**4,839,170**	**0**	**0**	**280,954**	**0**	**0**	**0**	**0**	**0**		

Time of Concentration Calculation - Existing Conditions

Project: San Luis Ranch - Tentative Map
Updated: 6/7/2016

Calculation Description

The following calculations are based on the procedures presented in the San Luis Obispo Drainage Design Manual and the NRCS publication TR-55: Urban Hydrology for Small Watersheds (June 1986 edition)

Sheet Flow (Flow Over Plane Surfaces)

$$T_{sf} = \frac{0.007(nL)^{0.8}}{(I_2)^{0.5} s^{0.4}} * (60\,min/hr)$$

T_{sf} = Travel Time for Sheet Flow (min)
n = Manning's Roughness Coefficient (from Table 3-1)
I_2 = 2-year, 24-hour rainfall (in)
L = Flow Length (ft) - 300 ft maximum
s = Land Slope (ft/ft)

Table 3-1 from TR-55

Table 3-1 Roughness coefficients (Manning's n) for sheet flow

Surface description	n 1/
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses 2/	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:3/	
Light underbrush	0.40
Dense underbrush	0.80

1 The n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Shallow Concentrated Flow

$$T_{sc} = \frac{L}{60V} \qquad V = K_u k S_p^{0.5}$$

T_{sc} = Travel Time for Shallow Concentrated Flow (min)
L = Flow Length (ft) - 1000 ft maximum
V = Velocity (ft/s) (per Equation Above)
K_u = 3.28
k = Interception Coefficient
= 0.457 (Grassed Waterway)
= 0.491 (Unpaved)
= 0.619 (Paved Areas; Small Upland Gullies)
S_p = Slope (%)

Channel Flow

$$T_{ch} = \frac{L}{60V} \qquad V = \frac{1.49 R^{2/3} s^{0.5}}{n}$$

T_{ch} = Travel Time for Channel Flow (min)
V = Velocity (ft/s) (per Manning Equation Above)
R = Hydraulic Radius (ft) = A/P_w
A = Cross-sectional Flow Area (sf)
P_w = Wetted Perimeter (ft)
s = Channel Slope (ft/ft)
n = Manning's Roughness Coefficient

Time of Concentration to Inlet

$T_c = T_{sf} + T_{sc} + T_{ch}$

Lag Time

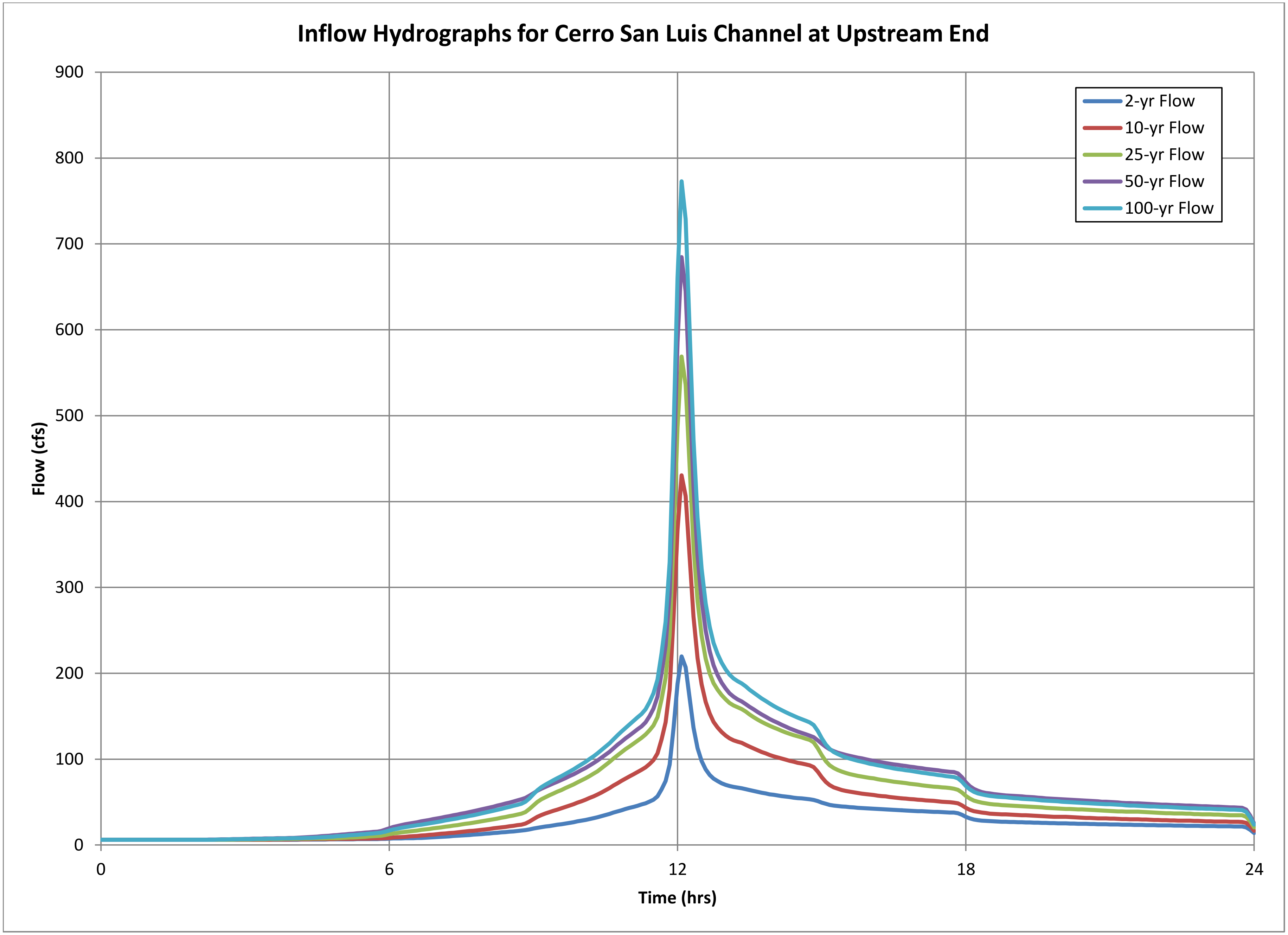
$T_L = 0.6 * T_c$

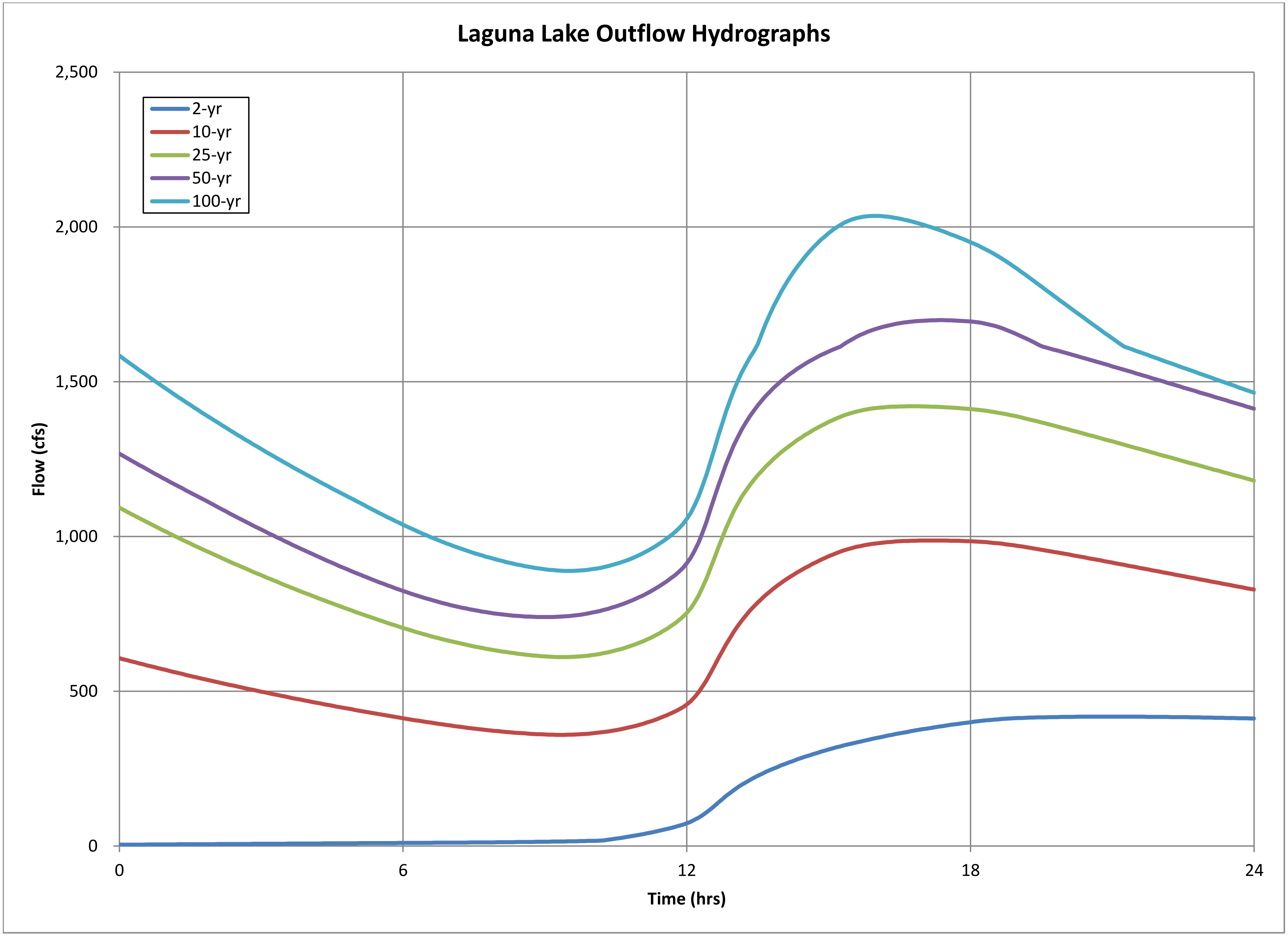
Time of Concentration Calculation

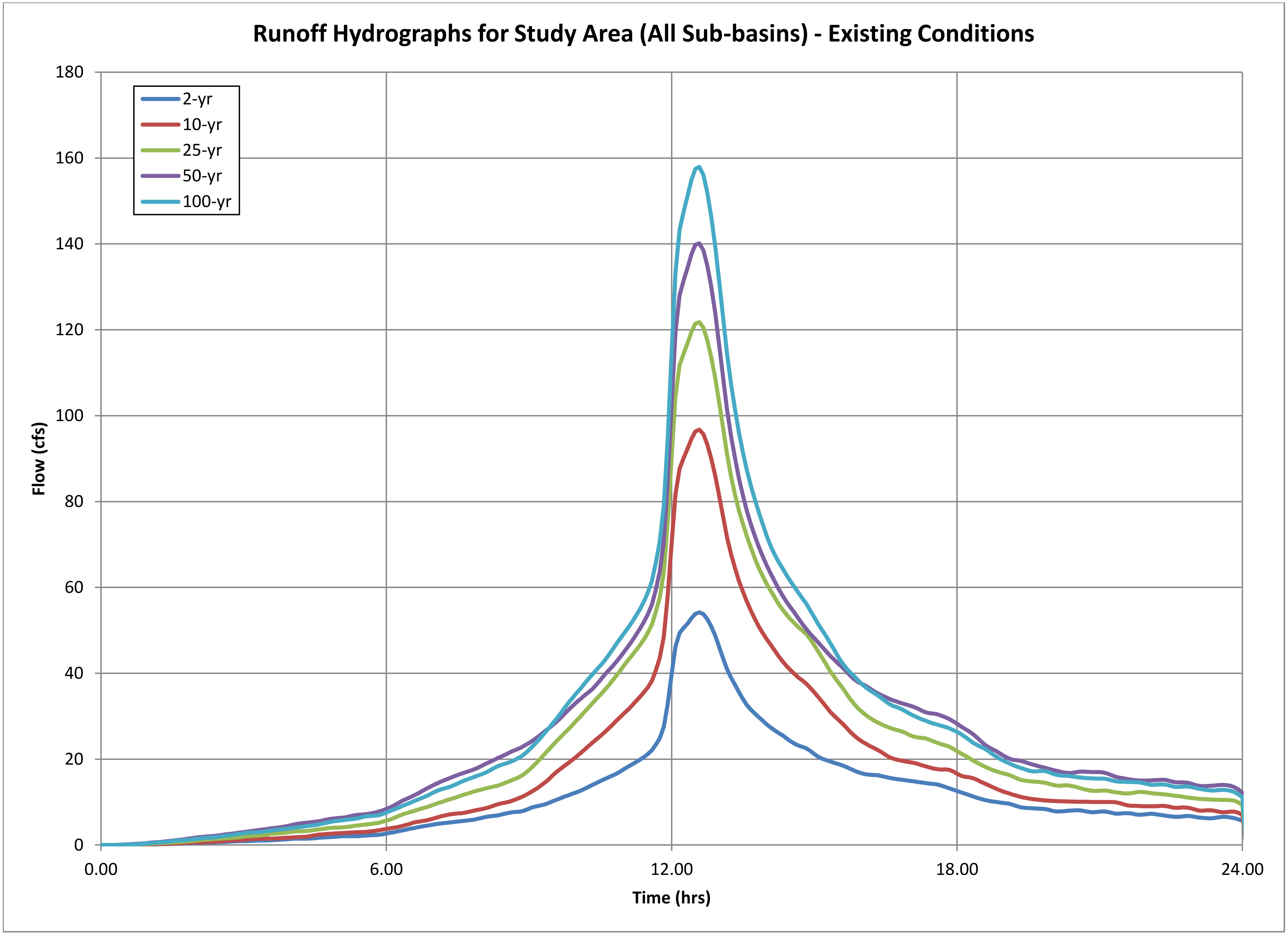
Sub-basin	Point of Discharge	Sheet Flow Time Calculation						
		n	Upper Elev (ft)	Lower Elev (ft)	L (ft)	I_2 (in)	s (ft/ft)	T_{SF} (min)
EXIST-1	Prefumo Reach 1	0.130	135.20	130.30	300	3.28	0.016	22.5
EXIST-2	Cerro San Luis Channel	0.130	136.30	130.00	165	3.28	0.038	9.9
EXIST-3	Prefumo Reach 2	0.170	132.60	131.30	300	3.28	0.004	47.5
EXIST-4	Prefumo Reach 3	0.170	134.70	132.10	300	3.28	0.009	36.0

Sub-basin	Shallow Concentrated Flow Time Calculation						
	Upper Elev (ft)	Lower Elev (ft)	L (ft)	k	Sp (%)	V (ft/s)	T_{sc} (min)
EXIST-1	130.3	120.1	412	0.457	2.5	2.36	2.9
EXIST-2	130.0	129.0	404	0.457	0.2	0.75	9.0
EXIST-3	131.3	127.1	1,000	0.457	0.4	0.97	17.2
EXIST-4	132.1	120.5	2,449	0.457	0.5	1.03	39.6

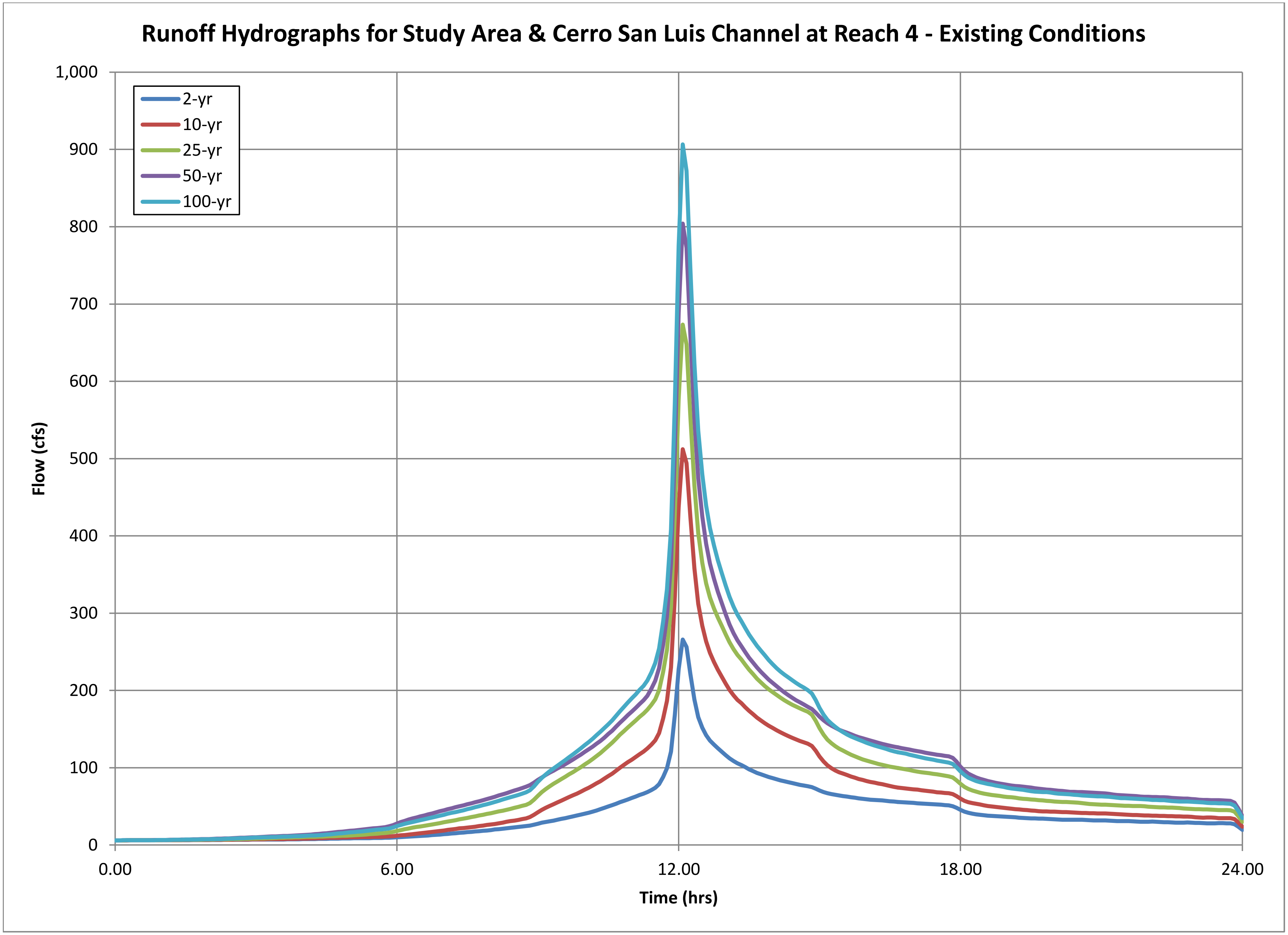
Sub-basin	Channel Flow Time Calculation										Time of Conc.	Lag Time	
	Upper Elev (ft)	Lower Elev (ft)	L (ft)	A (sf)	P_w (ft)	R (ft)	s (ft/ft)	n	V (ft/s)	T_{ch} (min)	T_c (min)	T_L (min)	
EXIST-1	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	25.5	15.3	
EXIST-2	125.7	116.7	996	80.00	29.89	2.68	0.009	0.045	6.07	2.7	21.7	13.0	*Channel Flow Calculations performed in Flo
EXIST-3	127.1	124.1	619	2.00	4.47	0.45	0.005	0.030	2.02	5.1	69.8	41.9	*Channel Flow Calculations performed in Flo
EXIST-4	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	75.6	45.3	

