Final Report

Virgin River Master Plan

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

Virgin River

Washington County, Utah

October 2007

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Submitted to:
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SECTION 1: INTRODUCTION

Project Description/Objectives

Extreme flooding in Washington County and Southern Utah during January 2005 revealed potential vulnerabilities to flood and erosion hazards and highlighted the need for coordinated master planning along the major river systems. Multi-jurisdictional master plans for the Santa Clara River and Ft. Pearce Wash have already been completed. This Master Plan for the Virgin River within the corporate boundaries of Washington and St. George cities will provide an integrated, comprehensive process to expedite rapid, appropriate administration of both immediate and future activities along these river systems. The Master Plan is being developed with the support of all affected State, County, Federal, and Municipal agencies

The Master Plan goals are to optimize the function and stability of the Virgin River in order minimize risk of erosion and property damage from future floods. The specific objectives of the plan include:

1) Minimize property damage from future lateral erosion and flooding along the Virgin River;
2) Assist private landowners and city governments in managing present land use and future development;
3) Provide long-term maintenance guidelines along the Virgin River;
4) Maintain the natural function of the Virgin River;
5) Enhance native riparian vegetation and associated wildlife habitats;
6) Increase aesthetics and recreation values

The Master Plan recommends specific stream stability protocols for the reconstruction of stream channel, floodplain, and terrace features; revegetation of the riparian areas for stability and wildlife; appropriate future land use along the rivers; and a long-term maintenance program to ensure project objectives are achieved. A companion study, the Virgin River Stability Study, was also prepared to support the Master Plan.

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 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 include Washington County, cities of Washington and St. George, Washington County Water Conservancy District, and Virgin River Program.

SW Utah Flood Flows

Peak flows during the January 2005 flood have been estimated by United States Geological Survey (USGS) and are presented in Table 1.

Table 1 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	~9,840 cfs	~20 years
Virgin River near Hurricane, UT	~21,000 cfs	~100 years
Virgin River at Bloomington, UT	~19,600 cfs	~100 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

The level of impact that a flood has on the surrounding landscape depends on many interacting factors, including the magnitude and duration of high water levels, and the shape and texture of the river channel and its surroundings. Magnitude refers to the size of a flood is just one variable that contributes to the potential for erosion and flood damage. The duration, or length of time, of the high flow event can also significantly affect flood damage. The January 2005 flood had two peaks roughly a day apart. Figure 1 is a reconstruction of the flood prepared by Washington County Water Conservancy District staff. Because the stream gages failed during the floods (dotted lines), peak flows were estimated based on the rising and falling limbs of the hydrograph. Based on these estimates, the Santa Clara and Virgin Rivers experienced high flows 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.

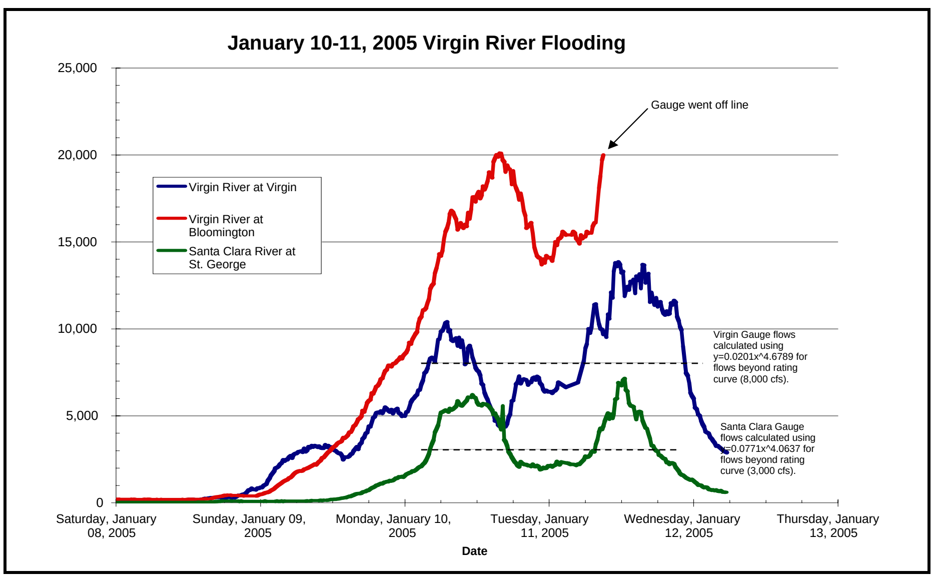


Figure 1 Reconstruction of January 2005 flood flows. (Cram, WCWCD)

Study Approach

This study uses a combination of empirical and analytical approaches. Stream channels are created and maintained by the process that transport water and sediment supplied by the watershed. In successfully performing these functions stream systems create distinct forms that can be identified, characterized and used to establish stability characteristics and limits. Direct surveys of the soils, geology, geomorphology, and vegetation of the active stream corridor were used to understand the physical and biological elements of the Virgin River. These observations were augmented and verified with analytical engineering tools.

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 (river) 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.

For this study, a number of river cross-sections were surveyed in stream reaches that received relatively moderate erosion. These surveys were compared with pre-flood cross-sections to characterize pre-flood conditions. Pre- and post-flood photos were evaluated to cmpare channel/floodplain/terrace dimension, meander pattern, and vegetation changes and the extent of lateral migration and flooding. From this information, the effects of the flooding and causes of damage were determined. Knowledge acquired during field visits to the Virgin River was combined with studies of aerial photographs, geomorphic surveys, regional hydrologic data, and anecdotal evidence to develop templates of channel dimensions. Channel template dimensions were further refined with additional hydraulic analyses.

Tasks

- Identify mechanisms of erosion/flooding
- Evaluate pre-flood cross-sections
- Evaluate regional channel morphology data
- Evaluate role of vegetation on flood impacts.

Products

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

Methods

Field Visits

Field visits were made to all sections of the project reach immediately following the flood event and again in the following months.

Aerial photographs

Washington County commissioned aerial photography 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. A final set of aerial photographs were taken in 2006.

Geomorphic surveys

Eleven representative cross-sections located in transition or meander sections were reconstructed from 1999 pre-flood FEMA and 2006 post-flood topographic maps. A longitudinal profile was recreated through the project reach was created using data from the pre- flood topography.

Regional Geomorphic Data

Surveys of the pre-flood channels in the Virgin River were limited to interpolating morphology from topographic maps produced from aerial photographs. To reinforce these assessments, morphologic data from 41 regional channel sites representing low-gradient gravel-sand bed channels located in southern Utah were also evaluated.

Master Plan Components

The Master Plan is designed to provide guidance to city/county governments and private landowners on the management and maintenance of the Virgin River. The information within the Plan is intended to provide a road map to reconstructing lands within the river corridor. The report is divided into the following sections:

Section 1: Introduction

Section 2: Project Description

This section provides the project background and describes existing conditions.

Section 3: Channel Stability Study

This section describes the analyses used to assess existing stream stability and areas of concern.

Section 4: Channel Stability Template

This section provides a general template recommendations to maintain and enhance stream stability including suggestions pertaining to channel pattern, channel/floodplain/terrace cross-section, vegetation, and land uses.

Section 5: Reach Recommendations

The final section identifies areas of concern and provides specific recommendations for each project reach.

Study Philosophy

The Virgin River Master Plan is based on the following philosophies:

Conservative: The goal of the Plan is to guide land uses within the stream corridor to minimize the potential for property damage and maximize public safety. With that goal in mind, the plan presents recommendations that are designed to be conservative. It is possible that detailed, site specific engineering analyses could be conducted to modify the recommendations presented here.

Defensible: The Master Plan methodologies are based on the best science available in analyzing and understanding stream processes. The results have been calibrated with relevant studies of other stream systems in the arid Southwestern U.S., and calibrated favorably with mathematical modeling techniques.

Advisory: The recommendations are intended to advise the public of methods to reduce the potential risk of damage from future flooding. There are other creative methods to decrease the risk of erosion and flooding. Therefore, with proper engineering, alternatives to the recommendations presented in this Plan can be implemented.

A Note About Stream Stability

Stream stability is the primary goal of this project but can be difficult to define within a dynamic system. For use in this study, stream stability is defined as the stream's ability to carry the water and sediment of its watershed while maintaining dimension, pattern, and profile without aggrading or degrading over time (Rosgen 1996). This definition allows the natural, moderate dynamics of erosion and deposition and lateral movement of the stream. Given the extreme hydrology of the southwestern U.S., stability must be considered a relative value dependent on the specific stream. In this region large flood events produce flows and energies that overwhelm geomorphic thresholds and produce significant and unpredictable change even in the most stable stream system. The purpose of the geomorphic assessment is to develop stable values for dimension, pattern, and profile for the project reach and to establish an understanding of the geomorphic thresholds or relative stability of the stream system.

The recommendations presented in this Plan are intended to minimize the speed and extent of channel change; not eliminate it. Infrequent but extreme flood events produce very high velocities and shear stresses that can be expected to produce significant erosion and channel change that may require repair and maintenance.

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 Virgin 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 while maintaining natural function of the river.

Does the Master Plan delineate the 100-year floodplain?

No, the goal of the Master Plan is to provide guidance to increase the stability of the Virgin River and minimize the potential for large lateral erosion during future flood events. The Erosion Hazard Boundary section in the Plan estimates the limits of lateral erosion along the river. The FEMA regulatory "100-year Floodplain" is delineated in other studies.

Do I need any regulatory permits to work on the river?

Yes. Any work within the river corridor including the removal of salt cedar, 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 help stabilize the river and create a continuous corridor of high quality 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 minimal risk of 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.

How can I protect my property against future bank erosion?

The recommendations included in the Plan are designed to minimize the potential for bank erosion. However, local erosion can be expected during flood events. In many areas native vegetation and proper channel-floodplain-terrace elevation and dimension will be adequate. In areas where local erosion potential is greater, engineered structural protection may be warranted.

How can I effectively remove salt cedar?

There are a number of manual and mechanical methods for removing saltcedar. However, removal will not guarantee this aggressive species does not reestablish. The best strategy for reducing the amount of salt cedar establishment is to plant native riparian plant species. Given an equal start these plants have been successful in out competing salt cedar and other non-native species.

How can I maintain or increase capacity of the river to carry flood flows?

A reduction in channel size or its ability to convey water can result in higher flood stages and/or increases erosive stream velocities. However, simply increasing channel capacity by removing sediment and/or dense vegetation may not provide a long-term solution. The removal of sediments and/or dense vegetation should be carefully considered and, if deemed necessary, should be implemented in a manner to maintain channel shape, slope, and meander pattern as described in the Master Plan. The Army Corps of Engineers, Utah State Engineers office, and local regulatory agencies should be notified and permits obtained prior to any work.

Regulatory Permitting

This manual provides guidance for private and public landowners in the short- and long-term reconstruction and restoration of the Virgin River. 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.

Army Corps of Engineers
Attn: Steve Roberts
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

Additional city or county grading permits may also be required.

SECTION 2: PROJECT DESCRIPTION

Project Area

This Master Plan covers approximately 16.7 miles of the Virgin River from the Washington Fields Diversion to the St. George city boundary (Figure 2). The river is a low-gradient meandering stream with an average slope of approximately 0.0023 foot/foot. The channel bed is gravel and sand. The project lies at an elevation of 2,500 feet and has a watershed area of approximately 4,000 square miles below the confluence of the Santa Clara River and Fort Pearce Wash.

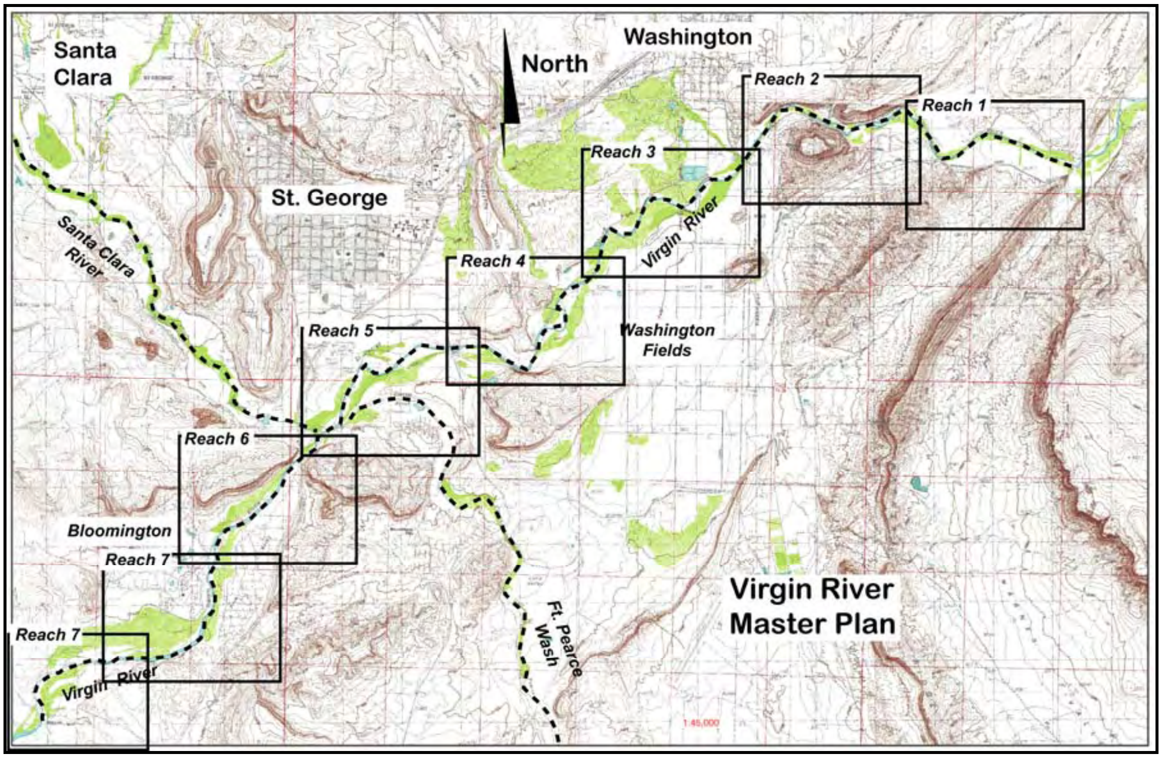


Figure 2 Map of Project Area: Virgin River.

This map presents the Virgin River in southwestern Utah. The river originates in the high elevations above Zion National Park and flows to the southwest before joining the Santa Clara River and Ft. Pearce Wash in the city of St. George, Utah. The project area is divided into 7 reaches.

Basin Description

The Virgin River originates in the high plateaus north of Zion National Park. The watershed is largely composed of sand and bare rock and has a watershed area of almost 4,000 square miles. There are no storage reservoirs located along the channel although base flows are diverted into Quail Creek and Sand Hollow Reservoirs. Several other diversions seasonally convey water for municipal and agricultural purposes. Since these structures divert base flows, none are expected to significantly affect large peak flood flows.

Project Reaches

The project area was divided into seven reaches to aid in assessment (Figure 2). Reach 1 is the most upstream reach beginning at the Washington City boundary at Washington Diversion and Reach 7 ends at the downstream extent of the Sun River development in St. George.

Table 2 Project Reaches

Reach	Begin		End	Stream Length (miles)
1	Washington Fields Diversion	-	Sunrise Valley Bridge	1.9
2	Sunrise Valley Bridge	-	Washington Fields Rd	2.5
3	Washington Fields Rd	-	Johnson Diversion	2.3
4	Johnson Diversion	-	River Road	2.8
5	River Road	-	Interstate 15	2.5
6	Interstate 15	-	Man of War Bridge	1.6
7	Man of War Bridge	-	Atkinville Wash	3.2
			Total length	16.7

The relatively flat and fertile Virgin River valley has been utilized for agriculture and housing since the late 19^{th} century. Historically, the areas adjacent to the Virgin River were agricultural and the higher terrain to the north of the river developed into the communities of St. George and Washington. But the agricultural areas are rapidly converting to subdivision developments.

Natural geologic control narrows the stream corridor in Reaches 2, 3, 5, and 6. Development density varies by reach but pressure exists to develop throughout the project area. Vegetation along the river is relatively dense and consists of both native and non-native riparian species. However, for most of the project area, riparian areas are dominated by dense thickets of invasive salt cedar (*Tamarix spp*).

Prior to the 2005 flood, structural stream bank protection was limited to bridges and other local infrastructure. Following the flooding, stone peak dikes were designed and installed by Natural Resource Conservation Service (NRCS) along significant portions of the project reach.

Hydrology

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 exceedance probability. A 10-year flood has a 10% chance of occurring in any year. A 25-year flood has only a 4% chance of occurring in any one year.

Small floods occur frequently and have high exceedance probabilities and low recurrence intervals. Larger floods are less frequent and have lower exceedance 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.

Project hydrology

Four stream gages at Virgin, Hurricane, St. George, and Bloomington have recorded flows on the Virgin River near the project area. The gage sites have different watershed areas and years of stream flow record. Flood frequencies for each site were estimated by the USGS and are provided in Table 3. Despite the widely differing watershed areas, flow magnitudes are relatively consistent suggesting that large flow events are generated in the high terrain upstream of the Virgin, UT stream gage.

Table 3 Flood Frequencies: Virgin River stream gages

Flow magnitudes for various flood frequencies were estimated by the USGS following the 2005 flooding. Two methods were used to estimate flows and a weighted estimate derived from those methods. The weighted estimate is presented in this table.

Recurrence Interval (years)	**Virgin, UT** (9406000) (cfs)	**Hurricane, UT** (9408150) (cfs)	**Bloomington, UT** (9413200) (cfs)	**St,George, UT** (9413500) (cfs)
2	3,630	3,880	3,590	2,600
5	6,740	6,170	6,120	4,460
10	9,350	7,790	8,280	6,430
25	13,300	10,100	11,700	10,000
50	16,700	12,100	14,800	13,400
100	20,500	14,100	18,000	17,200
Years of record	88	18	18	13
WS Area (sq mi)	934	1,499	3,853	4,123

Flooding is not uncommon on the Virgin River. Figure 3 presents annual instantaneous peak flows for various flood frequencies at four stream gages. Although the graph shows wetter and drier periods, peak flows are relatively consistent, ranging between 5,000 and 15,000 cfs. Three substantially larger natural floods occurred in the last half of the last century (1967, 1978, and 2005). The 1989 flood event was generated by failure of an upstream reservoir rather than natural storm events. The larger Virgin River flood events are presented in Table 4 and suggests that between 1922 and the 1960's larger flood events were primarily generated by summer and fall storms. Since 1967, these events have been generated by large winter frontal storms.

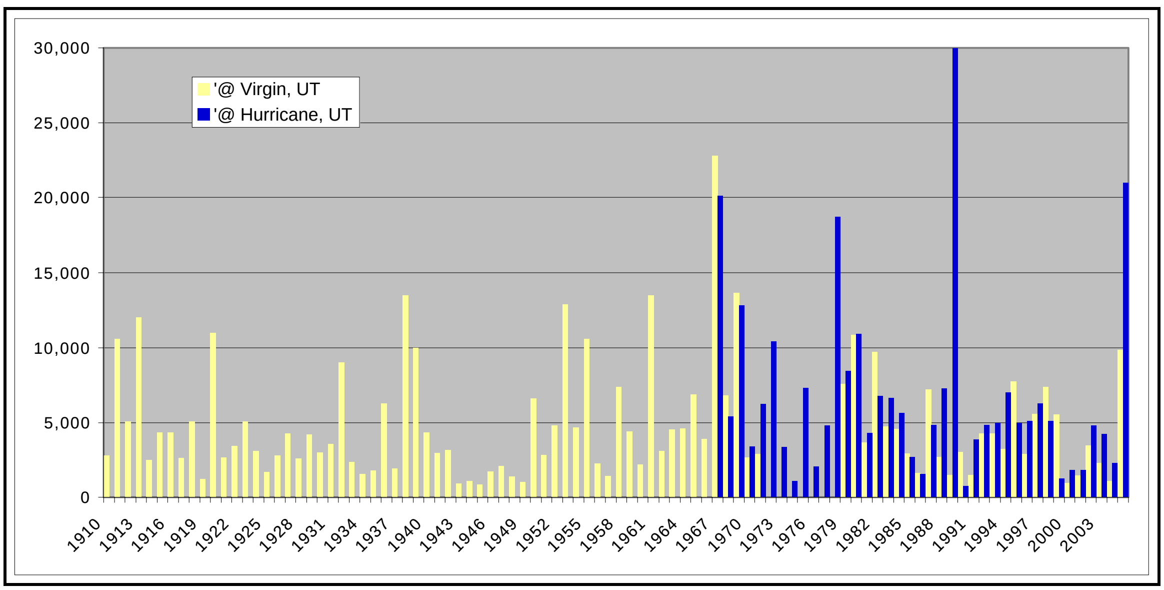


Figure 3 Virgin River Peak Flows at Virgin and Hurricane, UT stream gage stations

The 1989 flood event of ~ 60,000 cfs was generated by reservoir failure rather than natural storm generated flood flow.

Table 4 Large flood events.

Large flood events on Virgin River can be generated by local, high intensity storms in the late summer and early fall or by large winter frontal storms.

Year	Month	Virgin, UT (9406000) (cfs)	Hurricane, UT (9408150) (cfs)	St,George, UT (9413500) (cfs)	Bloomington, UT (9413200) (cfs)
1911	September	10,600	*	*	*
1913	October	12,000	*	*	*
1920	August	11,000	*	*	*
1938	March	13,500	*	*	*
1939	September	10,000	*	*	*
1953	August	12,900	*	*	*
1951	August	2,800	*	11,600	*
1955	August	10,600	*	13,800	*
1961	September	13,500	*	*	*
1967	December	22,800	20,100	*	*
1969	January	13,660	12,800	*	*
1978	March	*	18,700	*	17,000
1980	September	10,830	10,910	*	-
	February	-	-	*	10,000
1989 [1]	January	1,500	66,000	55,000	60,000
2005	January	9,840	21,000	19,600	19,600

** no data*

[1] 1989 flood was generated by reservoir failure.

The bankfull or channel maintenance flow is also useful in the assessment of stream channel geomorphology. Research on a large number of gaged sites within the region suggests the recurrence interval for this flow averages 1.5 years and is commonly 50% of the magnitude of the 2-year flow. Based on the USGS estimates, flow magnitudes for various flood frequencies used in this report, including bankfull stage, are presented in Table 5.

Table 5 Project flood flow values.

Recurrence interval	Exceedence Probability (%)	Discharge (cfs)
1.5-year (Bankfull)	67%	1,800
2-year	50%	3,600
5-year	20%	6,100
10-year	10%	8,000
25-year	4%	12,000
50-year	2%	14,800
100 year	1%	18,000

SECTION 3: STREAM CHANNEL STABILITY ANALYSIS

The purpose of this section is to characterize existing stream channel morphology, determine stable channel parameters, and identify areas of concern. The assessments are based on field surveys conducted in the spring and summer of 2006 and evaluation of aerial photographs from the same period.

Stream Channel Processes

Nature of Rivers

Natural stream channels are created and maintained by the forces of their watersheds. Their primary functions are to transport sediment, convey flood flows, and dissipate energy. A stream adjusts its size, slope, and sinuosity to accommodate typical stream flows and to move sediment through the system. Stream channels create alluvial (sediment) forms that will most efficiently perform these functions. Although dynamic, these forms represent the most stable condition possible for the channel.

Generally speaking, a stream is constantly dissipating energy as it moves downstream. In a low gradient stream, 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 accelerated lateral and/or vertical erosion, especially during large flow events.

Table 6 Definitions of common geomorphic terms

Bankfull stage is defined as the elevation where the channel transitions to the geomorphic floodplain. This "point of incipient flooding" commonly represents a discharge with a recurrence interval between 1 and 2 years (Leopold 1994, Moody et al 2003). This stage can be identified in the field and provides a consistent, common point of reference for quantifying the channel dimension.

Geomorphic floodplain: Defined as a level alluvial feature adjacent to the channel, overtopped by moderate, frequent flow events, and created in the present climate.

Terrace: Defined as a floodplain abandoned by channel incision or a higher alluvial feature created by large infrequent flood flows. Terraces are commonly inundated by large flood events but lie at no consistent elevation.

Floodprone Width: Defined as the width of the geomorphic floodplain at an elevation twice maximum bankfull depth. This stage represents a common to moderate flood event depending on the local hydrology.

Super Floodprone Width: Defined as the width of the geomorphic floodplain/terrace at an elevation 3 times maximum bankfull depth. This stage represents a moderate to extreme flood event depending on the local hydrology.

Width-depth Ratio: Defined as bankfull width divided by mean depth, this criteria describes the relative channel shape and sediment transport capacity.

Entrenchment Ratio: Defined as Floodprone width divided by bankfull channel width, this criterion describes the stream's ability to spread common flows (~3-5 year) on an adjacent floodplain.

Super Entrenchment Ratio: Defined as Super Floodprone width divided by bankfull channel width, this criterion describes the stream's ability to spread large to extreme flows on an adjacent alluvial terrace.

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, sinuosity, and slope 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. The channel that carries this amount of flow is called the bankfull channel.

All channels have a characteristic meander or pattern (Figure 4). 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.

