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Santa Clara Creek Restoration

Scott Cameron
Santa Clara Univeristy

Santa Clara Univeristy

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SANTA CLARA UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING

Date: May 28, 2015

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Scott Cameron

ENTITLED

Santa Clara Creek Restoration

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

X ______________________

Thesis Advisor

X ______________________

Department Chair

Santa Clara Creek Restoration

By

Scott Cameron

Senior Design Project Report

Submitted in partial fulfillment for the requirements

of the degree of

Bachelor of Science in Civil Engineering

Santa Clara, California

2015

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St. Claire River Restoration
Scott Cameron

Department of Civil Engineering
Santa Clara University 2015

Abstract

The Santa Clara River Valley is an area that has traditionally had a considerably high water table and that remains relatively true today as a result of a local adoption of imported surface water to meet most needs. Historically, the result of this high water table was a network of meandering waterways throughout the valley, several of which came extremely close to our own Santa Clara University. Despite this, there are no natural surface water systems that exist in this location today. In 1851, a Santa Clara county surveyor report showed one creek in particular that flowed nearly to the Santa Clara Mission. This area has undergone a great deal of infrastructural improvements, but the essential hydrogeological features as well as the main water systems are intact. The purpose of this report is to find the location of this fated water system, to find what circumstances would need to exist for it to resurface, and to develop design criteria for the restoration of this water system based on current conditions. The stream was located and a theory was developed to explain its disappearance. A plan was developed for the restoration of this stream that would bring a running water system back to Santa Clara University and the surrounding city. The stream was found and was redesigned such that it could be constructed in its natural location as it currently exists. Stable flow conditions were then estimated, an erodible channel was designed, and a cost estimate was created.

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Chapter 1

Introduction and Background

Since the beginning of human civilization, rivers have served as a community gathering point. Man drank from the river, washed in the river, played as a child and rested as a man by the river, he even worshipped the river. Contemporary research has found that natural running water provides mental health benefits. This project aims to bring a particular avenue of achieving this benefit to the attention of the future planners of the City of Santa Clara and of Santa Clara University, as well as provide some historical context to the state of the area as it exists today.

Contemporary research has found that individuals exposed to the mere sound of running water recovered from sympathetic stress 9-35% fasters than those without (Alvarson 2013). Research done for the American Journal of Sociological Research found that children and teenagers who listened to the sound of running water reported a 10% reduction in anxiety while waiting for a dentist appointment than those without (Tanja-Dijkstra 2014). Research done by the Geographisches Institut in Berlin, Germany found that areas of foliage and running water were highly beneficial to human mental health (Heidt 2010).

A county surveyor's map from 1851 has revealed that there once flowed a stream of some unknown size through what is now the city of Santa Clara, specifically the area occupied by Santa Clara University. The major geographic and hydrogeological features of the Santa Clara valley have remained relatively the same and, based on the location and flow of the stream, I have theorized that if the requisite earthen channel was created, the stream would resurface. Using recommended design criteria, current GIS data, and historical maps the stream has been located and a cross-sectional creek-bed with erodible channel design has been created. This project is important for several key reasons. Natural drainage systems such as surface creeks and streams increase biodiversity of an area as well as alleviate some of the pressure on manmade drainage systems.

Historical Site Information

At the time of the 1851 survey, what is now the city of Santa Clara was primarily dominated by wet, lowland meadows with dense clay soils and oak savannas. The stream ran through one of these lowland meadows with limited drainage and, according to analyses conducted by the San Francisco Estuary Institute, flooded regularly. Substantial modifications to the stream network of the Santa Clara Valley had been underway by 1851 by the Santa Clara Mission and nearby city of San Jose, both of which were wedded to the Guadalupe River. The largest difference between the modern stream network and the historical one is that today the network has been engineered via drainage systems and manmade channels, such that the majority of streams flow indirectly to the Bay, whereas the historical network was largely disconnected. Additionally, many of the waterways have been dredged and cut multiple times in an attempt to reduce their sinuosity and make them workable. These two points are important to note, as the shift in drainage potentially could account for some of the reason that the stream does not show up in surveying maps post-1880, and the reduction in sinuosity could have cut off this stream, as an extension of a larger river. The vast majority of the smaller naturally occurring ponds in the region disappeared by the late 1800s as a result of this drainage and increased water use for agriculture, hence a decline in groundwater level.

The stream was found to be underneath where The Alameda, a major thoroughfare near Santa Clara University, now lies. The stream was then actually found to be a drainage ditch used to keep the path dry in times of flooding, which explains its unique geometry. As can be seen in Figure 1 below, rows of willow trees lined the stream in order to increase its stability.

Later in the early 1900s, after many of the ponds had drained, the President of the University, Father Kenna rerouted a local stream to fill a swimming pool that was constructed for the students. Using GIS, I modeled this rerouting and surmised that a smaller stream that fed into our Alameda stream was likely used. As such, this may have been a contributing factor to the present nonexistence of the stream.

The following figures are the maps used to locate this stream.

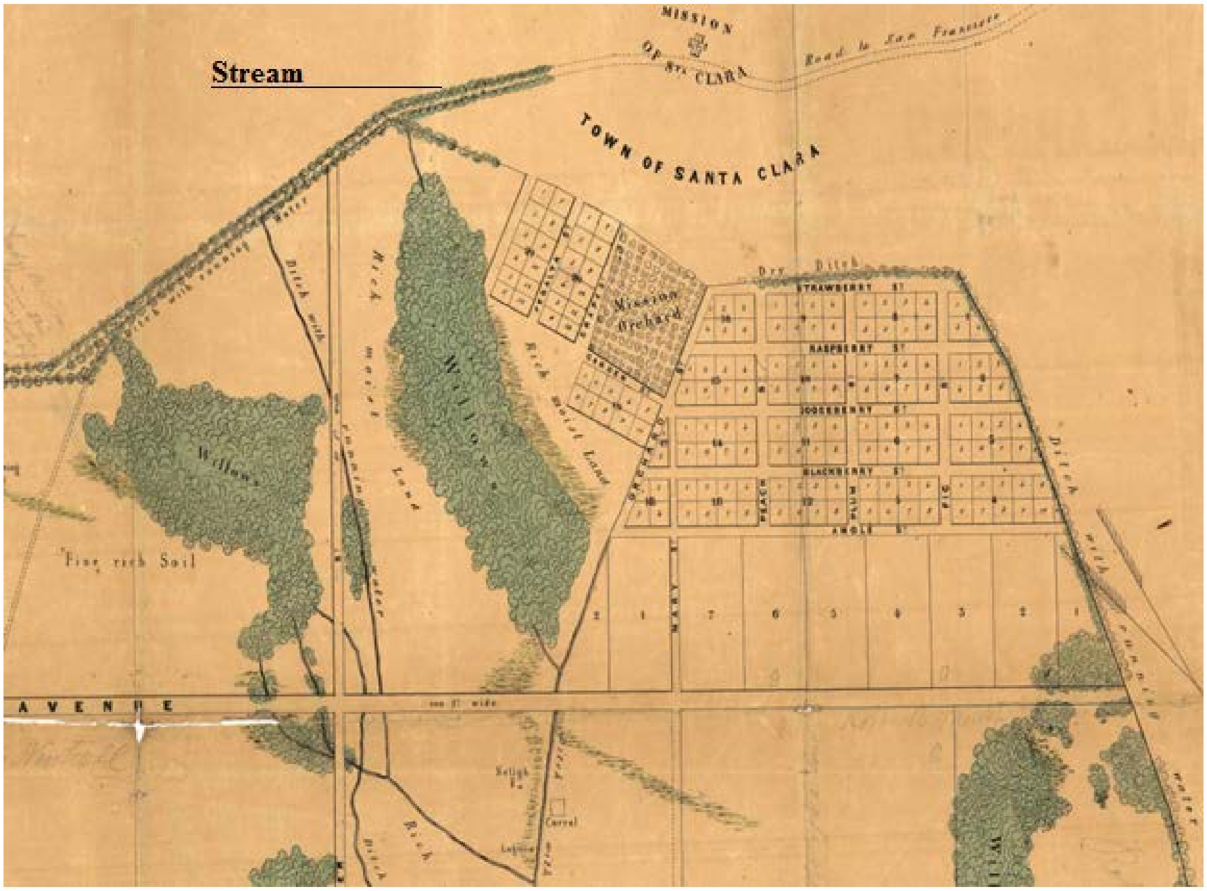


Figure 1 - The Original 1851 County surveyor's map of the Santa Clara Valley that shows the stream to be restored, annotated above. [Francisco Estuary Institute]

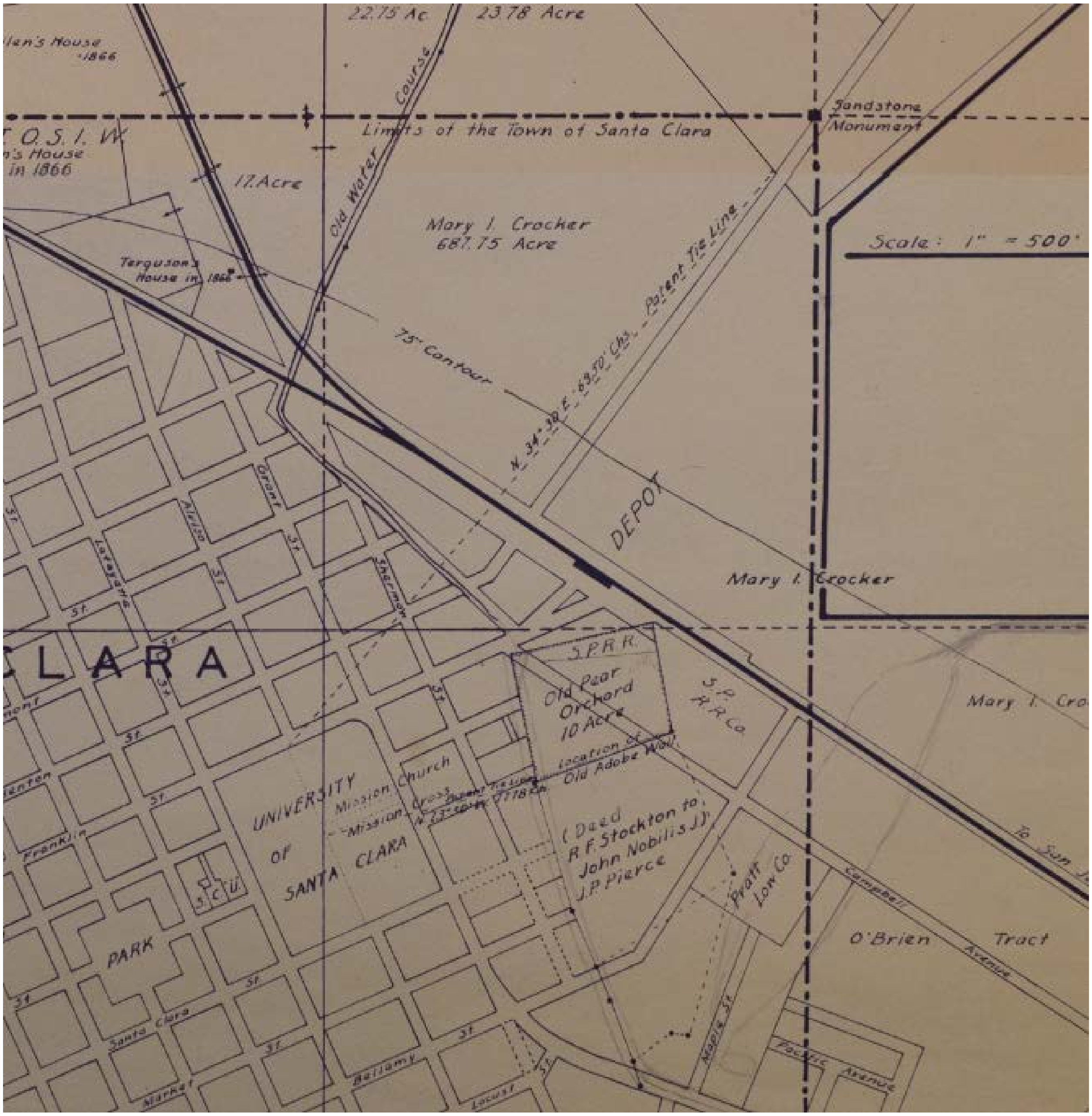


Figure 2 - Map of the city of Santa Clara Circa 1900. The perimeter of the University and the Old Pear Orchard were used to locate the stream in Figure 1 in current space. [Santa Clara University records]

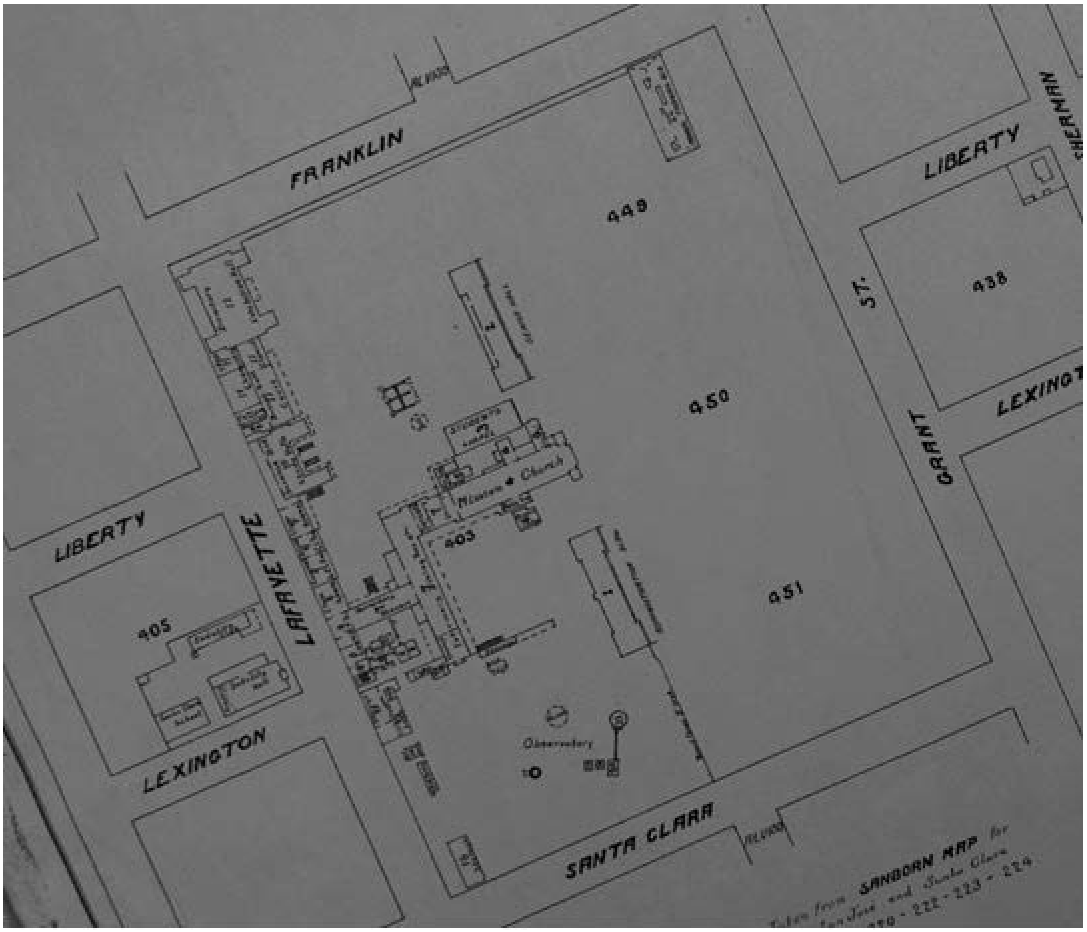


Figure 3 - Map showing the 1890s location of the mission church Mission Orchard. Noteworthy in that the location of the church O'Connor Hall, called Senior Hall at the time, have not moved since the time of this maps creation. This fact enabled the map to have these consistent locations referenced with Figure 2. [Santa Clara University records]

