Master Plan

A road map for reconstruction, management, and long-term maintenance

Santa Clara River

Washington County, Utah

September 2005

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Submitted to:
Washington County Water Conservancy District
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SECTION 1: INTRODUCTION

PROJECT DESCRIPTION/OBJECTIVES

A large flood event occurred on the Santa Clara and Virgin Rivers in January 2005 (Figure 1-1). These floods caused considerable damage to property and infrastructure. While flooding was a problem for areas along both rivers, the primary damage was the result of large lateral erosion that resulted in the loss of homes, roads, utility infrastructure, and private lands. Damage was most severe along the Santa Clara River in the communities of Gunlock, Santa Clara, and St. George. Although the January 2005 floods were very powerful hydrologic studies suggest that larger flood events can be expected in the future. In response to this community emergency, the county and city governments combined resources to prepare this Master Plan for the region.

The study objectives are to:

1) Assist in the assessment, planning and prioritization of geomorphic and engineering strategies in coordination with NRCS and other technical agencies to assist in the effective and timely implementation of flood repair and stream bank stabilization along the Santa Clara River and
2) Develop a Master Plan that will assist city and county governments in managing development, guide additional stabilization, and provide long-term maintenance along the Santa Clara River in order to minimize risk of lateral erosion, flooding, and property damage from future floods.

The primary goal of the Master Plan is to minimize the risk of flooding and bank erosion along the Santa Clara and Virgin Rivers. Aesthetics, reestablishment of riparian vegetation, and wildlife habitat are additional goals of the project. The Master Plan recommends specific protocols for the reestablishment of stream channel, floodplain, and terrace features; revegetation of the riparian areas for stability and wildlife; address appropriate future land use along the rivers; and recommend a long-term maintenance program to ensure project objectives are achieved.

This is not a formal FEMA study to establish regulation of the 100-year floodplain. The Master Plan is primarily concerned with the risk of loss of property due to bank erosion. A separate FEMA study to determine post-flood 100-year floodplain boundaries will be conducted separately. The Master Plan is based on the premise that floods of greater magnitudes will occur in the future and local governments and landowners should be prepared.

The Master Plan extends along the Santa Clara River from its confluence with Magotsu Creek/Moody Wash to the confluence with the Virgin River. The plan was prepared by Natural Channel Design, Inc., J. E. Fuller Hydrology and Geomorphology, and Rosenberg Associates under contract with the Washington County Water Conservancy District. Project sponsors in include Washington County, cities of Santa Clara and St. George, Washington County Water Conservancy District, and Virgin River Resource Management and Recovery Program.

STUDY APPROACH

This study uses an empirical approach to understanding the physical and biological elements of the Santa Clara and Virgin River systems. Sometimes called the geomorphic approach, the study examines the dimension, pattern, and profile of relatively stable stream reaches to identify mechanisms for instability and stable channel parameters. Because virtually every channel section was altered to some extent during the recent floods, survey data collected regionally in other streams throughout the region is also used to establish stable, reference information.

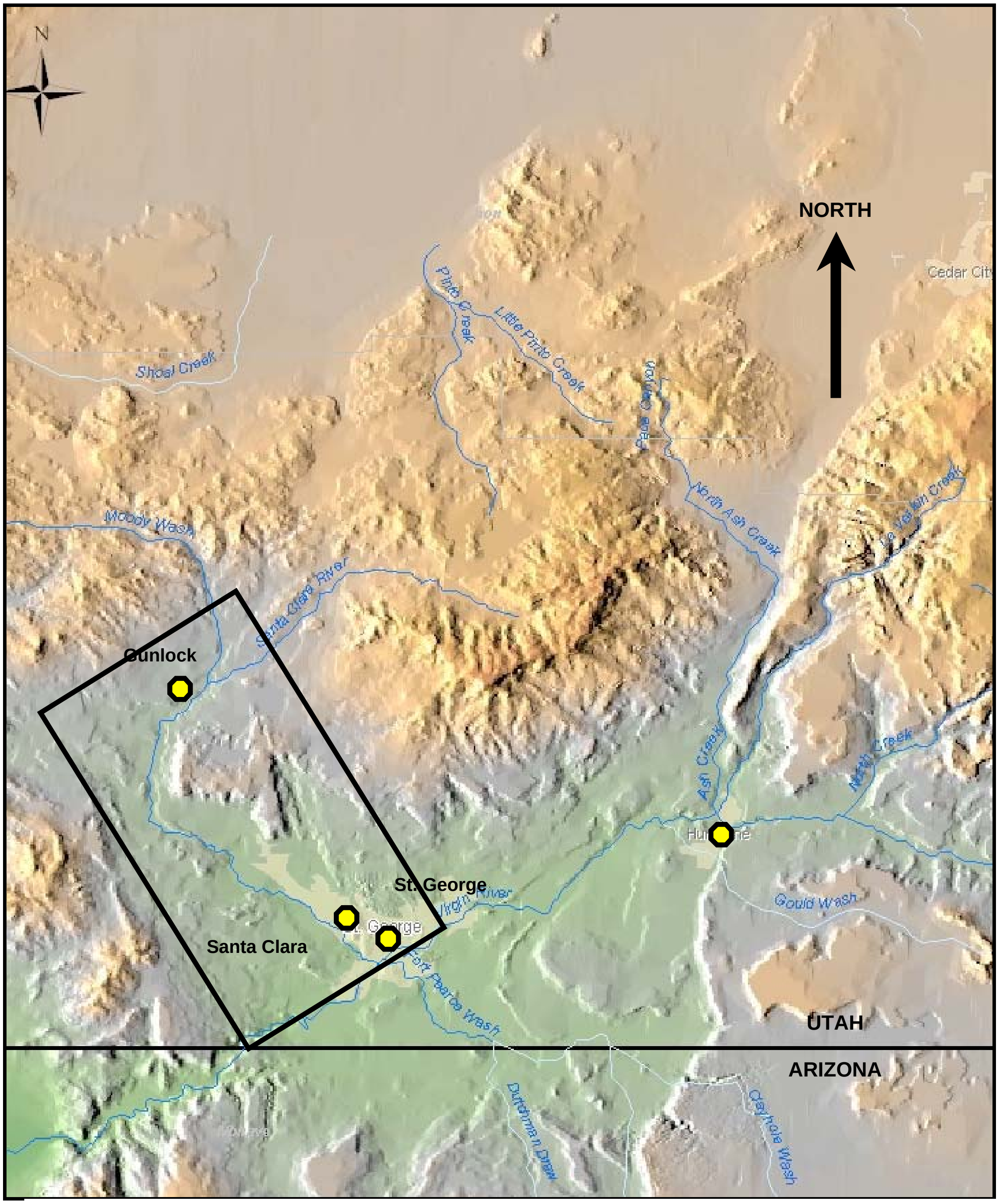


Figure 1-1. Location Map. Santa Clara and Virgin Rivers in SW Utah.

For this study, a number of post-flood cross-sections were surveyed in stream reaches that received relatively moderate erosion. These surveys were compared with pre-flood cross-sections to develop an understanding of pre-flood conditions. Pre- and post-flood photos were evaluated to understand the effects of the flooding and the causes of the damage. From this information channel/floodplain/terrace dimension, meander pattern, and vegetation composition were characterized.

It should be clear that the assessment and understanding of any natural system has an inherent level of uncertainly. Large flood events result in erosion and deposition in any alluvial system. The recommendations included in this study should be implemented with the understanding that the measures are designed to minimize rather than eliminate the future risk of flooding and erosion.

HOW TO USE THIS REPORT

The master plan is designed to provide guidance to city and county government officials and staff as well as private landowners in the restoration of the Santa Clara River. The information within the plan should provide a road map to reconstructing lands within the river corridor. The report is divided into the following sections:

SECTION 1: INTRODUCTION
SECTION 2: ASSESSMENT
Introduction/Geomorphic Assessment:

- Provides background information on the project area, technical assessment, and development of Master Plan recommendations.

SECTION 3: RECOMMENDATIONS
Guiding Principles:

- This section describes the general guiding principles for restoration or rehabilitation of the river corridor. Topics include physical features, revegetation strategies, bank stabilization, appropriate land uses, and maintenance efforts.

Channel Reconstruction/revegetation Practices:

- Specific recommendations for channel-floodplain-terraces reconstruction, bank stabilization, revegetation, and maintenance.

Bank Stabilization – Bioengineering/structural Practices:

- Specific recommendations for removal of exotic species and revegetation of the Santa Clara River for long-term stability.

SECTION 4: REACH MAPS/RECOMMENDATIONS
SECTION 5: IMPLEMENTATION
This section describes the tasks and timelines to successfully implement the Master Plan.

This manual provides guidance for private and public landowners in the short- and long-term reconstruction and restoration of the Santa Clara and Virgin Rivers. However, implementation of these recommendations generally requires permitting from the Army Corps of Engineers and the Utah State Engineers Office. Do not initiate any activities within the riparian corridor without notifying these agencies and obtaining necessary permits.

Army Corps of Engineers
Attn: Grady McNure
321 North Mall Drive, Suite L101
St. George, UT 84790
435-986-3979

Utah State Engineers Office
Attn: Chuck Williamson
1594 W. North Temple, Suite 220
Salt Lake City, UT 84114
801-538-7467

FREQUENTLY ASKED QUESTIONS

What does the Master Plan contain?
The Master Plan should be considered a "road map" to restoring and maintaining stream stability along the Santa Clara River. It should be understood that all stream channels are dynamic, changing with large and small flow events. Erosion and deposition will continue along the river, the objective of the Master Plan is to minimize the potential for large bank erosion.

Minimization of erosion implies stabilization while not going to the extent (except where necessary) to harden streambanks. This plan preserves physical and biological stream processes while preserving wildlife habitats,maintaining aesthetics, and protecting life and property.

Does the Master Plan delineate the 100-year floodplain?
No, the Master Plan is to minimize the potential for large lateral erosion during future flood events. A separate study is underway to delineate the regulatory 100-year floodplain.

Do I need any regulatory permits to work on the river?
Yes. Any significant work within the river corridor, especially by mechanical means requires permitting from the Utah State Engineers Office, the Army Corps of Engineers, and/or the local city/county agencies. However, the Master Plan is intended to streamline this process significantly. Always check with these entities before beginning activities.

Can I improve wildlife habitat while protecting my property.
Yes. The reestablishment of native vegetation as described in the Master Plan will create a continuous corridor of riparian habitat to benefit wildlife.

When is the best time to implement the Master Plan on my property?
Construction activities should be implemented during periods when water levels are low, there is a minimum risk of high flows, and that mimimizes disturbance to aquatic and riparian wildlife. In addition, bare pole plantings of willow and cottonwood are much more successful if planted during the dormant season. For these reasons, late fall and winter are the recommended work periods.

Will the NRCS dikes protect my property from all floods and erosion?
The NRCS dikes were designed and constructed to protect properties from floods equal to the magnitude of the January 2005 floods. While there was considerable property damage from that flood, hydrologic analyses suggest higher flood events can be expected. These floods will overtop the dikes, flooding areas above and behind them. However, the dikes are structurally designed to withstand large flood events and should reduce catastrophic lateral bank erosion.

Can I rebuild my home behind the NRCS dikes?
In general the answer is yes. However, there may be specific properties in sections where the width between dikes is very narrow and/or are on the outside of relatively sharp meanders that require additional engineering analyses and protection for the upper banks. A site specific review and analysis should be conducted before rebuilding or reclaiming land behind NRCS dikes.

<u>What should be constructed behind the dikes?</u>

The areas behind dikes should be raised to elevations greater than the dikes tops. Guidelines are included in the Master Plan. Where the areas behind dikes are relatively very large, the amount of fill necessary may be cost prohibitive. In these areas some fill should be added and the areas should be divided into cells to limit the ability of the river to flow uninhibited behind the dikes.

<u>How can I create access to the river between dikes?</u>

The rock dikes present a steep and difficult barrier to the river. However, the dikes should not limit access to the river by local landowners. Stairways made of wood, steel, or ungrouted rock can be used to provide a path to the river. Stairways should not be permanently attached to the dikes and can be cabled to swing away during the infrequent high flow event. However, no concrete or other "hard" structures should be constructed within the dikes. These structures could deflect flows and increase the risk of erosion.

<u>Can I reestablish my agricultural lands in terraces?</u>

Generally the answer is yes. The low and high terrace areas can be used effectively as agricultural fields. These areas will periodically flooded but, with proper vegetation along the banks and on the terraces, erosion potential will be minimized.

<u>How can I protect my property against future bank erosion?</u>

In those areas where no dikes or other structural control, a variety of options are available. In many areas native vegetation and proper channel-floodplain-terrace elevation and dimension will be adequate. In areas where erosion potential is greater, the Master Plan includes a variety of bioengineering and structural options.

<u>How can I make sure saltcedar doesn't become established?</u>

The best strategy for reducing the amount of saltcedar establishment is to plant native riparian plant species. Given an equal start these plants have been successful in out competing saltcedar and other non-native species.

<u>How can I maintain or increase capacity of the river to carry flood flows?</u>

In general the January 2005 floods significantly increased the flow capacity of the Santa Clara River. However, one of the primary mechanisms of large lateral erosion identified in the Master Plan was debris blockage in relatively vegetation choked channels. As a result a long-term maintenance program is recommended to keep a 100-foot wide path clear of large woody (tree species) vegetation along the central channel. The maintenance should initially be completed manually.

SECTION 2: ASSESSMENT

PROJECT AREA

The Master Plan covers approximately 30 miles of the Santa Clara River in southwestern Utah. The project area was divided into 3 sections (Figure 2-1).

Santa Clara River

- Gunlock Section 1 – Confluence of Magotsu Creek/Moody Wash to Gunlock Reservoir – ~8.1 miles
- Shivwitts Section 2 - Gunlock Reservoir to Santa Clara City. - ~14.0 miles
- Santa Clara-St. George Section 3 – Santa Clara City to Virgin River confluence - ~8.4 miles

Several of these areas were further divided into smaller units (reaches) to facilitate assessment and recommendations.

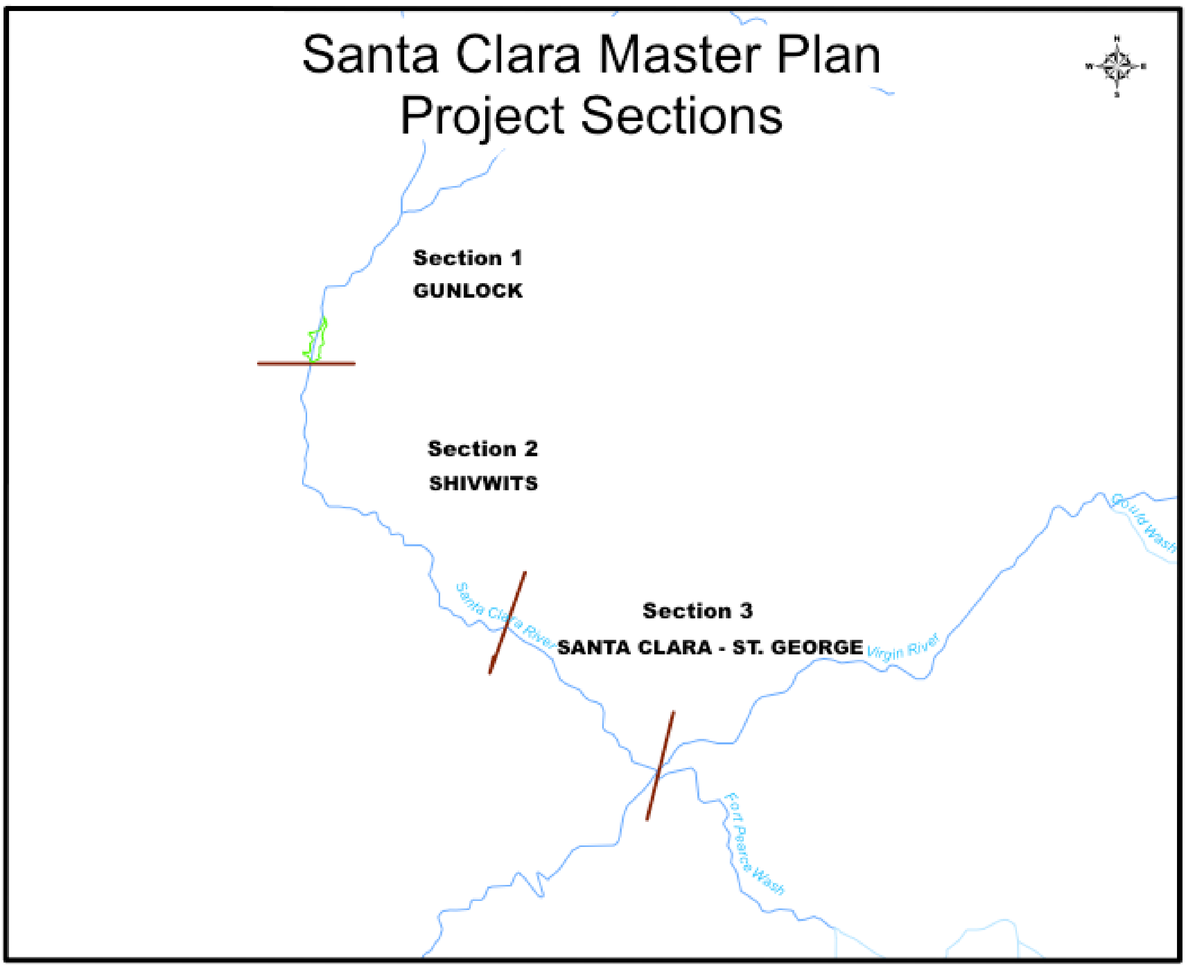


Figure 2-1. Map of Project River Sections along Santa Clara River

BASIN DESCRIPTION

The Santa Clara River is both fed by a large watershed. The catchment area at Gunlock is approximately 270 square miles and at St. George over 500 square miles. Two relatively small reservoirs are located on the Santa Clara, Baker Reservoir (1,160 acre-feet) and Gunlock Reservoir (10,884 acre-feet). These reservoirs are managed to store water for agricultural and domestic uses; not for flood control. As such the reservoirs can be expected to be relatively full during wet periods and provide little relief from extreme flooding. Due to their size, these reservoirs probably have the greatest effect on medium-sized floods that could be expected to periodically scour vegetation and clear channels. Both reservoirs were full and overflowing during the January 2005 floods. There are a number of diversions along the Santa Clara to provide water for agricultural purposes. These diversions primarily affect low flows and are not significant during flood flows.

HYDROLOGY

Flooding is not uncommon on the Santa Clara River. Flood flows are produced by storm events and can occur in any season. Table 2-1 presents annual instantaneous peak flows for stream gages on the Santa Clara River at Gunlock and St. George.

Table 2-1. Annual peak flows; Santa Clara River. Stream gages have not operated continuously on the Santa Clara River.

YEAR	Santa Clara @ Gunlock (cfs)	Santa Clara @ St. George (cfs)	YEAR	Santa Clara @ Gunlock (cfs)	Santa Clara @ St. George (cfs)
1951	*	1270	1977	783	*
1952	*	521	1978	324	*
1953	*	3240	1979	2620	*
1954	*	520	1980	2810	*
1955	*	4200	1981	74	*
1956	*	1070	1982	199	*
1957	*	*	1983	1560	*
1958	*	*	1984	484	160
1959	*	*	1985	47	55
1960	*	*	1986	25	192
1961	*	*	1987	44	1250
1962	*	*	1988	154	990
1963	*	*	1989	56	1740
1964	*	*	1990	174	684
1965	*	*	1991	370	1360
1966	**	**	1992	496	1460
1967	*	*	1993	959	529
1968	*	*	1994	134	6000
1969	*	*	1995	2830	397
1970	73	*	1996	59	4860
1971	183	*	1997	2030	849
1972	335	*	1998	889	346
1973	902	*	1999	118	471
1974	1360	*	2000	681	217
1975	273	*	2001	200	49
1976	658	*	2002	154	53
			2003	65	*
			2004	1520	*

* No gage in operation. Data not available.
** A large flood was generated from high rain on snow in 1966 but not recorded.

FREQUENCY OF FLOODING

Flood flows are commonly characterized using a flood frequency analysis. This statistical analysis commonly ranks peak annual floods into a probability or recurrence interval. A flood with a 10-year recurrence interval means a flow of this magnitude or greater can be expected to occur approximately every 10 years, or 10 times in 100 years. Another way of looking at it is in terms of probability. A 10-year flood has a 10% chance of occurring every year. A 25-year flood has only a 4% chance of occurring in any one year. Small floods occur frequently and have high probabilities and low recurrence intervals. Larger floods are less frequent and have lower probabilities and higher recurrence intervals. Floods can be generally placed into 4 classes based on their magnitude and probability.

Common floods (1 – 5-year recurrence interval):

These floods have a high probability (20% - 90%) of occurring in any year. These floods have relatively small magnitudes and are considered to be critical in eroding and creating bars, transporting sediment, extending meander, and generally doing morphological work.

Moderate Floods (5 – 20-year recurrence interval):

These floods are less common but larger in magnitude. They have a 5% - 20% probability of occurring in any year. In the southwest these floods can have relatively large flood peaks and can produce significant erosion especially in unstable systems or channels with relatively low stability.

Large Floods (20 - 50-year recurrence interval):

These floods are unusual, having a less than 2% to 5% probability of occurring in any year. But they are very powerful and can be expected to produce significant and unpredictable bank and channel erosion and property damage.

Extreme Floods (50-year or greater recurrence interval):

These “once in a lifetime” events significantly alter channels and floodplains in unpredictable ways and produce enormous property and infrastructure damage especially in urban areas.

Peak discharge estimates (cubic feet per second) for indicated recurrence intervals computed by the United States Geological Survey (USGS) are shown in Table 2-2. The values were calculated using a weighted estimate using two standard methods for determining flow frequencies; regional regression models and flood frequency analysis of the gaging record. The data is provisional and

Table 2-2. Santa Clara Flood Frequencies[1]

	Recurrence Interval (years)					
USGS gage site	2	5	10	25	50	100
Santa Clara @ Gunlock	320	1,010	1,880	3,600	5,410	7,680
Santa Clara @ St. George	640	1,980	3,560	6,540	9,490	13,000

Table 2-3. January 2005 peak flows; Santa Clara & Virgin Rivers

Gage Site	Estimated Peak Flow	Approx. Recurrence Interval
Santa Clara River at Gunlock, UT	~5,200 cfs	~50 years
Santa Clara River at St. George, UT	~6,200 cfs	~25 years
Virgin River at Virgin, UT	~11,800 cfs	~20 years
Virgin River at Bloomington, UT[2]	~21,000 cfs	>25 years

[1]Source: Flood in Virgin River basin, Southwestern Utah, January 9-11, 2005. U.S Geological Survey URL:http://ut.water.usgs.gov/FLOODING/Virgin_flood.html
[2] Short flow record creates uncertainty in infrequent high flood magnitudes estimates.

subject to revision. Peak flows during the January 2005 flood have been estimated by USGS and are presented in Table 2-3.

Based on the classes described above, the Santa Clara River flood flows of January 2005 would be considered “extreme” at Gunlock and “large” at Santa Clara-St. George. The Virgin River flows of January 2005 would be considered “moderate to large” at Virgin and St. George-Bloomington. It should be noted that the stream flow data on the Virgin River at Bloomington, UT is limited and the recurrence interval for infrequent flow events (i.e., 50-year, 100-year floods) may not be accurate. Nevertheless the January 2005 flood was large.

Magnitude or size of a flood is just one variable that contributes to the potential for erosion and flood damage. The duration of the high flow event can have a significant effect on flood damage. The January 2005 flood had two peaks roughly a day apart. Figure 2-2 is a reconstruction of the flood prepared by Washington County Water Conservation District staff. for a total of almost 24 hours. The fact that peak flows on the Virgin roughly coincided with the Santa Clara may have further contributed to the impacts.

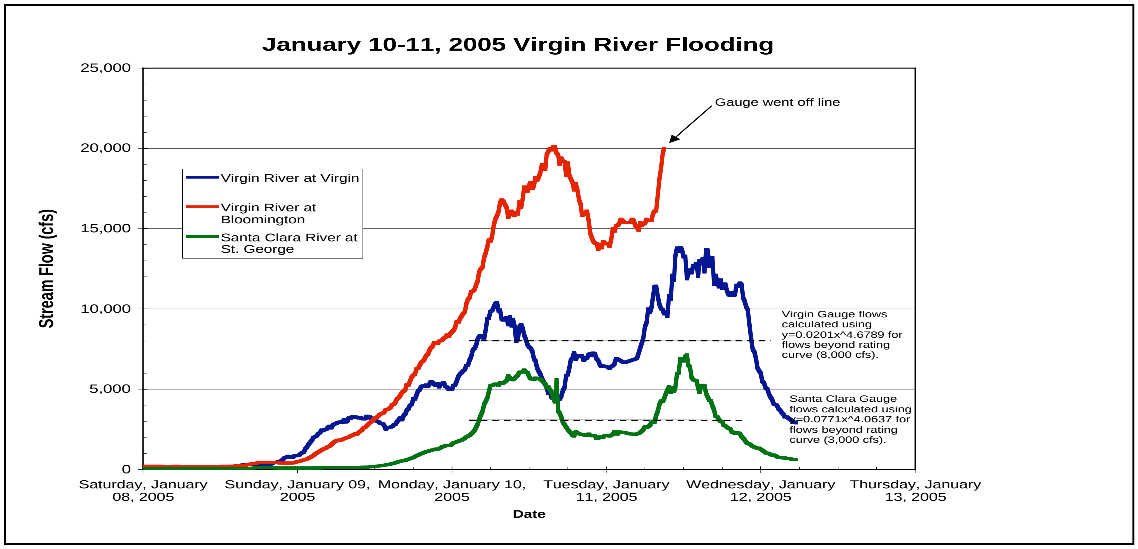


Figure 2-2. Reconstruction of January 2005 flood flows. (Cram, WCWCD)

EFFECTS OF UPSTREAM REGULATION

Baker and Gunlock Reservoirs collect waters from the Santa Clara River. Like all reservoirs they alter the natural hydrology of the stream system to some extent depending on their size and objectives. Baker and Gunlock are intended to store water rather than provide flood control. As a result they are kept as full as possible. The larger the reservoir the greater the effect on moderating flood flows. Very large reservoirs like Hoover Dam have enough capacity to completely eliminate flood flows. However neither Gunlock or Baker are in this category.

The result is that during wetter periods (when runoff is high and floods more common) these reservoirs are full or nearly full and do not affect downstream flows. This was the case in the 2005 floods. However, during drier periods reservoir levels are more likely to be low and can contain common and moderate flood events. These moderate, frequent flows provide an important service to the stream channel downstream; they scour young vegetation from the central channel. If these flows are reduced, a greater concentration of trees and other woody vegetation grows in a narrow central channel increasing instability during high flow events. This was graphically demonstrated during the January 2005 flood events.

TECHNICAL APPROACH

NATURE OF RIVERS

A stream adjusts its size, slope, and sinuosity to accommodate typical stream flows and to move sediment through the system. Generally speaking, a stream is constantly dissipating energy as it moves downstream. In a low gradient channel, bars, meanders and a broad floodplain are important features for dissipating excess energy. If unable to expend this energy the channel is inherently unstable and prone to lateral and/or vertical erosion, especially during large flow events.

Stream channels are created and maintained by moderate, frequent flood events with return intervals in the range of one to two years (Moody et al 2003). In many gravel bed streams, this flow has been shown to carry the greatest amount of sediment over time (Andrews, 1980) and is considered the stream forming flow, channel maintenance flow or bankfull flow. The stability of any natural channel is dependent on an appropriate dimension, pattern, and profile of the bankfull channel and associated floodplain (Leopold, Wolman, & Miller, 1964). A natural channel approach to design seeks to identify the stable geomorphic dimensions of a channel and incorporate those into designs to meet specific objectives. Closely matching the central tendencies of the natural channel results in a design that works with the existing channel rather than against it. The approach achieves greater success at less maintenance cost.

ROLE OF RIPARIAN VEGETATION

The banks of both the Virgin and Santa Clara Rivers are composed of sandy, easily erodible soils. Bank stability is increased dramatically by the colonization of riparian vegetation. This is especially obvious in the Santa Clara River. A 1997 stability study of the Santa Clara River found little historic meander along the river and attributed it to the stable vegetation (Fuller 1997).

Riparian vegetation provides critical benefits to the physical stream system. Vegetation rooting provides additional strength to erodible banks. Equally important the vegetation increases roughness or resistance to flow along the channel and banks slowing flow velocities and dissipating energy. The species and distribution of vegetation is largely dependent on two critical variables; soil moisture and disturbance. Flooding is the driver for both of these variables. As a result both soil moisture and disturbance are highest closest to the stream channel and decrease laterally moving away and up. Plants adapted to varying degrees of soil moisture and disturbance thrive along zones running parallel to the stream channel.

TECHNICAL ASSESSMENT

The floods of January 2005 produced significant channel change to virtually all project reaches of the Santa Clara and Virgin Rivers. However, changes varied in degree and extent from reach to reach. In general, the Santa Clara River experienced lateral erosion and limited associated flooding.

Channel widening is a predictable result of the high velocities and depths of large flood flows but the extent of lateral erosion was excessive in many places along the Santa Clara River. These areas of excessive erosion were largely focused in areas with substantial human infrastructure resulting in large economic damages. Property losses were greatest in the communities of Gunlock, Santa Clara, and St. George where roads, bridges, agricultural fields, and homes were undercut and/or completely destroyed. Despite the damage, the Santa Clara flood was not an extreme flow event in the communities of Santa Clara and St. George. The 25-year return interval suggests that equal or larger flood events can be expected in the future.

Despite the extent of erosion and damage, not all stream reaches experienced severe erosion or flooding. Within these relatively stable reaches geomorphic change was limited to moderate widening and local scour of alluvium and vegetation. On the Santa Clara River these reaches were identified in areas above Gunlock town and within Santa Clara-St. George boundaries. These reaches were compared to other reaches with greater instability to complete the following tasks.

Geomorphic Assessments

- Identify mechanisms or erosion/flooding
- Identify/survey stable stream reference reaches
- Evaluate regional channel morphology data
- Create channel dimension templates based on evaluations of reference reaches and regional data
- Evaluate velocities and depths of template channel, floodplain, terraces

Recommendations

- Create a set of guiding principles for stream stability to address erosion mechanisms
- Prepare channel template recommendations
- Prepare revegetation strategy recommendations
- Prepare bioengineering bankstability recommendations
- Prepare structural bank stability recommendations
- Prepare recommendations for specific stream reaches
- Develop recommendations for management and long-term maintenance

A combination of field observations, geomorphic surveys, aerial photographs, regional geomorphologic data, anecdotal evidence, and hydraulic analyses will be used complete these tasks.

MECHANISMS OF CHANNEL CHANGE

Virtually all areas of the Santa Clara River experienced morphologic changes including channel widening, scour of vegetation, lateral erosion of floodplains and terraces, local aggradation and degradation, and accumulation of woody debris. Channel widening, predictable during high flow events, is evident throughout the river corridor. However, observations during the flood suggested two additional mechanisms contributed to the extreme erosion along the Santa Clara River (R. Rosenberg, Santa Clara city, J. Sandberg, St. George city, personal communication).