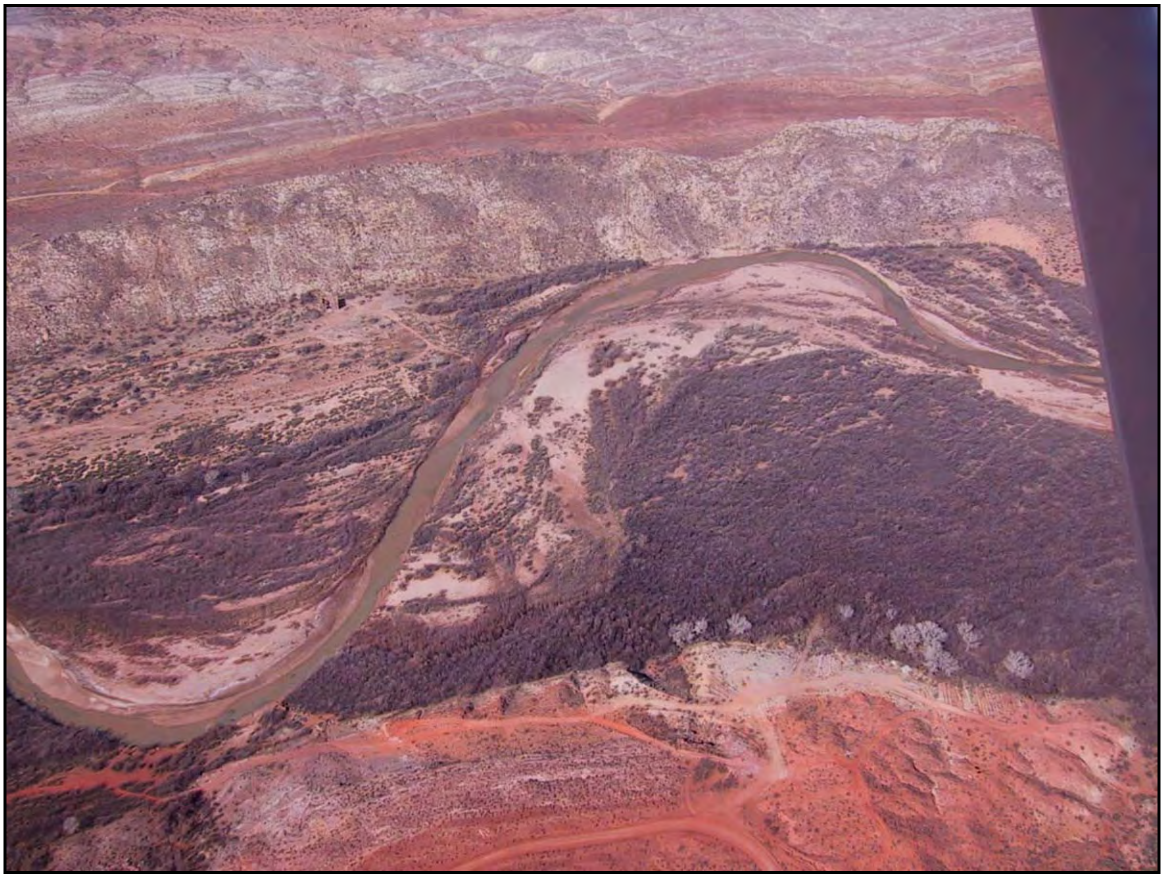
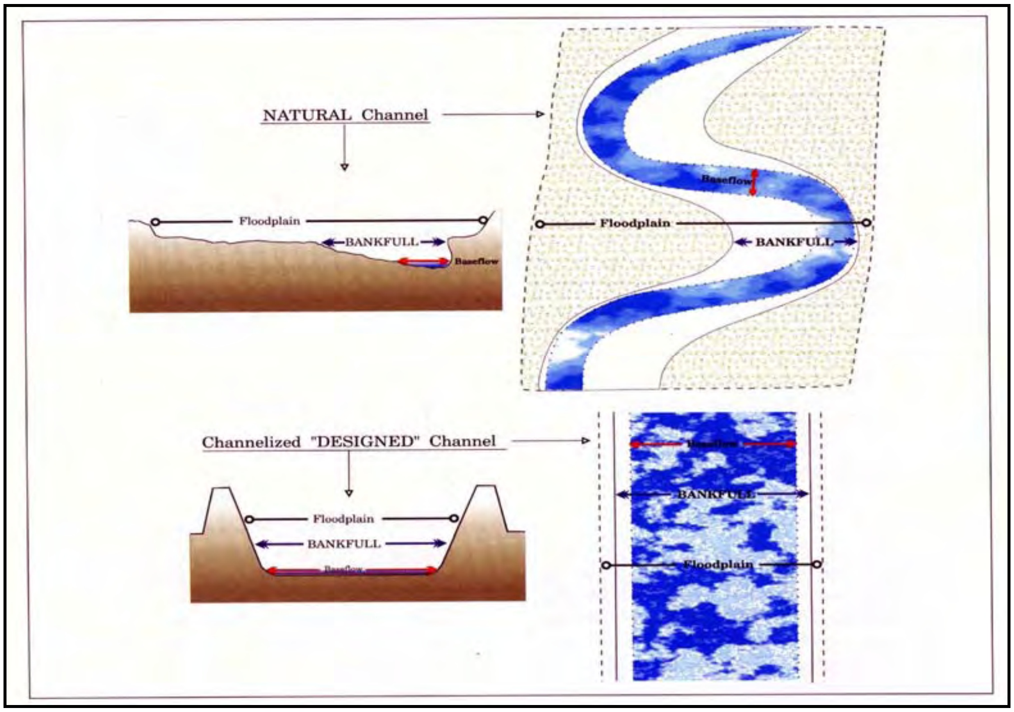


Figure 4 Typical Virgin River meander upstream of project area.

Effects of Channel Modification

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). Traditional “designed” or engineered channels remove the natural patterns (Figure 5) reducing the stream’s ability to perform its basic functions. The Master Plan has attempted to identify the stable geomorphic dimensions of the Virgin 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.



Applied River Morphology. Rosgen, 1996

Figure 5. Natural vs. “Designed” Channels.

The lack of geomorphic floodplains in the “designed” channel reduces sediment transport, increasing deposition and reducing flood protection.

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 and/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 can contribute to stream bank erosion. Without armoring, the stream channel will simply return to its pre-modified condition (Figure 6).

Levying/widening

Channel widening is generally intended to increase the capacity of a stream to carry flood flows (Figure 5). 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 the pre-modification channel width and geomorphic floodplain elevation, thereby negating the modification (Figure 6). In widened 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 6 Channel meander and adjustments

All stream channels meander. The flowing water in the photo on the left creates a uniform set of meanders within the straight irrigation canal. On the right the Walla Walla River reestablishes its meander pattern during a large flood event. The stream channel works to regain natural patterns when altered.

Role of Riparian Vegetation

Riparian vegetation provides critical benefits to the physical stream system. Plant roots provide additional strength for 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 are largely dependent on two critical variables: soil moisture and disturbance. Flooding is the driver for both of these variables. As a result of flooding, both soil moisture and disturbance are highest closest to the stream channel and decrease laterally moving away and upward. 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 (Hoag, et al, 2001). Each zone supports a different community, complimenting stream processes and creating habitats (Figure 7). For example, the Toe zone adjacent to the perennial flow supports lush, wetland plants; the Bank and Overbank zones are 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 increase as one moves away from the central stream channel. In the Master Plan the Toe, Bank, and lower Overbank zones belong in the Geomorphic Floodplain. The higher Overbank Zone is found in the Low Terrace. The High Terrace includes the Transition and Upland Zones.

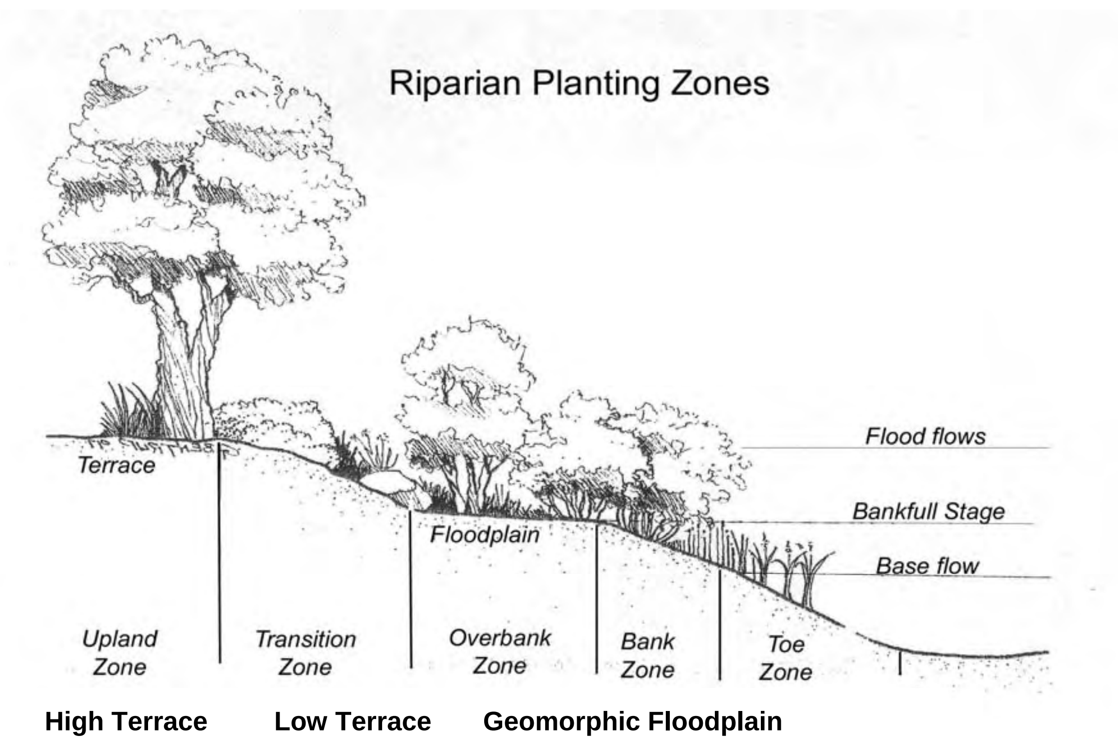


Figure 7 Riparian Planting Zones

Riparian vegetation grows in distinct bands or zones that lie parallel to the stream channel. The zones are defined by differing soil moisture and levels of disturbance.

Mechanisms of Channel Change

Most of the Virgin River watershed is undeveloped, with flows originating in steep mountains and plateaus and then meandering through wide plains and low rolling hills. The watershed is formed by high elevation plateaus above Zion National Park. Large storm events are commonly produced by large winter frontal storms but can also be generated by intense, short duration summer monsoon events. Winter flood flow magnitudes are often dramatically increased when warm rains fall on existing snow pack.

Stream channels are dynamic and local scour and deposition is normal as it adjusts to changes in water and sediment inputs. 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.

However, when these adjustments are large and/or rapid, they can threaten adjacent property and infrastructure. The most common of these threats and their associated mechanisms are described below.

Lateral migration: Bank erosion is common especially along the outside of channel meanders during flow events. The erosion is the result of higher velocities and shear stresses along the outer bank that overwhelms the stability supplied by bank materials and/or vegetation. Contrary to conditions on the outside of the bend, the inside of the meander is a zone of deposition and commonly builds toward the outer bank as it erodes.

Channel Incision: Incision is the lowering of the channel bed and is the result of velocities and shear stresses greater than the strength of the channel bed. The process generally produces one or more “nick points” or vertical ledges that migrate rapidly upstream. Incision can threaten upstream infrastructure including bridge piers and road crossings either by undercutting or by lateral erosion following incision.

Overbank deposition: Sediment loads in the Virgin River are substantial. Normally the majority of sediment is transported in the high velocities associated with the central stream channel. However, if high velocity flows are allowed to enter overbank areas substantial amounts of sediment can be deposited. Deposition on the Sun River golf course during the 2005 Virgin River flood provides an example.

Scour and stream capture: Erosive overbank flows that are separated from the central channel can cause substantial local scour and, in extreme cases, can capture the main stream channel. This occurs in natural systems but can be exacerbated by topography created during development that allows high flows to be carried away from the central channel or thick vegetation within the central channel that forces flows onto the smoother adjacent overbanks. Property damage along the Santa Clara River during the 2005 flood provides numerous examples.

Geomorphic Assessments

The morphology of a stream channel can be characterized by three parameters: dimension, pattern, and profile. Dimension refers to the shape and size of the channel, floodplain, and terraces in a cross-section (frontal) view. Pattern refers to the planiform shape (view from above), or the meander of the stream. Profile refers to the slope of the channel and its features in a longitudinal (sideways) view.

Methods

Knowledge acquired during field visits to project area was combined with studies of aerial photographs, geomorphic surveys, regional hydrologic data, and anecdotal evidence to develop templates of channel dimensions.

Bankfull Stage

Bankfull stage was used as the reference point for quantifying dimension, pattern, and profile in morphological assessments in this project. Bankfull stage is defined as the elevation where the channel transitions to the geomorphic floodplain. This "point of incipient flooding" commonly represents a discharge with a recurrence interval between 1 and 2 years (Leopold 1994, Moody et al 2003). This stage can be identified in the field and provides a consistent, common point of reference for quantifying the channel dimension. A system has been developed to classify stream channels using bankfull stage (Rosgen 1996).

The elevation of the geomorphic floodplain (bankfull stage) and associated alluvial features were identified using procedures developed in Dunn and Leopold, (1978). Alluvial features representing the geomorphic floodplain were identified at several cross-sections. Cross-sectional dimensions at these elevations were compared to regional values for validation. This water surface elevation represents a flow event with a frequency between one and two years.

Assessments of channel dimension were not limited to the frequent, moderate flow events represented by bankfull stage. Dimensions of higher alluvial surfaces (geomorphic floodplains, terraces) were also quantified to prepare a channel template that would function at all flood stages.

Field Visits

Field visits were made to all project reaches of the Virgin River in the spring and summer of 2006. These visits included walking and/or floating surveys of the reaches and cross-section/profile surveys along the river through the project area.

Aerial photographs:

Pre- and post- flood aerial photographs (2003 & 2006) were used to evaluate channel change and natural meander pattern.

Geomorphic surveys:

Eleven pre-and post-flood cross-sections located in relatively stable transition or riffle sections were evaluated to characterize the natural and altered channel morphology.

Regional Geomorphic Data

To validate the field assessments, survey data was compared to morphologic data from 41 regional low-gradient gravel-sand bed channels located in southern Utah.

Channel-Floodplain Dimension

Alluvial channels are composed of distinct physical features (channel, floodplain, terraces) created and maintained by the stream processes (Figure 8). Research suggests that these features are critical to primary stream functions of conveying water, transporting sediment, and disippating energy. A central (or bankfull) channel carries moderate, frequent flow events and is responsible for the transport of the greatest volume of sediment over time. An adjacent geomorphic floodplain allows the conveyance of high flows and spread water to dissipate energy (reduce velocities). Terrace features occur at a higher elevation and are remnants of previous floodplains or bars created by high flow events.

- **Central (bankfull) 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. 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 than the floodplain and terraces, 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 permanent structures.
- **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.

  Low terraces can be expected to be flooded by moderate floods (~ 10-year) and 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 (100-year) but can be used for agricultural and recreational uses. However, appropriate roughness should be maintained to inhibit scour and stream capture during large flow events.

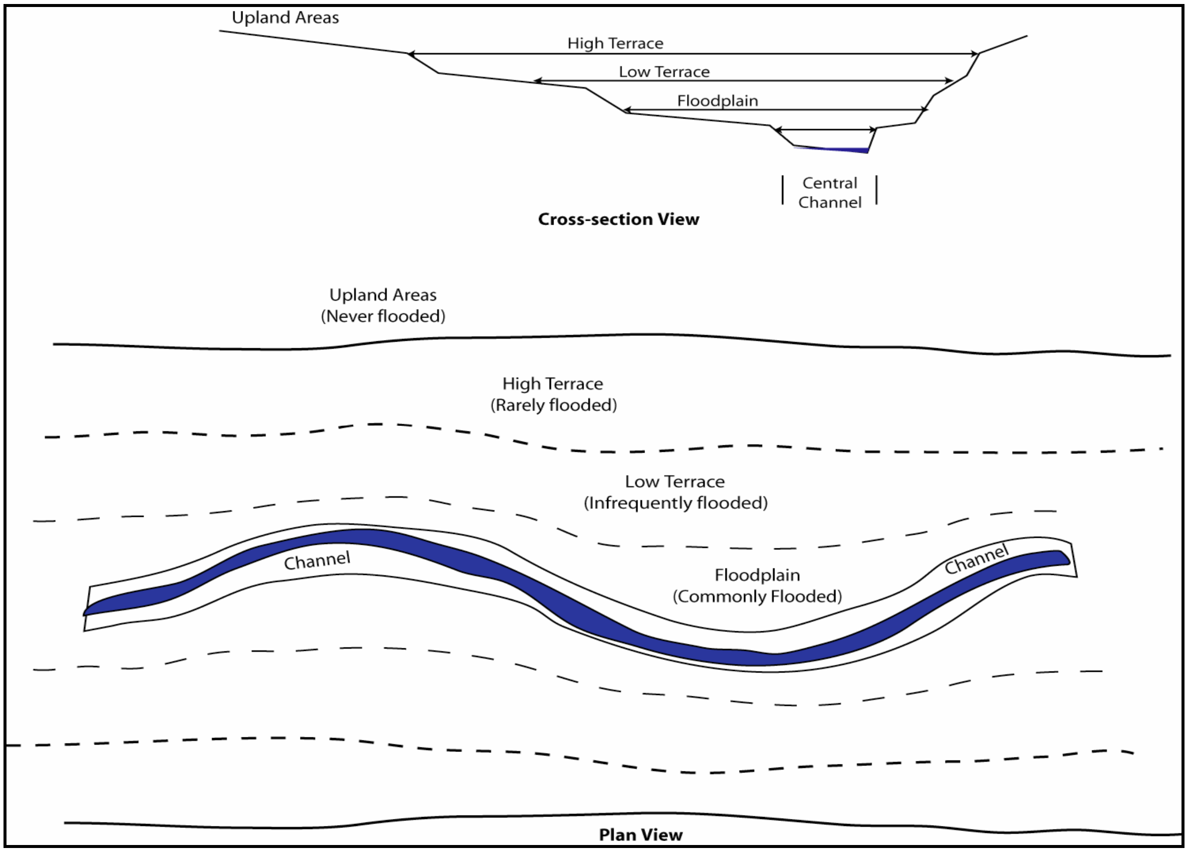


Figure 8 Channel, floodplain, terrace features.

Bankfull stage was used as a common reference point to identify width, depth, and other dimensions. Bankfull stage was estimated by identifying sets of consistent alluvial features at each survey site. The features were surveyed and assessed using standard methods (Dunne and Leopold 1978).

The stream channel geomorphology of the Virgin River has a wide range of variability. An assessment of pre-flood channel cross-sections suggests that the central or bankfull channel has cross-sectional areas between 310 and 460 square feet with an average of 350 square feet. Assuming a bankfull discharge of ~1,800 cfs (see hydrology section) a cross-sectional area of 350 ft^2 produces an average velocity of ~5 feet per second, consistent with other systems in the region.

The results of the surveyed cross-sections are provided in Table 7. The Virgin River stream channel would be classified as a C channel type in the Natural Channel Classification System (Rosgen 1996); a low gradient meandering channel with broad adjacent floodplains to spread flood flows. Substrate is dominated by coarse sand with some gravels and cobbles. The delineative criteria for classification are presented in Table 8. A summary of typical cross-section dimension values is presented in Table 9.

Table 7 Virgin River Cross-section data.

Representative cross-section data was developed from pre-flood topography in riffle or transition sections. The dimension of channel, floodplain, and terrace features were evaluated.

XS	Reach	XS Area (sq feet	Bankfull channel Width (feet)	Max depth (feet)	Mean depth (feet)	FPW[1] (feet)	Super FPW[2]
XS A	3	402	90	6.0	4.5	550	1200
XS B	3	347	100	4.0	3.5	600	1700
XS C	4	320	200	3.0	1.6	400	480
XS D	4	400	140	4.0	2.9	400	850
XS F	4	434	120	4.0	3.6	600	920
XS 1	5	350	75	6.0	4.7	420	450
XS 2	5	466	92	6.0	5.1	200	1050
XS 3	5	325	87	4.5	3.7	480	1100
XS 5	6	310	100	4.0	3.1	440	800
XS 6	6	315	120	3.0	2.6	280	350
Typical values		350	120	4.5	3.5	400	750

[1] Floodprone Width: Defined as the width of the geomorphic floodplain at an elevation twice maximum bankfull depth. This stage represents a common to moderate flood event depending on the local hydrology.

[2] Super Floodprone Width: Defined as the width of the geomorphic floodplain/terrace at an elevation 3 times maximum bankfull depth. This stage represents a moderate to extreme flood event depending on the local hydrology.

Table 8 Delineative channel dimension criteria at Virgin River cross-sections

Delineative criteria consists of dimensionless ratios that allow comparison with stream channels of differing sizes.

	Reach	W/D Ratio[1]	Ent. Ratio[2]	Super Ent. Ratio[3]	D50 (est)	Slope	Sinuosity	Channel Type
XS A	3	20	6.1	13.3	Sand	0.0023	1.3	C5
XS B	3	29	6.0	17.0	Sand	0.0023	1.3	C5
XS C	4	125	2.0	2.4	Sand	0.0023	1.2	C5
XS D	4	49	2.9	6.1	Sand	0.0023	1.2	C5
XS F	4	33	5.0	7.7	Sand	0.0023	1.2	C5
XS1	5	16	5.6	6.0	Sand	0.0023	1.3	C5
XS2	5	18	2.2	11.4	Sand	0.0023	1.3	C5
XS3	5	23	5.5	12.6	Sand	0.0023	1.3	C5
XS5	6	32	4.4	8.0	Sand	0.0023	1.1	C5
XS6	6	46	2.3	2.9	Sand	0.0023	1.1	C5
Typical value		39	3.0	6.0	Sand	0.0023	1.2	C5

[1] W/D Ratio: Defined as bankfull width divided by mean depth, this criteria describes the relative channel shape and sediment transport capacity.

[2] Entrenchment Ratio: Defined as Floodprone width divided by bankfull channel width, this criterion describes the stream's ability to spread common flows (~3-5 year) on an adjacent floodplain.

[3] Super Entrenchment Ratio: Defined as Super Floodprone width divided by bankfull channel width, this criterion describes the stream's ability to spread large flood flows on an adjacent terrace.

Table 9 Summary of existing channel/floodplain/terraces dimensions

	Recommended Target Value		Range of Variability
Central Channel			
Cross-sectional Area (ft^2)*	350	feet	+/- 10%
Width-depth ratio**	40		+/- 25%
Top Width	120	feet	+/- 15%
Bottom width	Varies depending on design top width to achieve cross-sectional area, commonly 50% of top width		
Geomorphic Floodplain			
Entrenchment Ratio	3		+/- 15%
Elevation above channel	4	feet	
Width	350	feet	+/- 15%
Low Terrace			
Elevation above channel	8	feet	
Width	350	feet	+/- 25%
High Terrace			
Elevation above channel	12	feet	
Width	700	feet	+/- 25%

* Central channel cross-sectional area should be a prime design parameter.

** Width-depth ratio: Top width divided by mean depth.

*** Top width is dependent on design width depth ratio

Channel Profile

Profile refers to the slope of the stream channel and its various bedforms. Channel slope provides the delicate balance between adequate sediment transport and channel aggradation/incision. Channel slope is a sensitive parameter. Slight decreases in slope can reduce sediment transport and induce aggradation leading to lateral widening of the stream channel. On the other hand increasing slope can lead to excessive channel scour, headcutting, and incision. All streams display a range of stable channel slopes. Based on pre- and post-flood surveys, channel slopes varied from 0.0022 & 0.0023 ft/ft above the Santa Clara River/Ft. Pearce Wash confluence and 0.0016 ft/ft downstream of that point.

An evaluation of historic channel bed elevation in the reaches upstream of the Santa Clara suggests that the elevations have remained relatively stable even through flows as large as the 2005 event (see Virgin River Stability Study Update). Below the confluence some sediment accumulation was evident in the burying of the Webb Hill fish barrier. The channel has since been excavated and no comprehensive post-flood evaluation was performed.

Meander Pattern

Meander pattern describes the stream channel's planiform shape across the landscape. All stream channels meander. Meander is critical to the stream's function of burning or dissipating energy. The smaller the radius, the tighter the turn and the greater the forces against the outside bank. Lack of sufficient meander can result in excess energy manifested in increased velocities and risk of bank erosion.

A variety of factors including slope, bedload, and surrounding geology influence a stream's meander pattern. The Virgin River has a relatively low sinuosity (stream length divided by valley length) but is consistent with regional values (Table 10).

Table 10 Channel sinuosity by reach

Reach	Begin		End	Stream length (feet)	Valley length (feet)	Sinuosity
1	Washington Fields Diversion	-	Sunrise Valley Bridge	9,800	8,200	1.2
2	Sunrise Valley Bridge	-	Washington Fields Rd	13,200	11,800	1.1
3	Washington Fields Rd	-	Johnson Diversion	11,900	8,900	1.3
4	Johnson Diversion	-	River Road	14,600	12,400	1.2
5	River Road	-	Interstate 15	13,300	10,450	1.3
6	Interstate 15	-	Man of War Bridge	8,300	7,900	1.1
7	Man of War Bridge	-	Atkinville Wash	17,000	14,900	1.1
			Total length	88,100	74,550	1.2

Stream channels exhibit characteristic meander pattern values specific to the stream channel, hydrology, and bank strength (Leopold 1994). Based on an evaluation of meanders from aerial photos of the Virgin River a range of stable meander pattern values were identified. Meander length (straightline length of a single meander), meander width (lateral extent of meander pattern), and radius of curvature were measured (Figure 9). As in most natural systems, the range of values is as important as average values in assessing the natural variability.

