HYDROLOGY AND HYDRAULIC STUDY

FOR

COTATI CONDOMINIUMS

APN: 046-286-018
APN: 046-286-019
COTATI, CA 94806

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1. Introduction

The Hydrology and Hydraulic Study examines the proposed storm drainage system for Cotati Condominiums site improvement bounded by Redwood Drive to the east, and Gravenstein Highway (Highway 116) on the south as shown in **Figure 1**.

The total project area is 9.67-acr, the existing site divides the stormwater into 3 sections, two of which flow eastward and one fully drains to the west. The first section begins sheet flowing from the South West corner and continues towards the North West corner of the site, where there is an existing catch basin from a neighboring development that captures the runoff. The second section contains a large stockpile of dirt in the most northern corner of the site; this large mound creates a highpoint for flow to spread in all directions. The majority of the runoff sheet flows eastward and heads southeast to a localized swale. The final section moves runoff from the bulk of the south western edge, where there is a high point, and sheet flows towards the middle of site. From this point, the stormwater is collected into a large natural swale that creates a channel and assists in gathering all the westward flow. The runoff then moves toward the eastern edge of the site, where there is to a low point that contains an existing catch basin that collects everything. From here, it is discharged into an existing storm drain easement that ties into an off-site detention pond that remains along the north eastern border of the site.

The proposed site will be graded such that the storm water runoff will drain to bioretention areas in the development and outfall to an existing detention pond to the north east as shown in **Appendix B**.

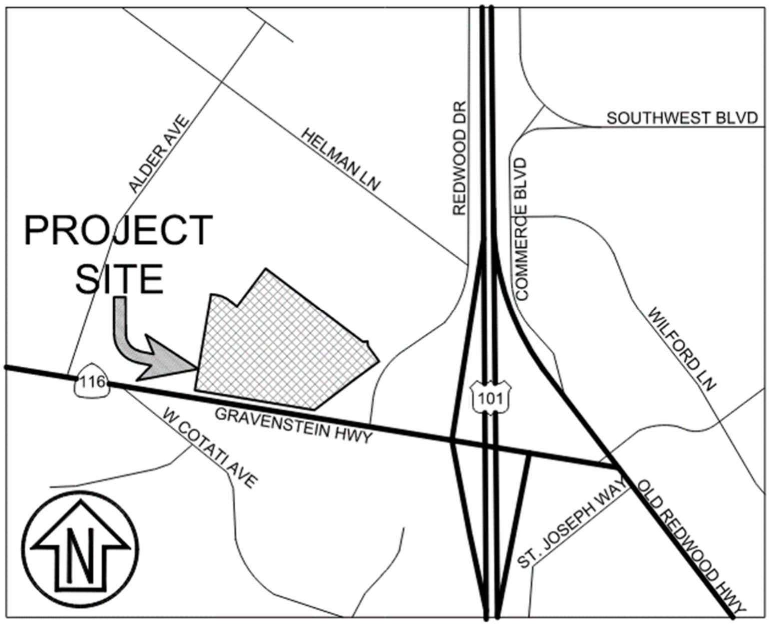


Figure 1: Vicinity Map

2. Analysis

2.1. Criteria

The Sonoma County Flood Management Design Manual utilizes the Rational Method to calculate proposed peak flow rates and recommends utilizing precipitation data from the National Oceanic and Atmospheric Administration (NOAA). Rainfall intensities for use with Rational Method are developed from Intensity-Duration-Frequency data available from the NOAA Annual Precipitation Frequency Data charts. The City of Cotati prepared a stormwater master plan in 2002 that details the adequacy of the major storm drainage facilities serving the City of Cotati. This study provides preliminary design recommendations for future improvement projects. The proposed storm drain system adheres to the design criteria stated in the City of Cotati Storm Drain Master Plan (See Attachment G).

2.2. Hydrology

Rational Method: the Rational Method was used to estimate the runoff quantities of the undeveloped site and the developed site. The Rational Method is based on the following formula:

$$\mathbf{Q = C*I*A}$$

Q = Flow Rate (cubic feet per second, cfs),
C = Runoff coefficient (unitless).
I = Rainfall Intensity (inches per hour, in/hr)
A = Tributary Area (acres, ac)

a. Time of Travel: Overland flow travel Time based on equation 3.4 of the Sonoma County Flood Management Design Manual, note if calculated at less than five minutes then five minutes will be used:

$$\mathbf{Tc = 0.94*L^{0.6}*n^{0.6}/(C*I)^{0.4}*S^{0.3}}$$

Tc = Time of Concentration (hrs)
L = Overland Flow Length (ft)
n = roughness for overland surface
S = Slope of overland flow (ft/ft)
C = runoff coefficient
I = Rainfall intensity (inches/hr)

b. Rainfall Intensity: Intensities for Rational Method calculations were determined using the intensity duration frequency (IDF) curves created from the Contra Costa County Duration-Frequency-Depth Curves for the 10-year storm event.

c. Runoff Coefficient: For impervious surfaces (pavement and roofs), a runoff coefficient of 0.9 was used. For pervious surfaces, a runoff coefficient of 0.4 was used. For areas of mixed surface types, a weighted runoff coefficient was calculated.

d. Hydraulic Calculations: The hydraulic model for the proposed storm drain system main line was prepared using the computer modeling program Hydraflow Storm Sewers Extension for Autodesk AutoCAD Civil 3D 2023.

3. Results and Conclusion

The calculations located in **Appendix C** show the pre-construction flow and **Appendix D** provides the post-construction flows. The results indicate there is sufficient capacity in the proposed storm drain network to convey the 10-year storm event to the treatment areas and offsite. The proposed storm drain network is compliant with the City of Cotati Storm Drain Master Plan