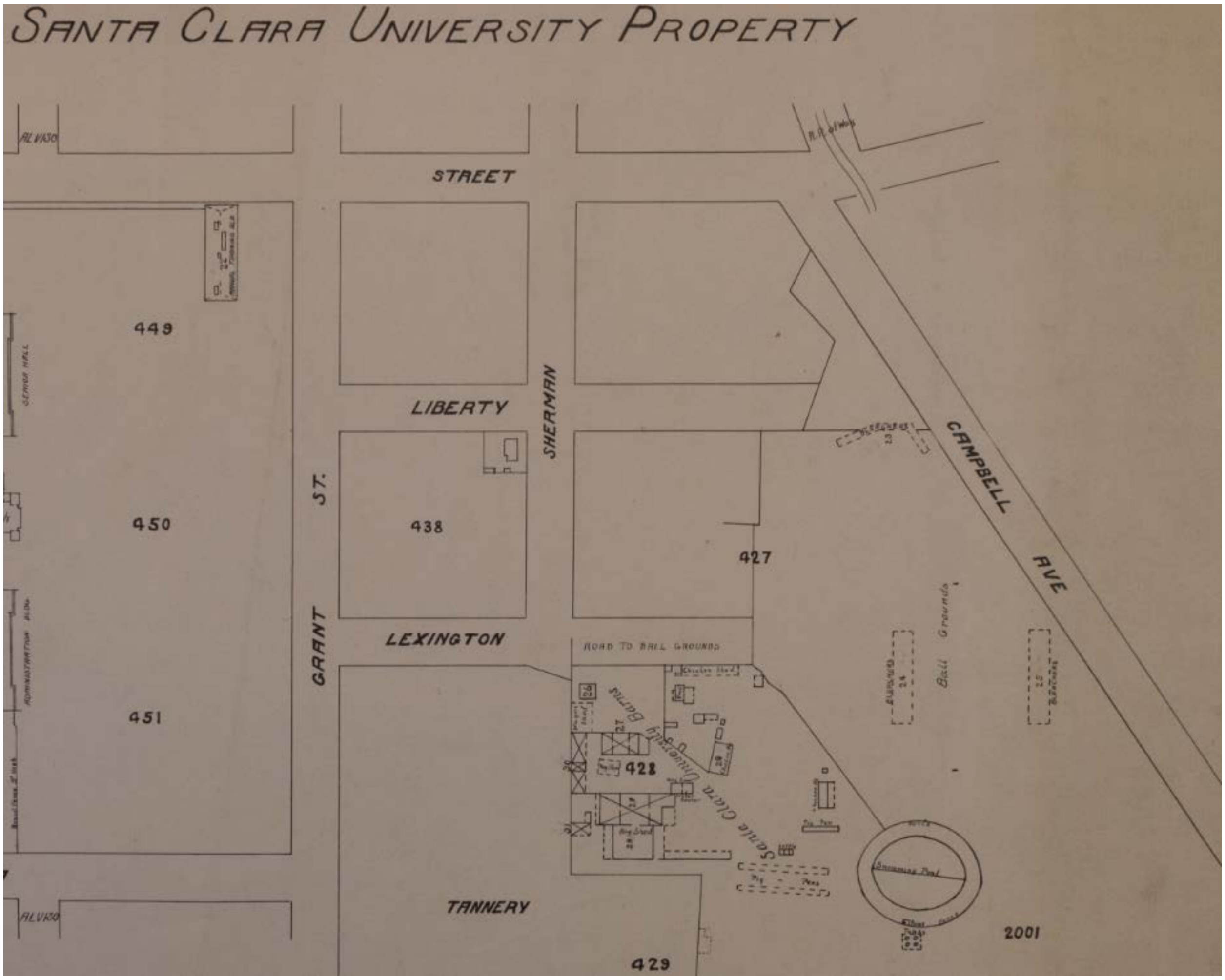


Figure 4 - Map of the University Circa 1905, shows The University Pool in the bottom right. [Santa Clara University records]

Present Site Information

In recent history, the entire Santa Clara Valley has been subject to heavy flooding due to the rapid buildup of infrastructure in San Jose nearly. We have a sprawling metropolis built atop wetlands, but the only remaining natural surface water in the vicinity is the Guadalupe River which is, and has historically been about 1.5 – 2 miles from Santa Clara University. The natural ponds as well as all tributaries in Figure 1 are completely gone. Figure 5 below shows the main historical tributaries as they can best be modeled excluding the stream in question. These channels are unnamed, and run as close as ¼ mile to the campus, branching a little over a mile from the main river. When shown over Figure 1, these tributaries appear to flow from the same source as the stream of interest. The following image shows the historical tributaries that have previously been mapped out.

Figure 5 - Map of present city of Santa Clara overlaid with previously known historical channels. [Map generated in Arc GIS 10.1, data courtesy of SFEI 2011, provided by ESRI]

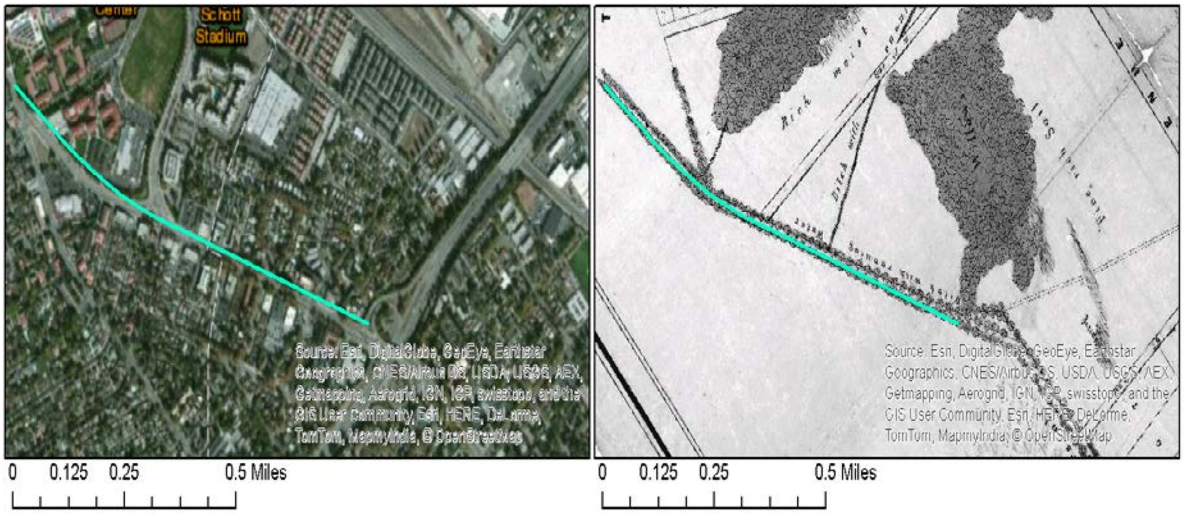
Chapter 2

Channel Location

After sorting through dozens of university archival maps, three were found that could be used to discern the location of the stream by means of Georeferencing. Georeferencing is a process in the ESRI Arcmap software that enables one to assign scaled modern geospatial coordinates to non-scaled maps and images. By this process I was able to place these historic maps in current space in the NAD 1983 coordinate system. The following figure shows the georeferenced location of the stream on both the map and the real-world basemap. Centered in the modern map is the intersection of The Alameda and El Camino, on the left in the same map is the intersection of Park Avenue and The Alameda. The stream flows to the right and begins to flow almost completely under The Alameda and continues in this fashion for some time. Further referential views of this can be seen in appendices A and B.

Analysis of Historical overlay data

As the following Figure 6 shows, the historical location of the creek is extremely close to that of the modern Alameda. Historical accounts of the region mentioned a path that connected the University to the neighboring cities that progressed through a flood-prone region that had a drainage ditch to keep the path clear. The creek does look somewhat manufactured. It is reasonable to assume that, over time, this path that lies next to the stream was paved over with the expansion of the city and the stream was likewise filled in with the installation of municipal drainage systems.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap

Figure 6 - Georeferenced comparison of creek location.

As mentioned prior, it was theorized that the stream indicated in Figure 1 was the same stream that was mentioned in the journal of Fr. Kenna, former president of Santa Clara University, when he refers to a stream that was diverted to fill a manmade swimming pool for the students, visible in figure 4. Unfortunately, the creek still does not flow through the area indicated, meaning that the stream spoken of in the journal, is unlikely to refer to the creek in question. However, the most likely candidate for Fr. Kenna's stream does feed into our stream and therefore the diversion could have been a contributing factor, though the Alameda stream is unlikely to have still existed by the time of Fr. Kenna's swimming pool.

Chapter 3

Erodible Channel Design

The original plan for the design of the channel was an earthen channel that estimated all flow conditions based on soil type and percolation averages. The issue with this design was that it did not allow for a steady flow in drought conditions, which was one of the main requirements for the design. The decision was made for this project to design a relief drain. The relief drain is explained extensively later in this document, but essentially guarantees stable low-flow conditions year-round. The channel is to be designed at high flow however, and high flow conditions were calculated using rainfall intensity predictions from the National Oceanic and Atmospheric Administration's (NOAA) Hydrometeorological Precipitation Frequency Estimate map and runoff accumulation based on geography obtained from LIDAR data via the Rational Method as outlined in the Santa Clara County Drainage Manual. Finally, with these conditions the channel geometry was defined over the 6000 foot length of the reach.

Figure 7 was constructed in Autocad and details a length profile of the stream with the street level shown in yellow and the water-table level shown in green. The white section is the relief drain and the teal portion is the stream itself.

The original Autocad file was created by the City of Santa Clara and the stream section was drawn over.

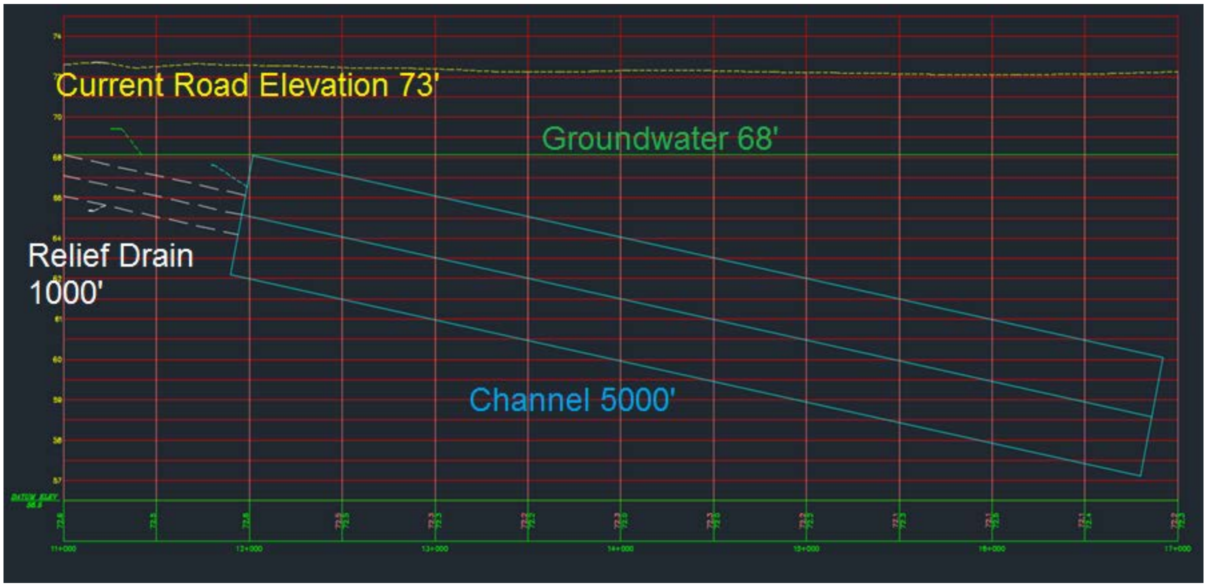


Figure 7 - Autocad length profile of the proposed stream, overlaid over constructed length of municipal design.

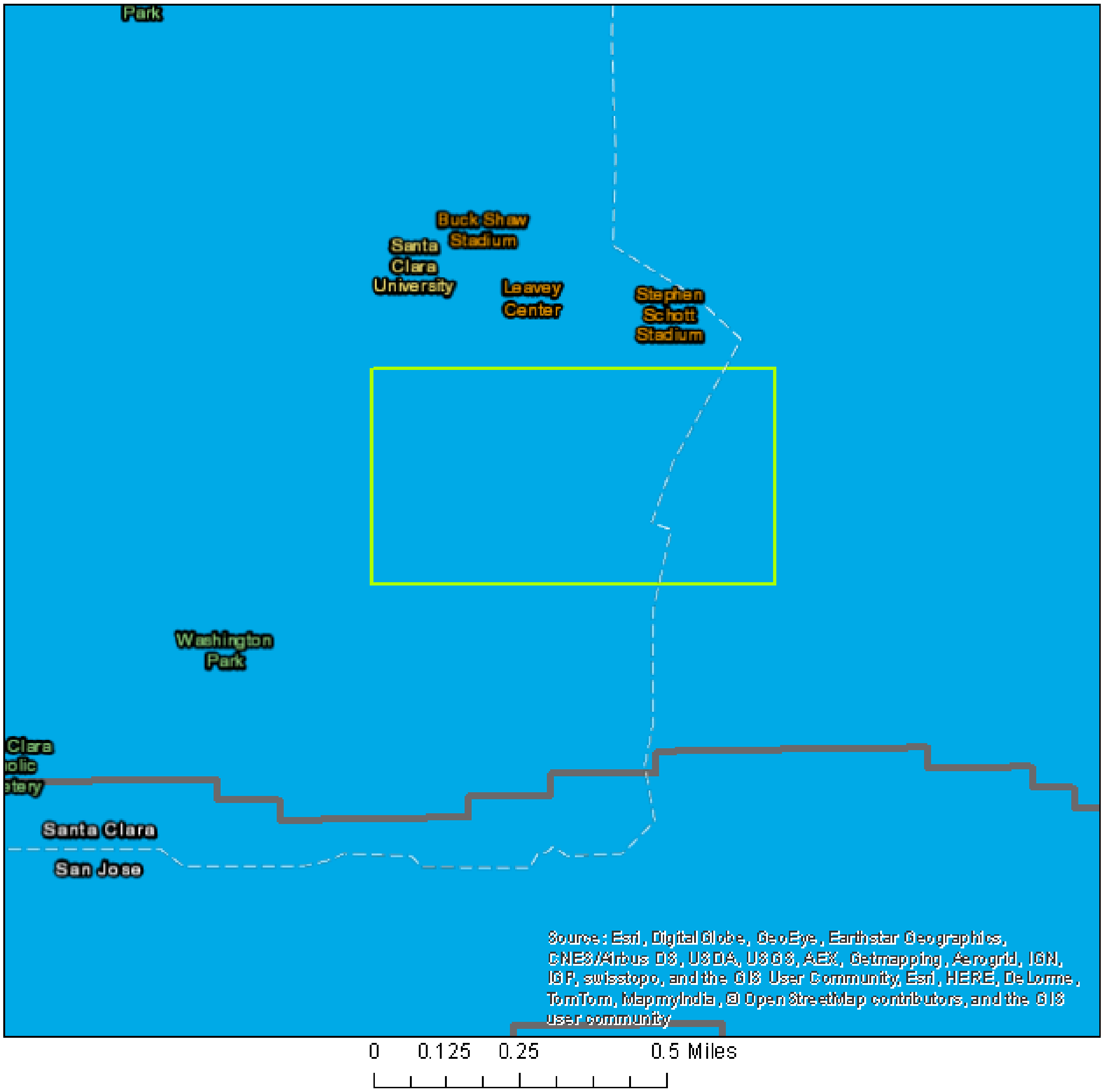
Figure 8 is an aerial profile of the channel and shows the relief drain connected to the channel.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 8 - Arcmap aerial plan view of the channel with connecting relief drain.