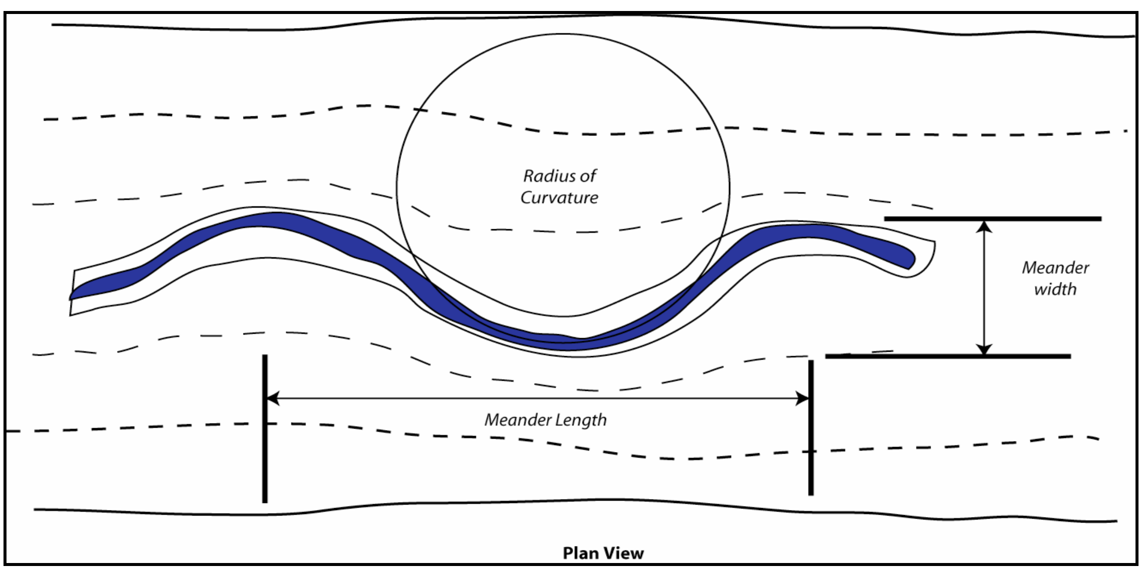


Figure 9 Meander Pattern Parameters.

Measurements of channel meander pattern were made using pre-flood aerial photos which are more likely to represent the long-term natural meander pattern (Figures 10 & 11). Dimensionless ratios were created by dividing meander pattern parameters by bankfull channel width to allow comparison with other channel systems in the region.

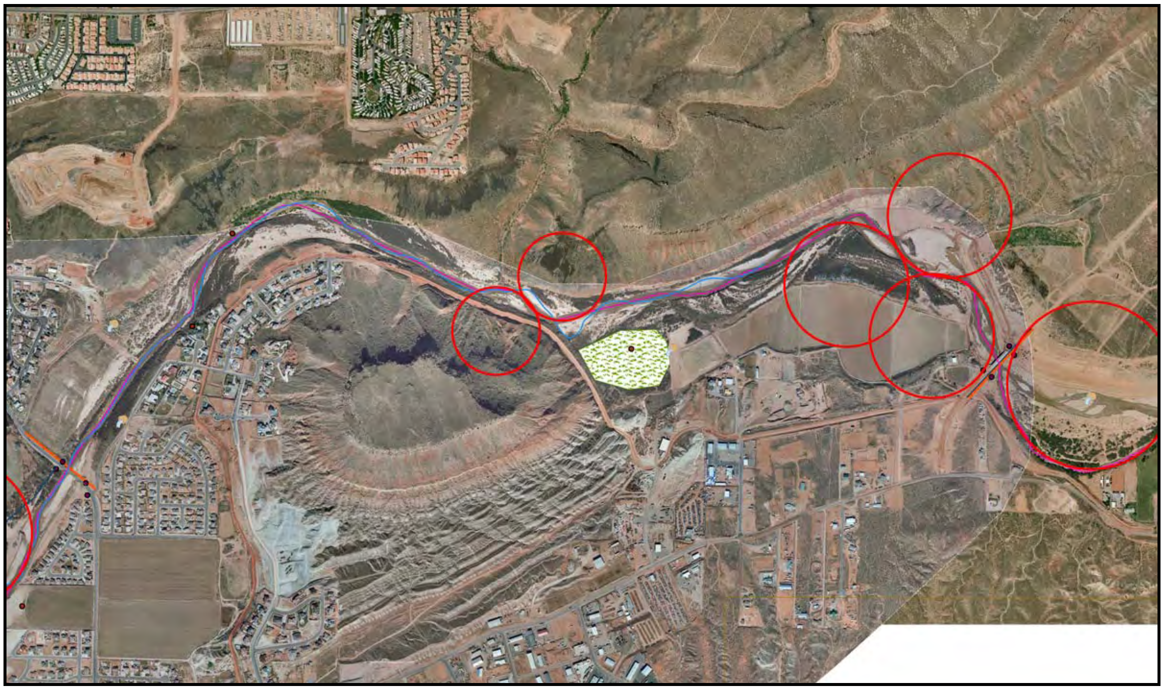


Figure 10 Reach 1 meander pattern measurements.

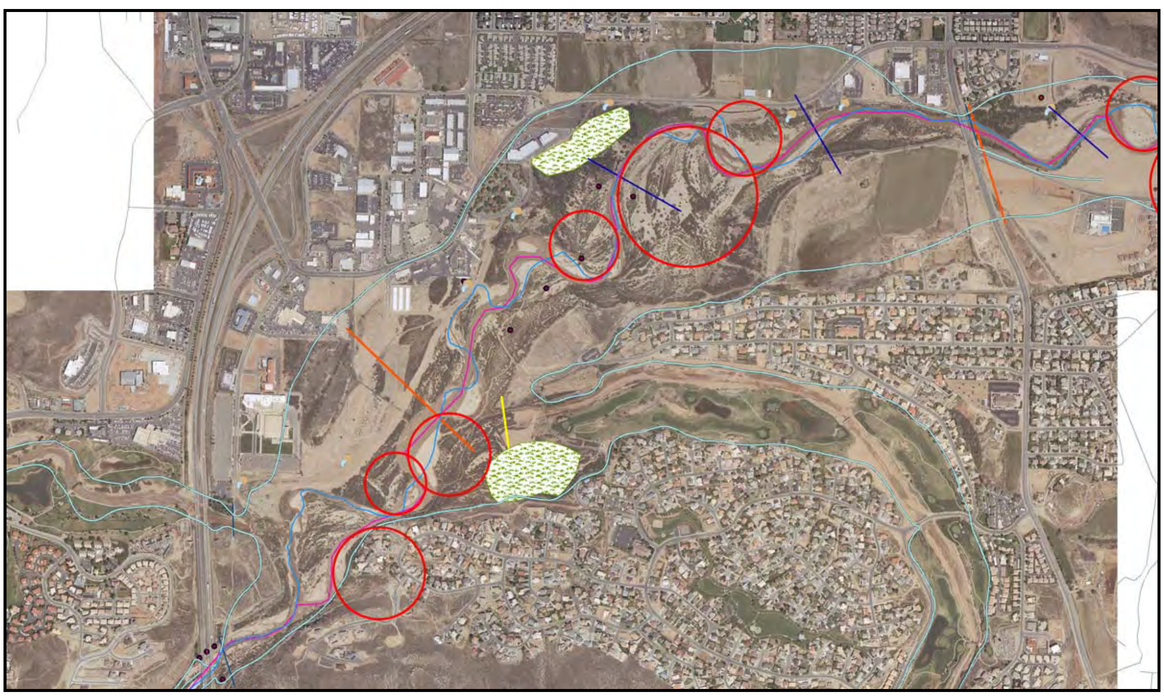


Figure 11 Reach 5 meander pattern measurements.

The pre-flood meander values were compared with similar meander data measured from post-flood aerials in Reaches 6 and 7. In general, the range of values were surprisingly consistent with pre-flood values. The exceptions were that tighter radius meanders were generally eroded to create a larger, gentler meander, an understandable result of the large flood. This suggests that although the alignment of the stream channel may migrate laterally across the stream corridor, it recreates a relatively stable, consistent meander pattern.

Table 11 Pre- & post-flood meander patterns

Radius of Curvature	***Pre-flood***		***Post-flood***	
	Radius (feet)	**Rc Ratio***	**Radius** (feet)	**Rc Ratio***
Average	725	4.5	761	4.8
Minimum	150	0.9	450	2.8
Maximum	1,500	9.4	1,500	9.4

Meander Width	***Pre-flood***		***Post-flood***	
	Rc Radius (feet)	**Rc Ratio***	**Radius** (feet)	**Ratio***
Average	385	1.7	462	2.1
Minimum	200	0.9	200	0.9
Maximum	500	2.2	600	2.7

Meander Length	***Pre-flood***		***Post-flood***	
	Radius (feet)	**Rc Ratio***	**Radius** (feet)	**Rc Ratio***
Average	1,104	4.7	991	4.4
Minimum	300	1.3	450	2
Maximum	3,000	13.3	3,000	13.3

* Rc Ratio: Ratio of radius of curvature to channel width at bankfull stage.
** Meander width ratio: Ratio of Meander width to channel width at bankfull stage.
***Meander length ratio: Ratio of meander length to channel width at bankfull stage.

A summary of meander pattern measurement is presented in Table 11. As in the channel/floodplain geometry, a relatively wide range of variability was evident. In natural systems the range of variability is as important as some average value. To eliminate extreme values, the 10% and 90% of each data set is provided along with the average value. The range of values for the dimensionless ratios are consistent with other systems in the region. Typical meander values are presented in Table 12.

Table 12 Meander pattern dimensions

These values characterize the range of meander pattern dimensions and ratios along the Virgin River. The range of variability is as important as an average value.

	Radius of Curvature (feet)	Meander length (feet)	Meander width (feet)	Radius of curvature Ratio*	Meander Length Ratio**	Meander Width Ratio***
90%	818	1,970	682	8.2	19.7	6.8
Average	552	1,491	530	5.6	14.7	5.2
10%	400	1,110	340	4.0	11.1	3.4

* Radius of Curvature Ratio: Ratio of radius of curvature to channel width at bankfull stage.
**Meander length ratio: Ratio of meander length to channel width at bankfull stage.
*** Meander width ratio: Ratio of Meander width to channel width at bankfull stage.

It should be noted that stability in meander form does not preclude lateral channel movement. Alluvial streams naturally migrate across the landscape over time and the location of the channel alignment changes. However, in a stable pattern, values for the frequency, amplitude and radius of individual meanders remains consistent. These values provide guidance for assessing existing meander pattern or in the design of new channel alignments.

Hydraulic Analysis

An analysis of the hydraulic characteristics was conducted for the channel cross-section template developed in the channel dimension section to create a baseline condition. The shape and dimension of the bankfull channel and geomorphic floodplain are considered critically important to successful sediment transport.

WinXSPro, a cross-section analyzer developed by the USDA Forest Service and Bureau of Land Management was used to evaluate the cross-section. Each cross-section was divided into 5 sections including a central channel (bankfull), geomorphic floodplain (both banks), and low/high terrace (both banks). The central channel extends to the 4-foot stage and is expected to be largely free of vegetation. The geomorphic floodplain extends from 4- to 8-feet above channel bed. The low terraces is located at elevations from 8 – 10 feet and the high terrace rises to a stage of 13 feet in order to carry the extreme (100-year) flood event.

WinXSPro uses Mannings equation to relate slope, channel geometry, and roughness to determine stage and velocity. This analysis is simplistic in many ways but provides reasonable method to evaluate stage-discharge relationships and velocities in different channel sections. Mannings equation is sensitive to slight variations in roughness.

Roughness coefficients were chosen to be approximate actual resistance to flow but may vary in specific situations depending on vegetation type and density. They are however, within the range commonly used for natural channels. Roughness coefficients were slightly higher in shallow flows than at higher stages.

The geomorphic floodplain and terraces that lie adjacent to the central channel are expected to have the greatest variety in roughness. These areas currently support dense stands of salt cedar (*Tamarisk spp*). It is also expected to have sufficient soil moisture to support supple native willow species and cottonwoods. Roughness values are presented in Table 13.

Table 13 Roughness coefficients (*Mannings n*) used in hydraulic model

Composite roughness coefficients decreased slightly with depth of flow.

Roughness Coefficients	Shallow flow (1 ft)	Deep flow (6-12 ft)
Channel	0.035	0.030
Floodplain without veg	0.035	0.030
Floodplain with supple willows	0.050	0.030
Floodplain with dense salt cedar	0.100	0.050
High/low terraces	0.035	0.030

Mean velocities estimated for each zone within the design channel template at various discharges are presented in Table 14. Although there is considerable variability in channel/floodplain width and shape throughout the project, this cross-section is meant to represent existing stable conditions. Velocities on the floodplain and terrace areas are less than 5 feet per second in all but extreme flow events. The 100-year flood event rises to a stage of 10.5 feet and the 10-year flood is contained at an elevation of 8 feet above the channel bed.

Table 14 Hydraulic results; 700 foot wide channel template

The 700-foot wide channel template produced relatively low velocities in the floodplains and terrace areas.

			Mean Velocities				
Flow Type	Discharge (cfs)	Stage (feet)	XS Average (fps)	Channel (fps)	Floodplain (fps)	Terrace (fps)	Froud #
Bankfull	1,800	4.0	4.4	4.4			0.41
2 yr	3,560	6.0	5.6	6.4	1.8		0.56
5 yr	6,120	7.5	6.3	8.1	2.8		0.60
10 yr	8,280	8.0	6.5	8.7	3.2		0.61
25 yr	11,700	9.0	7.4	10.0	4.5	1.0	0.62
50 yr	14,800	10.0	8.4	11.4	5.8	1.2	0.66
100 yr	18,000	10.5	8.9	12.1	6.5	1.3	0.69

Actual depths and velocities will vary depending on the actual widths at specific sites. Widening the geomorphic floodplain and terrace areas will decrease velocities and the potential for erosion across these features. By the same token narrowing these features will increase velocities and erosion potential. The central channel width and cross-section are critical to adequate sediment transport and should not be substantially widened or narrowed.

Effects of vegetation

Vegetation can increase or reduce stability in perennial stream channels. However, an evaluation of the 2005 flood suggests that dense thickets of salt cedar did not provide effective protection from lateral migration along the Virgin River.

Supple woody species like the native willow bend with flows dissipating energy and slowing velocities. At the same time, their dense root mass strengthens the stream banks further reducing the risk of erosion. The existence of dense willows on the geomorphic floodplain extending approximately 100 feet on either side of the central channel was assumed in the hydraulic model presented in Table 14. The willows lower velocities across the floodplains without increasing the stage for the 100-year flow. The benefits from the energy dissipation created by the vegetation are not represented in the model.

Dense, rigid vegetation, on the other hand, can have the opposite effect. A comparison of salt cedar dominated and native vegetation cross-sections along Ft. Pearce Wash (see Ft. Pearce Master Plan) suggested that the salt cedar thickets drastically reduce velocities in the floodplain section but dramatically increase velocities and the risk of scour/erosion in both the channel and terraces sections. In practice the stiff salt cedar collects debris further reducing flow in its area. Another consequence is the vertical buildup over time within the thickets as fine sediments are deposited by slow velocities during moderate flows. The rising floodplain elevations constrict flows to the channel and increase the risk of incision. These scenarios were responsible for substantial damage along the Santa Clara River during the 2005 flood.

See revegetation section for specific recommendations.

Conclusions

Based on the hydrologic, geomorphic, and hydraulic analyses described above the design channel template was identified and is presented below (Table 15, Figure 12). The cross-section is intended to:

- Effectively maintain sediment transport
- Effectively dissipate flow energy
- Minimize the potential for scour and erosion from high velocities
- Contain the 100-year flood event
- Contain the 10-year flood event within the low terraces

The design template is presented for guidance purposes only. Additional site specific engineering analyses are recommended.

Table 15 Design cross-section template and meander pattern dimensions

	Elev abv channel bed (ft)	Channel Width (ft)	Side slopes	Approximate Flood hazard*
Channel				
Bottom width	0	80	NA	NA
Top width	4	100	3:1	1.5 - 2 year
Geomorphic floodplain	8	350	30:1	10 year
Low Terrace	10	400	13:1	50 year
High Terrace	13	700	50:1	100 year
Daylight to natural grade				> 100-year flood hazard

* Flood hazard estimates are approximate and depend on local conditions.

Meander Pattern

	Radius of Curvature (feet)	Meander length (feet)	Meander width (feet)
90%	818	1,970	682
Average	552	1,491	530
10%	400	1,110	340

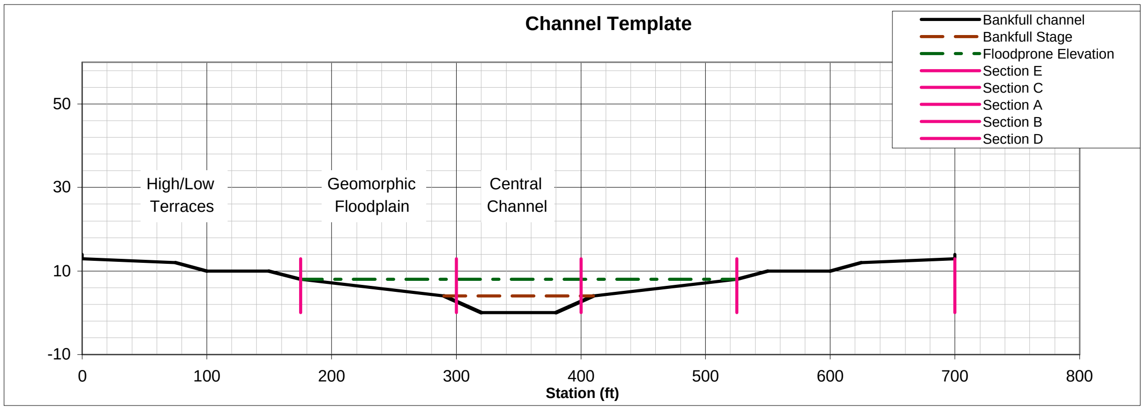


Figure 12 Design Cross-section Template

SECTION 4: STREAM STABILITY TEMPLATE

Floods of equal or greater magnitude of the 2005 flood are likely to occur again on the Virgin River. 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. The following principles are presented to guide in the emergency repair work now underway.

The purpose of this section is to provide recommendations to maintain and enhance natural stream stability in order to minimize the speed and extent of lateral channel migration and associated bank erosion. The recommendations are based on field surveys conducted in the spring and summer of 2006 and evaluation of aerial photographs from the same period.

The following elements of the channel stability model are discussed below:

- Guiding Stability Principles
- Riparian corridor zones
- Channel Cross-section Templates
- Channel Corridor Alignment
- Corridor Maintenance Plan

Guiding Stability 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 (Figure 13). For the Virgin River steps of approximately 4.0 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 (Figure 14). 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.

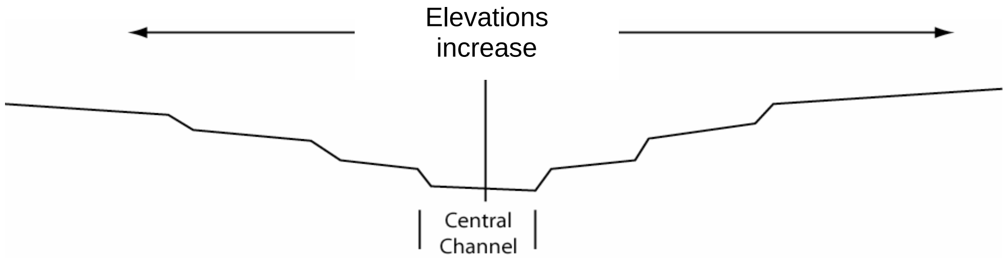
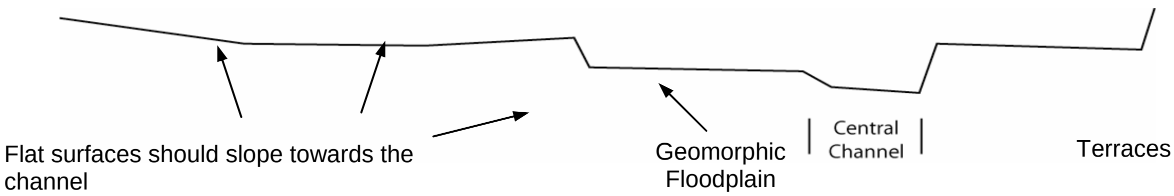
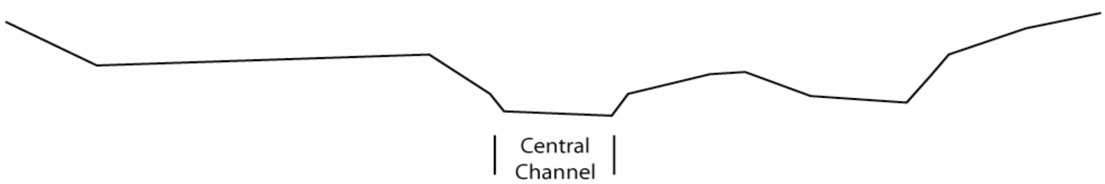


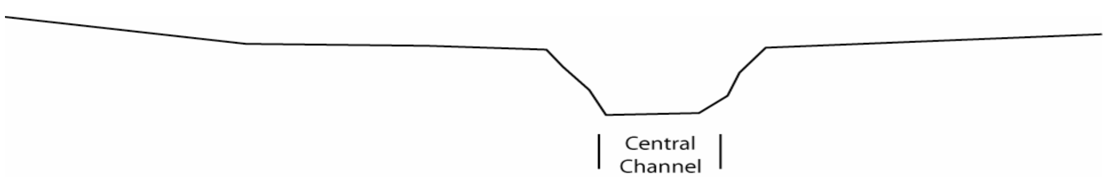
Figure 13 Appropriate channel/floodplain elevations



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.

Figure 14 Incorrect channel/floodplain elevations

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 15). 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. Areas with no resistance and/or structures that completely stop or redirect flow across the floodplain/terrace should be avoided (Figure 16).

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. However, these areas should be designed to discourage high flow velocities.

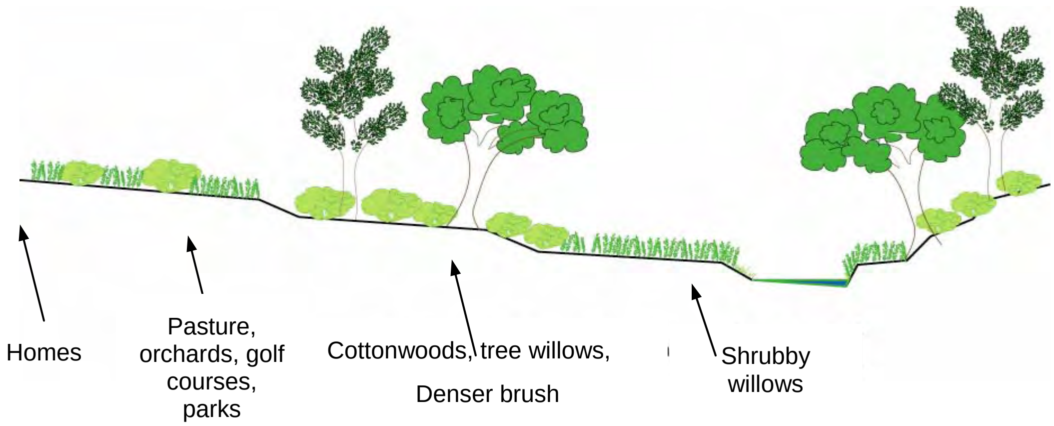


Figure 15 Appropriate overbank roughness.

Vegetation provides increasing roughness to keep high velocities in central channel.

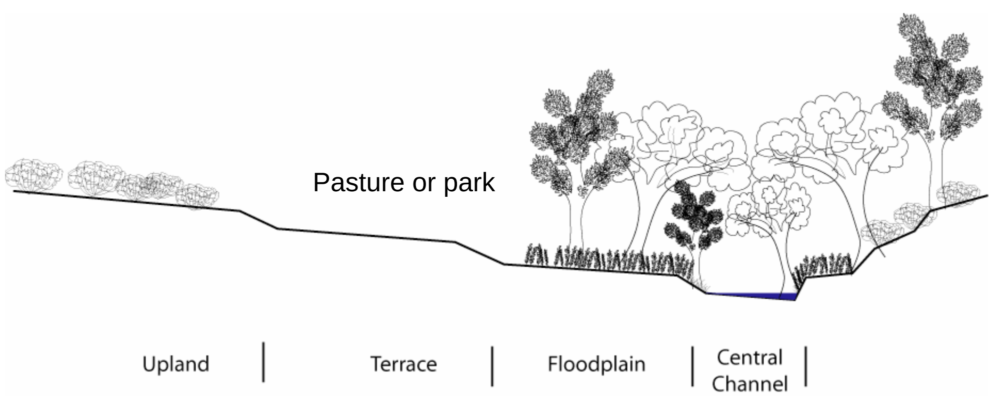


Figure 16 Incorrect overbank roughness.

Dense stiff native or exotic vegetation chokes channel. Smooth surface of pasture creates high velocities and erosion.

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 17). Such constrictions force increases in velocity and water elevations that can increase erosion.