APPENDIX A
Existing Conditions Hydrology Map

HYDROLOGY LEGEND

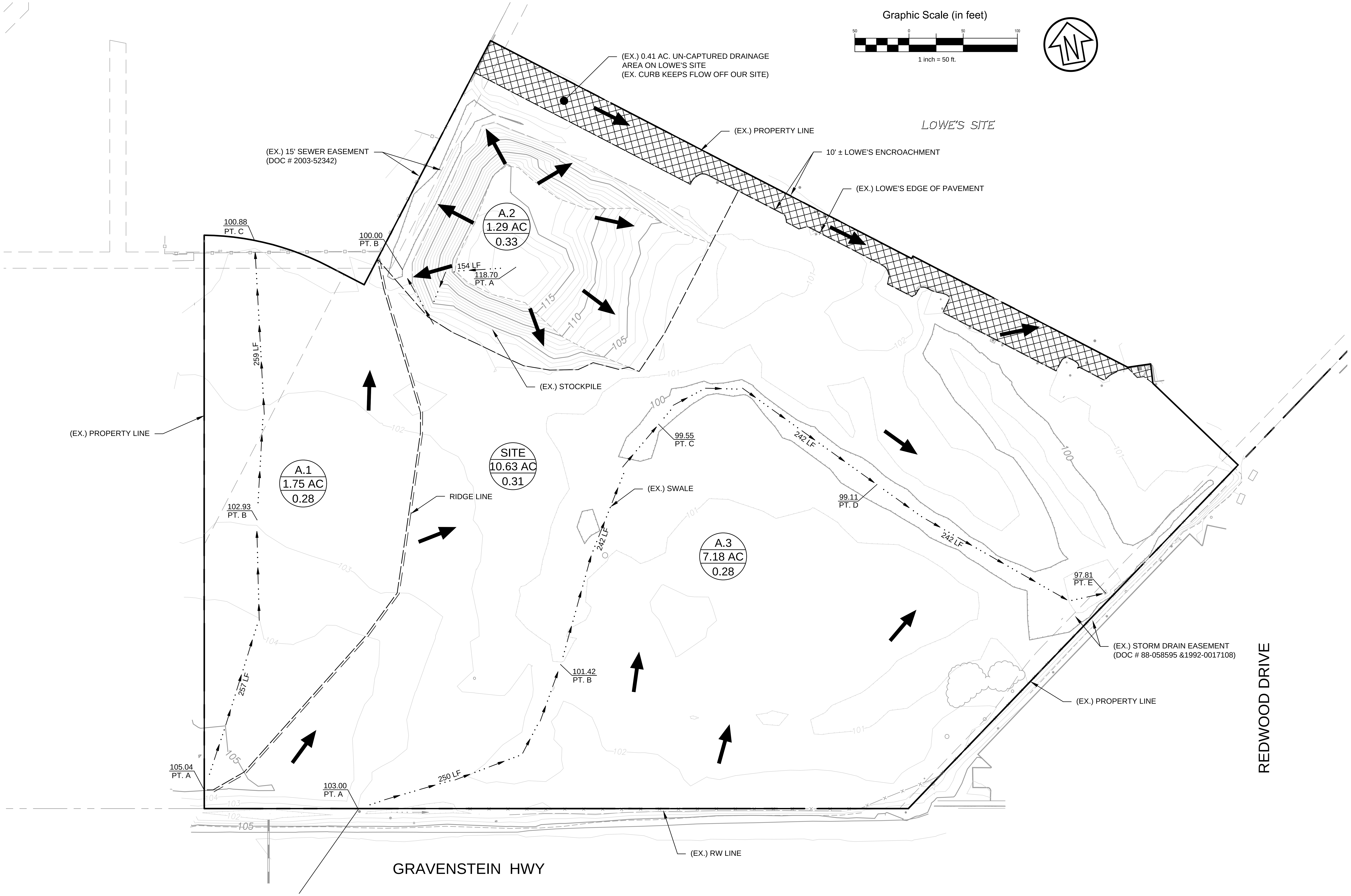
/ XXX AC / CN — DRAINAGE SUB-AREA DESIGNATION
SUB-AREA IN ACRES
CURVE NUMBER
OVERLAND FLOW DIRECTION
DRAINAGE AREA BOUNDARY
DRAINAGE SUB-AREA BOUNDRY
FLOW PATH

IMPERVIOUS PRE-PROJECT AREA

TOTAL AREA: 463,021 SF (10.63 AC)

LANDSCAPE: 445,121 SF (10.22 AC)

ASPHALT/CONCRETE: 17,900 SF (0.41 AC)



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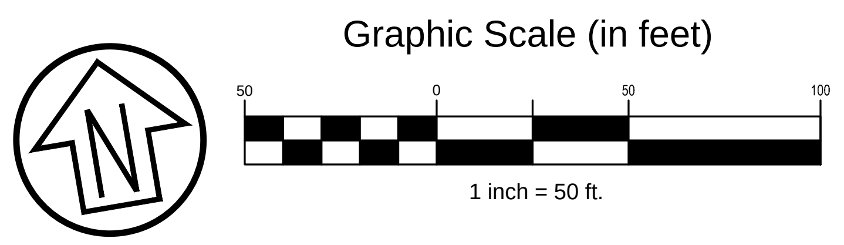
EX. HYDROLOGY CONDITIONS PLAN

H—0

SCALE: 1:50
DATE: 12.15.2023
PROJECT: 317068.00

APPENDIX B

Proposed Development Hydrology Map



HYDROLOGY LEGEND

#	DRAINAGE SUB-AREA DESIGNATION
XXX AC	SUB-AREA IN ACRES
C	RUNOFF COEFFICIENT
➡	OVERLAND FLOW DIRECTION
	DRAINAGE AREA BOUNDARY
— — — —	DRAINAGE SUB-AREA BOUNDRY
·····▸···▸···	STREAM FLOWLINE