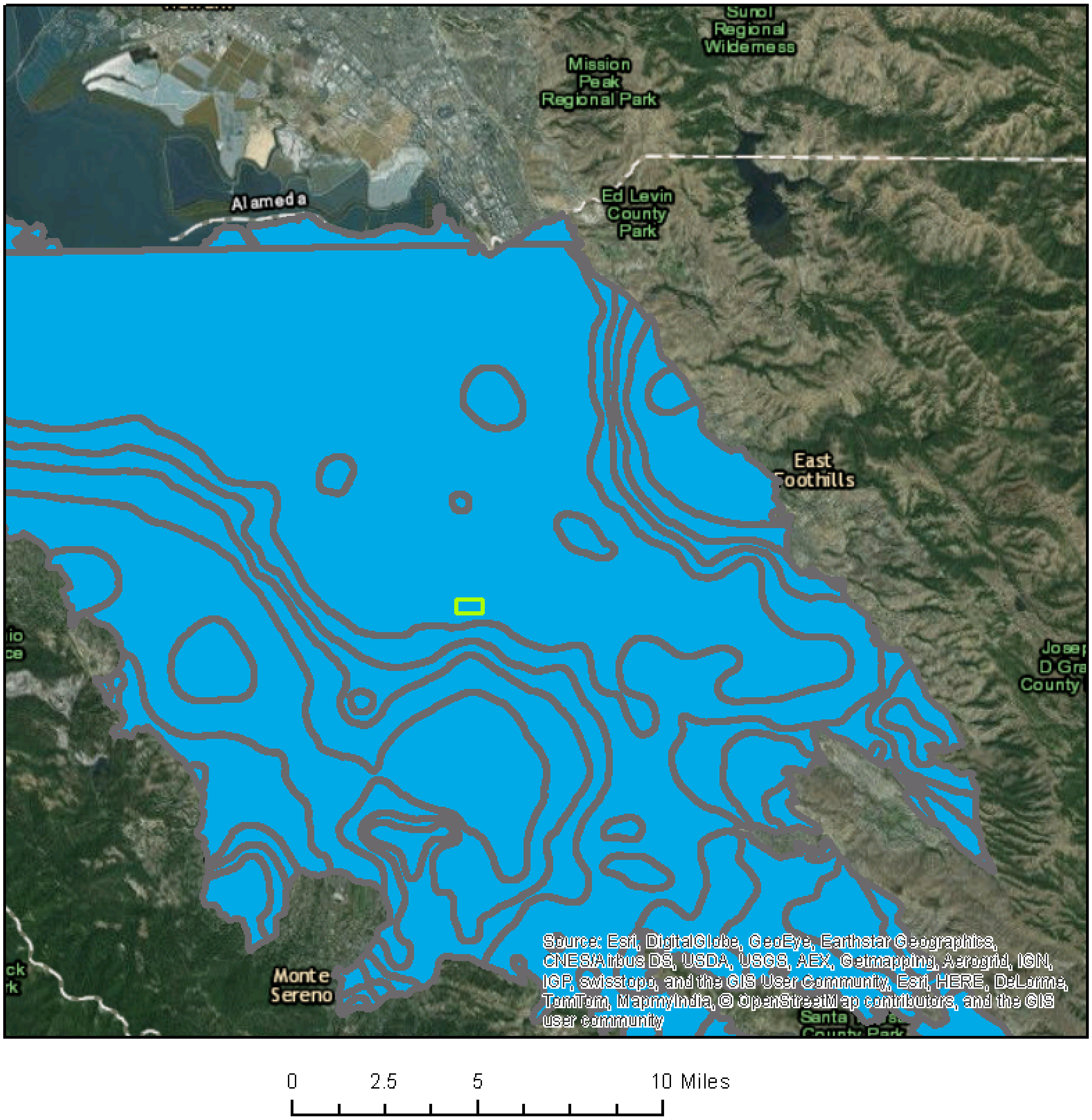
Water Table Analysis

Figure 9 was rendered in Arcmap using Groundwater data to show the depth to first groundwater for the area surrounding Santa Clara University. This render shows that the depth to first groundwater in the area of interest is approximately 5 ft. under the city of Santa Clara. Figure 10 shows the specific location of the area being worked in within the Santa Clara Valley Water District.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 9 - Arcmap rendering of groundwater depth in Santa Clara, green box is the area worked in. [Courtesy of Santa Clara Valley Water District]



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 10 - Arcmap rendering of groundwater depth in Santa Clara Valley. Small green rectangle indicates the view from Figure 8. [Santa Clara Valley Water District]

Relief Drain

To maintain low flow conditions in periods of low rainfall, a relief drain is required. A relief channel is essentially a form of subsurface drainage that intercepts flow from the watershed and empties into the channel above. These are typically used to lower the water table in a particular area or remove excess moisture from soil but can also be used to maintain a stable flow based on the position of the water table. A relief drain is a 1000' long PVC pipe with drilled holes, surrounded by #57 gravel and wrapped in filter cloth that pierces into a water table along its length and surfaces at the end into an open channel and delivering flow. The moving surrounding groundwater infiltrates into the pipe and, over the course of the length of the pipe, develops into a flow which upon exiting becomes our low-flow. This system is similar to a pumping mechanism but utilizes a gravity outlet.

Figure 11 is a standard relief channel that would normally be used for agriculture, but suits the purposes of filling a like channel. The PVC pipe is perforated with 1mm holes, surrounded by a three inch thick cover of gravel, and wrapped in filter cloth. This channel is embedded into the aquifer and the moving water along the 1000' of the pipe filters into the pipe which slowly collects over the length of the pipe to create a flowing stream.

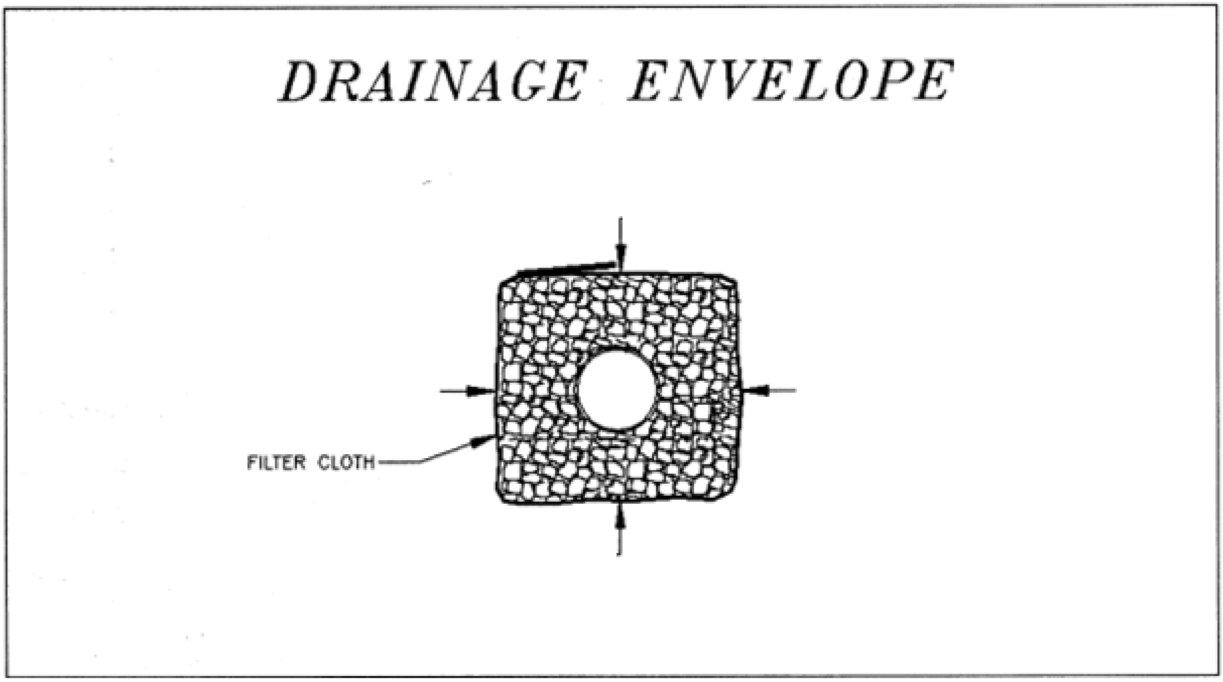


Figure 11 - Relief Drain with Drainage Envelope [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

The relief drain would only moderately increase the cost of the project, as can be seen in the cost estimate in Table 2 on page 26, while enabling the channel to maintain low flow conditions. This flow is controlled by soil texture estimates and the length of the pipe within the soil. Soil texture determines the maximum moisture contained in an area of land and only affects the theoretical maximum volumetric flow rate that can be yielded by an area of land. As we are not approaching these maximums, the flow rate in the channel would only be marginally affected by the heaviness of the soil. According to the Virginia Department of Soil and Water Conservation, the minimum velocity to prevent clogging by silting under poorest conditions in our pipe is 1.4 ft/s and the pipe will be graded and sized to achieve a much higher velocity than this. The drain will be constructed of concrete with an assumed Manning roughness (n) value of 0.015, surrounded by #57 gravel and cotton filter cloth. #57 gravel was chosen due to it being porous enough to allow easy water transfer and large enough to prevent clogging. Figure 12 graph shows the volumetric flow that a relief channel can provide as a function of drain diameter.

Further specifications relating to the design decisions made can be found in Appendix C.

The following figure shows expected volumetric flow as a function of pipe diameter and hydraulic gradient. A 12-inch diameter was chosen for the pipe to be constructed at a depth of 5 ft. below present grade. Low-flow is therefore approximated to be $1.1\frac{ft^3}{s}$.

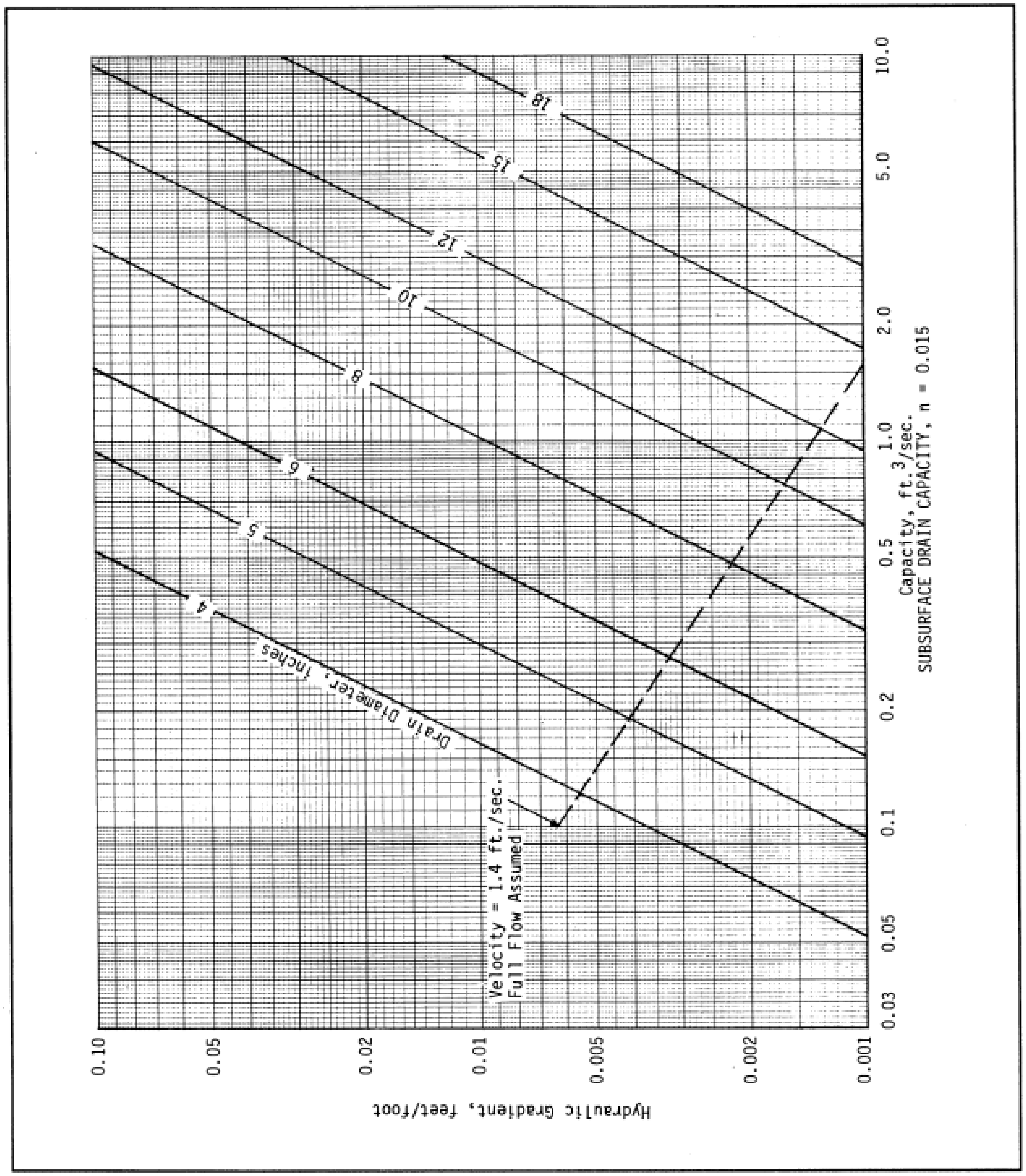


Figure 12 - Graph plotting capacity flow rate as a function of hydraulic gradient and diameter. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

Runoff Analysis

While the dry portion of the year will necessitate a relief drain through the water table to maintain flow conditions, peak flow will occur during the rainy season, which promises greatly increased flow conditions. The typical high flow needs of the channel were calculated using the rational method as it is outlined in the Santa Clara Valley Water District drainage manual.

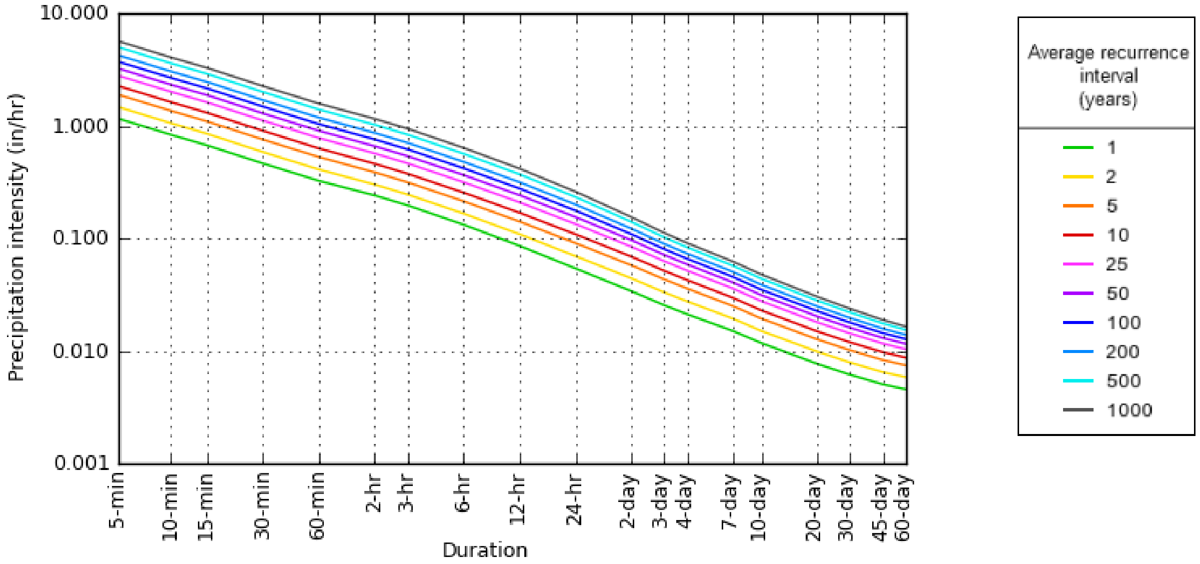
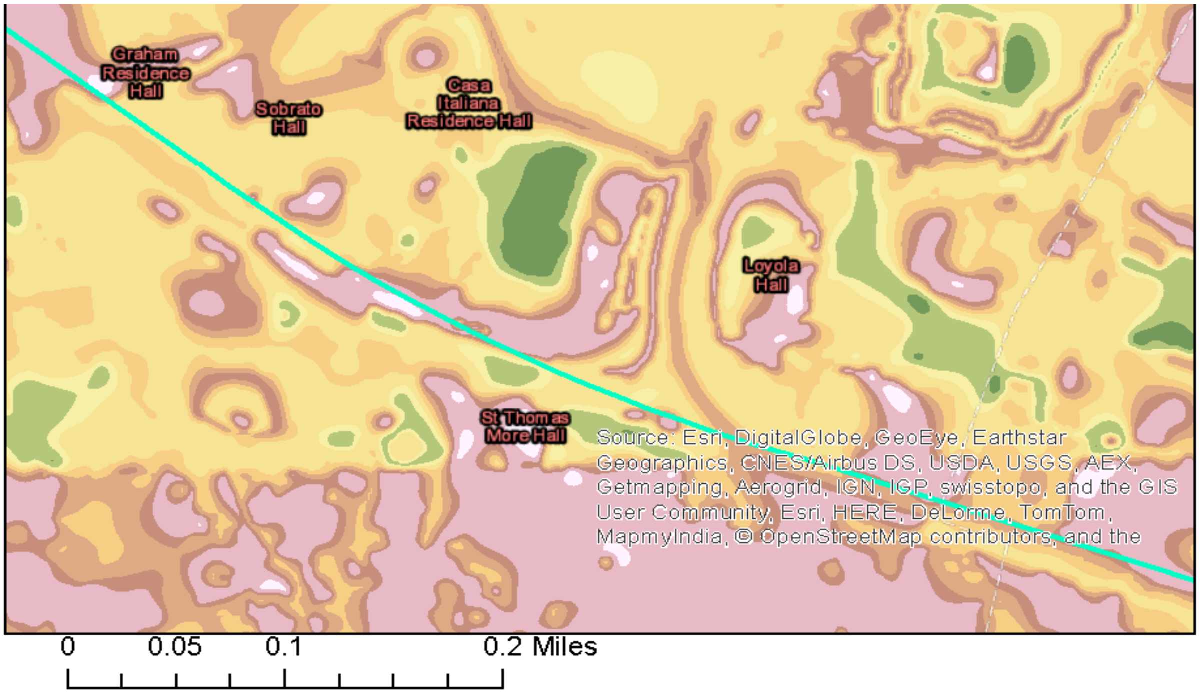