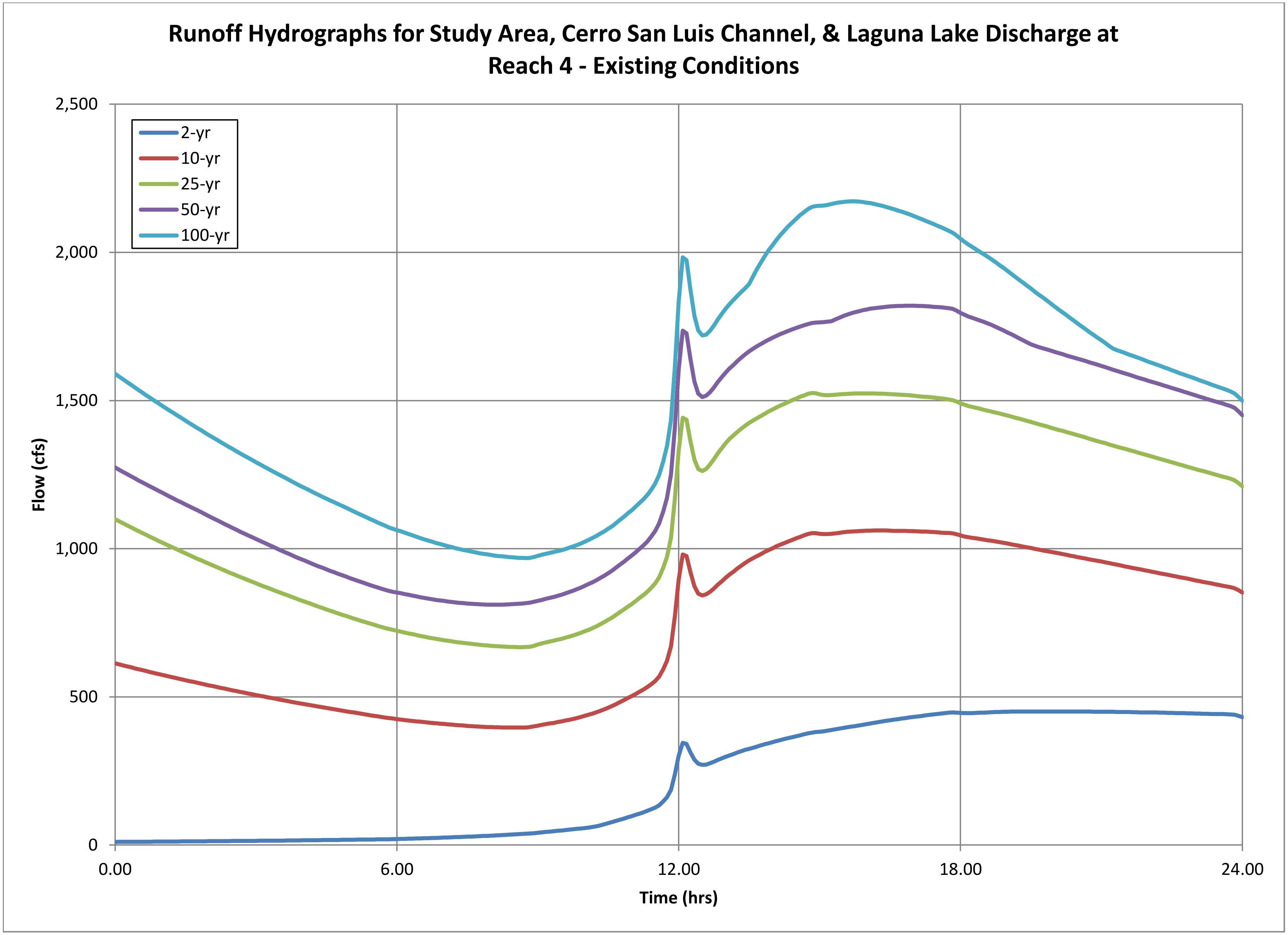

Inflow Hydrographs for Cerro San Luis Channel at Upstream End
Flow (cfs)
Time (hrs)
900
800
700
600
500
400
300
200
100
0
0
6
12
18
24
2-yr Flow
10-yr Flow
25-yr Flow
50-yr Flow
100-yr Flow


Laguna Lake Outflow Hydrographs
2-yr
10-yr
25-yr
50-yr
100-yr
Flow (cfs)
2,500
2,000
1,500
1,000
500
0
0
6
12
18
24
Time (hrs)



Runoff Hydrographs for Study Area (All Sub-basins) - Existing Conditions
180
160
140
120
100
80
60
40
20
0
Flow (cfs)
2-yr
10-yr
25-yr
50-yr
100-yr
0.00
6.00
12.00
18.00
24.00
Time (hrs)


Runoff Hydrographs for Study Area & Cerro San Luis Channel at Reach 4 - Existing Conditions
2-yr
10-yr
25-yr
50-yr
100-yr
1,000
900
800
700
600
500
400
300
200
100
0
Flow (cfs)
0.00
6.00
12.00
18.00
24.00
Time (hrs)


Runoff Hydrographs for Study Area, Cerro San Luis Channel, & Laguna Lake Discharge at Reach 4 - Existing Conditions
2-yr
10-yr
25-yr
50-yr
100-yr
2,500
2,000
1,500
1,000
500
0
Flow (cfs)
0.00
6.00
12.00
18.00
24.00
Time (hrs)

Appendix C

Hydrologic Analyses of Proposed Conditions

Composite Runoff Coefficient and Curve Number Calculations - Proposed Conditions

Project: San Luis Ranch - Tentative Map
Updated: 7/27/2016

Runoff Coefficients (from Table 4-1 SLO DDM) and Curve Numbers (from Table 2-2a TR-55)

Type of Development	Hydrologic Soil Goup	Runoff Coefficient, *C*	Curve Number, *CN*	Description
SFR Medium (s < 2%)	C	0.45	90	SLO DDM: 6,000 sf lots; TR-55: 1/8 acres or less (town houses)
SFR Medium (s < 2%)	D	0.50	92	
SFR Medium (s = 2-10%)	C	0.50	90	
SFR Medium (s = 2-10%)	D	0.60	92	
SFR Medium (s > 10%)	C	0.60	90	
SFR Medium (s > 10%)	D	0.65	92	
SFR Medium-High (s < 2%)	C	0.48	92	Average of LDR and HDR
SFR Medium-High (s < 2%)	D	0.55	94	
SFR Medium-High (s = 2-10%)	C	0.55	92	
SFR Medium-High (s = 2-10%)	D	0.65	94	
SFR Medium-High (s > 10%)	C	0.65	92	
SFR Medium-High (s > 10%)	D	0.73	94	
MFR High(s < 2%)	C	0.50	94	SLO DDM: Apartments; TR-55: Commercial
MFR High(s < 2%)	D	0.60	95	
MFR High(s = 2-10%)	C	0.60	94	
MFR High(s = 2-10%)	D	0.70	95	
MFR High(s > 10%)	C	0.70	94	
MFR High(s > 10%)	D	0.80	95	
Commercial (s < 2%)	C	0.50	94	SLO DDM: Neighborhood Commercial; TR-55: Commerical
Commercial (s < 2%)	D	0.65	95	
Commercial (s = 2-10%)	C	0.60	94	
Commercial (s = 2-10%)	D	0.75	95	
Commercial (s > 10%)	C	0.70	94	
Commercial (s > 10%)	D	0.80	95	
Impervious (s < 2%)	C	0.80	98	Impervious Surfaces
Impervious (s <2%)	D	0.85	98	
Impervious (s = 2-10%)	C	0.85	98	
Impervious (s = 2-10%)	D	0.87	98	
Impervious (s > 10%)	C	0.90	98	
Impervious (s > 10%)	D	0.90	98	
Moderate Vegetation (s < 2%)	C	0.25	82	SLO DDM: Moderate Vegetation; TR-55: Woods-grass Combination (poor hydrologic condition)
Moderate Vegetation (s < 2%)	D	0.25	86	
Moderate Vegetation (s = 2-10%)	C	0.30	82	
Moderate Vegetation (s = 2-10%)	D	0.35	86	
Moderate Vegetation (s > 10%)	C	0.35	82	
Moderate Vegetation (s > 10%)	D	0.45	86	
Park/Treatment (s < 2%)	C	0.10	74	SLO DDM: Unimproved Vacant Lots; TR-55: Moderate Vegetation (good hydrologic condition)
Park/Treatment (s < 2%)	D	0.15	80	
Park/Treatment (s = 2-10%)	C	0.15	74	
Park/Treatment (s = 2-10%)	D	0.20	80	
Park/Treatment (s > 10%)	C	0.20	74	
Park/Treatment (s > 10%)	D	0.30	80	
Agricultural (s < 2%)	C	0.15	82	SLO DDM: Agriculture; TR-55: Row Crops, Straight Rows, Crop Residue Cover (good hydrologic condition)
Agricultural (s < 2%)	D	0.20	85	
Agricultural (s = 2-10%)	C	0.15	82	
Agricultural (s = 2-10%)	D	0.20	85	
Agricultural (s > 10%)	C	0.20	82	
Agricultural (s > 10%)	D	0.25	85	

Calculation Description

Composite runoff coefficients and curve numbers are calculated by using the Area Weighted Average method as follows:

$$Composite\ C = \frac{\sum(C_1A_1 + C_2A_2 + \ldots + C_nA_n)}{\sum(A_1 + A_2 + \ldots + A_n)}$$

Composite Runoff Coefficient and Curve Number Calculation

Sub-basin	Total Area (sf)	Total Area, *A* (ac)	Hydrologic Soil Group	SFR Medium Density Area (sf)			SFR Medium-High Density Area (sf)			MFR High Density Area (sf)			Commericial Area (sf)			Impervious (sf)			Moderate Vegetation Area (sf)			Park/Treatment Area (sf)			Agricultural Area (sf)			Composite Runoff Coefficient, *C*	Composite Curve Number, *CN*
				s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%	s < 2%	s = 2-10%	s > 10%		
PROP-1	157,587	3.62	C	0	0	0	0	0	0	0	0	0	0	0	0	55,287	0	0	0	102,300	0	0	0	0	0	0	0	0.48	88
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-2A	125,139	2.87	C	0	0	0	0	0	0	0	0	0	0	0	0	100,677	0	0	18,475	0	0	5,987	0	0	0	0	0	0.69	94
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-2B	349,480	8.02	C	0	0	0	0	0	0	0	0	0	0	0	0	126,959	0	0	111,261	111,261	0	0	0	0	0	0	0	0.47	88
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-2C	161,647	3.71	C	0	0	0	0	0	0	0	150,146	0	0	0	0	11,501	0	0	0	0	0	0	0	0	0	0	0	0.61	94
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-2D	259,375	5.95	C	0	0	0	0	0	0	0	247,672	0	0	0	0	11,703	0	0	0	0	0	0	0	0	0	0	0	0.61	94
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-3A	561,436	12.89	C	133,144	0	0	177,300	0	0	0	0	0	0	0	0	187,149	0	0	0	0	0	63,843	0	0	0	0	0	0.53	91
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-3B	53,499	1.23	C	32,153	0	0	0	0	0	0	0	0	0	0	0	11,962	0	0	0	0	0	9,384	0	0	0	0	0	0.47	89
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-3C	133,093	3.06	C	81,760	0	0	0	0	0	0	0	0	0	0	0	45,956	0	0	0	0	0	5,377	0	0	0	0	0	0.56	92
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-3D	87,818	2.02	C	66,995	0	0	0	0	0	0	0	0	0	0	0	7,869	0	0	0	0	0	12,954	0	0	0	0	0	0.43	88
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-3E	102,817	2.36	C	0	0	0	0	0	0	0	0	0	0	0	0	6,346	0	0	48,236	48,236	0	0	0	0	0	0	0	0.31	83
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4A	55,029	1.26	C	0	0	0	0	0	0	0	0	0	0	0	0	42,284	0	0	0	5,035	0	7,710	0	0	0	0	0	0.66	93
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4B	30,577	0.70	C	0	0	0	0	0	0	0	0	0	0	0	0	26,677	0	0	0	863	0	3,037	0	0	0	0	0	0.72	95
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4C	71,202	1.63	C	0	0	0	0	0	0	0	0	0	0	0	0	0	58,506	0	0	0	0	0	12,696	0	0	0	0	0.73	94
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4D	640,780	14.71	C	237,897	0	0	103,335	0	0	0	0	0	0	0	0	225,106	0	0	1,679	0	0	72,763	0	0	0	0	0	0.54	91
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4E	226,440	5.20	C	146,200	0	0	0	0	0	0	0	0	0	0	0	69,816	0	0	0	0	0	10,424	0	0	0	0	0	0.54	92
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4F	394,644	9.06	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	394,644	0	0	0.15	82
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
PROP-4G	2,637,322	60.54	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,637,322	0	0	0.15	82
			D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Total:	**6,047,885**	**138.84**		**698,149**	**0**	**0**	**280,635**	**0**	**0**	**0**	**397,818**	**0**	**0**	**0**	**0**	**929,292**	**58,506**	**0**	**179,650**	**267,694**	**0**	**191,479**	**12,696**	**0**	**3,031,966**	**0**	**0**		

Time of Concentration Calculation - Proposed Conditions

Project: San Luis Ranch - Tentative Map
Updated: 7/27/2016

Calculation Description

The following calculations are based on the procedures presented in the San Luis Obispo Drainage Design Manual and the NRCS publication TR-55: Urban Hydrology for Small Watersheds (June 1986 edition)

Sheet Flow (Flow Over Plane Surfaces)

$$T_{sf} = \frac{0.007(nL)^{0.8}}{(I_2)^{0.5} s^{0.4}} * (60\,min/hr)$$

T_{sf} = Travel Time for Sheet Flow (min)
n = Manning's Roughness Coefficient (from Table 3-1)
I_2 = 2-year, 24-hour rainfall (in)
L = Flow Length (ft) - 300 ft maximum
s = Land Slope (ft/ft)

Table 3-1 from TR-55

Table 3-1 Roughness coefficients (Manning's n) for sheet flow

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Shallow Concentrated Flow

$$T_{sc} = \frac{L}{60V} \qquad V = K_u k S_p^{0.5}$$

T_{sc} = Travel Time for Shallow Concentrated Flow (min)
L = Flow Length (ft) - 1000 ft maximum
V = Velocity (ft/s) (per Equation Above)
K_u = 3.28
k = Interception Coefficient
= 0.457 (Grassed Waterway)
= 0.491 (Unpaved)
= 0.619 (Paved Areas; Small Upland Gullies)
S_p = Slope (%)

Channel Flow

$$T_{ch} = \frac{L}{60V} \qquad V = \frac{1.49 R^{2/3} s^{0.5}}{n}$$

T_{ch} = Travel Time for Channel Flow (min)
V = Velocity (ft/s) (per Manning Equation Above)
R = Hydraulic Radius (ft) = A/P_w
A = Cross-sectional Flow Area (sf)
P_w = Wetted Perimeter (ft)
s = Channel Slope (ft/ft)
n = Manning's Roughness Coefficient