The first is debris blockage, primarily by large woody trees scoured from upstream areas, blocking narrow central channels. Pre-flood channels were often lined with large woody tree species. Once the central channel was dammed, high velocity flows were diverted obliquely against highly erodible bank areas (Figure 2-3). The relatively long duration of the flood produced substantial lateral channel migration and property loss.

The second mechanism was created when overbank flows were separated from the main channel by vegetation, structure or topography (Figure 2-4). The elevated overbank flows reentered the channel downstream forming powerful headcuts when reentering the main channel. The headcuts migrate upstream sustantially widening the channel. The relatively smooth, flat surfaces of agricultural fields adjacent to the stream corridor created conditions for high overbankflow velocities and accelerated these events.

Figure 2-3. Debris blockage. Below Swiss Village the pre-flood stream ran through the dense stands of cottonwood and saltcedar trees. Once the channel was blocked, high velocity flows were diverted against the near bank eroding the erodible agricultural field. The entire area in the lower portion of the photo was eroded during the flood. (Rick Rosenberg photo)

Figure 2-4. Overbank flows. Although the central channel remains open, overbank flows spread across open fields and reenter the river several hundred feet downstream. The elevation change at the reentry point creates a headcut that erodes the fields on one or both sides of the channel.
(Rick Rosenberg photo)

GEOMORPHIC ASSESSMENTS

FIELD VISITS

Field visits were made to all sections of the project reach immediately following the flood event and again a month following the event. The entire length of stream channel was walked in areas of critical concern (Gunlock, Santa Clara, St. George cities). Bank composition, existing and scoured vegetation composition/distribution, debris blockages, channel & floodplain width/elevations, and general observations were recorded during these visits.

AERIAL PHOTOGRAPHS:

Washington County commissioned aerial photographs of the project area immediately after the January 2005 flood event. These photographs were compared with pre-flood aerials (2002) to assess changes in channel alignment, channel widening, meander patterns, pre-and post-flood vegetation composition and distribution, and extreme channel avulsion.

GEOMORPHIC SURVEYS (PRE- & POST-FLOOD):

Field observations, aerial photos, and anecdotal evidence were used to identify stable reaches along the Santa Clara River in the Gunlock and Santa Clara/St. George sections. Although channel widening, local scour and deposition, and vegetation removal were common in these reaches, lateral channel movement was limited to the existing riparian corridor and little property was lost.

Surveys of channel morphology were completed at 17 sites within these stable reaches (Figure 2-5). A set of three cross-sections were surveyed at each site from the extent of flooding on each bank. Alluvial features (channel, floodplain, and terraces) were identified. Longitudinal profiles were created at each site to evaluate channel slope and elevation. Pre-flood topographic maps were used to create unaltered cross-sections and profiles to assess changes. Because no stable reaches were located in the town of Gunlock, a separate longitudinal profile was surveyed to evaluate channel elevation change.

Alluvial channels are constructed of distinct physical features.

- Channel: a central, active, or bankfull channel that carries moderate flows and transports bedload sediments;
- Geomorphic floodplain: an adjacent level surface created by the river in the current climate and inundated by moderate, frequent flood events. For this study, the vertical extent of this feature is twice maximum channel (bankfull) depth;
- Low Terrace: this feature extends to an elevation above the floodplain and is flooded less frequently. For this study, this feature extends to an elevation 3 times maximum channel (bankfull) depth; and
- High Terrace: this feature is rarely inundated and vegetated with a mixture of obligate and facultative riparian species. For this study, this feature extends to an elevation 4 times maximum channel (bankfull) depth.

Channel bed elevations; channel width and cross-sectional area; floodplain/terrace widths; and depth/lateral extent of the 2005 flooding were evaluated at each site and summarized in Tables 2-4, 2-5, 2-6 & 2-7.

Table 2-4. Summary of Gunlock Surveys

- Channel flowline elevation remained relatively stable through the flood. The exceptions were local incisions of 3-4 feet immediately below major tributaries.
- Pre-flood central channel averaged 54 feet in width. Floodplains averaged 86 feet, low terraces 140 feet, and high terraces 165 feet.
- Erosion and scour widened channels at virtually all cross-sections, a common result of large floods. Widening was greatest at the channel and floodplain elevations with increases of 50% and 17% respectively. Terrace widths increased only slightly or not at all.
- The stage of the January 2005 flood waters ranged from 6 – 9 feet in depth and extended laterally 85 - 200 feet in width.

Table 2-5. Pre- & Post Flood Channel data; Gunlock Reach

			Widths (feet)							
			Channel		Floodplain		Low Terrace		High Terrace	
			Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Set 1	-	XS 2	24	59	34	71	78	84	100	102
Set 2	-	XS 2	38	73	86	80	104	103	124	112
Set 3	-	XS 2	75	75	90	100	133	115		120
Set 3	-	XS 3	60	90	105	128		161		
Set 4	-	XS 1	60	95	90	120	150	195	206	201
Set 4		XS 4	66	91	113	107	230	230	233	237
		min	24	59	34	71	78	84	100	102
		max	75	95	113	128	230	230	233	237
		Average	**53.8**	**80.5**	**86.3**	**101.0**	**139.0**	**148.0**	**165.8**	**154.4**
		% change		**50%**		**17%**		**6%**		**-7%**

Table 2-6. Summary of Santa Clara/St. George Surveys

- Channel flowline elevation remained relatively stable through the flood. The exceptions were incisions of 5-6 feet in the area immediately above Swiss Village in upper Santa Clara city. This incision may have been resulted from high velocity flows through the narrow channel at Swiss Village. No similar downcutting was recorded in downstream survey sites.
- Pre-flood central channel averaged ~44 feet in width. Floodplains averaged 70 feet, low terraces 215 feet, and high terraces 350 feet.
- Erosion and scour widened channels at virtually all cross-sections, a common result of large floods. Widening was greatest at the channel and floodplain elevations with increases of 146% and 98% respectively. Low terrace widths increased only 29% and high terraces remained relatively stable.
- The stage of the January 2005 flood waters ranged from 9 – 12 feet in depth and extended laterally 300 – 500 feet in width.

Table 2-7. Survey data; Santa Clara/St. George Reach

		Widths (feet)							
		Channel		Floodplain		Low Terrace		High Terrace	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Set 3 -	XS 2	62	76.5	142	127	348	167	360	193
Set 4 -	XS 2	40	66	70	73	340	78	395	103
Set 5 -	XS 2	42	117	52	123	97	182	126	399
Set 6 -	XS 2	40	180	61	193	130	585	390	645
Set 7 -	XS 1	42	138	58	145	90	811	795	825
Set 8 -	XS 2	38	119	49	143	67	190	130	275
Set 9 -	XS 2	54	80	113	110	245	329	440	441
Set 10 -	XS 2	19	145	35	181	63	190	150	235
Set 11 -	XS 1	24	81	38	90	80	118	150	215
Set 12 -	XS 1	70	95	118	198	185	285	265	348
Set 13 -	XS 2	50	83	38	86	260	195	282	310
Set 14 -	XS 2	50	125	67	195	680	210	705	365
	Minimum	19	66	35	73	63	78	126	103
	Maximum	70	180	142	198	680	811	795	825
	Average	**44.3**	**108.8**	**70.1**	**138.7**	**215.4**	**278.3**	**349.0**	**362.8**
	% change		**146%**		**98%**		**29%**		**4%**

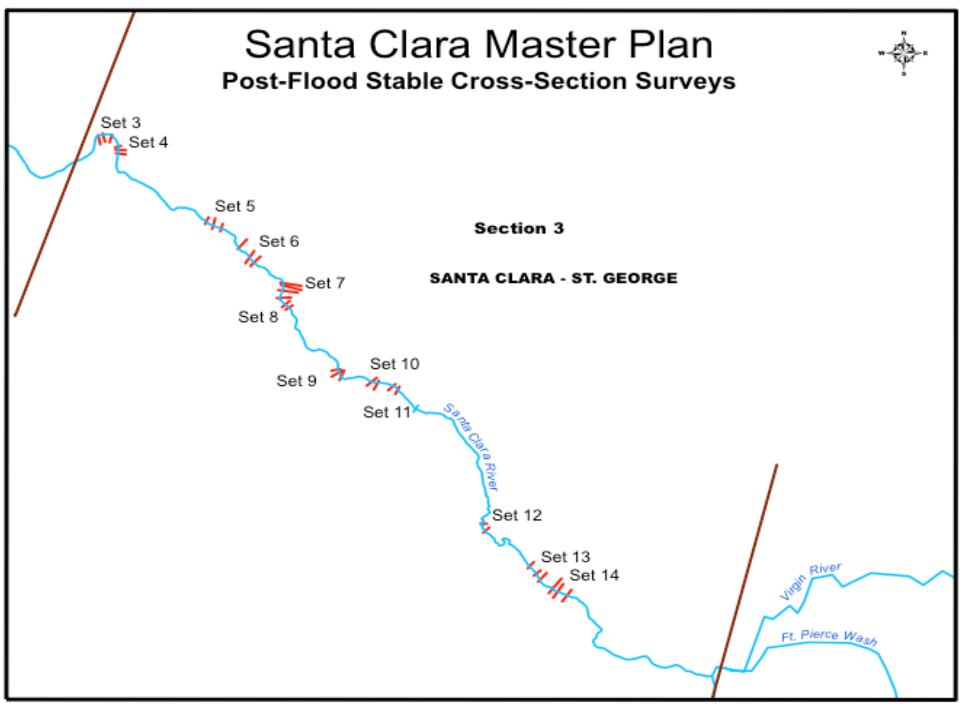


Figure 2-5. Survey sites in Santa Clara-St. George Section. Gunlock survey sites are located upstream of Town of Gunlock.

<u>STABLE REFERENCE REACHES:</u>

To aid in the development of channel/floodplain/terrace recommendations. Field observations, aerial photos, and anecdotal evidence were used to identify stable reaches on the Santa Clara River. Although channel widening, local scour and deposition, and vegetation removal were common in these reaches, lateral channel movement was limited to the existing riparian corridor and little property was lost. In the Gunlock Section, these areas were located above Gunlock town.

Two reference reaches were identified in the Santa Clara-St. George Section. The first is located immediately upstream of Dixie Drive along Rivers Edge Drive (Figure 2-6). A second reference reach was identified along the Gubler property upstream of Tonoquint Park (Figure 2-7). Stream channels widened in both reaches during the flood but floodplain and terrace dimensions remained relatively constant. The stream maintained its pre-flood alignment in both reaches through the flood although most of the pre-flood underbrush in the floodplain and low terraces was removed by the flood waters.

The reaches share several characteristics that contributed to their stability. Stream banks rise in elevation as distances increase away from the central channel increases. The riparian corridors in each reach are relatively consistent in width and well vegetated in both reaches. An evaluation of cross-sections within the reaches surveyed post-flood suggest that the width of flooding ranged from 300 – 400 feet. Corridor width in the Rivers Edge reach averages 380 feet and is dominated by mature cottonwood and willow trees. The Gubler reach averages over 500 feet in width and is dominated by dense tamarisk thickets.

Figure 2-6. Rivers Edge Reference Reach. This reach is located directly upstream of Dixie Drive and is dominated by mature cottonwood, willow, and ash trees. Santa Clara River flows right to left in the post-flood photo.

Figure 2-7. Gubler Reference Reach. Reach is located just upstream from Tonoquint Park. Riparian corridor is dominated by tamarisk thickets. Santa Clara River flows left to right in the post-flood photo.

REGIONAL GEOMORPHIC DATA

Surveys of the pre-flood channels in the Santa Clara and Virgin Rivers were limited to interpolating morphology from topographic maps used in previous FEMA studies. While valuable, the pre-flood data has an inherent level of error. To reinforce these assessments, morphologic data from 41 regional channel sites were also evaluated. These sites represented low-gradient gravel-sand bed channels located in southern Utah. A listing of the site data is presented in Table 2-8.

In order to characterize stream channel morphology, a common reference point must be established. This common reference point provides a consistent, accurate measurement of width, depth and other physical channel, floodplain, and terraces features. The concept of "bankfull stage" was developed by Luna Leopold and others in the USGS to provide this common point. Bankfull stage is defined as the point of incipient flooding or geomorphic floodplain elevation. The geomorphic floodplain is a level area adjacent to the steam, created in the current climate, and overtopped by moderate, frequent flow events. Research in the southwestern U.S. has confimed the ability to consitently and accurately identify bankfull stage in the field and suggests that the feature is commonly overtopped by 1 – 2 year flow events (Moody et al 2003).

The bankfull or active channel below bankfull stage has the primary function of transporting sediment in the fom of bedload. The floodplain and terrace areas above bankfull elevation carry high flows and disappate energy. The systematic measurement of natural stream channels using bankfull stage as a common point has identified a number of useful patterns. One of the strongest is the strong correlation between cross-sectional area of the bankfull channel and watershed area. Figure 2-8 shows a graphic of this correlation using regional morphologic data. Southern Utah sites are clustered along the lower E. Arizona/New Mexico curve. Using this correlation, the size of the pre-flood or natural bankfull channel for the Santa Clara River at Gunlock (65 ft^2) and Santa Clara-St. George (90 ft^2) was estimated.

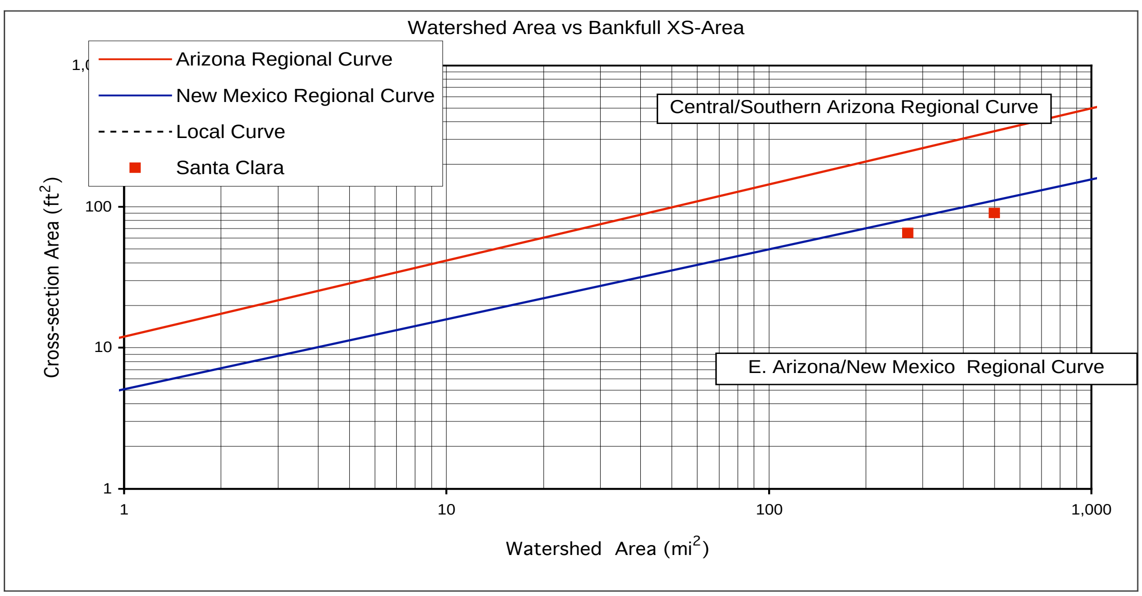


Figure 2-8. Regional Curve for Southern Utah channel sites. Santa Clara River sites at Gunlock and Santa Clara/St. George are represented by the data symbols.

The Natural Channel Classification System (Rosgen 1996) was developed to incorporate the concept of bankfull stage and is widely used by stream practitioners throughout the west. This classification uses several dimensionless morphological parameters to describe the channel and floodplain. These delineative criteria include:

- Width/Depth Ratio: Defined as the channel width at bankfull stage divided by mean depth at the same point. This criteria describes the shape of the channel and the associated sediment transport competence.
- Entrenchment Ratio: Defined as the width of the floodplain (measured at an elevation twice bankfull depth) divided by bankfull channel width. The criteria describes the ability of a channel to spread across an adjacent floodplain surface.
- Sinuosity: Defined as stream length divided by valley length. This criteria describes the relative degree of meander.
- Slope: Defined as the fall in elevation divided by the distance of a stream segment.
- Bed/Bank Materials: The median particle (D50) of the bankfull channel.

Santa Clara River is well-vegetated low-gradient, meandering gravel bed stream with a well-developed floodplain. The stream would be classified as a C4 channel.

The Virgin River is a well-vegeted low-gradient, meandering sand bed stream with a well-developed floodplain. The stream would be classified as a C5 channel.

All regional channel sites (Table 2-7) are low gradient, gravel/sand streams. The mean values for Width/Depth Ratio and Entrenchment Ratio are 26.5 and 2.5 respectively for these channels. Because these values are dimensionless they are not limited by scale.

Table 2-7. Regional Stream Morphology Data

	WS AREA (mi2)	BKF XS AREA (ft2)	BKF WIDTH (ft)	MEAN DEPTH (ft)	W/D RATIO	ENT RATIO	STREA TYPE
Confluence Park Sites							
La Verkin - confluence XS1	95	73	28.0	2.6	11	1.6	B4c
La Verkin - confluence XS2	95	69	22.0	3.1	7	1.7	B4c
La Verkin - confluence XS3	95	75	43.0	1.7	25	1.4	B4c
La Verkin - confluence XS4	95	65	24.0	2.7	9	1.5	B4c
La Verkin - confluence XS5	95	68	38.0	1.8	21	1.6	B4c
La Verkin - confluence XS6	95	71	33.0	2.2	15	1.6	B4c
La Verkin - confluence XS7	95	68	32.0	2.9	11	1.4	B4c
La Verkin - confluence XS8	95	64	25.0	2.6	10	1.5	B4c
Ash Creek-Confluence XS1	85	36	15.0	2.4	6	5.3	C4
Ash Creek-Confluence XS2	85	51	19.0	2.7	7	2.5	C5
Ash Creek-Confluence XS3	85	43	18.0	1.3	14	1.9	B4c
Ash Creek-Confluence XS4	85	49	20.0	2.5	8	1.7	B4c
Ash Crrek							
Ash Creek, Litchfield: XS 1	80	35	25.00	1.4	18	2.2	C4
Ash Creek, Litchfield: XS 2	80	36	17.00	2.1	8	4.7	E4
Ash Creek, Litchfield: XS 3	80	36	33.00	1.1	30	2.4	C4
Ash Creek, Litchfield: XS 4	80	36	33.00	1.1	30	2.4	C4
Ash Creek, Litchfield: XS 5	80	33	23.00	1.4	16	2.2	C4
Grafton Townsite							
At Rockville Lagoons	770	187	56.0	3.3	17	2.9	C4
Electric Fence crossing	780	175	68.0	2.6	26	1.2	F4
Along Hwy Revetment	780	213	72.0	3.0	24	1.3	F5
Above coal pits	780	200	80.0	2.5	32	4.4	C5
Below Bedrock	790	198	74.0	2.7	28	2.2	C4
STA 7525	790	204	100.0	2.0	49	2.0	C5
Above lowest meanders	810	230	110.0	2.1	25	2.3	C5
Virgin River							
Coal Pits Wash	19	20	26.0	0.8	33	1.7	B4c
E. Virgin River @ Mt. Carmel Jct	179	59	50.0	1.2	42	3.0	C6
No. Virgin River @Springdale	344	187	56.0	3.3	17	1.4	B3c
E. Fork Virgin at Shunesburg	340	130	42.0	3.1	14	6.2	C5
Zion Canyon Sites							
North Fork Virgin @ Narrows	290	182	75.0	2.4	31	1.5	B4c
Virgin at Hereford	291	198	70.0	2.8	25	1.4	B4c
Virgin at big bend	291	189	120.0	1.6	76	2.0	C4
Virgin @ Great White Throne	300	199	100.0	2.0	50	2.4	C4
Virgin @ Great White Throne	300	188	75.0	2.5	30	2.0	C4
No. Virgin River @ Grotto Cpgd	320	230	72.0	3.2	23	1.5	B4c
Montezuma Creek							
Horsehead Creek	5	6	10.0	0.6	17	1.5	B4c
So. Creek abv Lloyds Lake	9	12	15.0	0.8	19	3.0	C4
North Creek abv Golf Course	9	9	11.0	0.8	13	1.9	C4
Montezuma Creek blo G.C.	27	12	12.0	1.0	12	2.3	E4
Montezuma Creek blo Millsite	29	14	17.0	0.8	21	2.6	C4
Sevier River nr Panguitch							
XS1	570	144	54.0	2.7	20	3.0	C4
XS2	570	129	54.0	2.4	23	2.8	C4

CONCLUSIONS

CHANNEL TEMPLATES

A set of channel templates were created that describe the widths and depths of alluvial features for Santa Clara River sections. These templates are based on an evaluation of regional channel morphology, hydrology, and surveys of stable stream reaches where erosion was minimized (Table 2-8). The dimensions of channel, floodplain, and terraces are designed to carry the water and sediment of the stream while minimizing velocities and risk of lateral erosion. These channel templates are based on the naturally stable forms for each stream and will be maintained by flows over time as each stream recovers from the January 2005 flooding. They provide the framework to be used to guide all repair, reconstruction, and maintenance projects.

Cross-section templates are divided into 4 areas: central channel, floodplain, low terrace, and high terrace (Figure 2-9). All areas are subject to periodic flooding; the higher areas less frequently than those nearer the channel. The bankfull channels are larger and floodplain-terraces wider in Santa Clara-St. George to accommodate larger flood events.

Every stream channel has 3 primary functions; carry water and sediment of the watershed and dissipate energy. To achieve these functions, distinct physical features are constructed by the stream. These alluvial features are channel, floodplain, and terraces. The width of terraces will be constrained in areas with NRCS dikes on both banks. Alluvial features should be included within these armored reaches to maintain sediment transport and stability created by riparian vegetation.

Channel*:* The stream channel represents the center of the stream. Commonly called active or bankfull channel, this feature carries base flows and moderate, frequent flood events. The primary function of the channel is to successfully transport sediment. In adequate size and shape of the channel can reduce or alter sediment transport and increase instability. In addition the channel experiences the highest flow velocities and depths and transports the greatest portion of sediment through the system. The channel bed is generally coarser, composed of more resistant sands, gravels, or cobbles.

Geomorphic Floodplain*:* The geomorphic floodplain is defined as a level feature adjacent to the stream channel, created by the stream and overtopped by moderate, frequent flow events. The floodplain is flooded annually or every couple of years. Disturbance is naturally high due to the common flooding and the surface is relatively close to ground water ensuring good soil moisture. This low feature should not be confused with the 100-year floodplain identified for regulatory purposes. The channel and floodplain are inundated by common floods and should remain clear of all human activities.

Low and High Terraces**:** Terraces are generally old floodplains abandoned when channel elevations are lowered by erosion. These surfaces can also be created by alluvial bars deposited during high flow events. Terraces and high bars lie at higher elevations. As a result they are flooded less often and have lower levels of disturbance and soil moisture.

- **<u>Low terraces</u>** can be expected to be flooded by moderate floods and can be used for trails and other infrastructure that can withstand periodic flooding and does not interfere with riparian vegetation.
- **<u>High terraces</u>** are flooded by high and extreme floods but can be used for agricultural and recreational uses. However, appropriate roughness should be maintained.

Setback Levees: Levees can be installed to control the width of overbank flooding. However, these levees should be sited outside the high terrace areas.

Areas within NRCS Dikes: Bottom width of NRCS dikes vary from 130 feet to 200 feet. Alluvial features within the dikes correspond to the central channel, floodplain, and low terrace.

Appropriate riparian vegetation is a critical component to the stability of these channel templates. Revegetation recommendations are described in Section 3, Recommendations.

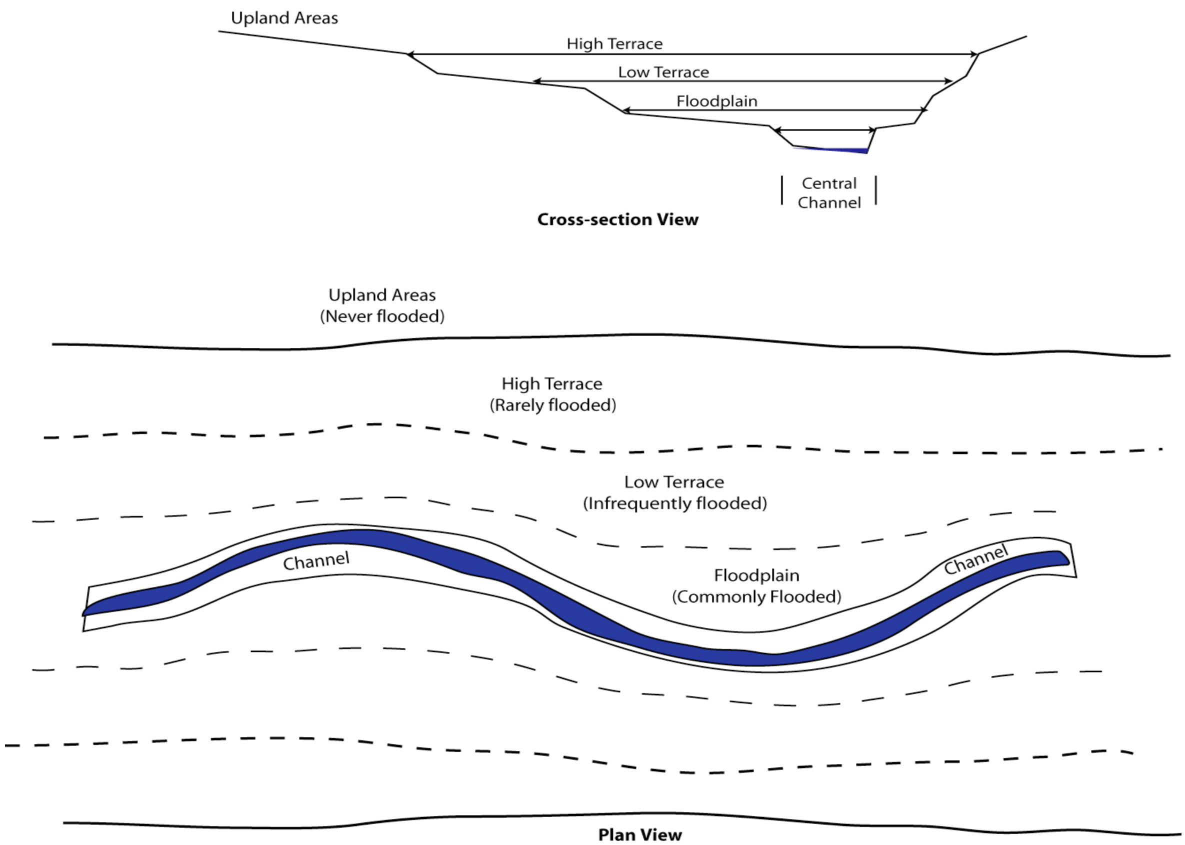


Figure 2-9. Channel Template, no dikes; Channel, floodplain, terrace features

TABLE 2-8. CHANNEL TEMPLATE DATA

	Gunlock	Santa Clara/ St. George	Source
Watershed Area:	270 sq miles	500 sq miles	Topographic map
Bankfull Cross-sectional Area (A):	65 sq feet	90 sq feet	Regional Curves
Width/Depth Ratio (W/D):	25	25	Regional Data
Bankfull width (W):	40 ft	45 ft	$W=(w/d*A)^{0.5}$
Bankfull mean depth (d_{mean}):	1.6 ft	2.0 ft	$d_{mean}=A/W$
Bankfull maximum depth (d_{max})	2.0 ft	2.5 ft	$d_{max}=d_{mean}/0.6$
Entrenchment Ratio (Ent):	2.5	2.2	Regional Data
Floodplain width (FPW):	90 ft	100 ft	FPW=Ent*W
Low Terrace width:	120 ft	150 ft	Reference Reaches
High terrace width:	150 ft	360 ft	Reference Reaches
Setback levees:	200 ft	400 ft	Reference Reaches

MEANDER PATTERN

Meander pattern describes the stream channel's planiform shape across the landscape. Although some of the Santa Clara River meander pattern is determined by bedrock and high, historic terraces, the easily erodible soils of the banks allow channel adjustment. Several parameters are used to characterize this pattern (Figure 2-10).

Meander Length: Describes the length of one full meander (right turn – left turn).
Meander Width: Describes the width used by the channel meander.
Radius of Cuvature: Describes how "tight" the channel turns stream flow

The smaller the radius, the tighter the turn and the greater the forces against the outside bank. On the other hand, all stream channels meander. Meander is critical to the stream's function of burning or dissipating energy. Lack of sufficient meander can result in excess energy manifested in increased velocities and risk or erosion.

Stream channel exhibit characteristic, stable radius of curvature values specific to the stream channel, hydrology, and bank strength. Based on an evaluation of meanders in the Santa Clara River a range of stable radius of curvature values were identified (Table 2-9).

Table 2-9. Meander pattern values

	Magotsu Creek/Moody Wash – Gunlock Reservoir	Gunlock Reservoir – Santa Clara/St. George
Average radius of Curvature:	160 feet	180 feet
Minumum Radius of Curvature:	100 feet	120 feet
Range of Meander widths:	120 – 170 feet	135 – 190 feet
Range of Meander lengths:	500 – 700 feet	550 – 800 feet

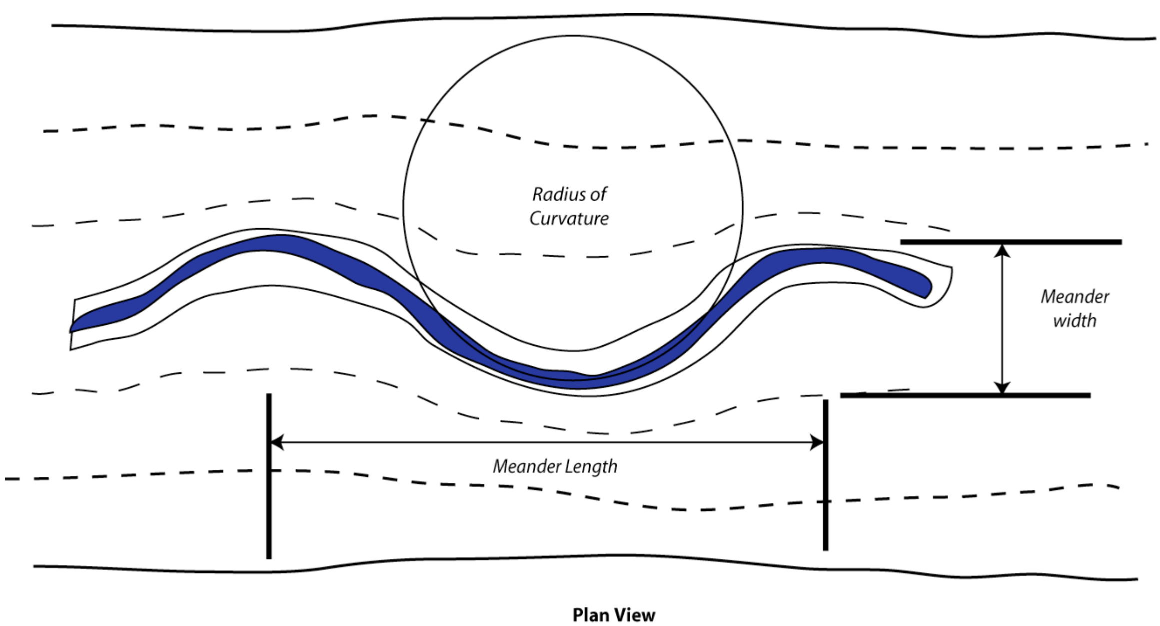


Figure 2-10. Meander Pattern Characteristics.