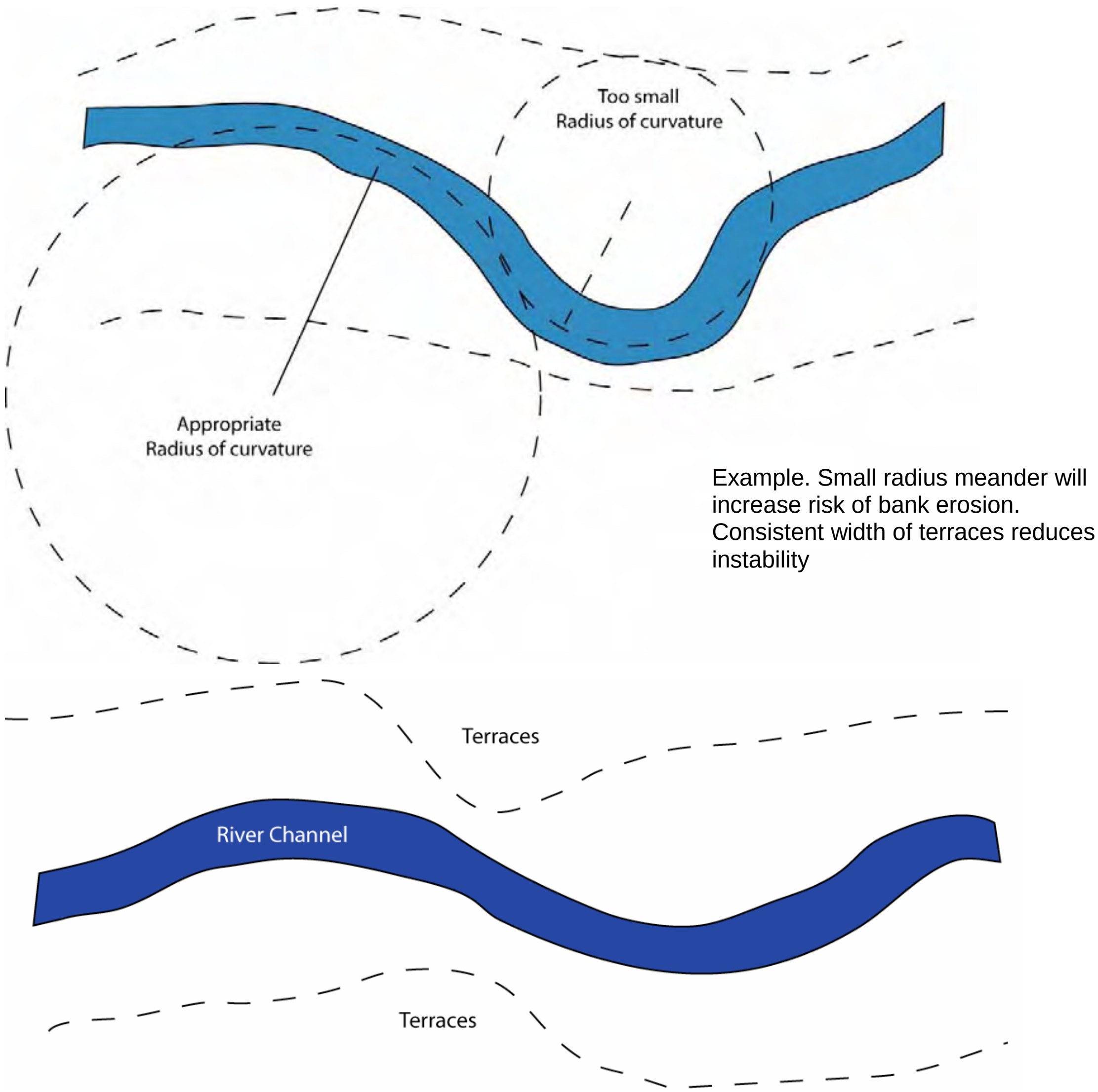


Figure 17 Incorrect channel transitions.

Sudden narrowing of terrace or floodplain increases potential for erosion.

Riparian Corridor Zones

The riparian corridor can be divided into 4 distinct zones: central channel, geomorphic floodplain, flood terraces, and uplands (Table 16, Figure 18). The first three zones are subject to periodic flooding; the higher areas less frequently than those nearer the channel. Upland areas surround the riparian corridor but at an elevation to precludes flooding.

All stream channels have 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, geomorphic floodplain, and terraces. Each has a distinctive shape, elevation, and width.

Central 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.

This zone includes the central (bankfull) channel and adjacent frequently inundated floodplain. No development should occur within the geomorphic floodplain and should be dedicated solely for flood conveyance and open space. Trails may be located with this area but they will be subject to damage from moderate frequent flow events. The geomorphic floodplain should contain the 10-year flood and contains USACE jurisdictional area (Waters of the U.S.).

Flood terraces:

Terraces are commonly old floodplains abandoned when channel elevations are lowered by erosion but can also be created as alluvial bars deposited during high flow events. These surfaces are inundated by moderate, high, and extreme floods but can be used for trails and other infrastructure that can withstand periodic flooding and does not interfere with riparian vegetation however appropriate roughness in the form of riparian vegetation should be maintained.

The elevated flood terrace is located on one or both sides of the geomorphic floodplain. The flood terrace can be stepped with one or more levels all of which should be sloped to drain toward the geomorphic floodplain at a minimum cross-slope of two percent. A wide variety of flood-tolerant activities may occur on the flood terraces including trails, active recreation facilities, recharge basins, and constructed wetlands. 100-year flood velocities and depths should be minimized to limit scour and erosion. The flood terraces lie within the regulatory (100-year) floodplain and, unless adequate erosion protection is provided at the edge of the geomorphic floodplain, are considered to be within the Virgin River erosion hazard zone (EHZ).

Uplands:

Upland areas are the lands located outside the flood terraces and above the 100-year flood elevations. Upland areas are outside the regulations but may be located within an erosion hazard zone (EHZ).

Table 16 Stream corridor zones

Riparian Corridor Zones	Regulatory Issues	Approximate Width	Flood Protection	Vegetation	Uses
Central channel/ Geomorphic Floodplain	USACE Jurisdictional Area	360 ft	< 10-year	Native riparian willows, cottonwoods *	Pedestrian only, trails, no other improvements
Flood Terrace	FEMA Regulatory Floodplain	350 - 700 ft	< 100-year	Native xeric species, others with irrigation	Trails, parks, nurseries, golf courses, constructed wetlands
Flood Terrace	Erosion Hazard Boundary	Variable	> 100-year	Variable	Developable with engineered protection
Uplands	Development ordinances	> 700 ft	> 100-year	Landscaping	Fully developable Unless in EHZ

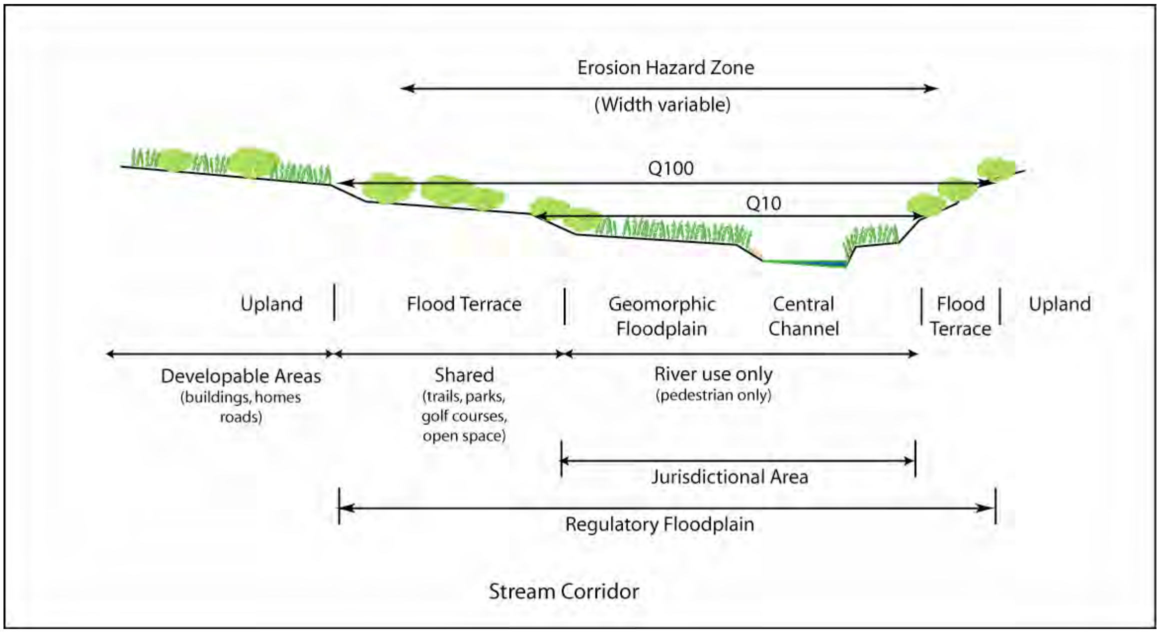


Figure 18 Stream corridor zones

Channel Realignment

Generally, it is recommended that channel alignments be maintained in their existing locations. However, if realignment is necessary, new alignments should be constructed consistent with the Guiding Principles, channel cross-section template, and meander pattern recommendations presented below. Realignments should not adversely impact upstream or downstream properties. All disturbed areas should be revegetated with appropriate native plant species.

Channel Cross-section Template

A channel template was created to describe the width and depth of alluvial features for Virgin River project reaches (Table 16). The template is based on an evaluation of regional channel morphology, watershed hydrology, and surveys of unaltered stream reaches where erosion was minimal. The cross-section templates provide guidance in the relative widths and depths of alluvial features to minimize erosive velocities in the vulnerable flood terrace areas (see hydraulics section). Dimensions for reconstructing channel-floodplain-terrace features in Virgin River are given in Table 17 and Figure 19. Meander pattern recommendations are presented in Table 18 and Figure 20.

The design template is presented for guidance purposes only. For example, stream reaches such as near I-15 crossing are controlled by existing geology must be narrower. Additional site specific engineering analyses are recommended.

Table 17 Cross-section Template data

		Recommended Target Value		Range of Variability
Central Bankfull Channel				
Cross-sectional Area (ft^2)*		350	Square feet	+/- 10%
Width-depth ratio**		40		+/- 25%
Top Width	A	120	feet	+/- 15%
Bottom width	Varies depending on design top width to achieve cross-sectional area, commonly 1/2 of top width			
Geomorphic Floodplain				
Entrenchment Ratio		3		+/- 15%
Elevation above channel		8	feet	
Width	B	350	feet	+/- 15%
Low Flood Terrace				
Elevation above channel		10	feet	
Width	C	450	feet	+/- 25%
High Flood Terrace				
Elevation above channel		13	feet	
Width	D	700	feet	+/- 25%

* Central channel cross-sectional area should be a prime design parameter.

** Width-depth ratio: Top width divided by mean depth.

*** Top width is dependent on design width depth ratio

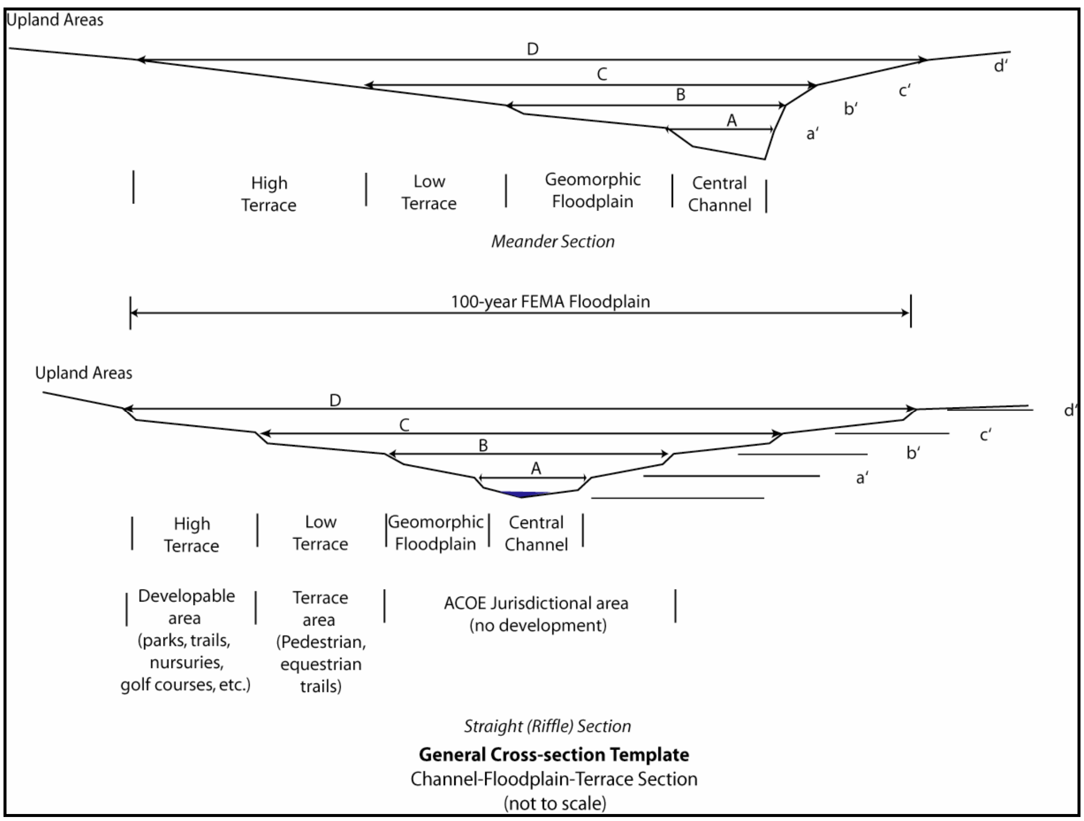


Figure 19 Cross-section template

Table 18 Recommended meander pattern dimensions

	Radius of Curvature (feet)	Meander length (feet)	Meander width (feet)
Maximum	708	1660	606
Average	552	1,491	530
Minimum	424	1200	400

[1] Maximum-minimum values represent the 80th and 20th percentiles respectively of measured values.

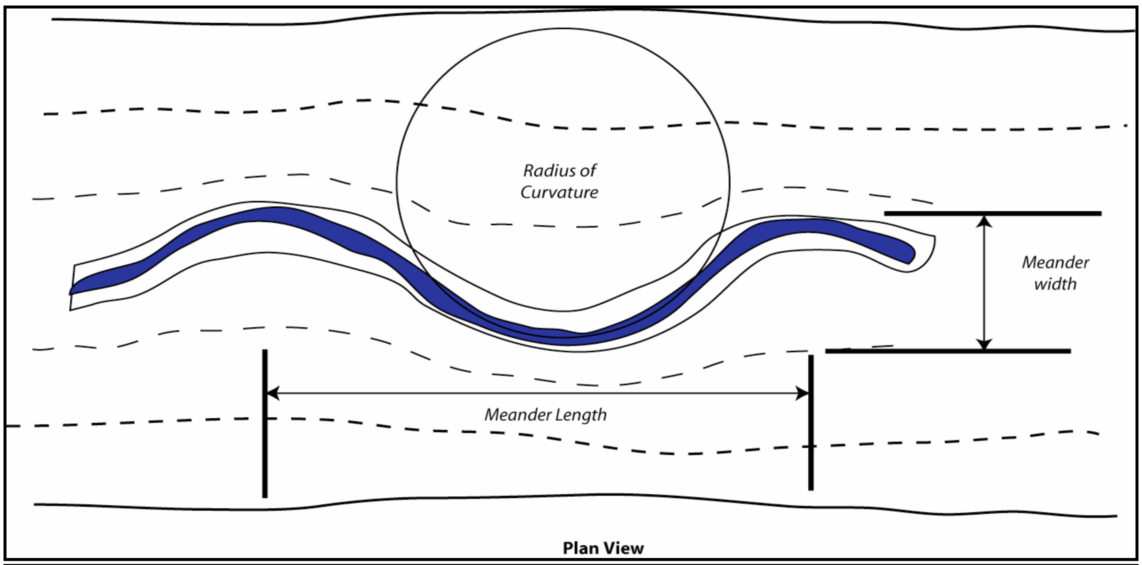


Figure 20 Meander pattern characteristics

Revegetation Strategies

Riparian vegetation is an important component in providing channel stability and reducing bank erosion along the Virgin 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 within areas that share similar soil moisture and flood disturbance regimes. 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. To be successful plant communities must be located in zones with appropriate soil moisture and disturbance.

It is expected that revegetation activities will occur under the following scenarios:

- Locally to enhance stability, increase habitat, and enhance recreation/aesthetics;
- In support of structural bank stabilization;
- Following removal of salt cedar and other exotic vegetation.

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 to remain in the central channel rather than the more erodible overbank areas. Revegetation should focus on geomorphic floodplains and terraces. The following describes the plant types for each of the alluvial features described in the preceding section (Figure 21).

Central Channel: Well rooted herbaceous plants, emergent wetland species and supple, shrubby woody species along stream banks.

Geomorphic Floodplain/ Low Flood Terrace: Supple woody species including willow and baccharis species should be placed in areas immediately adjacent to the channel. Stiffer shrubs and trees can be planted in higher areas. Vegetation composition should be carefully integrated with human uses to maintain resistance to flow (roughness) as described in the guiding principles. Due to their inability to endure high soil salinity, the establishment of willow and cottonwood species will be dependent on the local soil conditions.

High Flood Terrace/Upland Areas: High flood terraces can support a wide variety of native and cultivated vegetation depending on the use but will generally require irrigation. In addition, if the vegetation cover is sparse with 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.

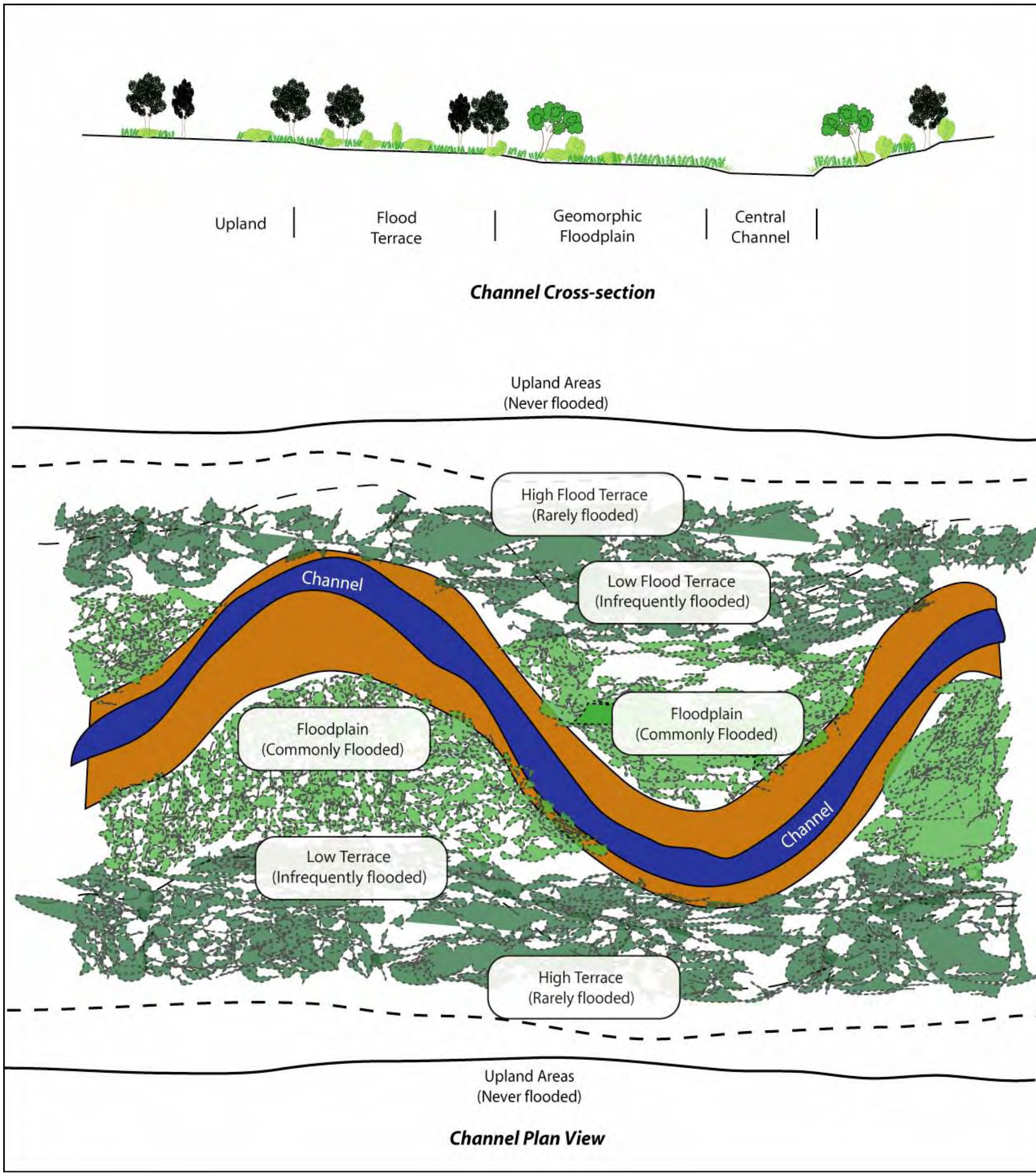


Figure 21 Areas of re-vegetation

Planting Recommendations

Appropriate composition, distribution, and density of riparian vegetation will be essential to maximizing stream stability and minimizing erosion risk. Specific plant communities (Table 19) should be established or maintained on alluvial features as described below.

Table 19 Partial list of appropriate plant species for revegetation

Common Name	Scientific Name
<u>Bank Zone/floodplain</u>	
Seep willow	*Baccharis salicifolia*
Coyote Willow	*Salix exigua*
Alkalai sacaton	*Sporobolus airoides*
<u>Floodplain</u>	
Grasses	
Indian ricegrass	*Oryzopsis hymenoides*
Cane bluestem	*Bothriiochloa barbinodis*
Plains bristlegrass	*Setaria macrostachya*
Gelleta grass	*Hilaria jamesii*
Spike dropseed	*Sporobolus contractus*
Forbs	
Evening primrose	*Oenothera spp*
Desert Sand verbena	*Abronia villosa*
Fragrant sand verbena	*Abronia elliptica*
Penstemon	*Penstemon spp*
Shrubs	
Quailbush	*Atriplex lentiformis*
Desert Broom	*Baccharis sarothroides*
4-wing saltbush	*Atriplex canescens*
Apache plume	*Fallugia paradoxa*
Small Trees	
Catclaw acacia	*Acacia greggii*
Western Redbud	*Cercis occidentalis*
Desert willow	*Chilopsis linearis*
Large Trees	
Cottonwood	*Populus fremontii*
Black willow	*Salix gooddingi*
Velvet Ash	*Fraxinus velutina*

Common Name	Scientific Name
<u>Flood Terrace</u>	
Grasses	
Indian ricegrass	*Oryzopsis hymenoides*
Cane bluestem	*Bothriiochloa barbinodis*
Plains bristlegrass	*Setaria macrostachya*
Gelleta grass	*Hilaria jamesii*
Spike dropseed	*Sporobolus contractus*
Forbs	
Purple sage	*Salvia dorii*
Desert marigold	*Bailya multiraadiata*
Mohave aster	*Xylorhiza tortifolia*
Desert dandylion	*Malacothrix glabrata*
Shrubs	
Three-leaf Sumac	*Rhus trifoliate*
Blackbrush	*Coleogyne ramosissima*
Indigo bush	*Amorpha fruticosa*
Brittlebush	*Encelia farinose*
Roundleaf Buffaloberry	*Shepherdia rotundifolia*
Fremont Mahonia	*Mahonia fremontii*
Golden current	*Ribes aureum*
Small Trees	
New Mexico Locust	*Robinia neomexicana*
Hop tree	*Ptelea crenulata*
Single leaf ash	*Fraxinus anomala*
Large Trees	
Netleaf hackberry	*Celtis reticulata*
Box elder	*Acer negundo*

Appropriate land uses

The Virgin River runs through the communities of Washington and St. George, Utah. Fertile lands and access to water have historically linked agricultural lands to the river. But, as was evident in January 2005, there are risks associated with living adjacent to a river.

Rivers flood. Common floods inundate areas closest to the central channel; higher, less frequent floods affect higher areas. In terms of use, riparian corridors can divided into four zones (Figure 22). The first and second are the lowest in elevation and include 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.

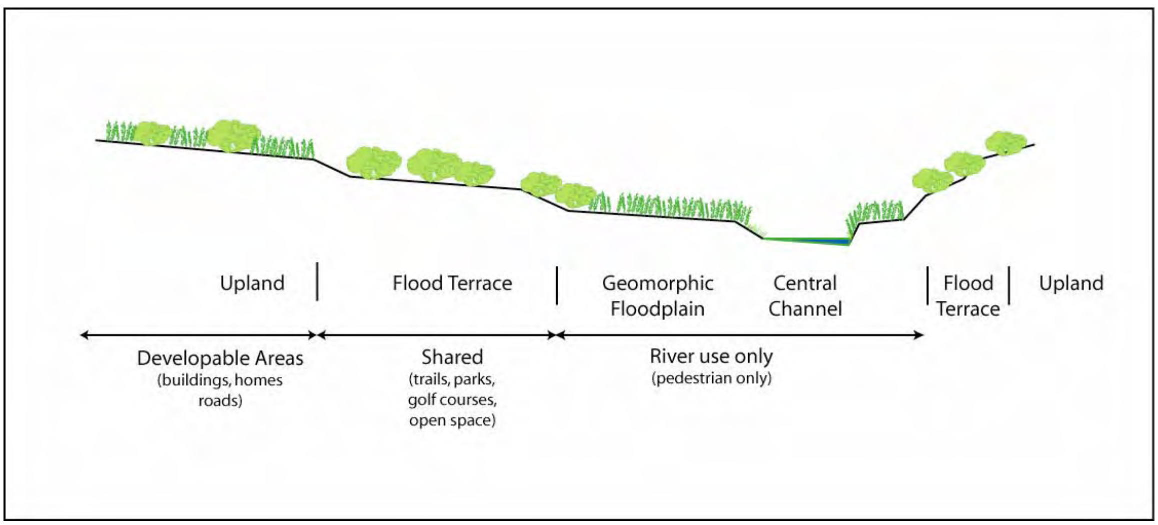


Figure 22 Appropriate land uses.

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.

Flood (high/low) Terraces

Agricultural fields that can be flooded periodically. Constructed pedestrian/bike trails, recreation areas (parks, golf courses), plant nurseries without hard infrastructure. 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 for agricultural and urban uses based on flood and erosion hazard risk.

Channel Capacity Excavation

The need for channel excavation to increase flow capacity should be assessed through careful engineering studies to identify the contributing factors, describe the location for excavation, and quantify the volume to be removed. These studies should include the analysis of a longitudinal profile to determine the channel slope well above and below the proposed excavation site. If the channel grade is consistent, excavations of the channel bed will create a low point that will require periodic maintenance. A series of channel cross-sections surveyed over time should be assessed to determine whether the channel is currently aggrading or stable.

Should excavation be warranted, channel/floodplain/terrace dimension should be maintained (Figure 23). Lowering geomorphic floodplain and terrace elevations will lead to an overwidened channel (Figure 24). An over-widened channel reduces sediment transport and increases deposition. The result can be a reduction of flow capacity below initial conditions. In addition, over-widening the channel often accelerates lateral channel migration and increased bank erosion. All excavations should be consistent with the guiding principles; i.e., the floodplain/terrace should rise as it moves away from the channel and roughness should increase away from the channel (Figure 25). Eventually coyote willow or other supple native woody species should be planted where the tamarisk is removed.