Figure 13 - Precipitation Intensity graph for various flood recurrances over duration [NOAA]

The National Oceanic and Atmospheric Administration’s Hydrometeorological predictions for precipitation frequency estimates rainfall intensity at various recurrence intervals. This data yields an intensity value of 1.07 in/hr for a 100-year flood for a 1 hour increment. The area of runoff was found using the Lidar, or Light Detection and Ranging data, which is the extremely accurate elevation data in Figure 14. This data was run through several analysis programs in Arcmap to give Figure 15 and finally Figure 16 gives flow by the accumulated drainage area. This area was found to be approximately 5 acres along the length. An in-depth analysis of this process can be found in Appendix B.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User community

Figure 14 – Lidar Data contour map of the City of Santa Clara [Courtesy of the SCVWD]



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the

Figure 15 - Topographical map of Santa Clara University.

Figure 15 is figure 14 after it has undergone an Arcmap transformation from a LIDAR raster image to a topographic map. This form allows it to be manipulated further into a topo fill map and finally a flow direction map and a flow accumulation map, as can be seen in Figure 16. Further information can be found in Appendix B

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 16 - Flow Accumulation visual rendering of Santa Clara University in ArcGIS

Figure 16 above presents the information given by the Lidar data in a usable form as Flow Accumulation is the area of land in acres that accumulates flow in the form of precipitation and flows along the colored lines.

The following equation is known as the Rational Method and estimates peak discharge in cubic feet per second(cfs). The Santa Clara Valley Water District recommends this method for any area less than 200 acres.

$Q =$ Peak runoff discharge

$c =$ runoff coefficient, estimated at 0.5 for Santa Clara, CA. Obtained via the Santa Clara Valley Stormwater Manual.

$i = \text{rainfallfall intensity} = 1.07 \left(\frac{\text{inches}}{\text{hour}}\right)$

$A = \text{drainage area(acres)} = 5$

[**Equation 1**]

$$Q = ciA = 2.5\ cfs$$

Channel Dimensions

The channel parameters are almost completely dependent on the expected flow rate. Low flow conditions are estimated to be the constant minimum flow rate delivered by the Relief drain. High flow conditions are estimated to be low flow conditions in addition to peak runoff derived from the Rational Method as it is outlined in the SCVWD Drainage Manual. The dimensions of the channel itself are derivative of hydraulic efficiency equations found in the Federal Highway Administration's Design of Roadside Channels with Flexible Linings Manual, optimized with Manning's formula to yield hydraulically optimized channel dimensions.

A = Cross-sectional area (ft^2)
R = Hydraulic radius (ft)
Q = Discharge rate (cfs)
n = Manning's roughness coefficient, 0.22 for 6''-12'' Rip-Rap channel (courtesy of NCRS)
S_f = Friction Gradient, Energy Grade line slope

Starting with Manning's formula,

[**Equation 2**]

$$V = \frac{1.486 * R^{\frac{2}{3}} S_f^{\frac{1}{2}}}{n}$$

In terms of volumetric flow, [Equation B-2]

[**Equation 2**]

$$Q = VA = \left(\frac{1.486}{n}\right) A R^{\frac{2}{3}} \sqrt{S_f}$$

At a designated discharge, the slope, roughness, and cross-section, theoretical max velocity requires a theoretical minimum wetted-perimeter. For our purposes, the main design constraint, other than flow, is the optimal freeboard to create an aesthetically pleasing and flowing stream. The following figure is a diagram of a sample channel cross section.

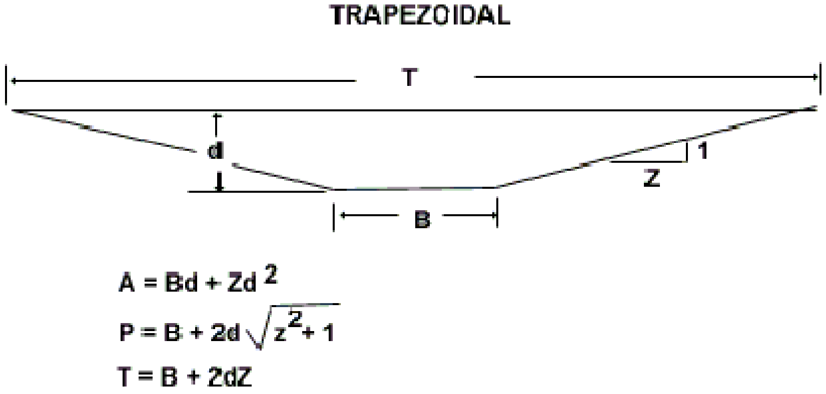


Figure 17 - Trapezoidal channel diagram [Design of Roadside Channels with Flexible Linings, Federal Highway Administration]

$P =$ Wetted Perimeter

$d =$ Water Depth

[**Equation 3**]

$$P = 4d(1 + Z^2)^{\frac{1}{2}} - 2Zd$$

And the resulting cross-sectional area:

[**Equation 4**]

$$A = Bd + Zd^2$$

We can optimize this area with the following equation.

[**Equation 5**]

$$C_M = \left(\frac{\left(k + 2(Z^2+1)^{\frac{1}{2}}\right)^{\frac{2}{3}}}{1.486(k+Z)^{\frac{5}{3}}} \right)^{\frac{3}{8}}$$

Then we can calculate depth by rearranging Equation B-2, providing us with an equation for uniform flow when the equation equals zero, which can be solved via iterative process.

[**Equation 6**]

$$\frac{\mathrm{Qn}}{1.486\sqrt{\mathrm{S_f}}} - (Bd + Zy^2)\mathrm{R}^{\frac{2}{3}} = 0$$

By rearranging this optimal hydraulic efficiency and Equation 5, we can find an optimal depth based on our known flow rate(3.6).

[**Equation 7**]

$$d_{opt} = 2^{\frac{1}{4}} \left(\frac{Q}{\left(1.49\sqrt{1+Z^2} - Z\right) S_0^{\frac{1}{2}}} \right)^{\frac{3}{8}} = 3.4\ ft.$$

Then we can further use this value to find our optimized width.

[**Equation 8**]

$$B_{opt} = 2\left(\sqrt{1+Z^2} - Z\right) d_{opt} = 1.6\ ft$$

Table 1 contains all values related to the design and construction of the channel.

Table 1. Final Values of Designed Channel

	ft
Qr(Relief drain flow)(cfs)	1.1
i(intensity)(in/hr)	1
c	0.5
Accumulated Area of Runoff(acres)	5
b(base width)	1.5
Z(Side slope ratio)	2
A(Area)	28.2
y(depth)	3.4
So(slope)(ft/ft)	0.001
P(Channel Perimeter)	16.7
R(Channel Radius)	1.7
T(Channel width)	15.1
Qrain(Additional flow delivered by runoff)	2.5
Qdes(designed flow rate)(cfs)	3.6
Water Depth(Low Flow)	0.59
Water Depth(High Flow)	1.04
Velocity(Low Flow)(ft/s)	0.7
Velocity(High Flow)(ft/s)	0.96
Fr(Froude Number)	0.21

An AutoCAD rendering of the side-section of the stream can be found in Appendix A-1, and a cross section can be found in Appendix A-2.

Channel Stability

For a flowing creek, channel bed stability must be maintained to ensure that sediment does not fill the basin and the channel. The calculated maximum permissible unit shear stress to prevent scour of 6-12'' grade riprap is 4.16 lb/ft^2, corresponding to a maximum velocity of 14 ft/s, both of which our channel falls underneath for all examined flood events even up to a 100 year flood. The slope, being less than 1%, does not necessitate flume analysis. An additional index of hydrodynamic force equations can be found in Appendix D.

Bank Stabilization

Due to the simple nature of the stream and the design assumption of a straight channel, the urban surroundings of the bank made the process of counter-weighing and placing rock at the toe of a slope to prevent sliding, unfeasible and much more expensive than alternatives. Keying and notching were the chosen methods as they offer additional creep and slippage resistance and would be far cheaper. The process of notching involves cutting a trench into a bank corner and the process of keying involves cutting a bench into the surface of the slope and filling these indentations. Figure 18 below is an example of both keying and notching.

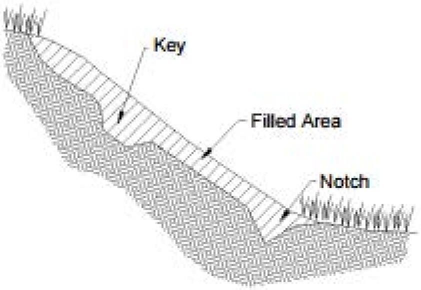


Figure 18 - Key and Notch diagram [Environmental Protection Agency, Bank Stabilization Manual]

Additionally, grass seeding is to be conducted in the area at the border of the rip-rap to the 2 inch soil cover. This is the most effective method of bank stabilization and maintains a slip buffer around the rip-rap cover of the channel.

Chapter 4

Feasibility and Cost Estimate

At the inception of the project, the location of the stream was estimated to be within the confines of land owned by Santa Clara University. In reality, the historical location of the stream was found to be under the Alameda, a parcel owned by the city of Santa Clara. This presents several unique problems, as the historic waterway flowed underneath where now lies an important thoroughfare.

Table 2 was generated using required items from like projects including the Wind River USDA creek restoration project and the Cuyaga Creek Habitat restoration project. Services and costs were taken from the ENR materials cost index. Planning, Design, and CEQA costs are typical across all similar projects. Heavy Equipment rentals are also standard. Labor costs are largely driven by access and, as this project takes place in the city, access is a non-issue.

Table 2. Estimated Costs Breakdown.

	Labor, services, and Equipment Rental Breakdown				
	Item	Unit	Quantity	Unit Price	Total Cost
1	Supervisor	HR	140	$97.0	$13,580.0
1	Heavy Equipment Operator	HR	76	$85.0	$6,460.0
4	Maintenance Worker	HR	140	$80.0	$11,200.0
1	Excavator	Day	7	$1,700.0	$11,900.0
1	Bulldozer	Day	7	$1,000.0	$7,000.0
	Hauling	yd^3	500	$3.6	$1,800.0
1	Crew Truck	HR	36	$60.0	$2,160.0
	Misc Equipment	Bulk	1	$1,200.0	$1,200.0
	Site Security(5pm-6am)	HR	180	$30.0	$5,400.0
	Equipment Transportation	Bulk	1	$1,000.0	$1,000.0
	Total				$61,700.0

	Materials Breakdown				
	Rip Rap	yd^3	300	$30.0	$9,000.0
	Revegetation	Bulk	1	$1,400.0	$1,400.0
	Relief Drain	Ft	1000	$5.0	$5,000.0
	Dirt	Ton	4	$15.0	$60.0
	Total				$15,460.0

	Flat Costs				
	Planning, Design, and CEQA	Bulk	1	$45,000.0	$45,000.0
	Total				$122,160.0

Table 3. Comparative Cost Estimate.

	Liberal Estimate (Cost/Linear Mile)	$350,000.0
	Conservative Estimate(Cost/Linear Mile)	$65,000.0
	Expected(Cost/Linear Mile)	$122,160.0

Chapter 5

Summary and Conclusions

My senior capstone design project is a proposed Creek Restoration project for a portion of what I have begun calling University Creek that once ran where The Alameda now lies next to Santa Clara University. This project was a proof of concept for location, cost, and estimations of geometry. This is by no means comprehensive for design but is intended to serve as a base point for future projects that would explore the topic further. I believe that this project is important to the long-term planning for both the University and the City, and that a running water source would be an important and central feature of the region. The benefits of water exposure to both aesthetic appearance and mental health have been enumerated previously. This is not a noticeable need, but rather a need that is unrecognized and, should it be given to the public, will become indispensable in short order. I believe that if this stream ever restored, it will become an integral part of campus life and forever change the culture of Santa Clara University and the greater city of Santa Clara.

It is not recommended that this stream be constructed in the near future. This is not out of a lack of faith in product, but rather that The Alameda is a major thoroughfare and demolishing it would be initially damaging to the several businesses in the area. Considering the surrounding urban environment, the stream would likely end up with a large accumulation of garbage. All of that is to say that it is not recommended that this stream be constructed immediately, but rather that this design and the philosophy of reassociating ourselves with natural water systems in our environment be incorporated into the design of the city of tomorrow.

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Appendix A

Creekbed Construction Views

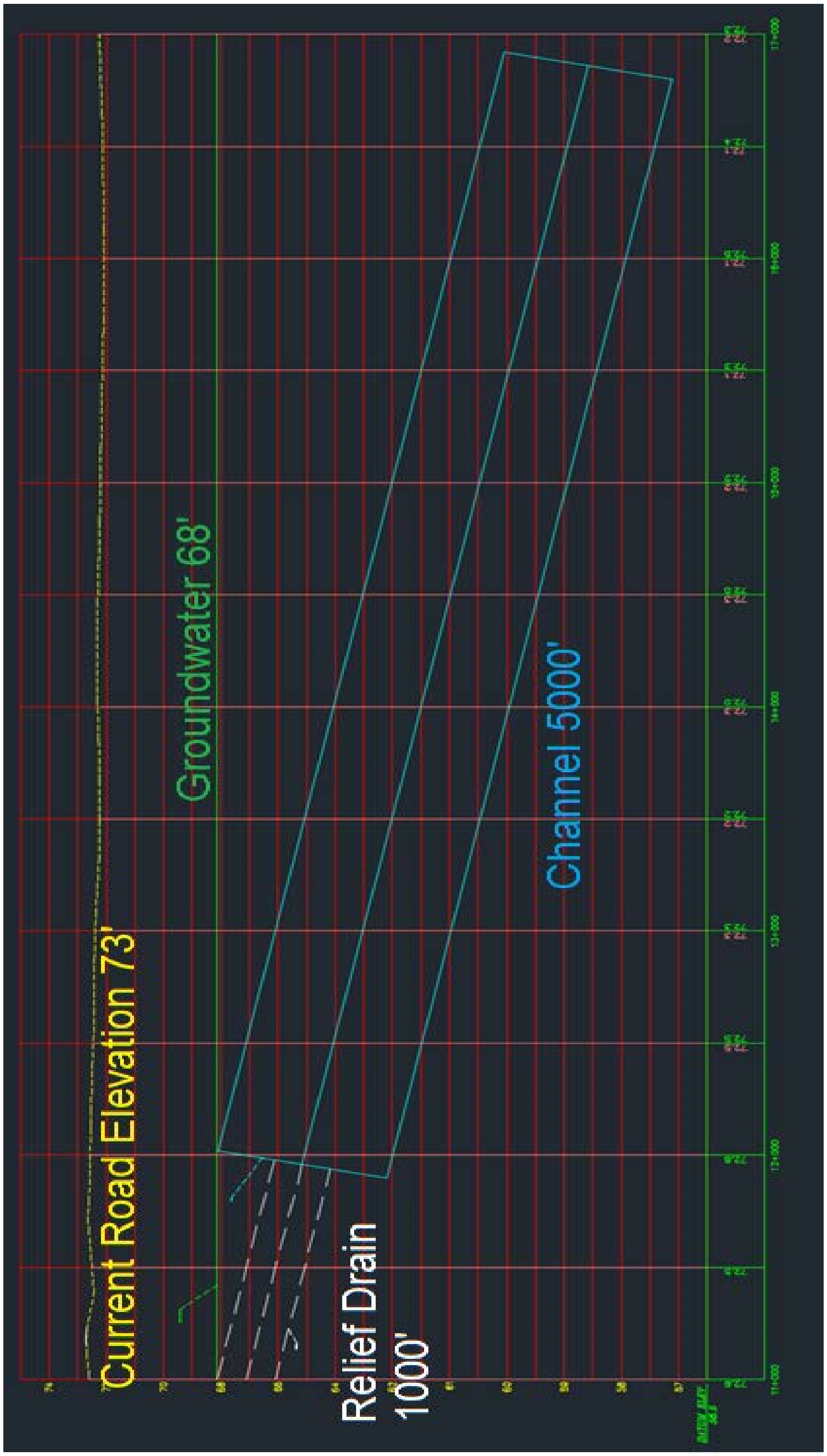


Figure A1 - Side section of proposed creek. Creek construction in blue, relief channel in grey, current water table in green, and current ground level in yellow.