POST-FLOOD STRUCTURAL EROSION CONTROL

Following the January 2005 flood, the Natural Resources Conservation Service (NRCS) installed rock revetments along significant portions of the Santa Clara River (Figure 2-11). These revetments are located in the urbanized reaches of Santa Clara and St. George cities. In accordance with the stipulations of the Emergency Watershed Protection program, the revetments were designed to protect properties from events equal in magnitude to the flood that created the damage.

The design calls for an 8-foot top width and a minimum of 130 feet channel width when there are revetments along both banks.

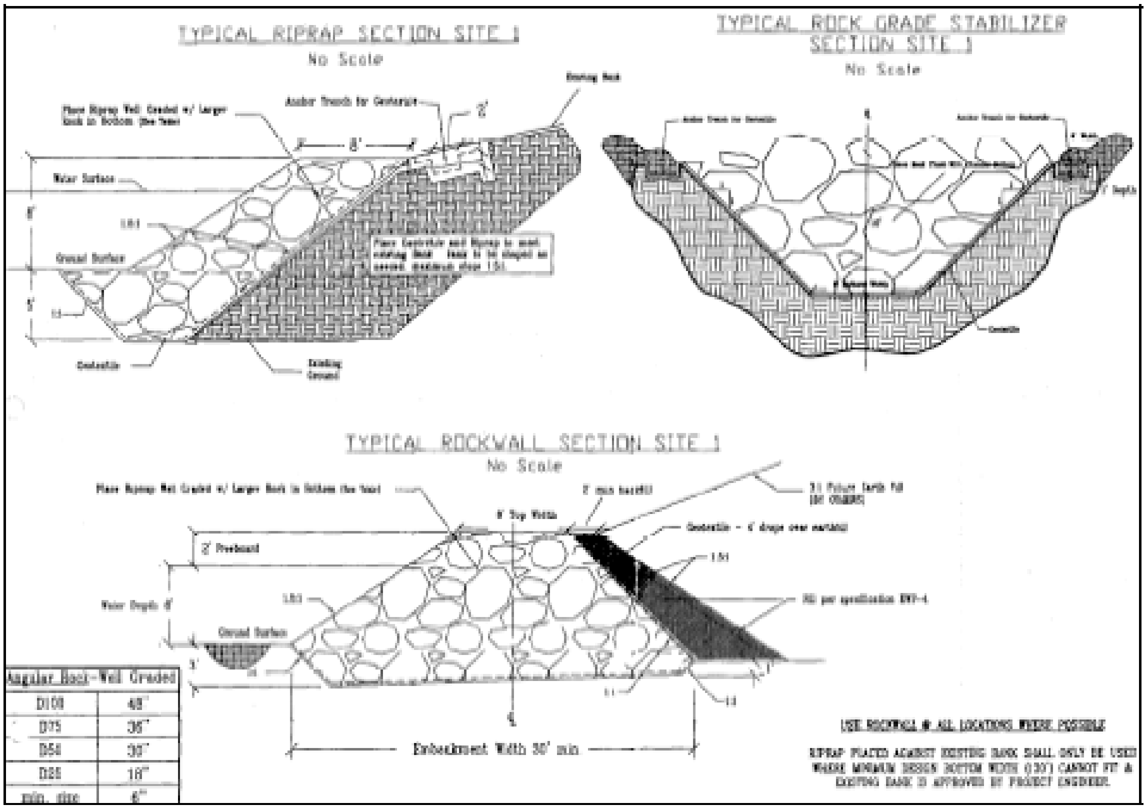


Figure 2-11. NRCS Rock Stabilization Design.

In the area between revetments, the stream channel is relatively flat and featureless following the January 2005 floods (Figure 2-12). However, over time stream channel processes are expected to build floodplain and low terrace features between the dikes (Figure 2-13). These features are expected to mimic the shape and dimensions described in the channel templates for areas without dikes.

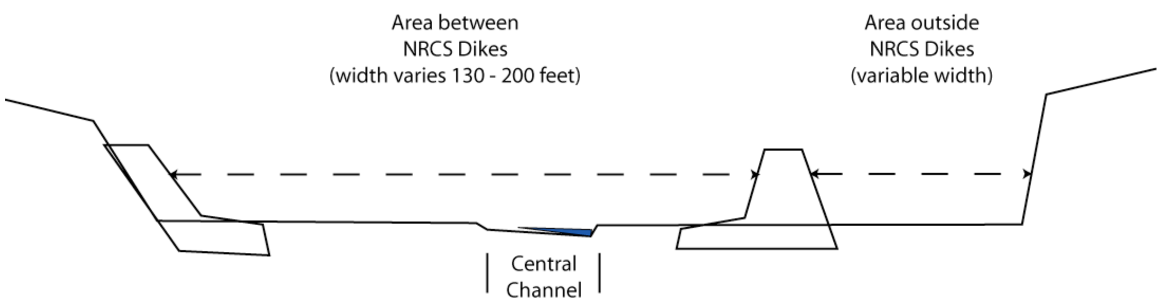


Figure 2-12 . Dikes after construction.

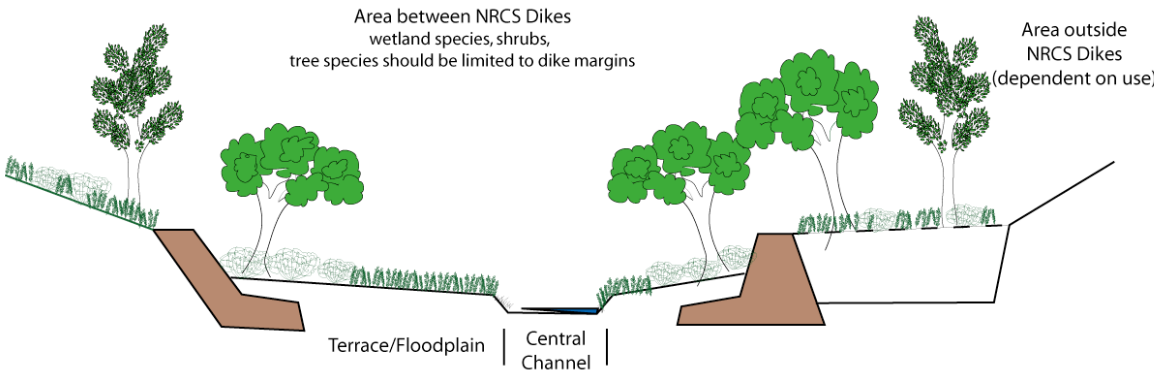


Figure 2-13. Alluvial features and vegetation between dikes.

HYDRAULIC ASSESSMENTS

Stage discharge relationships were modeled for transition (straight) sections of each channel template using the WinXSPro, a cross-section analyzer developed by the Bureau of Land Management and USDA Forest Service. Each channel was assumed to have fully developed alluvial features and riparian vegetation.

Roughness Coefficients

The Central Channel was assumed to have minimum vegetation and moderate roughness as a function of substrate and bedforms. The Floodplain and Low Terrace were assumed to be densely vegetated with willow and cottonwood as described in the revegetation strategy section. The High Terrace was assumed to be partially vegetated with large trees and periodic hedgerows as described in the revegetation strategies section. Roughness coefficients (Mannings n) are listed in Table 2-10. These coefficients may be conservative as considerable amounts of vegetation can be expected to be removed during extreme floods.

Table 2-10. Roughness coefficients for hydraulic modeling.

FEATURE	LOW STAGE	HIGH STAGE
CHANNEL	0.06	0.03
Floodplain/low terrace	0.10	0.03
High Terrace	0.06	0.03

AREAS WITH NO NRCS DIKES

Figure 2-14 depicts the channel-floodplain-terrace features and vegetation for design templates in no dike areas. The model outputs suggest that, as expected, channel and floodplains velocities will be high during extreme events but high terrace velocities will be low. Mean velocities for selected discharges for Gunlock and Santa Clara/St. George design channels are presented in Table 2-11.

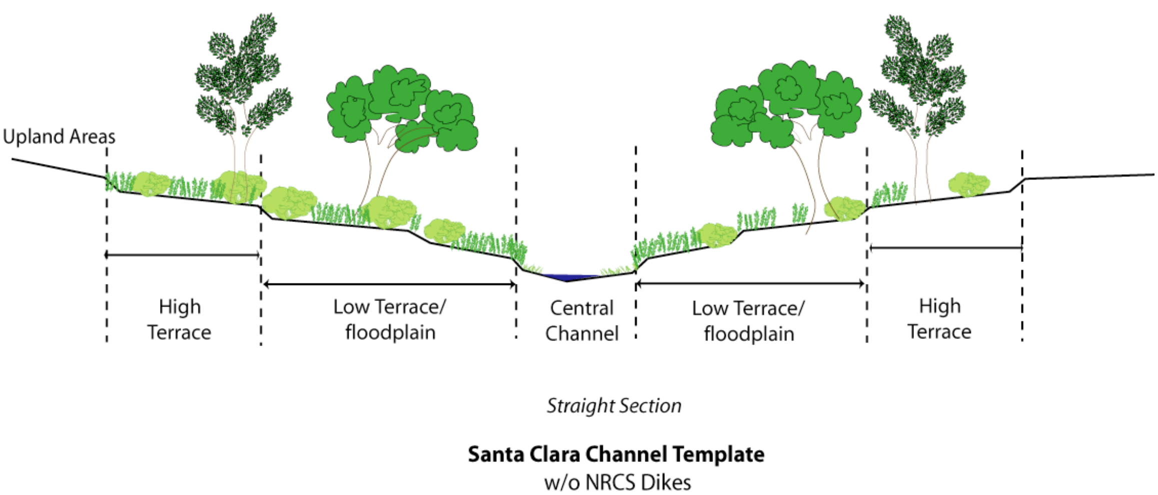


Figure 2-14. Channel-Floodplain-Terraces in no dike sections

TABLE 2-11. STAGE AND MEAN VELOCITIES FOR NON-DIKE CHANNEL TEMPLATES

Gunlock Channel Template (with vegetation & alluvial features)

RI (years)	Discharge (cfs)	Stage (ft)	Mean Velocities (fps) Channel (0-2')	Floodplain/ Low terrace (2' - 6')	High Terrace (6' - 8')
1.5	160	1.5	3.6		
2	320	2.0	4.4		
5	1,010	3.5	7.4	1.3	
10	1,880	4.8	10.0	2.5	
25	3,600	6.0	13.1	4.1	
50	5,410	7.0	15.9	7.0	1.5
100	7,680	7.5	17.4	9.3	2.4

Santa Clara/St. George design channel (with vegetation & alluvial features)

RI (years)	Discharge (cfs)	Stage (ft)	Mean Velocities (fps) Channel (0-2.5')	Floodplain/ Low Terrace (2.5' - 8')	High Terrace (8' - 12')
1.5	320	2.5			
2	640	3.5			
5	1,980	5.5			
10	3,560	7.0			
25	6,540	9.0	14.3	3.4	
50	9,490	10.0	16.2	5.3	1.5
100	13,000	10.5	17.3	6.5	1.7

AREAS WITH NRCS DIKES

The design height of the dikes is 8 feet. The dikes were designed to contain an 8,500 cfs flow with 2 feet of freeboard. However, as discussed previously, floodplain/low terrace features and appropriate riparian vegetation can be expected to naturally form within the dikes. These features are expected to mimic pre-flood conditions in dimension and extent. Not only would continual removal of the alluvium and vegetation be very costly but it would reduce channel stability. The geomorphic floodplain and other alluvial features are essential to adequate sediment transport over time. Without them, sediment deposition and scour during large floods will be unpredictable. The lack of vegetation will decrease soil strength and raise water velocities and increase the threat of scour at the base of the dikes. In additional this sediment/vegetation removal would negatively impact wildlife habitats and aesthetics without.

Figure 2-15 depicts the channel-floodplain-terrace that are expected to form between the dikes. Native vegetation can be planted or will colonize the alluvium. Reconstruction will speed the natural processes and increase stability. Stages, discharges, and velocities were modeled using the WinXSPro software for NRCS dike design sections with alluvial forms and vegetation (Table 2-12).

With the alluvium and vegetation the January 2005 flood flow just overtop the dikes. Upper banks must be designed to withstand forces during higher flows. All modeling results should be considered approximate due to the many variables and assumptions inherent in the exercise.

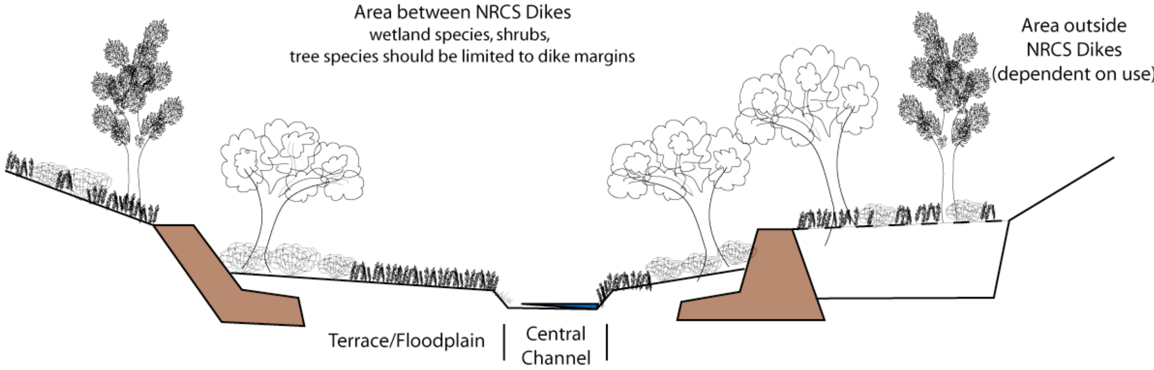


Figure 2-15. Channel-floodplain-terraces in dike sections.

Table 2-12. Stage-discharge-velocities in NRCS dikes; with alluvial features/vegetation

NRCS Dike, w/alluvial features & vegetation; 3:1 slopes above dikes

			Mean Velocities (fps)		
RI (years)	Discharge (cfs)	Stage (ft)	Channel (0-2.5')	Floodplain (2.5' - 8')	Terrace (8' - 12')
1.5	320	2.5	4.1		
2	640	3	4.9	0.5	
5	1,980	5.5	8.6	1.7	
10	3,560	6.8	10.5	2.8	
25	6,540	8.5	13.5	4.9	1.1
50	9,490	9.5	15.4	6.8	2.6
100	13,000	10.3	16.9	8.6	3.8

AREAS BEHIND NRCS DIKES

Mean Velocities were modeled for areas above the NRCS dikes to evaluate the need for bank protection above NRCS dikes. Three setbacks were evaluated: 1) Minimum 12-foot setback (3:1 slope), 2) 50-foot setback, and 3) 100-foot setback. The design dike cross-section provided by the NRCS and minimum dike bottom width of 130 feet were used in the model.

As shown in Table 2-15, velocities are reduced with the broader setback. These values should not be considered precise due to the many variables and assumptions involved in the modeling. Placement of the bank on meander or straight section, actual height of dike, form and elevation of alluvial features within dikes, and actual flows may significantly increase these values. As a result a minimum 50-foot setback is recommended.

Table 2-15. Velocities and flow depths behnd NRCS dikes

Discharge	*12-foot Setback*		*50-foot Setback*		*100-foot Setback*	
(cfs)	Velocity (fps)	Depth (ft)	Velocity (fps)	Depth (ft)	Velocity (fps)	Depth (ft)
320	-	-	-	-	-	-
640	-	-	-	-	-	-
2,000	-	-	-	-	-	-
3,500	-	-	-	-	-	-
6,500	1.1	0.5	1.0	0.4	0.8	0.3
9,500	2.6	2.0	2.1	1.5	1.7	1.3
13,000	3.8	2.4	3.2	2.3	2.6	2.1

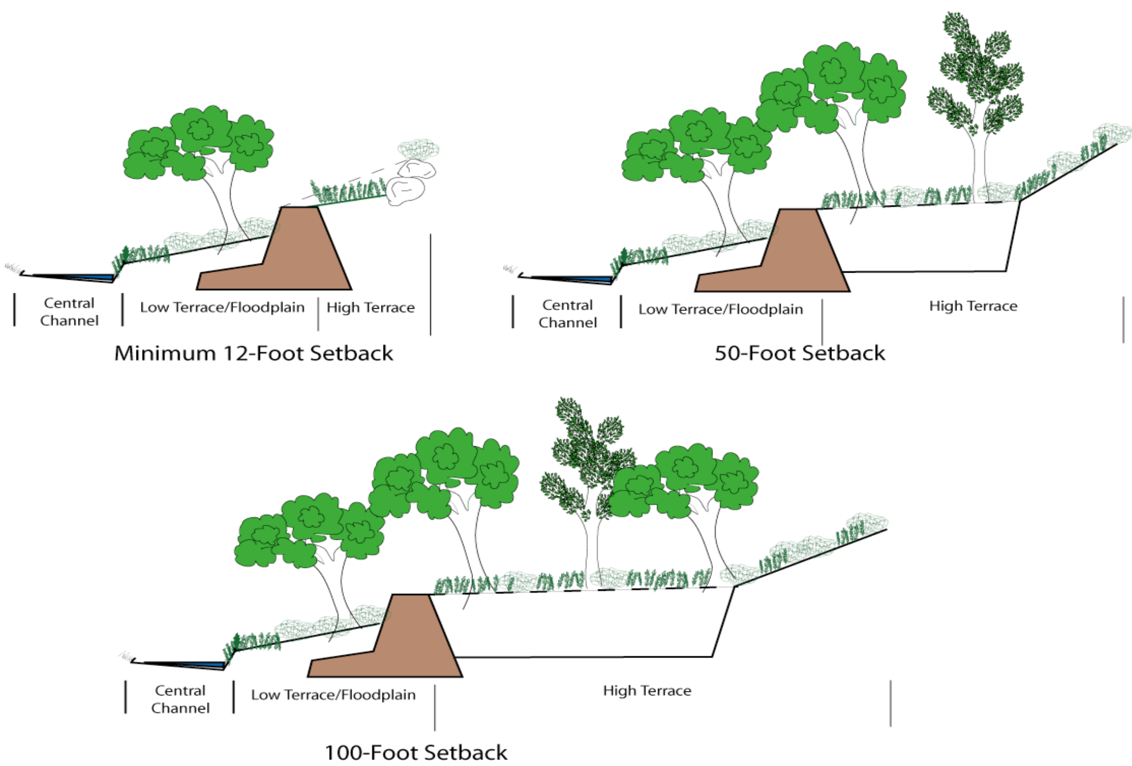


Figure 2-16. Alternative setbacks behind NRCS levees

SECTION 3: RECOMMENDATIONS

SUMMARY

GENERAL RECOMMENDATIONS

- Guiding Principles should guide all reconstruction, management, and maintenance of the Santa Clara River.
    - Elevation should rise with distance away from the central channel
    - Roughness (resistance to flow) should increase with distance away from the channel.
    - Transitions including meanders and terrace constrictions should be smooth and gradual.
- Channel alignments should remain in the post-flood alignments unless landowners on both banks agree to alter it. New alignments should be consistent with the Guiding Principles and channel/floodplain/terrace templates and constructed accordingly.
- Channel templates should be used for all reconstruction of the stream channel.
- To the extent possible, all parts of the riparian area should be revegetated with native riparian species consistent with recommendations.
- A long-term maintenance plan should be adopted to remove large woody stems (>2-inch diameter at breast height or DBH) from the channel and floodplain (approx. 100 feet width) to reduce the risk of future debris flows.

AREAS BEHIND NRCS DIKES

- Areas behind dikes should be filled to the level of the dike and slope upward to the existing banks. These areas should be revegetated and managed in accordance with the Master Plan guidelines.
- Where large areas of erosion (meanders) behind the dikes are not filled, dikes should be constructed to divide the low area into cells. Culverts should connect the cells to equalize water levels.
- All structures should have a 50-foot minimum setback from the top of dikes. In areas where existing houses are nearer, the upper banks should be protected by appropriate rock armoring.

ADDITIONAL STABILIZATION MEASURES

- **Bioengineering**
    - A variety of cost-effective bioengineering practices are available to stabilize stream banks.
- **Structural**
    - A variety of cost-effective structural practices are available to further stabilize stream banks.

EXOTIC SPECIES REMOVAL

- Existing programs to remove tamarisk and other exotic species should continued.
- The best strategy for minimizing the colonization of tamarisk in the flood disturbance areas is to replant with native riparian species. There is no need for large-scale herbicide application prior to replanting.
- When thickets are removed (Tonoquint Park), they should be removed in bands parallel to the stream beginning at the stream margin. Areas should be replanted with native vegetation. Thickets on the terraces should not be removed unless another method of roughness can be utilized to slow overbank flows.

NATURE OF RIVERS

An alluvial stream channel is a product of watershed processes. Its purpose is to successfully transport water and sediment originating in the watershed. A stream channel adjusts its size, slope, and sinuosity to accommodate a range of stream flows and to move sediment through the system. Generally speaking, a stream is also constantly dissipating energy as it moves downstream. In a low gradient channel, bars, meanders and a broad floodplain are important features for dissipating excess energy. If unable to expend this energy the channel is inherently unstable and prone to lateral and/or vertical erosion, especially during large flow events.

A stream creates a set of physical features (central or bankfull channel, geomorphic floodplain, low & high terraces) to accomplish the transport of water and sediment. Each feature provides an essential purpose. The central or bankfull channel transports the majority of sediment load along the channel bottom. The geomorphic floodplain lies adjacent to the central channel and is overtopped by moderate, frequent flow events. Low and high terraces are abandoned floodplains or bars created by infrequent, large flood events. The floodplain and terraces spread high flows dissipating energy and slowing velocities. The geomorphic floodplain should not be confused with the regulatory 100-year floodplain. The 100-year floodplain is not an alluvial feature but the lateral extents inundated during a 100-year flood event. Generally, channel, geomorphic floodplain, and terraces all lie within the 100–year floodplain.

In the southwest as in other regions, the channel and geomorphic floodplain are created and maintained by moderate, frequent flood events with return intervals in the range of one to two years (Moody et al 2003). In many gravel bed streams, this flow has been shown to carry the greatest amount of sediment over time (Andrews, 1980) and is considered the stream forming flow, channel maintenance flow or bankfull flow.

All channels have a characteristic meander or pattern (Figures 3-1 & 3-2). Low gradient streams are more sinuous than steep ones. The lateral extent, frequency, and radius of curvature are a function of flows, sediment supply, slope, and bank material. Meander allows a low gradient stream to dissipate energy. In gravel streams, bedforms (riffles, pools, and runs) are closely correlated to channel pattern.

Figure 3-1. Alternating bars in a constructed canal demonstrates meander within straight channel.

Figure 3-2. Meander pattern in Walla Walla River. Flood waters erode dikes to restore stream channel pattern.

The stability of any natural channel is dependent on an appropriate dimension, pattern, and profile of the bankfull channel and associated floodplain (Leopold, Wolman, & Miller, 1964). The Master Plan has attempted to identify the stable geomorphic dimensions of the Santa Clara River and incorporate those into designs to meet specific project objectives. Closely matching the central tendencies of the natural channel results in a design that works with the existing stream processes rather than against it reducing erosion and maintenance cost.

EFFECTS OF CHANNEL MODIFICATION

Because a stream channel is dynamic, modifications often create responses in channel function. Sometimes the responses are inconsistent with the original objectives.

Straightening

Often stream channels are straightened in an effort to increase sediment transport, utilize additional lands or decrease lateral movement. However, the loss of meander increases stream power raising the potential for the stream to erode banks in an effort to dissipate energy. In addition, the stream's natural tendency to restore its characteristic meander pattern will also contribute to stream bank erosion. Without armoring, the stream channel will simply return to its pre-modified condition (Figure 3-2).

Levying/widening

Channel widening is generally intended to increase the capacity of a stream to carry flood flows (Figure 3-3). Initially this is the case. However, overwidening of the bankfull or central channel decreases sediment transport. In channels with meander, point bars will build restoring pre-modification channel width and geomorphic floodplain elevation and negating the modification. In straightened channels, sediment deposition over time can raise the channel bed decreasing capacity and increasing the risk of flooding. Channel aggradation also increases the tendency to meander increasing the risk of bank erosion.

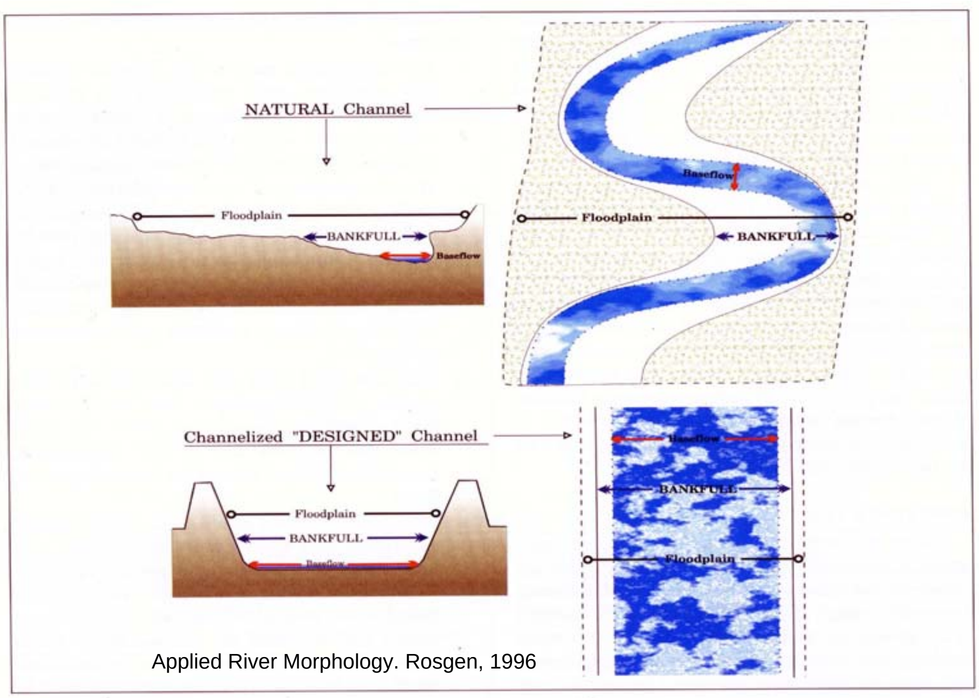


Figure 3-3. Natural vs. "Designed" Channels. The lack of geomorphic floodplains in the "designed" channel reduces sediment transport.

ROLE OF RIPARIAN VEGETATION

Riparian vegetation provides critical benefits to the physical stream system. Vegetation rooting provides additional strength to erodible banks. Equally important the vegetation increases roughness or resistance to flow along the channel and banks slowing flow velocities and dissipating energy. The species and distribution of vegetation is largely dependent on two critical variables; soil moisture and disturbance. Flooding is the driver for both of these variables. As a result both soil moisture and disturbance are highest closest to the stream channel and decrease laterally moving away and up. Plants adapted to varying degrees of soil moisture and disturbance thrive along zones running parallel to the stream channel.

Researchers at the NRCS Plant Materials Center in Idaho have divided the riparian corridor into discreet planting zones: Toe, Bank, Overbank, Transition, and Upland (Hoag, et al, 2001). Each zone supports a different community complimenting stream processes and creating habitats (Figure 2-4). For example, the toe zone adjacent to the perennial flow supports lush, wetland plants, the bank and overbank zone is dominated by grasses and shrubby willows, and the transition zone supports more arid grasses, shrubs and trees. The stiffness of vegetation (and associated roughness) generally increases as it moves away from the central stream channel.

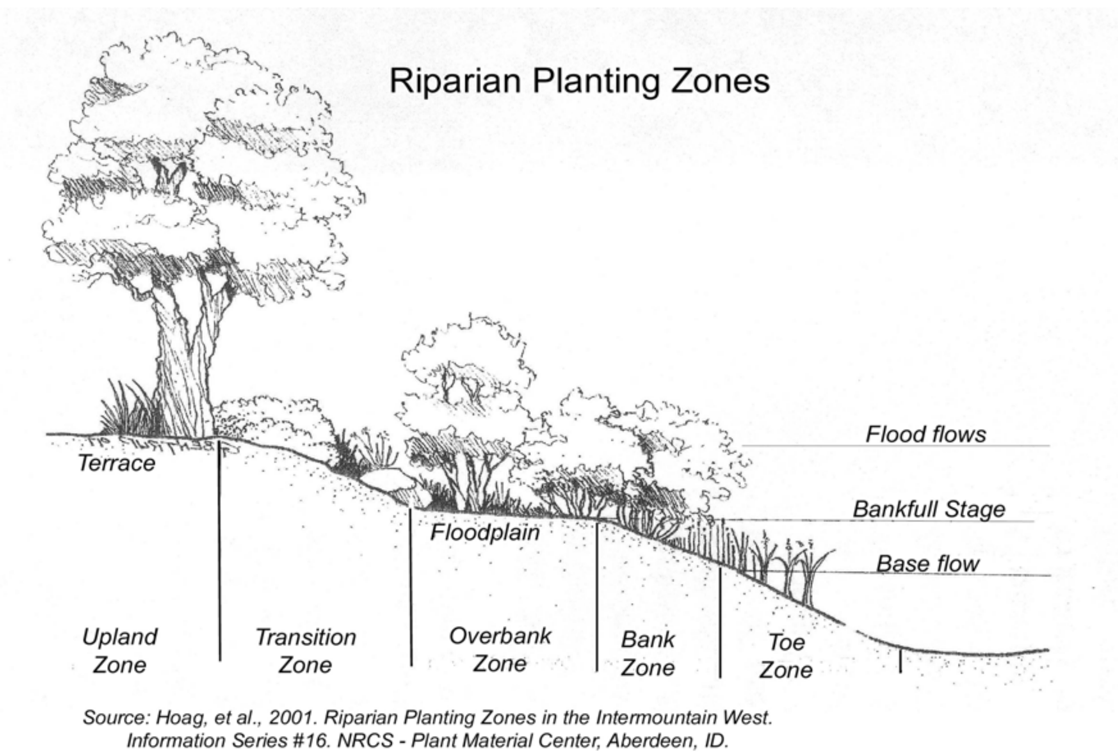


Figure 3-4. Riparian Planting Zones

LIVING WITH A RIVER

The Santa Clara and Virgin Rivers run through the communities of Gunlock, Santa Clara, and St. George, Utah. Fertile lands and access to water has historically linked agricultural lands to the river. The large trees, cooler temperatures, and aesthetic features make properties near the river more valuable. But, as was evident in January 2005, there are risks associated to living adjacent to a river.

Rivers flood. Common floods inundate areas closest to the central channel; higher, less frequent floods affect higher areas. Riparian corridors can be thought of as composed of three zones (Figure 3-5). The first is the lowest and includes the central channel and adjacent floodplain. This area is flooded frequently and sometimes for long periods of time. While it can be used for passive activities such as hiking and birding, alterations to this area can severely impact the essential processes of the stream. This area should be thought of as belonging entirely to the river.

The second area includes the low and high terraces and bars above the flood plain. These areas are inundated by Moderate and High floods but can be used for parks, agricultural fields, and recreational areas. This common area can be used by both the river and humans. Flooding will periodically scour areas and deposit sediments but damage should be manageable. No permanent structures should be constructed in these areas. Structures can constrict and/or redirect flows destabilizing the stream and creating additional flooding and erosion risks.