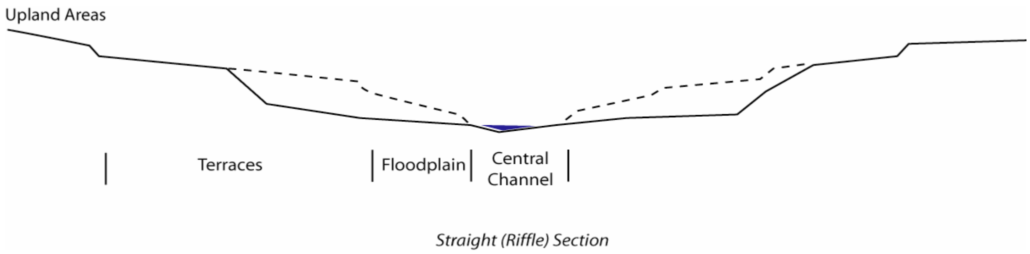


Figure 23 Channel excavation

If needed to increase conveyance, channel excavations should follow dotted line in this graphic preserving the alluvial forms critical to sediment transport.

Figure 24 Over-widened channel excavations

Excavations to increase conveyance have removed all alluvial features and associated riparian vegetation decreasing sediment transport and increasing the risk of lateral erosion.

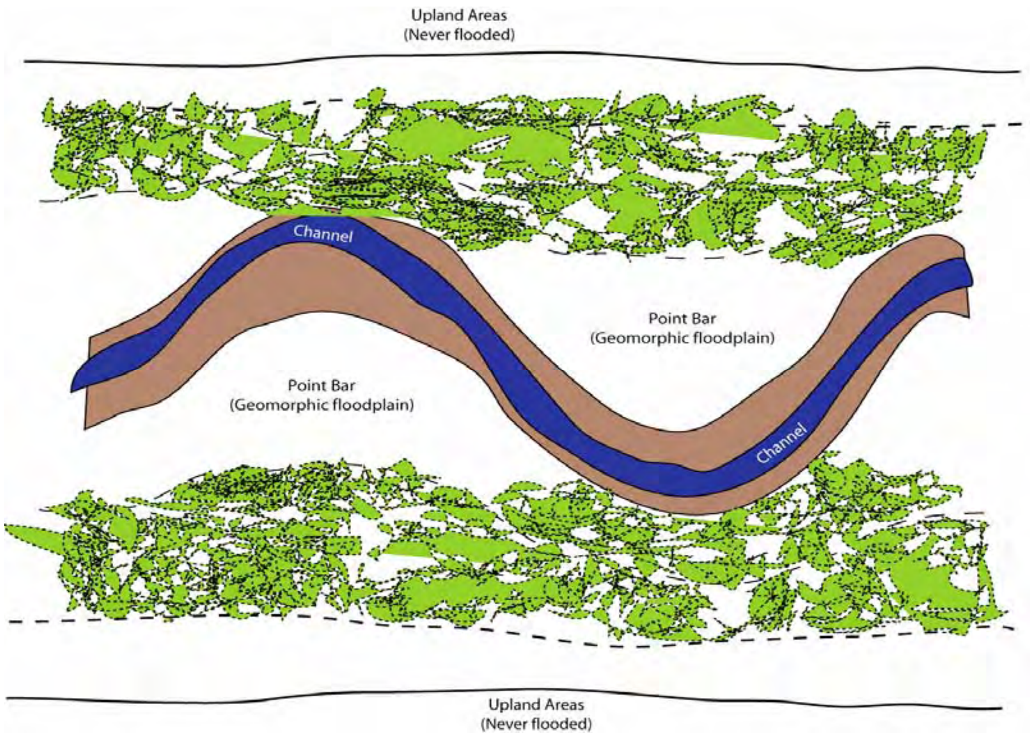


Figure 25 Channel excavation areas.

*To increase flow conveyance, dense thickets of salt cedar and other exotic species may be removed from point bar areas. Willows and other native vegetation should **not** be removed. Disturbed areas should be replanted with native vegetation.*

Exotic Plant Species Removal & Re-vegetation

The removal of exotic plant species can be implemented to increase flow conveyance (see channel modification), restore appropriate channel dimension, or reestablish native riparian habitats. Dense thicket of non-native salt cedar and other plant species can excessively constrain overbank flows and increase channel instability. However, these plants have successful strategies for recruitment and survival and are not easy to remove.

Recent research suggests that salt cedar 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).

The strategy for removing large stands of exotic vegetation is important to maintaining channel stability. When thickets are removed, 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.

Isolated plants can be cut with chainsaws. However, they sprout quickly and a powerful herbicide must be applied by a licensed applicator to kill the plant. Burning will not kill the salt cedar and appears to stimulate growth. Large stands of salt cedar are most effectively removed mechanically by heavy equipment by cutting the roots approximately 3-feet below the ground surface.

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 for Exotic Plant Species Removal

The exotic species strategy consists of three elements:

- Minimize saltcedar recolonization through mechanical, chemical, or manual means,
- Enhance the reestablishment of native species through aggressive revegetation and
- 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 for Exotic Plant Species Removal

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 to 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 inches. 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 along many areas of the Virgin River. 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 or in discontinuous patches 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. (Figures 26-29).

In order to maximize protection for adjacent lands, a thin strip of salt cedar may be left along the outer edges of the riparian corridor to increase roughness and reduce velocities.

Figure 26 Exotic species removal: Stage I.

Initial removal of salt cedar should be in areas adjacent to the active channel. Point bars on the inside of meander bends are prime candidates. These areas have higher soil moisture levels and a disturbance regime that will benefit the native species.

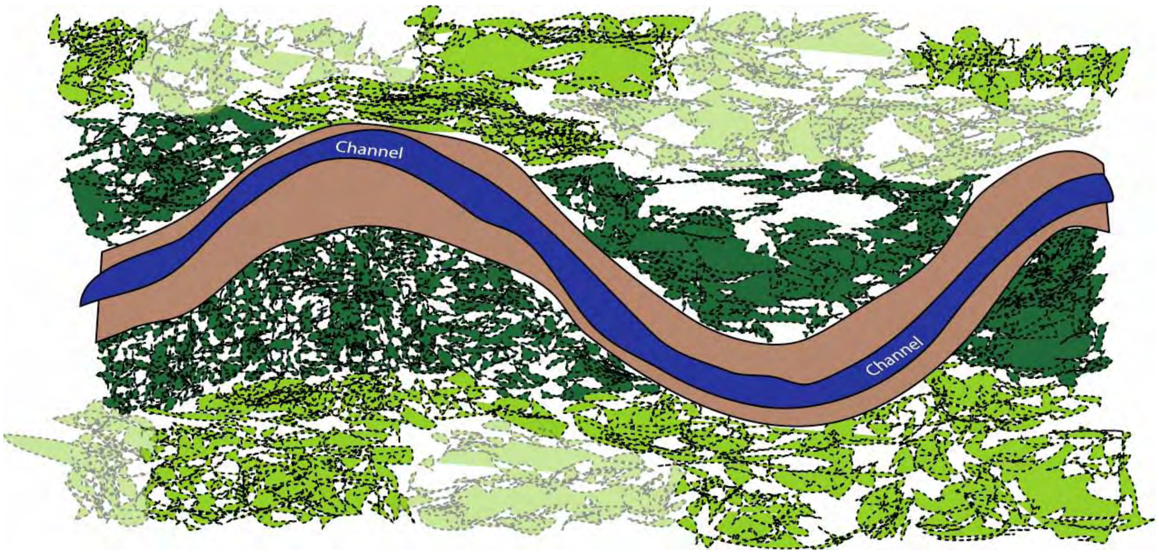


Figure 27 Exotic species removal: Stage II.

Once native riparian vegetation has become sufficiently established to resist flow velocities, non-continuous patches of vegetation should be removed from floodplains and terraces and replanted with native species. Irrigation may be necessary to speed establishment. Manual removal and herbicide application may be necessary to limit recruitment of salt cedar in re-vegetated areas.

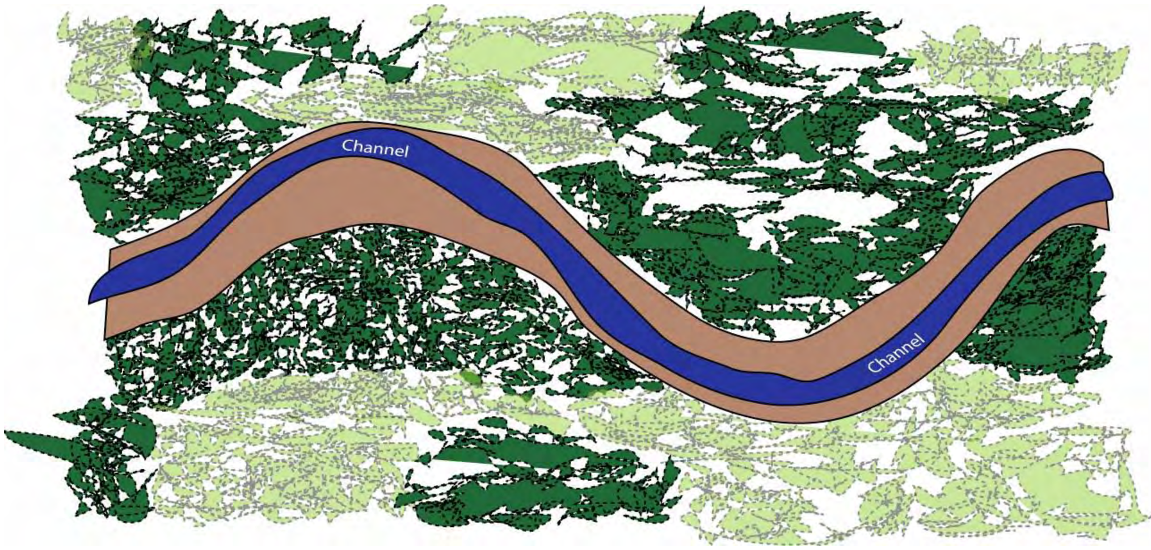


Figure 28 Exotic species removal: Stage III.

When native vegetation has been established, remove more discontinuous patches of exotic vegetation and replant with natives. Manual removal and herbicide application may be necessary to limit recruitment of salt cedar in revegetated areas.

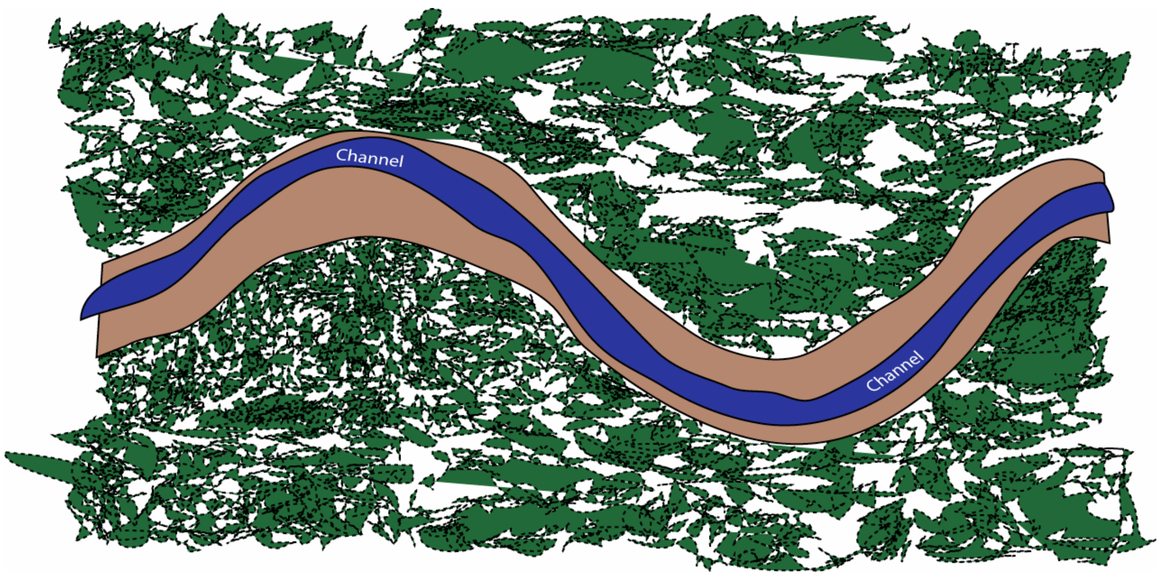


Figure 29 Exotic species removal: Stage IV.

Complete revegetation. Manual removal and herbicide application may be necessary to limit recruitment of salt cedar in revegetated areas. A thin band of salt cedar at the outer edge of the corridor may provide additional erosion protection.

Controlling Overbank Flow

During large floods, floodplain and terrace areas are inundated by overbank flows. These flows are generally diffuse and low velocity. As the flood stage rises the waters spread across the features and collect again in the central channel as discharges fall. However, if overbank flows are allowed to concentrate and/or are separated from the main channel, they can be very destructive.

Overbank flows can result in damage to properties from flooding, erosion, and/or sediment deposition. Flooding is the most well-known and least destructive. Second, concentrated overbank flows with high velocities can be very erosive. In extreme cases, the separated overbank flows can erode new channels and "capture" the main flow (Figure 30). This was the cause for much of the property damage along the Santa Clara River in the January 2005 flood. Secondly, overbank flows often carry significant fine sediment loads. If the flows are separated from the main flow spread and/or pond, the lack sufficient velocity will result in the deposition of sediments. The Sun River golf course provided a good example during the 2005 flood.

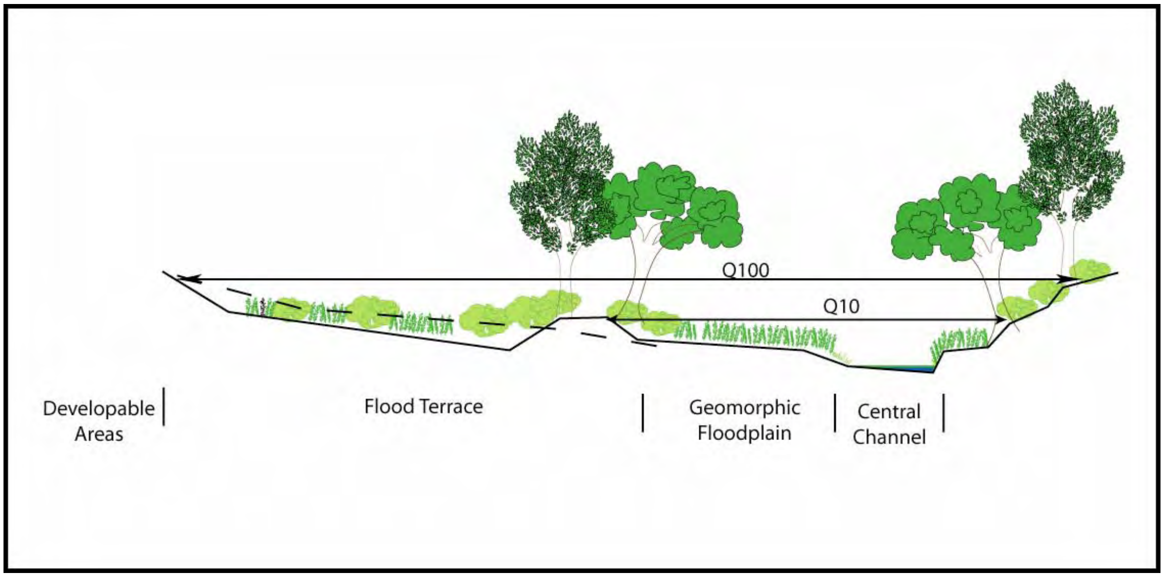


Figure 30 Overbank flow separation

In this graphic the levee contains the 10-year flow, but higher flows overtop the structure and are trapped on the back side of the levee. High velocities can create scour/erosion. Low velocities allow sediment deposition. Instead of a levee, the overbank areas should gently rise away from the central channel and vegetation be planted in such a way as to discourage high velocity overbank flows.

Strategies

It is critical that overbank flows are separate from the main flow and that velocities be moderate. While overbank flows cannot be eliminated during very large flood events, impacts can be minimized by redirecting overbank flows back toward the river. The following strategies based on the Guiding Principles should be incorporated in areas that can be flooded by high flows.

- Elevations should rise away from the central channel
- Vegetation thickness (resistance to flow) should increase away from the channel.
- Vegetation and/or low structures on high, level terrace areas adjacent to the river should be placed perpendicular to the river to inhibit overland flow and redirect water back towards the river.

Erosion can be created by high velocity flows on the high overbank areas and 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. On the other hand low velocity flows stranded on terrace features can deposit substantial volumes of sediment. In order to increase roughness and redirect overbank flows toward the central channel, series of hedgerows can 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 31). Hedgerows, dikes, or other structure should never be constructed in continuous sections parallel to the stream flow because they will reduce the ability for overbank flows to return to the river.

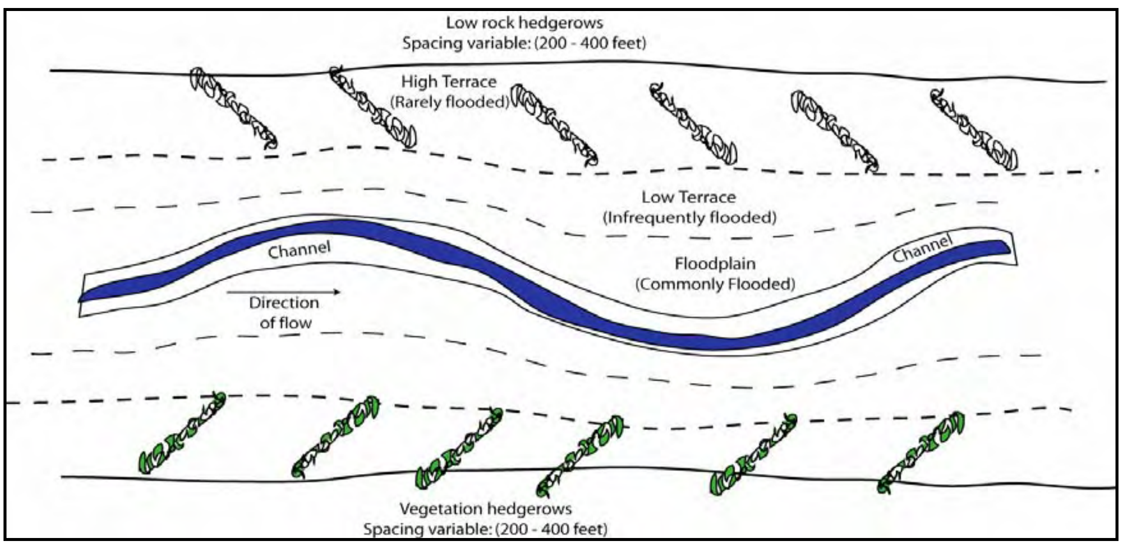


Figure 31 Terrace stabilization strategies

Flood terrace areas should be designed to slow overbank flows and encourage their return to the main channel. This can be accomplished with vegetation, topography, a series of low berms, or structure.

Bank Stabilization Measures

Maintaining the Guiding Principles of the Master Plan will reduce the risk of property loss due to lateral erosion. For example, properly elevated and vegetated geomorphic floodplains and terraces will tend to keep high velocities within the active channel. However, these principles will not completely eliminate the potential for lateral erosion.

Bank stabilization may be needed when the active channel has migrated adjacent to properties or to the edge of the Erosion Hazard Zone. Due to the high magnitudes of Virgin River floods, structural measures will generally be needed to protect eroding banks. Rock size, angle, and scour depth of all structural practices should be carefully engineered to withstand the depths and velocities of the design flood stage. The integration of bioengineering practices with the structural will increase the protection and provide additional habitats. Appropriate channel cross-section dimension/elevation and pattern should also be considered to reduce hydraulic forces against the bank (Figure 32).

- **Bank protection should not be used for flood control:**
  Bank stabilization should focus on protecting stream banks from lateral erosion, not flood control. Structural stabilization within the corridor should be installed should be installed at an elevation that will not restrict overbank flows. Constricting flows can increase flow velocities and increase the risk of erosion.

- **Focus on protection of the base or "toe" of the stream bank:**
  Velocities and shear stresses are greatest at the base of the stream bank and decrease with elevation. Structural and bioengineering is most effective at the critical toe of the bank. Higher bank areas can often be more effectively protected with vegetation.

- **All structural protection must be well "keyed" into the stream bank**
  In order for stabilization to be effective flow must not be allowed to "outflank" it by eroding around the structure.

- **Ensure adequate scour protection**
  Shear stress and scour are greatest along the base of a streambank. All structural practices should extend below the local scour depth.

- **Incorporate bioengineering into all stabilization**
  Where soil moisture is adequate, native vegetation provides the most economical and effective stabilization. These "bioengineering" practices can be implemented alone or integrated with structural measures.

Additional bank stabilization practices are included in Appendix A.

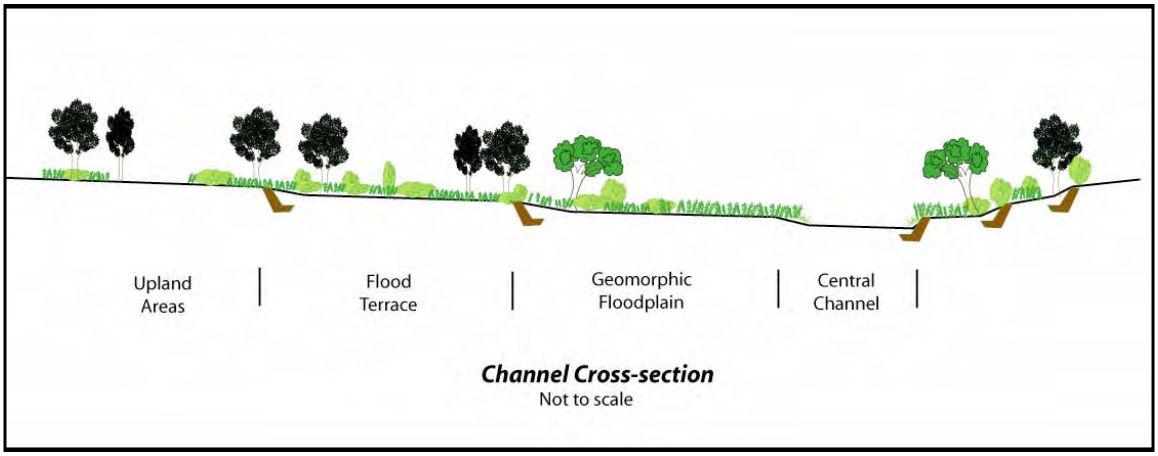


Figure 32 Bank stabilization strategies

Lateral migration protection should not be confused with flood control. Bank protection can be installed at any point within the riparian corridor depending on specific objectives. However, the structural protection should not extend above the elevation or interfere with overbank flows onto the associated feature (channel, geomorphic floodplain, flood terrace).

Nuisance and Stormwater Flows

The Virgin River is a perennial stream with base flows supplied by upstream groundwater and flood flows generated by storm events. In addition, small discharges from industrial, domestic, or agricultural sources often enter the channel during non-storm periods. These flows can provide additional stability or instability to the system. Additionally, the stream corridor collects storm water flows generated by the surrounding develop areas.

Storm water

Storm water is collected in developed areas and conveyed to the Virgin River at designated points (see Reach Maps). These flows are often unpredictable, large in magnitude and short in duration. In addition they can contain significant amounts of pollutants washed off streets and other paved surfaces. “Wetlands” constructed on the flood terraces can provide some biological “polishing” treatments for these waters. However, storm events are most common in the winter and late summer/fall and uncommon during the hot late spring and early summer months. In order to function these storm water wetland areas must be supplied with sufficient water from dedicated sources during the seasonally dry periods to maintain the vegetation. Agricultural return flows can provide water at this time but as the area evolves to urban, flow timing will be altered.

Agricultural Return Flows

These flows are often timed to the growing season and can support an off channel native wetland or marsh plant community that provide additional wildlife habitat. Agricultural returns most often meet these criteria and can be used to augment the “polishing” wetlands created at stormwater collection points.

Wetlands and Water Quality

As the Master Plan is implemented, certain areas can be opportunistically converted to wetland habitats. Places where the floodplain is wide and unusable for other types of development should be considered for wetland creation. Optimal sites will have a water source provided by storm water drainage or irrigation returns. Wetlands help to clean wastewater of roadside pollutants and the excess nutrients that can run off of agricultural lands. Rather than spilling directly into the river, water slowly filters through sediments while plants draw out nutrients. As flows are slowed in this way, more water is able to seep into the water table, encouraging groundwater recharge.

Creating diversified habitats (riparian forests, wet meadows, open pools) will invite a greater diversity of plants and animals into an area. In this way, Master Plan implementation can be combined with other goals such as creating habitat for species on the Utah Sensitive Species List, providing opportunities for birdwatching, and improving water quality in the Virgin River.

Appropriate hydrology will be a critical component for the success of these systems. Stormwater alone may not be sufficient to support these ecosystems because flows are not frequent during the hot, dry summer growing season. Some periodic water augmentation may be necessary.

A good example of this opportunity is Seegmiller Marsh located in Reach 4. This marsh area has naturally formed in the abandoned meander scars of the Virgin River. Agricultural return flows support perennial water. Careful design of the marsh or management of its hydrology can create a variety of rare habitats (Figures 33 & 34).