DRAINAGE SUMMARY

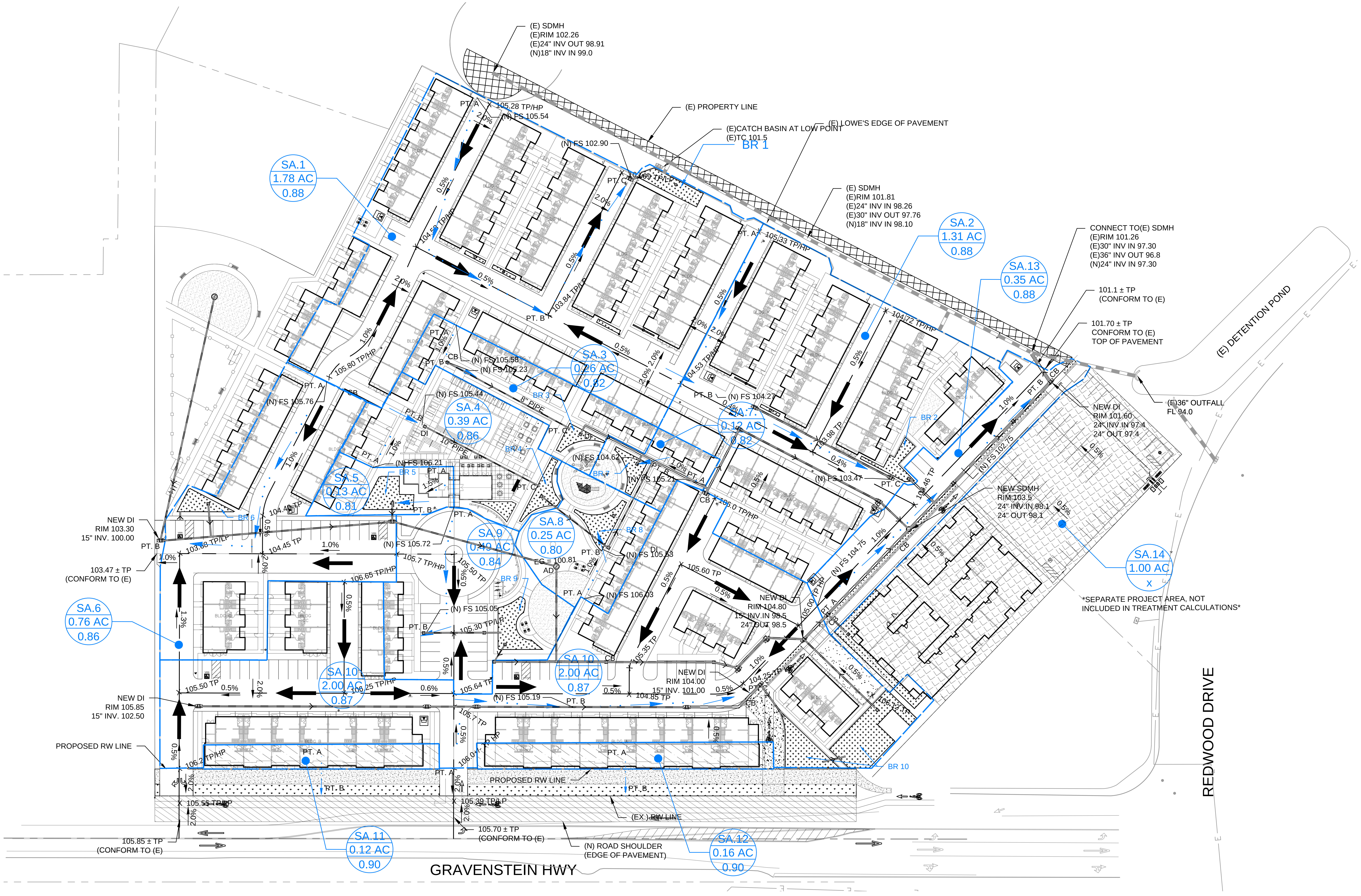
LAND DISTURBED: 99,000 SF

EXISTING IMPERVIOUS SURFACE: 69,000 SF

PROPOSED IMPERVIOUS SURFACE: 65,000 SF

HATCH LEGEND

▨	BIORETENTION AREA
▨	SELF-TREATING AREA
▨	NOT TREATED AREA



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PRO. HYDROLOGY CONDITIONS PLAN

H-1

PAGE NO.: OF 13
SCALE: 1:50
DATE: 12.15.2023
PROJECT: 317068.00

APPENDIX C
Existing Hydrology Calculations

Area A.1:

1. **Find Tc:**

   Overland Flow $_{A\text{-}B}$:
   -Use overland Flow Formula: $1.8(1.1-C)*L^{1/2} \div (S*100)^{1/3}$; C= 0.28, L= 257 LF, S= 0.8%
   Therefore, Tc= 25.5 Minutes

   Shallow Concentrated Flow $_{B\text{-}C}$:
   Δy = 2.05 LF, L= 259 LF, S= 0.8%

   -Use the TR-55 Manual [Figure 3-1] to find Velocity (V): Using S= 0.8% & "Unpaved" Conditions to find V= 1.42 ft./sec.

   -Find Tc= 259 Ft. ÷ 1.42 Ft./Sec. ÷ 60 Sec./Min. = 3.04 Min.

   Tc Total= 25.5 Min. + 3.04 Min. = 28.5 Minutes

2. **Find Rainfall Intensity: Using NOAA Point Precipitation Frequency Estimates, we can use our calculated time of concentration (Tc) to find the Intensity. Based on the Table, the Tc is interpolated to give us a rain fall intensity of 1.45 in/Hr. for a 10-year storm.**

3. **Calculate Q: Q= CIA; C= 0.28, I= 1.45 in/Hr., A= 1.75 AC**
   Therefore Q= 0.71 CFS

Area A.2:

1. **Find Tc:**

   Overland Flow $_{A\text{-}B}$:
   -Use overland Flow Formula: $1.8(1.1-C)*L^{1/2} \div (S*100)^{1/3}$; C= 0.33, L= 154 LF, S= 12.1%
   Therefore, Tc= 2.3 Minutes*
   ***Tc cannot be less than 5 minutes for rational method therefore, we must divert to the lowest time on the rainfall intensity chart, which is 5 minutes.**

   Tc Total= 5.0 Minutes

2. **Find Rainfall Intensity: Using NOAA Point Precipitation Frequency Estimates, we can use our calculated time of concentration (Tc) to find the Intensity. Based on the Table, the Tc is interpolated to give us a rain fall intensity of 3.43 in/Hr. for a 10-year storm.**

3. **Calculate Q: Q= CIA; C= 0.33, I= 3.43 in/Hr., A= 1.29 AC**
   Therefore Q= 1.46 CFS

Area A.3:

1. **Find Tc:**

   Overland Flow $_{A\text{-}B}$:
   -Use overland Flow Formula: 1.8(1.1-C)*$L^{1/2}$ ÷ $(S*100)^{1/3}$; C= 0.28, L= 250 LF, S= 0.6%
   Therefore, Tc= 27.7 Minutes

   Shallow Concentrated Flow $_{B\text{-}C}$:
   Δy = 1.87 LF, L= 242 LF, S= 0.8%

   -Use the TR-55 Manual [Figure 3-1] to find Velocity (V): Using S= 0.8% & "Unpaved" Conditions to find V= 1.42 ft./sec.

   -Find Tc= 242 Ft. ÷ 1.42 Ft./Sec. ÷ 60 Sec./Min. = 2.84 Min.

   Shallow Concentrated Flow $_{C\text{-}D}$:
   Δy = 0.44 LF, L= 242 LF, S= 0.2%* *Slope too shallow, therefore must assume 0.5% for TR-55*

   -Use the TR-55 Manual [Figure 3-1] to find Velocity (V): Using S= 0.5% & "Unpaved" Conditions to find V= 1.15 ft./sec.

   -Find Tc= 242 Ft. ÷ 1.15 Ft./Sec. ÷ 60 Sec./Min. = 3.51 Min.

   Shallow Concentrated Flow $_{D\text{-}E}$:
   Δy = 1.30 LF, L= 242 LF, S= 0.5%

   -Use the TR-55 Manual [Figure 3-1] to find Velocity (V): Using S= 0.5% & "Unpaved" Conditions to find V= 1.15 ft./sec.