The final area includes lands that are above the level of all river flooding. These areas belong to humans and can contain houses and other permanent structures.

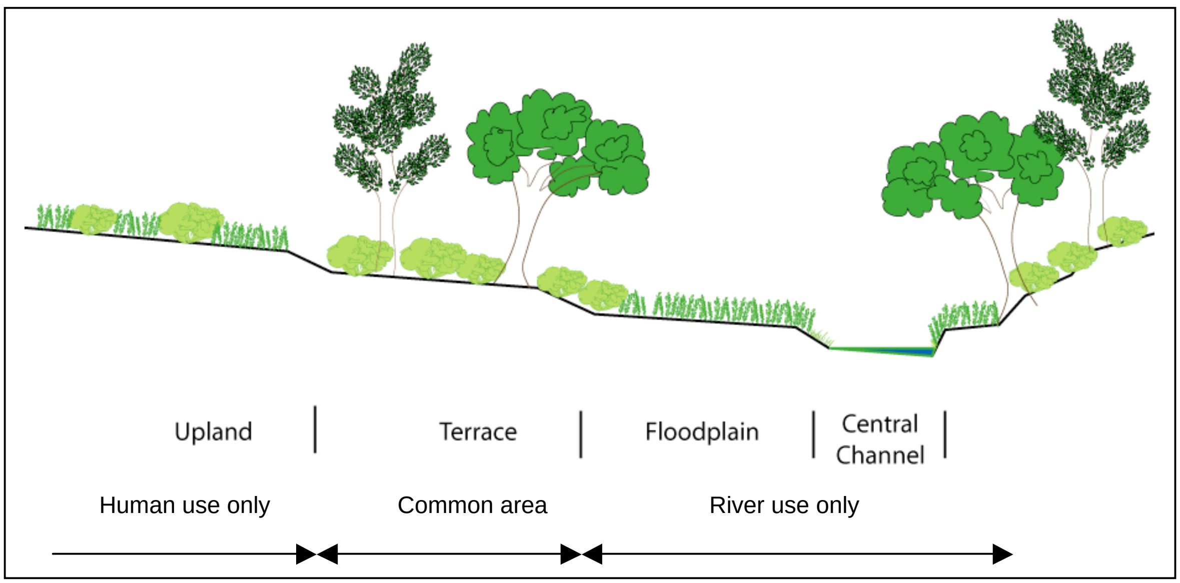


Figure 3-5. Areas of Use

Initial field observations, first hand testimony of many who witnessed the flooding along the Santa Clara suggest that the extreme bank erosion was commonly initiated as tree trunks and other floating debris blocked the narrow main channel redirecting the force of the flow against unprotected banks. Once outside the vegetated riparian area, the redirected flows spread across pasture or other surfaces often eroding a new main channel.

The banks of the Santa Clara and Virgin Rivers have very little inherent strength. Channel stability in the past has largely depended upon thick stands of vegetation surrounding and containing the channel/floodplain. This vegetation strengthened banks and tended to keep the strongest stream flow in the central channel flowline. However, in many instances during the January 2005 flood, uprooted vegetation blocked the central channel and diverted flows against unprotected banks. To maximize channel stability during future flood events, all physical and vegetation elements of the reconstructed channel, floodplains, and terraces should combine to maintain the highest velocities in the center of the stream channel and away from the more fragile stream banks.

Floods of equal or greater magnitude are likely to occur again on both Santa Clara and Virgin Rivers. The following principles are presented to guide in the emergency repair work now underway. These basic principles are central to keeping the stream in the central channel and minimizing future erosion along the Santa Clara River from floods of equal or greater magnitudes.

GUIDING PRINCIPLES

1. Elevations within the corridor should rise away from the central channel.

The central channel flowline must be the lowest point across the riparian area and the channel banks, floodplains, and terraces should slope upward continuously away from the channel. The banks will be most stable if they can be stepped as they rise away from the channel. For the Santa Clara steps of approximately 2.5 feet are recommended. Slopes at these steps should be 3:1 or flatter. All flat areas should slope toward the river. If they are level or slope away from the river they will tend to divert overbank flows away from the main channel and could contribute to greater erosion. Banks on the outside of meanders are expected to rise more rapidly than those on the inside but should still be stepped if at all possible.

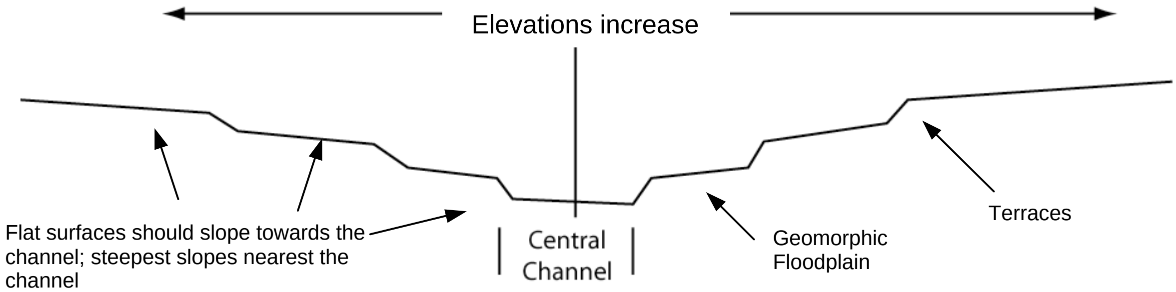
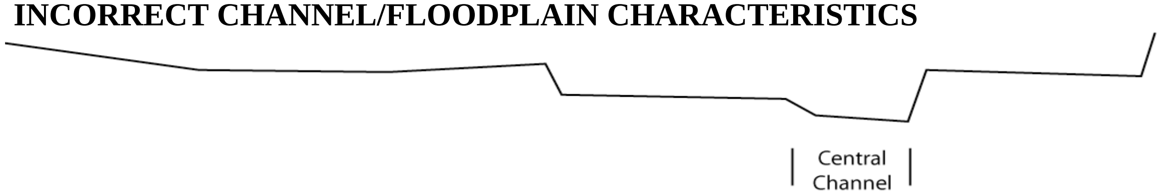
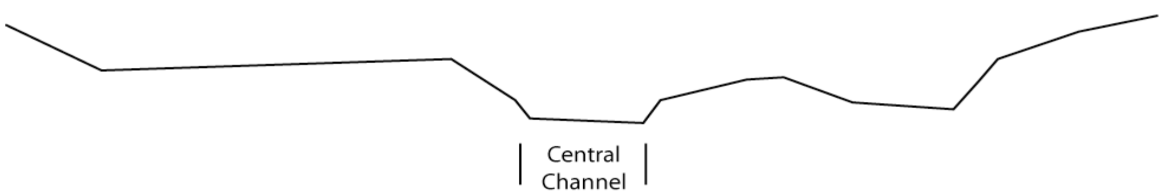


Figure 3-6. Appropriate channel/floodplain elevations

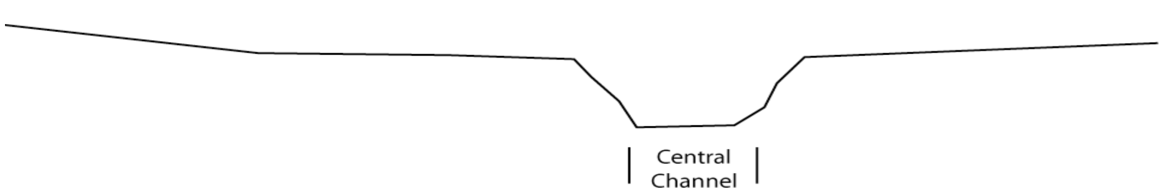
INCORRECT CHANNEL/FLOODPLAIN CHARACTERISTICS



In this example, overbank areas are not sloped toward the central channel. Flow that overtops these banks may be trapped away from the channel and create erosion along the surfaces or gullies as the flow reenters the channel downstream.



In this example, a secondary channel to the right may capture the main flow and increase erosion along that bank. Overflow channels can provide important “safety valves” for spreading flows but must be well vegetated (generally more thickly vegetated than the central channel) and reconnect to the main channel.



In this example, lack of a set of stepped floodplain/terrace features contains the flows but increases the velocities and erosion potential within the central channel. Once the banks begin to give way, the erosion can be extreme and unpredictable. Eventually flow will overtop the high banks and create erosion across the surface as well. High banks are often well above permanent ground water and cannot sustain robust plant communities.

2. Roughness should increase away from the central channel.
Roughness is resistance to flow contributed by vegetation, rough surfaces, or structures. Increasing roughness away from the central channel tends to center high flows and slows velocities against the more erosive stream banks and terraces. For example, the central channel should be relatively free of vegetation and other obstructions. The areas immediately adjacent to the channel (floodplains) should support dense thickets of shrubby vegetation (i.e., willows, etc) that bend with the flows (Figure 3-7). Areas further away from the channel (terraces) support stiffer woody vegetation (cottonwoods, Black willow, etc) that further slows flows. It should be noted that roughness implies a slowing of the flow not necessarily stopping the flow (Figures 3-7 & 3-8). Structures that completely stop or redirect flow across the floodplain/terrace should be avoided.

Terraces are features that can be used by both humans and the river. These areas are infrequently flooded and can be used for agricultural fields, orchards, parks, and other open spaces without permanent structures.

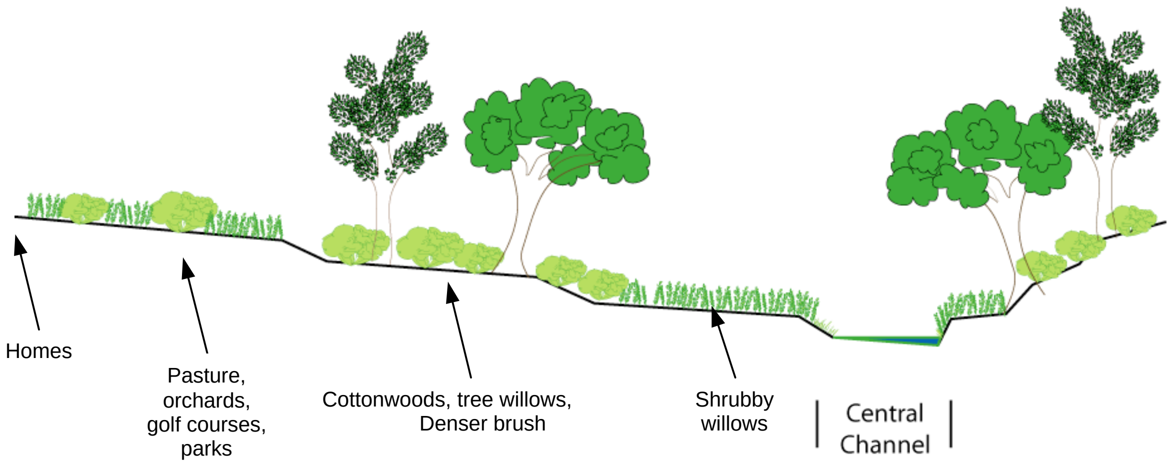


Figure 3-7. Appropriate Roughness. Vegetation provides increasing roughness to keep high velocities in central channel.

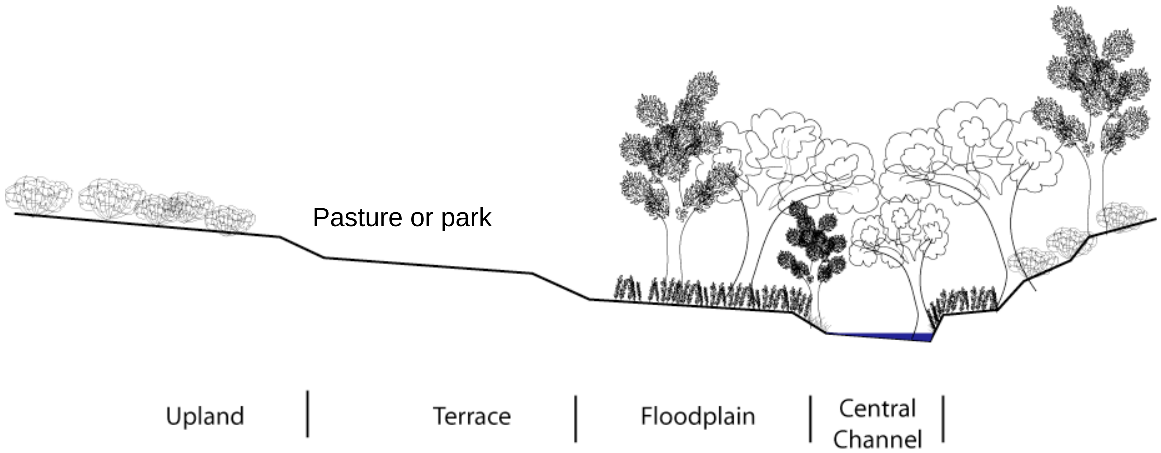


Figure 3-8. Incorrect Roughness. Dense stiff vegetation chokes channel. Smooth surface of pasture creates high velocities and erosion.

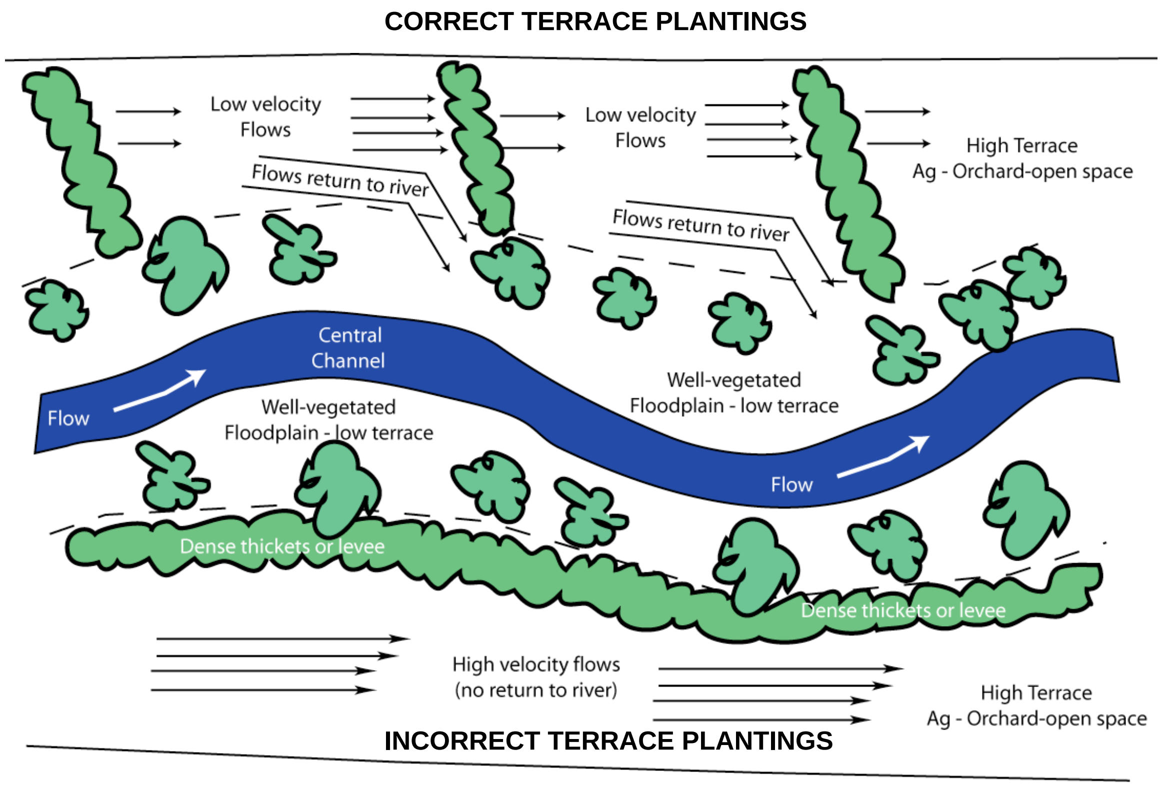


Figure 3-9. Terrace vegetation. Terrace areas used for pastures, orchards, parks or other areas with short, smooth surfaces increase erosional flow velocities. Vegetative buffers or hedgerows should be established to slow flows and redirect toward the river (top of figure).

Narrow, dense thickets of vegetation and/or levees parallel to the river should be avoided. These features trap erosional flows and inhibit return to the river (bottom of figure).

3. Transitions should be gradual.

In order to minimize the risk of lateral bank erosion, water should flow smoothly through the stream corridor. While meander is a natural part of stream processes, tight turns can create excessive pressure to weak stream banks and increase erosion. Meanders should be gradual and within the dimensions described in specific recommendations. Floodplains and terraces should not be suddenly narrowed by buildings or other structures (Figure 3-10). Such constrictions force increases in velocity and water elevations that can increase erosion.

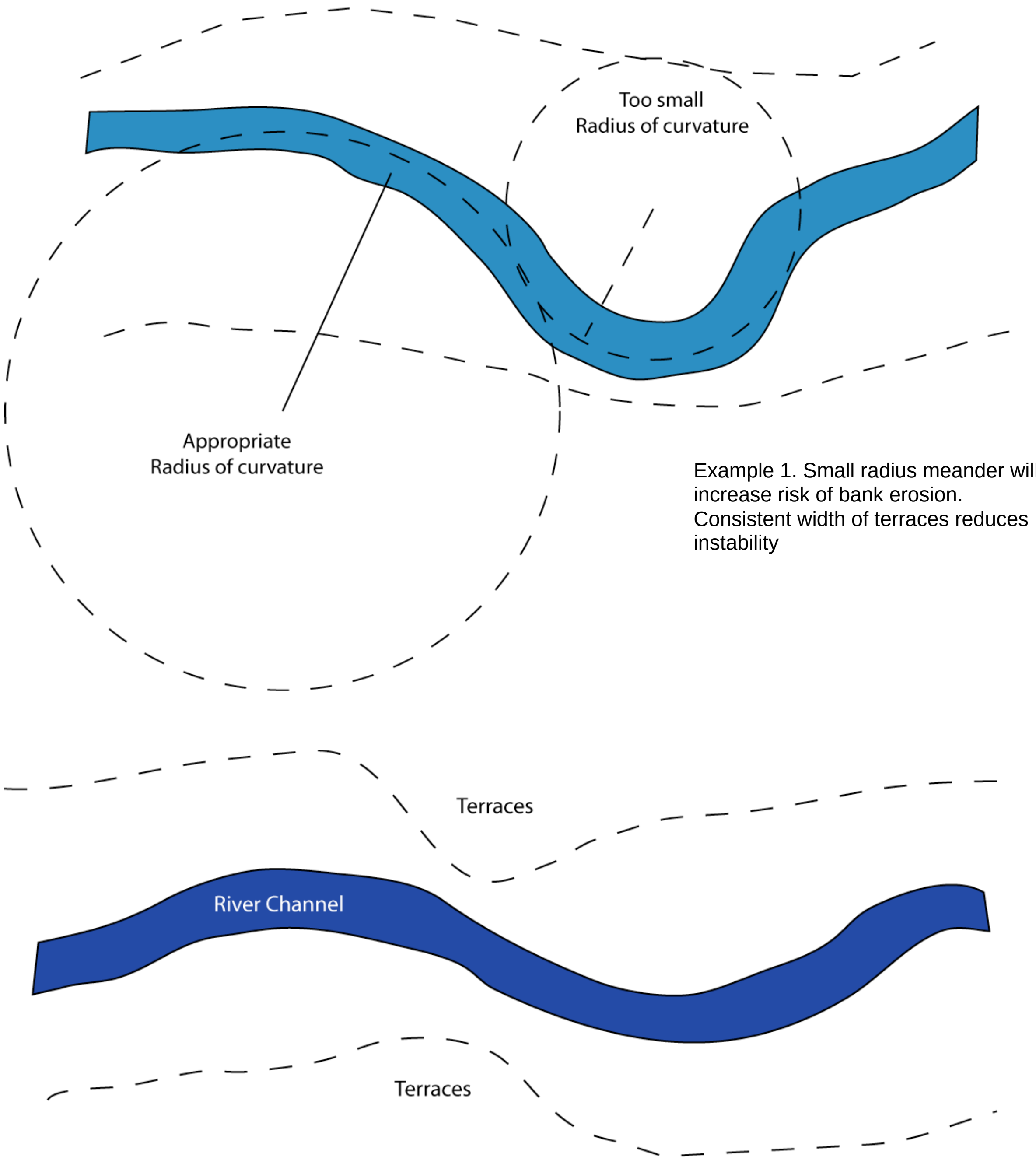


Figure 3-10. Incorrect transitions. Sudden narrowing of terrace or floodplain increases potential for erosion.

CHANNEL RECONSTRUCTION

CHANNEL FEATURES

The cross-section templates provide guidance in the relative widths and depths of alluvial features. The channel cross-section templates are different for Gunlock and Santa Clara-St. George reaches of the Santa Clara River due to the difference in watershed sizes. Due to the larger flood flows experienced in the lower river, terrace areas are wider in Santa Clara-St. George than in Gunlock.

Cross-section templates are divided into 5 areas: central channel, floodplain, low terrace, high terrace, and upland. All areas are subject to periodic flooding; the higher areas less frequently than those nearer the channel. The bankfull channels are larger and floodplain-terraces wider in Santa Clara-St. George than in the Gunlock area as a result of larger flood events.

Channel/floodplain/terrace system

Every stream channel has 3 primary functions; carry water and sediment of the watershed and dissipate energy. To achieve these functions, distinct physical features are constructed by the stream. These alluvial features are channel, floodplain, and terraces. The width of terraces will be constrainted in areas with NRCS dikes on both banks. Alluvial features should be included within these armored reaches to maintain sediment transport and stability created by riparian vegetation.

Channel: The stream channel represents the center of the stream. Commonly called active or bankfull channel, this feature carries base flows and moderate, frequent flood events. The primary function of the channel is to successfully transport sediment. Inadequate size and shape of the channel can reduce or alter sediment transport and increase instability. In addition the channel experiences the highest flow velocities and depths and transports the greatest portion of sediment through the system. The channel bed is generally coarser, composed of more resistant sands, gravels, or cobbles.

Geomorphic Floodplain*:* The geomorphic floodplain is defined as a level feature adjacent to the stream channel, created by the stream and overtopped by moderate, frequent flow events. The floodplain is flooded annually or every couple of years. Disturbance is naturally high due to frequent flooding and the surface is relatively close to ground water ensuring good soil moisture. This low feature should not be confused with the 100-year floodplain identified for regulatory purposes. The channel and floodplain are inundated by common floods and should remain clear of all human activities.

Low terraces: Terraces are generally old floodplains abandoned when channel elevations are lowered by erosion but can also be created by alluvial bars deposited during high flow events. These surfaces are inundated by moderate floods but can be used for trails and other infrastructure that can withstand periodic flooding and does not interfere with riparian vegetation.

High terraces are flooded by high and extreme floods but can be used for agricultural and recreational uses. However, appropriate roughness should be maintained.

Uplands: Uplands are areas that are rarely flooded by stream flows. These areas should be regulated and managed based on the flood and erosion hazard risk.

Areas within NRCS Dikes: Bottom width of NRCS dikes varies from 130 feet to 200 feet. Alluvial features within the dikes correspond to the central channel, floodplain, and low terrace.

CHANNEL ALIGNMENT

Generally, it is recommended that post-flood channel alignments be maintained in their post-flood location (see maps in Section 4). The post-flood alignments follow the lowest point in the stream corridor. Substantial shifts in alignment will entail large volumes of earthmoving and revegetation. However, in many places the river has eroded significant private property. In these cases the existing alignment may differ significantly from the pre-flood channel. In cases where adjacent property owners agree to realign the stream channel, realignment should incorporate the qualitative and quantitative principles described in this plan. Regardless of the alignment, appropriate channel/floodplain/terrace dimension and meander as described in the Master Plan is essential to long-term channel stability.

APPROPRIATE LAND USES

Human uses vary on these alluvial surfaces depending on the risk of flooding. The following are recommended uses for each.

Channel

Pedestrian use primarily. These areas can also be utilized by livestock. However, management is required to ensure that the integrity of the riparian plant community is not impacted.

Geomorphic Floodplain

Pedestrian use primarily. These areas can also be utilized by livestock. However, management is required to ensure that the integrity of the riparian plant community is not impacted.

Low Terrace

Agricultural fields that can be flooded periodically. Constructed pedestrian/bike trails & bridges, recreation areas (parks, golf courses) without habitable infrastructure. Human uses should be carefully integrated with the vegetation to maintain resistance to flow (roughness) as described in the guiding principles.

High Terrace

Agricultural fields, constructed pedestrian/bike trails, recreation areas (parks, golf courses) with some hard infrastructure such as picnic tables, shades, playground equipment. Human uses should be carefully integrated with the vegetation to maintain resistance to flow (roughness) as described in the guiding principles.

Uplands:

Uplands are areas that are rarely flooded by stream flows. These areas should be regulated and managed based on the flood and erosion risk.

Areas within NRCS Dikes:

Use should be limited to pedestrian/bike/golf trails and associated bridges within the dikes. Rock riprap or other structural revetments may be installed when necessary to protect trails, bridges and other infrastructure. Trail bridges should be designed to “break away” during flow events and should not constrict flow area by more than 10% or deflect flows against dikes. Human uses should be carefully integrated with the vegetation to maintain resistance to flow (roughness) as described in the guiding principles.

Areas behind NRCS Dikes:

These areas should be treated as High or Low Terraces depending on the elevation of the land and its risk of flooding.

CHANNEL TEMPLATES

MAGOTSU CREEK/MOODY WASH - GUNLOCK DAM

Channel/floodplain/terrace

Dimensions for reconstructing channel-floodplain-terrace features in the Magotsu Creek/Moody Wash to Gunlock Dam section of the Santa Clara river are given in Table 3-1 and Figure 3-11.

Table 3-1. Channel Template dimensions for Magotsu Creek/Moody Wash -Gunlock Dam reach

PARAMETERS			DIMENSIONS		
Bkf Area	65	sq ft	Bkf Width	40.0	feet
W/D Ratio	25		Mean Depth	1.6	feet
Ent Ratio	2.5		Max Depth	2.0	feet
Floodplain stage:	4	feet	Width	100	feet
Low Terrace stage:	6	feet	Width	120	feet
High Terrace stage:	8	feet	Width	150	feet

If setback levees are constructed to limit overbank flooding, the distance between setback levees should be no less than 200 feet.

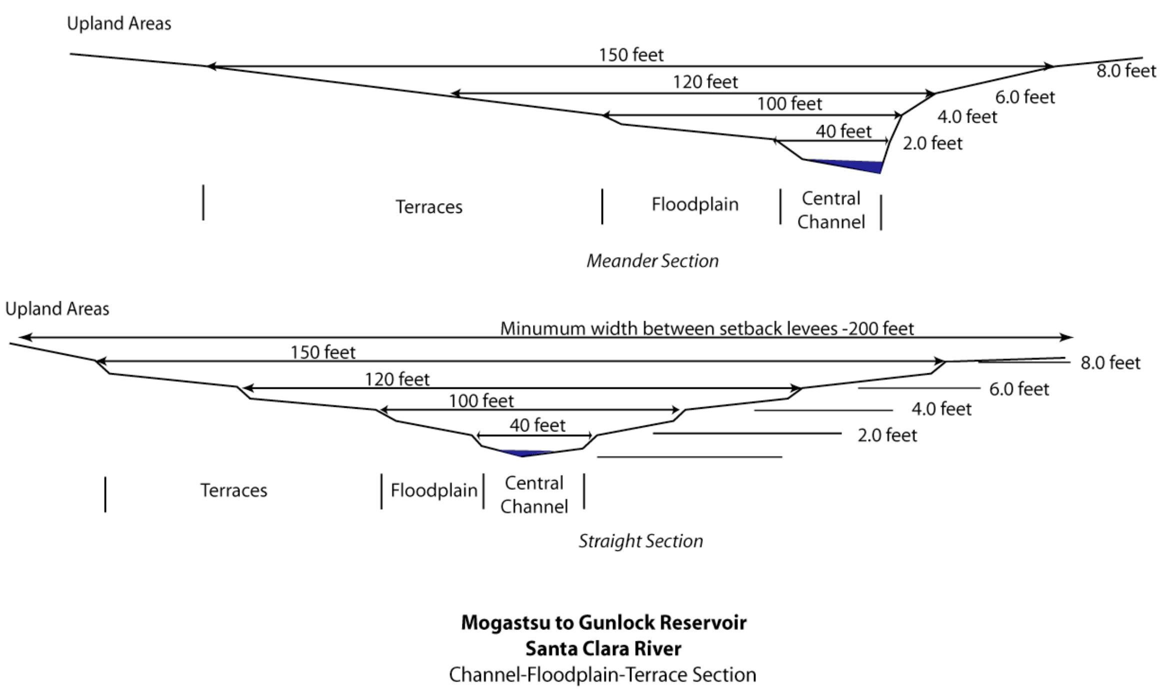


Figure 3-11. Magotsu Creek/Moody Wash -Gunlock Dam channel template

GUNLOCK DAM – VIRGIN RIVER CONFLUENCE

Channel/floodplain/terrace

Dimensions for reconstructing channel-floodplain-terrace features in the Magotsu Creek/Moody Wash to Gunlock Dam section of the Santa Clara river are given in Table 3-2 and Figure 3-12.

Table 3-2. Channel template for Gunlock Dam-Virgin River confluence reach

PARAMETERS			CHANNEL DIMENSIONS		
Channel Area	80	sq ft	Bkf Width	45.0	feet
W/D Ratio	25		Mean Depth	2.0	feet
Ent. Ratio	2.2		Max Depth	2.5	feet
Floodplain stage:	5	feet	Width	100	feet
Low Terrace stage:	7.5	feet	Width	250	feet
High Terrace stage:	10	feet	Width	360	feet

If setback levees are constructed to control overbank flooding, the distance between levees should be no less than 400 feet.

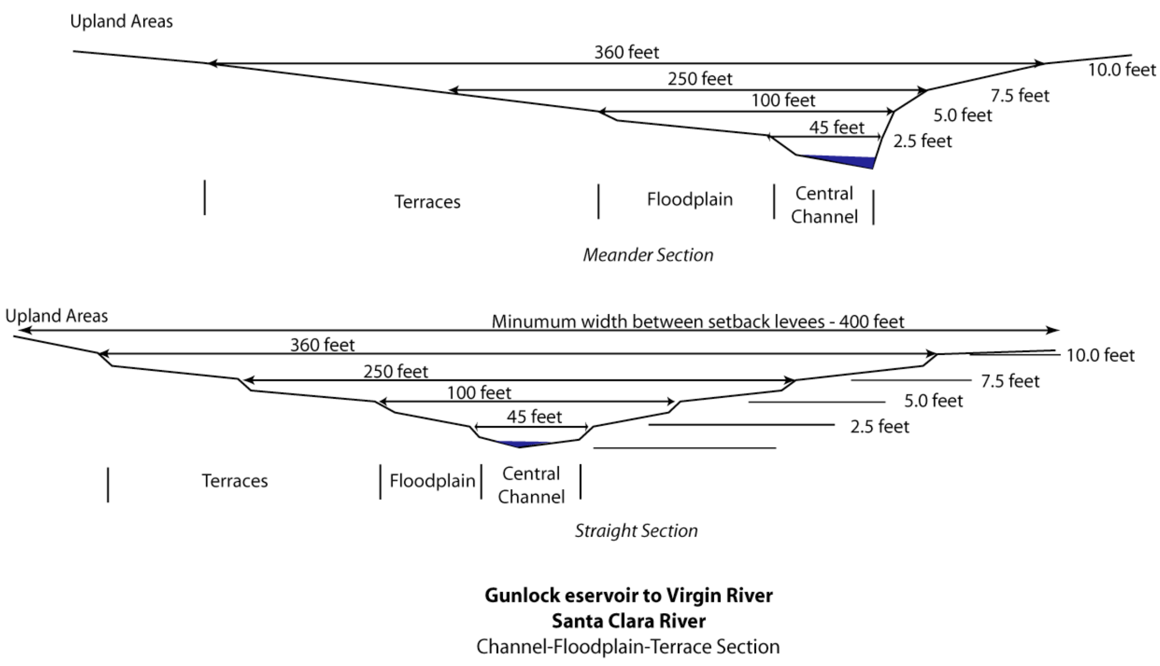


Figure 3-12. Gunlock Dam-Virgin River confluence channel template

AREAS BETWEEN NRCS DIKES

The natural channel is altered in areas with dikes constructed by the Natural Resource Conservation Service. These dikes have been generally constructed in areas too narrow to accommodate the width of stable terraces. Dimensions for alluvial features between NRCS dikes is presented in Table 3-3 and Figure 3-13.

