Draft Final Report

Fort Pearce Wash Master Plan

A road map for reconstruction,

management, and long-term maintenance

Fort Pearce Wash

Washington County, Utah

Submitted to:
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April 2007

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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 the Virgin River have already been completed. Although flow magnitudes in Fort Pearce Wash were not large in 2005, future flooding has the potential to create damage property and infrastructure. This master plan for Ft. Pearce Wash upstream of the Santa Clara River confluence 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 Fort Pearce Wash in order to 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;
2) Assist private landowners and city governments in managing present land use and future development;
3) Provide long-term maintenance guidelines along Fort Pearce Wash;
4) Maintain the natural function of Ft. Pearce Wash;
5) Enhance native riparian vegetation and associated wildlife habitats;
6) Increase aesthetics and recreation values

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. Two companion studies, Fort Pearce Wash Mining Plan and Fort Pearce Wash Stability Study, were 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 stream instability and subsequent bank erosion. Studies to determine post-flood 100-year regulatory floodplain boundaries will be conducted separately. The Master Plan is based on the premise that large magnitude floods will occur in the future and local governments and landowners should be prepared.

The plan was prepared by Natural Channel Design, Inc., with assistance from J. E. Fuller Hydrology and Geomorphology and Rosenberg Associates under contract with the Washington County Water Conservancy District. Project sponsors include Washington County, cities Washington and St. George, Washington County Water Conservancy District, and Virgin River Program.

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 its 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 Fort Pearce Wash. These observations were augmented and verified using 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.

Study Philosophy

The Fort Pearce Wash 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 to mathematical modeling techniques.

Advisory: The recommendations are intended to be used to advise the public of potential risk of future damage from flood-related damage. 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 US, 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 that not eliminate it. In frequent but exteme flood events produce very high velocities and shear stresses that can be expected to produce significant erosion and channel change that will require repair and maintenance.

Master Plan Components

The master plan is designed to provide guidance to city/county governments and private landowners. The information within the plan is intended to provide a road map for managing 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 conducted in assessing existing stream stability and areas of concern.

SECTION 4: CHANNEL STABILITY TEMPLATE

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

SECTION 5: REACH RECOMMENDATIONS

The final section provides specific recommendations for each project reach.

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 Fort Pearce Wash. 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 Master Plan is to minimize the potential for large lateral erosion during future flood events. Separate studies will be conducted to delineate the regulatory 100-year floodplain.

Do I need any regulatory permits to work on the river?
Yes. Any significant work within the river corridor 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 create a continuous corridor of riparian habitat to benefit wildlife.

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

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 it 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 saltcedar 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 Fort Pearce Wash. 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 9 miles of Fort Pearce Wash from the St. George city boundary downstream to its confluence with the Virgin River (Figure 1). The river is a low-gradient meandering stream with an average slope of approximately 0.005 foot/foot. The channel bed is gravel and sand. The project lies at an elevation of 2,800 feet.

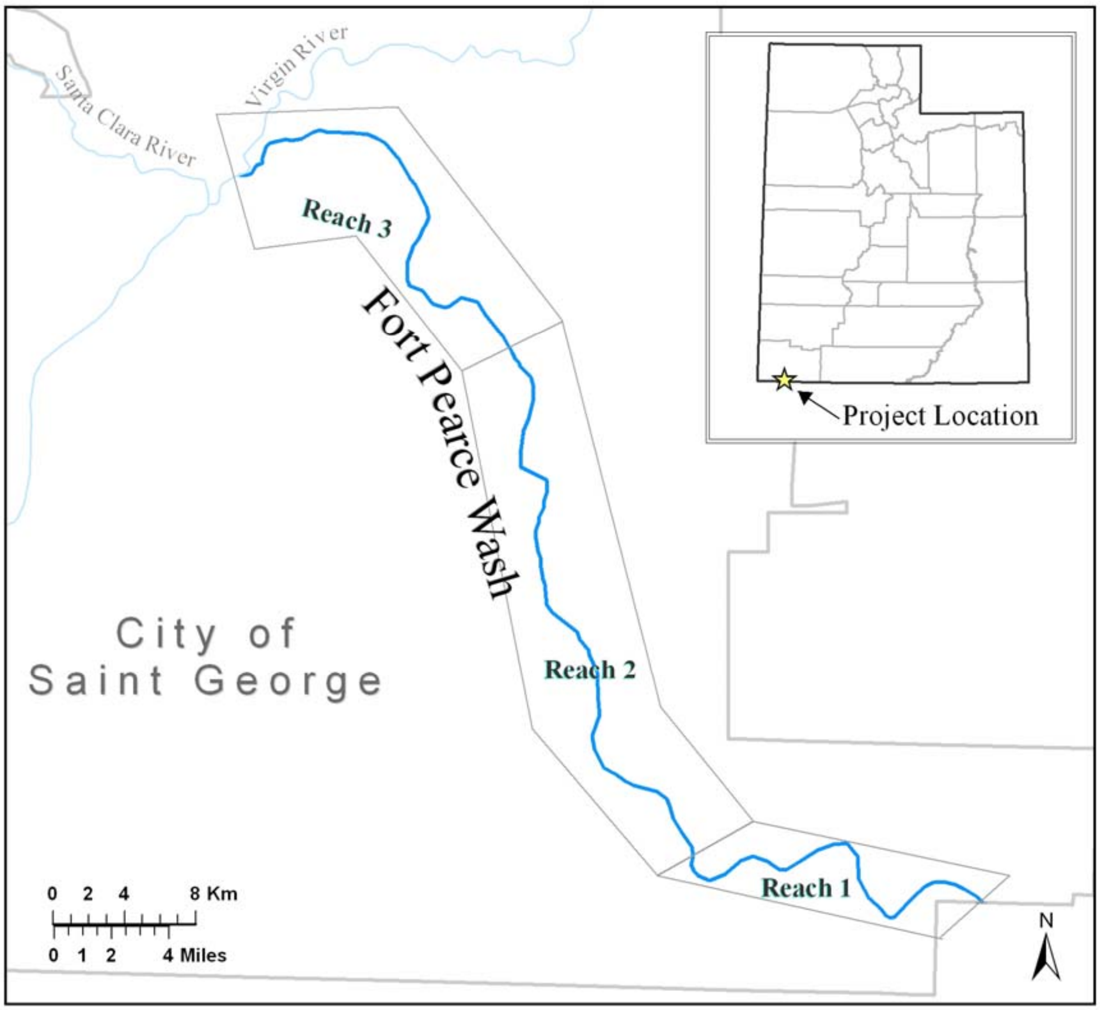


Figure 1 Map of Project Area; Fort Pearce Wash.

This map presents Fort Pearce Wash in southwestern Utah. The Wash flows to the Northwest and drains the arid lands to the south and joins the Virgin River near its confluence with the Santa Clara River in the city of St. George Utah. The confluence with the Virgin River is shown in the upper left corner of the map.

Basin Description

Fort Pearce Wash is largely composed of sand and bare rock and has a catchment area of approximately 1,685 square miles. Most of the watershed is in Mohave County, AZ, with portions in Washington and Kane Counties, UT. Waters originate in the arid highlands surrounding Mount Trumbull, AZ to the south and Colorado City, AZ to the east. There are no storage reservoirs or major diversions located along the channel that would affect peak flood flows.

Project Reaches

The project area was divided into three reaches to aid in assessment (Figure1). Each reach has unique characteristics and activities. Reach 1 is the most upstream reach and covers the area from the state boundary with Arizona down to the Quality Excavations operations (2006). Although this reach is currently in a relatively natural condition, it expected to be utilized for gravel mining and ultimately urban development in the near future. Reach 2 extends downstream to River Road and includes the current active mining zone. Reach 3 extends to the confluence with the Virgin River. This reach lies within the urban development of St. George Utah, the stream corridor largely utilized by golf courses with some adjacent home developments.

Table 1 Project Reaches

Reach	Begin	End	Approximate Length (miles)
1	City limits	Quality Excavations	2.4
2	Quality Excavations	River Road	3.8
3	River Road	Virgin River	2.6

At present, human use occurs primarily along the 6 miles of river directly upstream of the confluence with the Virgin River. Along this corridor, upland areas provide homesites and agricultural land, while the river and its banks are used for golf courses, pedestrian recreation, and sand and gravel mining.

Some channel and bank modifications have accompanied these developments. Excavation of the riverbed has created a narrowed channel below Fort Pearce Drive. Upstream of Fort Pearce Drive, a high berm along the golf course may offer protection during smaller floods, but low areas behind the berm threaten to trap flow away from the river without a return path to the main channel. Patches of the exotic tree saltcedar (*Tamarix spp*) occur along the wash. Sediment trapping pools are spaced intermittently throughout the channel. Upstream, sand and gravel is mined from the river bottom and banks. Specific project reach descriptions are presented below.

Reach 1:

This reach extends from the St. George city corporate boundaries to the upstream extents of current (Fall 2006) gravel mining operations. This reach is largely undeveloped with channel morphology and vegetation influenced by unaltered stream flows. The stream channel is composed a series of relatively stable meanders largely controlled by adjacent geology. Cutoff channels across meander point bars are common and appear active.

The lack of consistent base flow supports little native riparian vegetation with scattered pockets of salt cedar (*Tamarix ssp*) along channel margins. Although this area is currently natural, development is expected in the next decade.

Reach 2:

This reach extends from the end of Reach 1 to River Road and includes the currently active gravel mining operations. However, these operations are expected to evolve into more industrial and residential developments over the next decade. The stream channel is heavily influenced by historic and current mining operations. Channel alignment has remained relatively constant but channel and floodplain/terrace widths, shapes, and elevations have been significantly altered. Large, active excavation pits lie on one or both sides of the stream channel.

The lack of perennial base flows limits the extent of riparian vegetation to patches of salt cedar (*Tamarix ssp*) except in the downstream (northern) extend of the reach where commercial discharges support an ponded area dominated by cattail (*Typha ssp*) and bulrush (*Scirpus ssp*).

Reach 3:

This reach extends from River Road bridge to the confluence with the Virgin River. This reach is largely lined with golf courses and some homes. The stream channel morphology has been substantially altered by the adjacent development. The reach vegetation differs significantly from upstream reaches as agricultural return flows produce intermittent to perennial base flow. Riparian vegetation is dominated by salt cedar (*Tamarix ssp*) but also contains saltbush, willow, cottonwood, and other native species.

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

Small floods occur frequently and have high probabilities and low recurrence intervals. Larger floods are less frequent and have lower probabilities and higher recurrence intervals. Floods can be generally placed into 4 classes based on their magnitude and probability.

Common Floods (1 – 5-year recurrence interval):
These floods have a high probability (20% - 90%) of occurring in any year. These floods have relatively small magnitudes and are considered to be critical in eroding

and creating bars, transporting sediment, extending meander, and generally doing morphological work.

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

Large Floods (20 - 50-year recurrence interval):
These floods are unusual, having a less than 2% to 5% probability of occurring in any year. But they are very powerful and can be expected to produce significant and unpredictable bank and channel erosion and property damage.

Extreme Floods (50-year or greater recurrence interval):
These "once in a lifetime" events significantly alter channels and floodplains in unpredictable ways and produce enormous property and infrastructure damage especially in urban areas.

Project hydrology

Fort Pearce Wash drains a large area of Southern Utah and Northern Arizona. Its 1,350 square mile watershed includes the areas south and east of St. George, Utah. Surface flow records are minimal. The United States Geological Survey (USGS) installed and operates a gaging station in Reach 1 of the project but has collected only 8 years of flow records.