   -Find Tc= 242 Ft. ÷ 1.15 Ft./Sec. ÷ 60 Sec./Min. = 3.51 Min.

   Tc Total= 27.7 Min. + 2.84 Min. + 3.51 Min. + 3.51 Min. = 37.53 Minutes

2. **Find Rainfall Intensity: Using NOAA Point Precipitation Frequency Estimates, we can use our calculated time of concentration (Tc) to find the Intensity. Based on the Table, the Tc is interpolated to give us a rain fall intensity of 1.29 in/Hr. for a 10-year storm.**

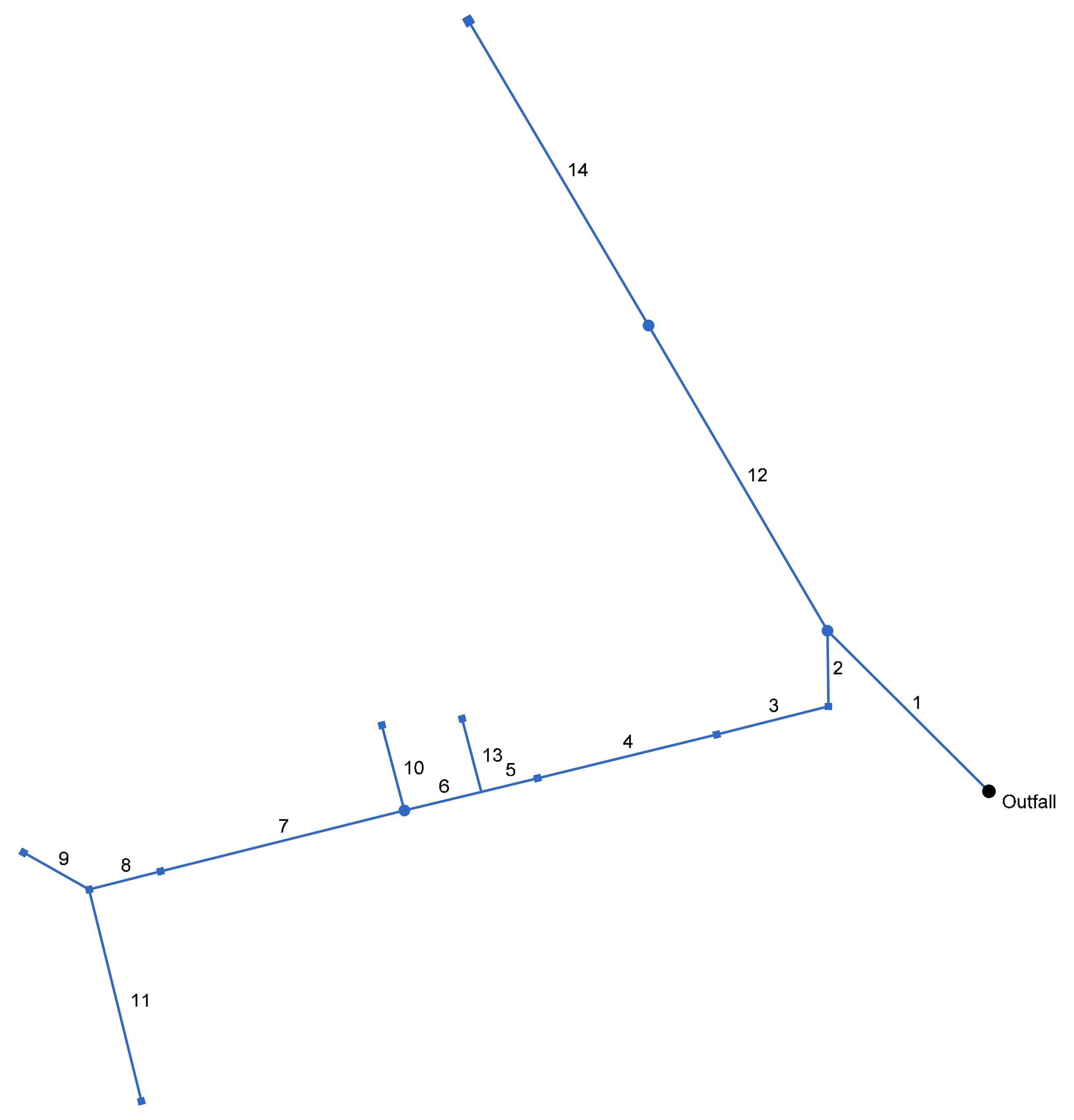
3. **Calculate Q: Q=CIA; C= 0.28, I= 1.29 in/Hr., A= 7.18 AC**
   Therefore Q= 2.59 CFS

Calculate Total Q= 0.71 + 1.46 + 2.59 = 4.76 CFS

Therefore, the existing project will produce a runoff rate of 4.76 CFS for a 10-Year storm.