Time of Concentration to Inlet

$T_c = T_{sf} + T_{sc} + T_{ch}$

Lag Time

$T_L = 0.6 * T_c$

Time of Concentration Calculation

Sub-basin	Point of Discharge	Sheet Flow Time Calculation							Shallow Concentrated Flow Time Calculation							Channel Flow Time Calculation										Time of Conc.	Lag Time
		n	Upper Elev (ft)	Lower Elev (ft)	L (ft)	I_2 (in)	s (ft/ft)	T_{SF} (min)	Upper Elev (ft)	Lower Elev (ft)	L (ft)	k	Sp (%)	V (ft/s)	T_{sc} (min)	Upper Elev (ft)	Lower Elev (ft)	L (ft)	A (sf)	P_w (ft)	R (ft)	s (ft/ft)	n	V (ft/s)	T_{ch} (min)	T_c (min)	T_L (min)
PROP-1	Prefumo Reach 1					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-2A	Cerro San Luis Channel					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-2B	Cerro San Luis Channel					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-2C	Cerro San Luis Channel					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-2D	Cerro San Luis Channel					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-3A	Prefumo Reach 2					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-3B	Prefumo Reach 2					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-3C	Prefumo Reach 2					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-3D	Prefumo Reach 2					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-3E	Prefumo Reach 2					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-4A	Prefumo Reach 3					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-4B	Prefumo Reach 3					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-4C	Prefumo Reach 3					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-4D	Prefumo Reach 3					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-4E	Prefumo Reach 3					3.28	#DIV/0!	#DIV/0!	0.0				#DIV/0!	#DIV/0!	#DIV/0!	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	10.0	6.0
PROP-4F	Prefumo Reach 3	0.170	136.000	134.800	300	3.28	0.004	49.0	134.8	132.0	600	0.457	0.5	1.02	9.8	0.0	0.0	0	0.00	0.00	0.00	0.000	0.000	0.00	0.0	58.8	35.3
PROP-4G	Prefumo Reach 3	0.170	133.000	131.400	300	3.28	0.005	43.7	131.4	120.5	2,331	0.457	0.5	1.03	37.9	120.5						#DIV/0!		0.00	0.0	81.6	49.0

Peak Flow Calculations Using Rational Method - Proposed Conditions

Project: San Luis Ranch - Tentative Map
Updated: 7/27/2016

Calculation Description

The following calculations are based on the Rational Method as

$$Q = C*i*C_a*A$$

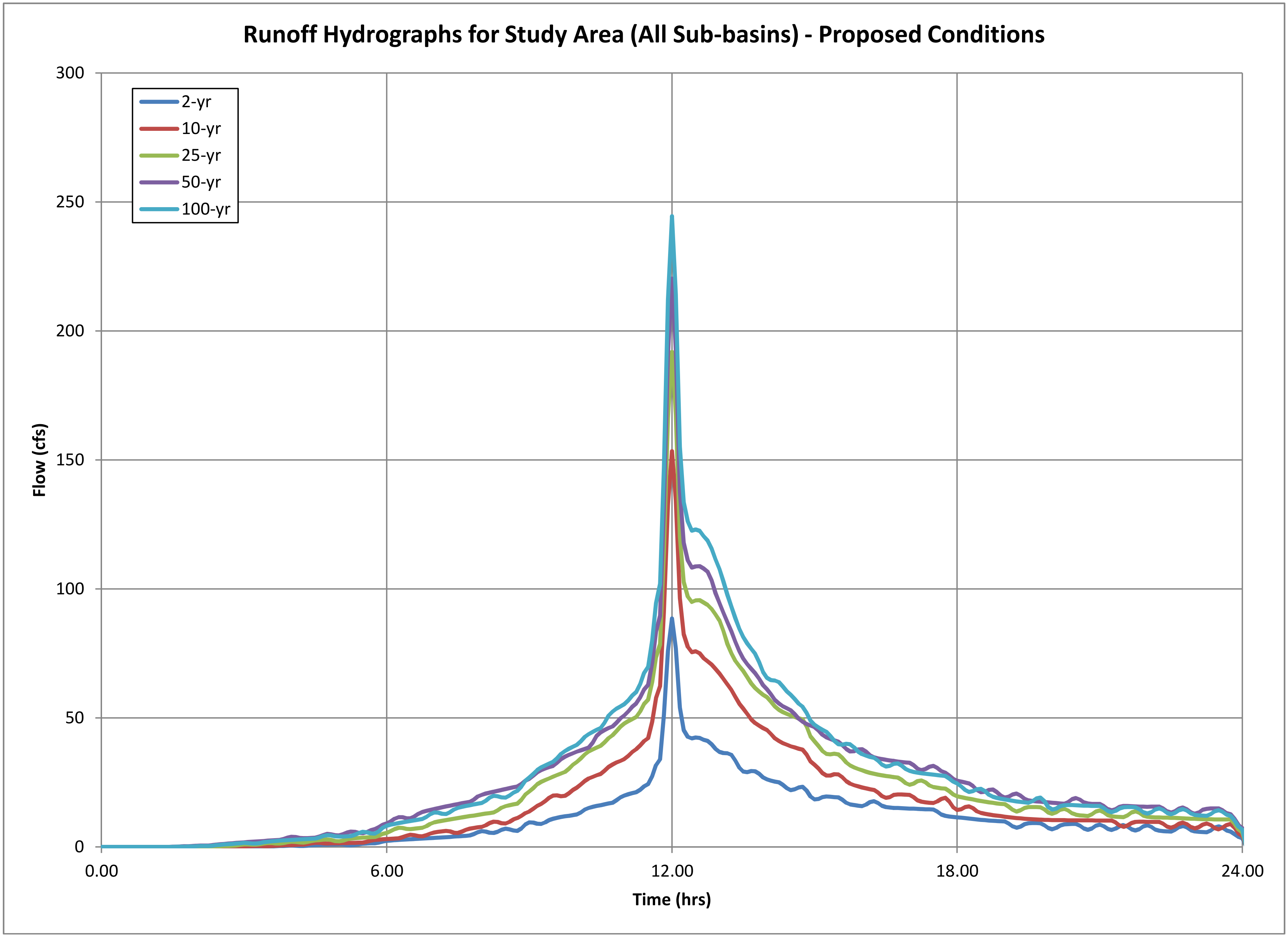
Q = Peak Rate of Runoff (cfs)
C = Runoff Coefficient
i = Rainfall Intensity (in/hr)
C_a = Antecedent Moistuer Factor
A = Drainage Area (acres)

Parameters for Peak Flow Calculations for Areas with 550 mm to 700 mm Annual Rainfall (from Table 4-2 and Table 4-6 SLO DDM)

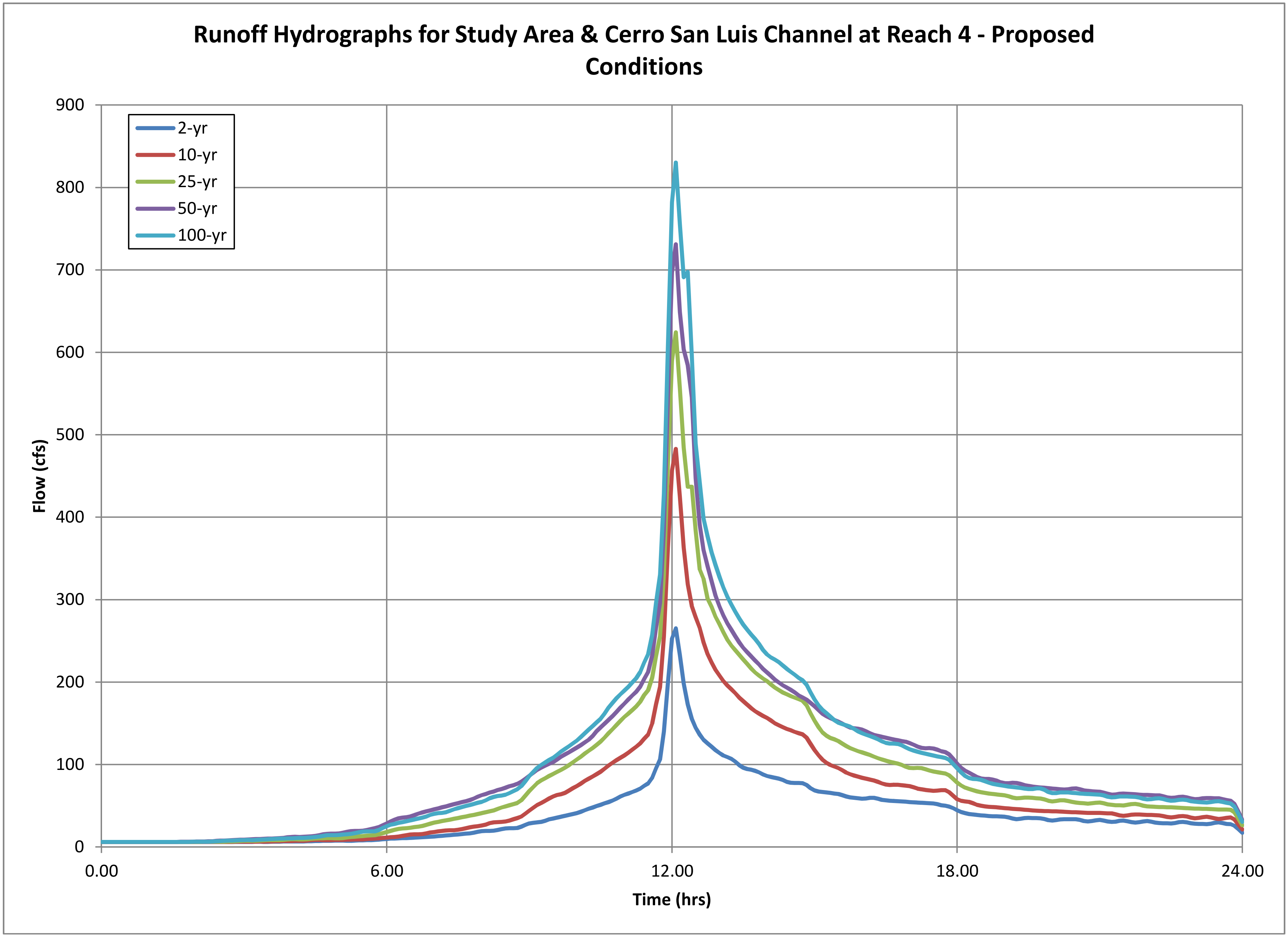
Recurrence Interval (years)	Antecedent Moisture Factor, C_a	Rainfall Intensity (in/hr) for Duration Given					
		10 min	15 min	30 min	60 min	120 min	180 min
2	1.00	2.09	1.81	1.18	0.75	0.55	0.47
10	1.00	3.58	2.99	2.09	1.30	0.91	0.83
25	1.10	4.02	3.50	2.40	1.50	1.10	0.98
50	1.20	4.61	3.90	2.60	1.69	1.30	1.14
100	1.25	5.00	4.29	2.91	1.85	1.38	1.22

Peak Flow Calculations

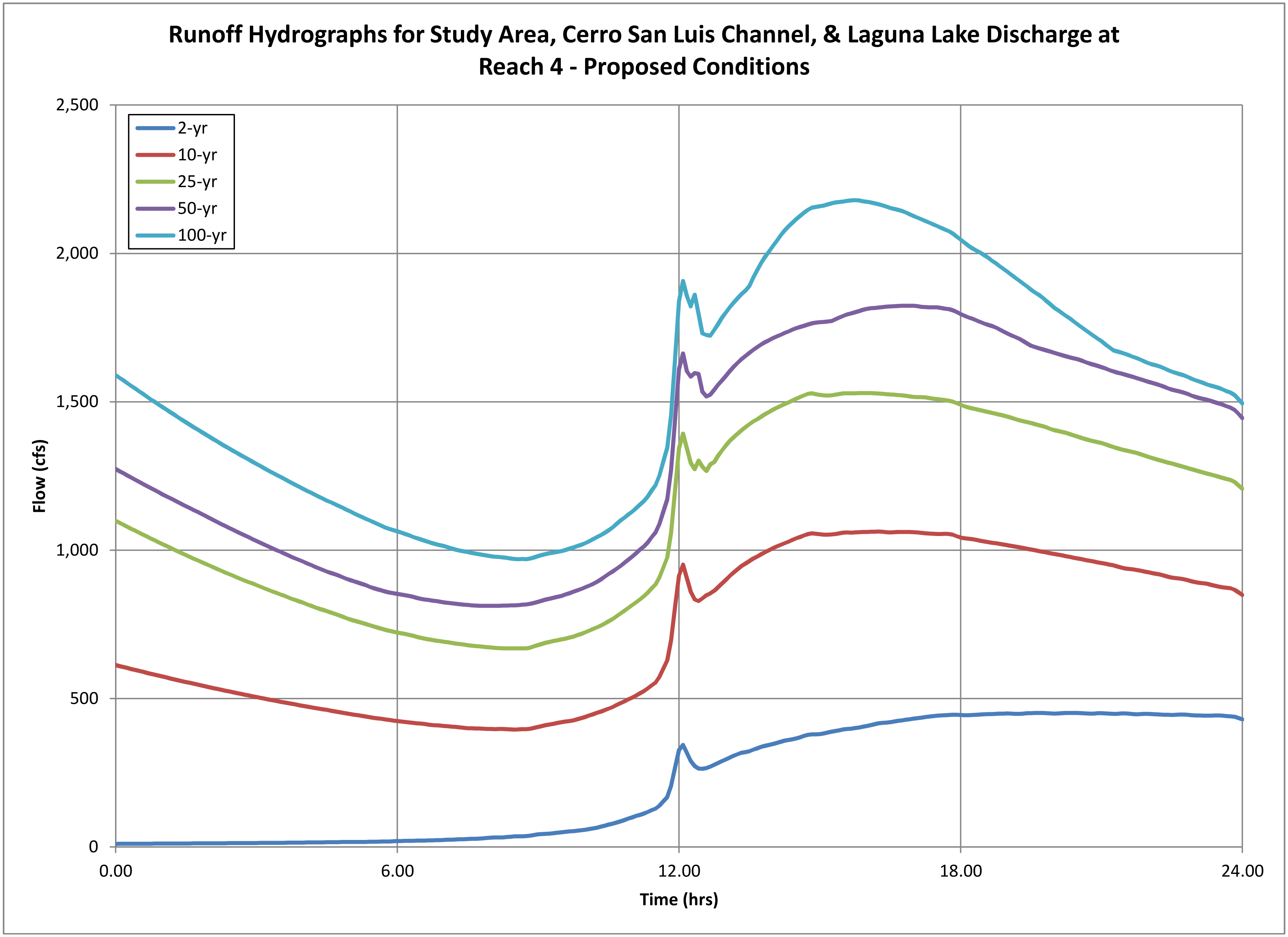
Sub-basin	Total Area, *A* (ac)	Composite Runoff Coefficient, *C*	Time of Conc. T_c (min)	Rainfall Intensity, *i* (in/hr)					Peak Flow (cfs) ($Q=C*i*C_a*A$)					Point of Discharge
				2-yr	10-yr	25-yr	50-yr	100-yr	2-yr	10-yr	25-yr	50-yr	100-yr	
PROP-1	3.62	0.48	10.0	2.09	3.58	4.02	4.61	5.00	3.59	6.16	7.60	9.51	10.75	Prefumo Reach 1
PROP-2A	2.87	0.69	10.0	2.09	3.58	4.02	4.61	5.00	4.11	7.05	8.70	10.88	12.30	Cerro San Luis Channel
PROP-2B	8.02	0.47	10.0	2.09	3.58	4.02	4.61	5.00	7.80	13.39	16.51	20.65	23.35	Cerro San Luis Channel
PROP-2C	3.71	0.61	10.0	2.09	3.58	4.02	4.61	5.00	4.76	8.17	10.07	12.60	14.25	Cerro San Luis Channel
PROP-2D	5.95	0.61	10.0	2.09	3.58	4.02	4.61	5.00	7.57	12.99	16.02	20.05	22.66	Cerro San Luis Channel
PROP-3A	12.89	0.53	10.0	2.09	3.58	4.02	4.61	5.00	14.38	24.69	30.45	38.10	43.08	Prefumo Reach 2
PROP-3B	1.23	0.47	10.0	2.09	3.58	4.02	4.61	5.00	1.20	2.05	2.53	3.17	3.58	Prefumo Reach 2
PROP-3C	3.06	0.56	10.0	2.09	3.58	4.02	4.61	5.00	3.55	6.09	7.51	9.40	10.63	Prefumo Reach 2
PROP-3D	2.02	0.43	10.0	2.09	3.58	4.02	4.61	5.00	1.81	3.10	3.83	4.79	5.41	Prefumo Reach 2
PROP-3E	2.36	0.31	10.0	2.09	3.58	4.02	4.61	5.00	1.51	2.60	3.21	4.01	4.53	Prefumo Reach 2
PROP-4A	1.26	0.66	10.0	2.09	3.58	4.02	4.61	5.00	1.73	2.97	3.66	4.58	5.18	Prefumo Reach 3
PROP-4B	0.70	0.72	10.0	2.09	3.58	4.02	4.61	5.00	1.05	1.80	2.22	2.78	3.14	Prefumo Reach 3
PROP-4C	1.63	0.73	10.0	2.09	3.58	4.02	4.61	5.00	2.47	4.25	5.24	6.55	7.41	Prefumo Reach 3
PROP-4D	14.71	0.54	10.0	2.09	3.58	4.02	4.61	5.00	16.47	28.29	34.88	43.64	49.35	Prefumo Reach 3
PROP-4E	5.20	0.54	10.0	2.09	3.58	4.02	4.61	5.00	5.88	10.09	12.44	15.57	17.60	Prefumo Reach 3
PROP-4F	9.06	0.15	58.8	0.77	1.33	1.53	1.73	1.89	1.04	1.81	2.29	2.82	3.22	Prefumo Reach 3
PROP-4G	60.54	0.15	81.6	0.68	1.16	1.35	1.55	1.68	6.15	10.51	13.53	16.90	19.07	Prefumo Reach 3
Total:	**138.84**								**78.91**	**135.51**	**167.14**	**209.10**	**236.46**	