The Fort Pearce watershed is semi-arid, relatively low in elevation, and receives little snow accumulation. The stream is ephemeral with natural surface flows generated from storm events. As a result storm flows are historically generated by local intense storm events (monsoons) in the late summer and early fall (Table 2).

Table 2 Large flood events.

Large flood events on Fort Pearce Wash are generated by local, high intensity storms and have historically occurred in the late summer and early fall.

Date	Peak Discharge(cfs)	Comments	Source
August 1902	Unknown	Two floods occurred	Newspaper
1951	13,000	2nd largest in record	USACE, 1973 (FIS)
August 25, 1955	7,500		USACE, 1973 (FIS)
August 11, 1959	3,180		USACE, 1973 (FIS)
September 14, 1962	5,500		USACE, 1973 (FIS)
August 14, 1964	8,760		USACE, 1973 (FIS)
August 1977	15,000	Flood of record	USACE, 1991
August 17, 1989	5,000	Golf course damaged	USACE, 1992

Information obtained from 1997 CH2M Hill report

Peak discharge estimates (cubic feet per second) for indicated recurrence intervals were estimated by the USGS following the 2005 flood (are shown in Table 3). The values were calculated using a weighted estimate of two standard methods for determining frequencies; regional regression models and flood frequency analysis of the gaging record.

Table 3. Flood frequency flow values.

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.

Recurrence interval	Region 8 regression equations[1]	Bulletin 17B	Weighted estimate
2	4,180	1,250	1,310
5	8,240	3,790	4,240
10	11,500	6,940	7,940
25	16,800	13,500	14,700
50	21,500	2,090	21,200
100	26,300	31,200	28,500

[1] *Regression equations valid for watershed 1.0 - 1,990 sq. miles.*

A recent hydrology study prepared to support a Flood Insurance Study for Washington County set a flow magnitude of 25,000 cfs for the 100-year storm event on Fort Pearce Wash (Bowen, Collins 2006). The bankfull or channel maintenance flow is also useful in the assessment of stream channel geomorphology. Research on a large number of rivers 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. The flows for various flood frequencies used in this report are presented in Table 4.

Table 4 Project flood flow values.

Recurrence interval	Excedence Probability (%)	Peak Discharge (cfs)
1.5-year (Bankfull)	67%	650
2-year	50%	1,310
5-year	20%	4,240
10-year	10%	7,940
25-year	4%	14,700
50-year	2%	21,200
100 year	1%	25,000

SECTION 3: STREAM CHANNEL STABILITY ANALYSIS

Natural stream channels are created and maintained by the forces of their watersheds. The primary functions are to transport sediment, convey flood flows, and dissipate energy. Stream channels create alluvial forms to most efficiently perform these functions. Although dynamic, these forms represent the most stable condition.

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.

Steam Channel Processes

The Nature of Rivers

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

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

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

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

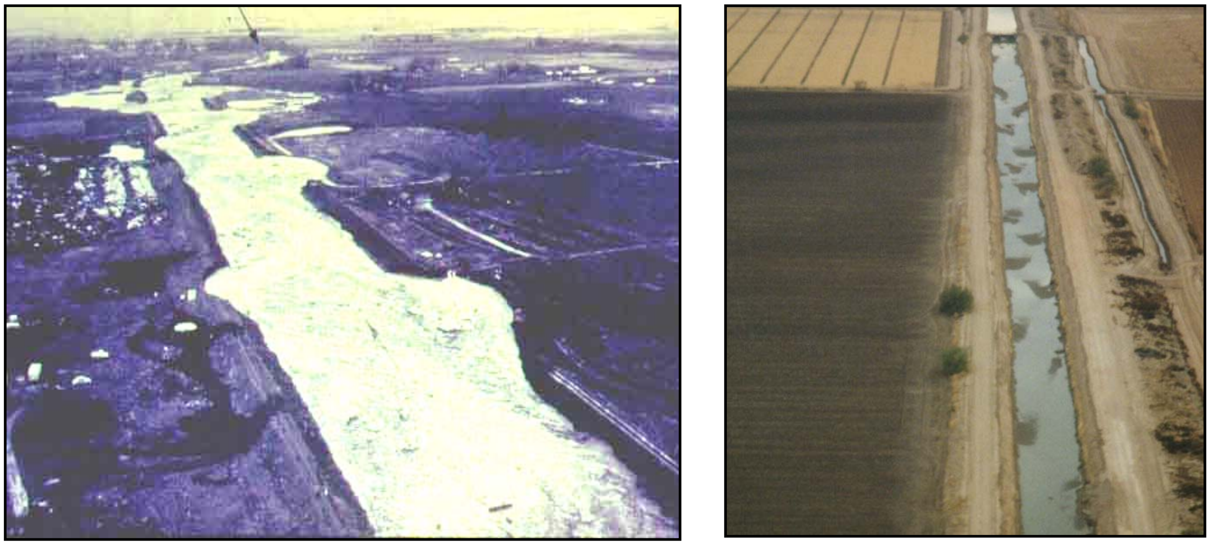


Figure 2 Stream channel meander

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

The stability of any natural channel is dependent on an appropriate dimension, pattern, and profile of the bankfull channel and associated floodplain (Leopold, Wolman, & Miller, 1964). The Master Plan has attempted to identify the stable geomorphic dimensions of the 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.

Effects of Channel Modification

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

Straightening

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

Levying/widening

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

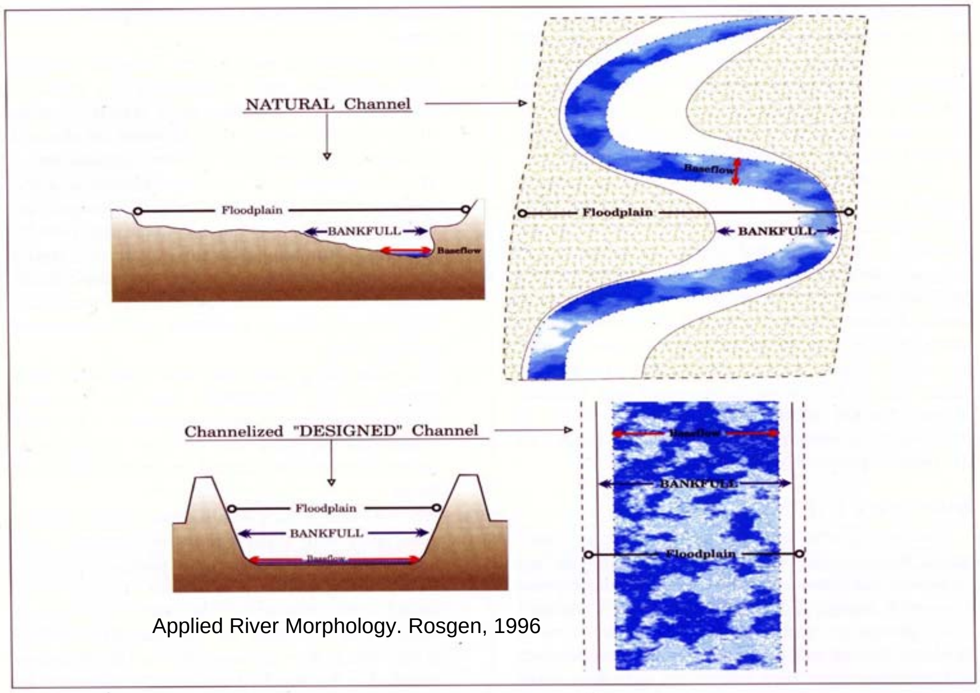


Figure 3 Natural vs. "Designed" Channels.

The lack of geomorphic floodplains in the "designed" channel reduces sediment transport.

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

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

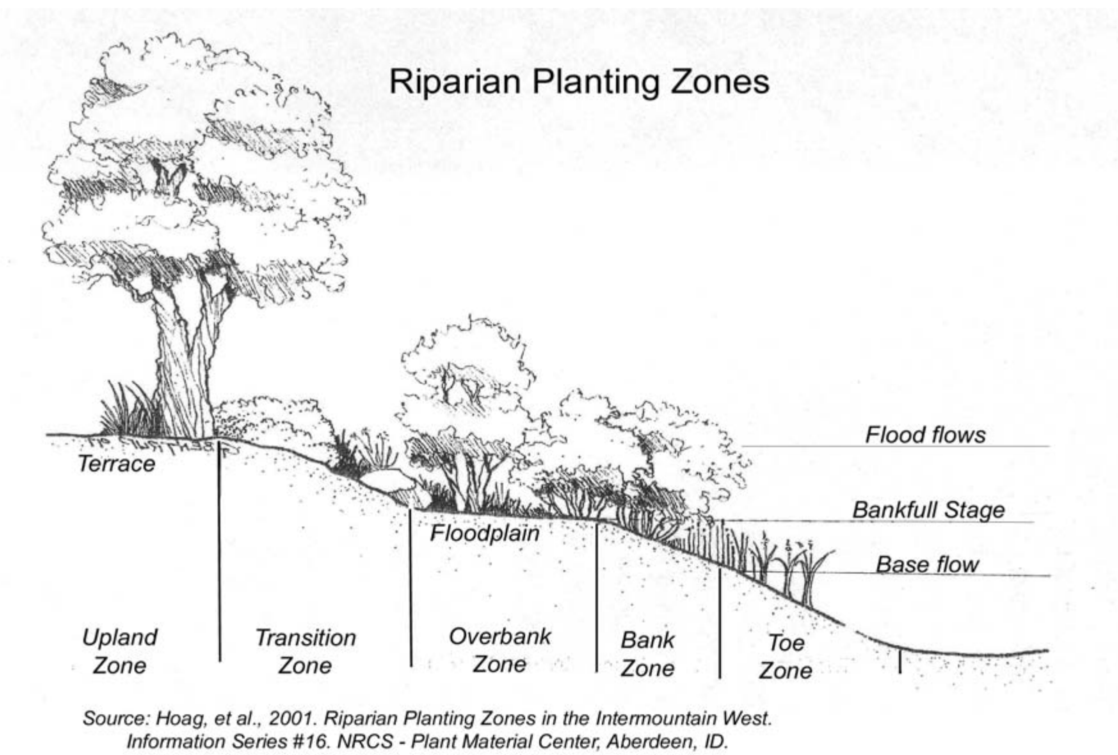


Figure 4 Riparian Planting Zones

Mechanisms of Channel Change

Most of the Fort Pearce Wash watershed is undeveloped, with washes originating in steep mountains and plateaus and then meandering through wide plains and low rolling hills. The climate is arid and supports sparse vegetation. Storm events are commonly produced by intense, short duration summer monsoon events but can be also generated by large winter frontal storms. The combination of poor vegetation and intense storm events can produce high magnitude flow events.

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 Fort Pearce Wash 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 Fort Pearce Wash was combined with studies of aerial photographs, geomorphic surveys, regional hydrologic data, and anectdotal 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 each cross-section. 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 was 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 reaches of Fort Pearce Wash in the spring and summer of 2006. These visits included walking surveys of the reaches and cross-section/profile surveys along the Wash.

Aerial photographs:

The most recent aerial photographs (2006) were used to evaluate channel pattern.

Geomorphic surveys:

Five surveys were conducted in Reaches 1 and 2 to characterize the natural and altered channel morphology. No surveys were conducted in Reach 3 due to recent excavation of the stream channel.

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 5). 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.