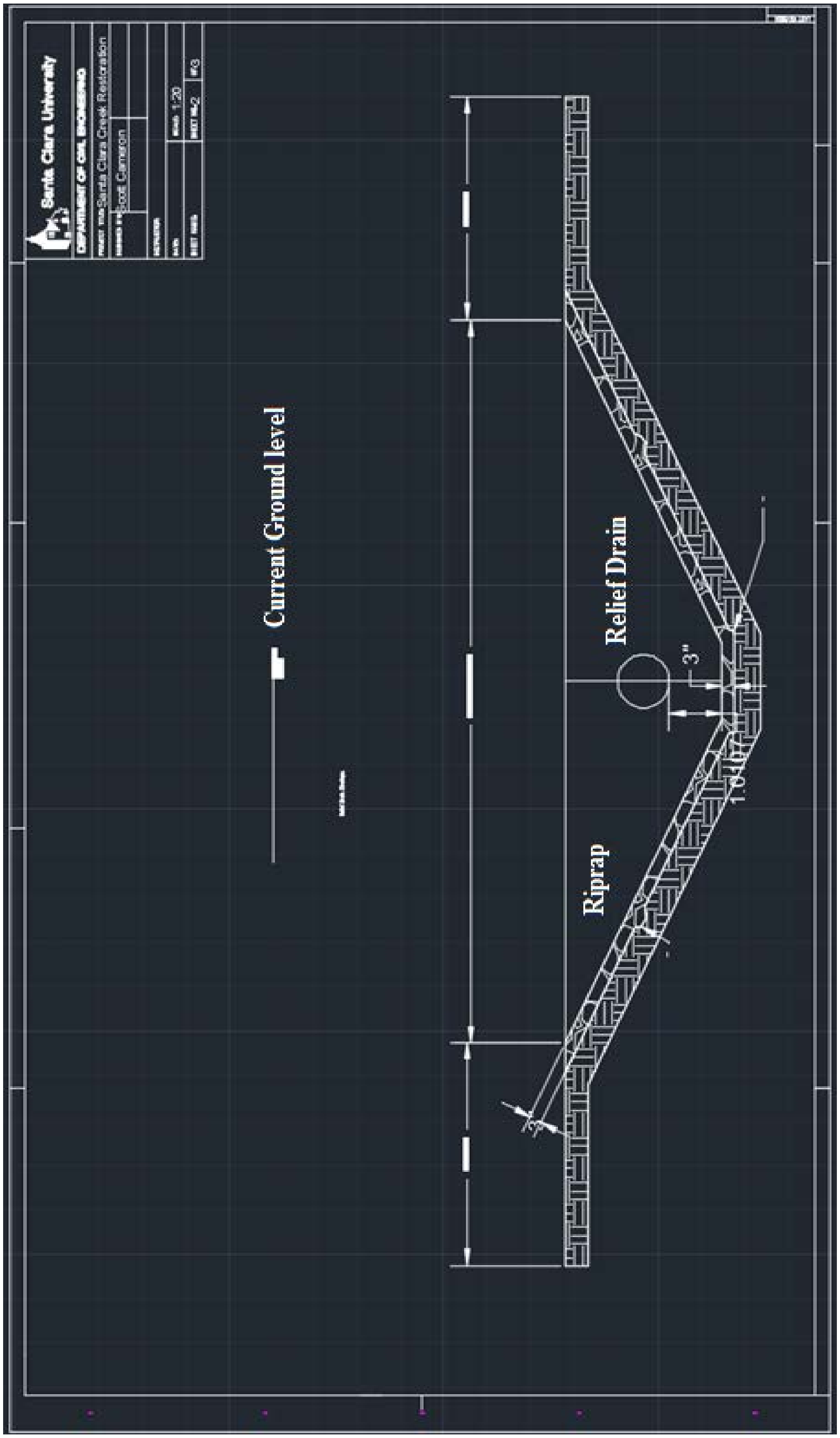


Figure A2 - 1:20 scale stream cross-section, showing current ground level and water table.

Appendix B

Arcmap Runoff Analysis Views

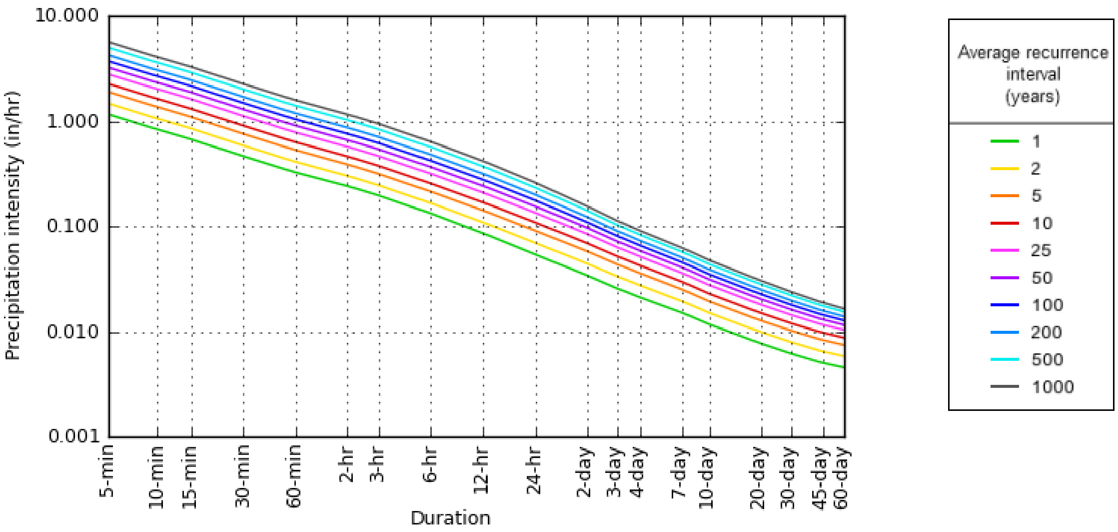
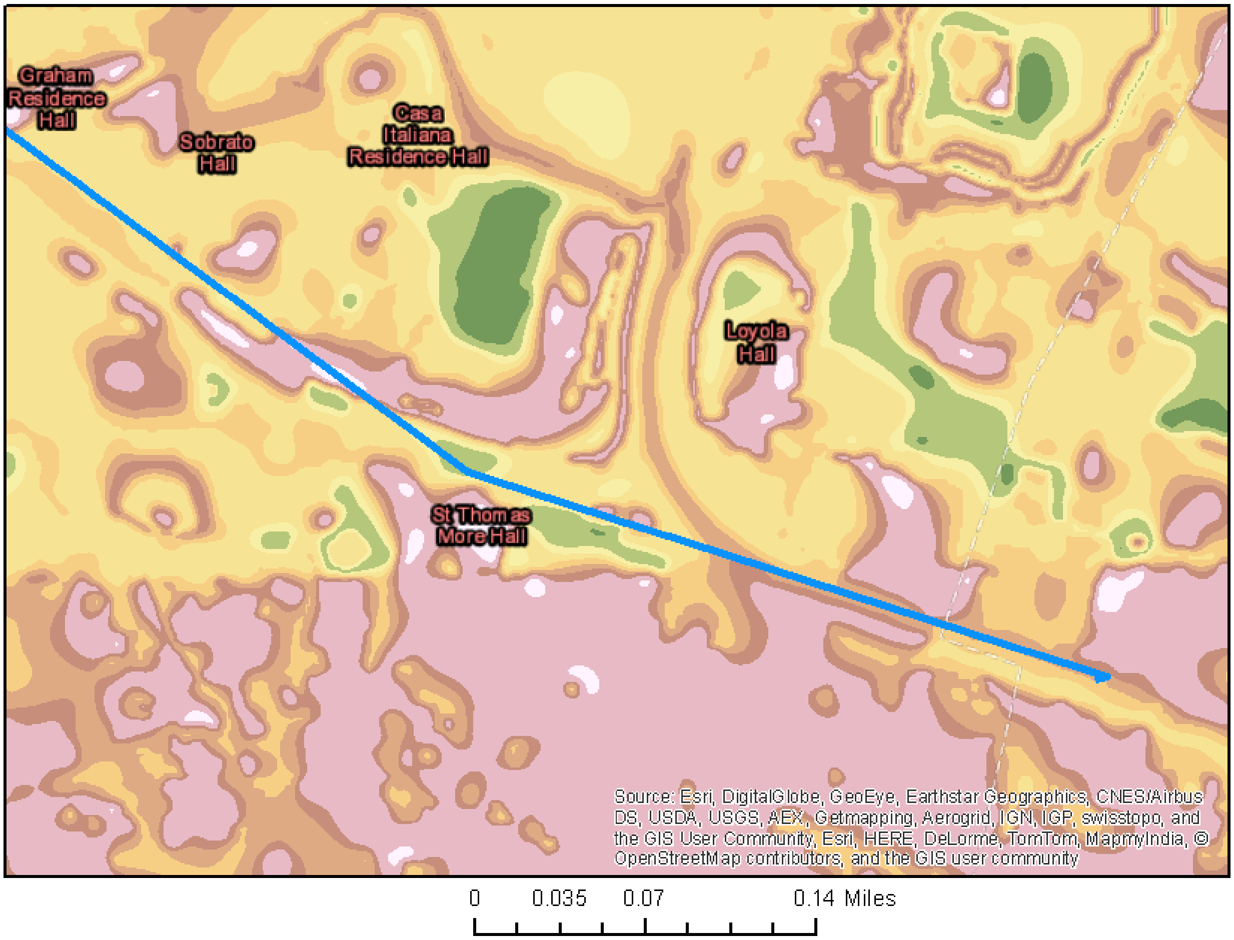


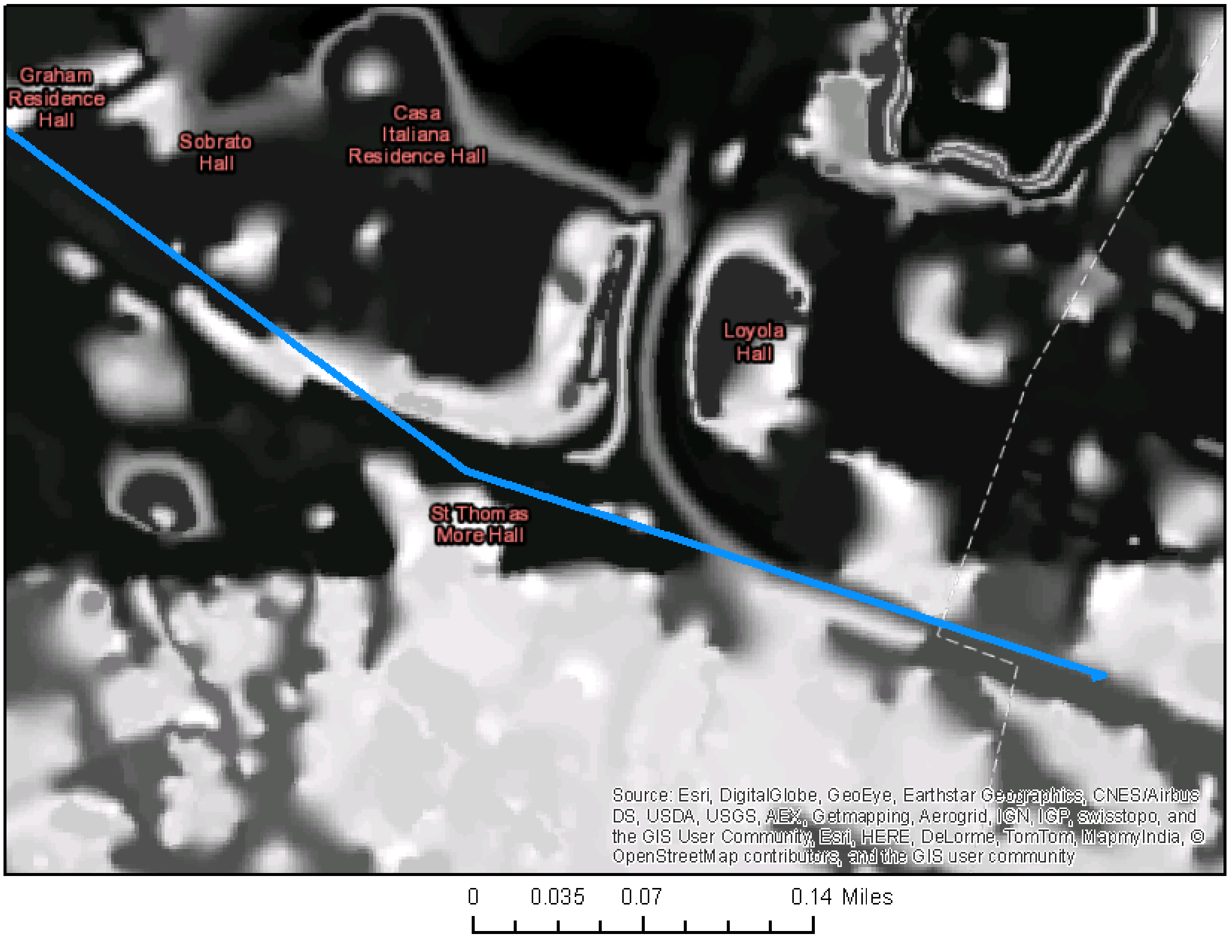
Figure B1 - Hydrometeorolgical precipitation frequency estimate chart. [NOAA]

Figure B2 - Raw imported Lidar data in ArcGIS.