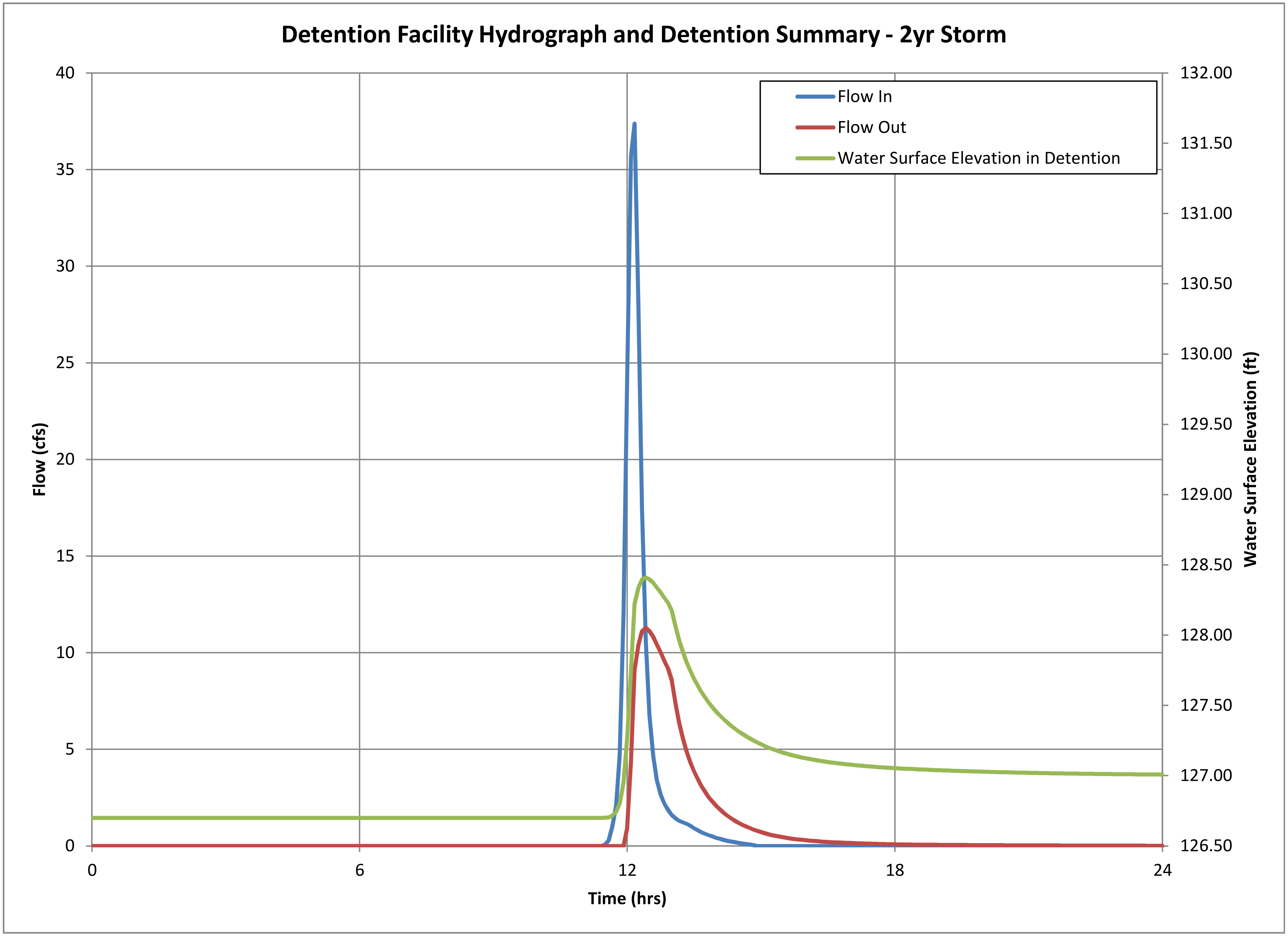


Runoff Hydrographs for Study Area (All Sub-basins) - Proposed Conditions
Flow (cfs)
Time (hrs)
300
250
200
150
100
50
0
0.00
6.00
12.00
18.00
24.00
2-yr
10-yr
25-yr
50-yr
100-yr

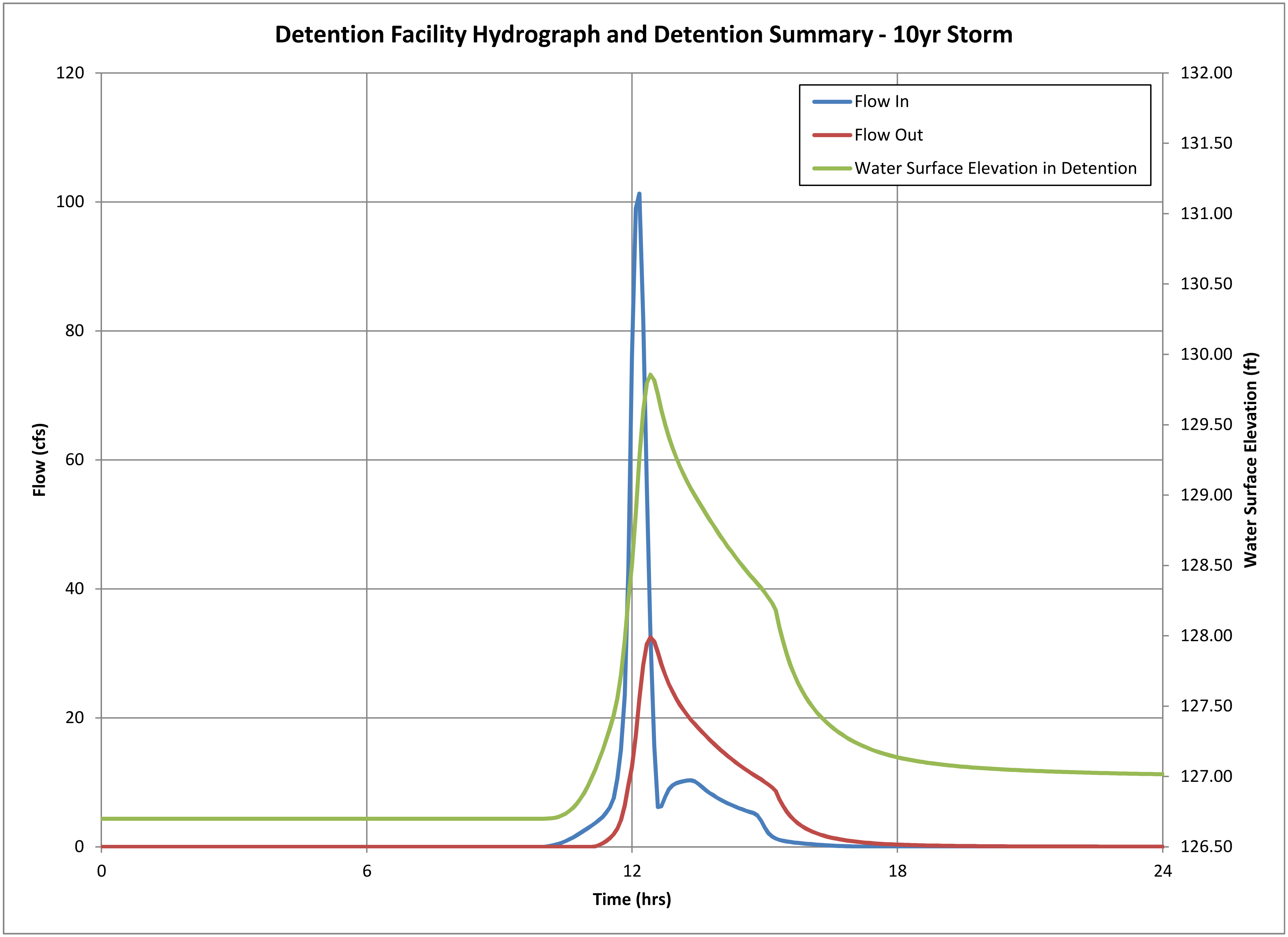


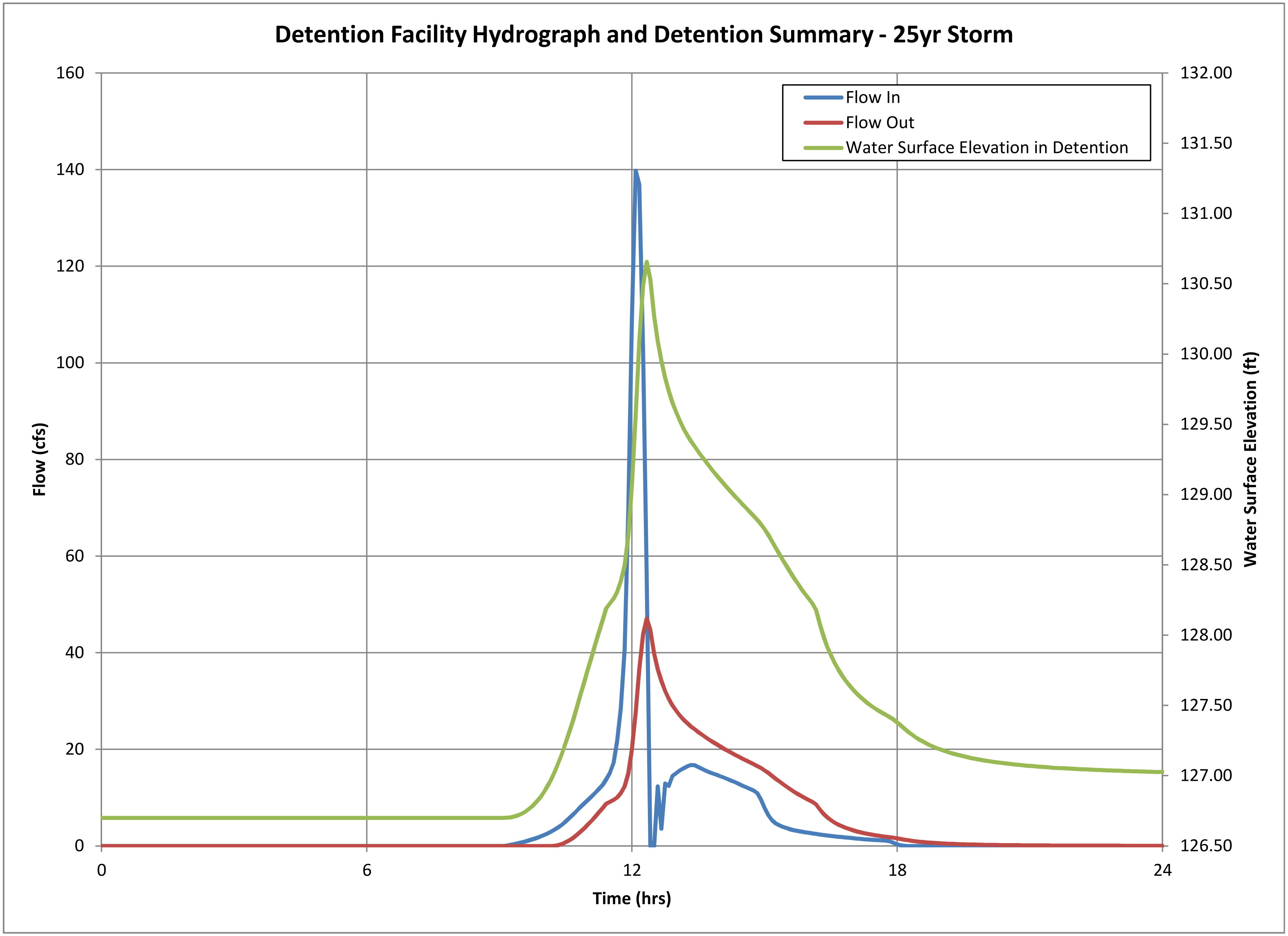
Runoff Hydrographs for Study Area & Cerro San Luis Channel at Reach 4 - Proposed Conditions
2-yr
10-yr
25-yr
50-yr
100-yr
Flow (cfs)
0
100
200
300
400
500
600
700
800
900
0.00
6.00
12.00
18.00
24.00
Time (hrs)


Runoff Hydrographs for Study Area, Cerro San Luis Channel, & Laguna Lake Discharge at Reach 4 - Proposed Conditions
2-yr
10-yr
25-yr
50-yr
100-yr
Flow (cfs)
0
500
1,000
1,500
2,000
2,500
Time (hrs)
0.00
6.00
12.00
18.00
24.00

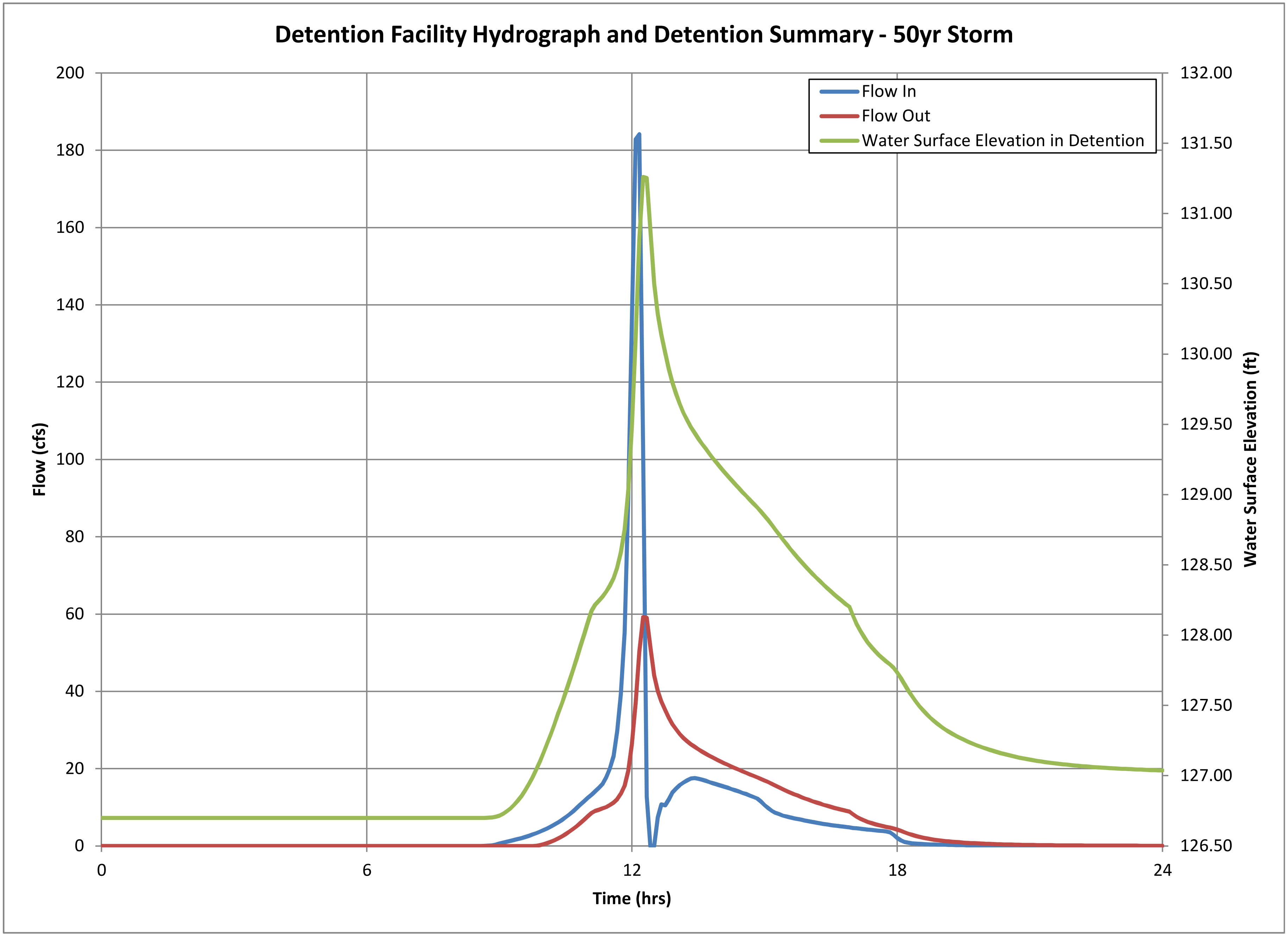


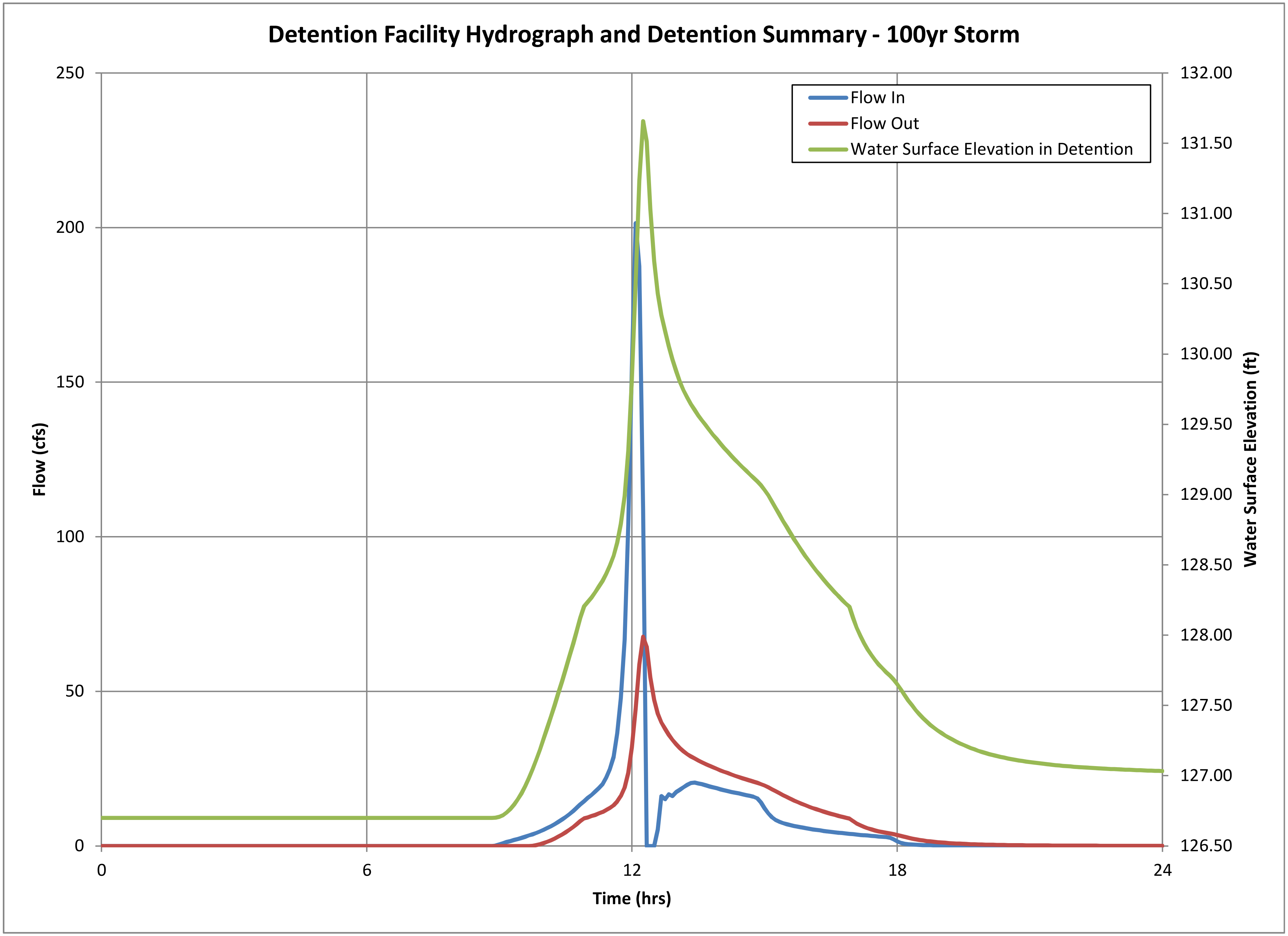
Detention Facility Hydrograph and Detention Summary - 2yr Storm
Flow In
Flow Out
Water Surface Elevation in Detention
Flow (cfs)
Water Surface Elevation (ft)
Time (hrs)
40
35
30
25
20
15
10
5
0
132.00
131.50
131.00
130.50
130.00
129.50
129.00
128.50
128.00
127.50
127.00
126.50
0
6
12
18
24