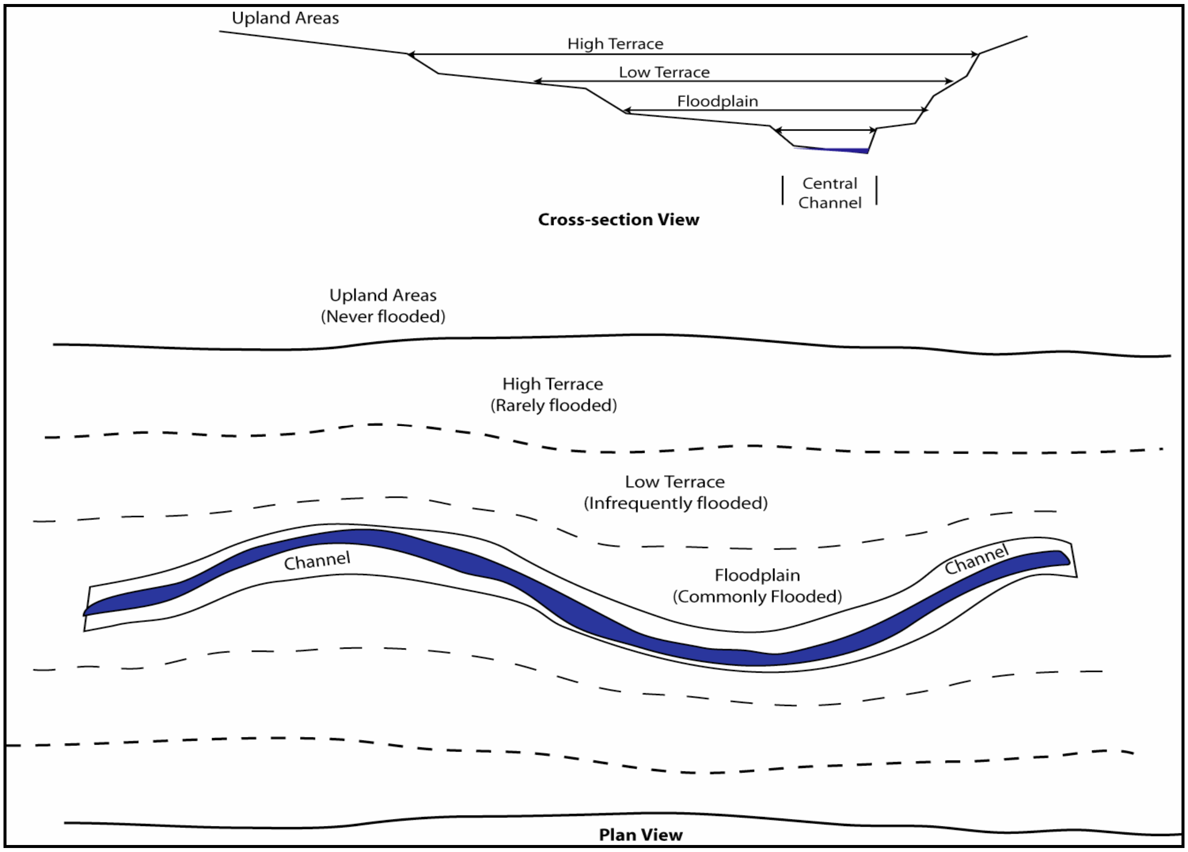


Figure 5 Channel, floodplain, terrace features.

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). Bankfull stage was used as a common reference point to identify width, depth, and other dimensions.

An assessment of the channel cross-sections suggests that the bankfull channel has consistent cross-sectional areas between 115 and 180 square feet with an average of 135 square feet. Assuming a bankfull discharge of ~650 cfs (see hydrology section) a cross-sectional area of 135 ft^2 produces an average velocity of ~5 feet per second also consistent with regional data. Although the adjacent geomorphic floodplains are relatively narrow (2-3 channel widths, the cross-sections widen dramatically in the terrace areas to 5-8 times the central channel width.

The results of the surveyed cross-sections are provided in Tables 5. The Fort Pearce Wash stream channel would be classified as a C channel type; a low gradient meandering channel with adjacent floodplains to spread flood flows. Substrate is dominated by coarse sand and/or gravel. The delineative criteria for classification are presented in Table 6.

Table 5 FPW Cross-section survey data.

XS	XS area (sq ft)	Bankfull channel width (ft)	Mean depth (ft)	Max. depth (ft)	Floodprone width[1] (ft)	Super floodprone width[2] (ft)	Notes
1	115	43	2.6	3.9	110	350	Below Church Farm
2	150	62	2.4	3	225	400	Above USGS gage site
3	135	62	2.2	2.6	140	320	Immediately above mining
4	180	70	2.6	5.8	240	440	Active headcut, unstable
5	130	65	2	3.8	190	200	Within mining district

[1] Floodprone Width: Defined as the width of the geomorphic floodplain at an elevation twice maximum bankfull depth. This criterion commonly corresponds to stage that corresponds to a common (3-5-year) flood event in the southwest.

[2] Super Floodprone Width: Defined as the width of the geomorphic floodplain at an elevation 3 times maximum bankfull depth. This criterion commonly corresponds to stage that corresponds to a moderate (10-year) flood event in the southwest.

Table 6 Delineative channel dimension criteria at FPW survey sites.

XS	W/D ratio[1]	Ent. Ratio[2]	Super Ent. Ratio[3]	D50 (est.) (mm)	Slope	Sinuosity	Stream type
1	16	2.6	8.1	35	0.003	1.1	C4
2	26	3.6	6.5	10	0.006	1.1	C4
3	29	2.3	5.2	5	0.001	1.1	C4
4	27	3.4	6.3	7	0.002	1.1	C4
5	33	2.9	3.1	35	0.006	1.1	C4

[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 moderate (1~10-year) flows on an adjacent floodplain.

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 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. Slopes at the surveyed project cross-sections varied from 0.001 to 0.006 ft/ft. The project reach has an average slope of approximately 0.005 ft/ft.

Channel bed elevation does not remain static over time with changes often triggered by alterations to the stream corridor. Long-term data on channel bed elevations is not available but changes in elevations were evaluated using topography produced in 1993, 2003, and 2006. Channel bed elevations in Reach 1 have remained relatively constant since 1993. In Reach 3, there has been net aggradation between River Road and Fort Pearce Drive and net degradation between Ft. Pearce Drive and the Virgin confluence. The greatest variation in bed elevations occurred in Reach 2 corresponding with the manipulations of the channel connected with gravel mining.

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. Fort Pearce Wash has a relatively low sinuosity (stream length divided by valley length) with gentle meander radius. The channel alignment has remained relatively stable over the past 40 years (see River Stability Study Update).

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 Fort Pearce Wash 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 6). The majority of pattern measurements were made in the relatively unaltered channel of Reach 3 (Figure 7). The meander pattern in Fort Pearce Wash is longer and more gradual than regional averages. The broader radius of curvature and long meander lengths may be attributed to the high bedload carried by the stream.

As in most natural systems, the range of values is as important as average values in assessing the natural variability (Table 7).

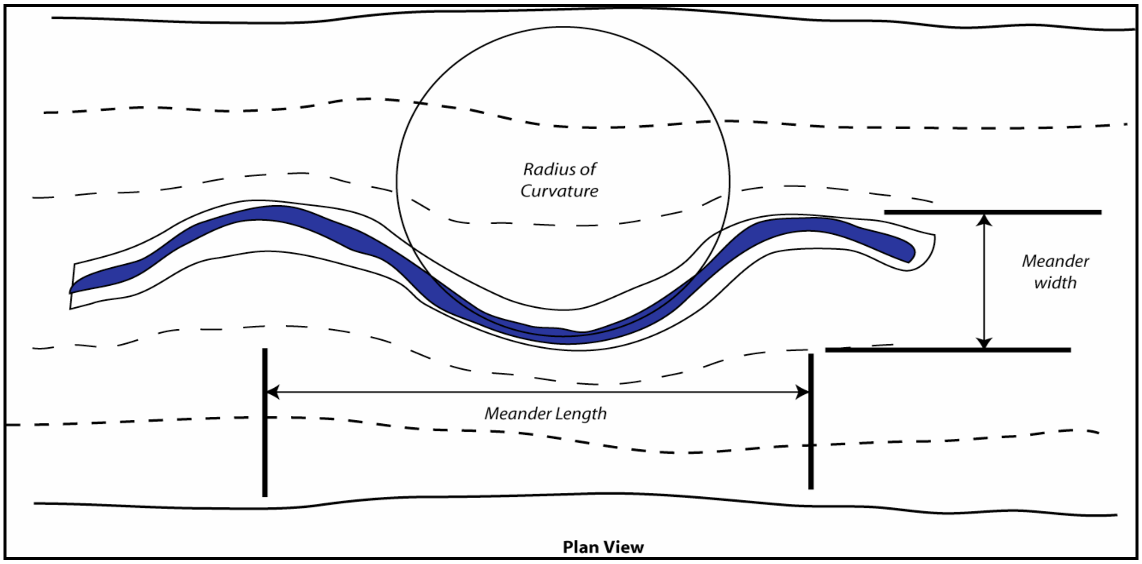


Figure 6 Meander Pattern Characteristics.

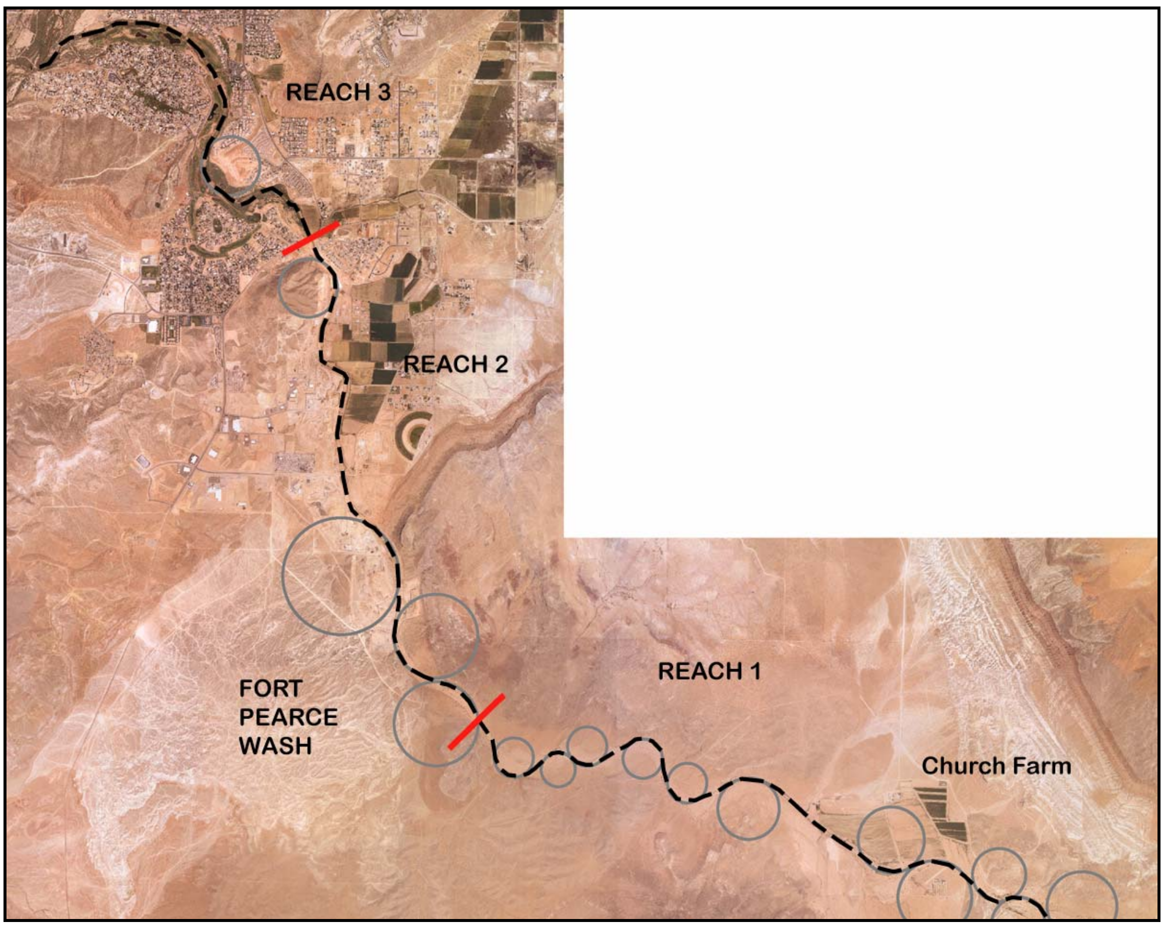


Figure 7 FPW meander pattern.