Table 3-3. Channel template between NRCS dikes

PARAMETERS			CHANNEL DIMENSIONS		
Channel Area	80	sq ft	Bkf Width	45.0	feet
W/D Ratio	25		Mean Depth	2.0	feet
Ent. Ratio	2.2		Max Depth	2.5	feet
Floodplain stage:	5	feet	Width	100	feet
Low Terrace stage:	7.5	feet	Width	Width between dikes	
High Terrace stage:	10	feet	Width	NA	feet

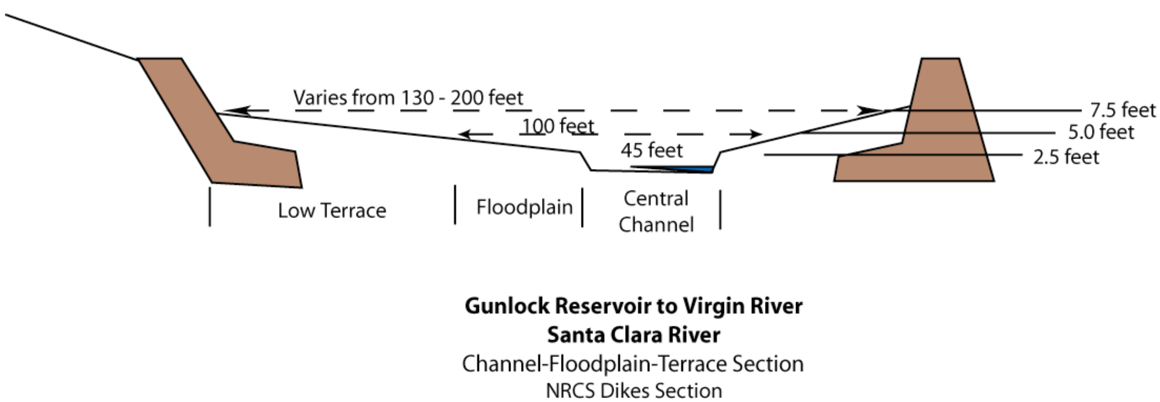


Figure 3-13. Channel template between NRCS dikes

AREAS BEHIND NRCS DIKES

NARROW AREAS

Areas behind NRCS dikes should be filled and revegetated whenever possible to minimize the risk of erosion. Based on the velocities and depth information generated from the hydraulic modeling, it is recommended that all structure and infrastructure be setback a minimum of 50 feet from the top of the NRCS dikes. The areas should be stabilized using strategies described in the Master Plan. Setback areas can be sloped or stepped up in one or more low terraces.

In areas where the minimum setback is not available, rock should be used to provide additional erosion protection to banks.

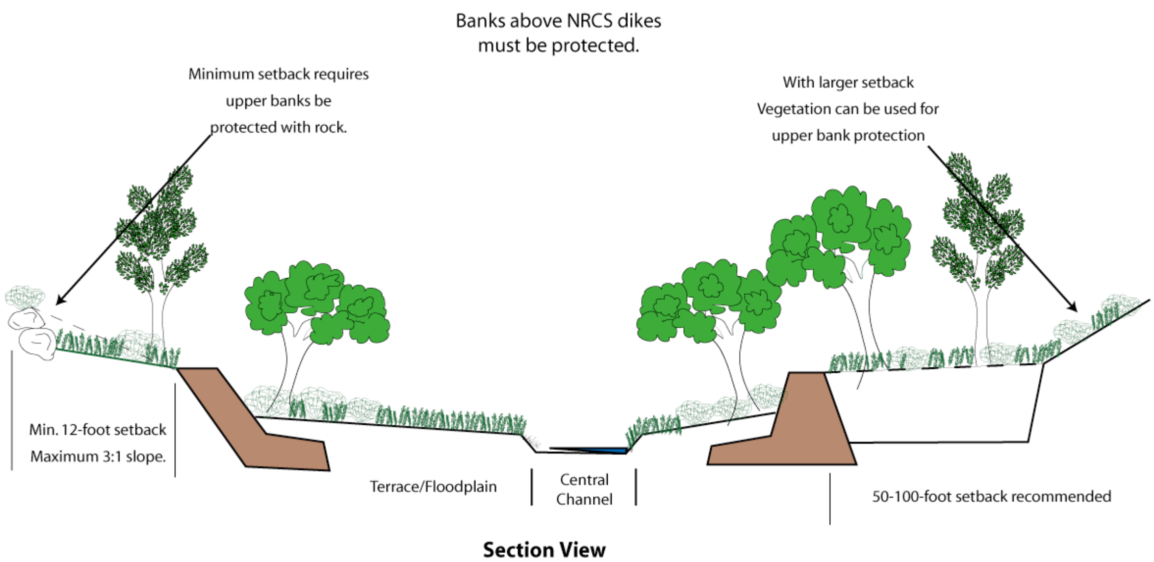


Figure 3-14. Setbacks in areas outside NRCS dikes

BROAD AREAS

Several large areas eroded by the January 2005 floods are now behind NRCS dikes. Untreated, these areas pose a risk to the dikes increasing the risk of future erosion. Hydraulic studies suggest future flood waters will overtop the dikes. If not properly contained these flows could erode behind the dikes and reduce their structural integrity.

It is recommended that these areas be filled where possible to the elevation of the top of the dikes. The fill should rise in elevation as distances increase away from the dikes. Areas should be revegetated in accordance with the high terrace recommendations.

If complete filling is not feasible, the area can remain at an elevation below the top of dikes. However, it is recommended that dikes be installed across the areas to divide them into separate cells. The divisions will reduce the risk of erosive flows on the back side of the dikes. Culverts should be installed in the dikes to equalize water elevations between the cells.

The lower areas can be used as parks or agricultural fields. No structures should be constructed within the cells.

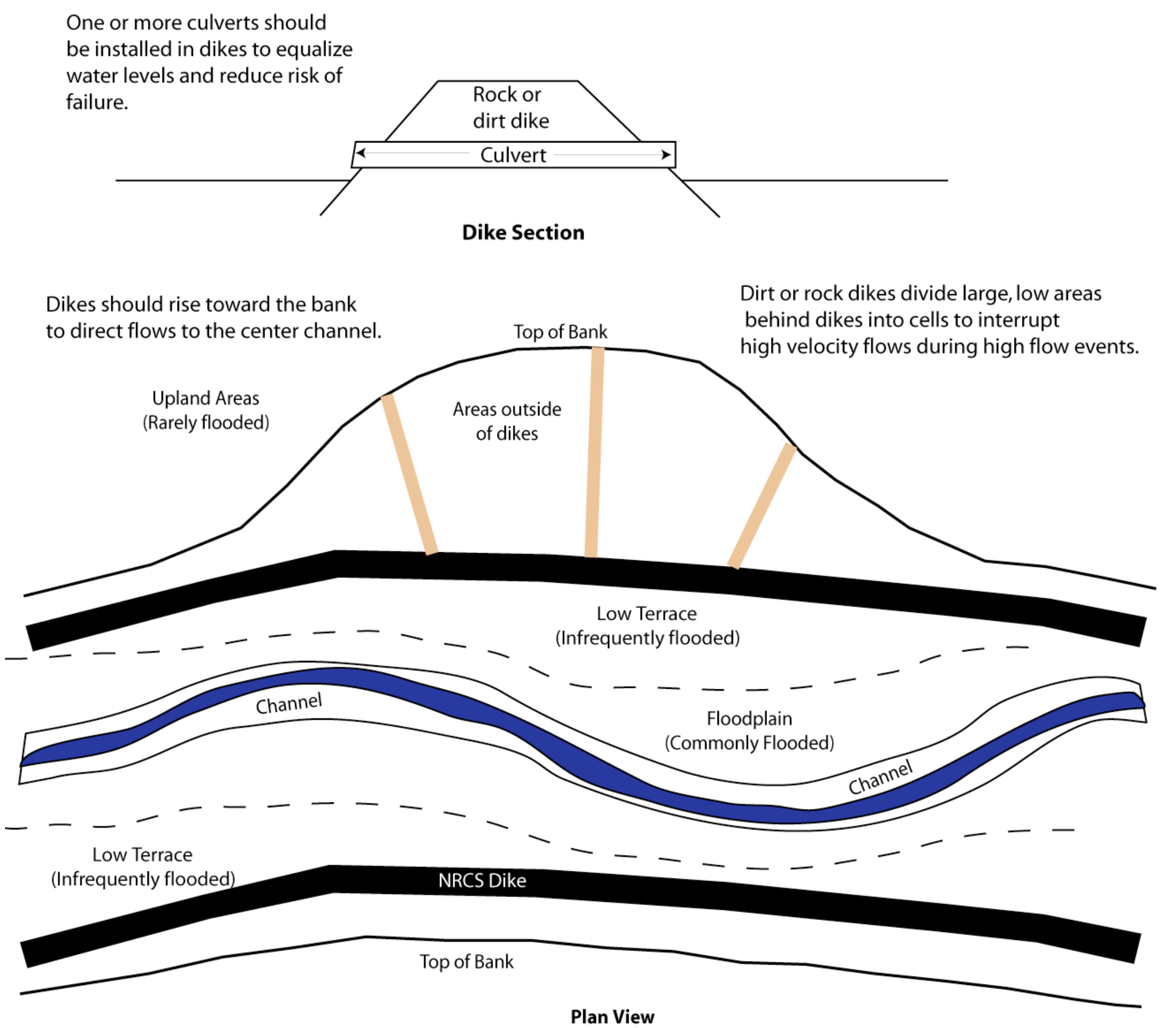


Figure 3-15. Strategies for large areas outside dikes.

REVEGETATION –
GENERAL STRATEGIES

Riparian vegetation is a critical component in the channel stability and the reduction of bank erosion on the Santa Clara River. As described earlier, riparian plants combine with the physical features of the channel/floodplain/terrace to slow flows, reduce hydraulic forces, and stabilize bank materials. Plant species have specific characteristics specially adapted to provide stability. Because of this, specific plant communities are located. Dense, tough roots of rush and sedge species strengthen the soil. Supple woody species of willow and baccharis bend with the flows to slow velocities as well as stabilize soils. Rigid trees and shrubs further slow flows. Plant communities must be located in zones with appropriate soil moisture and disturbance.

Plant community characteristics should follow the guiding principle that roughness or resistance to flow should increase moving away from the channel itself. This principle encourages the highest velocities remain in the central channel rather than the more erodible banks. The following describes the plant types for each of the alluvial features described in the preceding section.

> ***Channel (Toe/Bank Zones):*** Well rooted herbaceous plants, emergent wetland species, supple, shrubby woody species. Periodic removal of woody tree species may be necessary to reduce resistance to flow (roughness) in the floodplain.
>
> ***Floodplain (Lower Overbank Zone):*** Supple woody species. Periodic removal of woody tree species may be necessary to reduce resistance to flow (roughness) in the floodplain.
>
> ***Low Terrace (Upper Overbank Zone):*** Supple, shrubby woody species as well as willow, ash, cottonwood, box elder tree species. Vegetation composition should be carefully integrated with human uses to maintain resistance to flow (roughness) as described in the guiding principles.
>
> ***High Terrace (Transition Zone):*** High terraces can support a wide variety of native and cultivated vegetation depending on the use. However, if the vegetation cover is relatively low resistance to flow, revegetation guidelines including the installation and maintenance of hedgerows or low berms aligned at right angles or angled downstream to the stream flow to provide increased resistance to flow across these surfaces. Levees or hedgerows should never be placed parallel to stream flow. Bare ground should be avoided.
>
> ***Hedgerows****:* In the high terrace and upland areas riparian vegetation is naturally more sparse due to greater distances from ground water. In addition many of these areas will be utilized for non-structural human uses. Agricultural fields, orchards, pastures, parks, and golf courses are generally composed of vegetation with low flow resistance (roughness). In order to slow overland flows and divert them back to the river, a series of hedgerows should be installed perpendicular to stream flow. These hedgerows can consist of dense hedges of stiff, shrubby plant species (native species, ornamental species, grape arbors). Hedges should be dense or planted in multiple rows. Hedgerow features can also be created by constructing low berms (1-2 feet) of rock or compacted soil. Soil berms should be planted to stabilize soils. (See structural stabilization: Terraces)
>
> ***UPLAND AREAS****:* It is recommended that upland areas be vegetated consistent with high terrace recommendations.

AREAS WITHOUT NRCS DIKES

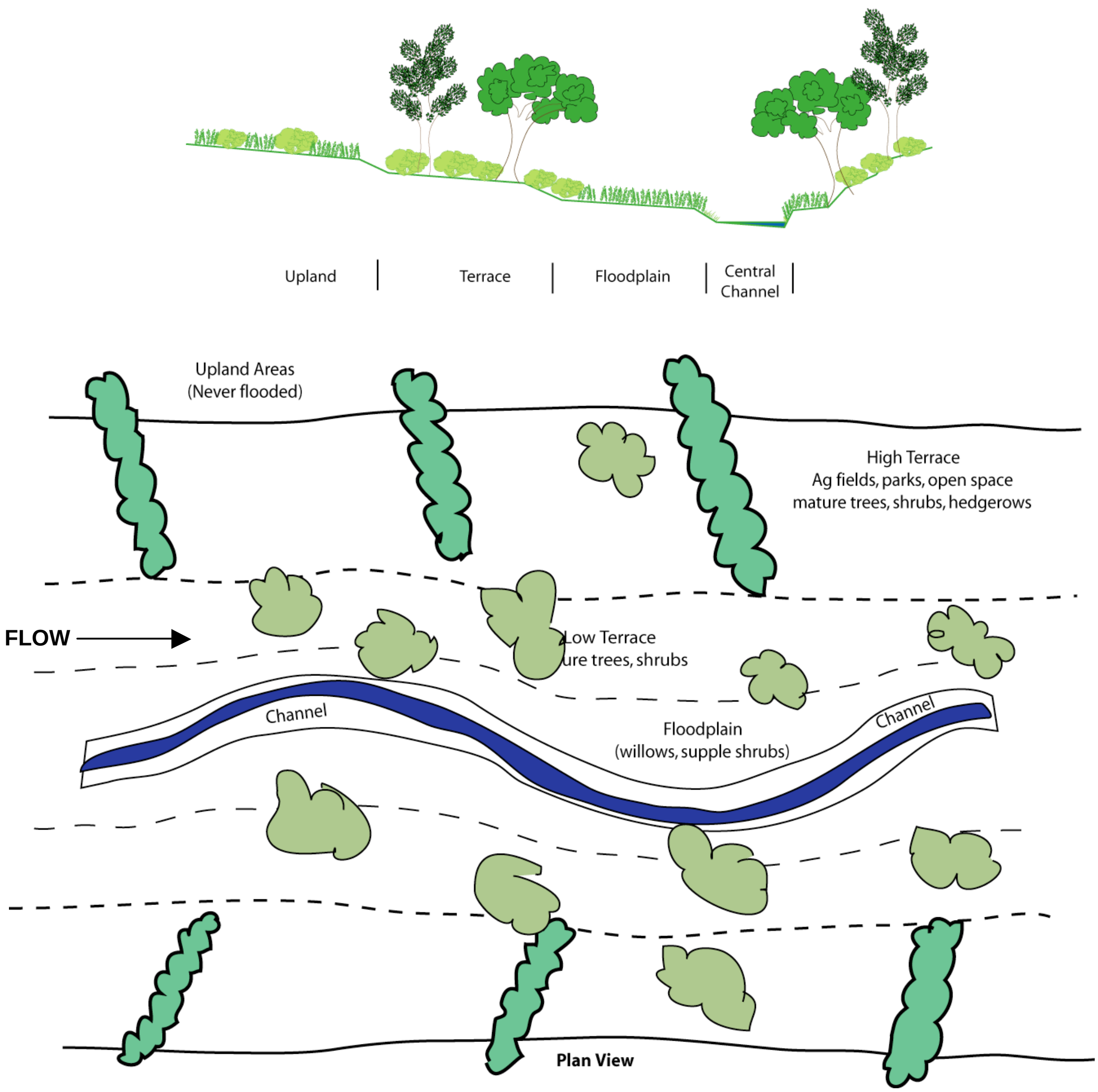


Figure 3-16. Riparian revegetation in areas without dikes.

AREAS WITH NRCS DIKES

Areas within NRCS dikes: Composition and distribution of riparian plant communities will be identical to the channel, floodplain, and low terrace prescriptions presented in the reaches without revetments. Vegetation composition should be carefully integrated with human uses to maintain resistance to flow (roughness) as described in the guiding principles.

Areas behind NRCS dikes*:* the composition and distribution of plants should be consistent with recommendations for high terrace and upland areas.

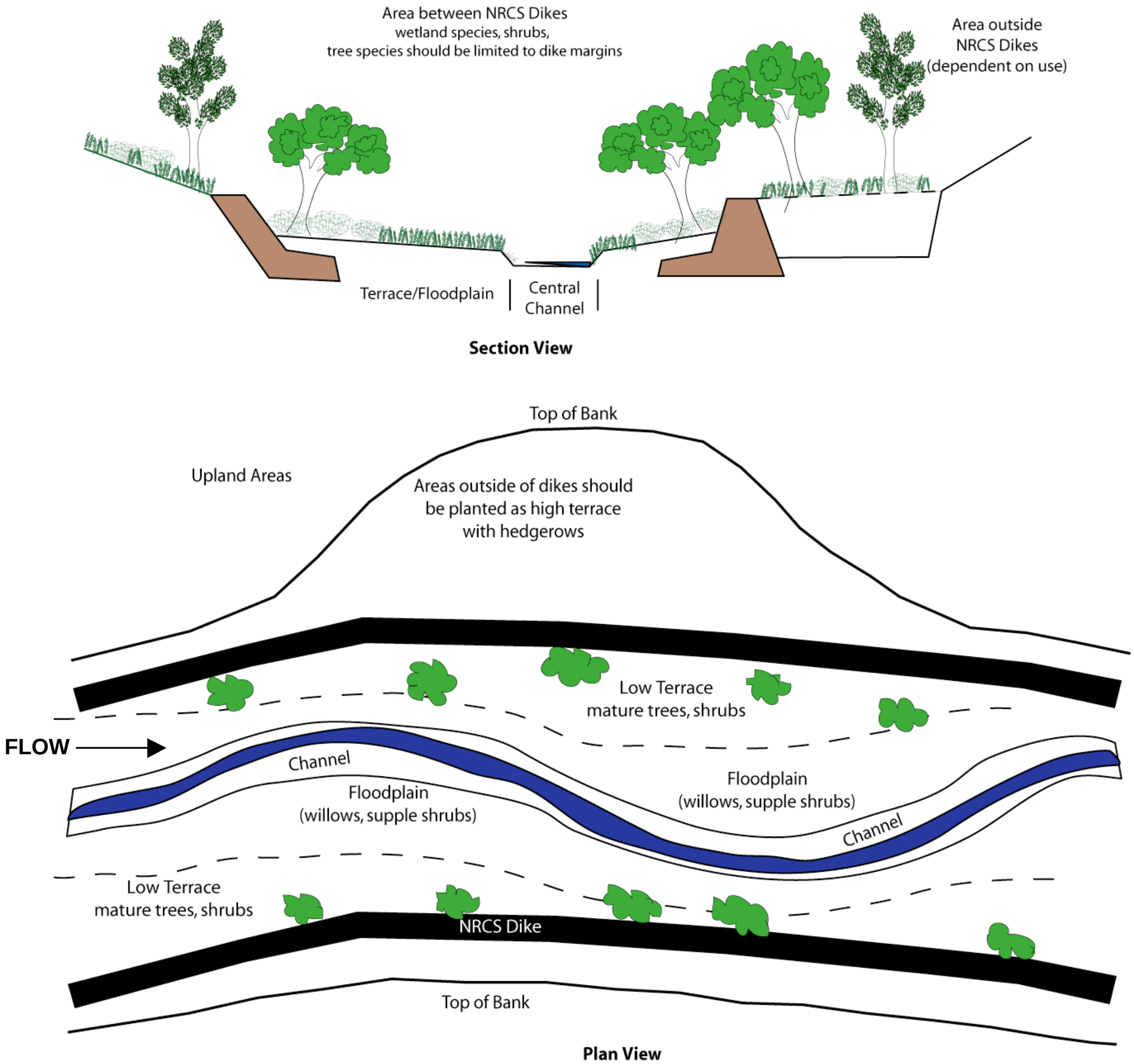


Figure 3-17. Riparian revegetation in areas with dikes.

PLANTING RECOMMENDATIONS

Appropriate composition, distribution, and density of riparian vegetation will be essential to maximizing stream stability and minimizing erosion risk. Specific plant communities should be established or maintained on alluvial features as described below.

(The following recommendations are adapted from NRCS-Plant Materials Center field report, Hoag & Ogle.)

CHANNEL AREA

(Toe and Bank zone)
These zones experience high soil moisture conditions and high stream scour. Plants must have well developed root systems and be able to tolerate a wide range of soil moistures.

creeping spikerush (*Eleocharis palustris*)
sedge species – Not many here, most common would probably be porcupine sedge (*C. hystercina*)
Baltic rush (*Juncus balticus*)
Coyote willow (*Salix exigua*), **mule's fat** (*Baccharis viminea*) and **seep willow** (Baccharis salicifolia) can be planted or naturally come in at the top of the bank because they have very flexible stems so when water hits them in a flood situation, they will lay down, allow the water to continue down the channel with some reduced erosive potential, and once the water is gone they come right back up to full height.
knotgrass (*Paspalum distichum*) (sometimes called vine mesquite but is not a vine but really a native grass). Knotgrass can tolerate high salinity and a waterlogged environment. It has no tolerance of shade. It sometimes can be troublesome by blocking irrigation ditches. Knotgrass reproduces from rhizomes, stolons, and seeds. It can be easily established by sowing stolons in damp holes. If planted in water, knotgrass will remain green throughout the year.

In backwater wetland areas where high flood water could spread, consider planting herbaceous plugs of **creeping spikerush** (*Eleocharis palustris*), **hardstem bulrush** (*Scirpus acutus*), and **threesquare bulrush** (*Scirpus pungens*).

Planting herbaceous plugs is expensive. However, natural regeneration is going to be much slower, weedy species will find suitable places to quickly invade, and the specific species that are hoped for may not naturally show up for a number of years. An alternative to planting the entire area would be to plant patches that are more or less perpendicular to the streamflow. Seed areas in between the patches (caution: seeding wetland plants has limited establishment success).

Cottonwoods or large shrub species such as Gooding willow or saltcedar should not be allowed in this area. Woody species such as coyote willow that have flexible stems and good root systems are the most desirable in this zone. As the larger species get established in this zone, consider removing them as they get to 2-3 inches in diameter or larger.

GEOMORPHIC FLOODPLAIN AREA
(Lower Overbank Zone)

The floodplain area should be planted to mainly woody species:
Coyote willow (*Salix exigua*),
mule's fat (*Baccharis viminea*) and
seep willow (Baccharis salicifolia).

In addition, consider planting these species in the upper overbank zone.
skunkbush sumac (*Rhus Trilobata*),
golden current (*Ribes aureum*), **roundleaf buffaloberry** (*Shepherdia rotundifolia*),
redosier dogwood (*Cornus sericea*) and
Fremont's mahonia (*Mahonia fremontii*)

These riparian plants are commonly found in semi-wet to dry situations yet they can withstand inundation for a couple of weeks. Interseed with grasses to ensure that the open spaces are occupied that will result in less reinvasion by weeds.

<u>LOW TERRACE AREA</u>
(Upper Overbank Zone)
The low terrace area lies above the geomorphic floodplain and includes the areas adjacent to the NRCS dikes. In addition to the species recommended for the geomorphic floodplain, native tree species can also be planted.

Fremont cottonwood (*Populus fremontii*)
Black willow (*Salix gooddingsi*)
Velvet ash (*Fraxinus velutina*)
Box-elder (*Acer negundo*)

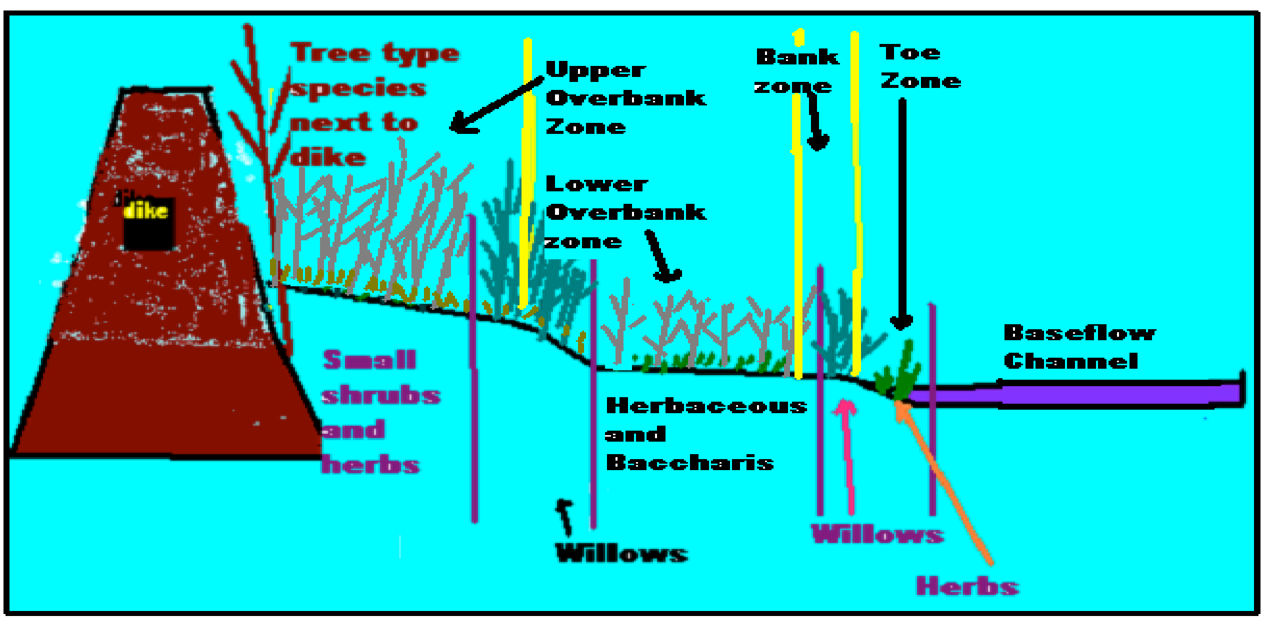


Figure 3-19: Plantings between dikes. A drawing of where to plant various types of plant species from the edge of the baseflow channel to the dike or undisturbed bank.

HIGH TERRACE AREA
(Upper overbank & Transition Zones)
The high terrace includes drier areas removed from the soil moisture from base stream flows. This are generally requires supplemental irrigation to get started though, once established, many native plants can survive. In many areas the high terrace will be utilized as pasture, parks, golf courses, or other non-native uses. Individual plantings will vary greatly in these areas depending on the use.

In areas where native vegetation is desired the following hardy native shrubs thrive in arid conditions.

Four-wing salt bush (*Atriplex canescens*)
Quailbush (*Atriplex lentiformis*)

Between the dike and the bank
The area between the dikes and the streambank will vary in size. Generally it will be about 15-20 ft. This is the perfect place to plant cottonwood species and Gooding willow that will provide both shade and water quality improvement benefits. These can be planted with poles that are harvested from local trees and large shrubs along the river. The procedure is to cover the dike with a 1- 3 ft layer of good topsoil. Angle the poles from the bottom of the hole to at least 1 ft over the top of the dike. The same should be done at the streambank side. Place cottonwood poles on the streambank side and willow poles on the dike side. Lay them on the topsoil about 3-4 ft apart. Depending upon the percent establishment success, they can be thinned as they mature. Fill in with good quality topsoil. Place an irrigation pipe in the middle of the fill to water the poles as needed. An engineer can determine the size of the pipe and the holes that should be in it to effectively water the plants when they attain a mature size.

Plant a dryland seeding mix (see Condition 3 species list below) in between the poles to provide competition with weeds.

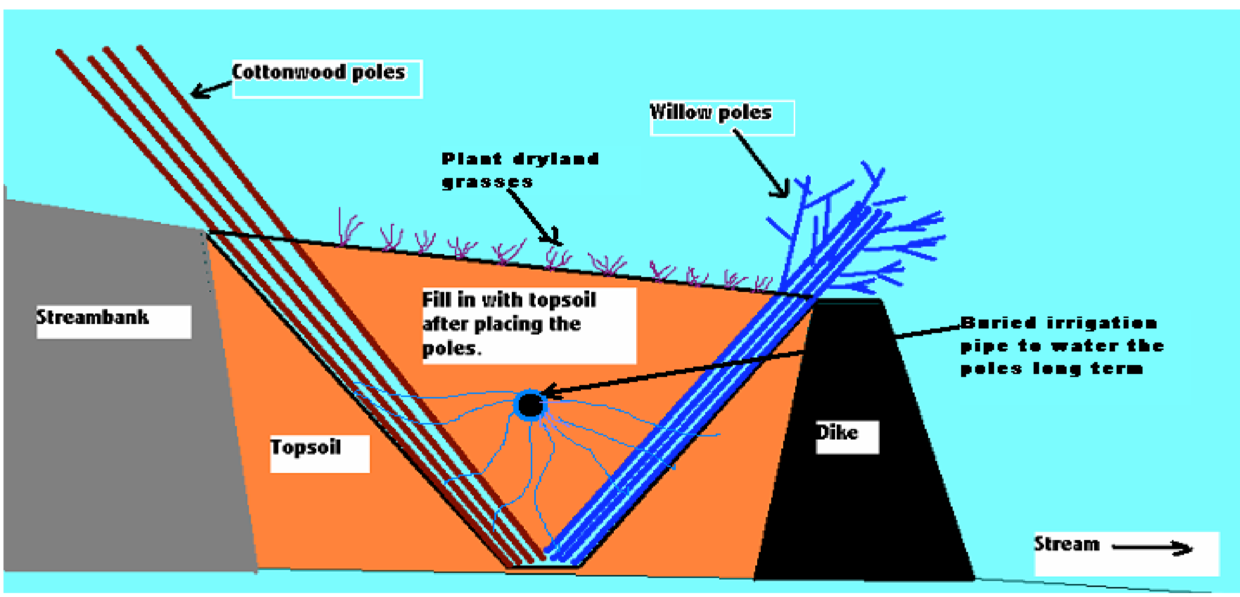


Figure 3-19: Plantings outside dikes. A drawing of how to plant the 15-20 ft area between the dike and the bank. Supplemental irrigation will be necessary for long-term survival of the cottonwoods and willows.