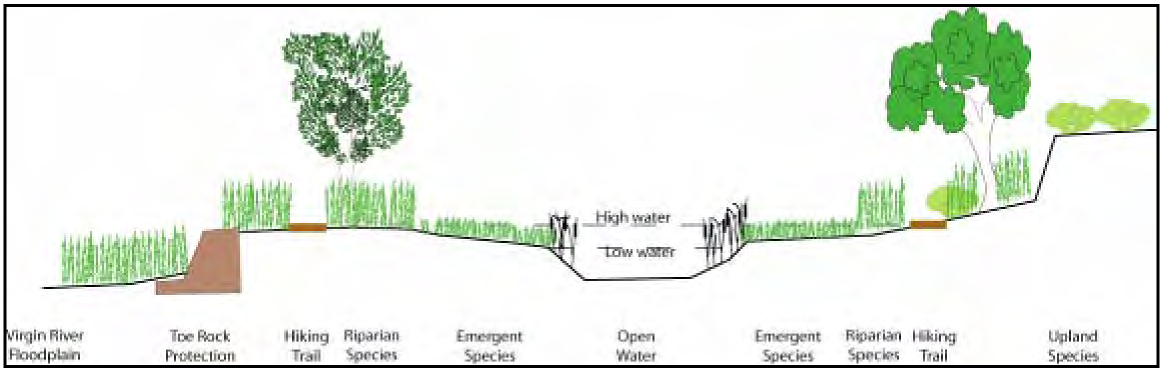


Figure 33 Typical design marsh/trail/rock cross-section

Marsh and surrounding riparian areas should provide a complex and diverse mixture of plant communities. Each community is dependent on different soil moistures dictated by topography and depth to groundwater. Trails and other amenities can be easily incorporated into the design.

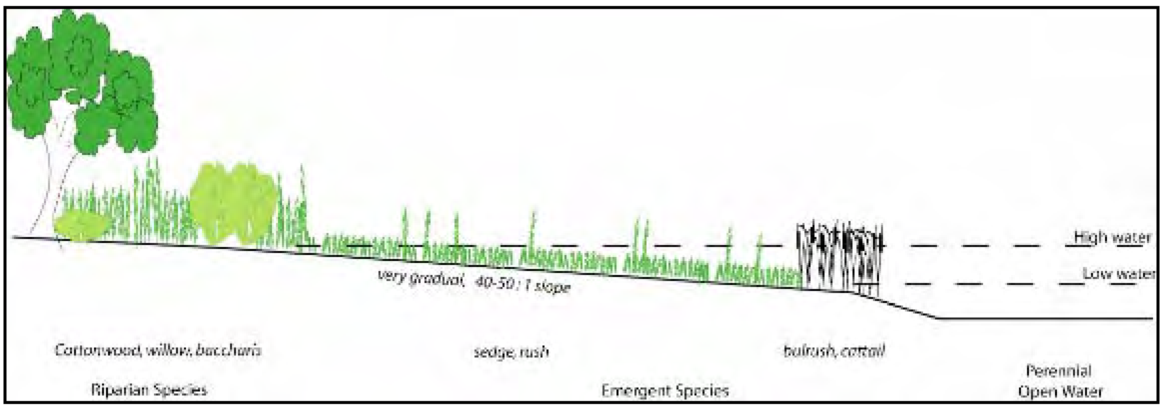


Figure 34 Typical design wetland cross-section

Depth of water and immersion times dictate distribution and composition of emergent plant communities. Shallow shore areas are alternately inundated and dried as water levels fluctuate. Sedge/rush species are well adapted for these zones. Deeper waters support cattails (Typhus spp) and bulrush (Scirpus spp). Water depths greater than 4 – 5 feet generally remain clear of all emergent vegetation

Long-term Riparian Corridor Monitoring/Maintenance

Living with natural stream channels in an urban environment provides many challenges. Often infrastructure and property are too valuable to allow the stream channel to take its natural course. In order to maintain stability, some long-term maintenance will be necessary.

Growth of stiff woody species in the central channel and geomorphic floodplain should be controlled. If dense growths of salt cedar, cottonwood, or black willow are allowed to colonize, they will divert flood flows increasing the risk if lateral channel migration. Growth of large woody species should be monitored and periodically managed within the 360-foot wide channel-floodplain by cutting all stems with a diameter at breast height (DBH) greater than 2 inches or simply removing the vegetation (Figure 35). The vegetation should be removed carefully to minimize damage to the other stabilizing native species.

Ongoing monitoring of river and vegetation conditions will inform maintenance activities and future projects. A well designed monitoring program will reveal whether practices are effective, recognize trouble spots that emerge, ensure continued flood protection, and understand how the ecosystem is affected by activities in the river. Also, consistent monitoring will allow the creation of trigger points when maintenance actions are needed. For example, in sites where tamarisk is removed, it is important to determine how quickly new sprouts appear so that an adequate removal schedule can be determined. In addition, wetland areas should be monitored to ensure that they do not attract exotic species or harbor undesirable levels of pests such as mosquitoes.

Following large flood events, the dimension, pattern, and profile of areas with significant erosion should be restored in accordance with the Master Plan stability template.

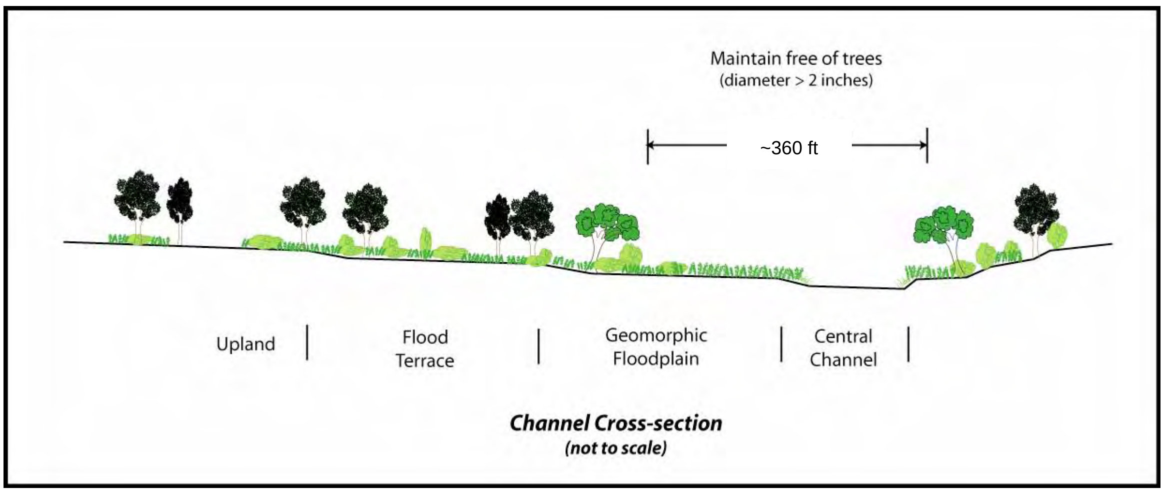


Figure 35 Channel maintenance

Long-term stability depends on maintaining a clear channel. Large stiff woody species such as salt cedar, cottonwood, or willows should not be allowed to colonize the central channel areas. These species should be removed when they reach a diameter at breast height (DBH) of 2 inches.

Transportation Corridors

As the population grows in and around St. George, the city will need to expand its transportation system appropriately and add new river crossings. Two transportation projects are currently planned that will directly affect the Virgin River. A bridge will be constructed to carry Mall Drive across the Virgin River in Reach 4. In Reach 5, a street link between the Dixie Center and Santa Clara is planned. Other projects are planned along the flood terraces on either side of the river and more will certainly contemplated as urban populations grow. Careful planning the placement and design of new bridges will decrease the chance of hazardous conditions developing during future floods.

Road crossings should be designed to minimize disturbance to flood flows across the floodplain and flood terraces. Bridges should occur along straight sections because erosional pressure on the outside of meanders can cause the river to migrate laterally and may undermine bridges or roads during high floods. Roadways should span the central channel and geomorphic floodplain. A second or third span should cross the flood terraces so that they are above the level of the highest floods and do not interfere with river processes. Bridges that are too small will not only become dangerous during high flows; as they constrict the channel they will force water up out of the channel and may cause the river to behave unpredictably.

The lateral migration of the Virgin River is an important component of its dynamic stability. The meander is one of the stream's important methods for dissapating energy. When the amount of migration is restricted excess energy will be utilized at other downstream portions of the river. Transportation corridors that parallel the river should generally remain outside the Erosion Hazard Zone to minimize restricting flood flows and/or lateral stream migration.

Trails, Parks, and Open Space

People enjoy recreating along rivers, and terraces susceptible to infrequent flooding are great places to put trails and parks. Greenways along rivers also benefit property values, as people enjoy having views of and access to trees and open spaces. Bike and pedestrian trails can provide safe transportation corridors away from busy roads. Sports fields, picnic sites, and equestrian trails will diversify opportunities for recreation.

Parks/golf courses

Open parks and golf courses should be carefully designed so that they don't create large smooth surfaces where floodwaters will move quickly and scour away soils. Rows of vegetation or gentle swales placed perpendicular to or angling toward the river will slow overbank flows and lead water back to the main channel.

Pedestrian/equestrian Trails

Portions of the St. George urban trail system follows the river through much of the project area and additional trail sections are planned. These trails are appropriate uses in the low and high flood terraces. However, asphalt trails provide little roughness and can capture overbank flows. The resulting high velocities can damage the trail and contribute to increases lateral erosion. Trail design should conform to the Guiding Principles and Controlling Overbank Flows sections described earlier in this section.

- Trails should be located above the 10-year flood risk to minimize maintenance.
- Trails should wind close to and away from the river channel to discourage capture of overbank flows (Figure 36).
- Trails should vary in elevation between the 10-year and higher flood stages to discourage erosive high velocity flows from capture of overbank flow capture (Figure 37).

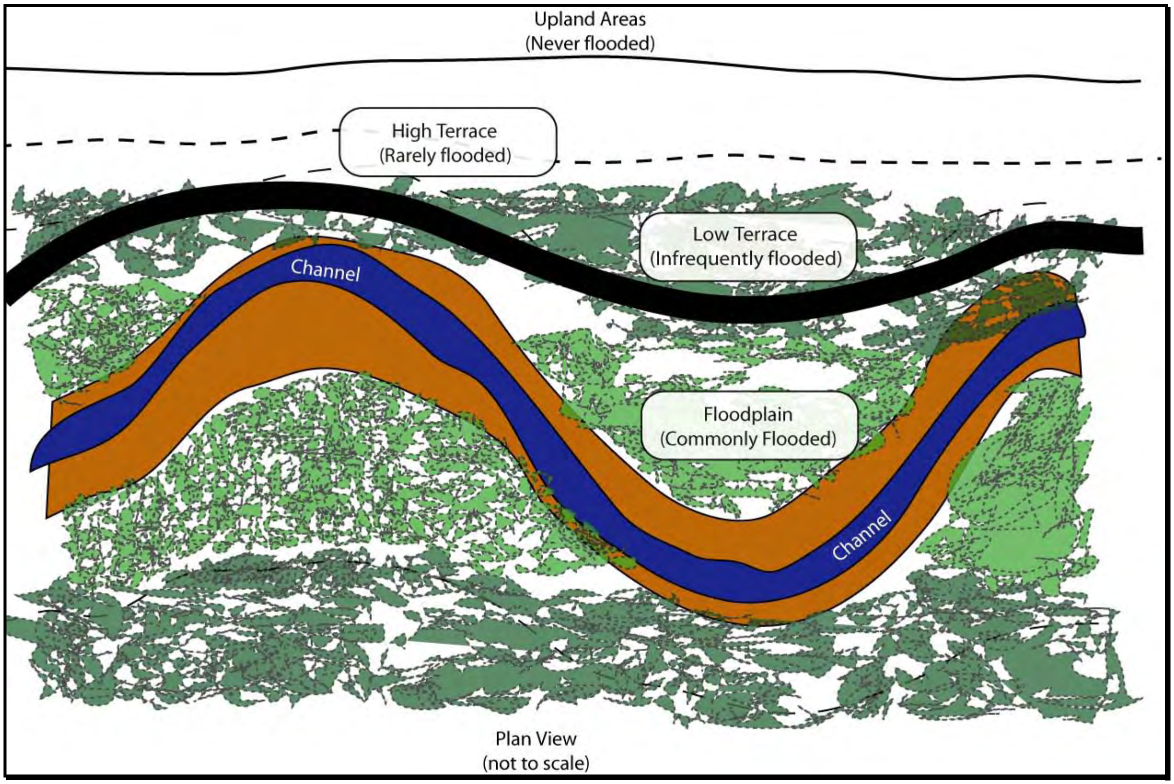


Figure 36 Pedestrian trail; plan view

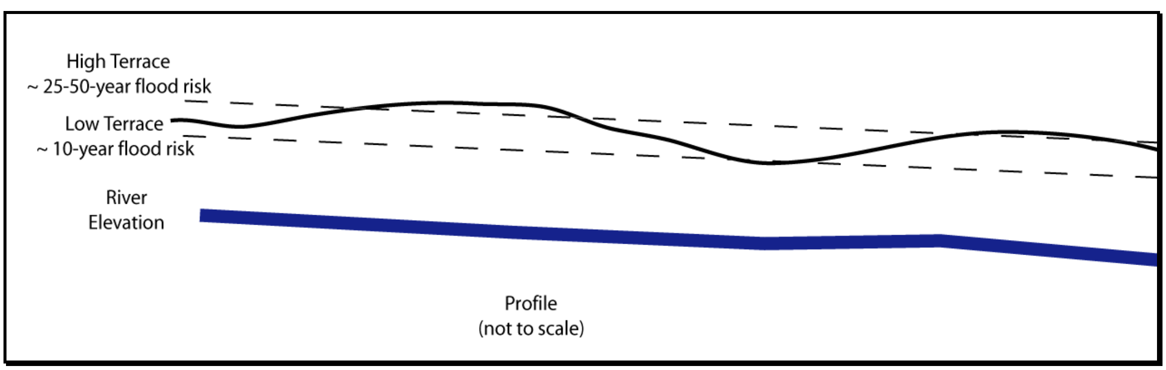


Figure 37 Pedestrian trails; profile

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 and will not provide adequate native plant materials for restoration of the Virgin River. However, local nurseries can be established on fallow agricultural lands with irrigation or in riparian areas with sufficient soil moisture to support plants.

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

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

Public Outreach and Education

Education will be important to the public acceptance of the Plan. Acceptance is usually built over time. Initial meetings will be attended by the interested public; however, more skeptical citizens will hold back. Many persons are best convinced by friends, neighbors, and peers. Having a successful example “on the ground” has tremendous power. A successful “pilot project” provides an opportunity to demonstrate practices to those who are readily interested while providing a silent example to others.

The following components are recommended for public outreach:

- *Initial education meetings:*
  Informal meetings with local landowners and interested persons provides a forum for discussing Master Plan components and answering questions.
- *Public meetings:*
  More formal meetings may be necessary in connection with the potential adoption of city/county ordinances. These meetings are important for discussion but may not provide the best venue for education.
- *Bioengineering Workshops:*
  Annual workshops are effective tools to continually build long-term support for the restoration and maintenance of the Virgin River. The workshops can be coordinated with public projects, or annual maintenance efforts.
- *“River Days” Festival:*
  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 curricula 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)

SECTION 5: REACH RECOMMENDATIONS/MAPS

This section describes areas of concern and provides specific recommendations for each project reach (Figure 38). Locations of stormwater drains were from GIS coverage supplied by St. George and Washington cities. Potential wetland areas were based on field observations and comments provided by resource agency staff.

NRCS levee locations are based on field observations in the fall of 2006 and locations should be considered approximate. Additional bank protection may be installed subsequent to this report. It should be remembered that the NRCS dikes were placed for erosion control rather than flood control. They may still be overtopped during extreme flood events.

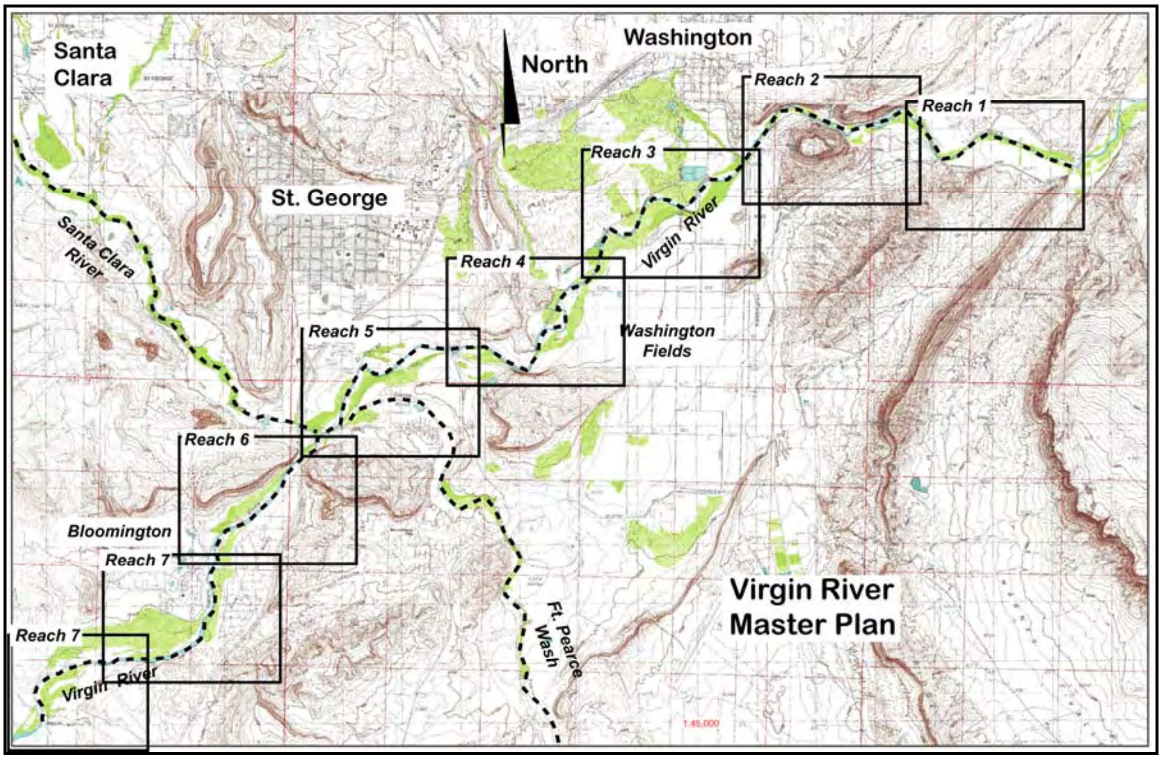


Figure 38 Index to reach maps

Reach 1

This reach includes the river between Washington Fields Diversion and Sunrise Valley Bridge (Figure 39). The river is relatively straight and undeveloped. Although the upstream sections are dominated by thick stands of salt cedar along one or both banks, it is mixed with considerable amounts of native vegetation. The reach appears relatively stable and changed little as a result of the 2005 flooding, however, the extreme width of the Erosion Hazard Zones (EHZ) increases the risk of large scale lateral channel movement. Existing and future sand and gravel mining operations can increase the chances of instability and post-mining rehabilitation should be carefully planned and executed. Future development of the agricultural areas on the south side of the river should be consistent with Master Plan recommendations.

1. Operation and rehabilitation of sand and gravel mining on north side of the river should be carefully planned and implemented.
2. If developed agricultural areas to the south should be consistent with Master Plan recommendations.
3. Existing point bars and floodplains upstream of the Sunrise Valley bridge should be left undeveloped to spread flood flows. Rock bank protection has been installed on the inside of this meander.
4. Thick invasive vegetation should be replaced by appropriate native species.

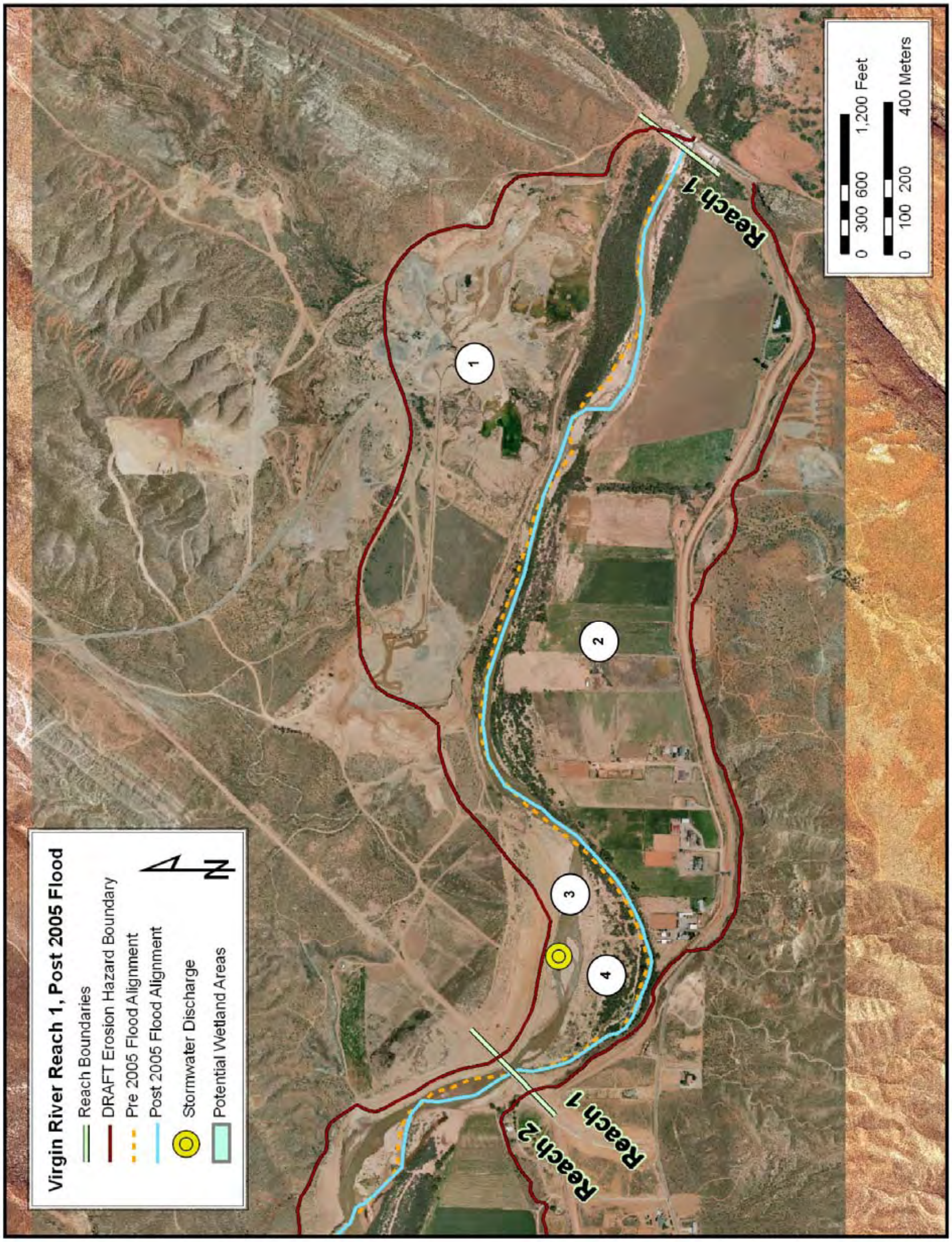


Figure 39 Reach 1 map

Reach 2

This reach includes the river from Sunrise Valley Bridge to the Washington Fields Road Bridge (Figure 40). Most of this reach lies within a relatively narrow bedrock valley with high quality native vegetation associated with small spring areas. Agricultural fields at upstream and downstream ends of the reach have potential for development. However, the EHZ is relatively wide in these areas increasing the risk of lateral channel movement. The narrow bedrock canyon is suitable for trails and other recreational amenities. An open area at the head of the canyon has potential for constructed wetlands for wildlife habitats and stormwater treatment.

5. If agricultural areas are developed planning should be consistent with Master Plan recommendations.
6. A large stand of relatively high quality native riparian plant community is located above the narrow valley and could provide a location for wetland creation and stormwater treatment.
7. Most of reach in narrow geologic control valley with little development potential, area is appropriate for trails.

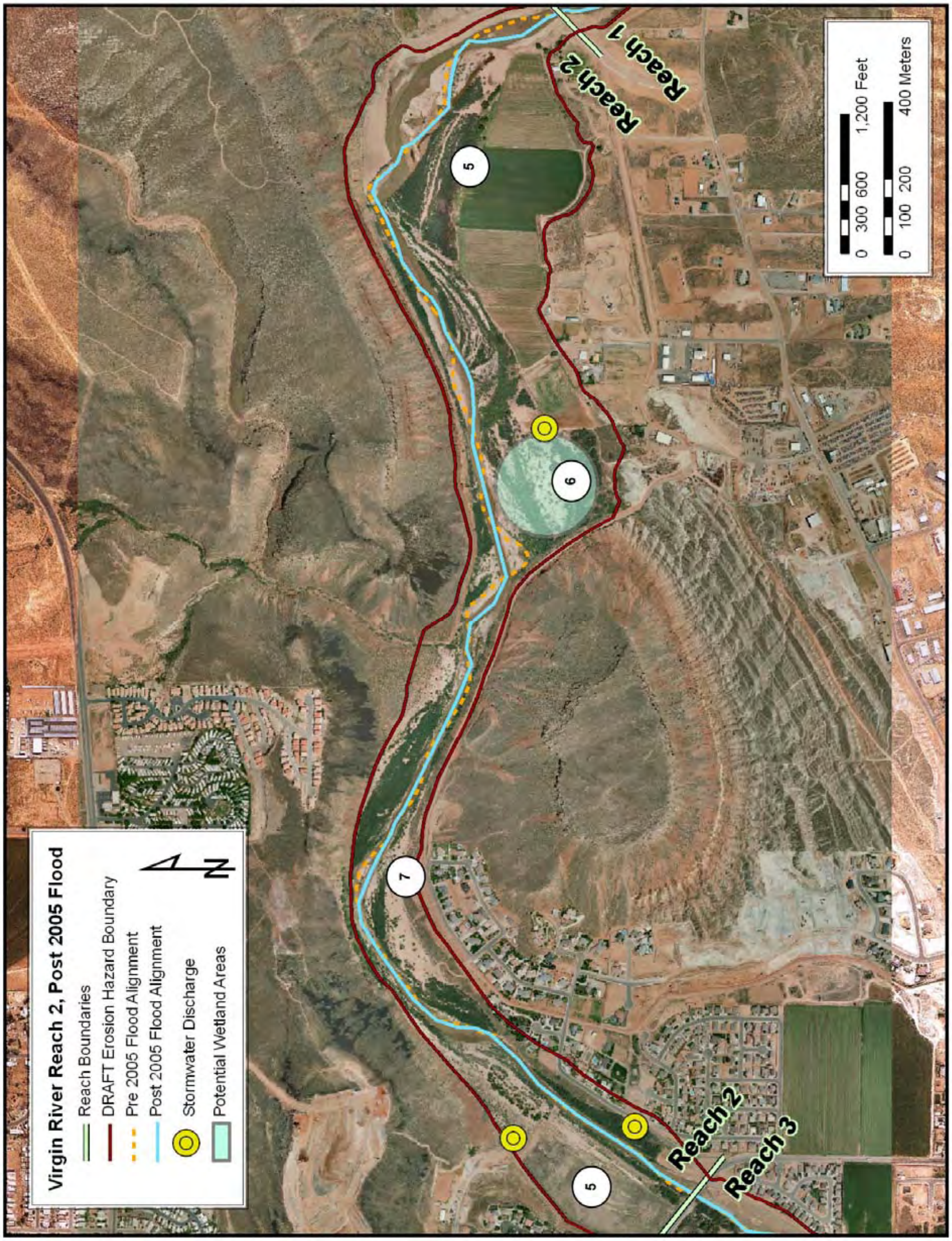


Figure 40 Reach 2 map

Reach 3

This reach includes the river from Washington Fields Drive bridge to the Johnson Diversion (Figure 41). The riparian corridor represented by the EHZ is relatively broad and old meander scars suggest that lateral channel movement is common in this reach. This meander is important to dissipating stream energy and should not be substantially narrowed. The broad corridor provides several areas suitable for habitat enhancement and stormwater treatment. NRCS bank protection is limited to short segments and, in some instances, may increase risk of property damage. Some existing housing lies within the EHZ and is at risk from erosion.