Table 7 Meander pattern dimensions

These values characterize the range of meander pattern dimensions for the unaltered reaches of Fort Pearce Wash. The range of variability is as important as an average value.

	Radius of curvature (feet)	Meander width (feet)	Meander length (feet)
Maximum	1,950	1,500	5,500
Average	1,015	983	3,492
Minimum	575	670	2,500

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.

Summary

Fort Pearce Wash is an ephemeral low-gradient, meandering gravel bed stream with a narrow but well-developed floodplain. Bankfull channel and floodprone widths are consistent with regional geomorphic data. Low and high terraces widen appreciably in the unaltered reaches above current mining operations. Table 8 presents representative values for the existing channel/floodplain/terrace cross-section. Meander patterns are gentle with gradual meanders and large radius turns.

Table 8 Summary of existing channel/floodplain/terraces dimensions

	Elev abv channel bed (ft)	Channel Width (ft)	Side slopes (ft)	Approximate Flood hazard
Channel				
Bottom width	0	30	NA	NA
Top width	3	60	5:1	1.5 - 2 year
Geomorphic floodplain	3-6	180	20:1	4-5 year
Low Terrace	6-9	340	25:1	10 year
High Terrace	9-12	450	18:1	100 year
Daylight to natural grade			40:1	> 100-year flood hazard

Hydraulic Analysis

An analysis of the hydraulic characteristics was conducted for the existing channel cross-section and for several potential design channels. Natural stream channel create and maintain their alluvial features. The shape and dimension of the bankfull channel and geomorphic floodplain are considered critically important to successful sediment transport. As a result, the dimensions of these features were incorporated into all potential design cross-sections. The goal of the hydraulic analysis was to evaluate the risk of scour and erosion largely based on velocities.

WinXSPro, a cross-section analyzer developed by the USDA Forest Service and Bureau of Land Management was used to evaluate cross-sections. Each cross-section was divided into 5 sections including a central channel (bankfull), geomorphic floodplain, and low/high terrace. The central channel extends to the 3 foot stage and is expected to be largely free of vegetation. The geomorphic floodplain extends from 3- to 6-feet above channel bed. The low terraces is located at elevations from 6 – 9 feet and the high terrace rises to a stage of 15 feet in order to carry the extreme (100-year) flood event. One goal of the analysis is to contain the 10-year flow event in the low terrace to allow for non-structural uses in the high terraces.

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 not be accurate. They are however, within the range commonly used for natural channels. Roughness coefficients were slightly higher in shallow flows than at higher stages. The terraces were assigned similar values with the expectation that terrace areas may be used for a variety of purposes but will not be heavily vegetated.

The geomorphic floodplain (3-6 feet above channel bed) that lies adjacent to the central channel may have the greatest variety in roughness especially in Reach 3 below River Road. The nuisance flows from agricultural return flows create an intermittent to perennial base flow and has supported dense stands of Salt Cedar (*Tamarisk ssp*). It is also expected to have sufficient soil moisture to support supple native willow species and cottonwoods. Roughness values are presented in Table 9.

Table 9 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

Results for an existing cross-section (XS3) is presented in Table 10. This cross-section is represented by the cross-section values given in Table 4. Because the cross-section was surveyed in the ephemeral portion of the Wash, no vegetation component was included in the roughness values. The 100-year flood event rises to a stage of 11.5 feet and the 10-year flood is contained at a depth of 8 feet. Average velocities are reasonable for flows up to the 25-year frequency but quite high and potentially erosive at extreme flow levels. This suggests that these infrequent flow events can be expected to create regardless of channel cross-section. This is supported by evidence of extensive scour channels well away from the central channel in the unaltered project Reach 1.

Table 10 Hydraulic results; Existing cross-section (XS3)

Surveyed cross-section #3 in the lower section of Reach 1 was modeled to identify existing conditions. The site is considered stable and functioning.

Hydraulic summary			Velocities				
Frequency	Discharge	Stage	XS Average	Channel	Floodplain	Terrace	Froud #
	(cfs)	(ft)	(fps)	(fps)	(fps)	(fps)	
Bankfull	650	3	5.4	5.4			0.63
2 yr	1,300	4	6.7	7.0	1.7		0.76
5 yr	4,200	6.5	8.7	10.8	4.4	1.2	0.87
10 yr	8,000	8	9.7	13.1	6.7	2.9	0.94
25 yr	14,700	10	10.4	16.1	9.5	4.2	1.00
50 yr	21,200	11	11.1	17.7	10.9	6.0	0.95
100 yr	25,000	11.5	11.7	18.5	11.6	6.8	0.94

The width at the 100-year flow of the existing channel is almost 450 feet. A narrower cross-section intended to optimize the use of areas surrounding Fort Pearce Wash was evaluated. The total channel width is 300 feet with a 200-foot width (9-foot stage) to carry the 10-year flow. No roughness from vegetation was included in the model run (Table 11). Narrowing the channel produced substantially higher velocities in all cross-section areas especially for the less frequent floods events. These velocities can be considered highly erosive.

Table 11 Hydraulic results; 300 foot design channel

The 300-foot wide design channel carried has higher velocities in all channel units compared to the existing conditions.

Hydraulic Summary							
Flow	Q	Stage	XS Average	Channel	Floodplain	Terrace	Froud #
	(cfs)	(ft)	(fps)	(fps)	(fps)	(fps)	
Bankfull	650	3	5.4	5.4			0.63
2 yr	1,300	4	6.7	7.0	1.7		0.76
5 yr	4,200	6.5	8.8	10.8	4.4	1.2	0.84
10 yr	8,000	8.5	10.6	13.8	7.4	3.6	0.89
25 yr	14,700	10.5	12.0	16.9	10.2	4.7	0.99
50 yr	21,200	11.5	13.0	18.5	11.6	6.4	0.97
100 yr	25,000	12.5	14.1	20.2	13.0	7.9	0.98

A wider 350-foot channel was modeled. The distance between low terraces was narrowed to 150 feet in an attempt to maximize the terrace areas above that stage. The wider cross-section reduces flow velocities in the floodplain and terraces but remained excessive in the central channel section (Table 12).

Table 12 Hydraulic results; 350 foot design channel, narrow section

This 350-foot wide cross-section has a narrow floodplain section to increase useable areas on the low terrace. Terrace velocities were reduced but floodplain and central channel velocities remain high.

Hydraulic Summary							
Frequency	Discharge	Stage	XS Average	Channel	Floodplain	Terrace	Froud #
	(cfs)	(ft)	(fps)	(fps)	(fps)	(fps)	
Bankfull	650	3	5.4	5.4			0.63
2 yr	1,300	4	6.7	7.0	1.7		0.76
5 yr	4,200	6.5	8.8	10.8	4.4		0.82
10 yr	8,000	8.5	11.0	13.8	7.0		0.84
25 yr	14,700	10.5	12.5	16.9	9.7	2.6	1.09
50 yr	21,200	12	13.3	19.4	11.8	5.1	1.05
100 yr	25,000	12.5	13.7	20.2	12.5	5.9	1.03

Table 13 presents results for a 350-foot wide channel with a width of 210 feet across low terraces. As expected the velocities are reduced especially in the central channel. Velocities are similar to those in the existing XS 3 (Table 10). This cross-section is considered a reasonable balance between the maximizing the ability of landowners to utilize lands adjacent to Fort Pearce Wash and a reasonable minimization of the risk of scour and erosion.

Table 13 Hydraulic results; 350-foot design channel, wide section

This cross-section has a wider floodplain section and reduced velocities in the channel and terrace areas.

Hydraulic Summary			Velocities				
Frequency	Discharge	Stage	XS Average	Channel	Floodplain	Terrace	Froud #
	(cfs)	(ft)	(fps)	(fps)	(fps)	(fps)	
Bankfull	650	3	5.2	5.2			0.62
2 yr	1,300	4	6.3	6.8	1.9		0.77
5 yr	4,200	6	7.3	9.5	4.1		0.8
10 yr	8,000	8	9.4	12.1	7.1		0.78
25 yr	14,700	9.5	11.1	13.9	9.2	1.2	0.86
50 yr	21,200	11	12.2	15.7	11.2	3.1	0.97
100 yr	25,000	12	13.0	16.9	12.5	5.0	0.94

Effects of vegetation

Vegetation can increase or reduce stability in perennial stream channels. 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 70 feet on either side of the central channel was modeled and results presented in Table 14. As expected, 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. Table 15 presents the results of an analysis of the same design cross-section with dense stands of salt cedar across the floodplain. In practice, the vegetation may actually extend further into the low and high terrace areas. 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.

Table 14 Hydraulic results; Dense floodplain willows (*Salix exigua*)

Shubby willows planted along the floodplain of the 350-foot channel reduce floodplain velocities.

Hydraulic Summary				Velocities			
Frequency	Discharge	Stage	XS Average	Channel	Floodplain	Terrace	Froud #
	(cfs)	(ft)	(fps)	(fps)	(fps)	(fps)	
Bankfull	650	3	5.2	5.2			0.62
2 yr	1,300	4	6.2	6.8	1.3		0.76
5 yr	4,200	6.5	7.2	10.2	3.7		0.72
10 yr	8,000	8	8.6	12.1	5.5		0.71
25 yr	14,700	10	10.5	14.5	8.1	1.9	0.83
50 yr	21,200	11.5	11.7	16.3	10.3	4.1	0.89
100 yr	25,000	12	12.2	16.9	11.1	5.0	0.89

Table 15 Hydraulic results; Dense floodplain salt cedar (*Tamarix ssp*)

Dense tamarisk thickets restrict flows across the floodplain/terrace increasing velocities in the channel/high terrace.

Hydraulic Summary				Velocities			
Frequency	Discharge	Stage	XS Average	Channel	Floodplain	Terrace	Froud #
	(cfs)	(ft)	(fps)	(fps)	(fps)	(fps)	
Bankfull	650	3	5.2	5.2			0.62
2 yr	1,300	4	6.1	6.8	0.7		0.75
5 yr	4,200	6.5	6.5	10.2	1.9		0.65
10 yr	8,000	9	7.8	13.3	3.6		0.59
25 yr	14,700	11	8.9	15.7	5.2	3.1	0.70
50 yr	21,200	12.5	10.0	17.5	6.7	5.9	0.70
100 yr	25,000	13	10.5	18.1	7.3	6.7	0.71

Conclusions

Based on the hydrologic, geomorphic, and hydraulic analyses described above the design channel template was identified and is presented below. 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 cross-section template should also support native riparian plant species in the wetter Reach 3 section providing additional stability, wildlife habitat, and aesthetics. Dense stands of salt cedar reduce channel capacity, increase velocities, and raise the potential for scour and erosion.

The design template (Table 16, Figure 8)is presented for guidance purposes only. Additional site specific engineering analyses are recommended.