<u>HIGH TERRACE GROUP</u> - vegetative alternatives for the riparian transition and upland planting zones

Condition 1 – Irrigation Available Long Term (irrigated fields)

These areas are used primarily for pasture and should be planted to aggressive species with deep-strong roots with good upland weed and erosion control characteristics.

Recommended Irrigated Pasture Species and Seeding Rates
(Bulk seeding rates will be higher)(PLS = Pure Live Seed)(Critical Area Planting Rates)
(Recommend using an Entophyte free variety of tall fescue to avoid fescue foot disease)

CULTIVAR	SPECIES	PLS RATE	DESIRED	PER ACRE	ACRES	NEEDED
	tall fescue	10	100	10		0
				0		0

An area of 35-50 ft from dike into upland should be treated with a planting of dense shrubs and trees.

Near dike shrub species might include coyote willow and skunkbush (squawbush) sumac (squawbush) and tree species might include Gooding willow, Fremont cottonwood, velvet ash and box elder.

Condition 2 – Irrigation Available Long Term (settings between homes and rock dikes)

These areas are used primarily as a buffer transition zone between the dikes and homes. They should be planted to species with deep root systems that have good upland weed and erosion control characteristics. We do not recommend planting common sod grass species such as creeping red fescues, bentgrasses or Kentucky bluegrass in this zone. In addition we do not recommend these areas be mowed and treated as an extension of the homeowner’s back yards because this will reduce the general vegetative roughness of the area and reduce the erosion control – sediment trapping characterizes for future site protection.

Recommended Irrigated Species and Seeding Rates
(Bulk seeding rates will be higher)(PLS = Pure Live Seed)(Critical Area Planting Rates)
(Recommend using an Entophyte free variety of tall fescue to avoid fescue foot disease)

CULTIVAR	SPECIES	FULL PLS RATE	% MIX DESIRED	RATE PER ACRE	ACRES	LBS PLS NEEDED
	tall fescue	10	30	3		0
	orchardgrass	8	40	3.2		0
	mammoth wildrye	15	30	4.5		

An area of 35-50 feet from dike into upland should be treated with a planting of dense shrubs and trees.

Near dike shrub species might include coyote willow and skunkbush sumac (squawbush) and tree species might include Gooding willow, Fremont cottonwood, velvet ash and box elder.

Condition 3 – Dryland or Rangeland Areas

These areas are generally found away from homes and irrigated pasture areas. They are characterized by the fact they generally do not have supplemental irrigation available and could be considered the most common condition found in the transition and upland zones. These areas would be considered transitional native riparian areas and rangelands. Many of these areas are being or may soon be subject to urbanization (new home sites, parks, golf courses, etc.). It is recommended that no permanent structures be allowed in this transition zone.

These upland areas are subject to very low natural rainfall conditions which average about 5-6 in of mean annual precipitation. Many of these areas are in damaged condition due to high flood flows that caused scouring of soils and vegetation and significant sedimentation depending on location. Many of these areas are expected to recover to a desired condition without planting.

Areas that were completely destroyed and will be reconstructed by filling with native soils will require planting and seeding. A very drought tolerant native species mix is recommended for this area. It is also recommended that when possible a temporary supplemental irrigation system be installed to irrigate these plantings for 1-2 growing seasons to ensure species establishment. Once plantings are established, this temporary system can be removed. Species are well established when they begin to grow reproductive stems (i.e. plants begin to produce seed).

The upland seed mix shall contain Indian ricegrass (*Achnatherum hymenoides*), mesa dropseed (*Sporobolus flexuosus*), knotgrass (*Paspalum distichum*), four-wing saltbush (*Atriplex canescens*), quailbush (*Atriplex lentiformis*) and desert almond (*Prunus fasciculata*) seeded at a rate of 8 lbs. pure live seed (PLS) per acre.

In areas where supplemental irrigation is not possible, this seeding mix should be planted with the understanding that plant establishment will be significantly reduced.

These areas may or may not be located near dikes. Whether they are near dikes or not, an area of 35-50 ft from dike or similar area into upland should be treated with a planting of dense shrubs and trees.

Near dike shrub species might include coyote willow and skunkbush sumac (squawbush) and tree species might include Gooding willow, Fremont cottonwood, velvet ash and box elder.

One other consideration under this condition may be to plant deep potted shrubs that were started under greenhouse or nursery conditions. These are shrubs planted in PVC pots that are 2-3 ft deep thus allowing a longer-deeper root system that is more likely to establish and survive in very dry/droughty locations. Research on the development of this technique has been conducted at Los Lunas, NM, Plant Materials Center (PMC). Contact Greg Fenchel at Los Lunas PMC, (505) 865-4684 for more information on this technology.

STABILIZATION STRATEGIES

BIOENGINEERING PRACTICES

Bioengineering is the use of native plant materials and associated “soft” structures to stabilize stream banks, floodplains, and terraces.

Brush Revetment: Brush or trees are secured to the streambanks to slow excessive erosion by diverting the current away from the bank edge’s. The revetment also traps sediment from the stream and sloughing streambank and provides cover for fish habitat. The revetment material does not need to sprout (most species used will not). Always plant live willows or other quickly sprouting species behind the revetment to provide permanent cover and roots.

Pole Planting: Pole plantings are cuttings from willow (*Salix* spp.) or cottonwood (*Populus* spp.) used to revegetate eroding streambanks. These cuttings will sprout and take root, stabilizing the streambank with a dense matrix of roots.

Post Planting: Post plantings use large diameter cuttings from cottonwood (*Populus spp*.) or willow (*Salix spp*.) to revegetate eroding streambanks and reservoir and lake edges. By using a stinger, posts may be planted into existing rip-rap. A stinger is a large metal punch bar mounted on a backhoe. These cuttings will sprout and take root, thus stabilizing the streambank with a dense matrix of roots.

Brush Mattress: This technique uses a mat of willow cuttings along the slope of an eroding streambank. The cut ends of the willows are placed in a trench at the toe of the slope and are anchored with a wattle. A grid of wire and wooden stakes is used to secure the mat to the slope. The willow cuttings will sprout and take root, thus stabilizing the streambank with a dense matrix of roots.

Fiberschines: This technique uses a coconut-fiber roll product to protect the streambank by stabilizing the toe of the slope and by trapping sediment from the sloughing streambank. Cuttings and herbaceous riparian plants are planted into the fiberschine and behind it. By the time the fiberschine decomposes, riparian vegetation will have stabilized the streambank.

Brush Layer: This technique uses bundles of willow cuttings (*Salix* spp.) in buried trenches along the slope of an eroding streambank. This willow "terrace" is used to reduce the length of slope of the streambank. The willow cuttings will sprout and take root, thus stabilizing the streambank with a dense matrix of roots. Some toe protection such as a wattle, fiberschine, or rock may be necessary with this technique.

Brush Trench: This technique uses bundles of willow cuttings (*Salix* spp.) in a buried trench along the top of an eroding streambank. This willow "fence" filters runoff before it enters the stream and is a good method for alleviation of piping problems. The willow cuttings will sprout and take root, thus stabilizing the streambank with a dense matrix of roots. This technique should be used in combination with toe and mid-bank protection methods such as wattles, fiberschines, brush revetment, brush mattress, rock., etc.

Vertical Bundles: This technique uses bundles of willow cuttings (*Salix* spp.) placed in vertical trenches along an eroding streambank. The willow cuttings will sprout and take root, thus stabilizing the streambank with a dense matrix of roots. Revetment and/or erosion control fabric should be used to protect the bundles until they have become established. This technique is good for areas with fluctuating water levels.

Source: The Practical Steambank Bioengineering Guide, Gary Bentrup and J. Chris Hoag. USDA-Natural Resources Conservation Service, Plant Materials Center. Aberdeen, Idaho. 1998.

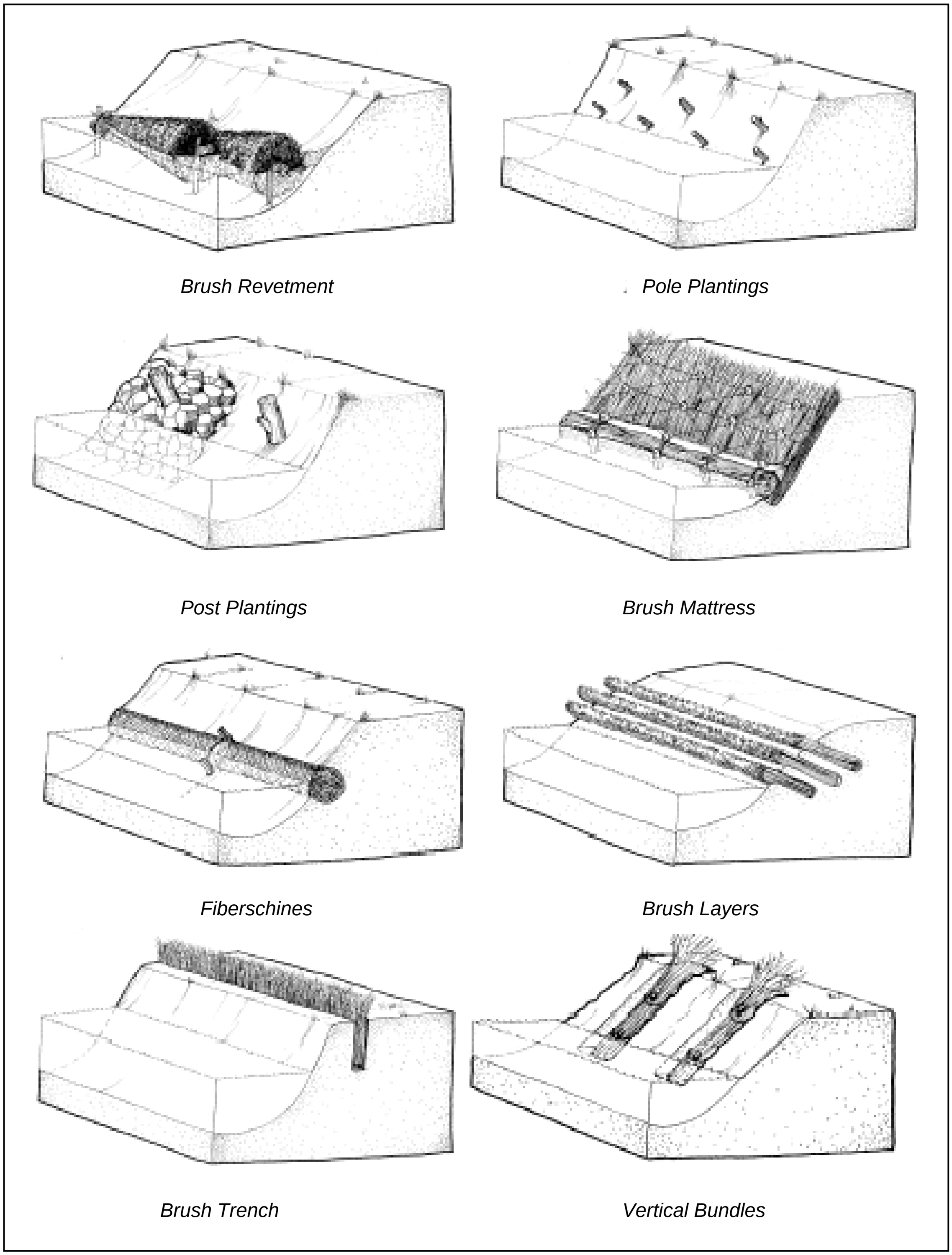


Figure 2-20. Bioengineering Practices.
Source: The Practical Steambank Bioengineering Guide, Gary Bentrup and J. Chris Hoag.
USDA-Natural Resources Conservation Service, Plant Materials Center. Aberdeen, Idaho. 1998

TECHNICAL REFERENCES:

The best resource for planting native vegetation to reduce bank erosion is the USDA-NRCS Plant Materials Center in Aberdeen, Idaho. A sample of their technical publications are listed below:

- Bentrup, G. and J.C. Hoag. 1998. The Practical Streambank Bioengineering Guide. USDA-NRCS Aberdeen Plant Materials Center, Aberdeen, ID. May 1998. 151p. (3.5 MB) (ID# 116)
- Hoag, J.C. and J. Fripp. 2002. Streambank Soil Bioengineering Field Guide for Low Precipitation Areas. USDA-NRCS Aberdeen Plant Materials Center and the USDA-NRCS National Design, Construction and Soil Mechanics Center, Aberdeen, ID. December, 2002. 64p. (6.65 MB) (ID# 3883)
- Hoag, J.C. 1993. Technical Note 23: How to plant willows and cottonwoods for riparian rehabilitation. USDA-NRCS, Boise, ID. ID-TN23, Sept. 1993. 15p. (37 KB) (ID# 1043)
- Hoag, J.C. 2003. Technical Note 13: Harvesting, Propagaing, and Planting Wetland Plants. USDA-NRCS Aberdeen Plant Materials Center, Boise, ID. TN-13, Dec. 2003. 11p. (653 KB) (ID# 5160)
- Ogle, D., J.C. Hoag, and J. Scianna. 2000. Technical Note 32: Users guide to description, propagation and establishment of native shrubs and trees for Riparian Areas in the Intermountain West. USDA-NRCS, Boise, ID and Bozeman, MT. ID-TN32, Feb. 2000. 22p. (573 KB) (ID# 2251)
- Hoag, J.C. 2003. Technical Note 42: Willow Clump Plantings. USDA-NRCS Aberdeen Plant Materials Center, Boise, ID. TN-42, Dec. 2003. 8p. (1.6 MB) (ID# 5159)
- Hoag, J.C., F.E. Berg, S. K. Wyman, and R.W. Sampson. 2001. Riparian/Wetland Project Information Series No. 16: Riparian Planting Zones in the Intermountain West. USDA-NRCS Aberdeen Plant Materials Center, Aberdeen, ID. Mar. 2001. 24p. (2.2 MB) (ID# 1084)

These and more technical publications can be obtained at:

http://www.plant-materials.nrcs.usda.gov/idpmc/riparian.html

STRUCTURAL PRACTICES

Structural bank stabilization may be necessary to protect valuable properties or infrastructure. Structural practices should always be integrated with bioengineering practices described in the previous sections.

For additional technical information see:

Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

BANK STABILIZATION: Bank sloping

Mechanical and/or manual bank sloping greatly reduces the erodibility of stream banks. Structural stabilization such as rock generally require slopes of 1.5: or less. Bioengineering is much more successful if slopes are less than 3:1. Not only are banks more stable but vegetation grows more vigorously on gradual slopes (Figure 3-21).

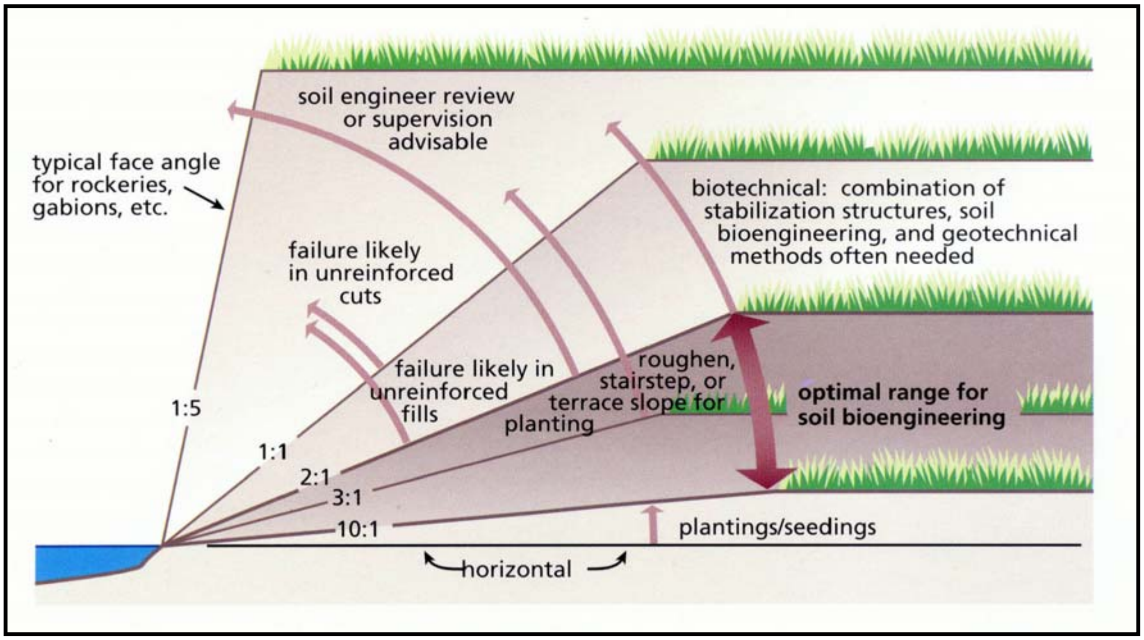
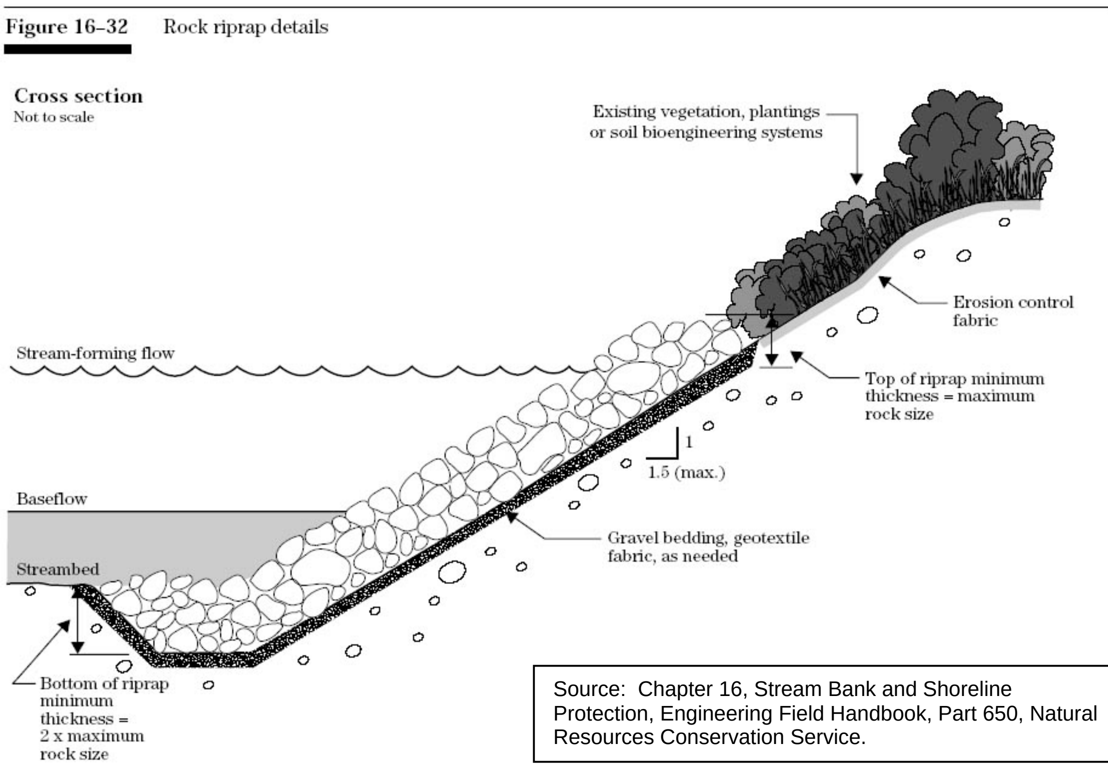


Figure 3-21. Stream bank slope stability. Stream banks with more gradual slopes are less erodible and easier to stabilize with native plant species. (Stream Corridor Restoration, Federal Interagency Stream Restoration Working Group).

BANK STABILIZATION: Toe Rock

Toe rock is a structural practice using properly sized and graded angular rock to stabilize the toe of the bank (Figure 3-22). These practices are generally only necessary on the outside of a meander. Rock is installed to the floodplain elevation (Gunlock: 4-feet, Santa Clara-St. George: 5-feet) to allow flows to spread across the active floodplain. Rock sizing/grading, scour depth, and tie back requirements should be determined for the specific site using appropriate NRCS or other engineering procedures. Bioengineering practices should be installed along the bank above the toe rock.



Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

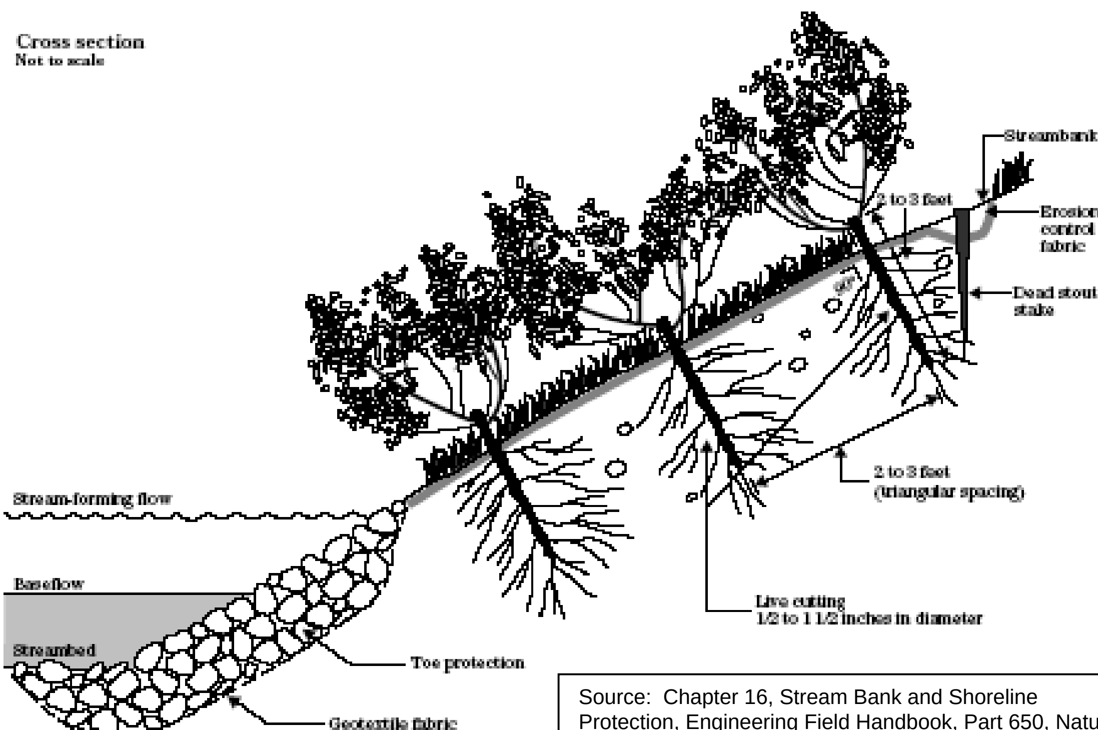
Figure 3-30. Toe Rock. This structural practice is generally installed along the outside of a meander bend to reduce the risk of lateral erosion.

BANK STABILIZATION: Live stakes

Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground. If correctly prepared, handled, and placed, the live stake will root and grow.

A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out a bank soon after installation (Figure 3-22).

Figure 16–4 Live stake details

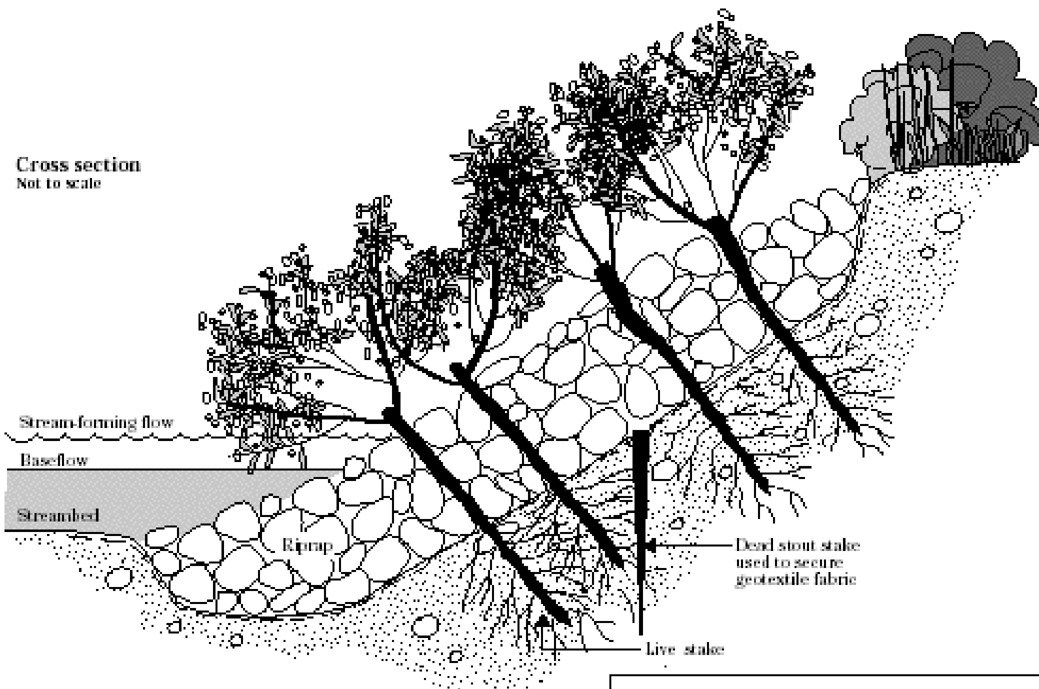


Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 3-23. Live Stakes. This structural practice can be installed with or without structural stabilization.

BANK STABILIZATION: Joint Planting

Joint planting or vegetated riprap involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope (Figure 3-24). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.

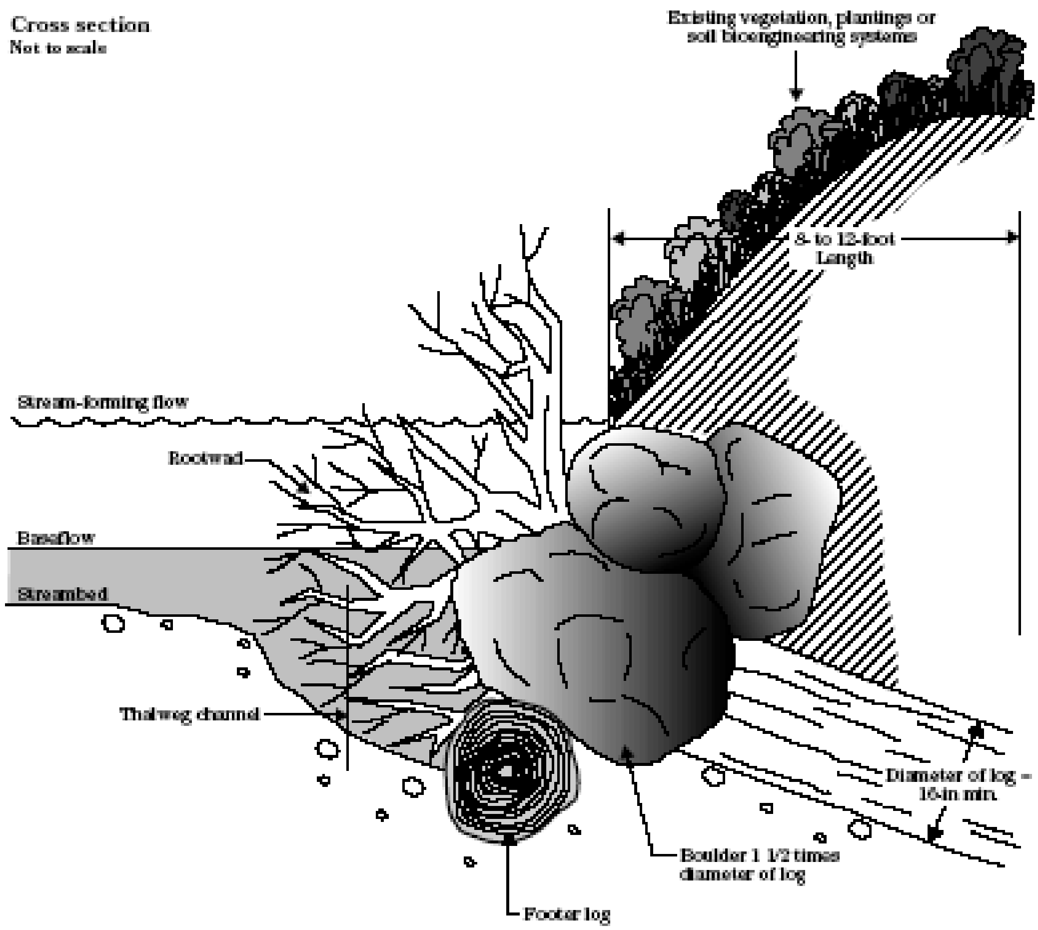


Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 3-24. Joint planting. Native vegetation combined with rock stabilization.

BANK STABILIZATION: Root Wads

These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks (Figure 3-25). These revetments can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms, and increased stream velocity that results in sediment flushing and deeper scour pools.

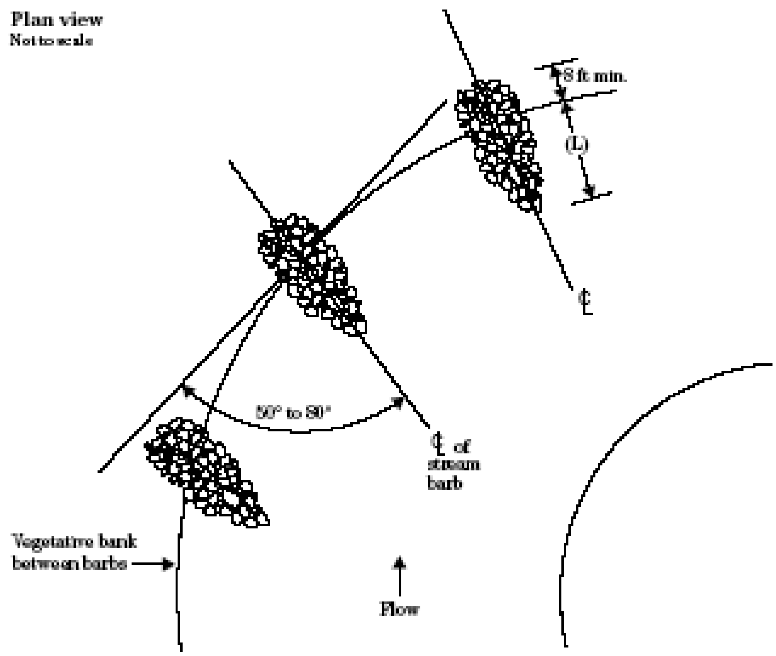


Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 3-25. Root wads. The root system provides structural protection and increases aquatic habitats.