Detention Facility Hydrograph and Detention Summary - 10yr Storm
Flow In
Flow Out
Water Surface Elevation in Detention
Flow (cfs)
Water Surface Elevation (ft)
Time (hrs)
120
100
80
60
40
20
0
132.00
131.50
131.00
130.50
130.00
129.50
129.00
128.50
128.00
127.50
127.00
126.50
0
6
12
18
24



Detention Facility Hydrograph and Detention Summary - 25yr Storm
Flow In
Flow Out
Water Surface Elevation in Detention
Flow (cfs)
Water Surface Elevation (ft)
Time (hrs)
160
140
120
100
80
60
40
20
0
132.00
131.50
131.00
130.50
130.00
129.50
129.00
128.50
128.00
127.50
127.00
126.50
0
6
12
18
24


Detention Facility Hydrograph and Detention Summary - 50yr Storm
Flow In
Flow Out
Water Surface Elevation in Detention
Flow (cfs)
Water Surface Elevation (ft)
Time (hrs)
0
20
40
60
80
100
120
140
160
180
200
126.50
127.00
127.50
128.00
128.50
129.00
129.50
130.00
130.50
131.00
131.50
132.00
0
6
12
18
24


Detention Facility Hydrograph and Detention Summary - 100yr Storm
Flow In
Flow Out
Water Surface Elevation in Detention
Flow (cfs)
Water Surface Elevation (ft)
Time (hrs)
0
50
100
150
200
250
126.50
127.00
127.50
128.00
128.50
129.00
129.50
130.00
130.50
131.00
131.50
132.00
0
6
12
18
24

Appendix D

Miscellaneous Calculations

1. Detention Intake Channel Calculation
2. Riprap Sizing at Storm Drain Outfalls

PROJECT: San Luis Ranch	COMPUTED BY: STS	DATE: 6/21/2016
SUBJECT: Detention Intake Channel Hydraulic Calcs	CHECKED BY:	SHT. 1 OF 4
		PART:

CALCULATION COVER SHEET

This spreadsheet contains calculations for water surface elevation, depth, and velocity in the intake channel from the diversion structure in Cerro San Luis Channel to the detention system.

These calculations are based on the assumption that the flow in the channel is gradually varied. The analysis starts at the downstream end of the channel with the water surface elevation equal to the water surface elevation in the detention system. Each subsequent section uses the depth calculated at the previous section as the starting depth for the current section. The calculation iterates at intervals in x direction along the length of the pipe to calculate the water surface profile. The Runge-Kutta 4th Order Method is used to approximate the solution of the governing differential equation for steady, gradually varied flow.

It appears that a maximum flow of about 202 cfs can be conveyed by the flat channel without significantly raising (0.003') the water surface elevation at the upstream end of the channel at the diversion intake.

A Mannings friction coefficient of 0.014 was assumed .

These calculations do not account for minor losses due to transitions, bends, fittings, etc.

Review Comments:

Revision History:

Revision	Date:	Purpose	Checked By	Date
Original				
rev 1				
rev 2				
rev 3				

Governing Equations

Steady, Gradually Varied Flow Equation

$$\frac{dy}{dx} = \frac{S_o - S_f}{1 - F_r^2}$$

where:

y = flow depth at location x
x = channel station or stream length location
S_o = channel slope
S_f = friction slope
F_r = Froude Number

Ref: Mays, L.M. 2001. Water Resources Engineering. John Wiley & Sons, Inc. New York

Friction Slope

The friction slope is calculated using the Manning's Equation

$$S_f = \left(\frac{Vn}{1.49R^{2/3}}\right)^2$$

where:

V = velocity
n = Manning roughness
R = Hydraulic Radius (A/P)
A = Wetted Area
P = Wetted Perimeter

Ref: Mays, L.M. 2001. Water Resources Engineering. John Wiley & Sons, Inc. New York

Froude Number

The Froude Number is calcualted as follows:

$$F_r = \frac{V}{\sqrt{gy}}$$

Ref: Mays, L.M. 2001. Water Resources Engineering. John Wiley & Sons, Inc. New York

Runge-Kutta 4th Order Method for Ordinary Differential Equations

The Runge-Kutta (RK) 4th Order Method is a numerical technique used to approximate the solutions of ordinary differential equations. This method obtains an approximate solution by iteration, while maintaining reasonable bounds on errors. In this calculation, the RK method is applied to the steady, gradually varied flow equation to solve for the water depth along the length of the pipe. The water depth at the upstream end of the pipe is specifed, and this boundary condition is used to calculate successive water depths along the length of the pipe at discrete intervals.

The RK equation used is as follows:

$$y_{i+1} = y_i + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)h$$

where:

y_{i+1} = depth of water at next calculation step
y_i = depth of water at current calculation step
h = x_{i+1} - x_i, incremental change in x from current calculaiton step to next (Δx)
x_{i+1} = location along flume at next calculation step
x_i = location along flume at current calculation step
k_1 = $f(x_i, y_i)$
k_2 = $f(x_i + h/2, y_i + k_1 h/2)$
k_3 = $f(x_i + h/2, y_i + k_2 h/2)$
k_4 = $f(x_i + h, y_i + k_3 h)$

$$f(x_i, y_i) = \frac{S_{oi} - S_{fi}}{1 - F_{ri}^2}$$

So, the depth of water for the next calcuation step is calculated by the depth of water at the current calculation step, plus the Δx along the flume multiplied by the weighted average (calculated at 4 locations) of dy/dx.

Gradually Varied Flow Calculations

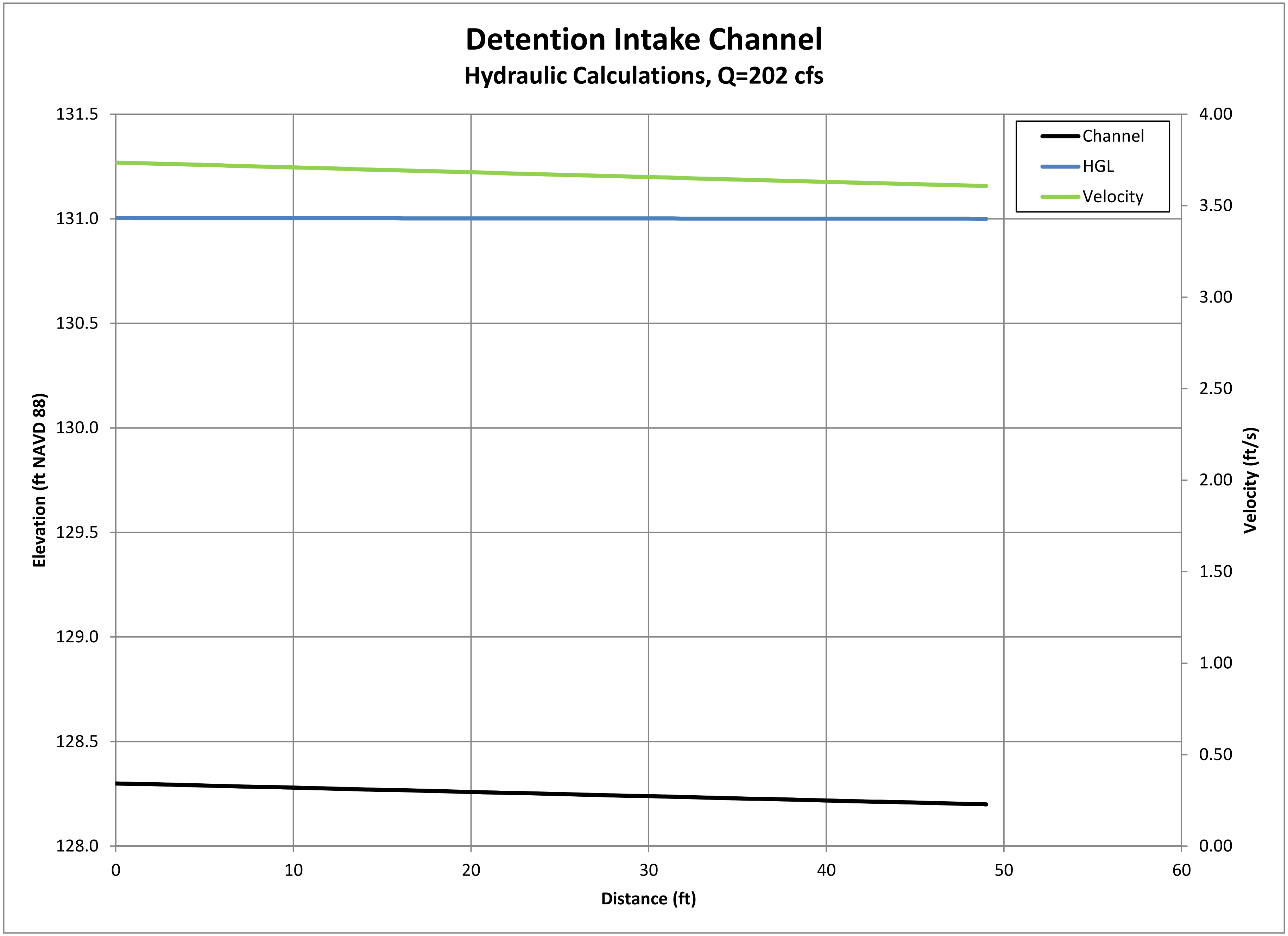
Input

Flow (cfs)	202.00	(100-yr peak inflow)
Downstream WSE (ft):	131.00	(Water surface elevation in detention system at 100-yr peak inflow)

			Invert Elevation (ft) (NAVD 88)					
Segment	Description	Width (ft)	Upstream	Downstream	Length (ft)	Slope	Mannings n	*dx* (ft)
A	Intake Channel	20.00	128.30	128.20	49	0.20%	0.013	0.49