Table 16 Design cross-section template dimensions

Design Channel

	Elev	Side slope	Width	Flood Risk
Channel Bottom	0	NA	30	NA
Channel top (Bankfull)	3	5	60	2-year
Floodprone Width	6	23	150	5-year
Low Terrace	9	2	200	10-year
High Terrace	15	12	350	> 25-year

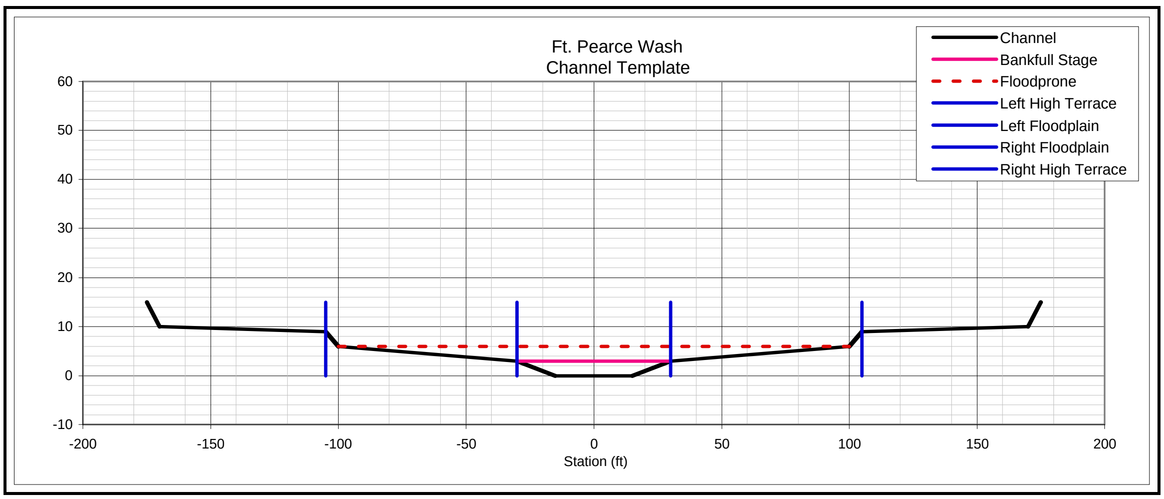


Figure 8 Design Cross-section Template

SECTION 4: STREAM STABILITY TEMPLATE

Large flood events will occur again on Fort Pearce Wash. 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

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 9). For Ft. Pearce Wash steps of approximately 3.0 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 10). 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.

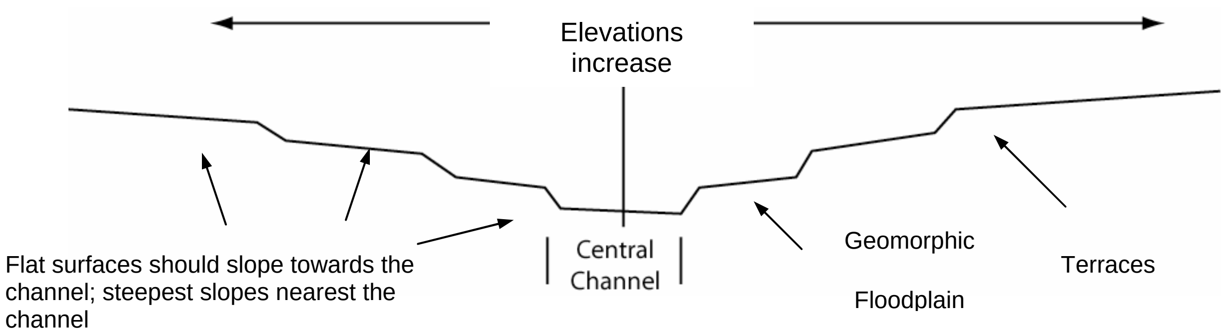
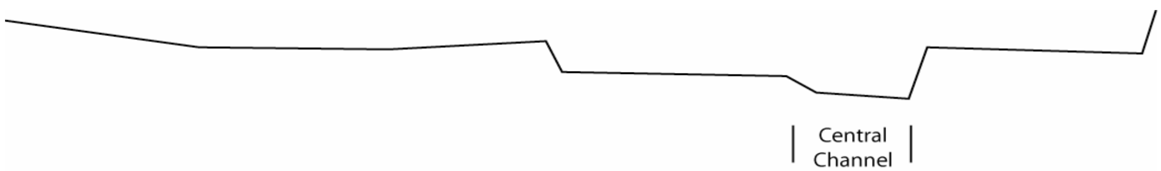
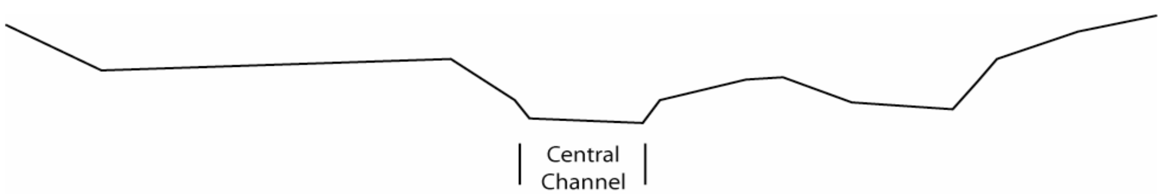


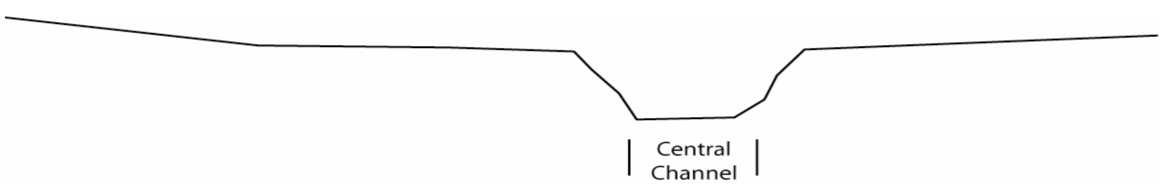
Figure 9 Appropriate channel/floodplain elevations



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 10 Incorrect channel/floodplain elevations

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 11). Areas further away from the channel (terraces) support stiffer woody vegetation (cottonwoods, Black willow, etc) that further slows flows. Open areas with little flow resistance separated from the central channel will increase the risk of erosion (Figure 12). It should be noted that roughness implies a slowing of the flow not necessarily stopping the flow. Structures that completely stop or redirect flow across the floodplain/terrace should be avoided.

Terraces are features that can be used by both humans and the river. These areas are infrequently flooded and can be used for agricultural fields, orchards, parks, and other open spaces without permanent structures. However, these areas should be designed to discourage high flow velocities.

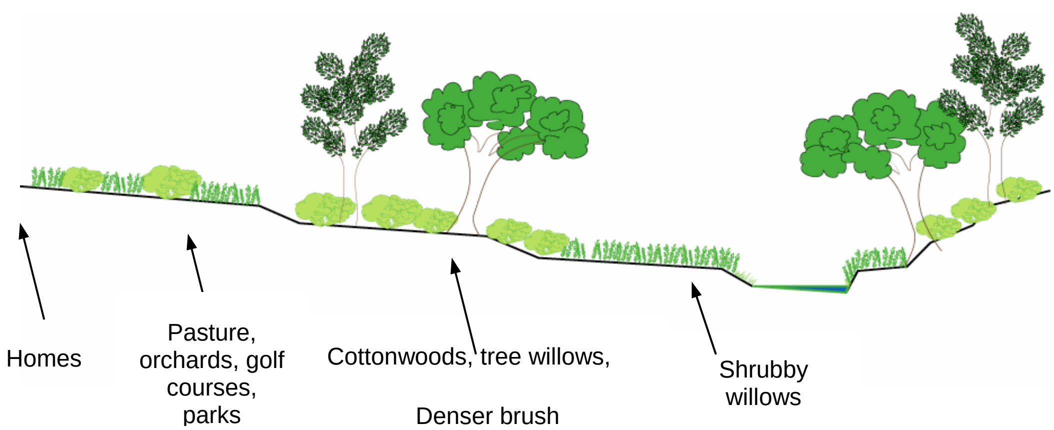


Figure 11 Appropriate overbank roughness.

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

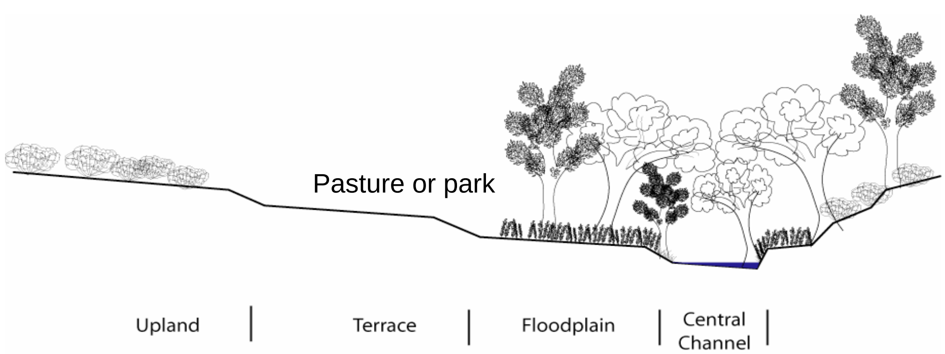


Figure 12 Incorrect overbank roughness.

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

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

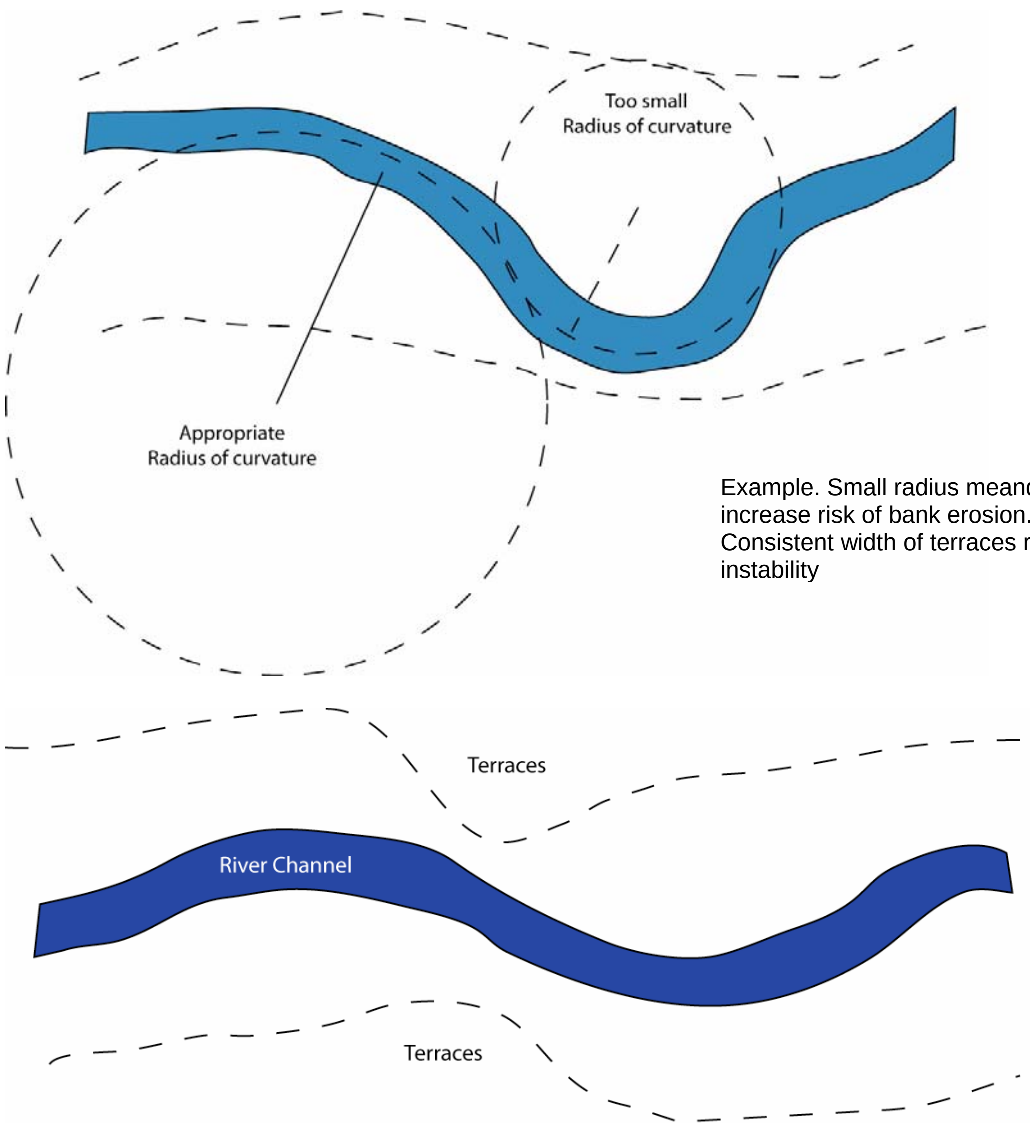


Figure 13. Incorrect channel transitions.