APPENDIX D
Proposed Hydraulic Calculations

Hydraflow Storm Sewers Extension for Autodesk® Civil 3D® Plan



Project File: Cotati_hydraflow_Outfall 2.stm	Number of lines: 14	Date: 10/4/2024

SD Design

Line No.	Inlet ID	Line ID	Drng Area (ac)	Total Area (ac)	Runoff Coeff (C)	Total CxA	Tc (min)	i Sys (in/hr)	Known Q (cfs)	Flow Rate (cfs)	Capac Full (cfs)	Vel Up (ft/s)	Line Size (in)	Line Slope (%)	Line Length (ft)	Invert Up (ft)	HGL Jnct (ft)	Gnd/Rim El Up (ft)	Rim-Hw (ft)
14	DI33	DI33TOEXSDMH01	1.78	1.78	0.88	1.57	10.0	2.39	0.00	3.74	11.23	3.20	24	0.29	154.000	98.41	99.37	101.82	2.45
13	DI30	DI30TONULL01	0.44	0.44	0.86	0.38	10.0	2.39	0.00	0.90	3.62	0.74	15	0.36	33.000	98.09	99.99	103.70	3.71
12	EXSDMH01	EXSDMH01TOSDMH01	0.01	1.79	0.88	1.58	10.8	2.30	0.00	3.62	25.12	3.78	30	0.44	154.000	97.97	98.59	101.82	3.23
11	DI 25	DI 25-DI 05	1.18	1.18	0.88	1.04	5.0	3.35	0.00	3.48	5.75	1.97	18	0.35	95.000	98.83	100.65	105.00	4.35
10	DI 27	DI 27-SDMH 02	1.85	1.85	0.85	1.57	5.0	3.35	0.00	5.26	11.74	1.70	24	0.31	38.394	98.22	100.18	103.60	3.42
9	DI 06	DI 06-DI 05	2.45	2.45	0.80	1.96	10.0	2.39	0.00	4.68	11.62	1.53	24	0.31	32.683	98.60	100.52	104.70	4.18
8	DI 05	DI 05-DI 04	0.18	3.81	0.88	3.16	10.4	2.35	0.00	7.41	11.13	2.46	24	0.28	32.021	98.50	100.47	104.80	4.33
7	DI 04	DI 04-SDMH 02	0.18	3.99	0.88	3.32	10.6	2.32	0.00	7.70	11.20	2.55	24	0.28	109.000	98.41	100.29	104.50	4.21
6	SDMH 02	SDMH 02-NULL 01	0.01	5.85	0.88	4.90	11.3	2.25	0.00	11.00	23.45	2.76	30	0.38	34.293	98.10	100.11	103.64	3.53
5	NULL 01	NULL 01-DI 03	0.18	6.47	0.88	5.43	11.5	2.23	0.00	12.10	22.79	3.09	30	0.36	25.125	97.97	99.98	103.60	3.62
4	DI 03	DI 03-DI 02	0.18	6.65	0.88	5.59	11.7	2.21	0.00	12.38	12.65	4.17	24	0.36	80.000	97.88	99.81	103.50	3.69
3	DI 02	DI 02-DI 01	0.18	6.83	0.88	5.75	12.0	2.18	0.00	12.56	12.95	4.41	24	0.38	50.000	97.59	99.44	102.30	2.86
2	DI 01	DI 01-SDMH 01	0.18	7.01	0.88	5.91	12.2	2.17	0.00	12.81	34.09	4.47	36	0.30	33.000	97.40	99.13	101.80	2.67
1	SDMH 01	SDMH 01-OUT	0.01	8.81	0.88	7.49	12.3	2.16	0.00	16.16	104.15	5.60	36	2.83	99.000	96.80	98.08	101.25	3.17

Project File: Cotati_hydraflow_Outfall 2.stm	Number of lines: 14	Date: 10/4/2024

NOTES: Intensity = 7.50 / (Inlet time + 0.10) ^ 0.50 -- Return period = 10 Yrs. ; ** Critical depth