BANK STABILIZATION: Stream Barbs/Rock Vanes

Stream barbs serve as an alternative to traditional rock armoring. Sometimes called vanes, the low structures redirect flows to the center of the channel reducing velocities against sensitive bank areas (Figure 3-26). The rock structures are angled upstream and dip downward from floodplain elevation at the bank to the channel bed. They never extend more than 1/3 of the way across the bankfull channel (Rosgen 2002). The structures are generally installed in series along the outside of a channel meander.



Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service. Page 16-58.

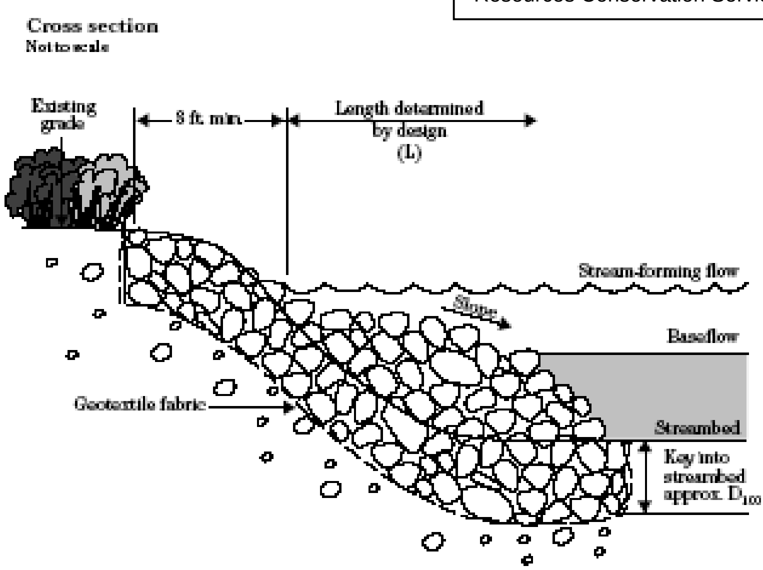


Figure 3-26. Stream barbs/rock vanes. These low structures redirect flows away from erodible banks and to the center of the stream channel.

TERRACE STABILIZATION: Terrace Hedgerows
The greatest threat to erosion along the terraces is high velocity flows separated from the central stream channel. Many of these areas will be used for recreational parks, golf courses, or agricultural fields and will not have dense, continuous vegetation. In order to increase roughness and redirect overbank flows toward the central channel, series of hedgerows should be constructed periodically along the terraces. These hedgerows can be created using low rock levees or well-rooted, stiff woody plant species. They can be installed perpendicular or angled downstream (Figure 3-27).

Woody hedgerows can be created using native vegetation, ornamental hedges, or even grape arbors. Hedgerows can be planted between fields and along fairways and city parks. Hedgerows should never be planted in continuous sections parallel to the stream flow because they will reduce the ability for overbank flows to return to the river.

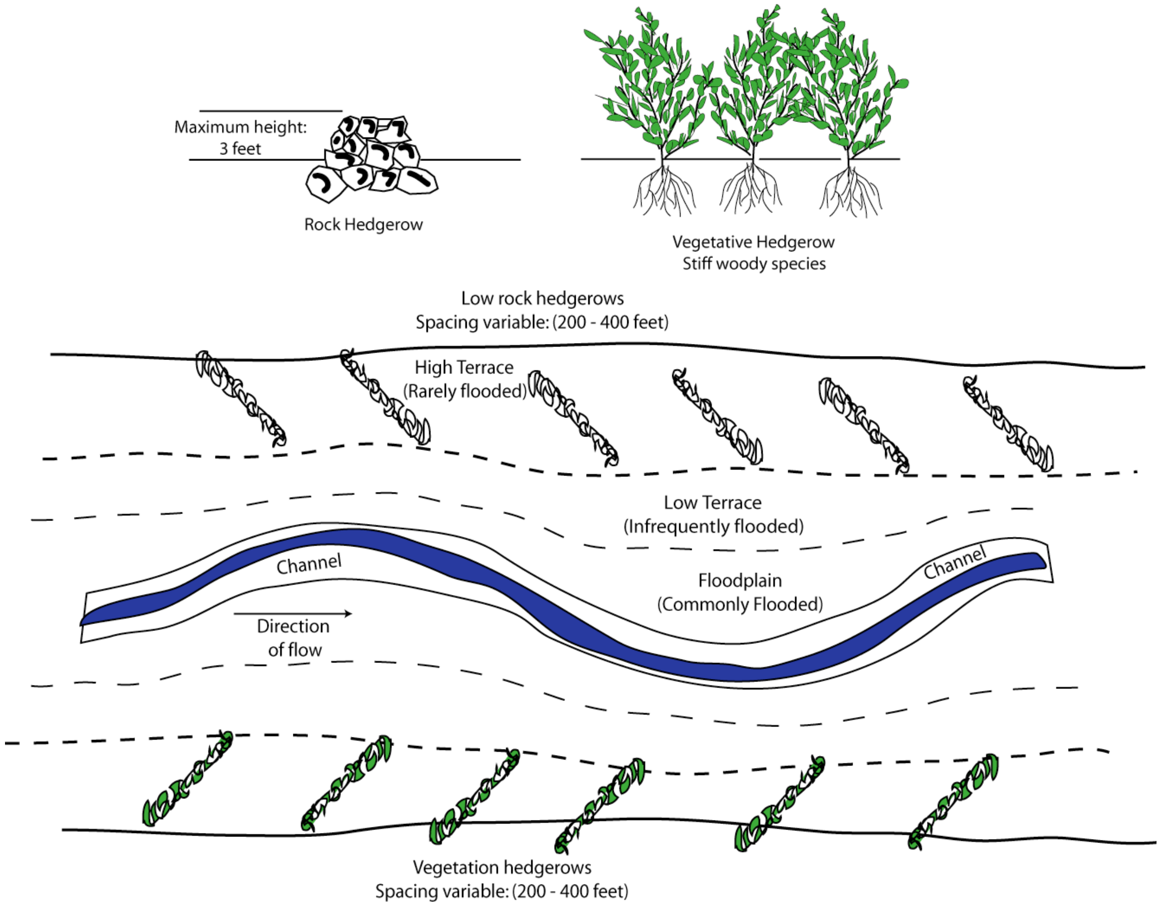


Figure 3-27 Terrace stabilization

MAINTENANCE:

REMOVAL OF EXOTIC PLANT SPECIES

Efforts have been underway for some period to eradicate saltcedar or tamarisk (*Tamarix ramosissima*) from the Santa Clara River corridor. Because saltcedar has the reputation for aggressively colonizing disturbed riparian areas, the minimization of tamarisk colonization following the January 2005 flooding is a prime objective of the Master Plan.

Recent research suggests that saltcedar does not have a competitive edge over native riparian species such as Coyote willow (Salix exigua) and cottonwood (Populus fremontii) with respect to seedling growth and establishment, at least under natural spring flood conditions (Glenn & Nagler 2005). However if sufficient seed bank for the native species is not available, the aggressive saltcedar seed dispersal strategy can be very successful. In cases where large scale disturbance of riparian areas occurs, through large flood events or mechanical removal of dense monotypic stands of exotic vegetation, active revegetation with native riparian species can substantially reduce the invasion of saltcedar and other exotics (Taylor & McDaniel 2004).

An exotic species strategy was created based on this information and the assessments of experts (Chris Hoag, NRCS-PMC; Fred Phillips, Fred Phillips Consulting; Curt Deuser, NPS-Exotic Removal Team) who evaluated the area.

GENERAL RECOMMENDATIONS

The exotic species strategy consists of three elements:

1) Minimize saltcedar recolonization through mechanical, chemical, or manual means,
2) Enhance the reestablishment of native species through aggressive revegetation and
3) Systematic/strategic removal of existing saltcedar and revegetation with native species.

- Focus on areas that have already been cleared and/or have valuable stands of native vegetation that are threatened by tamarisk

- Construct a reliable source of mass cottonwood and willow poles by creating some flood irrigated cells on the outer edge of the floodplain that can be planted with very dense cottonwood/willow trees and then cut down every year to have a sustainable supply of cuttings for restoration.

- Complete soil sampling and revegetation design for areas prior to saltcedar removal so there is a follow up plan to get native vegetation established as quickly as possible after site clearing.

- Develop community based education/volunteer programs that include volunteer planting days, weeding areas and educational events.

SPECIFIC AREA RECOMMENDATIONS

AREA 1: Wetland/low areas completely scoured by the river or currently being excavated;

- Since most of the tamarisk that will recolonize these areas will be seed borne, visual monitoring of these areas every 2-3 weeks should be conducted to detect the amount of seed borne tamarisk and what areas they are recolonizing. In areas where tamarisk is recolonizing, areas should be treated mechanically (scraped or disked), manually (handpulling), or with herbicides to remove seedlings before they reach a height of 3”. Areas should be retreated as needed. If revegetation will not occur immediately a cover crop of inland saltgrass, rye grass or sterile field crop should be planted to help outcompete tamarisk seedling until permanent planting occurs.

AREA 2: In upper terrace areas where there is a mix of tamarisk/cottonwood/willows

- Current efforts to remove tamarisk and other exotic species from the riparian corridor should be continued. Selective clearing is recommended in these areas to minimize disturbance and impacts to existing native habitat. Trees should be chain sawed at the base of the trunk and immediately sprayed with Garlon 4 or Pathfinder herbicide. Follow-up spraying should be applied as needed. Application of these herbicides requires training and state certification. Cleared materials should be mulched or burned.

AREA 3: In areas with monotypic stands of dense tamarisk

- Large monotypic stands of tamarisk are located in the lower Santa Clara near Tonoquint Park. In these areas the most effective method would be the wholesale removal of the stands with heavy equipment (dozers, excavators) and then either mulching, burning or piling cleared materials into windrows. In the high terrace areas, the material can be piled into windrows used to direct water flow and increase stream stability (see Terrace Stabilization). Follow-up herbicide treatment may be necessary to treat resprouting.

  Removal of these stands should be completed in a manner consistent with the guiding principles. Thickets should be removed in bands parallel to the stream channel beginning along the channel margins. Native riparian species should be established immediately to reduce the risk of erosion and/or recolonization of tamarisk. Only when the native vegetation is established should the next band be removed. Do not remove large thickets of established vegetation (native or non-native) in the low or high terrace areas without replacing them with structure of similar roughness. (See Terrace Stabilization).

CHANNEL CAPACITY

While riparian vegetation is crucial to maintaining channel stability and minimizing erosion risk, inappropriate vegetation can create conditions that increase erosion risk. The primary concern is the dense growth of stiff, tree species in the channel and floodplain areas. During periods with few floods, cottonwood, willow, and ash trees can sprout and thrive in these areas. When high flows return, these thickets of trees can redirect flows to more erodible bank areas.

Periodic maintenance is recommended to remove all woody stems greater than 2-inches in diameter at breast height (DBH) from the channel and geomorphic floodplain areas on the Santa Clara River (Figure 3-28). Maintenance recommendations apply equally to areas with NRCS dikes and those without. Woody plants should be removed manually (chainsaws) rather than using heavy equipment. Maintenance need not occur annually in all reaches. A rotating maintenance effort could target different reaches each year and incorporate community volunteers. Maintenance can be coordinated with dormant (winter) season planting efforts. Woody stems greater than 1/2 inch in diameter can be replanted in other more appropriate areas. Small plant materials can be left on the ground to provide organic matter and small mammal habitat.

Initially, all channel clearing should be completed manually. If manual methods are found to be insufficient to maintain a clear channel, effective mechanical means can be evaluated that minimizes impacts to the native riparian vegetation and alluvial features.

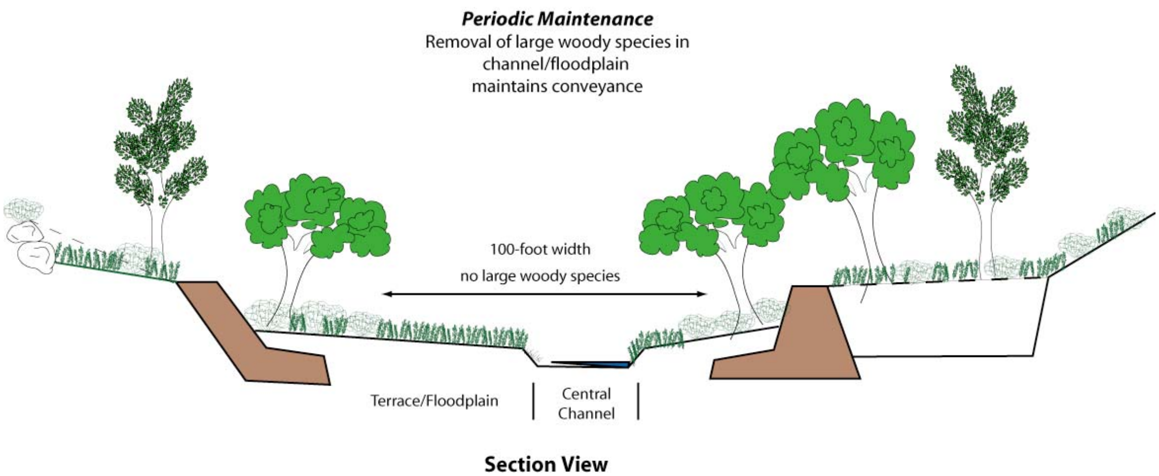


Figure 3-28. Maintenance of Riparian Vegetation. Large woody species (>2 inches) should be trimmed from the channel and floodplain in areas with and without dikes.

SECTION 4: SPECIFIC REACH MAPS/RECOMMENDATIONS

GENERAL GUIDELINES

The following general guidelines should be used in prioritizing areas for treatment and in determining appropriate

- Channel alignments on the maps are approximate and can be modified to accommodate property boundary, land reclamation, right-of-way, and other considerations. However, transitions should be gradual and meander pattern (radius of curvature, meander width, meander length) should be consistent with the Master Plan values. Floodplain and terrace elevations should be maintained low enough to allow high flows to spread and dissipate energy.
- Structural protection (rock riprap, levees, or similar) should be limited to valuable infrastructure threatened by stream flows.
- In general, structural protection should be installed only on the outside of a meander bend adjacent to the infrastructure to be protected. Geomorphic floodplains and terraces should be preserved.
- Channel, floodplain, and terrace widths should be protected and maintained to allow dissipation of high flow energies.
- All treated areas should be replanted with native riparian vegetation as described in the Santa Clara Master Plan.

MAGOTSU CREEK/MOODY WASH – GUNLOCK RESERVOIR

Magotsu Creek/Moody Wash – Gunlock Town (no map)

This reach is generally undeveloped, rural and dominated by public lands. The riparian corridor is well vegetated with native species. Although considerable local scour occurred throughout the reach, the channel is expected to heal naturally. There are several areas where infrastructure and/or private lands may require additional protection. Gunlock Springs, the Gunlock waterline, county roads and bridges, and private agricultural lands should be protected as needed.

a) All protection should be designed and installed in accordance with the Master Plan guidelines. Structural bank protection should be primarily limited to the outside of meanders. Floodplains and pointbars along the inside of meanders should be maintained to allow high flows to spread energies reducing velocities. Specific area recommendations are given below.
b) Roads, bridges, and other transportation infrastructure should be protected where threatened. Structural protection should be engineered with adequate rock sizing, thickness, and scour depth. Where there is space available, low toe rock should be installed to the height of the geomorphic floodplain (2-3 feet above channel bed) and 25 – 30 feet away from the road leaving a narrow gradually rising geomorphic floodplain. The toe rock protects the bank from erosion but does not prevent flooding. This floodplain area should be replanted with riparian vegetation to reduce flow velocities along the roadway.
c) The channel at Gunlock springs should be protected by structural toe rock along the base of the bank. The spring area received only minor damage during the January 2005 flood. However, toe protection reduces the threat of future erosion. The Gunlock waterline should be protected with structure where it is threatened by stream flows.

d) Agricultural fields should generally be protected with toe rock and bioengineering practices using native willows and cottonwoods. Structural protection should be limited to the outside of meander bends.

GUNLOCK TOWN (MAPS 1&2)

The Town of Gunlock experienced significant lateral erosion during the January 2005 flood. The road and water pipeline was damaged upstream of town and substantial areas of agricultural lands were eroded along the east bank of the river. Flows were concentrated in a narrow channel downstream of the town where the county bridge was overtopped and damaged. The channel bed elevation is affected by backwater effects from Gunlock Reservoir downstream. The riparian corridor is wide in this area and flooding was limited to properties along the narrow channel above the county bridge downstream of town.

The stream channel has been relocated to allow emergency repairs to the road and water line and a gravel levee installed to protect town properties. More substantial structural protection will be needed along the road and pipeline to reduce the long-term threat of lateral erosion. Agricultural fields can also be reclaimed if desired and protected with structural toe protection. However, the wide pre-flood corridor should be maintained and replanted with riparian vegetation as described in the Master Plan.

a) The county road and pipeline should be protected structurally to reduce the risk of future lateral erosion. All treated areas should be replanted with riparian vegetation.

b) Structural protection for homes and other town properties should be installed along the right (west) bank. The levees should be set back sufficiently to maintain the broad pre-flood riparian corridor.

c) Agricultural fields on both sides of the stream can be reclaimed consistent with the recommendations in the Master Plan. If fill is added to reclaim areas, the elevations should not limit flows from spreading during high flows. In general bioengineering practices using native willow and cottonwood can provide cost effective long-term protection and toe can be used to protect critical areas.

d) Homes and road along the narrow channel upstream of the county bridge should be protected to a level to reduce the threat of lateral erosion and the potential for flooding.

e) Dredging of the reservoir delta downstream of the county bridge should be continued.

GUNLOCK RESERVOIR – SANTA CLARA/ST. GEORGE

Much of the length of the Santa Clara River between Gunlock Reservoir and Santa Clara City is undeveloped public lands. These areas experienced limited damage are expected to recover naturally from the January 2005 flood. However, county roads, private agricultural lands, and St. George City water wells were damaged or threatened during the flooding. These areas should be protected as necessary. Structural toe protection may be appropriate along the outside of meander bends and where infrastructure value warrants the expense. All treated areas should be reestablished in all treated areas to provide additional long-term bank stability.

Recommendations for specific areas are described below.

SHIVWITTS RESERVATION (MAPS 3&4)

Significant erosion of agricultural fields within the Shivwitts Reservation occurred during the January 2005 flood.

- The county and state roads and bridges should be protected structurally to reduce the risk of future lateral erosion. All treated areas should be replanted with riparian vegetation.
- Agricultural fields can be reclaimed consistent with the recommendations in the Master Plan. If fill is added to reclaim areas, the elevations should not limit flows from spreading during high flows. In general bioengineering practices using native willow and cottonwood can provide cost effective long-term protection and toe can be used to protect critical areas.

THREE-MILE AREA (MAPS 5&6)

Private properties in the Three-mile area were damaged during the January 2005 flood. Significant lateral erosion occurred on the outside of all meander bends. The stream channel can be largely restored to pre-flood alignments if so desired. Where the channel is realigned, structural toe protection will likely be required to minimize the risk of erosion of the unconsolidated fill. Low areas in the eroded meanders and behind structural protection should be filled to floodplain elevation to the extent possible. If the areas cannot be filled, cells should be created (berms perpendicular to the river) as described in the Master Plan.

Where desired the outside of meander bends can be protected in place using structural and/or bioengineering practices. It is recommended that the riparian vegetation be reestablished in all areas to provide additional long-term bank protection.

The inside of meander bends (point bars) need not be protected structurally. The elevations of these areas should be maintained low enough to allow high flows to spread and dissipate energy. The stream corridor should not be narrowed beyond pre-flood widths.

SANTA CLARA – ST. GEORGE SECTION

REACH 1. SANTA CLARA CITY LIMITS TO DIVERSION (MAPS 7&8)

a) Historic diversion structure on BLM lands above Rosenbruck property is at risk of failure from bank erosion. Measures should be taken to reinforce the right side of the structure.
b) The majority of this property is located on the inside of a meander bend and not subjected to erosion stresses. However, toe rock and bioengineering can be installed to protect the upstream portion of this property. The agricultural fields are high terraces and were overtopped during the January 2005 flood. Flood waters trapped eroded in the downstream sections. To minimize future impacts; install hedgerows of vegetation across the fields to redirect waters back to river and reslope banks and remove levee along river to allow waters to return to river.
c) Revegetate section with native vegetation to stabilize channel.
d) Protect waterline on outside of meander with structural protection upstream of NRCS levees. Agricultural fields on point bar on inside of meander bend should be treated as in (b) above.
e) The narrow channel at Swiss Village will produce high velocities during future flood events increasing the risk of erosion on both sides of the river. If waters overtop the NRCS levees, it could threaten the state highway and other property downstream. Additional engineering analysis is recommended.
f) If the eroded meander is to be reclaimed, the stream channel can be realigned and stabilized with structural means. The area behind the levee should be filled to floodplain elevation if possible and treated as a low terrace per the Master Plan guidelines.
g) This wide area should be revegetated per the Master Plan. Agricultural fields can be reclaimed if desired. If high terraces are utilized as agricultural fields, hedgerows should be planted and maintained to redirect future high flows back into the river. If a low-water crossing is planned it should be sited in a straight (transition) section and should conform to the channel template cross-section. Channel alignment is approximate and can be modified to meet local objectives.

REACH 2. DIVERSION TO SUNBROOK GOLF COURSE (MAPS 9&10)

a) The main sewer line has been repaired and protected by a rock levee immediately below the diversion site. The area behind the levee should be filled and/or divided into cells as described in the Master Plan. Areas along the stream should be replanted with native vegetation.
b) These largely agricultural properties received little lateral erosion. However, the channel widened through the reach. Floodplain and low terraces areas can be reshaped and revegetated. High terrace areas are occupied by corrals and pastures. Hedgerows should be planted or constructed to redirect future high flows back to river.
c) Although these properties are being protected by NRCS levees, areas behind the structures should be treated as low and high terraces. Filled areas should slope upward away from the channel and be planted with hedgerows to redirect future high flows back to the river.
d) This meander may require toe rock to stabilize the outside bank. The ag fields should be contoured so that future high flows are redirected back to the river. A setback levee could be constructed to limit the flooding of adjacent fields. The setback levee should be protected by bioengineering or structure.
e) Low toe rock could be installed to reduce the risk of erosion of agricultural fields along the south bank.

f) Vegetation or structural hedgerows should be installed behind the NRCS levees to redirect future overland flows back to the river. Areas on the stream side of the levee should be replanted with native vegetation.

REACH 3. SUNBROOK GOLF COURSE TO DIXIE DRIVE (MAPS 11&12)

a) Upper part of Sunbrook Golf Course will require structural toe protection along outside of bends to minimize risk of future erosion. Appropriate bioengineering should be added to augment structural protection. Floodplains and low terraces should be replanted. Hedgerows should be installed or topography modified to redirect future high flows back into the river.
b) Middle of golf course should be replanted with riparian vegetation consistent with Master Plan and course layout.
c) River along Rivers Edge Drive should be replanted with riparian vegetation consistent with Master Plan.

REACH 4. DIXIE DRIVE TO OLIVE GROVE (MAPS 12 &13)

a) The unprotected areas around Mathis Park should be resloped and revegetated with riparian vegetation consistent with Master Plan.
b) Areas behind NRCS levees should be filled or broken into cells and replanted as described in the Master Plan.
c) Channel and floodplain areas within the NRCS levees should be shaped and replanted with native vegetation consistent with the Master Plan.
d) Areas behind NRCS levees should be filled or broken into cells and replanted as described in the Master Plan.

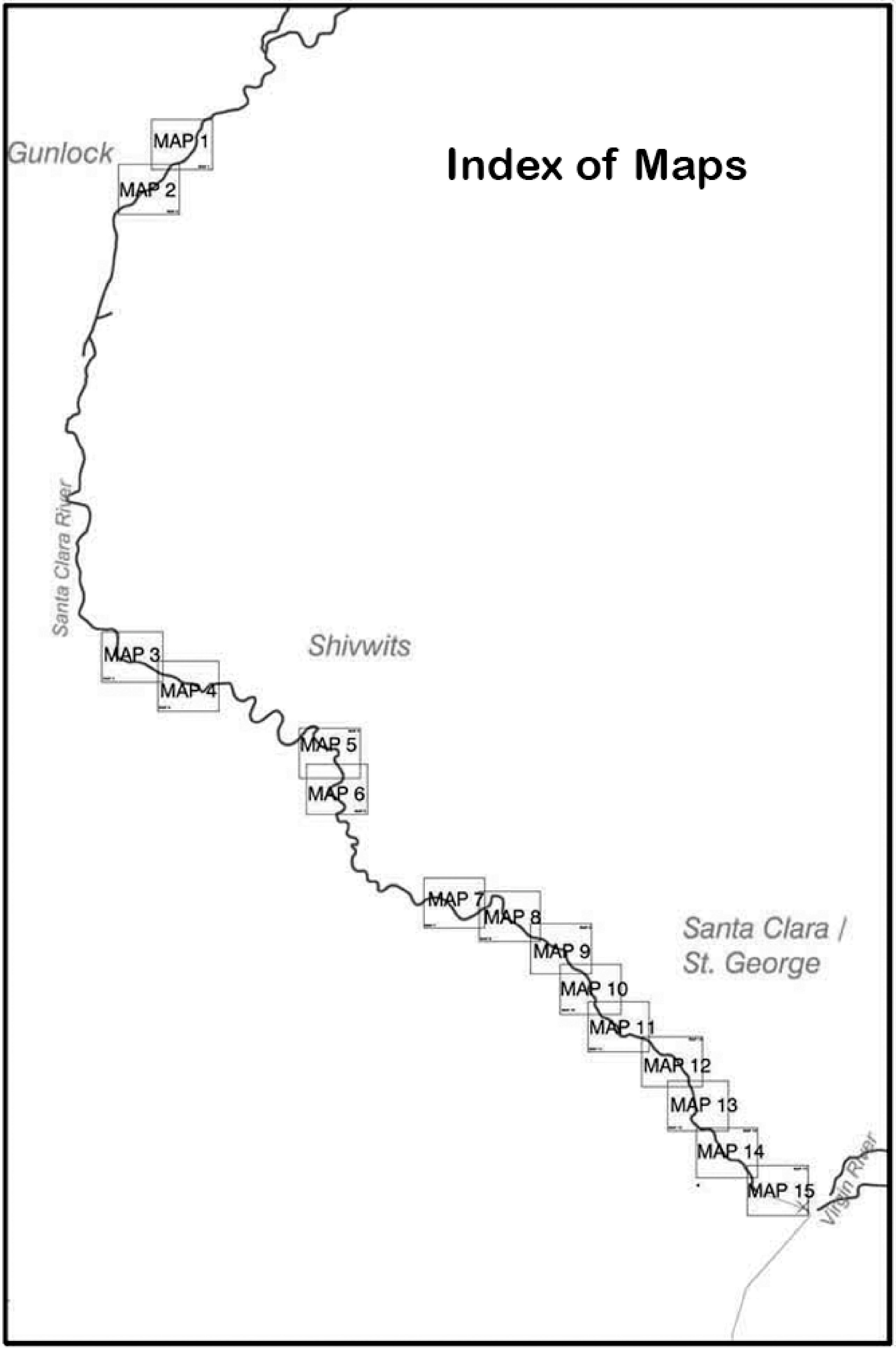
REACH 5. OLIVE GROVE TO TONOQUINT PARK (MAPS 13 &14)

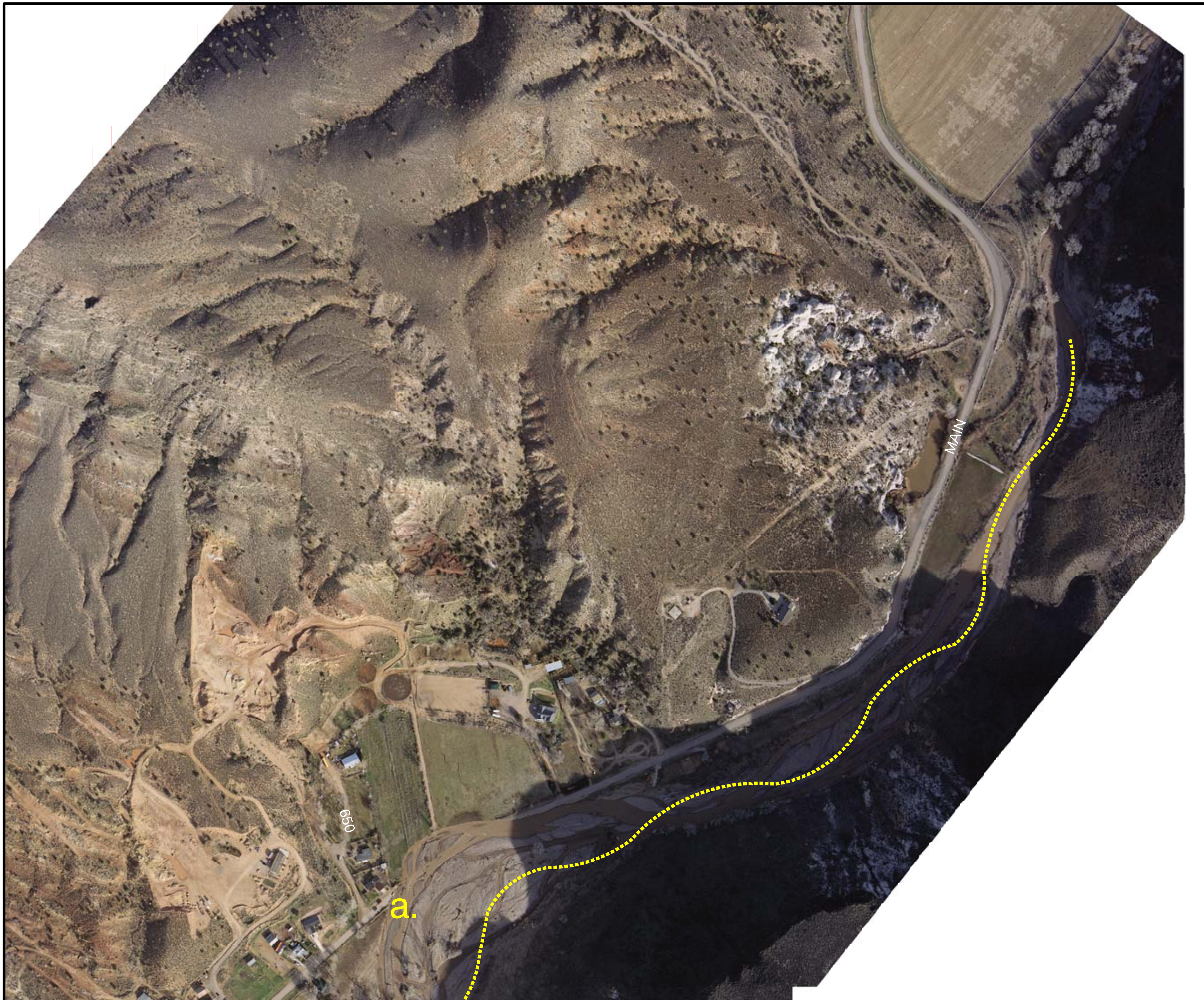
a) Areas behind NRCS levees should be filled or broken into cells and replanted as described in the Master Plan.
b) Channel and floodplain areas should be shaped and replanted with native vegetation consistent with the Master Plan.
c) Vegetative and/or structural hedgerows should be installed in high terrace areas to redirect future high flows back into river.
d) Tamarisk thickets should be removed and replanted with native vegetation. Areas along stream should be treated initially.
e) Vegetative and/or structural hedgerows should be installed in high terrace areas to redirect future high flows back into river. Setback levees could be constructed to limit flooding and redirect flows to river. Levees should maintain minimum corridor width consistent with Master Plan.