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 17, Figure 14). 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 occurs within the geomorphic floodplain which 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 road construction, parallel utility alignments, active recreation facilities, storage of inert materials, recharge basins, constructed wetlands, and parking. 100-year flood velocities and depths should be low 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 flooplain, are considered to be within the Fort Pearce Wash 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). The upland areas are potentially developable if located outside the EHZ or if adequate erosion protection is provided.

Table 17 Stream corridor zones

Riparian Corridor Zones	Regulatory Issues	Approximate Width	Flood Protection	Vegetation	Uses
Central channel/ Geomorphic Floodplain	USACE Jurisdictional Area	200 ft	< 10-year	Native riparian willows, cottonwoods *	Pedestrian only, trails, no other improvements
Flood Terrace	FEMA Regulatory Floodplain	350 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	> 350 ft	> 100-year	Lanscaping	Fully developable

* Where adequate soil moisture is available, currently only in Reach 3.

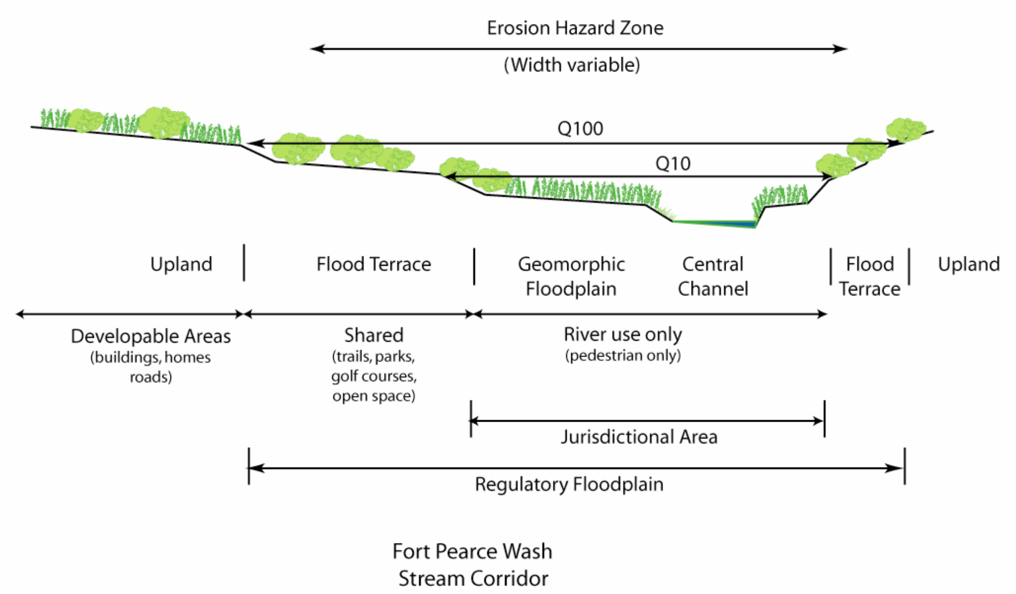


Figure 14 Stream corridor zones

Channel Cross-section Template

A channel template was created to describe the width and depth of alluvial features for Fort Pearce Wash project reaches. 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 Ft. Pearce Wash are given in Table 18 and Figure 15.

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

Table 18 Cross-section Template data

	See Figure	Elev abv channel bed (ft)	Channel Width (ft)	Side slopes	Comments
Channel					
Bottom width		0	30	na	Jurisdictional Area
Top width	A	3	60	5:1	Jurisdictional Area
Geomorphic floodplain	B	6	140	13:1	Jurisdictional Area
Low Terrace	C	9	200	10:1	> 10-year flood hazard
High Terrace	D	12	350	25:1	50-year - 100-year flood hazard
Daylight to natural grade			40:1	> 100-year flood hazard	

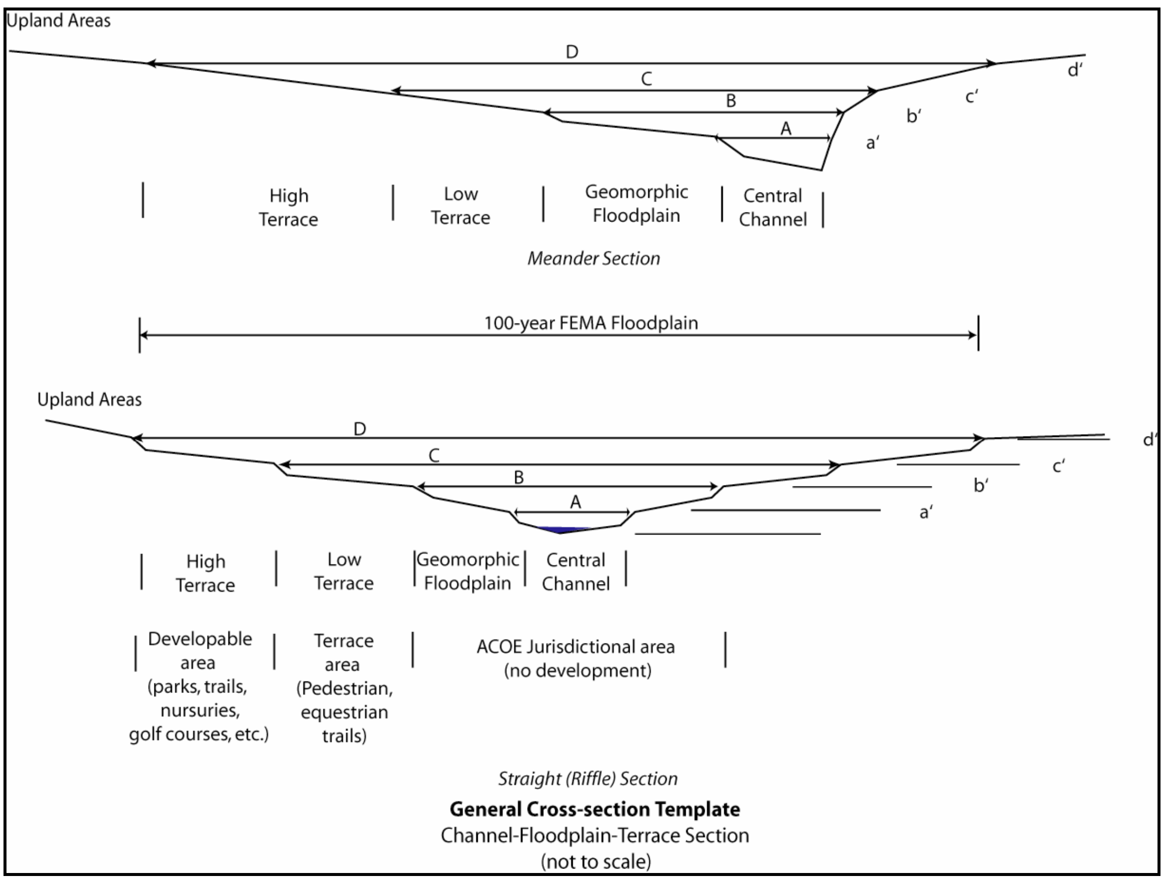


Figure 15 Cross-section template

Channel Alignment

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 (Table 19). Realignments should not adversely impact upstream or downstream properties. All disturbed areas should be revegetated with appropriate native plant species.

Table 19 Meander pattern template

	Radius of curvature (feet)	Meander width (feet)	Meander length (feet)
Maximum [1]	1,238	1,280	3,580
Average value	1,015	983	3,492
Minimum [1]	660	714	3,078

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

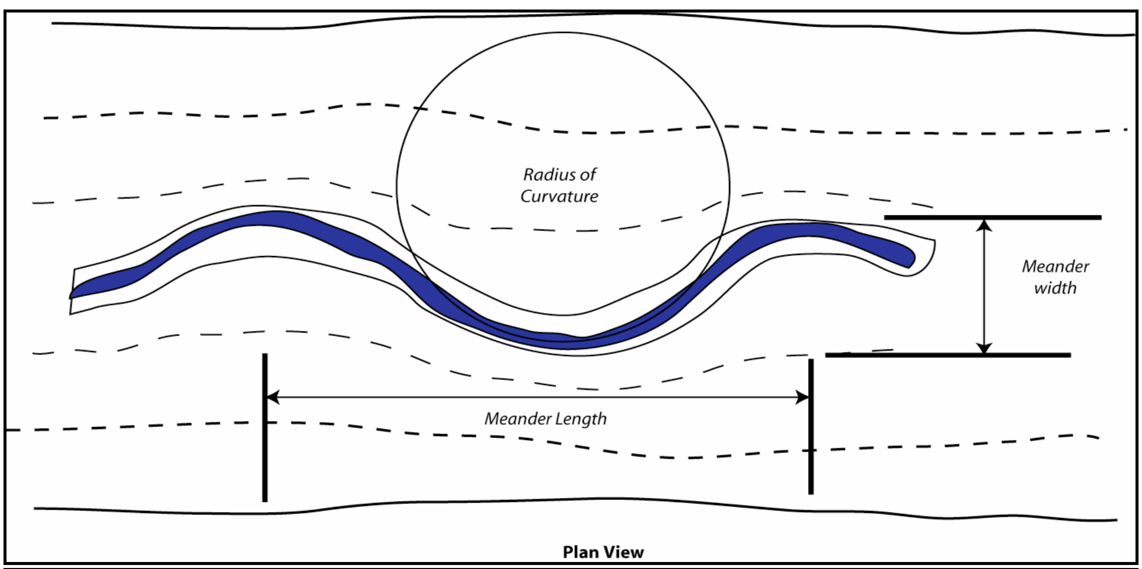


Figure 16 Meander pattern characteristics

Revegetation Strategies

Riparian vegetation can be an important component in providing channel stability and reducing bank erosion along Fort Pearce Wash. 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. In Reach 3 areas are currently dominated by dense salt cedar thickets. The following describes the plant types for each of the alluvial features described in the preceding section (Figure 17).

Central Channel: Well rooted herbaceous plants, emergent wetland species, supple, shrubby woody species. These species are expected to colonize naturally.

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.