Segment A

							k_1 Calculations							k_2 Calculations									k_3 Calculations									k_4 Calculations									
Step Counter, *i*	Station, *x* (ft)	Flow, Q (cfs)	Invert Elevation (ft)	HGL (ft)	EGL (ft)	Depth, *y* (ft)	Area (ft^2)	Velocity (ft/s)	Froude No.	P (ft)	R (ft)	S_f	$dy/dx = k_1$	$x_i+h/2$	$y_i+k_1*hx/2$	Area (ft^2)	Velocity (ft/s)	Froude No.	*P* (ft)	*R* (ft)	S_f	$dy/dx = k_2$	$x_i+h/2$	$y_i+k_2*h/2$	Area (ft^2)	Velocity (ft/s)	Froude No.	*P* (ft)	*R* (ft)	S_f	$dy/dx = k_3$	x_i+h	y_i+k_3*h	Area (ft^2)	Velocity (ft/s)	Froude No.	*P* (ft)	*R* (ft)	S_f	$dy/dx = k_4$	y_{i+1}
1	0.000	202.00	128.300	131.003	131.220	2.703	54.066	3.74	0.40																																
2	0.490	202.00	128.299	131.003	131.220	2.704	54.086	3.73	0.40	25.41	2.13	0.0004	0.002	0.245	2.704	54.076	3.74	0.40	25.41	2.13	0.0004	0.002	0.245	2.704	54.076	3.74	0.40	25.41	2.13	0.0004	0.002	0.000	2.703	54.066	3.74	0.40	25.41	2.13	0.0004	0.002	2.703
3	0.980	202.00	128.298	131.003	131.220	2.705	54.105	3.73	0.40	25.41	2.13	0.0004	0.002	0.735	2.705	54.095	3.73	0.40	25.41	2.13	0.0004	0.002	0.735	2.705	54.095	3.73	0.40	25.41	2.13	0.0004	0.002	0.490	2.704	54.086	3.73	0.40	25.41	2.13	0.0004	0.002	2.704
4	1.470	202.00	128.297	131.003	131.220	2.706	54.124	3.73	0.40	25.41	2.13	0.0004	0.002	1.225	2.706	54.115	3.73	0.40	25.41	2.13	0.0004	0.002	1.225	2.706	54.115	3.73	0.40	25.41	2.13	0.0004	0.002	0.980	2.705	54.105	3.73	0.40	25.41	2.13	0.0004	0.002	2.705
5	1.960	202.00	128.296	131.003	131.219	2.707	54.144	3.73	0.40	25.41	2.13	0.0004	0.002	1.715	2.707	54.134	3.73	0.40	25.41	2.13	0.0004	0.002	1.715	2.707	54.134	3.73	0.40	25.41	2.13	0.0004	0.002	1.470	2.706	54.124	3.73	0.40	25.41	2.13	0.0004	0.002	2.706
6	2.450	202.00	128.295	131.003	131.219	2.708	54.163	3.73	0.40	25.42	2.13	0.0004	0.002	2.205	2.708	54.153	3.73	0.40	25.42	2.13	0.0004	0.002	2.205	2.708	54.153	3.73	0.40	25.42	2.13	0.0004	0.002	1.960	2.707	54.144	3.73	0.40	25.41	2.13	0.0004	0.002	2.707
7	2.940	202.00	128.294	131.003	131.219	2.709	54.182	3.73	0.40	25.42	2.13	0.0004	0.002	2.695	2.709	54.173	3.73	0.40	25.42	2.13	0.0004	0.002	2.695	2.709	54.173	3.73	0.40	25.42	2.13	0.0004	0.002	2.450	2.708	54.163	3.73	0.40	25.42	2.13	0.0004	0.002	2.708
8	3.430	202.00	128.293	131.003	131.219	2.710	54.202	3.73	0.40	25.42	2.13	0.0004	0.002	3.185	2.710	54.192	3.73	0.40	25.42	2.13	0.0004	0.002	3.185	2.710	54.192	3.73	0.40	25.42	2.13	0.0004	0.002	2.940	2.709	54.182	3.73	0.40	25.42	2.13	0.0004	0.002	2.709
9	3.920	202.00	128.292	131.003	131.219	2.711	54.221	3.73	0.40	25.42	2.13	0.0004	0.002	3.675	2.711	54.211	3.73	0.40	25.42	2.13	0.0004	0.002	3.675	2.711	54.211	3.73	0.40	25.42	2.13	0.0004	0.002	3.430	2.710	54.202	3.73	0.40	25.42	2.13	0.0004	0.002	2.710
10	4.410	202.00	128.291	131.003	131.218	2.712	54.240	3.72	0.40	25.42	2.13	0.0004	0.002	4.165	2.712	54.230	3.72	0.40	25.42	2.13	0.0004	0.002	4.165	2.712	54.230	3.72	0.40	25.42	2.13	0.0004	0.002	3.920	2.711	54.221	3.73	0.40	25.42	2.13	0.0004	0.002	2.711
11	4.900	202.00	128.290	131.003	131.218	2.713	54.259	3.72	0.40	25.43	2.13	0.0004	0.002	4.655	2.712	54.250	3.72	0.40	25.42	2.13	0.0004	0.002	4.655	2.712	54.250	3.72	0.40	25.42	2.13	0.0004	0.002	4.410	2.712	54.240	3.72	0.40	25.42	2.13	0.0004	0.002	2.712
12	5.390	202.00	128.289	131.003	131.218	2.714	54.279	3.72	0.40	25.43	2.13	0.0004	0.002	5.145	2.713	54.269	3.72	0.40	25.43	2.13	0.0004	0.002	5.145	2.713	54.269	3.72	0.40	25.43	2.13	0.0004	0.002	4.900	2.713	54.259	3.72	0.40	25.43	2.13	0.0004	0.002	2.713
13	5.880	202.00	128.288	131.003	131.218	2.715	54.298	3.72	0.40	25.43	2.14	0.0004	0.002	5.635	2.714	54.288	3.72	0.40	25.43	2.13	0.0004	0.002	5.635	2.714	54.288	3.72	0.40	25.43	2.13	0.0004	0.002	5.390	2.714	54.279	3.72	0.40	25.43	2.13	0.0004	0.002	2.714
14	6.370	202.00	128.287	131.003	131.218	2.716	54.317	3.72	0.40	25.43	2.14	0.0004	0.002	6.125	2.715	54.308	3.72	0.40	25.43	2.14	0.0004	0.002	6.125	2.715	54.308	3.72	0.40	25.43	2.14	0.0004	0.002	5.880	2.715	54.298	3.72	0.40	25.43	2.14	0.0004	0.002	2.715
15	6.860	202.00	128.286	131.003	131.217	2.717	54.337	3.72	0.40	25.43	2.14	0.0004	0.002	6.615	2.716	54.327	3.72	0.40	25.43	2.14	0.0004	0.002	6.615	2.716	54.327	3.72	0.40	25.43	2.14	0.0004	0.002	6.370	2.716	54.317	3.72	0.40	25.43	2.14	0.0004	0.002	2.716
16	7.350	202.00	128.285	131.003	131.217	2.718	54.356	3.72	0.40	25.44	2.14	0.0004	0.002	7.105	2.717	54.346	3.72	0.40	25.43	2.14	0.0004	0.002	7.105	2.717	54.346	3.72	0.40	25.43	2.14	0.0004	0.002	6.860	2.717	54.337	3.72	0.40	25.43	2.14	0.0004	0.002	2.717
17	7.840	202.00	128.284	131.003	131.217	2.719	54.375	3.71	0.40	25.44	2.14	0.0004	0.002	7.595	2.718	54.366	3.72	0.40	25.44	2.14	0.0004	0.002	7.595	2.718	54.366	3.72	0.40	25.44	2.14	0.0004	0.002	7.350	2.718	54.356	3.72	0.40	25.44	2.14	0.0004	0.002	2.718
18	8.330	202.00	128.283	131.003	131.217	2.720	54.395	3.71	0.40	25.44	2.14	0.0004	0.002	8.085	2.719	54.385	3.71	0.40	25.44	2.14	0.0004	0.002	8.085	2.719	54.385	3.71	0.40	25.44	2.14	0.0004	0.002	7.840	2.719	54.375	3.71	0.40	25.44	2.14	0.0004	0.002	2.719
19	8.820	202.00	128.282	131.003	131.217	2.721	54.414	3.71	0.40	25.44	2.14	0.0004	0.002	8.575	2.720	54.404	3.71	0.40	25.44	2.14	0.0004	0.002	8.575	2.720	54.404	3.71	0.40	25.44	2.14	0.0004	0.002	8.330	2.720	54.395	3.71	0.40	25.44	2.14	0.0004	0.002	2.720
20	9.310	202.00	128.281	131.003	131.216	2.722	54.433	3.71	0.40	25.44	2.14	0.0004	0.002	9.065	2.721	54.424	3.71	0.40	25.44	2.14	0.0004	0.002	9.065	2.721	54.424	3.71	0.40	25.44	2.14	0.0004	0.002	8.820	2.721	54.414	3.71	0.40	25.44	2.14	0.0004	0.002	2.721
21	9.800	202.00	128.280	131.003	131.216	2.723	54.452	3.71	0.40	25.45	2.14	0.0004	0.002	9.555	2.722	54.443	3.71	0.40	25.44	2.14	0.0004	0.002	9.555	2.722	54.443	3.71	0.40	25.44	2.14	0.0004	0.002	9.310	2.722	54.433	3.71	0.40	25.44	2.14	0.0004	0.002	2.722
22	10.290	202.00	128.279	131.003	131.216	2.724	54.472	3.71	0.40	25.45	2.14	0.0004	0.002	10.045	2.723	54.462	3.71	0.40	25.45	2.14	0.0004	0.002	10.045	2.723	54.462	3.71	0.40	25.45	2.14	0.0004	0.002	9.800	2.723	54.452	3.71	0.40	25.45	2.14	0.0004	0.002	2.723
23	10.780	202.00	128.278	131.003	131.216	2.725	54.491	3.71	0.40	25.45	2.14	0.0004	0.002	10.535	2.724	54.481	3.71	0.40	25.45	2.14	0.0004	0.002	10.535	2.724	54.481	3.71	0.40	25.45	2.14	0.0004	0.002	10.290	2.724	54.472	3.71	0.40	25.45	2.14	0.0004	0.002	2.724
24	11.270	202.00	128.277	131.003	131.216	2.726	54.510	3.71	0.40	25.45	2.14	0.0004	0.002	11.025	2.725	54.501	3.71	0.40	25.45	2.14	0.0004	0.002	11.025	2.725	54.501	3.71	0.40	25.45	2.14	0.0004	0.002	10.780	2.725	54.491	3.71	0.40	25.45	2.14	0.0004	0.002	2.725
25	11.760	202.00	128.276	131.002	131.216	2.726	54.530	3.70	0.40	25.45	2.14	0.0004	0.002	11.515	2.726	54.520	3.71	0.40	25.45	2.14	0.0004	0.002	11.515	2.726	54.520	3.71	0.40	25.45	2.14	0.0004	0.002	11.270	2.726	54.510	3.71	0.40	25.45	2.14	0.0004	0.002	2.726
26	12.250	202.00	128.275	131.002	131.215	2.727	54.549	3.70	0.40	25.45	2.14	0.0004	0.002	12.005	2.727	54.539	3.70	0.40	25.45	2.14	0.0004	0.002	12.005	2.727	54.539	3.70	0.40	25.45	2.14	0.0004	0.002	11.760	2.726	54.530	3.70	0.40	25.45	2.14	0.0004	0.002	2.726
27	12.740	202.00	128.274	131.002	131.215	2.728	54.568	3.70	0.39	25.46	2.14	0.0004	0.002	12.495	2.728	54.559	3.70	0.40	25.46	2.14	0.0004	0.002	12.495	2.728	54.559	3.70	0.40	25.46	2.14	0.0004	0.002	12.250	2.727	54.549	3.70	0.40	25.45	2.14	0.0004	0.002	2.727
28	13.230	202.00	128.273	131.002	131.215	2.729	54.588	3.70	0.39	25.46	2.14	0.0004	0.002	12.985	2.729	54.578	3.70	0.39	25.46	2.14	0.0004	0.002	12.985	2.729	54.578	3.70	0.39	25.46	2.14	0.0004	0.002	12.740	2.728	54.568	3.70	0.39	25.46	2.14	0.0004	0.002	2.728
29	13.720	202.00	128.272	131.002	131.215	2.730	54.607	3.70	0.39	25.46	2.14	0.0004	0.002	13.475	2.730	54.597	3.70	0.39	25.46	2.14	0.0004	0.002	13.475	2.730	54.597	3.70	0.39	25.46	2.14	0.0004	0.002	13.230	2.729	54.588	3.70	0.39	25.46	2.14	0.0004	0.002	2.729
30	14.210	202.00	128.271	131.002	131.215	2.731	54.626	3.70	0.39	25.46	2.15	0.0004	0.002	13.965	2.731	54.617	3.70	0.39	25.46	2.15	0.0004	0.002	13.965	2.731	54.617	3.70	0.39	25.46	2.15	0.0004	0.002	13.720	2.730	54.607	3.70	0.39	25.46	2.14	0.0004	0.002	2.730
31	14.700	202.00	128.270	131.002	131.214	2.732	54.646	3.70	0.39	25.46	2.15	0.0004	0.002	14.455	2.732	54.636	3.70	0.39	25.46	2.15	0.0004	0.002	14.455	2.732	54.636	3.70	0.39	25.46	2.15	0.0004	0.002	14.210	2.731	54.626	3.70	0.39	25.46	2.15	0.0004	0.002	2.731
32	15.190	202.00	128.269	131.002	131.214	2.733	54.665	3.70	0.39	25.47	2.15	0.0004	0.002	14.945	2.733	54.655	3.70	0.39	25.47	2.15	0.0004	0.002	14.945	2.733	54.655	3.70	0.39	25.47	2.15	0.0004	0.002	14.700	2.732	54.646	3.70	0.39	25.46	2.15	0.0004	0.002	2.732
33	15.680	202.00	128.268	131.002	131.214	2.734	54.684	3.69	0.39	25.47	2.15	0.0004	0.002	15.435	2.734	54.675	3.69	0.39	25.47	2.15	0.0004	0.002	15.435	2.734	54.675	3.69	0.39	25.47	2.15	0.0004	0.002	15.190	2.733	54.665	3.70	0.39	25.47	2.15	0.0004	0.002	2.733
34	16.170	202.00	128.267	131.002	131.214	2.735	54.704	3.69	0.39	25.47	2.15	0.0004	0.002	15.925	2.735	54.694	3.69	0.39	25.47	2.15	0.0004	0.002	15.925	2.735	54.694	3.69	0.39	25.47	2.15	0.0004	0.002	15.680	2.734	54.684	3.69	0.39	25.47	2.15	0.0004	0.002	2.734
35	16.660	202.00	128.266	131.002	131.214	2.736	54.723	3.69	0.39	25.47	2.15	0.0004	0.002	16.415	2.736	54.713	3.69	0.39	25.47	2.15	0.0004	0.002	16.415	2.736	54.713	3.69	0.39	25.47	2.15	0.0004	0.002	16.170	2.735	54.704	3.69	0.39	25.47	2.15	0.0004	0.002	2.735
36	17.150	202.00	128.265	131.002	131.214	2.737	54.742	3.69	0.39	25.47	2.15	0.0004	0.002	16.905	2.737	54.733	3.69	0.39	25.47	2.15	0.0004	0.002	16.905	2.737	54.733	3.69	0.39	25.47	2.15	0.0004	0.002	16.660	2.736	54.723	3.69	0.39	25.47	2.15	0.0004	0.002	2.736
37	17.640	202.00	128.264	131.002	131.213	2.738	54.762	3.69	0.39	25.48	2.15	0.0004	0.002	17.395	2.738	54.752	3.69	0.39	25.48	2.15	0.0004	0.002	17.395	2.738	54.752	3.69	0.39	25.48	2.15	0.0004	0.002	17.150	2.737	54.742	3.69	0.39	25.47	2.15	0.0004	0.002	2.737
38	18.130	202.00	128.263	131.002	131.213	2.739	54.781	3.69	0.39	25.48	2.15	0.0004	0.002	17.885	2.739	54.771	3.69	0.39	25.48	2.15	0.0004	0.002	17.885	2.739	54.771	3.69	0.39	25.48	2.15	0.0004	0.002	17.640	2.738	54.762	3.69	0.39	25.48	2.15	0.0004	0.002	2.738
39	18.620	202.00	128.262	131.002	131.213	2.740	54.800	3.69	0.39	25.48	2.15	0.0004	0.002	18.375	2.740	54.791	3.69	0.39	25.48	2.15	0.0004	0.002	18.375	2.740	54.791	3.69	0.39	25.48	2.15	0.0004	0.002	18.130	2.739	54.781	3.69	0.39	25.48	2.15	0.0004	0.002	2.739
40	19.110	202.00	128.261	131.002	131.213	2.741	54.819	3.68	0.39	25.48	2.15	0.0004	0.002	18.865	2.740	54.810	3.69	0.39	25.48	2.15	0.0004	0.002	18.865	2.740	54.810	3.69	0.39	25.48	2.15	0.0004	0.002	18.620	2.740	54.800	3.69	0.39	25.48	2.15	0.0004	0.002	2.740
41	19.600	202.00	128.260	131.002	131.213	2.742	54.839	3.68	0.39	25.48	2.15	0.0004	0.002	19.355	2.741	54.829	3.68	0.39	25.48	2.15	0.0004	0.002	19.355	2.741	54.829	3.68	0.39	25.48	2.15	0.0004	0.002	19.110	2.741	54.819	3.68	0.39	25.48	2.15	0.0004	0.002	2.741
42	20.090	202.00	128.259	131.002	131.212	2.743	54.858	3.68	0.39	25.49	2.15	0.0004	0.002	19.845	2.742	54.848	3.68	0.39	25.48	2.15	0.0004	0.002	19.845	2.742	54.848	3.68	0.39	25.48	2.15	0.0004	0.002	19.600	2.742	54.839	3.68	0.39	25.48	2.15	0.0004	0.002	2.742
43	20.580	202.00	128.258	131.002	131.212	2.744	54.877	3.68	0.39	25.49	2.15	0.0004	0.002	20.335	2.743	54.868	3.68	0.39	25.49	2.15	0.0004	0.002	20.335	2.743	54.868	3.68	0.39	25.49	2.15	0.0004	0.002	20.090	2.743	54.858	3.68	0.39	25.49	2.15	0.0004	0.002	2.743
44	21.070	202.00	128.257	131.002	131.212	2.745	54.897	3.68	0.39	25.49	2.15	0.0004	0.002	20.825	2.744	54.887	3.68	0.39	25.49	2.15	0.0004	0.002	20.825	2.744	54.887	3.68	0.39	25.49	2.15	0.0004	0.002	20.580	2.744	54.877	3.68	0.39	25.49	2.15	0.0004	0.002	2.744
45	21.560	202.00	128.256	131.002	131.212	2.746	54.916	3.68	0.39	25.49	2.15	0.0004	0.002	21.315	2.745	54.906	3.68	0.39	25.49	2.15	0.0004	0.002	21.315	2.745	54.906	3.68	0.39	25.49	2.15	0.0004	0.002	21.070	2.745	54.897	3.68	0.39	25.49	2.15	0.0004	0.002	2.745
46	22.050	202.00	128.255	131.002	131.212	2.747	54.935	3.68	0.39	25.49	2.15	0.0004	0.002	21.805	2.746	54.926	3.68	0.39	25.49	2.15	0.0004	0.002	21.805	2.746	54.926	3.68	0.39	25.49	2.15	0.0004	0.002	21.560	2.746	54.916	3.68	0.39	25.49	2.15	0.0004	0.002	2.746
47	22.540	202.00	128.254	131.002	131.212	2.748	54.955	3.68	0.39	25.50	2.16	0.0004	0.002	22.295	2.747	54.945	3.68	0.39	25.49	2.16	0.0004	0.002	22.295	2.747	54.945	3.68	0.39	25.49	2.16	0.0004	0.002	22.050	2.747	54.935	3.68	0.39	25.49	2.15	0.0004	0.002	2.747
48	23.030	202.00	128.253	131.002	131.211	2.749	54.974	3.67	0.39	25.50	2.16	0.0004	0.002	22.785	2.748	54.964	3.68	0.39	25.50	2.16	0.0004	0.002	22.785	2.748	54.964	3.68	0.39	25.50	2.16	0.0004	0.002	22.540	2.748	54.955	3.68	0.39	25.50	2.16	0.0004	0.002	2.748
49	23.520	202.00	128.252	131.002	131.211	2.750	54.993	3.67	0.39	25.50	2.16	0.0004	0.002	23.275	2.749	54.984	3.67	0.39	25.50	2.16	0.0004	0.002	23.275	2.749	54.984	3.67	0.39	25.50	2.16	0.0004	0.002	23.030	2.749	54.974	3.67	0.39	25.50	2.16	0.0004	0.002	2.749
50	24.010	202.00	128.251	131.002	131.211	2.751	55.013	3.67	0.39	25.50	2.16	0.0004	0.002	23.765	2.750	55.003	3.67	0.39	25.50	2.16	0.0004	0.002	23.765	2.750	55.003	3.67	0.39	25.50	2.16	0.0004	0.002	23.520	2.750	54.993	3.67	0.39	25.50	2.16	0.0004	0.002	2.750
51	24.500	202.00	128.250	131.002	131.211	2.752	55.032	3.67	0.39	25.50	2.16	0.0004	0.002	24.255	2.751	55.022	3.67	0.39	25.50	2.16	0.0004	0.002	24.255	2.751	55.022	3.67	0.39	25.50	2.16	0.0004	0.002	24.010	2.751	55.013	3.67	0.39	25.50	2.16	0.0004	0.002	2.751
52	24.990	202.00	128.249	131.002	131.211	2.753	55.051	3.67	0.39	25.51	2.16	0.0004	0.002	24.745	2.752	55.042	3.67	0.39	25.50	2.16	0.0004	0.002	24.745	2.752	55.042	3.67	0.39	25.50	2.16	0.0004	0.002	24.500	2.752	55.032	3.67	0.39	25.50	2.16	0.0004	0.002	2.752
53	25.480	202.00	128.248	131.002	131.210	2.754	55.071	3.67	0.39	25.51	2.16	0.0004	0.002	25.235	2.753	55.061	3.67	0.39	25.51	2.16	0.0004	0.002	25.235	2.753	55.061	3.67	0.39	25.51	2.16	0.0004	0.002	24.990	2.753	55.051	3.67	0.39	25.51	2.16	0.0004	0.002	2.753
54	25.970	202.00	128.247	131.002	131.210	2.755	55.090	3.67	0.39	25.51	2.16	0.0004	0.002	25.725	2.754	55.080	3.67	0.39	25.51	2.16	0.0004	0.002	25.725	2.754	55.080	3.67	0.39	25.51	2.16	0.0004	0.002	25.480	2.754	55.071	3.67	0.39	25.51	2.16	0.0004	0.002	2.754
55	26.460	202.00	128.246	131.001	131.210	2.755	55.109	3.67	0.39	25.51	2.16	0.0004	0.002	26.215	2.755	55.100	3.67	0.39	25.51	2.16	0.0004	0.002	26.215	2.755	55.100	3.67	0.39	25.51	2.16	0.0004	0.002	25.970	2.755	55.090	3.67	0.39	25.51	2.16	0.0004	0.002	2.755
56	26.950	202.00	128.245	131.001	131.210	2.756	55.129	3.66	0.39	25.51	2.16	0.0004	0.002	26.705	2.756	55.119	3.66	0.39	25.51	2.16	0.0004	0.002	26.705	2.756	55.119	3.66	0.39	25.51	2.16	0.0004	0.002	26.460	2.755	55.109	3.67	0.39	25.51	2.16	0.0004	0.002	2.755
57	27.440	202.00	128.244	131.001	131.210	2.757	55.148	3.66	0.39	25.51	2.16	0.0004	0.002	27.195	2.757	55.138	3.66	0.39	25.51	2.16	0.0004	0.002	27.195	2.757	55.138	3.66	0.39	25.51	2.16	0.0004	0.002	26.950	2.756	55.129	3.66	0.39	25.51	2.16	0.0004	0.002	2.756