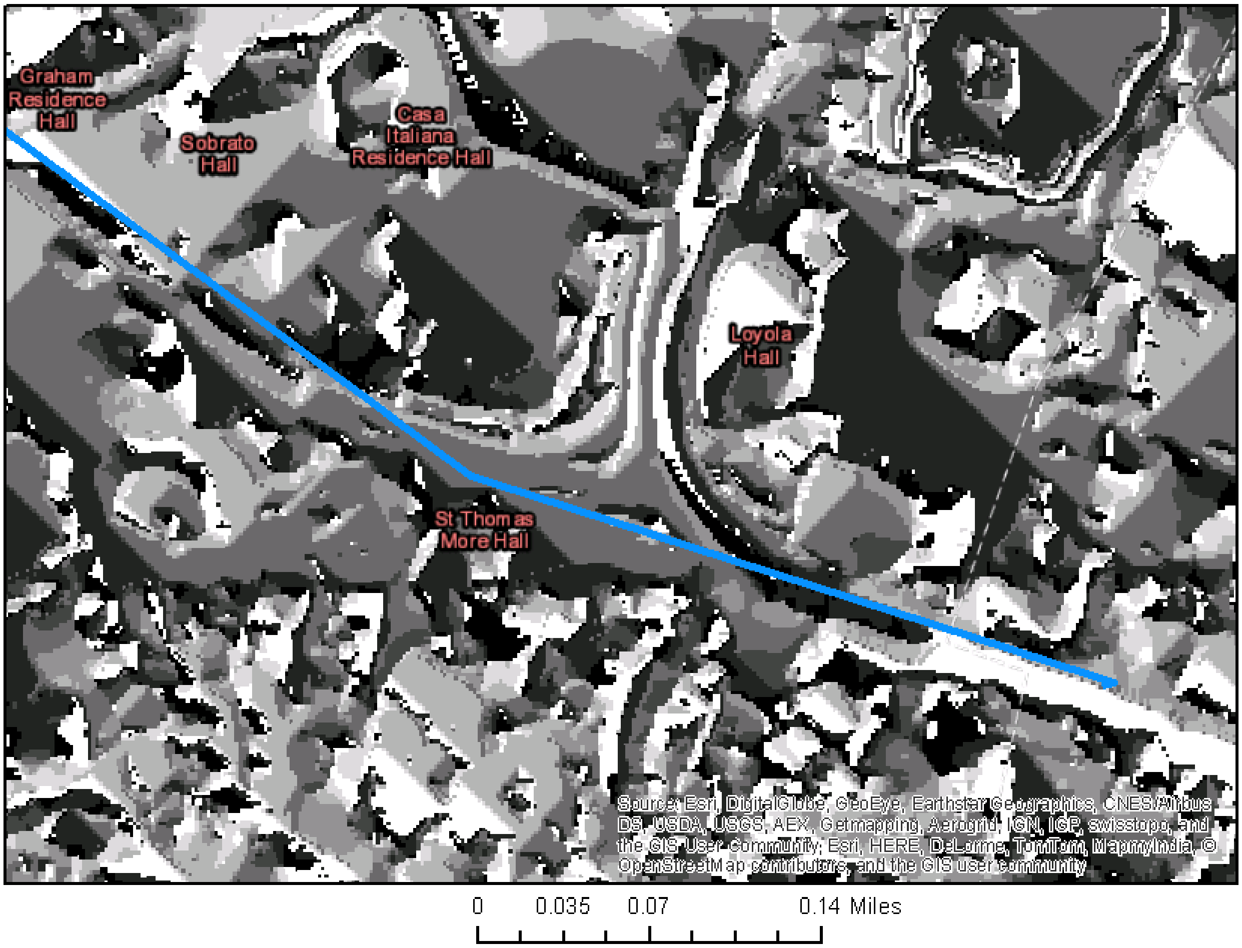
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure B3 - Topographical map, transformed from imported Lidar data in ArcGIS.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure B4 - Fill map created from transformed topographical rendering in ArcGIS.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community; Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure B5 - Map of rendered flow direction from transformed fill map in ArcGIS.

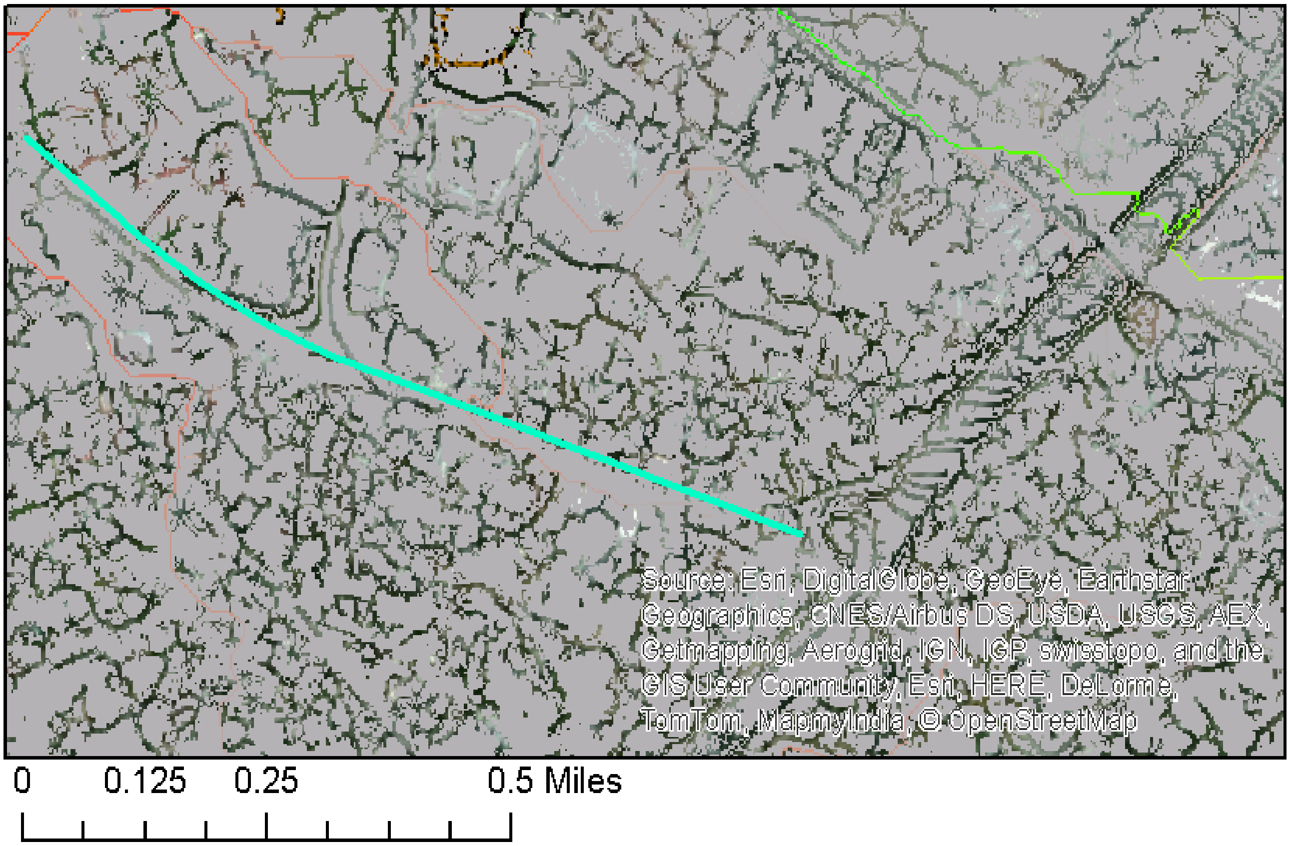
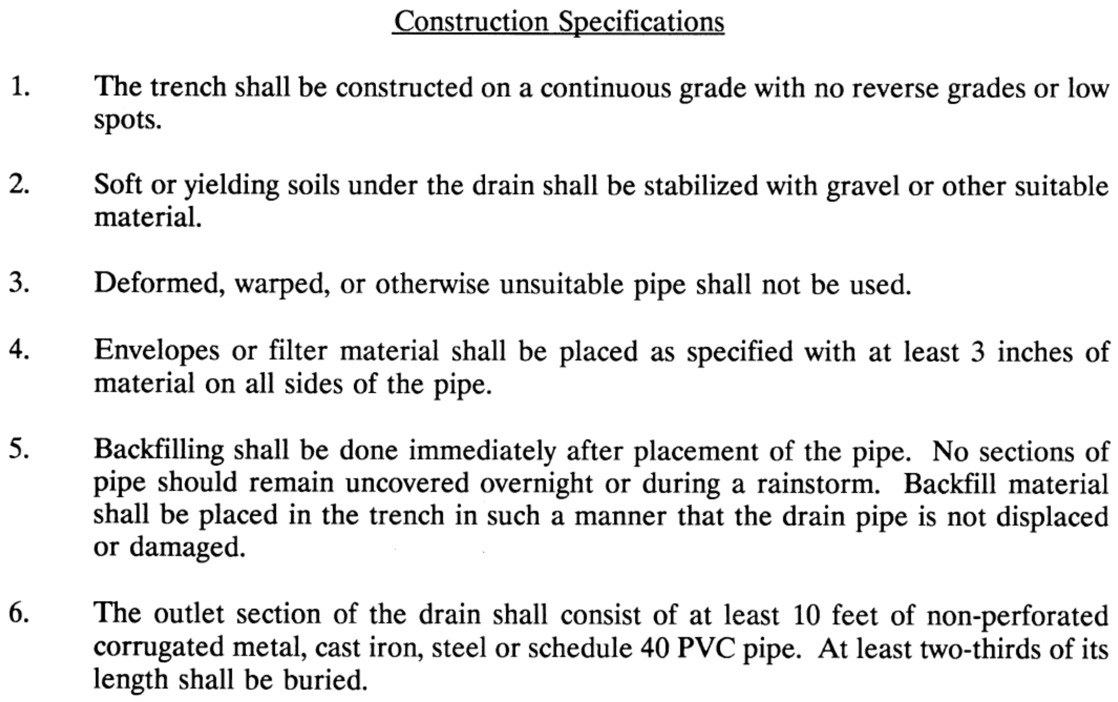


Figure B6 - Visual rendering of flow area accumulation in ArcGIS

Appendix C

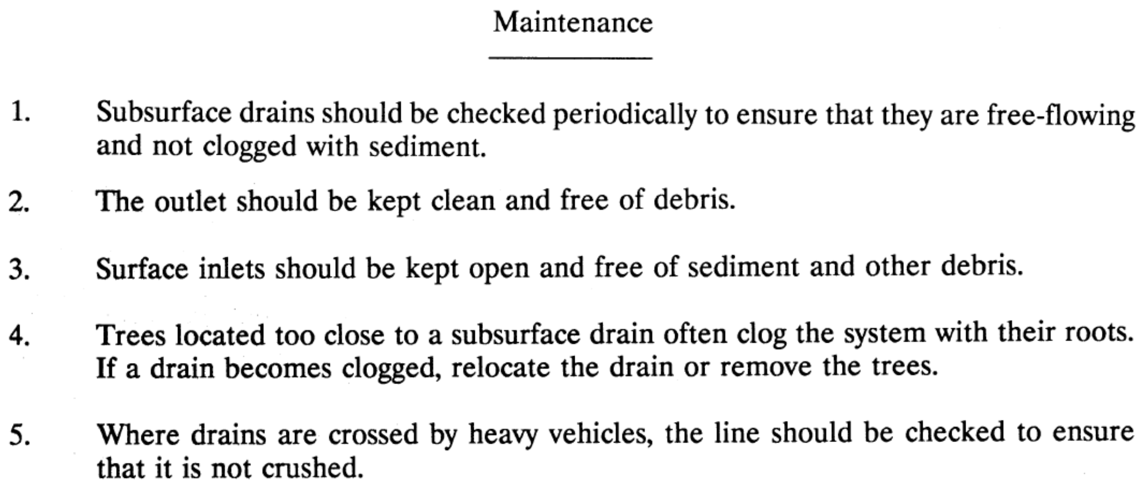
Relief Drain Specifications



Construction Specifications

1. The trench shall be constructed on a continuous grade with no reverse grades or low spots.
2. Soft or yielding soils under the drain shall be stabilized with gravel or other suitable material.
3. Deformed, warped, or otherwise unsuitable pipe shall not be used.
4. Envelopes or filter material shall be placed as specified with at least 3 inches of material on all sides of the pipe.
5. Backfilling shall be done immediately after placement of the pipe. No sections of pipe should remain uncovered overnight or during a rainstorm. Backfill material shall be placed in the trench in such a manner that the drain pipe is not displaced or damaged.
6. The outlet section of the drain shall consist of at least 10 feet of non-perforated corrugated metal, cast iron, steel or schedule 40 PVC pipe. At least two-thirds of its length shall be buried.

Figure C1 – Relief drain construction specifications. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]



Maintenance

1. Subsurface drains should be checked periodically to ensure that they are free-flowing and not clogged with sediment.
2. The outlet should be kept clean and free of debris.
3. Surface inlets should be kept open and free of sediment and other debris.
4. Trees located too close to a subsurface drain often clog the system with their roots. If a drain becomes clogged, relocate the drain or remove the trees.
5. Where drains are crossed by heavy vehicles, the line should be checked to ensure that it is not crushed.

Figure C2 – Relief drain maintenance specifications. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

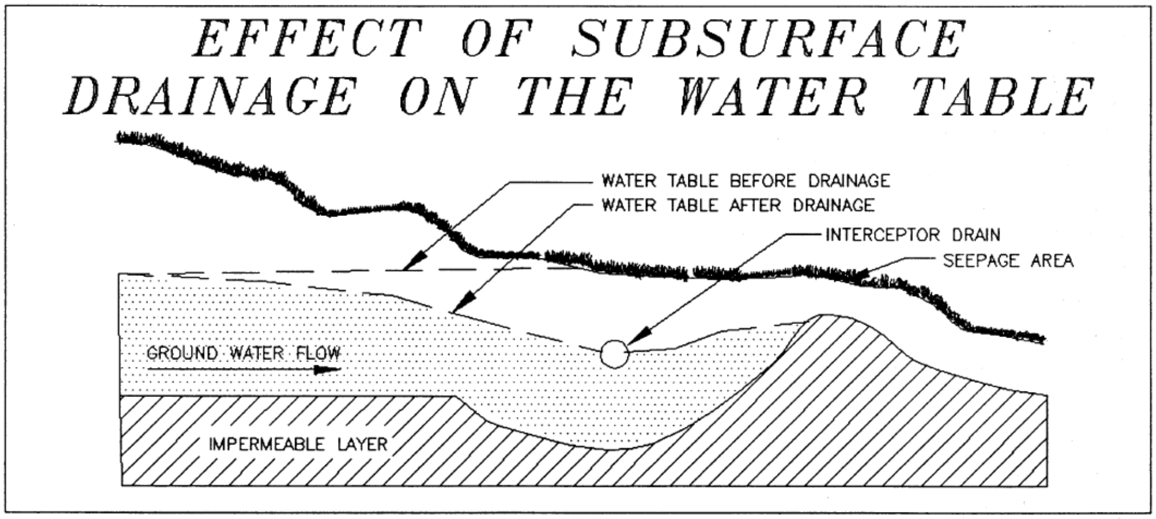


Figure C3 – Relief drain water table effects. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

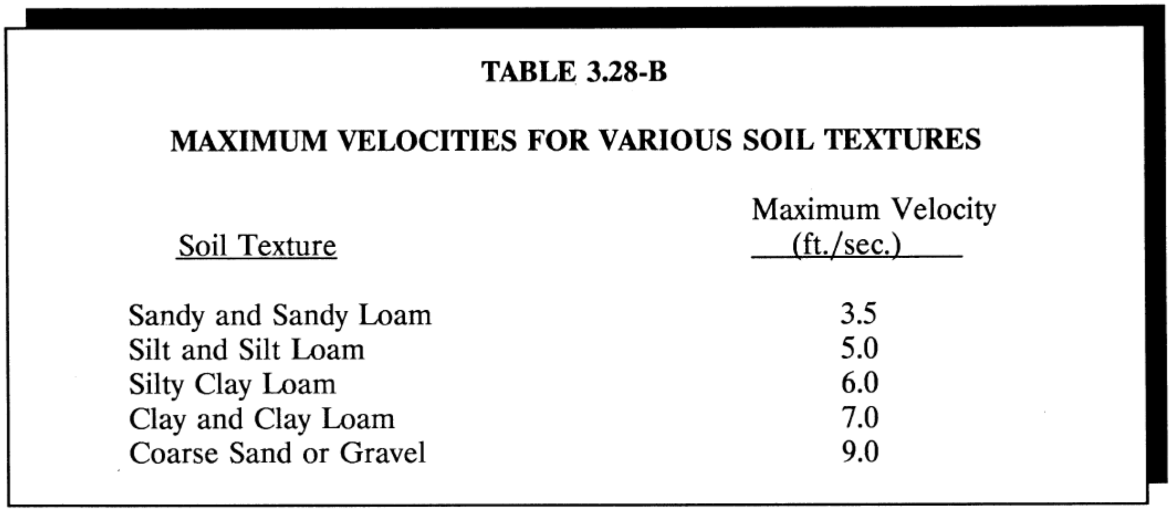


TABLE 3.28-B

MAXIMUM VELOCITIES FOR VARIOUS SOIL TEXTURES

Soil Texture	Maximum Velocity (ft./sec.)
Sandy and Sandy Loam	3.5
Silt and Silt Loam	5.0
Silty Clay Loam	6.0
Clay and Clay Loam	7.0
Coarse Sand or Gravel	9.0