REACH 6. TONOQUINT PARK TO VIRGIN RIVER CONFLUENCE (MAP 15)

a) Vegetative and/or structural hedgerows should be installed in high terrace areas to redirect future high flows back into river. Setback levees could be constructed to limit flooding and redirect flows to river. Levees should maintain minimum corridor width consistent with Master Plan.
b) Channel, floodplains, and terraces should be reshaped and planted with riparian vegetation consistent with Master Plan. Structural toe rock may be required along outside of meander bends to reduce the risk of future erosion.
c) Channel, floodplains, and terraces should be reshaped and planted with riparian vegetation consistent with Master Plan. Structural toe rock may be required along outside of meander bends to reduce the risk of future erosion.
d) Channel, floodplains, and terraces should be reshaped and planted with riparian vegetation consistent with Master Plan. Structural toe rock may be required along outside of meander bends to reduce the risk of future erosion.

Index of Maps





Santa Clara Master Plan

Channel Alignment

Gunlock Reach A

Typical Channel Alignment

Map 1

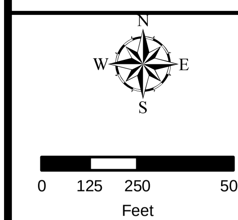
Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment
Gunlock Reach B

Typical Channel Alignment

Map 2



Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

Shivwits Section
Agriculture Fields
Reach A

Typical Channel Alignment

Map 3

Natural Channel Design, Inc

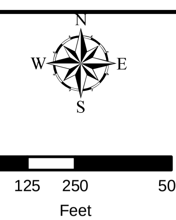
Santa Clara Master Plan

Channel Alignment

Shivwits Section
Agriculture Fields
Reach B

Typical Channel Alignment

Map 4



Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

Shivwits Section
3 Mile Area
Reach A

Typical Channel Alignment

Map 5

N
W E
S

0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

Shivwits Section
3 Mile Area
Reach B

Typical Channel Alignment

Map 6

N
W
E
S

0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

Santa Clara - St George Reach 1A

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

Map 7

N
W E
S

0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

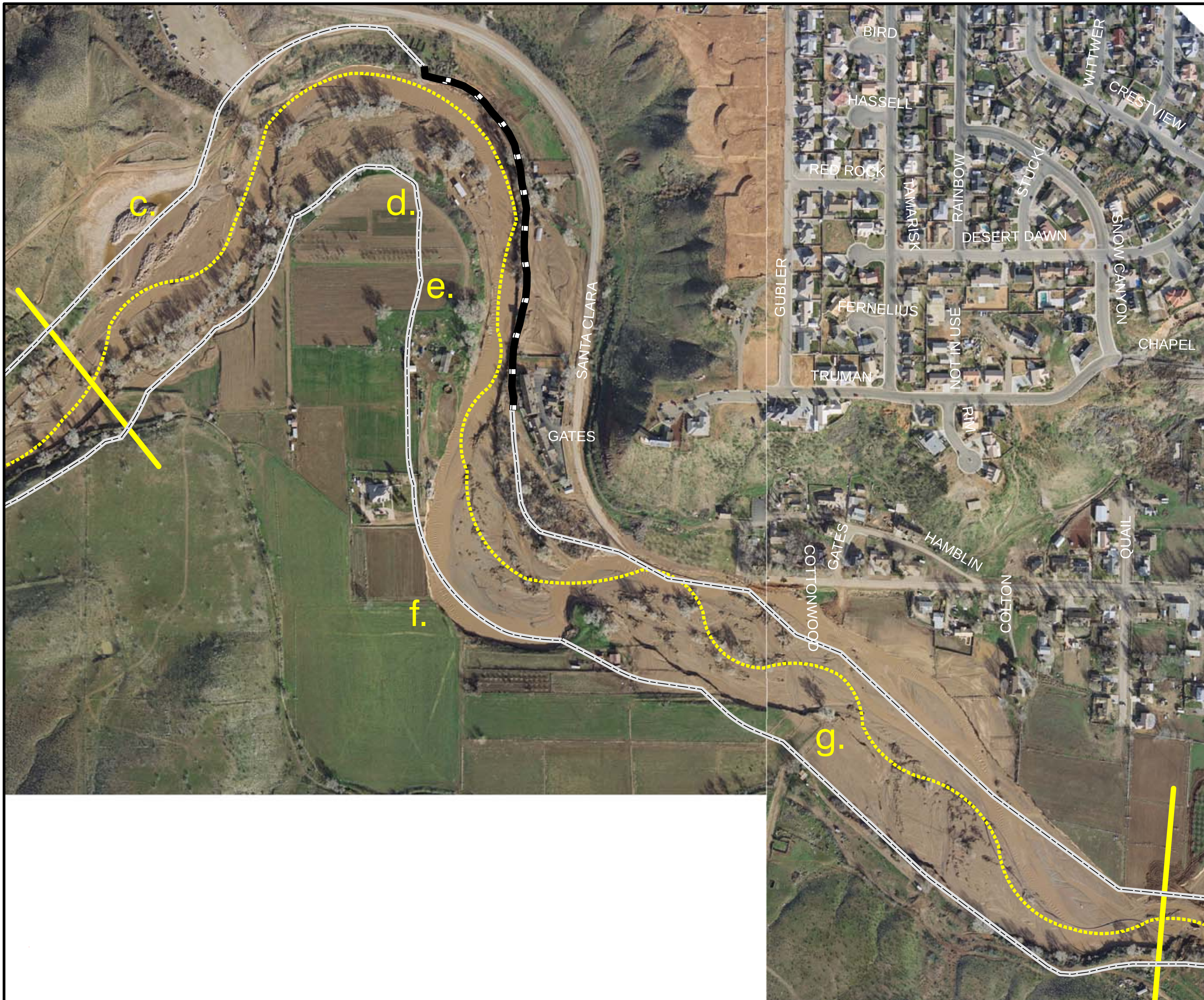
Santa Clara - St George
Reach 1B

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

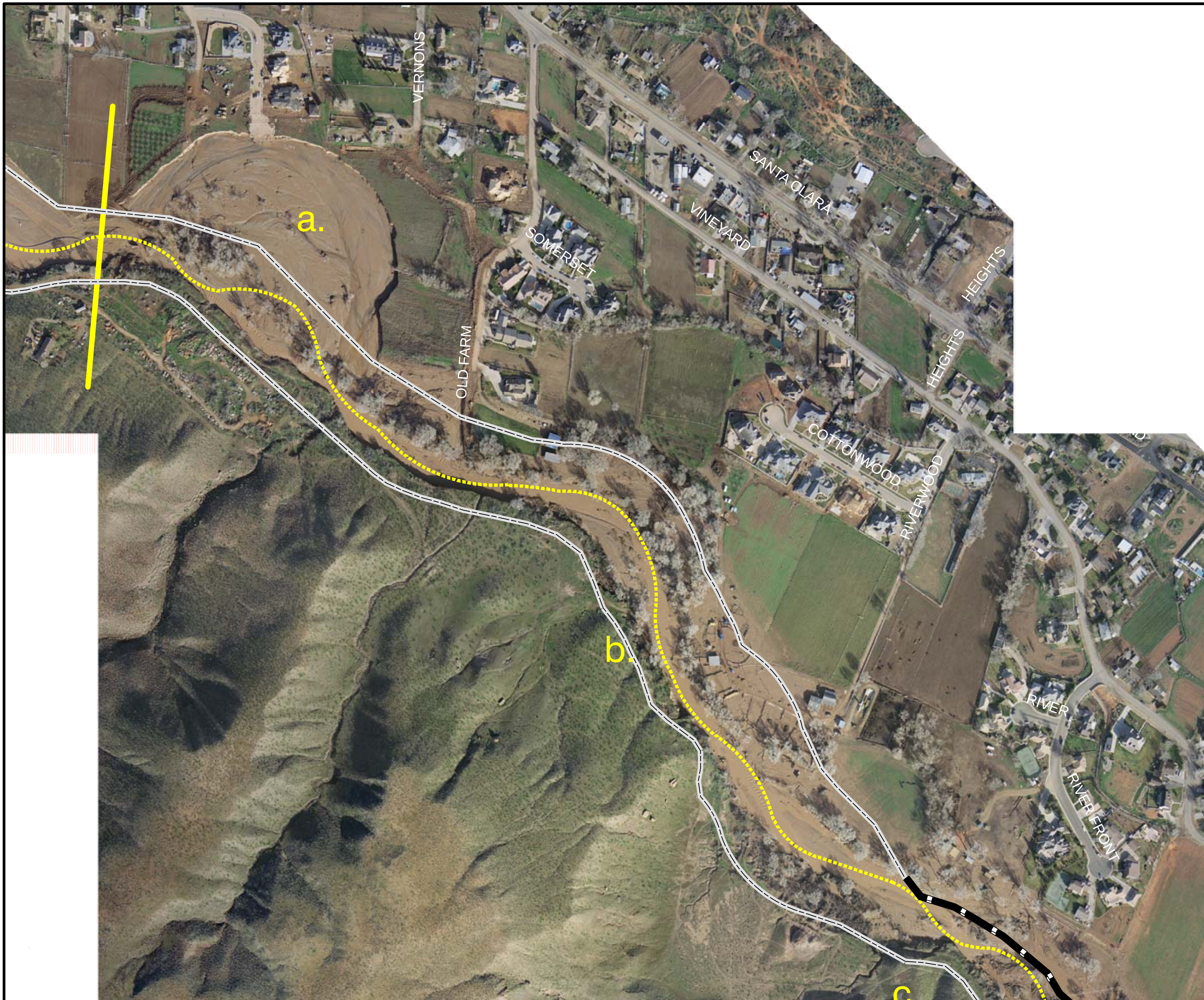
Map 8



N
W E
S

0 125 250 500
Feet

Natural Channel Design, Inc



Santa Clara Master Plan

Channel Alignment

Santa Clara - St George

Reach 2A

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

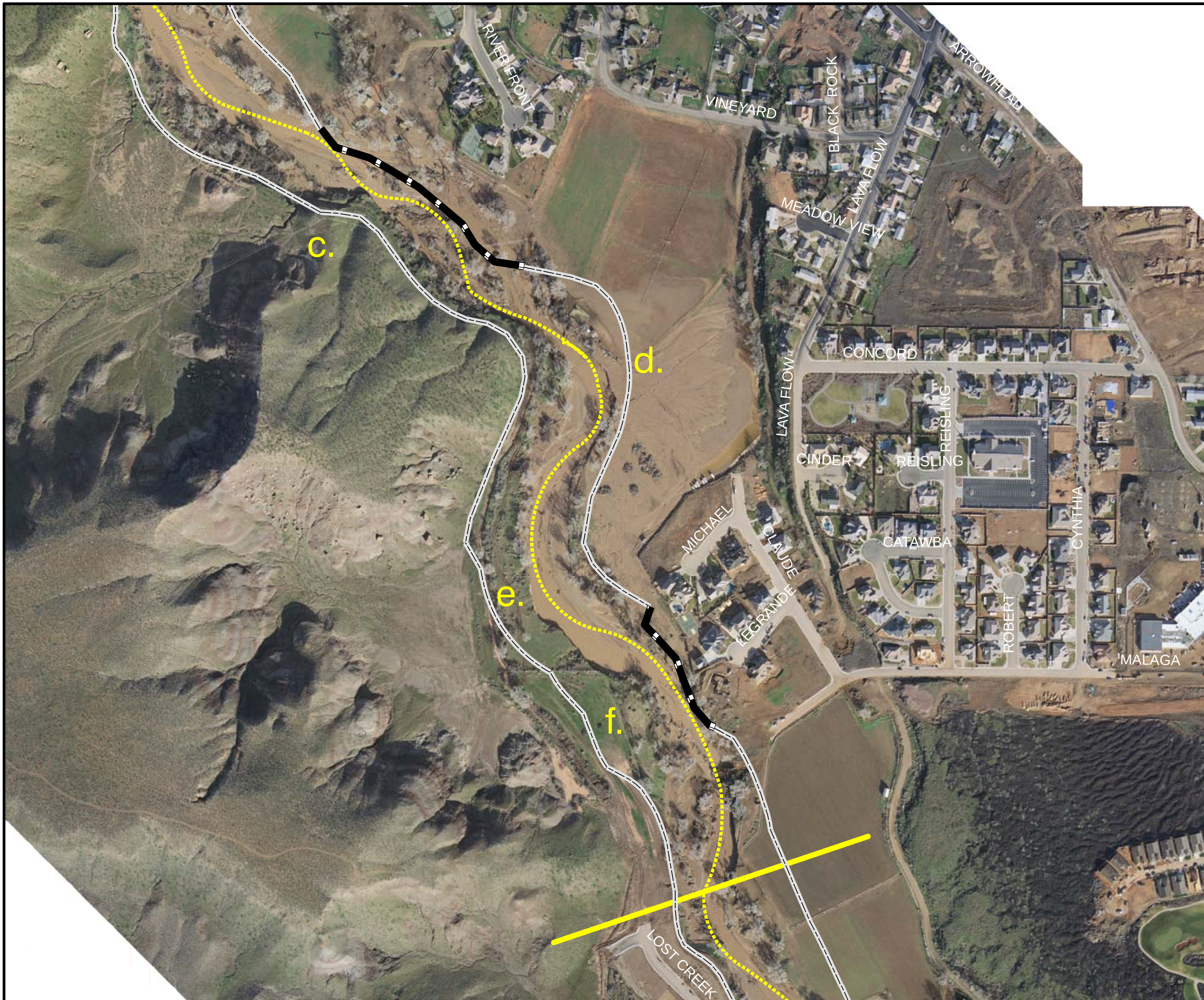
Map 9

N W E S

0 125 250 500

Feet

Natural Channel Design, Inc



Santa Clara Master Plan

Channel Alignment

Santa Clara - St George
Reach 2B

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

Map 10

N
W E
S

0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment
Santa Clara - St George
Reach 3A

Typical Channel Alignment
Extents of Riparian Corridor
NRCS Levees As of June 2005

Map 11

N W E S

0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

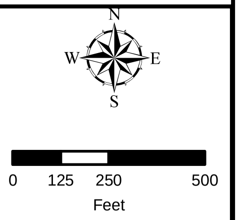
Santa Clara - St George
Reach 3B, 4A

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees
As of June 2005

Map 12



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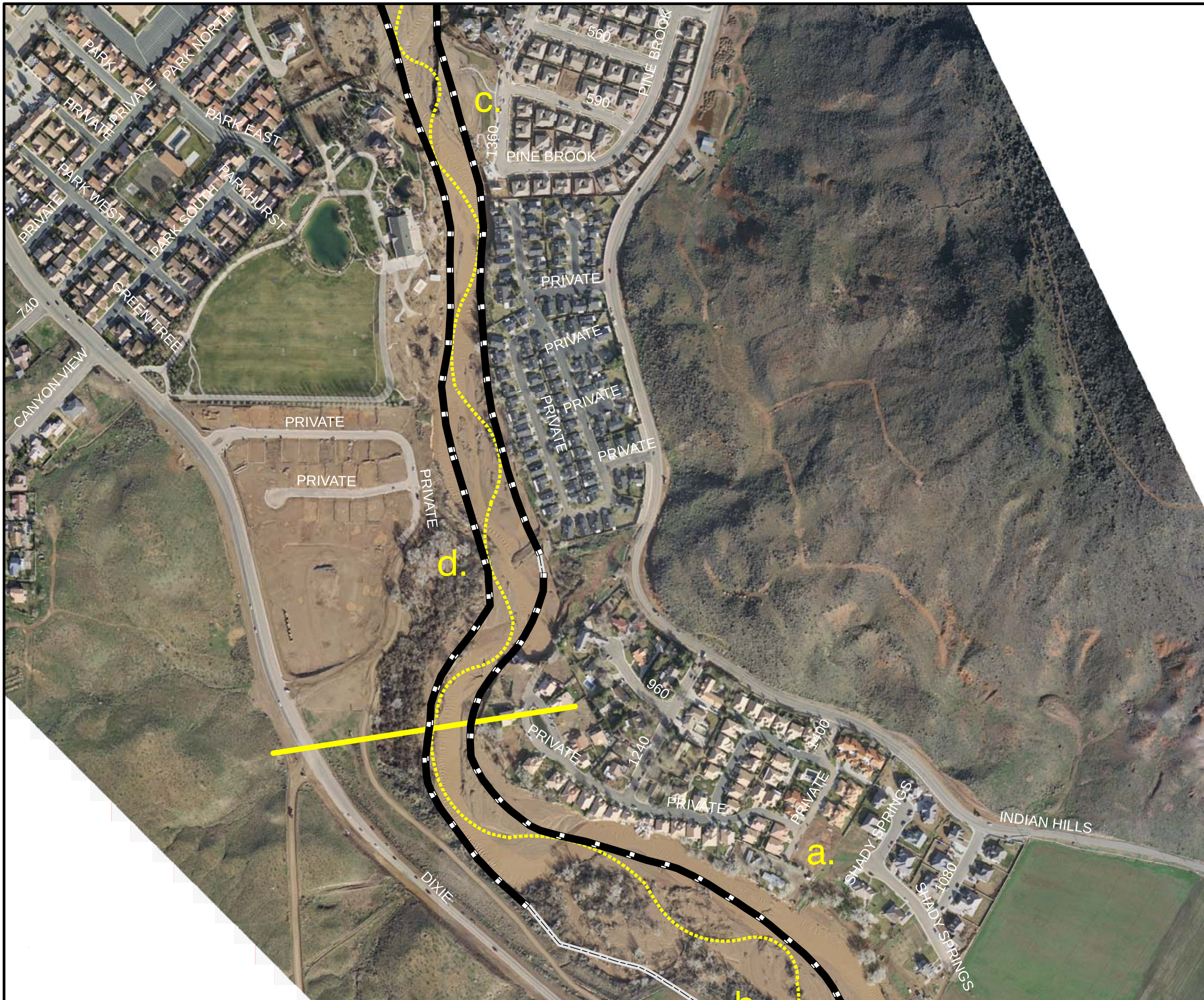


Santa Clara Master Plan

Channel Alignment

Santa Clara - St George
Reach 4B, 5A

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

Map 13

N
W E
S

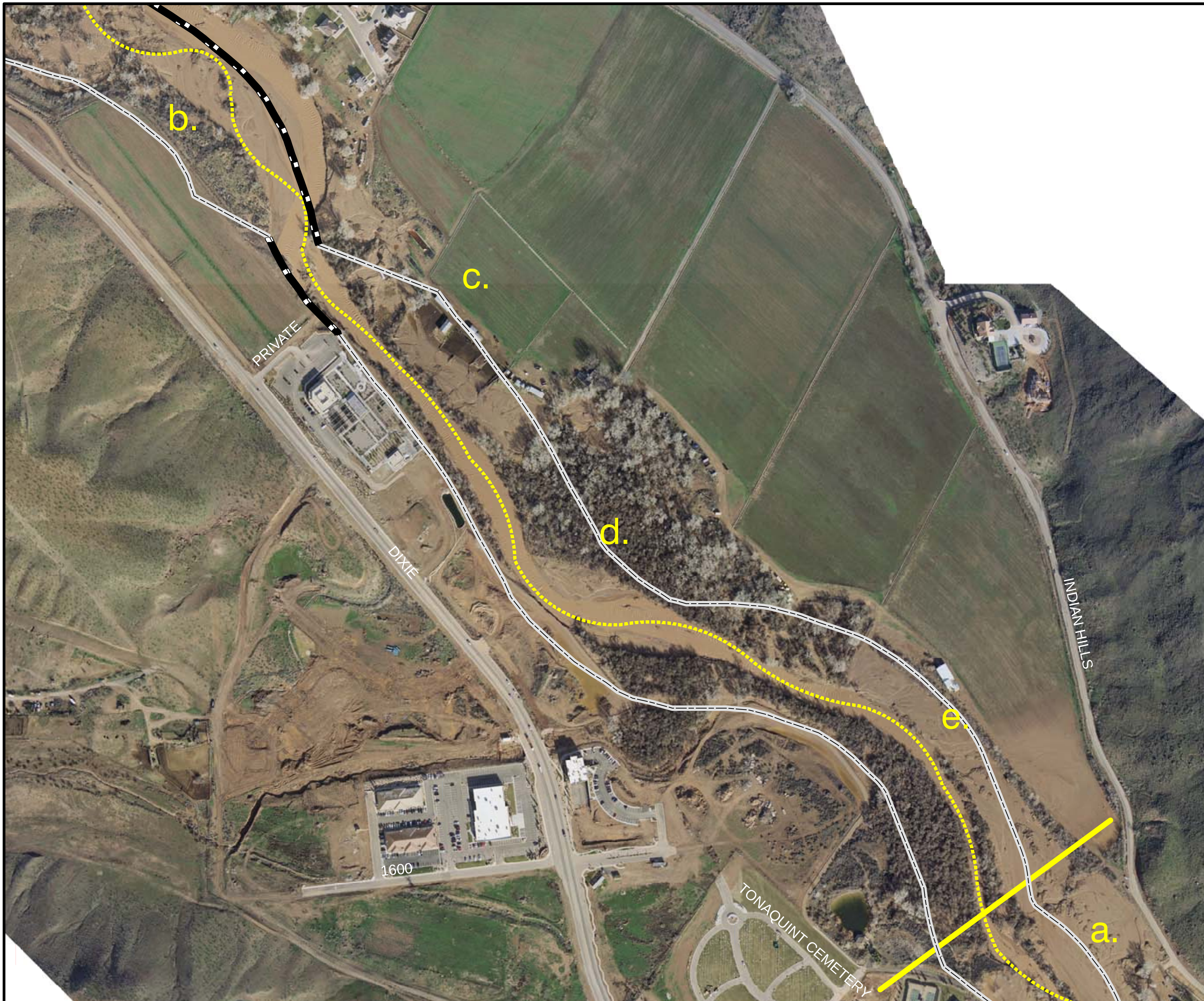
0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

Santa Clara - St George Reach 5B



Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

Map 14

N
W
E
S

0 125 250 500
Feet

Natural Channel Design, Inc

Santa Clara Master Plan

Channel Alignment

Santa Clara - St George

Reach 6

Typical Channel Alignment

Extents of Riparian Corridor

NRCS Levees As of June 2005

Map 15

N W E S

0 125 250 500

Feet

Natural Channel Design, Inc

SECTION 5: IMPLEMENTATION

COORDINATION:

Coordination will be a critical part of successful implementation of the Master Plan. The most obvious entities to serve the coordination role are city, tribal, and county governments. The individual cities of Gunlock, Santa Clara, and St. George and Washington County are already deeply involved in the support and development of the Plan. However, some level of overall coordination is also recommended. Washington County Water Conservancy District has been very effective at providing that service throughout the development of the Master Plan and is a good candidate for implementation as well.

A direct source that landowners can tap for technical assistance will be invaluable. This will be especially important in the first few months while priority projects are underway and until the plan components are understood. The Technical Contact should have a local presence and the technical understanding of the master plan.

IMPLEMENTATION TIMELINES:

A minimum 5-year implementation period should be expected. Long-term maintenance will be ongoing. The following is a partial list of implementation tasks and their timing.

Year 1 Tasks:

- Public outreach: education, workshops
- Incorporate Plan into appropriate city/county ordinances
- Coordinate with regulatory permitting agencies
- Assist local landowners in restoration of priorities areas
- Establish native plant "bare root" nurseries
- Implement Pilot project

Out-year Tasks:

- Public outreach: Establish annual "river days"
- Implement projects
- Establish native plant "container" nursery
- Maintain "bare root" nurseries
- Conduct maintenance program

NATIVE PLANT NURSERIES

An ongoing supply of native plant materials will be needed over the multi-year timeline of the Master Plan. Wild sources are limited will not provide adequate native plant materials for restoration of the Santa Clara River. However, local nurseries can be established on fallow agricultural lands with irrigation or riparian areas with sufficient soil moisture to support plants.

Willows, cottonwoods, and other "bare root" plants can be established from cuttings. These species are important for revegetation and can be harvested locally and readily cultivated provided adequate water is available. Several "bare root" nurseries should be established to minimize transportation expenses. Cuttings are harvested at the end of each growing season for use in revegetation efforts. The most effective time for planting bare pole cuttings is fall or winter.

Native plants that do not grow from cuttings will also be needed. These "container" plants can be cultivated in a dedicated nursery or contracted with local private plant nurseries.

REGULATORY PERMITTING

The effectiveness of the master plan is greatly increased if it can be coordinated with the regulatory requirements. An integrated permitting program should be created within the responsibilities of the following agencies:

Army Corps of Engineers
Utah State Engineers Office
US Fish and Wildlife Service
Utah Department of Natural Resources
City and county agencies

In an ideal situation, the programmatic permit would minimize the regulatory oversight for individual projects provided they comply with the guidelines of the Master Plan. However, regulatory responsibility of individual agencies must be satisfied. A programmatic permit is uncommon and will take time to complete and implement.

REVEGETATION PROJECTS

Revegetation should be considered a multi-year effort. Initial efforts should be directed at those properties with willing landowners. Coordination will be necessary between regulatory agencies, governmental units, and local landowners. Efforts should be scheduled in the dormant seasons for successful revegetation.

Pilot Project: A pilot project should be planned for the fall of 2005. A successful effort in the first year will be important to acceptance of the plan by local landowners. A pilot project should include a sizeable reach of river (1,000 + feet). The project could be conducted on public lands but would have greater impact on local landowners if constructed on private lands. The site should be identified by mid-summer in order to coordinate earthwork and regulatory permitting.

Because native plant materials will not be available from local nurseries in the first year, it is recommended that materials be obtained from local wild stands or commercial sources. One potential source is the state nursery in Las Vegas. Additional local wild sources should be identified. Implementation should be scheduled for November and could be integrated with a 2 to 3 day public workshop.

Individual projects: The master plan allows individual projects to be implemented when willing landowners, funding, and needs come together. A programmatic permitting process, readily available plant supplies, and the master plan guidelines will facilitate implementation and minimize the need for coordination.

LONG-TERM MAINTENANCE

An annual maintenance program should be established to facilitate the removal of exotic species (tamarisk) and maintaining the clear stream channel. Channel clearing requires the manual removal of all woody stems with a diameter greater than 2 inches from a 100 –foot swath along the central channel. An annual effort, coordinated with volunteers from the communities, could treat a section of stream channel. Specific reaches are estimated to need woody stem removal only every 4-5 years. Channel maintenance should be initially conducted using only manual labor. If this proves ineffective, mechanical means minimizing disturbance can be considered.

Exotic plant removal should be coordinated by federal, State, county, or city agencies. Herbicide application must be by a licensed individual.

PUBLIC OUTREACH/EDUCATION

Education will be important to the public acceptance of the plan. Public acceptance is usually built over time. Initial meetings will be attended by the interested public, however more skeptical members will hold back. Many persons are best convinced by fellow friends, neighbors, and peers. Having a successful example “on the ground” has tremendous power. A successful “pilot project” (see Revegetation Projects) provides an opportunity to demonstrate practices to those immediately interested and a silent example to others.

The following components are recommended for public outreach.

- *Initial education meetings: Summer/fall 2005*
  Informal meetings with local landowners and interested persons provides a forum for discussing master plan components and answer questions.

- *Public meetings: Summer 2005*
  More formal meetings may be necessary in connection with the potential adoption of city/county ordinances. These meetings are important but may not provide the best venue for education.

- *Bioengineering Workshop: November 2005*
  A 2-3 day workshop could be scheduled with the implementation of a “pilot project” of reshaping and revegetation. The workshop would include 1-1/2 days of lecture on the subject of the use of native plants for stream bank stability (bioengineering) and 1-1/2 days in the field installing bioengineering practices.

- *Bioengineering Workshops: Annually*
  Annual workshops are effective tools to continually build long-term support for the restoration and maintenance of the Santa Clara River. The workshops can be conducted in coordination with public projects, annual maintenance efforts, or annual “river days” celebrations.

- *“River Days” Festival: Annually*
  An annual festival focuses attention on the river’s benefits to wildlife and the community and can provide broad public support. The festival can be linked to local school curriculum to provide a valuable “laboratory” for youth education and can be the nexus for volunteer efforts along the river. The “Verde River Days” sponsored by the Verde Valley Watershed Association in central Arizona is a successful example. (www.vwa.southwest-water.org)

PRIORITY AREAS

A formal list of priority areas is not included in this Master Plan. Rather it is likely that priority areas will be more effectively identified by private and public landowners. Indeed the process has already been utilized in the protection of pipelines and other utilities, the siting of NRCS dikes, and the interest by local landowners. The Master Plan should provide the guidance to allow implementation of projects as needed.

REFERENCES:

Andrews, E.D., 1980. Effective and bankfull discharges of streams in the Yampa River Basin, Colorado and Wyoming. J. Hydrol., 46.

CH2MHill, and JE Fuller/Hydrology & Geomorphology, Inc., 1996. River Stability Study: Virgin River, Santa Clara River and Ft. Pearce Wash, City of St. George, UT.

Glenn, Edward P. and Pamela L. Nagler 2005. Comparative ecophysiology of Tamarix ramosissima and native trees in western U.S. riparian zones. Journal of Arid Environments 61 (2005) 419-446. Elsevier.

Hardy, T, P. Panja, and D. Mathias 2005, WinXSPro; a Channel Cross-section Analyzer , USDA Forest Service, Rocky Mt. Research Station. Ft. Collins, CO.

Hoag, J. Chris, Forrest E. Berg, Sandra K. Wyman, Robert W. Sampson, 2001. Riparian Planting Zones in the Intermountain West. Riparian/Wetland Project Information Series No. 16. NRCS Plant Materials Center, Aberdeen, ID.

Hoag, J. Chris and Dan Ogle, 2005. Washington County EWP Trip Report. NRCS-Plant Material Center, Aberdeen, ID.

Leopold, L.B., M. G. Wolman, and J. P. Miller, 1964. *Fluvial Processes in Geomorphology*. Freeman, San Francisco, CA.

Moody, Tom. Mark Wirtanen, & Stephanie Yard, 2003. Regional Relationships of Natural Channels of the Arid Southwest. Natural Channel Design, Inc. Flagstaff, AZ.

Rosenberg, Rick, 2005. Personal communication.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology, Ft. Collins, CO.

Rosgen, D.L., 2002. The Cross-vane, W-Weir and J-Hook Vane Structures. Their Description, Design, and Application for Stream Stabilization and River Restoration. Wildland Hydrology, Ft. Collins, CO.

Sandberg, Jay, 2005. Personal communication.

Taylor, John P., and Kirk C. McDaniel 2004. Revegetation strategies After Saltcedar (Tamarix spp.) Control in Headwaters, Transitional, and Depositional Watershed Areas. Weed Technology, Volume 18:1278-1282.

USDA Natural Resources Conservation Service, 1996. Streambank and Shoreline Protection. Chapter 16 – Engineering Field Handbook.

USDA Natural Resources Conservation Service, 1998. The Practical Streambank Bioengineering Guide. Plant Materials Center, Aberdeen, Idaho.

U.S. Geological Survey 1981. Guidelines for determining flood flow frequency, Bulletin # 17B, Hydrology Subcommittee, Interagency Advisory Committee on Water Data, Geological Survey, U.S. Department of the Interior.