58	27.930	202.00	128.243	131.001	131.210	2.758	55.168	3.66	0.39	25.52	2.16	0.0004	0.002	27.685	2.758	55.158	3.66	0.39	25.52	2.16	0.0004	0.002	27.685	2.758	55.158	3.66	0.39	25.52	2.16	0.0004	0.002	27.440	2.757	55.148	3.66	0.39	25.51	2.16	0.0004	0.002	2.757
59	28.420	202.00	128.242	131.001	131.209	2.759	55.187	3.66	0.39	25.52	2.16	0.0004	0.002	28.175	2.759	55.177	3.66	0.39	25.52	2.16	0.0004	0.002	28.175	2.759	55.177	3.66	0.39	25.52	2.16	0.0004	0.002	27.930	2.758	55.168	3.66	0.39	25.52	2.16	0.0004	0.002	2.758
60	28.910	202.00	128.241	131.001	131.209	2.760	55.206	3.66	0.39	25.52	2.16	0.0004	0.002	28.665	2.760	55.197	3.66	0.39	25.52	2.16	0.0004	0.002	28.665	2.760	55.197	3.66	0.39	25.52	2.16	0.0004	0.002	28.420	2.759	55.187	3.66	0.39	25.52	2.16	0.0004	0.002	2.759
61	29.400	202.00	128.240	131.001	131.209	2.761	55.226	3.66	0.39	25.52	2.16	0.0004	0.002	29.155	2.761	55.216	3.66	0.39	25.52	2.16	0.0004	0.002	29.155	2.761	55.216	3.66	0.39	25.52	2.16	0.0004	0.002	28.910	2.760	55.206	3.66	0.39	25.52	2.16	0.0004	0.002	2.760
62	29.890	202.00	128.239	131.001	131.209	2.762	55.245	3.66	0.39	25.52	2.16	0.0004	0.002	29.645	2.762	55.235	3.66	0.39	25.52	2.16	0.0004	0.002	29.645	2.762	55.235	3.66	0.39	25.52	2.16	0.0004	0.002	29.400	2.761	55.226	3.66	0.39	25.52	2.16	0.0004	0.002	2.761
63	30.380	202.00	128.238	131.001	131.209	2.763	55.264	3.66	0.39	25.53	2.16	0.0004	0.002	30.135	2.763	55.255	3.66	0.39	25.53	2.16	0.0004	0.002	30.135	2.763	55.255	3.66	0.39	25.53	2.16	0.0004	0.002	29.890	2.762	55.245	3.66	0.39	25.52	2.16	0.0004	0.002	2.762
64	30.870	202.00	128.237	131.001	131.208	2.764	55.284	3.65	0.39	25.53	2.17	0.0004	0.002	30.625	2.764	55.274	3.65	0.39	25.53	2.17	0.0004	0.002	30.625	2.764	55.274	3.65	0.39	25.53	2.17	0.0004	0.002	30.380	2.763	55.264	3.66	0.39	25.53	2.16	0.0004	0.002	2.763
65	31.360	202.00	128.236	131.001	131.208	2.765	55.303	3.65	0.39	25.53	2.17	0.0004	0.002	31.115	2.765	55.293	3.65	0.39	25.53	2.17	0.0004	0.002	31.115	2.765	55.293	3.65	0.39	25.53	2.17	0.0004	0.002	30.870	2.764	55.284	3.65	0.39	25.53	2.17	0.0004	0.002	2.764
66	31.850	202.00	128.235	131.001	131.208	2.766	55.322	3.65	0.39	25.53	2.17	0.0004	0.002	31.605	2.766	55.313	3.65	0.39	25.53	2.17	0.0004	0.002	31.605	2.766	55.313	3.65	0.39	25.53	2.17	0.0004	0.002	31.360	2.765	55.303	3.65	0.39	25.53	2.17	0.0004	0.002	2.765
67	32.340	202.00	128.234	131.001	131.208	2.767	55.342	3.65	0.39	25.53	2.17	0.0004	0.002	32.095	2.767	55.332	3.65	0.39	25.53	2.17	0.0004	0.002	32.095	2.767	55.332	3.65	0.39	25.53	2.17	0.0004	0.002	31.850	2.766	55.322	3.65	0.39	25.53	2.17	0.0004	0.002	2.766
68	32.830	202.00	128.233	131.001	131.208	2.768	55.361	3.65	0.39	25.54	2.17	0.0004	0.002	32.585	2.768	55.351	3.65	0.39	25.54	2.17	0.0004	0.002	32.585	2.768	55.351	3.65	0.39	25.54	2.17	0.0004	0.002	32.340	2.767	55.342	3.65	0.39	25.53	2.17	0.0004	0.002	2.767
69	33.320	202.00	128.232	131.001	131.208	2.769	55.380	3.65	0.39	25.54	2.17	0.0004	0.002	33.075	2.769	55.371	3.65	0.39	25.54	2.17	0.0004	0.002	33.075	2.769	55.371	3.65	0.39	25.54	2.17	0.0004	0.002	32.830	2.768	55.361	3.65	0.39	25.54	2.17	0.0004	0.002	2.768
70	33.810	202.00	128.231	131.001	131.207	2.770	55.400	3.65	0.39	25.54	2.17	0.0004	0.002	33.565	2.769	55.390	3.65	0.39	25.54	2.17	0.0004	0.002	33.565	2.769	55.390	3.65	0.39	25.54	2.17	0.0004	0.002	33.320	2.769	55.380	3.65	0.39	25.54	2.17	0.0004	0.002	2.769
71	34.300	202.00	128.230	131.001	131.207	2.771	55.419	3.64	0.39	25.54	2.17	0.0004	0.002	34.055	2.770	55.409	3.65	0.39	25.54	2.17	0.0004	0.002	34.055	2.770	55.409	3.65	0.39	25.54	2.17	0.0004	0.002	33.810	2.770	55.400	3.65	0.39	25.54	2.17	0.0004	0.002	2.770
72	34.790	202.00	128.229	131.001	131.207	2.772	55.438	3.64	0.39	25.54	2.17	0.0004	0.002	34.545	2.771	55.429	3.64	0.39	25.54	2.17	0.0004	0.002	34.545	2.771	55.429	3.64	0.39	25.54	2.17	0.0004	0.002	34.300	2.771	55.419	3.64	0.39	25.54	2.17	0.0004	0.002	2.771
73	35.280	202.00	128.228	131.001	131.207	2.773	55.458	3.64	0.39	25.55	2.17	0.0004	0.002	35.035	2.772	55.448	3.64	0.39	25.54	2.17	0.0004	0.002	35.035	2.772	55.448	3.64	0.39	25.54	2.17	0.0004	0.002	34.790	2.772	55.438	3.64	0.39	25.54	2.17	0.0004	0.002	2.772
74	35.770	202.00	128.227	131.001	131.207	2.774	55.477	3.64	0.39	25.55	2.17	0.0004	0.002	35.525	2.773	55.467	3.64	0.39	25.55	2.17	0.0004	0.002	35.525	2.773	55.467	3.64	0.39	25.55	2.17	0.0004	0.002	35.280	2.773	55.458	3.64	0.39	25.55	2.17	0.0004	0.002	2.773
75	36.260	202.00	128.226	131.001	131.207	2.775	55.496	3.64	0.39	25.55	2.17	0.0004	0.002	36.015	2.774	55.487	3.64	0.39	25.55	2.17	0.0004	0.002	36.015	2.774	55.487	3.64	0.39	25.55	2.17	0.0004	0.002	35.770	2.774	55.477	3.64	0.39	25.55	2.17	0.0004	0.002	2.774
76	36.750	202.00	128.225	131.001	131.206	2.776	55.516	3.64	0.38	25.55	2.17	0.0004	0.002	36.505	2.775	55.506	3.64	0.38	25.55	2.17	0.0004	0.002	36.505	2.775	55.506	3.64	0.38	25.55	2.17	0.0004	0.002	36.260	2.775	55.496	3.64	0.39	25.55	2.17	0.0004	0.002	2.775
77	37.240	202.00	128.224	131.001	131.206	2.777	55.535	3.64	0.38	25.55	2.17	0.0004	0.002	36.995	2.776	55.525	3.64	0.38	25.55	2.17	0.0004	0.002	36.995	2.776	55.525	3.64	0.38	25.55	2.17	0.0004	0.002	36.750	2.776	55.516	3.64	0.38	25.55	2.17	0.0004	0.002	2.776
78	37.730	202.00	128.223	131.001	131.206	2.778	55.555	3.64	0.38	25.56	2.17	0.0004	0.002	37.485	2.777	55.545	3.64	0.38	25.55	2.17	0.0004	0.002	37.485	2.777	55.545	3.64	0.38	25.55	2.17	0.0004	0.002	37.240	2.777	55.535	3.64	0.38	25.55	2.17	0.0004	0.002	2.777
79	38.220	202.00	128.222	131.001	131.206	2.779	55.574	3.63	0.38	25.56	2.17	0.0004	0.002	37.975	2.778	55.564	3.64	0.38	25.56	2.17	0.0004	0.002	37.975	2.778	55.564	3.64	0.38	25.56	2.17	0.0004	0.002	37.730	2.778	55.555	3.64	0.38	25.56	2.17	0.0004	0.002	2.778
80	38.710	202.00	128.221	131.001	131.206	2.780	55.593	3.63	0.38	25.56	2.18	0.0004	0.002	38.465	2.779	55.584	3.63	0.38	25.56	2.17	0.0004	0.002	38.465	2.779	55.584	3.63	0.38	25.56	2.17	0.0004	0.002	38.220	2.779	55.574	3.63	0.38	25.56	2.17	0.0004	0.002	2.779
81	39.200	202.00	128.220	131.001	131.205	2.781	55.613	3.63	0.38	25.56	2.18	0.0004	0.002	38.955	2.780	55.603	3.63	0.38	25.56	2.18	0.0004	0.002	38.955	2.780	55.603	3.63	0.38	25.56	2.18	0.0004	0.002	38.710	2.780	55.593	3.63	0.38	25.56	2.18	0.0004	0.002	2.780
82	39.690	202.00	128.219	131.001	131.205	2.782	55.632	3.63	0.38	25.56	2.18	0.0004	0.002	39.445	2.781	55.622	3.63	0.38	25.56	2.18	0.0004	0.002	39.445	2.781	55.622	3.63	0.38	25.56	2.18	0.0004	0.002	39.200	2.781	55.613	3.63	0.38	25.56	2.18	0.0004	0.002	2.781
83	40.180	202.00	128.218	131.001	131.205	2.783	55.651	3.63	0.38	25.57	2.18	0.0004	0.002	39.935	2.782	55.642	3.63	0.38	25.56	2.18	0.0004	0.002	39.935	2.782	55.642	3.63	0.38	25.56	2.18	0.0004	0.002	39.690	2.782	55.632	3.63	0.38	25.56	2.18	0.0004	0.002	2.782
84	40.670	202.00	128.217	131.001	131.205	2.784	55.671	3.63	0.38	25.57	2.18	0.0004	0.002	40.425	2.783	55.661	3.63	0.38	25.57	2.18	0.0004	0.002	40.425	2.783	55.661	3.63	0.38	25.57	2.18	0.0004	0.002	40.180	2.783	55.651	3.63	0.38	25.57	2.18	0.0004	0.002	2.783
85	41.160	202.00	128.216	131.001	131.205	2.785	55.690	3.63	0.38	25.57	2.18	0.0004	0.002	40.915	2.784	55.680	3.63	0.38	25.57	2.18	0.0004	0.002	40.915	2.784	55.680	3.63	0.38	25.57	2.18	0.0004	0.002	40.670	2.784	55.671	3.63	0.38	25.57	2.18	0.0004	0.002	2.784
86	41.650	202.00	128.215	131.000	131.205	2.785	55.709	3.63	0.38	25.57	2.18	0.0004	0.002	41.405	2.785	55.700	3.63	0.38	25.57	2.18	0.0004	0.002	41.405	2.785	55.700	3.63	0.38	25.57	2.18	0.0004	0.002	41.160	2.785	55.690	3.63	0.38	25.57	2.18	0.0004	0.002	2.785
87	42.140	202.00	128.214	131.000	131.204	2.786	55.729	3.62	0.38	25.57	2.18	0.0004	0.002	41.895	2.786	55.719	3.63	0.38	25.57	2.18	0.0004	0.002	41.895	2.786	55.719	3.63	0.38	25.57	2.18	0.0004	0.002	41.650	2.785	55.709	3.63	0.38	25.57	2.18	0.0004	0.002	2.785
88	42.630	202.00	128.213	131.000	131.204	2.787	55.748	3.62	0.38	25.57	2.18	0.0004	0.002	42.385	2.787	55.738	3.62	0.38	25.57	2.18	0.0004	0.002	42.385	2.787	55.738	3.62	0.38	25.57	2.18	0.0004	0.002	42.140	2.786	55.729	3.62	0.38	25.57	2.18	0.0004	0.002	2.786
89	43.120	202.00	128.212	131.000	131.204	2.788	55.768	3.62	0.38	25.58	2.18	0.0004	0.002	42.875	2.788	55.758	3.62	0.38	25.58	2.18	0.0004	0.002	42.875	2.788	55.758	3.62	0.38	25.58	2.18	0.0004	0.002	42.630	2.787	55.748	3.62	0.38	25.57	2.18	0.0004	0.002	2.787
90	43.610	202.00	128.211	131.000	131.204	2.789	55.787	3.62	0.38	25.58	2.18	0.0004	0.002	43.365	2.789	55.777	3.62	0.38	25.58	2.18	0.0004	0.002	43.365	2.789	55.777	3.62	0.38	25.58	2.18	0.0004	0.002	43.120	2.788	55.768	3.62	0.38	25.58	2.18	0.0004	0.002	2.788
91	44.100	202.00	128.210	131.000	131.204	2.790	55.806	3.62	0.38	25.58	2.18	0.0004	0.002	43.855	2.790	55.797	3.62	0.38	25.58	2.18	0.0004	0.002	43.855	2.790	55.797	3.62	0.38	25.58	2.18	0.0004	0.002	43.610	2.789	55.787	3.62	0.38	25.58	2.18	0.0004	0.002	2.789
92	44.590	202.00	128.209	131.000	131.204	2.791	55.826	3.62	0.38	25.58	2.18	0.0004	0.002	44.345	2.791	55.816	3.62	0.38	25.58	2.18	0.0004	0.002	44.345	2.791	55.816	3.62	0.38	25.58	2.18	0.0004	0.002	44.100	2.790	55.806	3.62	0.38	25.58	2.18	0.0004	0.002	2.790
93	45.080	202.00	128.208	131.000	131.203	2.792	55.845	3.62	0.38	25.58	2.18	0.0004	0.002	44.835	2.792	55.835	3.62	0.38	25.58	2.18	0.0004	0.002	44.835	2.792	55.835	3.62	0.38	25.58	2.18	0.0004	0.002	44.590	2.791	55.826	3.62	0.38	25.58	2.18	0.0004	0.002	2.791
94	45.570	202.00	128.207	131.000	131.203	2.793	55.864	3.62	0.38	25.59	2.18	0.0004	0.002	45.325	2.793	55.855	3.62	0.38	25.59	2.18	0.0004	0.002	45.325	2.793	55.855	3.62	0.38	25.59	2.18	0.0004	0.002	45.080	2.792	55.845	3.62	0.38	25.58	2.18	0.0004	0.002	2.792
95	46.060	202.00	128.206	131.000	131.203	2.794	55.884	3.61	0.38	25.59	2.18	0.0004	0.002	45.815	2.794	55.874	3.62	0.38	25.59	2.18	0.0004	0.002	45.815	2.794	55.874	3.62	0.38	25.59	2.18	0.0004	0.002	45.570	2.793	55.864	3.62	0.38	25.59	2.18	0.0004	0.002	2.793
96	46.550	202.00	128.205	131.000	131.203	2.795	55.903	3.61	0.38	25.59	2.18	0.0004	0.002	46.305	2.795	55.893	3.61	0.38	25.59	2.18	0.0004	0.002	46.305	2.795	55.893	3.61	0.38	25.59	2.18	0.0004	0.002	46.060	2.794	55.884	3.61	0.38	25.59	2.18	0.0004	0.002	2.794
97	47.040	202.00	128.204	131.000	131.203	2.796	55.922	3.61	0.38	25.59	2.19	0.0004	0.002	46.795	2.796	55.913	3.61	0.38	25.59	2.18	0.0004	0.002	46.795	2.796	55.913	3.61	0.38	25.59	2.18	0.0004	0.002	46.550	2.795	55.903	3.61	0.38	25.59	2.18	0.0004	0.002	2.795
98	47.530	202.00	128.203	131.000	131.203	2.797	55.942	3.61	0.38	25.59	2.19	0.0003	0.002	47.285	2.797	55.932	3.61	0.38	25.59	2.19	0.0004	0.002	47.285	2.797	55.932	3.61	0.38	25.59	2.19	0.0004	0.002	47.040	2.796	55.922	3.61	0.38	25.59	2.19	0.0004	0.002	2.796
99	48.020	202.00	128.202	131.000	131.202	2.798	55.961	3.61	0.38	25.60	2.19	0.0003	0.002	47.775	2.798	55.952	3.61	0.38	25.60	2.19	0.0003	0.002	47.775	2.798	55.952	3.61	0.38	25.60	2.19	0.0003	0.002	47.530	2.797	55.942	3.61	0.38	25.59	2.19	0.0003	0.002	2.797
100	48.510	202.00	128.201	131.000	131.202	2.799	55.981	3.61	0.38	25.60	2.19	0.0003	0.002	48.265	2.799	55.971	3.61	0.38	25.60	2.19	0.0003	0.002	48.265	2.799	55.971	3.61	0.38	25.60	2.19	0.0003	0.002	48.020	2.798	55.961	3.61	0.38	25.60	2.19	0.0003	0.002	2.798
101	48.559	202.00	128.201	131.000	131.202	2.799	55.983	3.61	0.38	25.60	2.19	0.0003	0.002	48.535	2.799	55.982	3.61	0.38	25.60	2.19	0.0003	0.002	48.535	2.799	55.982	3.61	0.38	25.60	2.19	0.0003	0.002	48.510	2.799	55.981	3.61	0.38	25.60	2.19	0.0003	0.002	2.799
102	48.608	202.00	128.201	131.000	131.202	2.799	55.984	3.61	0.38	25.60	2.19	0.0003	0.002	48.584	2.799	55.984	3.61	0.38	25.60	2.19	0.0003	0.002	48.584	2.799	55.984	3.61	0.38	25.60	2.19	0.0003	0.002	48.559	2.799	55.983	3.61	0.38	25.60	2.19	0.0003	0.002	2.799
103	48.657	202.00	128.201	131.000	131.202	2.799	55.986	3.61	0.38	25.60	2.19	0.0003	0.002	48.633	2.799	55.985	3.61	0.38	25.60	2.19	0.0003	0.002	48.633	2.799	55.985	3.61	0.38	25.60	2.19	0.0003	0.002	48.608	2.799	55.984	3.61	0.38	25.60	2.19	0.0003	0.002	2.799
104	48.706	202.00	128.201	131.000	131.202	2.799	55.988	3.61	0.38	25.60	2.19	0.0003	0.002	48.682	2.799	55.987	3.61	0.38	25.60	2.19	0.0003	0.002	48.682	2.799	55.987	3.61	0.38	25.60	2.19	0.0003	0.002	48.657	2.799	55.986	3.61	0.38	25.60	2.19	0.0003	0.002	2.799
105	48.755	202.00	128.201	131.000	131.202	2.800	55.990	3.61	0.38	25.60	2.19	0.0003	0.002	48.731	2.799	55.989	3.61	0.38	25.60	2.19	0.0003	0.002	48.731	2.799	55.989	3.61	0.38	25.60	2.19	0.0003	0.002	48.706	2.799	55.988	3.61	0.38	25.60	2.19	0.0003	0.002	2.799
106	48.804	202.00	128.200	131.000	131.202	2.800	55.992	3.61	0.38	25.60	2.19	0.0003	0.002	48.780	2.800	55.991	3.61	0.38	25.60	2.19	0.0003	0.002	48.780	2.800	55.991	3.61	0.38	25.60	2.19	0.0003	0.002	48.755	2.800	55.990	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
107	48.853	202.00	128.200	131.000	131.202	2.800	55.994	3.61	0.38	25.60	2.19	0.0003	0.002	48.829	2.800	55.993	3.61	0.38	25.60	2.19	0.0003	0.002	48.829	2.800	55.993	3.61	0.38	25.60	2.19	0.0003	0.002	48.804	2.800	55.992	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
108	48.902	202.00	128.200	131.000	131.202	2.800	55.996	3.61	0.38	25.60	2.19	0.0003	0.002	48.878	2.800	55.995	3.61	0.38	25.60	2.19	0.0003	0.002	48.878	2.800	55.995	3.61	0.38	25.60	2.19	0.0003	0.002	48.853	2.800	55.994	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
109	48.951	202.00	128.200	131.000	131.202	2.800	55.998	3.61	0.38	25.60	2.19	0.0003	0.002	48.927	2.800	55.997	3.61	0.38	25.60	2.19	0.0003	0.002	48.927	2.800	55.997	3.61	0.38	25.60	2.19	0.0003	0.002	48.902	2.800	55.996	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
110	48.961	202.00	128.200	131.000	131.202	2.800	55.998	3.61	0.38	25.60	2.19	0.0003	0.002	48.956	2.800	55.998	3.61	0.38	25.60	2.19	0.0003	0.002	48.956	2.800	55.998	3.61	0.38	25.60	2.19	0.0003	0.002	48.951	2.800	55.998	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
111	48.971	202.00	128.200	131.000	131.202	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.966	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.966	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.961	2.800	55.998	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
112	48.980	202.00	128.200	131.000	131.202	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.976	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.976	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.971	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
113	48.990	202.00	128.200	131.000	131.202	2.800	56.000	3.61	0.38	25.60	2.19	0.0003	0.002	48.985	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.985	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	48.980	2.800	55.999	3.61	0.38	25.60	2.19	0.0003	0.002	2.800
113	49.000	202.00	128.200	131.000	131.202	2.800	56.000	3.61	0.38	25.60	2.19	0.0003	0.002	48.995	2.800	56.000	3.61	0.38	25.60	2.19	0.0003	0.002	48.995	2.800	56.000	3.61	0.38	25.60	2.19	0.0003	0.002	48.990	2.800	56.000	3.61	0.38	25.60	2.19	0.0003	0.002	2.800