Figure C4 – Maximum relief drain deliverable velocities. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

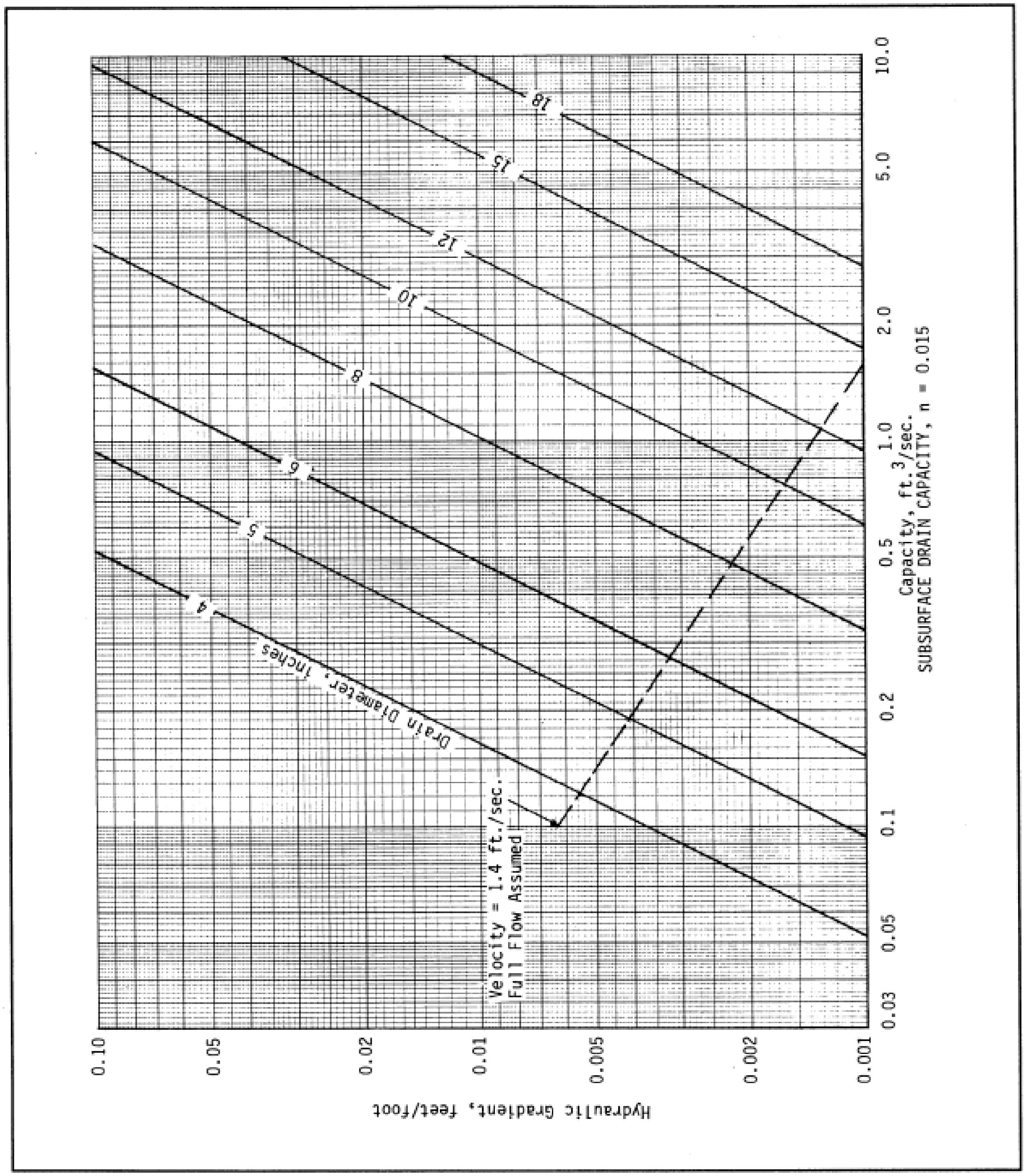


Figure C5 - Graph plotting capacity flow rate as a function of hydraulic gradient and diameter. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

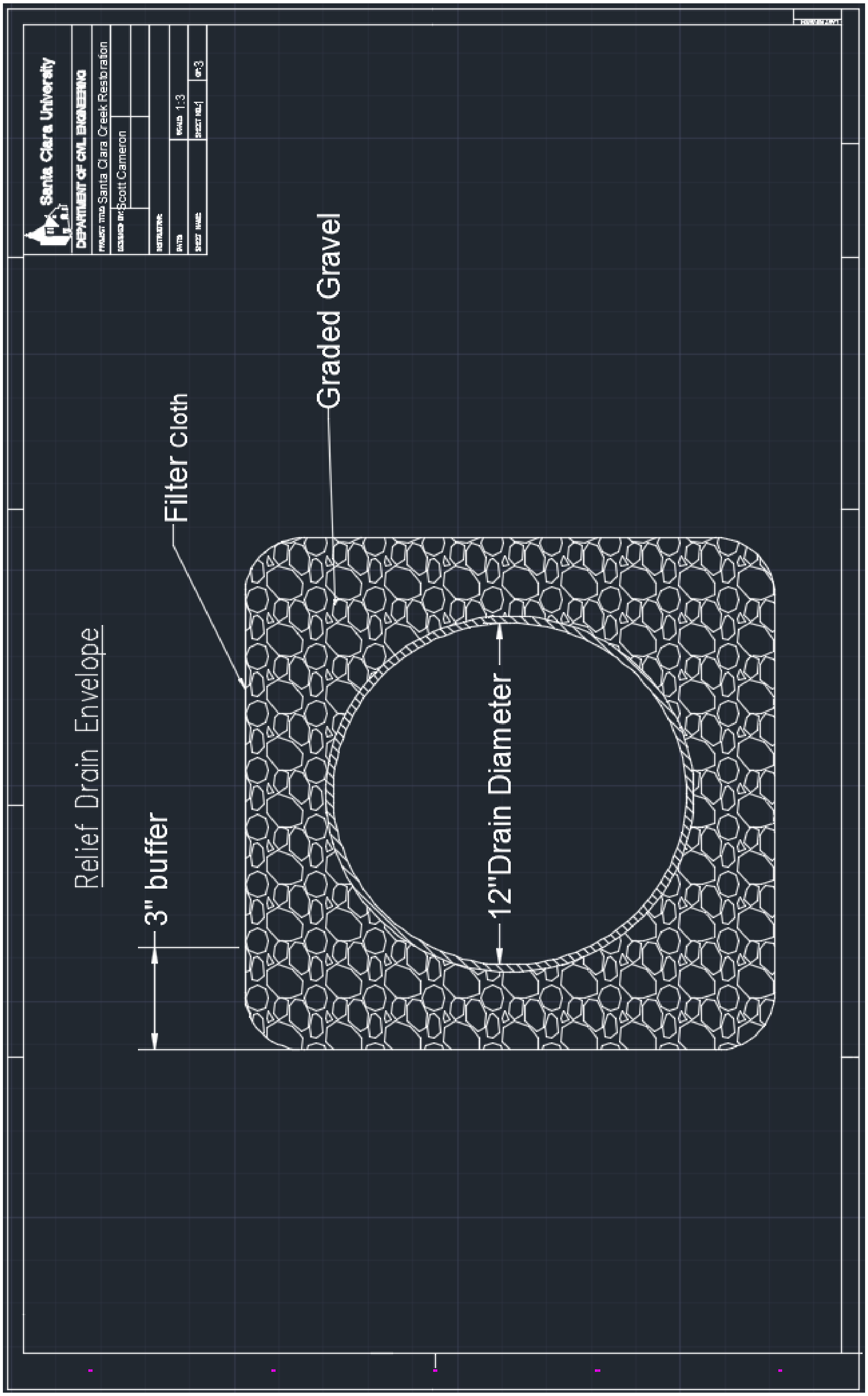


Figure C6 – Autocad rendering of relief drain used in this project.

Appendix D

Channel Stability Analysis

Permissible Unit Shear Stress as a Function of Particle Size

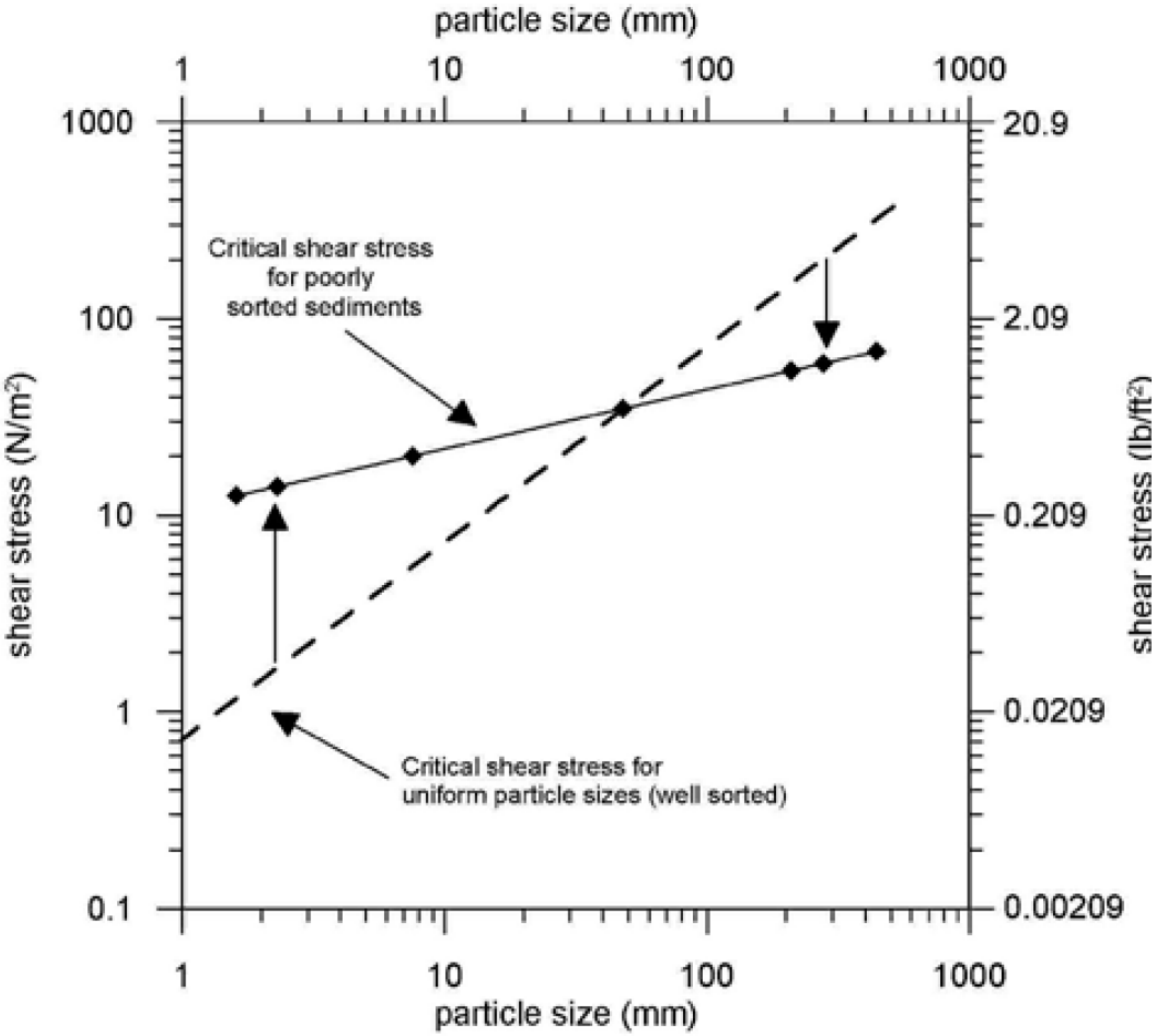


Figure D1 – Metric Empirical Graph Plotting Allowable Shear Stress for Channel Lining vs Particle Size at Average Riprap Unit Weight. [USDA, Methods for Streambed Mobility and Stability Analysis]

This figure utilizes reference particle size (D_{50}) to make a determinable shear stress to ensure stream stability. The following equation was used to find this critical shear stress used in the above graph.

τ_{ci} = critical shear stress at which the sediment particle of interest begins to move (lb /ft^2)

$\tau_{D50} = 0.054$ from figure D2

$D_{50} =$ Median particle size

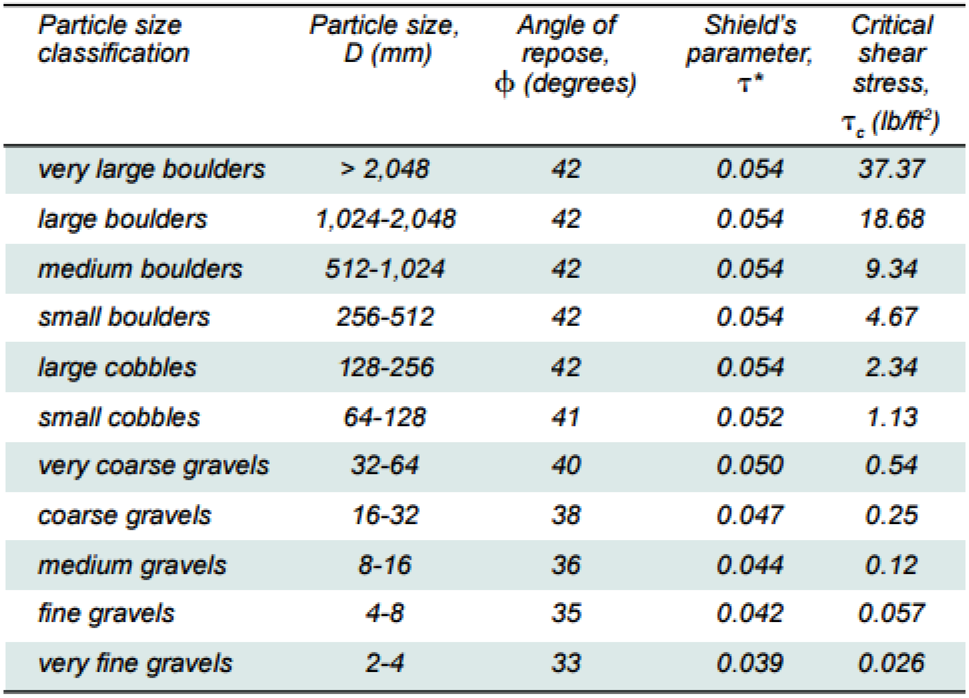
$D_i =$ diameter of particle size of interest

$\gamma_s = 165\ \mathrm{lb/ft^3}$

$\gamma = 62.4\mathrm{lb/ft^3}$

[**Equation D1**]

$$\tau_{ci} = \tau_{D50}(\gamma_s - \gamma)D_i^{0.3}D_{50}^{0.7} = 4.155$$



Particle size classification	*Particle size, D (mm)*	*Angle of repose, ϕ (degrees)*	*Shield's parameter, τ**	*Critical shear stress, τ_c (lb/ft²)*
very large boulders	*> 2,048*	*42*	*0.054*	*37.37*
large boulders	*1,024-2,048*	*42*	*0.054*	*18.68*
medium boulders	*512-1,024*	*42*	*0.054*	*9.34*
small boulders	*256-512*	*42*	*0.054*	*4.67*
large cobbles	*128-256*	*42*	*0.054*	*2.34*
small cobbles	*64-128*	*41*	*0.052*	*1.13*
very coarse gravels	*32-64*	*40*	*0.050*	*0.54*
coarse gravels	*16-32*	*38*	*0.047*	*0.25*
medium gravels	*8-16*	*36*	*0.044*	*0.12*
fine gravels	*4-8*	*35*	*0.042*	*0.057*
very fine gravels	*2-4*	*33*	*0.039*	*0.026*