APPENDIX E
National Oceanic and Atmospheric (NOAA) Precipitation Data

NOAA Atlas 14, Volume 6, Version 2
Location name: Cotati, California, USA*
Latitude: 38.3342°, Longitude: -122.7157°
Elevation: 104 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	1.93 (1.73-2.20)	2.38 (2.11-2.70)	2.95 (2.62-3.37)	3.43 (3.01-3.96)	4.12 (3.47-4.93)	4.64 (3.82-5.71)	5.21 (4.15-6.58)	5.80 (4.48-7.57)	6.61 (4.87-9.07)	7.27 (5.15-10.4)
10-min	1.39 (1.24-1.58)	1.70 (1.51-1.93)	2.12 (1.87-2.41)	2.47 (2.16-2.84)	2.95 (2.48-3.53)	3.33 (2.74-4.09)	3.73 (2.98-4.72)	4.15 (3.21-5.42)	4.74 (3.49-6.50)	5.21 (3.69-7.45)
15-min	1.12 (0.996-1.27)	1.37 (1.22-1.56)	1.70 (1.51-1.94)	1.99 (1.74-2.29)	2.38 (2.00-2.85)	2.68 (2.21-3.30)	3.01 (2.40-3.80)	3.35 (2.59-4.37)	3.82 (2.82-5.24)	4.20 (2.98-6.00)
30-min	0.784 (0.698-0.890)	0.960 (0.852-1.09)	1.20 (1.06-1.36)	1.39 (1.22-1.60)	1.67 (1.40-2.00)	1.88 (1.55-2.31)	2.11 (1.68-2.66)	2.34 (1.81-3.06)	2.68 (1.97-3.67)	2.95 (2.08-4.20)
60-min	0.556 (0.495-0.631)	0.681 (0.605-0.774)	0.848 (0.751-0.967)	0.987 (0.866-1.14)	1.18 (0.995-1.42)	1.33 (1.10-1.64)	1.49 (1.19-1.89)	1.66 (1.28-2.17)	1.90 (1.40-2.60)	2.09 (1.48-2.98)
2-hr	0.419 (0.372-0.475)	0.508 (0.452-0.578)	0.626 (0.555-0.714)	0.723 (0.634-0.833)	0.856 (0.721-1.02)	0.958 (0.788-1.18)	1.06 (0.849-1.34)	1.17 (0.906-1.53)	1.32 (0.973-1.81)	1.44 (1.02-2.06)
3-hr	0.352 (0.314-0.400)	0.427 (0.379-0.486)	0.525 (0.465-0.599)	0.604 (0.530-0.696)	0.712 (0.600-0.853)	0.794 (0.653-0.976)	0.878 (0.701-1.11)	0.965 (0.746-1.26)	1.08 (0.797-1.48)	1.17 (0.831-1.68)
6-hr	0.262 (0.233-0.297)	0.318 (0.282-0.361)	0.390 (0.345-0.445)	0.448 (0.393-0.516)	0.526 (0.443-0.630)	0.585 (0.481-0.719)	0.644 (0.515-0.815)	0.705 (0.545-0.922)	0.787 (0.579-1.08)	0.850 (0.601-1.21)
12-hr	0.179 (0.160-0.204)	0.221 (0.196-0.251)	0.273 (0.242-0.312)	0.316 (0.277-0.364)	0.372 (0.313-0.446)	0.414 (0.341-0.509)	0.457 (0.365-0.578)	0.500 (0.386-0.653)	0.558 (0.410-0.765)	0.602 (0.426-0.859)
24-hr	0.121 (0.109-0.137)	0.151 (0.136-0.172)	0.190 (0.170-0.216)	0.220 (0.196-0.253)	0.261 (0.225-0.308)	0.291 (0.247-0.350)	0.321 (0.266-0.395)	0.352 (0.285-0.444)	0.392 (0.306-0.514)	0.423 (0.320-0.572)
2-day	0.080 (0.072-0.091)	0.101 (0.091-0.115)	0.127 (0.114-0.145)	0.147 (0.131-0.169)	0.174 (0.150-0.206)	0.194 (0.164-0.234)	0.214 (0.177-0.263)	0.234 (0.189-0.295)	0.260 (0.202-0.340)	0.280 (0.211-0.378)
3-day	0.062 (0.055-0.070)	0.078 (0.070-0.088)	0.098 (0.087-0.111)	0.113 (0.101-0.130)	0.134 (0.116-0.158)	0.149 (0.126-0.180)	0.164 (0.136-0.202)	0.179 (0.145-0.226)	0.199 (0.155-0.260)	0.213 (0.161-0.288)
4-day	0.051 (0.046-0.058)	0.065 (0.058-0.074)	0.082 (0.073-0.093)	0.095 (0.084-0.109)	0.112 (0.097-0.132)	0.124 (0.105-0.150)	0.137 (0.113-0.168)	0.149 (0.120-0.188)	0.165 (0.128-0.216)	0.177 (0.134-0.239)
7-day	0.035 (0.032-0.040)	0.045 (0.040-0.051)	0.057 (0.051-0.065)	0.066 (0.058-0.075)	0.077 (0.067-0.091)	0.086 (0.073-0.103)	0.094 (0.078-0.116)	0.102 (0.083-0.129)	0.113 (0.088-0.148)	0.120 (0.091-0.163)
10-day	0.028 (0.025-0.032)	0.036 (0.032-0.041)	0.045 (0.041-0.052)	0.053 (0.047-0.060)	0.062 (0.053-0.073)	0.068 (0.058-0.082)	0.075 (0.062-0.092)	0.081 (0.066-0.102)	0.089 (0.069-0.117)	0.095 (0.072-0.128)
20-day	0.018 (0.017-0.021)	0.024 (0.021-0.027)	0.030 (0.027-0.034)	0.035 (0.031-0.040)	0.041 (0.035-0.048)	0.045 (0.038-0.054)	0.049 (0.040-0.060)	0.053 (0.042-0.066)	0.057 (0.045-0.075)	0.061 (0.046-0.082)
30-day	0.015 (0.013-0.017)	0.019 (0.017-0.022)	0.024 (0.022-0.028)	0.028 (0.025-0.032)	0.033 (0.028-0.039)	0.036 (0.030-0.043)	0.039 (0.032-0.048)	0.042 (0.034-0.053)	0.045 (0.035-0.059)	0.048 (0.036-0.064)
45-day	0.012 (0.011-0.014)	0.016 (0.014-0.018)	0.020 (0.017-0.022)	0.022 (0.020-0.026)	0.026 (0.022-0.031)	0.028 (0.024-0.034)	0.031 (0.025-0.038)	0.033 (0.026-0.042)	0.035 (0.027-0.046)	0.037 (0.028-0.050)
60-day	0.011 (0.010-0.012)	0.014 (0.012-0.016)	0.017 (0.015-0.020)	0.020 (0.017-0.023)	0.023 (0.020-0.027)	0.025 (0.021-0.030)	0.027 (0.022-0.033)	0.028 (0.023-0.036)	0.030 (0.024-0.040)	0.032 (0.024-0.043)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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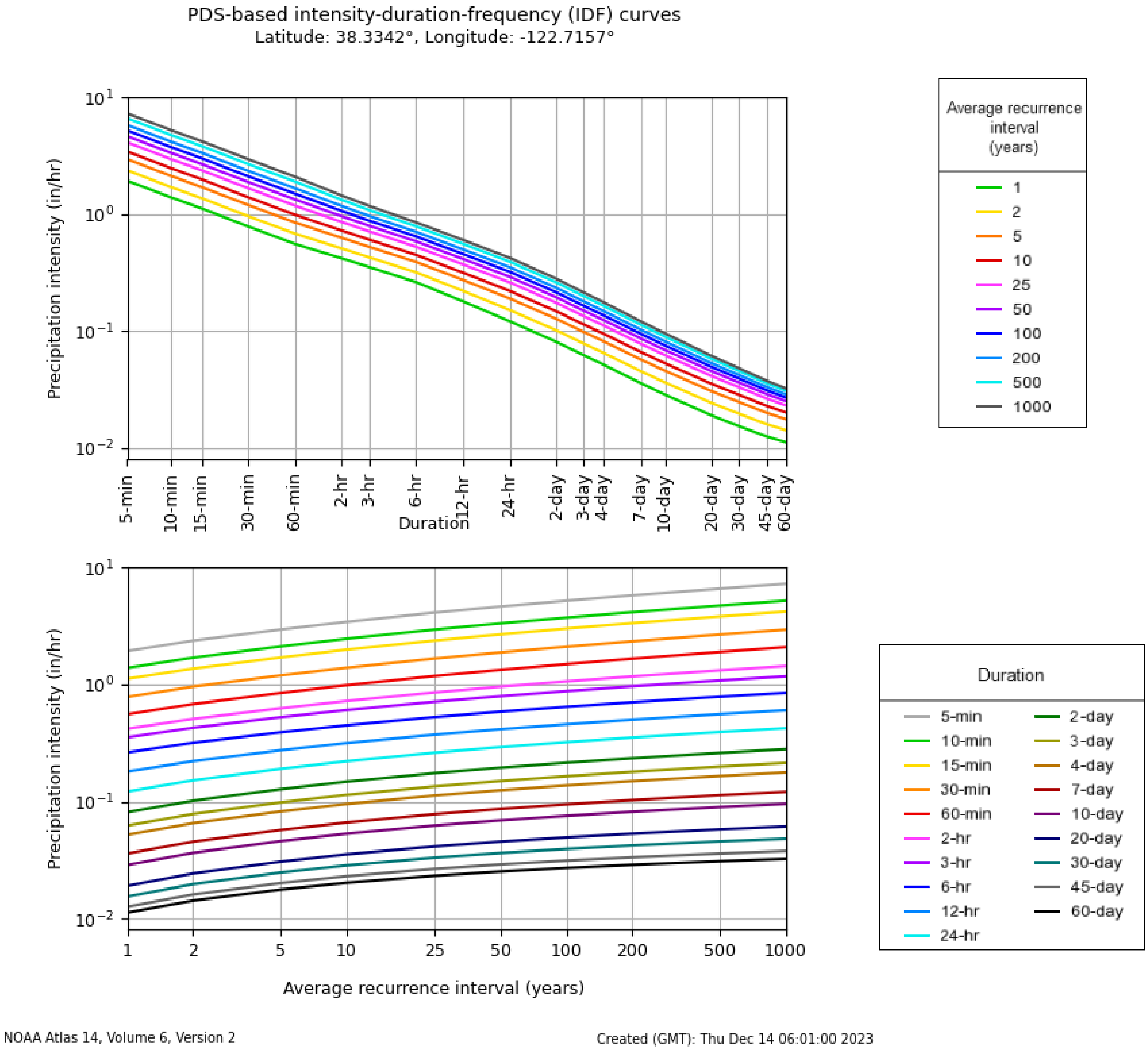
PF graphical