Detention Intake Channel
Hydraulic Calculations, Q=202 cfs
Channel
HGL
Velocity
Elevation (ft NAVD 88)
131.5
131.0
130.5
130.0
129.5
129.0
128.5
128.0
Velocity (ft/s)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
Distance (ft)

Pipe and Riprap Sizes at Creek Outlets

Updated: 8/11/2016

Creek Outlet	Design Storm	Peak Design Flow (cfs)	Pipe Size (in)	Min Riprap D50 (in)	Min Riprap Class	Specified D50 (in)	Specified Riprap Class	Apron Lenth Multiplier	Apron Depth Multiplier	Riprap Apron Dimensions*			
										W1 (ft)	W2 (ft)	L (ft)	H (in)
1	100-YR	11.5	24	3.05	1	6	2	4.00	3.30	6.0	11.3	8.0	19.8
2	100-YR	18.4	24	5.73	2	6	2	4.00	3.30	6.0	11.3	8.0	19.8
3	100-yr	67.2	42	8.71	3	10	3	5.00	2.40	10.5	22.2	17.5	24.0
4	100-YR	152.7	54	14.47	5	20	5	7.00	2.00	13.5	34.5	31.5	40.0

*Riprap Apron Dimensions based on methods in FHWA HEC. No 14

Appendix E

Model for Diversion Structure & Detention Facility

Description of Model for Diversion Structure and Detention Facility

8/17/16

Introduction

The proposed design for San Luis Ranch includes a diversion structure at the upstream end of Cerro San Luis Channel that diverts water from the channel to an underground detention system. The diverted water will be routed through the underground detention facility, through an outlet control structure, then into a pipe that discharges into Prefumo Creek.

Industry standard hydrologic modeling software, including HEC-HMS and Hydraflow Hydrographs Extension for AutoCAD Civil 3D, were explored to model the proposed diversion and detention facility, but they did not have the capacity to model a system with this complexity. HEC-HMS has the ability to model a diversion from a channel, but not the ability to account the water surface elevation in the downstream detention facility which affects the amount of water diverted. Hydraflow Hydrographs Extension for AutoCAD Civil 3D does not have the ability to model a diversion from a channel.

A custom numerical model was developed at part of this project to: (1) estimate the flow distribution at the diversion structure (how much flow stays in Cerro San Luis Channel and how much is diverted to the detention facility); and (2) estimate the routing of the diverted water through the detention facility (outflow and water surface elevation). The model was developed in Microsoft Excel.

Calculations

The model is based on a two-step process for performing all of the calculations. The first step in the process estimates the flow distribution at the diversion structure; the second step in the process involves the routing of flow through the detention facility. The calculations for each step are described below.

Flow Distribution at Diversion Structure

The first series of calculations in the model take the inflow at the upstream end of Cerro San Luis Channel from input hydrograph and calculate the distribution of that flow between Cerro San Luis Channel downstream of the diversion structure and flow into the detention facility. The model inputs for these calculations include:

1) hydrographs for Cerro San Luis Channel
2) diversion structure geometry
3) water surface elevation in the channel downstream of the diversion structure

4) water surface elevation in the detention facility
5) water surface elevation in the diversion structure forebay

Model inputs 1 and 2 are known values for all time steps. Model inputs 3 and 4 are taken from the solutions in the previous time step of the model. Model input 5, the water surface elevation in the diversion structure forebay, is the variable that the model solves for. In order to solve for the forebay water surface elevation, conservation of mass (continuity) was applied to the flow at the diversion structure, based on the following equation:

$$Q_{CU} = Q_{CD} + Q_{Din}$$

where:

Q_{CU} = known flow into CSL Channel at upstream end of diversion structure from input hydrograph (cfs)
Q_{CD} = flow out of the diversion structure into Cerro San Luis Channel (cfs)
Q_D = flow into (positive value) or out of (negative value) detention facility from diversion structure (cfs)

Flow out of the diversion structure into Cerro San Luis Channel is modeled as weir flow. The flow over the weir in the diversion structure is calculated using the free-flow weir equation or submerged weir equation, depending on the downstream water surface elevation.

Flow into and out of the detention facility is modeled as weir flow (free-flow or submerged) or orifice flow, depending on the water surface elevations of the diversion structure forebay and the detention facility. The calculations account for flow from the detention facility back into the channel in the event that the water surface elevation in the channel drops below the water surface elevation in the detention facility.

The forebay water surface elevation cannot be solved for directly in the continuity equation above because it is a variable in Q_{CD} and Q_D. An iterative numerical technique called the *secant method* was used to solve for the forebay water surface elevation at each time step. This is a method to find a numerical solution to the equation $f(x) = 0$ and is based on approximating the function with secant lines. Two initial approximations for the variable of interest, x_0 and x_i, are required. The equation for the subsequent estimates of x is:

$$x_{i+1} = x_i - \frac{x_i - x_{i-1}}{y_i - y_{i-1}} y_i$$

The continuity equation for the diversion structure was rearranged to the following format so that the secant method could be applied to it:

$$y = f(x) = Q_{CU} - (Q_{CD} + Q_D) = 0$$

The variable x is defined as follows:

x = water surface elevation in diversion structure forebay (ft)

Ten iterations are included in the model. Conversion occurs when $y \approx 0$, which means conservation of mass (continuity) is achieved for the flow into and out of the diversion structure.

Routing Flow through Diversion Structure

The second series of calculations in the model estimate the routing of the flow though the detention facility. The model inputs for these calculations include:

1) detention facility geometry
2) outlet structure geometry
3) flow into or out of detention facility from diversion structure

Model inputs 1 and 2 are known values for all time steps. Model input 3 is calculated in the first series of calculations for each time step and input into the routing calculations.

The *level pool routing* procedure as presented in Chow et al., 1988 was used to generate outflow hydrographs and calculate the change in storage for the detention facility. This procedure assumes a horizontal water surface elevation in a reservoir, so the storage and discharge from the reservoir are functions of the water surface elevation of the reservoir. This method requires that a *storage-discharge function* be developed for the reservoir.

The *storage-discharge function* was developed for the detention facility by combining an *elevation-discharge function* and an *elevation-storage function* for the facility. The *elevation-discharge function* was developed by modeling the discharge from the outlet structure as weir flow through a Cipoletti weir. The calculation assumes free-flow over the weir as the flow in the downstream pipe is supercritical as currently designed, so it should not affect the flow over the weir. The *elevation-storage function* was developed using the detention facility geometry, including a rock layer at the bottom of the facility and the void space within the chambers.

The *level pool routing* procedure calculates the change in storage volume over a time step with the following equation:

$$S_{j+1} - S_j = \frac{I_j + I_{j+1}}{2}\Delta t - \frac{Q_j + Q_{j+1}}{2}\Delta t$$

where:

S_{j+1} = storage at current time step (cf)
S_j = storage at previous time step (cf)
I_{j+1} = inflow at current time step (cfs)
I_j = inflow at previous time step (cfs)
Q_{j+1} = outflow at current time step (cfs)

Q_j = outflow at previous time step (cfs)
Δt = time interval (seconds)

This equation and the *storage-outfall function* are used in conjunction to solve for the outflow at the current time step. Once that is known, the change in storage volume can be computed. The cumulative total of the changes in storage volume was used calculate the total volume of water in the detention facility at each time step.

The water surface elevation in the detention facility was calculated at each time step using the total volume of water in the facility and the *elevation-storage function* for the facility.

Model Inputs

Hydrographs for Cerro San Luis Channel

Hydrographs for flow into the upstream end of Cerro San Luis Channel are required input for the model. Wallace Group has studied the hydrology for Cerro San Luis Channel and they provided the basis for the estimation of flows that are discharged into the upstream end of the channel. They used the City of San Luis Obispo's HEC-HMS model as a starting point for the analysis. The sub-basins within the City's model that contribute flow to Cerro San Luis Channel include the Madonna Inn and Lower Prefumo sub-basins. The Madonna Inn sub-basin is the area that contributes flow to the upstream end of the triple box culvert at Madonna Road. Wallace extracted from the Lower Prefumo sub-basin the area upstream of the San Luis Ranch project and designated it the Madonna Plaza sub-basin. Only a portion of the flow from the Madonna Plaza sub-basin contributes to Cerro San Luis Channel, as the remainder enters the project site at the north-east corner near Embassy Suites. Wallace estimated that 72% of the runoff from the Madonna Plaza sub-basin discharges into Cerro San Luis Channel.

Wallace provided hydrographs for the Madonna Inn and Madonna Plaza sub-basins for all of the design storms (2-, 10-, 25-, 50-, and 100-yr). Hydrographs for the flow into the upstream end of Cerro San Luis Channel were developed by combing the hydrograph from the Madonna Inn sub-basin and 72% of the hydrograph from the Madonna Plaza sub-basin. The resulting hydrographs for inflow into Cerro San Luis Channel for all of the design storms are shown in Appendix B.

Diversion Structure Geometry

The geometry for the diversion structure is required input for the model. The components include the elevation and length of the weir that spans the width of the diversion structure, and also the dimensions and elevation of the opening for the inlet into the detention facility. The inputs also include weir and orifice coefficients for these components.

Detention Facility

The geometry for the detention facility is required input for the model. The inputs include:

- bottom of rock elevation
- top of rock elevation
- rock area
- rock porosity
- top inside of concrete chamber elevation
- concrete chamber volume

The geometry for the outlet structure is required input into the model. The outlet structure was modeled as a Cipoletti weir. The required input includes:

- bottom width of weir
- weir invert elevation
- weir coefficient

Elevation-Flow Table for Cerro San Luis Channel Downstream of Diversion Structure

An elevation-flow table for Cerro San Luis Channel immediately downstream of the diversion structure is required input for the model. A table was developed based on data from Wallace Group's HEC-RAS model at station 15+50.

Governing Equations for Hydraulic Calculations

Flow Over Unsubmerged Sharp-crested Rectangular Weir (Free-discharge)

$$Q = C_w B H^{1.5}$$

where:

$Q =$ flow over weir (cfs)
$C_w =$ weir coefficient
$B =$ weir length (ft)
$H =$ upstream water height above the weir crest (ft)

Flow Over Submerged Sharp-crested Rectangular Weir

$$Q_{submerged} = Q_{unsubmerged}\left(1 - \left(\frac{H_{downstream}}{H_{upstream}}\right)^{1.5}\right)^{0.385}$$

where:

$Q_{submerged}$ = flow over submerged weir (cfs)
$Q_{unsubmerged}$ = flow over unsubmerged weir (cfs
$H_{downstream}$ = downstream water height above the weir crest (ft)
$H_{upstream}$ = upstream water height above the weir crest (ft)

Flow Over Unsubmerged Cipoletti Weir (Free-discharge)

$$Q = C_w B H^{1.5}$$

where:

Q = flow over weir (cfs)
C_w = weir coefficient (≈3.367 for US customary units)
B = length of horizontal portion of weir (ft)
H = upstream water height above the weir crest (ft)

Flow through an Orifice

$$Q = CA\sqrt{2gH}$$

where:

Q = flow through orifice (cfs)
C = orifice coefficient
A = open area of orfice (sf)
H = upstream water height above centroid of orifice for free-discharge condition (ft)
upstream water height above downstream water height for submerged condition (ft)
g = acceleration due to gravity (32.2 ft/s^2 for US customary units)

References

Chow, VT, Maidment, D.R., and Mays, L.W. 1988. *Applied Hydrology*. McGraw-Hill Book Company. Singapore.

Diversion Structure and Detention Facility Routing Model

Updated: 8/15/16

Diversion Structure

In-channel Weir		
Length:	45.00	ft
Weir Coeff:	3.20	
Elevation:	128.50	

Diversion Inlet		
Orifice Inv. Elev.:	129.00	ft
Orifice Height:	2.50	ft
Orifice Length:	13.50	ft
Orifice Coeff:	0.60	
Weir Coeff:	3.20	

Outlet Structure (Cipoletti Weir)

Bottom Width:	2.00	ft
Weir Invert Elev:	127.00	ft
Weir Coefficient:	3.37	

Detention Facility Parameters

Bottom Rock Elev.:	126.70	ft
Top Rock Elev.:	128.20	ft
Rock Area:	67,550	sf
Rock Porosity:	0.25	
Rock Volume:	25,331	cf
Top Inside Chamber Elev.:	131.70	ft
Chamber Volume:	210,070	cf

Detention Facility Elevation-Volume Table

Elev. (ft)	Cumulative Volume (cf)
126.70	0
128.20	25,331
131.70	235,401

Rating Curve for Station 15+50

(Data from Wallace's HEC-RAS Model in emails dated 10/1/15 and 10/2/15)

Flow (cfs)	WSE (ft)
0.00	127.94
226.57	129.86
393.15	130.56
478.92	130.88
556.51	131.14
616.09	131.33