Figure D2 – Shield’s parameter for different particle sizes. [USDA, Methods for Streambed Mobility and Stability Analysis]

Permissible Channel Velocity as a Function of Particle Size

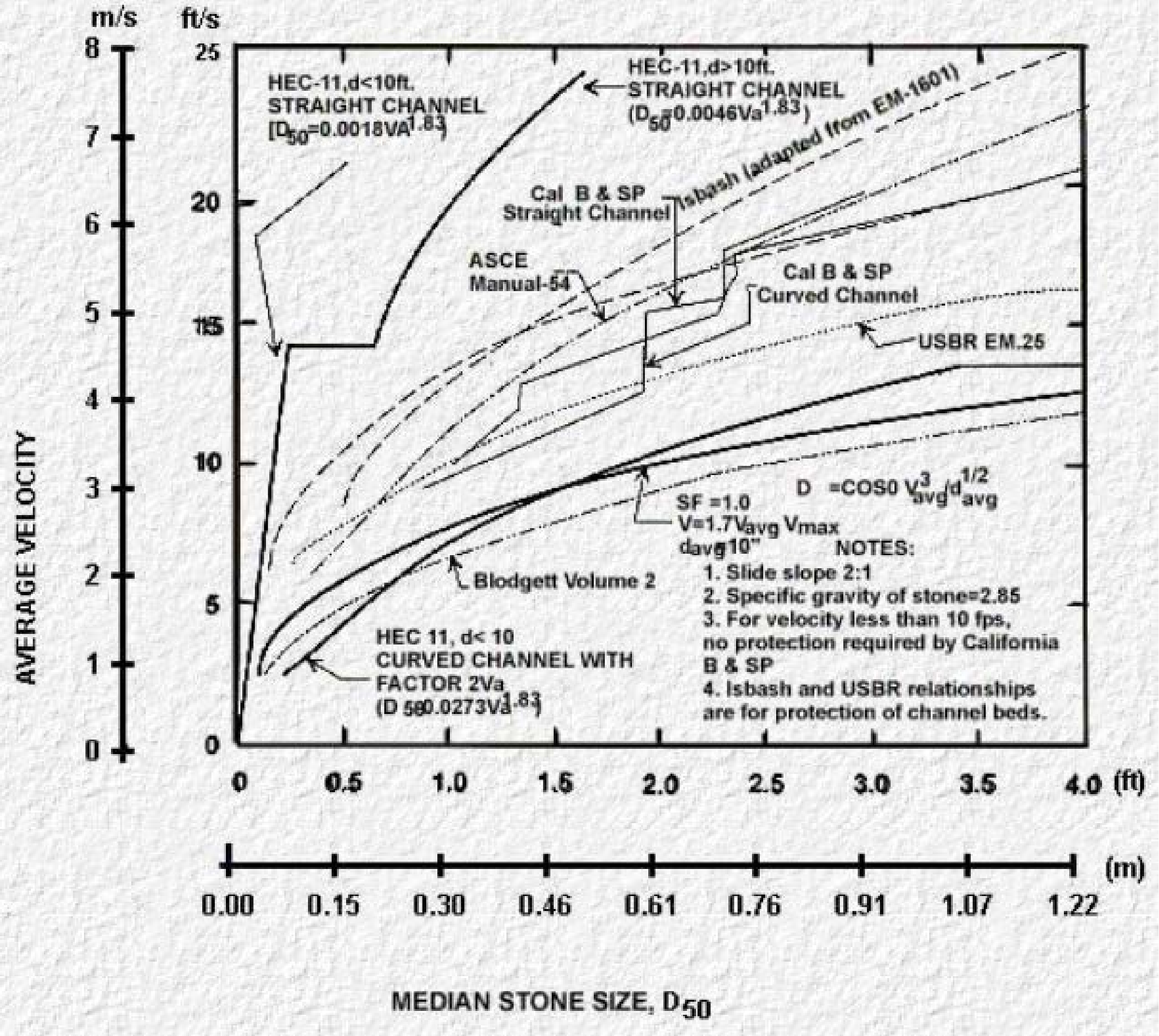


Figure D3 – Comparison of Procedures for Estimating Stone Size on Channel Bank Based on Permissible Velocities. [Federal Highway Administration, Design of Riprap Revetment]

The above figure shows permissible channel velocity as a function of Median riprap size. The channel we are using counts as a straight channel by HEC-11 with a diameter greater than 10ft, therefor the maximum permissible velocity for 6-12’’ riprap is 14 ft/s.

Appendix E

Alternative Design

1:1 Channel Design

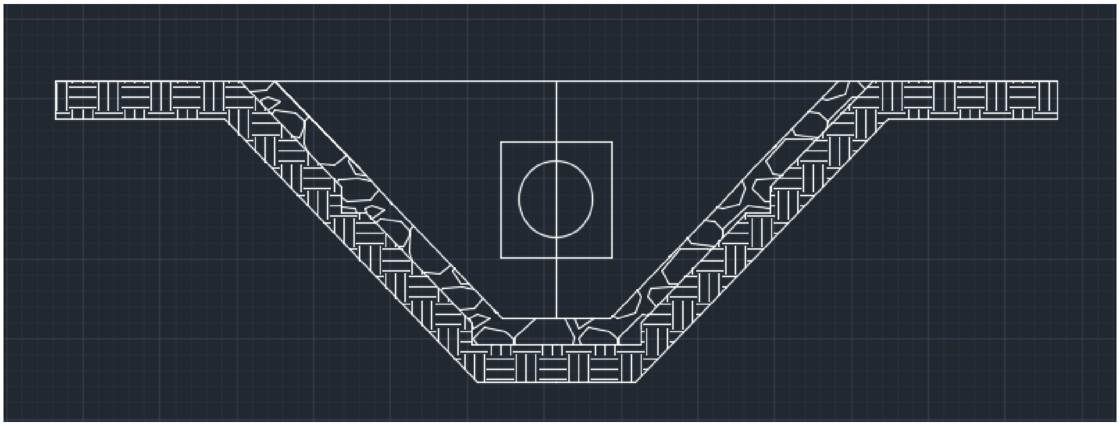


Figure D1 - Autocad rendering of channel cross section with 1:1 side slope.

This design utilized a 1:1 side slope Z and was intended to reduce the width of the channel and increase the water depth. However, this design change would have made a rip-rap channel nearly impossible to stabilize and would have necessitated a concrete channel. Further, this design would have created a safety hazard, as this channel would be far more difficult to climb out of.

Earthen Channel Design

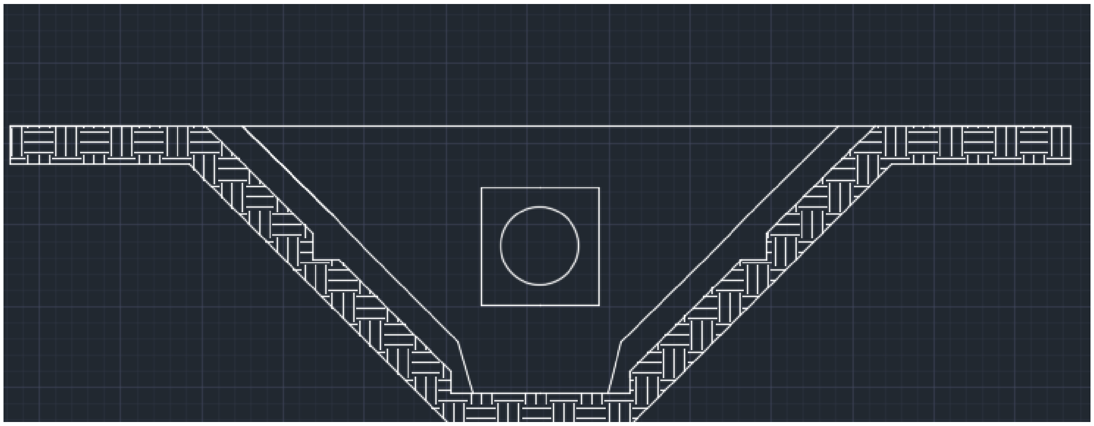


Figure E2 - Autocad rendering of channel cross section with earthen channel and 1:1 side slope.

The above design was considered to enable a greater degree of infiltration along the length of the channel. This, however would have significantly altered manning’s number and therefor the velocity of flow within the channel. Another design that consisted of an entirely earthen channel altered slope to maintain a minimal flow was considered, but this raised concerns over long-term channel stability.

Alternative Tributary

One design considered was the restoration of the center channel that is modeled in the following image. This channel also appear in Figure 1 from the main portion of the report. This channel was considered because it is better documented than the channel that was eventually chosen and it resided in an area that, now, would make restoration far simpler. It was ultimately decided against in the final scope of work as the intention of the project was to restore a channel that was as close to the University as possible, and this channel resided one quarter mile from the University at its closest point.

Figure E3 - Map of present city of Santa Clara overlaid with previously known historical tributaries. [Map generated in Arc GIS 10.1, data courtesy of SFEI 2011, provided by ESRI]

Relief Drain Flood Plain Array

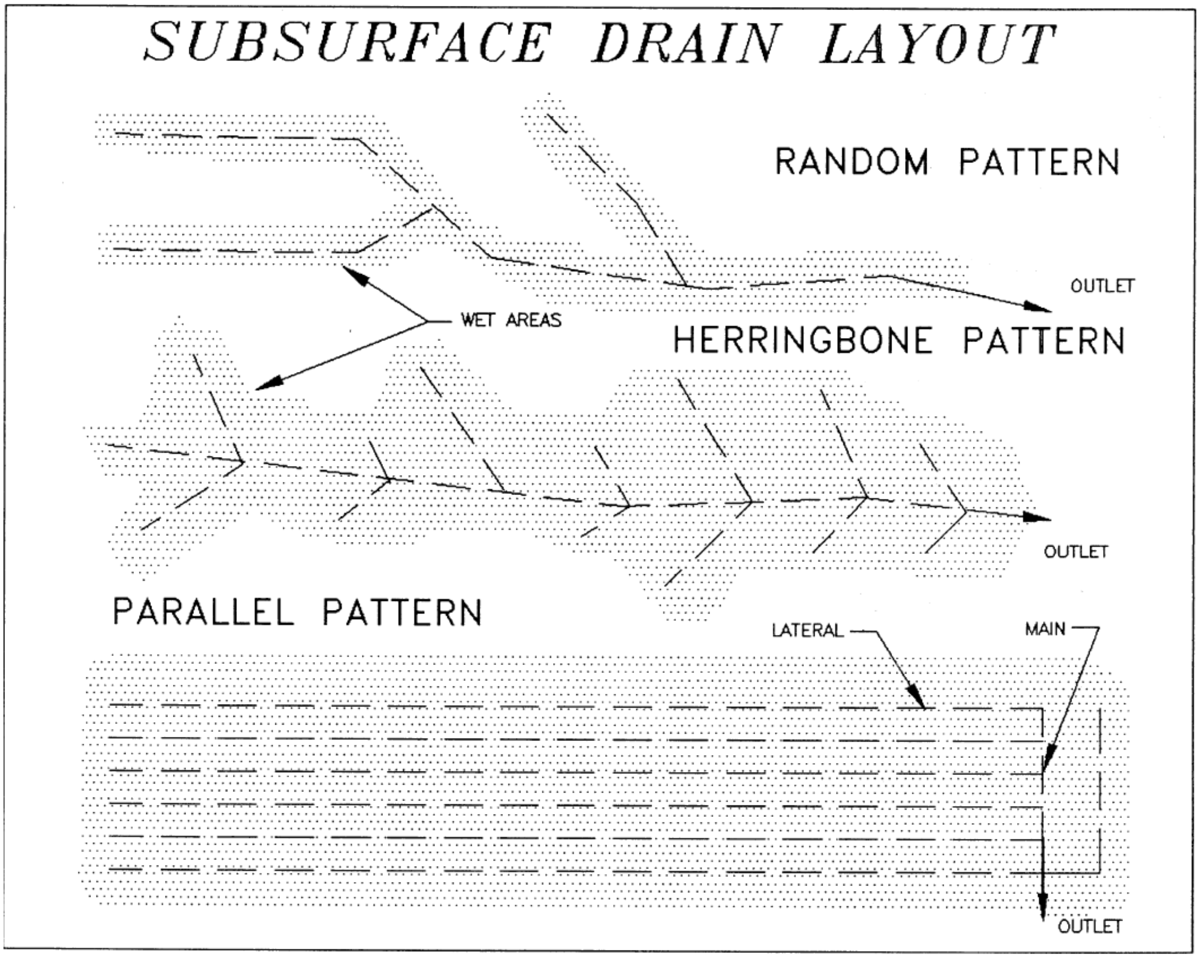


Figure E4 – Typical Relief drain layout. [Virginia Department of Soil Water Conservation, USDA-SCS, 1992]

Relief drains are typically used in the American Southeast as a way to prevent flooding fields from ruining crops through infiltration and oversaturation. They are typically arrayed at 500-1000 foot intervals, draining to a shared larger pipe and out into a basin of sorts, as can be seen in the figure above. It was considered that such an arrangement might allow for double or even triple low flow conditions, which are admittedly low. However, the nature of the region necessitated a conservative usage of space as a result of the clustered business and residential district that surrounds the design area, as well as the fact that the addition of more relief drains would exponentially increase the cost of construction. If such a design were to be implemented, it would better suit the alternative tributary restoration outlined above, placed behind the Santa Clara train station.

Rainfall Triangulation Modified Precipitation Estimate Method

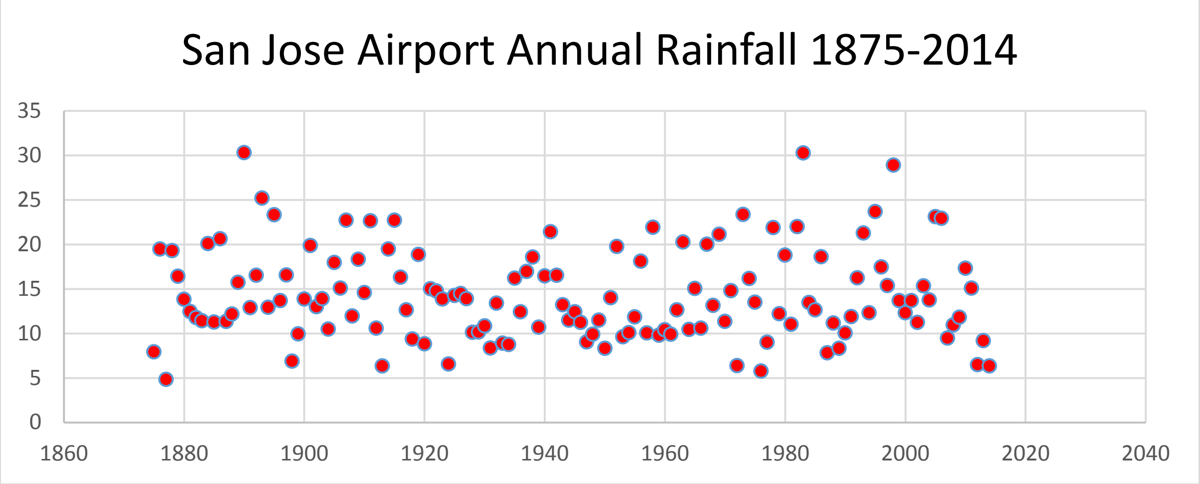


Figure E5 - Annual rainfall in inches for San Jose Airport and surrounding areas (in vs. year), 1875-2014 [Courtesy of SCVWD]

Rather than utilize the NOOA predictions, a modified rational method utilizing three rainfall gages surrounding the location of the stream was initially attempted. The most recent recorded precipitation from the gages: 1527 Vasona RF 125, 1453 San Jose RF 131, and 1511 West Yard RF 108 were compiled and modified with a constant of 2.5 that was derived by comparing the difference of most recent rainfall compared to the average over the 139 years of the San Jose RF 131, as seen in the graph above. This method, despite being highly nonstandard and less accurate, yielded a value nearly half of what was estimated by NOAA.