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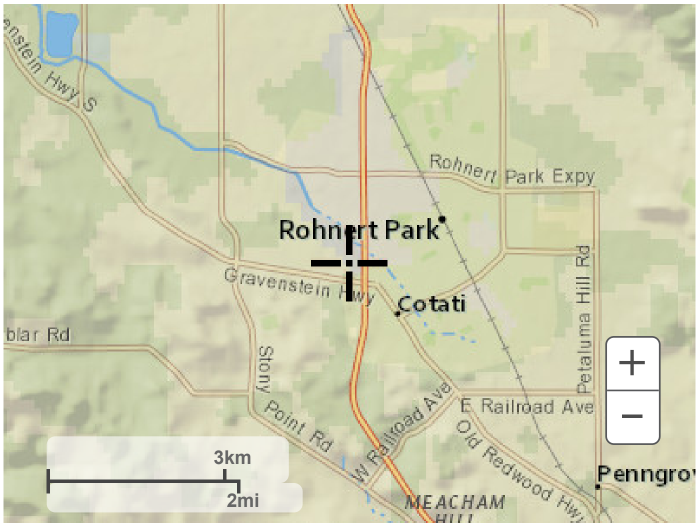
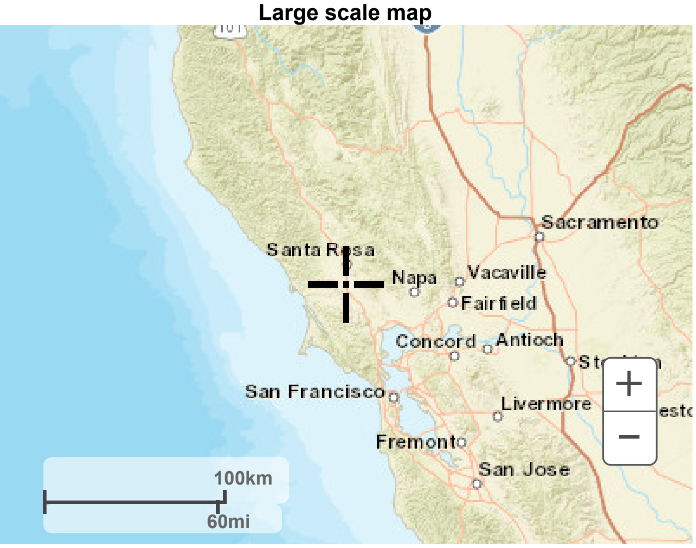
Maps & aerials

Small scale terrain



Large scale terrain

Large scale map



Large scale aerial

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APPENDIX F
Excerpts from Sonoma County Flood Management Design Manual

3.4.1 Incremental Rational Method

The rational formula (*Equation 3.1*) uses drainage area, a land cover runoff coefficient, and rainfall intensity to estimate the peak flow (Q_p) resulting from a design rainfall event. In use since the 19th century, the **Rational Method** is the simple application of the rational formula to characterize watershed runoff. The Incremental Rational Method[4] applies the rational formula incrementally to subwatersheds within the watershed of interest to provide a more detailed estimate of the cumulative peak flow based on the characteristics of each subwatershed. This section briefly describes each component of the rational formula and its application as the IRM.[5] Example Problem 1 in Appendix E.1 provides a sample application of the IRM.

The rational formula estimates the peak watershed runoff rate (Q_p) for a design rainfall event duration and frequency as a proportion of the rainfall intensity (I) corresponding to the same design event. Because the Rational Method uses a single coefficient (C) to estimate losses in each subbasin and assumes a uniform rainfall rate (I), Sonoma Water limits its use to watersheds of less than 200 ac. Each parameter used in the rational formula is discussed in detail following the description of the IRM.

Sonoma Water uses the rational formula as shown in *Equation 3.1*. Some forms of the rational formula include a conversion factor (k[6]) to convert acre-inches per hour to cubic feet per second (cfs); however, since the value of this conversion factor is approximately equal to one, it is often dropped from the equation, as it is in *Equation 3.1* below.

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[4] Because the term “Modified Rational Method” is used by engineers in reference to many different alternative Rational Method approaches, Sonoma Water uses the term “Incremental Rational Method” to describe Sonoma Water’s preferred method.

[5] The IRM analysis procedure described in this Manual does not differ significantly from the procedure described in the prior Flood Control Design Criteria Manual (FCDC Manual) (1983 edition).

[6] This “k” factor is entirely different from the “k” used in the prior FCDC Manual that was a coefficient to adjust a base 30 in of rainfall to the appropriate mean annual precipitation value for the location of interest.

$$Q_p = C * I * A \qquad (Equation\ 3.1)$$

Where,

Q_p is the peak flow rate for the design rainfall event (cfs);
C is the runoff coefficient (dimensionless);
I is the rainfall intensity (inches/hr) for the design rainfall event; and
A is the watershed or subwatershed area (ac).

For small, homogeneous watershed areas, the rational formula can be applied directly. Larger, heterogeneous watersheds should be subdivided into relatively homogeneous subwatersheds that are then evaluated using the IRM. When comparing hydrologic change among scenarios (e.g., comparing pre-project and post-project conditions), subwatershed boundaries should be consistent among scenarios, to the extent possible.

To apply the IRM, the rational formula is applied to each subwatershed to calculate a cumulative watershed Q_p. An overview of the nine steps of the IRM is provided in the call-out box below. In this description, letters (A, B, C, etc.) are used to designate subwatersheds and numbers (1, 2, 3, etc.) are used to designate computation points, as indicated in Figure 3-7, “Schematic for Application of the Incremental Rational Method.” Example Problem 1 in Appendix E.1 provides a detailed example of the analysis process.