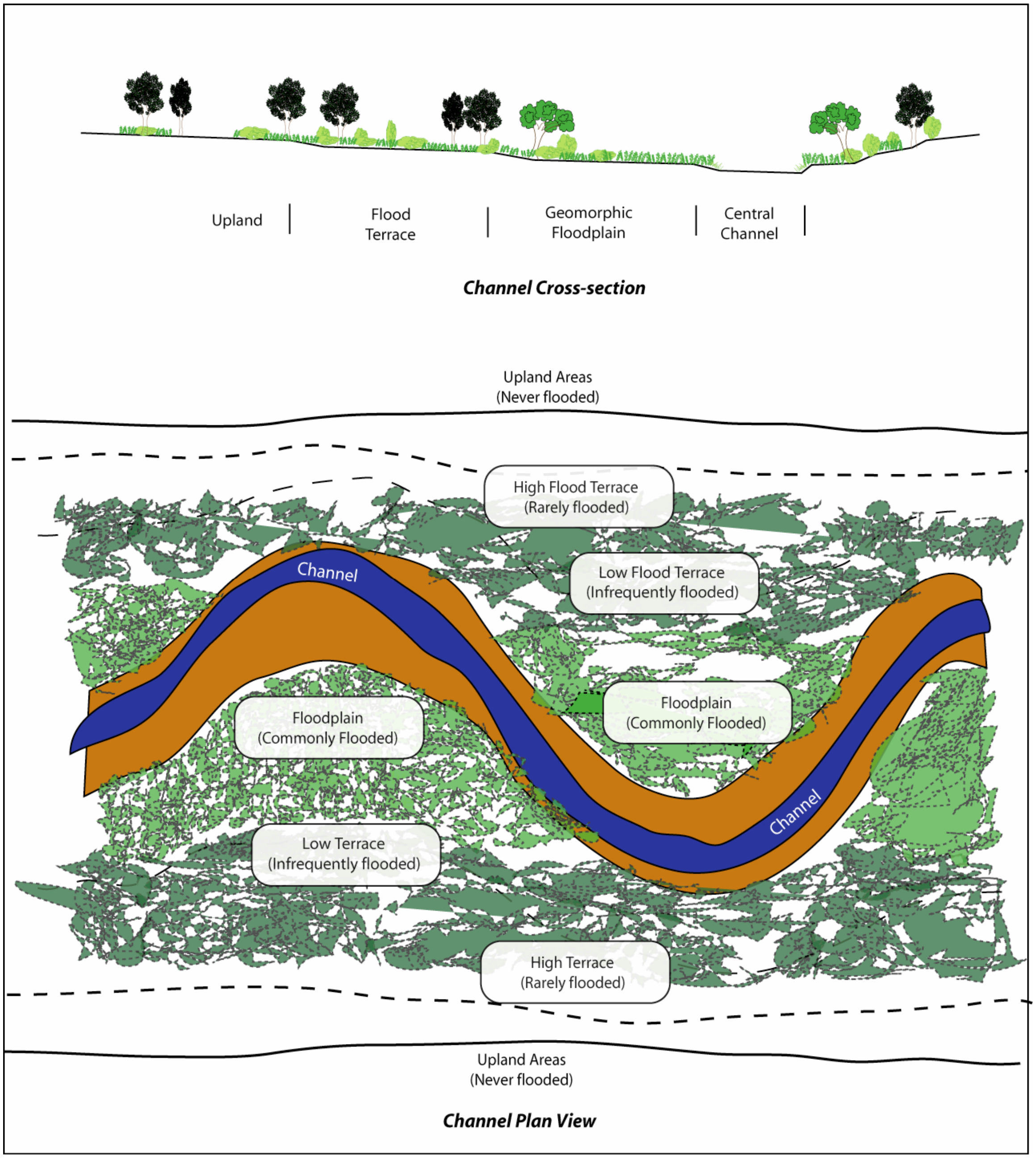


Figure 17 Areas of re-vegetation

Planting Recommendations

Appropriate composition, distribution, and density of riparian vegetation will be essential to maximizing stream stability and minimizing erosion risk. Specific plant communities should be established or maintained on alluvial features as described below. A partial list of appropriate plant species are presented in Table 20.

Table 20 Recommended plant species for revegetation

Common Name	Scientific Name
Bank Zone/floodplain	
Seep willow	*Baccharis salicifolia*
Coyote Willow	*Salix exigua*
Alkalai sacaton	*Sporobolus airoides*
Floodplain	
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 ssp*
Desert Sand verbena	*Abronia villosa*
Fragrant sand verbena	*Abronia elliptica*
Penstemon	*Penstemon ssp*
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
Flood Terrace	
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

Rivers flood. Common floods inundate areas closest to the central channel; higher, less frequent floods affect higher areas. Riparian corridors can be thought of as composed of three zones (Figure 18). The first is the lowest and includes the central channel and adjacent floodplain. This area is flooded frequently and sometimes for long periods of time. While it can be used for passive activities such as hiking and birding, alterations to this area can severely impact the essential processes of the stream. This area should be thought of as belonging entirely to the river.

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

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

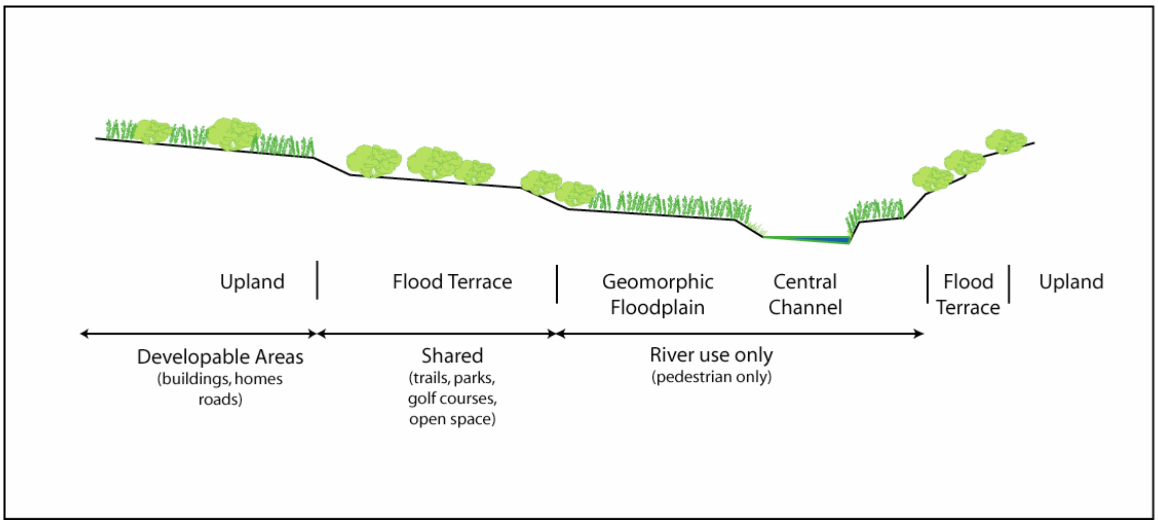


Figure 18 Appropriate land uses.

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.

<u>Geomorphic Floodplain</u>

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.

<u>Flood (high/low) Terraces</u>

Agricultural fields that can be flooded periodically. Constructed pedestrian/bike trails, recreation areas (parks, golf courses), 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.

<u>Uplands:</u>

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. Lowering geomorphic floodplain and terrace elevations will lead to an overwidened channel (Figure 19). 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. Eventually coyote willow or other supple native woody species should be planted where the tamarisk is removed.

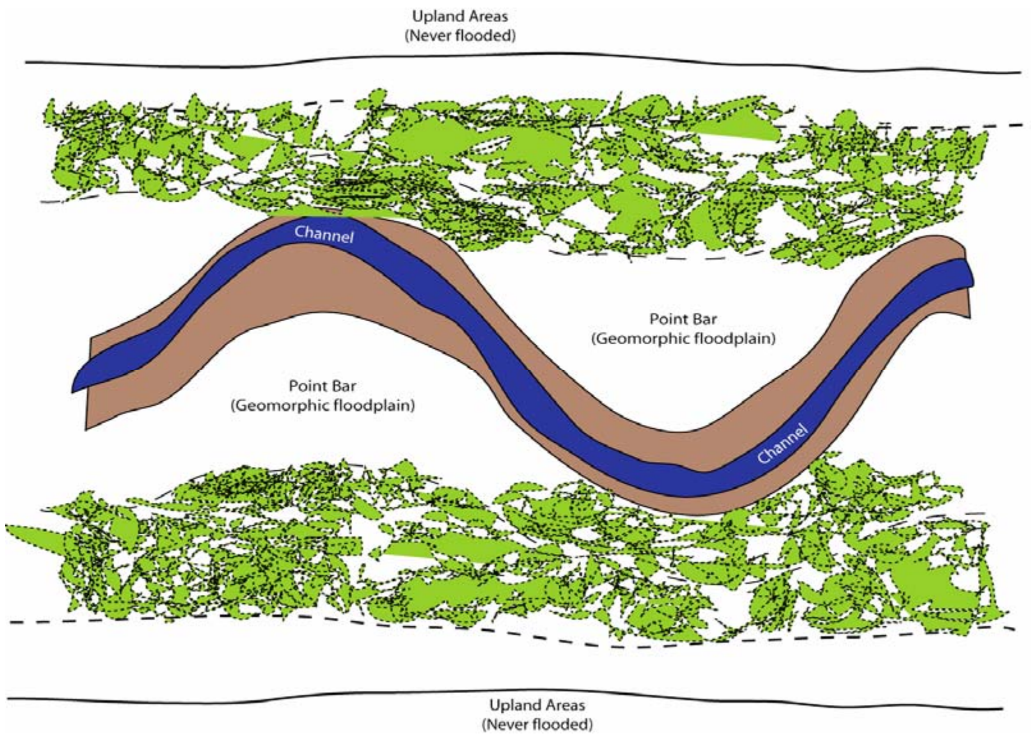


Figure 19 Channel excavation areas.

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 revegeted 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 Ft. Pearce Wash near below River Road. 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 20, 21, 22, 23).

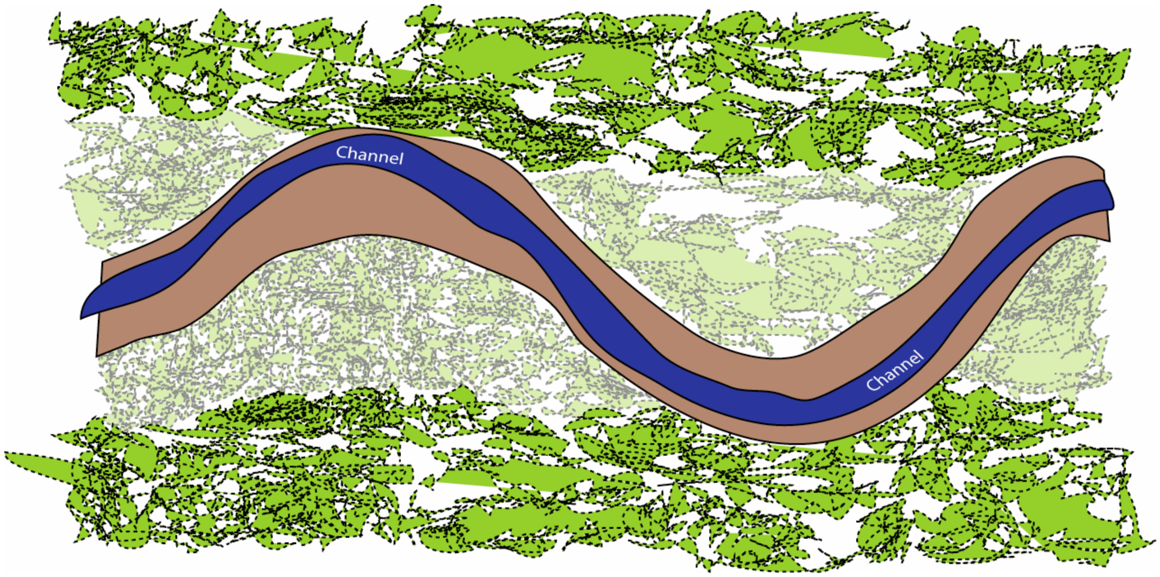


Figure 20 Exotic species removal: Stage I.