8. The subdivision immediately downstream of Washington Fields Drive bridge lies behind a NRCS levee but at a lower elevation. Should floods overtop the dike, waters separated from the river will flood the area. Flood protection should be increased either through raising of the adjacent levee and/or maintaining adequate conveyance on the opposite floodplain.
9. A connecting road is planned for the right side of the river. The road should not narrow the existing corridor or increase flood potential. There is the potential to create an urban park along/around roadway to maintain flood capacity and meet urban park goals.
10. Floodplain and flood terraces should be maintained to reduce flood risk.
11. Several areas have potential for wetland creation and stormwater treatment.
12. A short buried NRCS levee protects a waterline in this area. However, the levee does not extend to stable structure outside the EHZ. The levee has the potential to trap flows behind it increasing the risk of erosion to adjacent homes inside the EHZ. The lack of vegetation along the pipeline increases the risk of capture by the river. The structure should be extended to the edge of the EHZ.
13. Areas of thick salt cedar should be replaced by appropriate native species especially adjacent to the active stream channel.

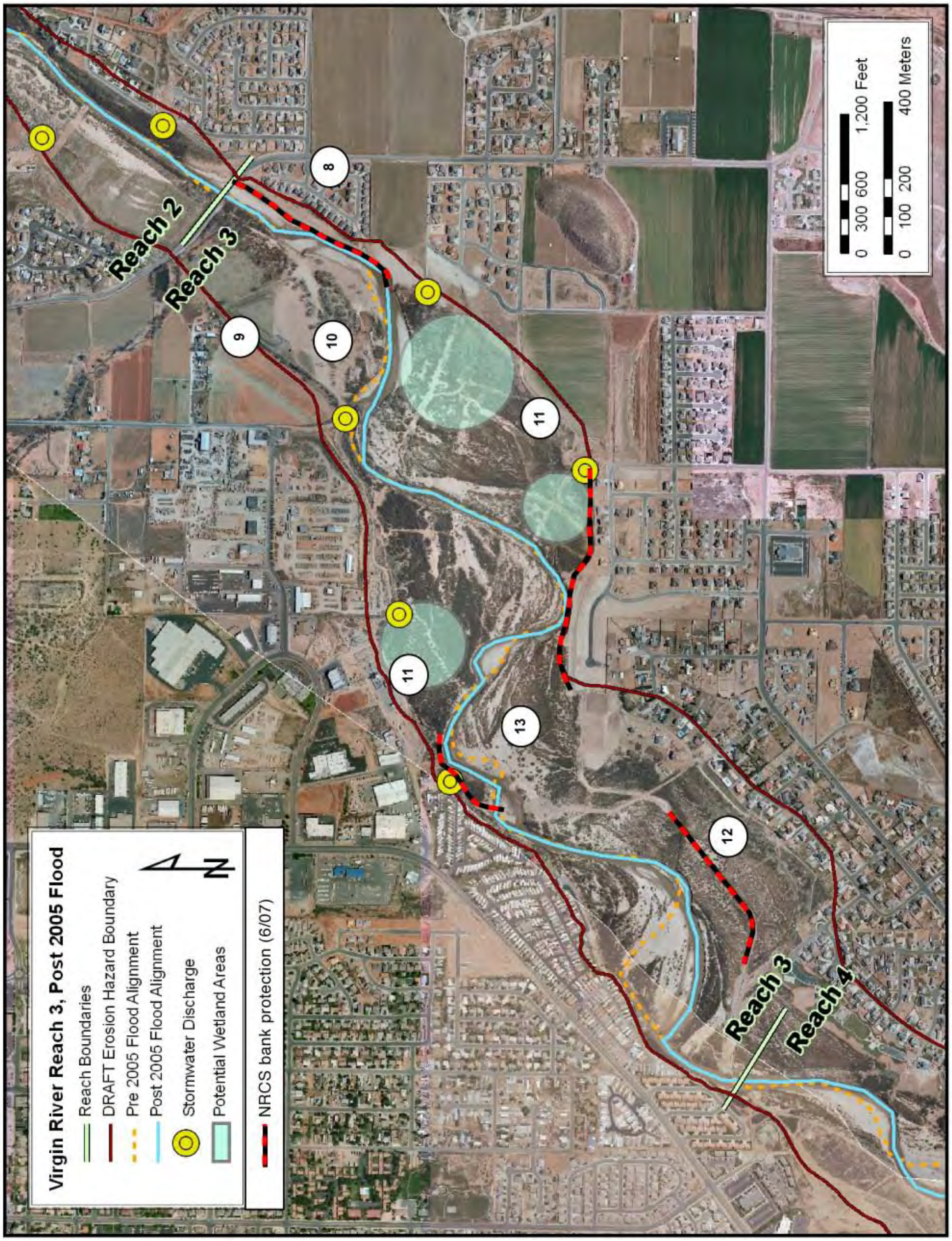


Figure 41 Reach 3 map

Reach 4

This reach includes the river between Johnson Diversion and River Road bridge (Figure 42). The EHZ and riparian corridor is relatively wide. Existing development is discontinuous but the large areas on both sides of the river have potential for development.

14. Infrastructure near or in EHZ is at risk of lateral erosion. Short sections of NRCS levees within reach do not appear to adequately protect existing infrastructure. The structures may increase risk of lateral erosion if flanked by high stream flows. Levees should be extended to the EHZ to protect adjacent properties.
15. Mall Drive bridge is planned for mid-reach (alignment approximate). The bridge spans should be wide enough to allow high flows to spread and should be centered in corridor to allow some continued natural channel meander.
16. Seegmiller Marsh provides potential for wetland creation, stormwater treatment, and recreation.
17. Throughout the reach areas of dense salt cedar should be replanted with appropriate riparian plant communities especially adjacent to the active stream channel.
18. Corridor is narrowed by geologic control (right side) and NRCS levees (left side). Area protected by levee should remain flood terrace and be planted with appropriate native riparian plant species.
19. Open flood terraces should not be developed with hard infrastructure but could be used for parks, golf courses, and other uses where occasional flooding is acceptable. Areas should be planted with appropriate native plant species.

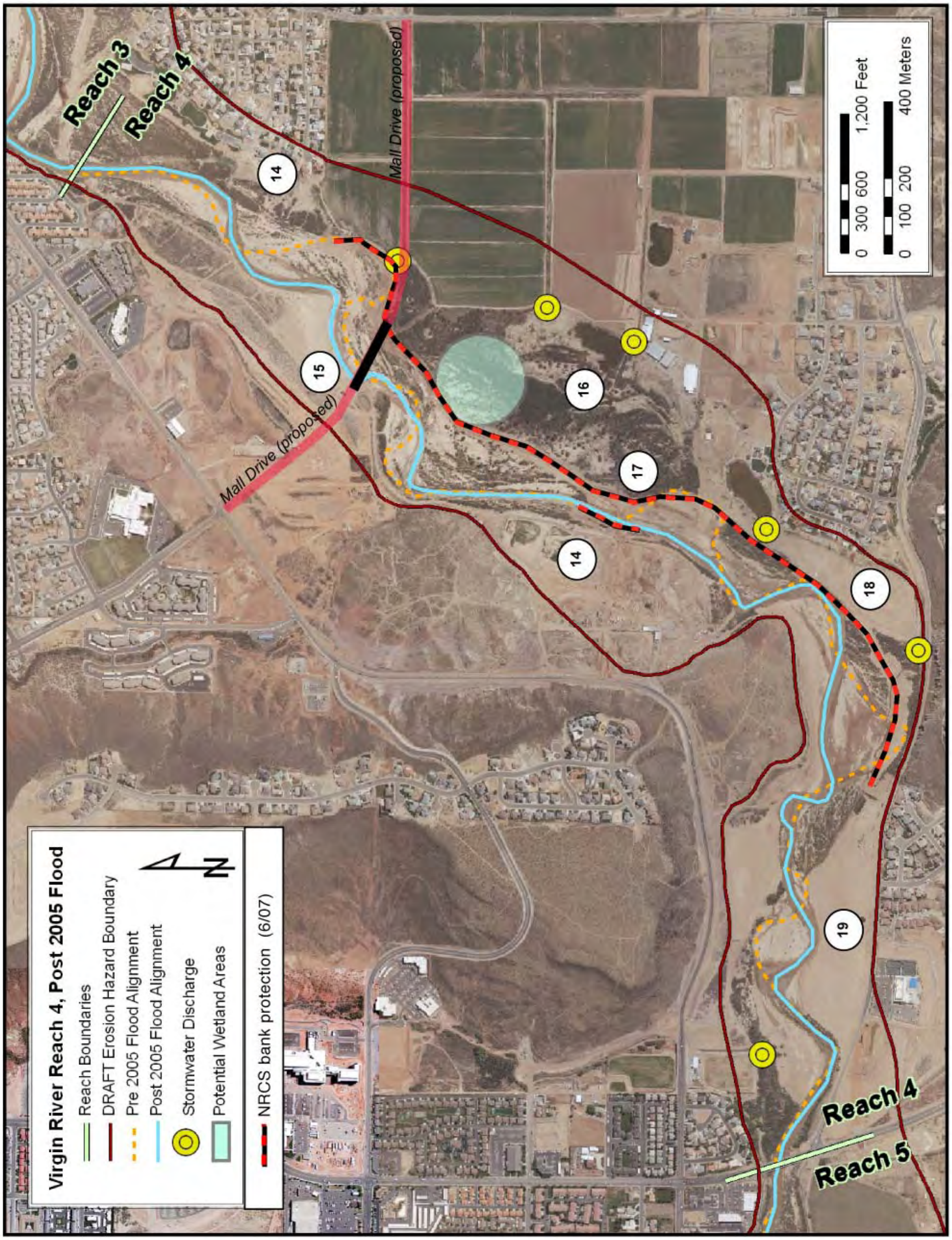


Figure 42 Reach 4 map

Reach 5

This reach includes the river corridor between River Road and I-15 (Figure 43). The River Road bridge creates a narrow constriction upstream but the riparian corridor and EHZ is relatively wide through most of the reach. The multitude of abandoned channel scars suggest that lateral movement is common. Substantial development has taken place within the EHZ on river left (North side) and two short NRCS levees have been installed for erosion protection. The riparian corridor narrows sharply between bedrock hills at the I-15 bridges.

20. River Road bridge creates tight constriction that may cause flooding or erosion along the south approach.
21. Short sections of NRCS levees within reach do not appear to adequately protect existing infrastructure. The structures may increase risk of lateral erosion if flanked by high stream flows. Levees should be extended to the EHZ to protect adjacent properties.
22. If agricultural fields are developed they should be consistent with Master Plan guidelines and recommendations.
23. Reach areas of dense salt cedar should be replanted with appropriate riparian plant communities especially adjacent to the active stream channel.
24. Removal of large areas of salt cedar within the riparian corridor should be carefully planned and replanted to reduce the risk of stream capture during high flow events. Higher flood terraces could be planted with mesquite and other xeric riparian species.
25. Several areas have potential for wetland creation and stormwater treatment.
26. Ft. Pearce/Santa Clara confluences. Sediment/flood inputs make this area very dynamic with the potential for periodic local aggradation and degradation depending on hydrology and sediment contributions from the three streams. The dynamics increase the potential for unpredictable lateral meander.
27. The planned connection between Dixie Center Drive to Hilton Drive should not reduce width or restrict flow across flood terraces in this critical area.

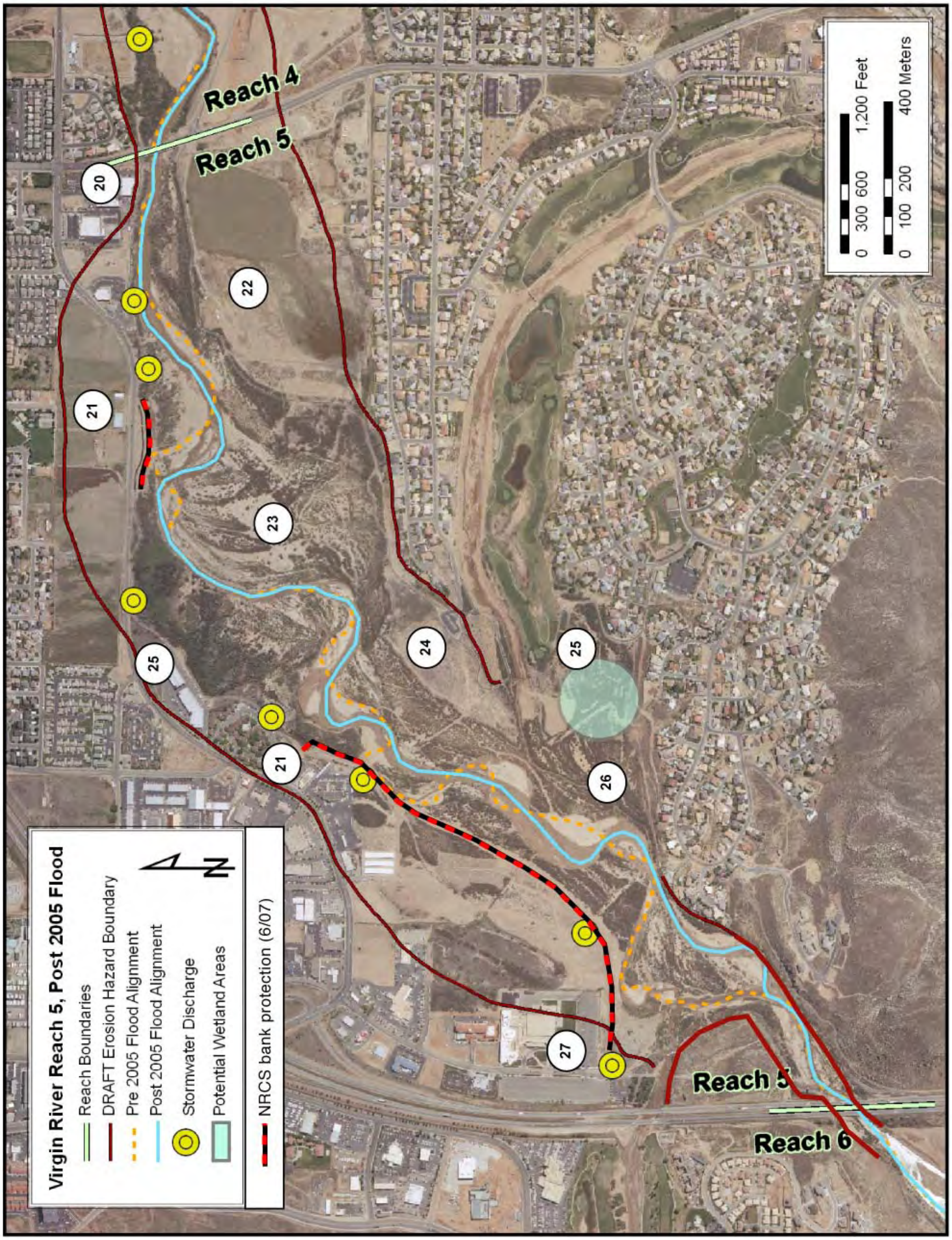


Figure 43 Reach 5 map

Reach 6

The reach includes the river between the I-15 bridge and Man of War bridge in Bloomington (Figure 44). The riparian corridor is narrowed by bedrock control and gradually widens downstream. Stream channel is relatively straight following the 2005 flood but can be expected to create meanders over time. The channel/floodplain areas were over-excavated following the 2005 flood and alluvial bars and other features are reforming. Areas to river right (East side) at Man of War bridge experienced flooding during 2005 when overbank flows were redirected away from the river and into neighborhoods.

28. Channel was excavated following the 2005 flood and should be planted with native vegetation to increase stability and discourage reestablishment by dense thickets of salt cedar.
29. Flooding of ball fields leads to drainage away from the river and across Man of War Drive. Topography and/or vegetation should be modified to encourage overbank flows return to the river.

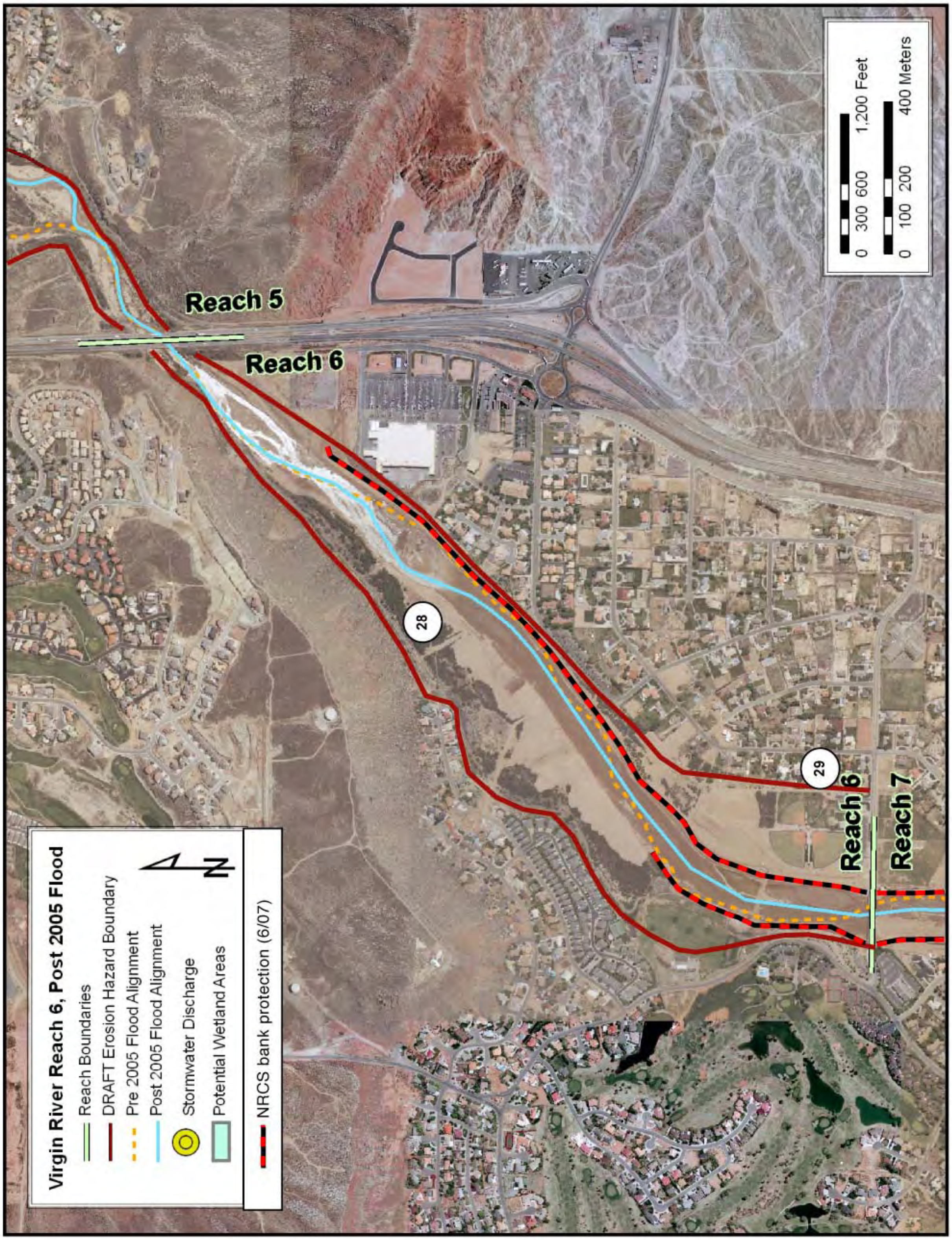


Figure 44 Reach 6 map

Reach 7

The reach includes the river between Man of War bridge and St. George city boundaries downstream of Atkinville Wash (Figure 45). The riparian corridor and EHZ are relatively narrow near Man of War bridge but widen considerably in mid-reach before narrowing as the river enters the bedrock canyon downstream. Scour scars suggest large active historic channel meandering through the wider sections of the reach. NRCS levees were installed along both sides of the river in the developed areas in Bloomington and should reduce the risk of property loss due to lateral migration. However, the levees will not necessarily reduce flood risk. Areas to river right (East side) at Man of War bridge experienced flooding during 2005 when overbank flows were redirected away from the river and into neighborhoods. The golf course at Sun River occupies much of the corridor and EHZ in the lower part of the reach and was flooded during 2005.

30. Flooding of ball fields leads to drainage away from the river and across Man of War Drive. Topography and/or vegetation should be modified to encourage overbank flows return to the river.
31. Areas throughout the corridor should be planted with native vegetation to increase stability and discourage reestablishment by salt cedar especially areas adjacent to the active stream channel. Point bars and floodplains should be dedicated to spreading flood flows. Salt cedar thickets should be replaced with appropriate native vegetation whenever possible.
32. Flooding of Sun Valley golf course during 2005 flood resulted in deposition of large volumes of sand. Upstream edge of golf course should be raised to reduce the risk of flooding and/or the course recontoured so that overbank flows are routed through the course to minimize sediment deposition.