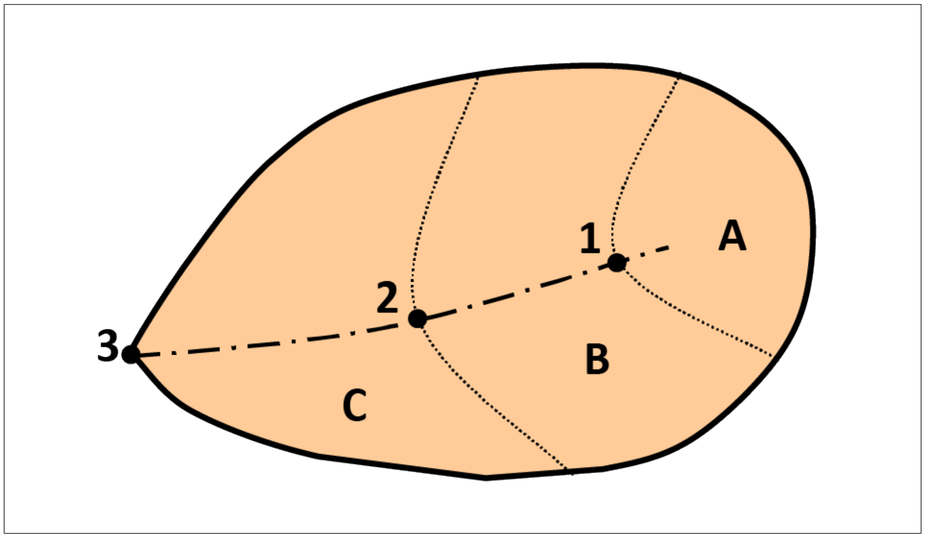

Figure 3-7. Schematic for Application of the Incremental Rational Method

This cumulative computation can be applied sequentially to any number of subwatersheds. Where tributaries enter, the tributary watershed should be added as an additional subwatershed. The travel time from the farthest point in the basin or subbasin through the drainage network to the outlet is termed the **time of concentration**, t_c (see Section 3.4.1.4).

3.4.1.3 IRM Rainfall Intensity

Rainfall intensity (I) is a function of the design event duration and frequency, with short, low-frequency events producing the highest rainfall intensities. When selecting I, the design event frequency is determined by the project design requirements. The design event duration is equal to the watershed or subwatershed time of concentration (t_c). Setting the event duration equal to t_c results in the maximum peak flow Q_p, since a longer duration would have a lower rainfall intensity and a shorter duration would not produce runoff from the entire watershed.

NOAA has developed tables of rainfall intensity by event frequency and duration, based on statistical analysis of rainfall gauge data as described in NOAA's *Atlas 14 (NOAA 2014)*. Sonoma Water requires *Atlas 14* as the source for rainfall intensities used in the rational formula.

Atlas 14 precipitation data for California are available from the NOAA Precipitation Frequency Data Server (PFDS) at hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ca. To retrieve rainfall intensity data, select: **Data type** = *Precipitation intensity*; **Units** = *English*; **Time series type** = *Partial duration* in the Data Description section. In the Select Location section, either manually enter the watershed or subwatershed latitude and longitude, or carefully select (double-click) the location on the map provided. Once the location is selected, a table will appear at the bottom of the page showing precipitation intensity by event duration and frequency. To develop values for intermediate time durations, the tabular values may be interpolated using a power curve (equation of the form $y = ax^b$) or other suitable interpolation method.

3.4.1.4 Time of Concentration

The time of concentration (t_c) is defined as the time required for runoff to travel from the most distant point in the watershed to the computation point where the flow is being estimated. It represents the time required for all areas within the watershed to contribute to runoff at the watershed outlet. Travel time is estimated based on three potential types of flow:

2. Overland flow (generally limited to 300 ft or less before tending to concentrate in a flow path),
3. Shallow concentrated flow (e.g., **gutter** or **swale**), and
4. Concentrated flow (e.g., pipe and/or channel).

min, the evaluation should be repeated using the calculated t_o select a new value for I. The process is repeated until the calculated t_o is within 1 min of the travel time used to select I.

$$t_o = \frac{0.94 * L_o^{0.6} * n_o^{0.6}}{(C * I)^{0.4} * S_o^{0.3}} \quad (Equation\ 3.4)$$

Where,

t_o is the overland flow travel time (min);
L_o is the overland flow length (ft);
n_o is the roughness for overland flow surface (dimensionless)
(see **Table 3-4**, “Values of Roughness (*no*) for Overland Flow Calculation”);
S_o is the slope of overland flow (ft/ft);
C is the runoff coefficient, ratio of runoff rate to rainfall intensity (inches/inch); and
I is the rainfall intensity (inches/hr).

Table 3-4. Values of Roughness (n_o) for Overland Flow Calculation

Surface Description	Overland Flow Roughness (n)
Smooth surfaces (Concrete, asphalt, gravel, or bare soil)	0.014
Fallow (No residue)	0.05
Cultivated soils (Residue cover < 20%)	0.06
Cultivated soils (Residue cover ≥ 20%)	0.17
Grass (Light turf)	0.25
Grass (Dense turf)	0.35
Woods (Light underbrush)	0.40
Woods (Dense underbrush)	0.80

Source: Adapted from SCS 1986 and Los Angeles County Department of Public Works 2006

Shallow Concentrated Flow Travel Time

To estimate shallow concentrated flow travel time, use Equation 3.5 and Equation 3.6 that are provided in Table 3-5, “Velocity Estimates for Shallow Concentrated Flow.”

APPENDIX G
Excerpts From The City of Cotati Storm Drain Master Plan

B. IMPROVEMENT PROJECTS

Winzler & Kelly conducted the preliminary design for improvement projects to correct each identified deficiency. The projects include new or modified closed conduit systems and culvert replacements. For closed conduits, the design consists of proposed pipe locations and dimensions, and numbers of manholes and drop inlets. The following criteria were used for the design of the majority of closed conduit systems (Exceptions to these criteria are noted in the project descriptions.):

- Minimum slope of 0.2%.
- Manholes shall be placed a maximum of 350 feet on center and at changes in pipe diameter.
- Standard manholes shall be 48 inches in diameter.
- Minimum pipe cover of 3 feet in roadways.
- Pipe material: Reinforced concrete pipe.
- New storm drain systems shall be sized to convey the design storm without surcharging.
- Modifications to existing storm drain systems shall not increase downstream surcharging or backwater effects.
- Closed conduits shall be located within the public right-of-way.

Table 6-2 presents the proposed improvement projects.

C. PROJECT DESIGN METHODS

The proposed projects were hydraulically analyzed through computer simulation to confirm that the hydraulic criteria were met. Closed conduit systems and culverts were modeled using StormCAD and Flowmaster respectively. The models were subjected to the design flow rates generated during the hydrology analysis.

D. COST ESTIMATE DEVELOPMENT

Cost estimates for the drainage improvements are developed using *Means Construction Cost Data*. The following items are added to this subtotal amount:

- General Conditions (30%)
- Sales Tax (4%)
- General Contractors Overhead and Profit (8%)
- Legal, Administration & Engineering (25%)
- Bond (0.15%)
- Contingency (10%)

The estimated cost of each project is presented in Table 6-2.

E. PROJECT PRIORITY ANALYSIS

The proposed drainage improvements will require a number of years to complete. The proposed improvement projects were ranked according to priority for construction. Priority rankings of low, medium, or high were attributed to each project based upon the criteria established below.