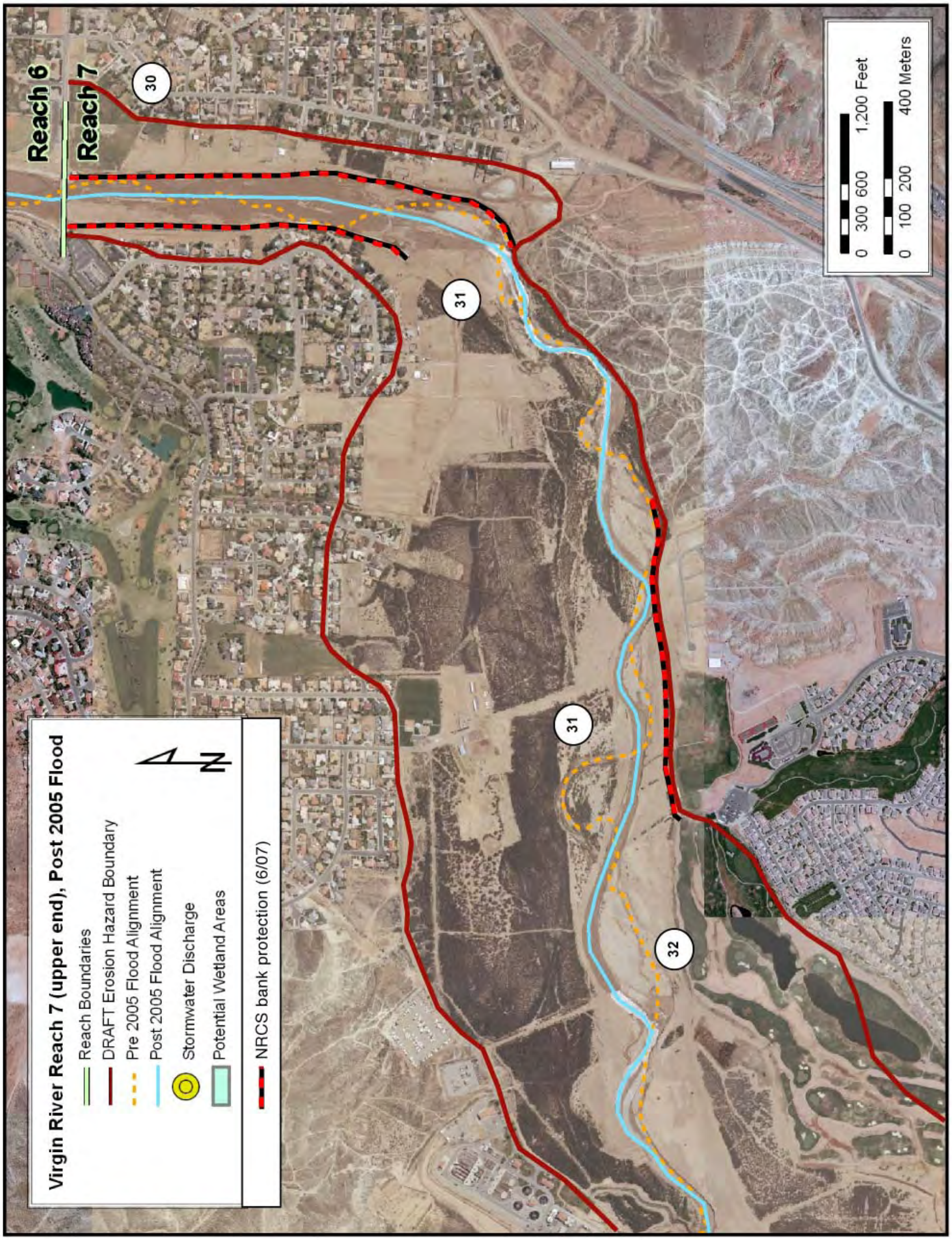


Figure 45 Reach 7 (upper)

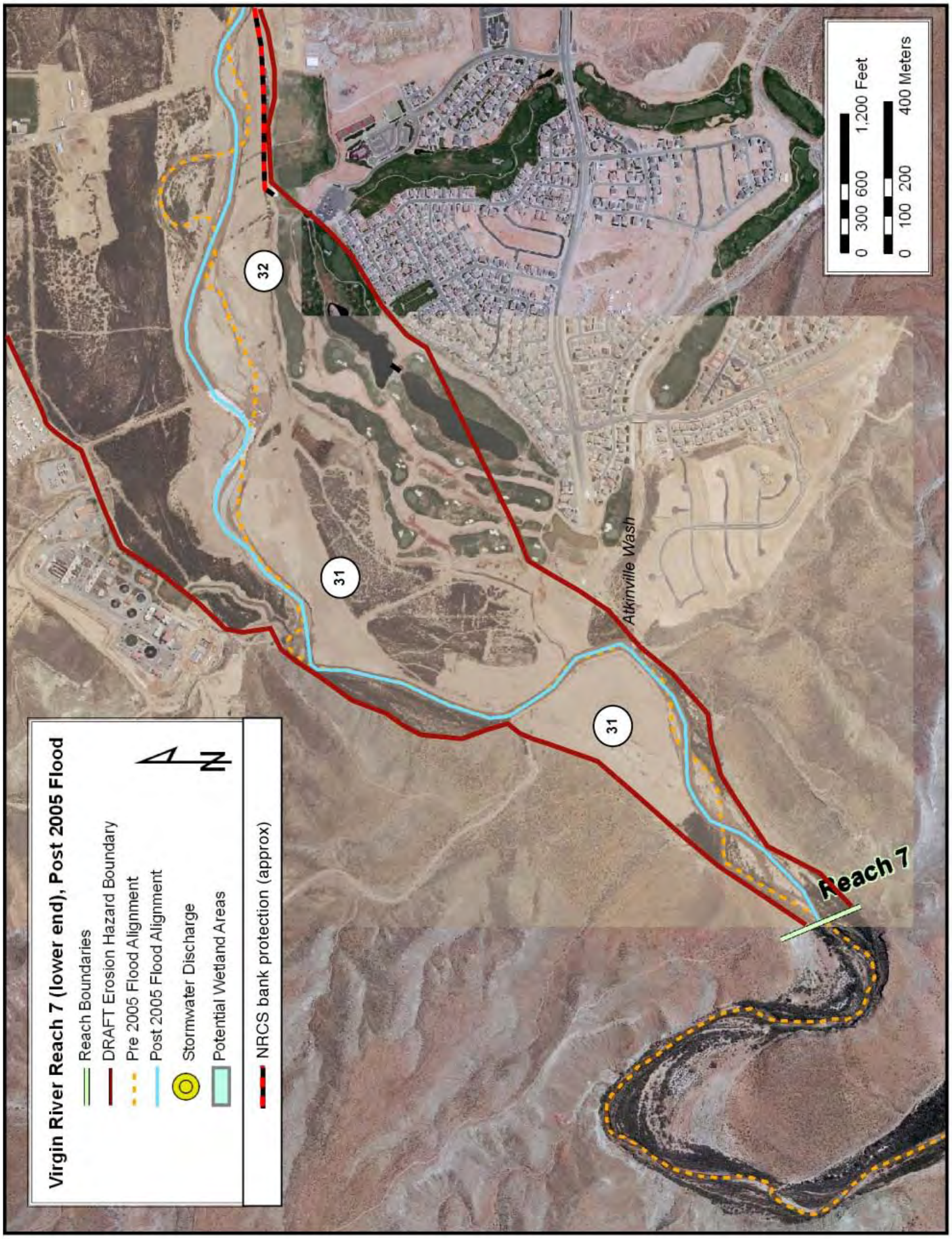


Figure 46 Reach 7 (lower)

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APPENDIX A. BANK STABILIZATION STRATEGIES

Due to the magnitudes of flood flows and their associated velocities, bank stabilization to protect properties along the Virgin River will generally require structural measures. However, bioengineering practices using native plants can improve the effectiveness, habitat quality, and aesthetics of structural revetments.

Bioengineering Practices

Bioengineering is the use of native plant materials and associated "soft" structures to stabilize stream banks, floodplains, and terraces (Figure 47).

Brush Revetment:

Brush or trees are secured to the streambanks to slow excessive erosion by diverting the current away from the bank edges. 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.)* are 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.

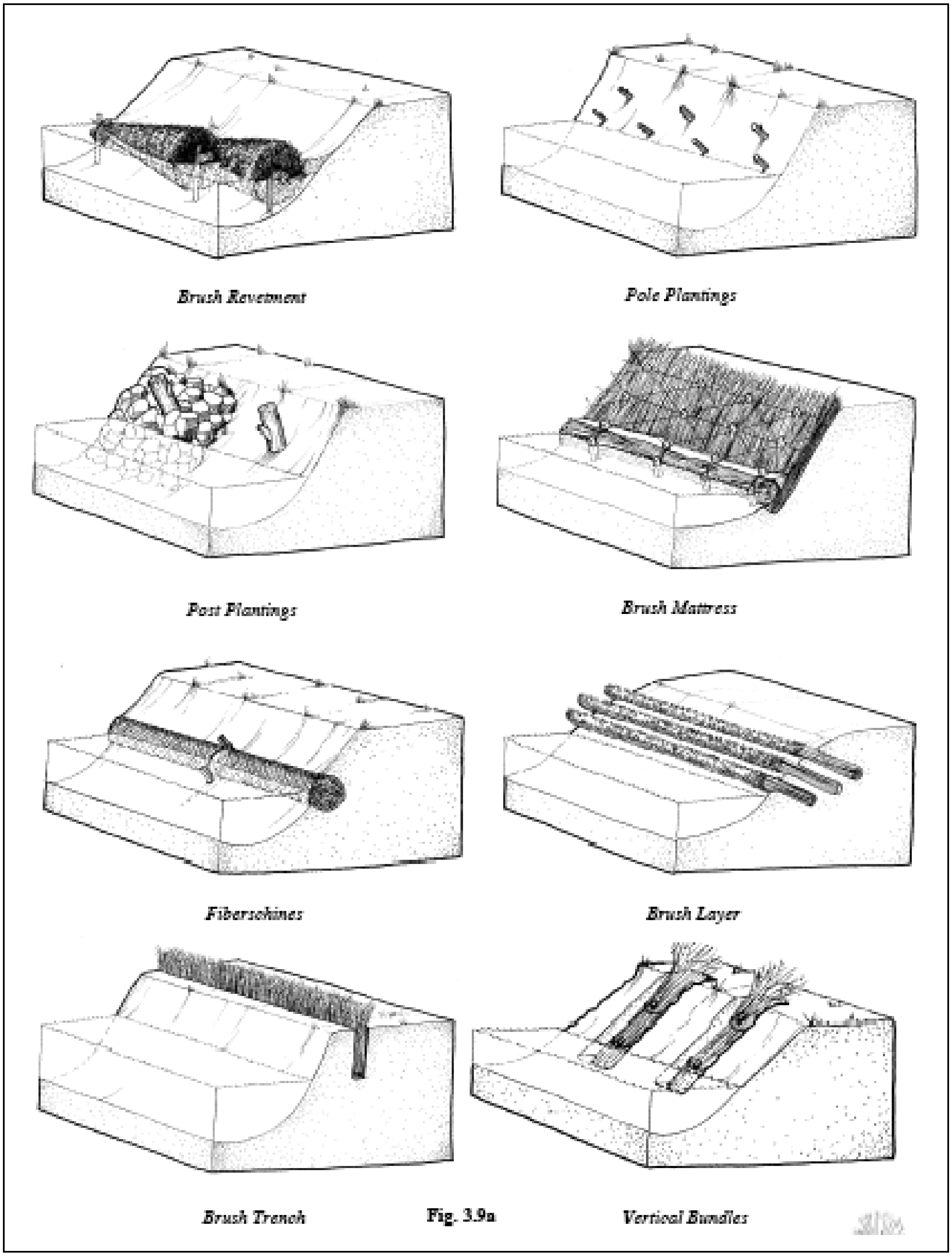

Figure 47 Bioengineering Practices.

Source: The Practical Steambank Bioengineering Guide, Gary Bentrup and J. Chris Hoag.

Technical References For Bioengineering:

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:

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These and more technical publications can be obtained at:

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

Structural Measures

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.

It is recommended that structural bank stabilization be carefully considered before being installed within the erosion hazard zones described in the Virgin River Stability Study except to protect existing or essential infrastructure. Structural practices should not alter the shape or dimension of the channel, geomorphic floodplain or terraces or that constrain the channels ability to meander across its riparian corridor. These alterations will increase the overall instability of the river and has the potential to increase lateral erosion.

For additional technical information see:

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

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 48).

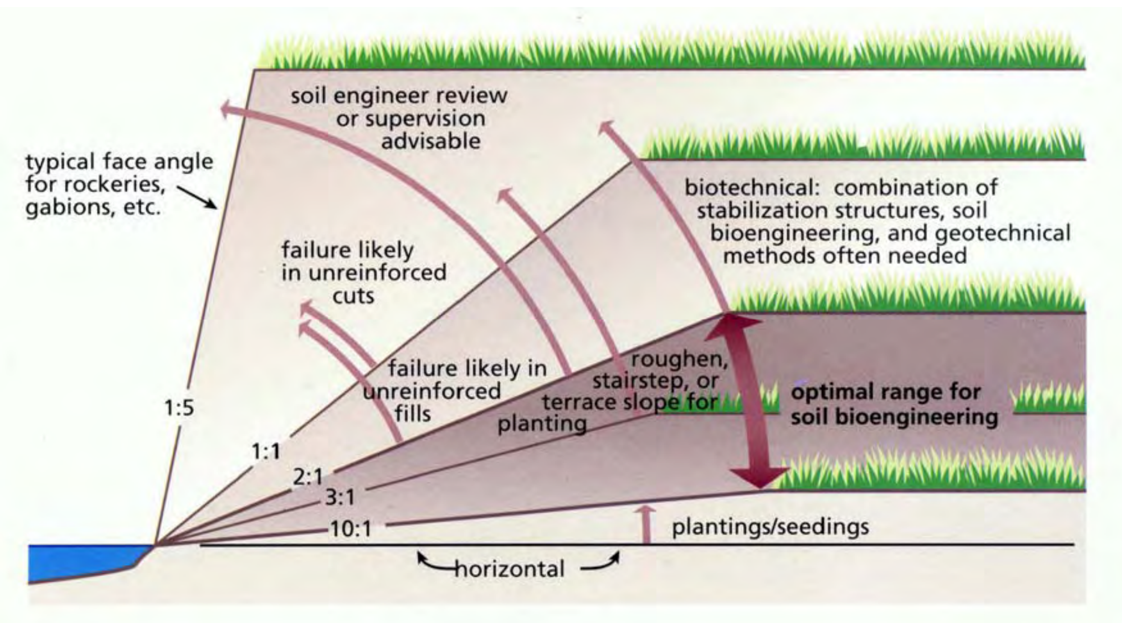


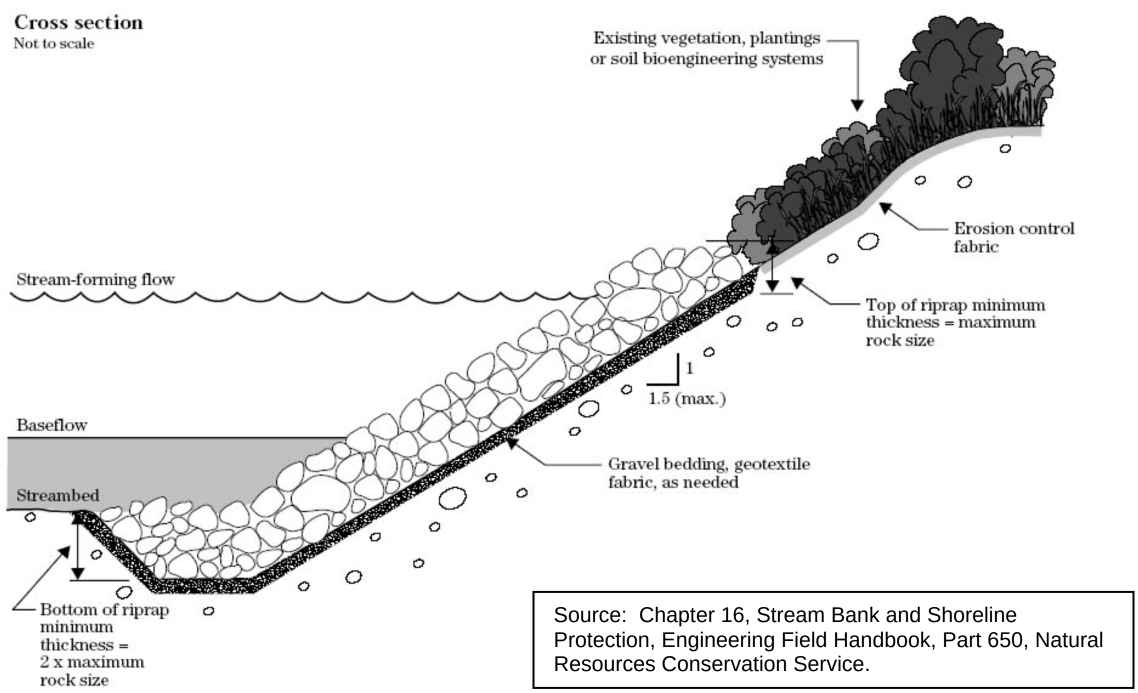
Figure 48 Stream bank slope stability

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).

Toe Rock

Toe rock is a structural practice using properly sized and graded angular rock to stabilize the toe of the bank (Figure 49). These practices are generally only necessary on the outside of a meander. Rock is installed to the floodplain elevation 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.

Figure 16–32 Rock riprap details



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

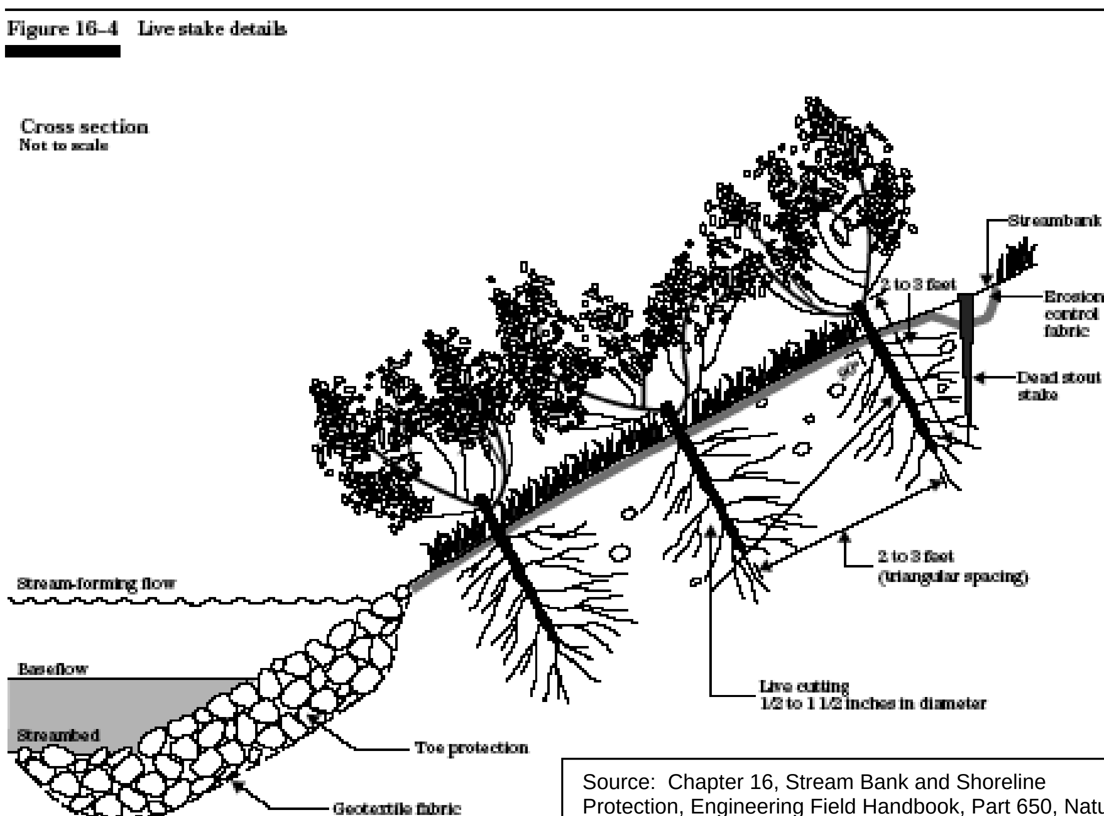
Figure 49 Toe Rock.

This structural practice is generally installed along the outside of a meander bend to reduce the risk of lateral erosion.

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 reducing near-shore flow velocities. Most willow species root rapidly soon after installation (Figure 50).



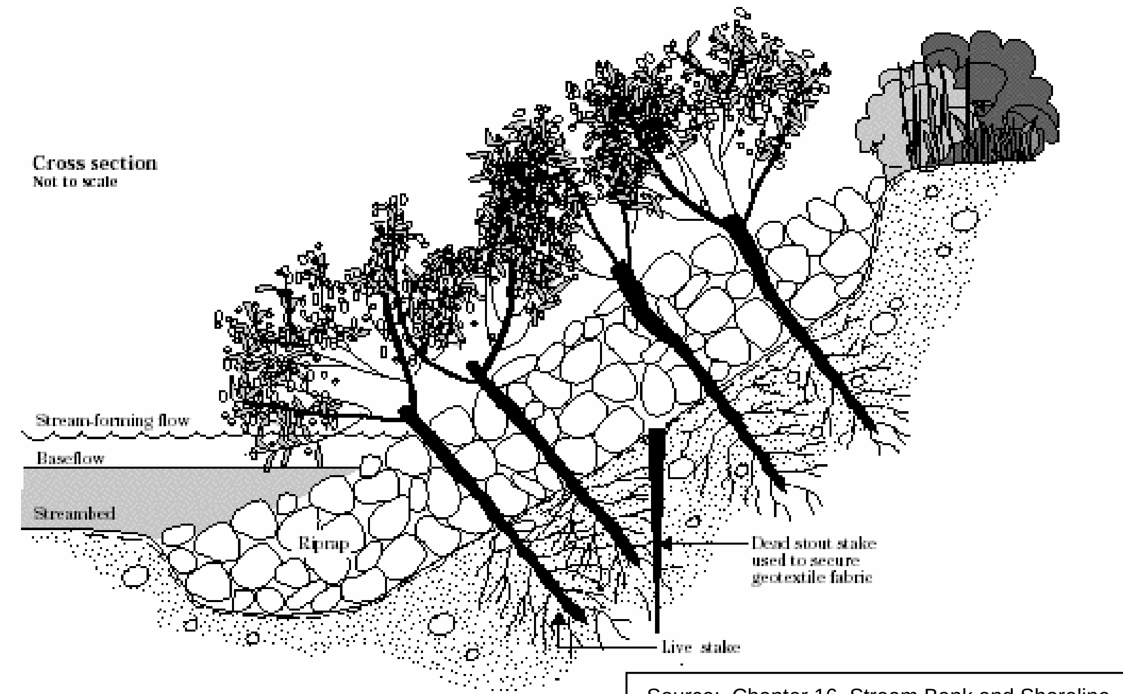
Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 50 Live Stakes.

This structural practice can be installed with or without structural 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 51). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.



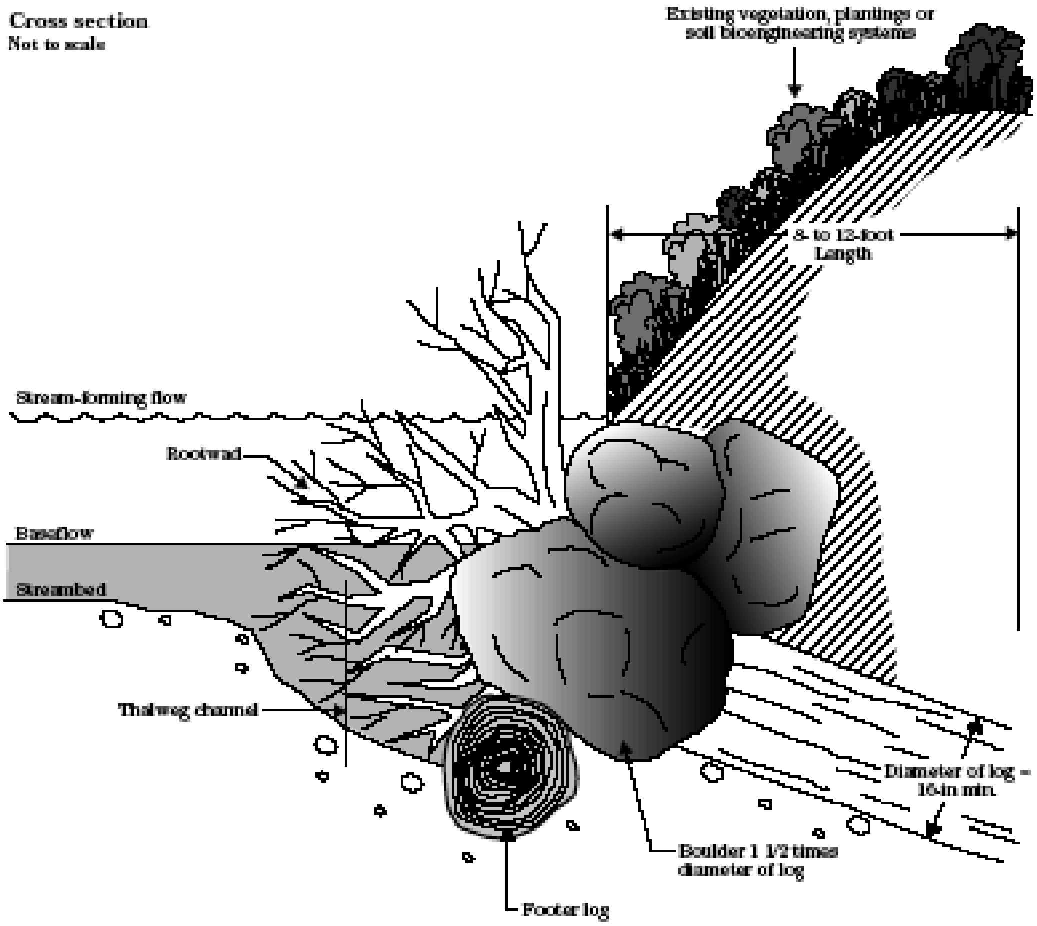
Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 51 Joint planting.

Native vegetation combined with rock stabilization.

Root Wads

These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks (Figure 52). 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 52 Root wads.

The root system provides structural protection and increases aquatic habitats.

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 53). The rock structures are angled sharply upstream (20˚ to 30˚) and dip gradually (4˚ to 7˚) 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.

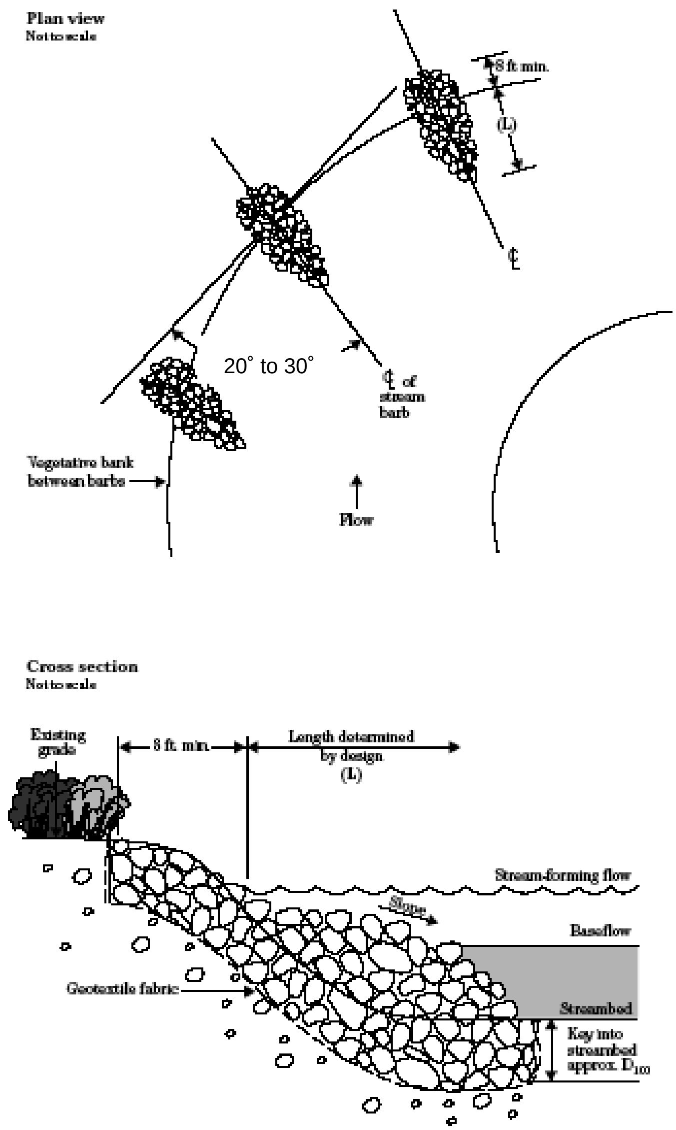


Figure 53 Stream barbs/rock vanes.

These low structures redirect flows away from erodible banks and to the center of the stream channel.