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.

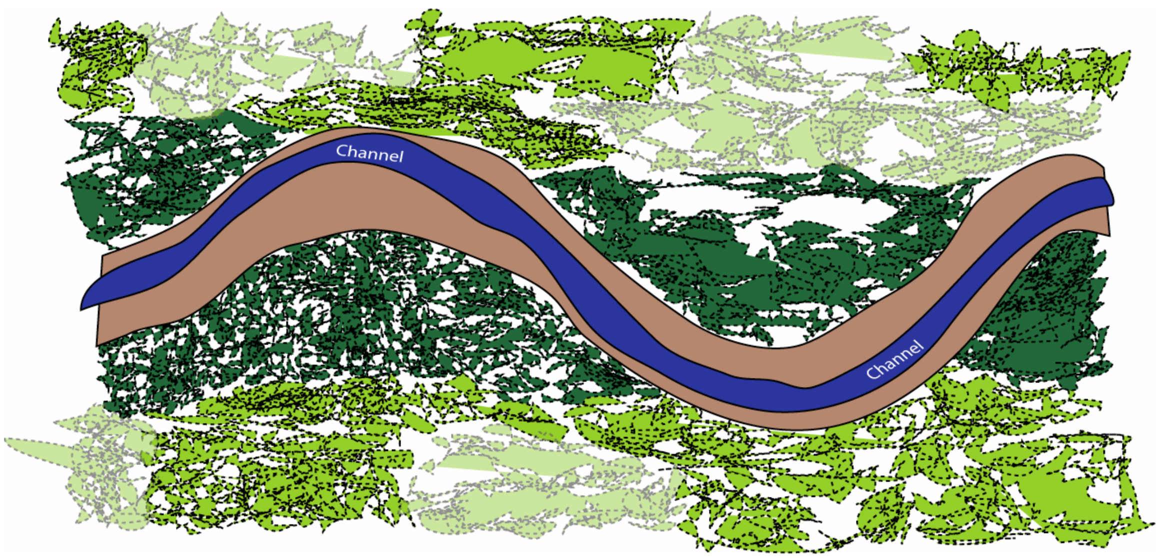


Figure 21 Exotic species removal: Stage II.

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.

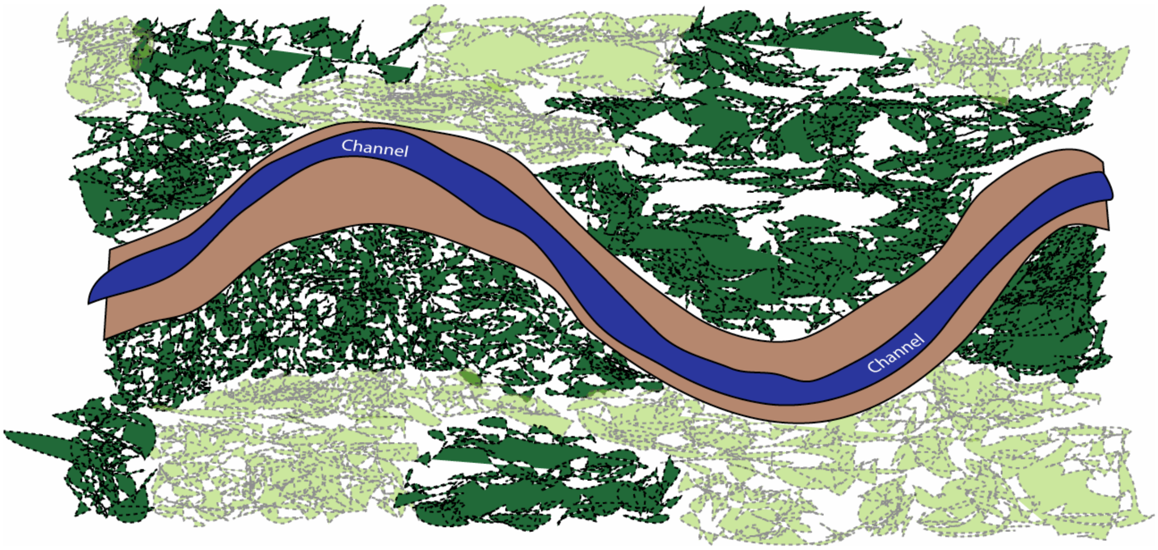


Figure 22 Exotic species removal: Stage III.

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.

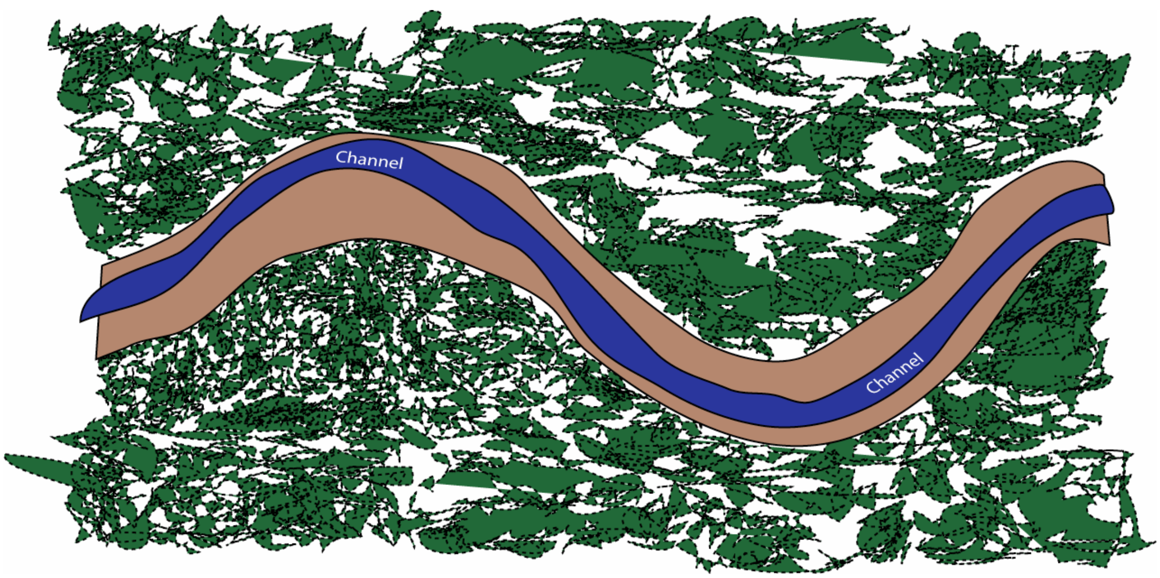


Figure 23 Exotic species removal: Stage IV.

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 24). 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. These conditions appear to be most common along Fort Pearce Wash in Reach 3 below River Road.

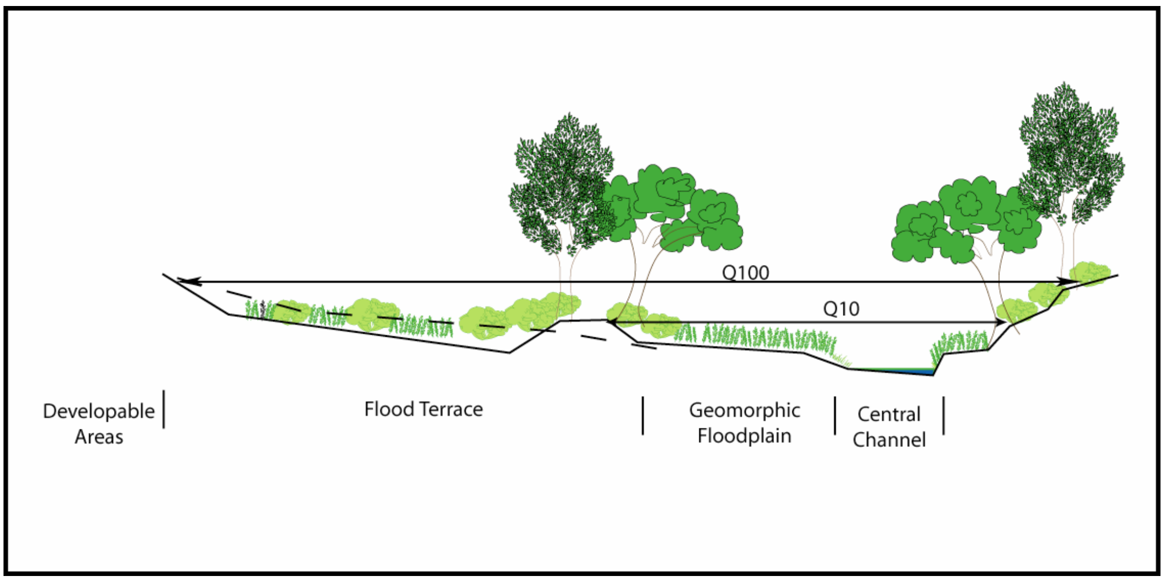


Figure 24 Overbank flow separation

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. This condition is common along Reach 3.

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 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 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 25). 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.

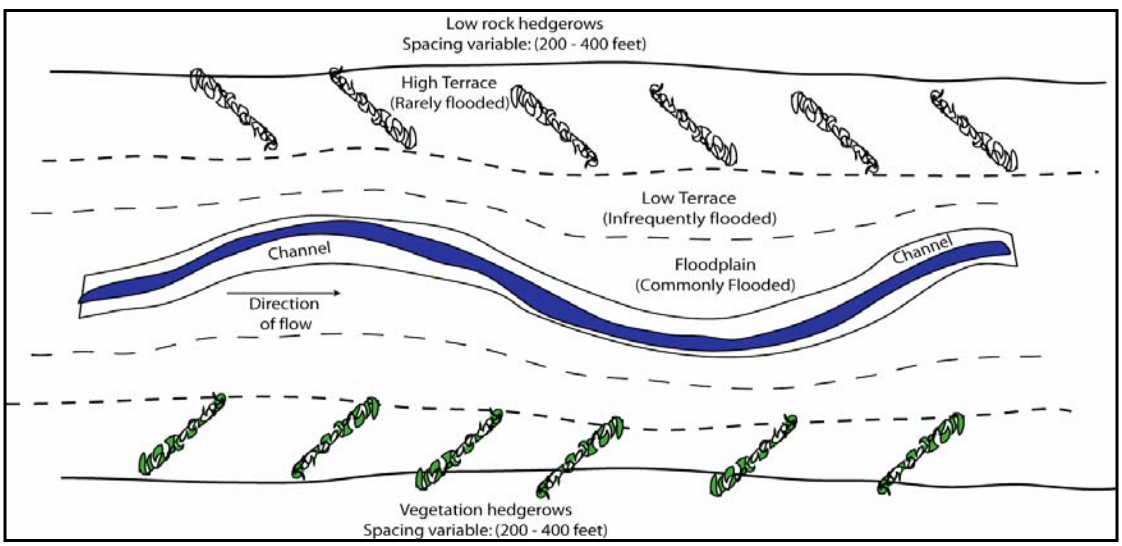


Figure 25 Terrace stabilization strategies

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 Fort Pearce Wash 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 dimension and pattern should also be considered to reduce hydraulic forces against the bank.

Structural stabilization can be installed within the Erosion Hazard Boundary to meet specific objectives. However, the structures should be installed consistent with the channel cross-section template (Figure 26).

- **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.

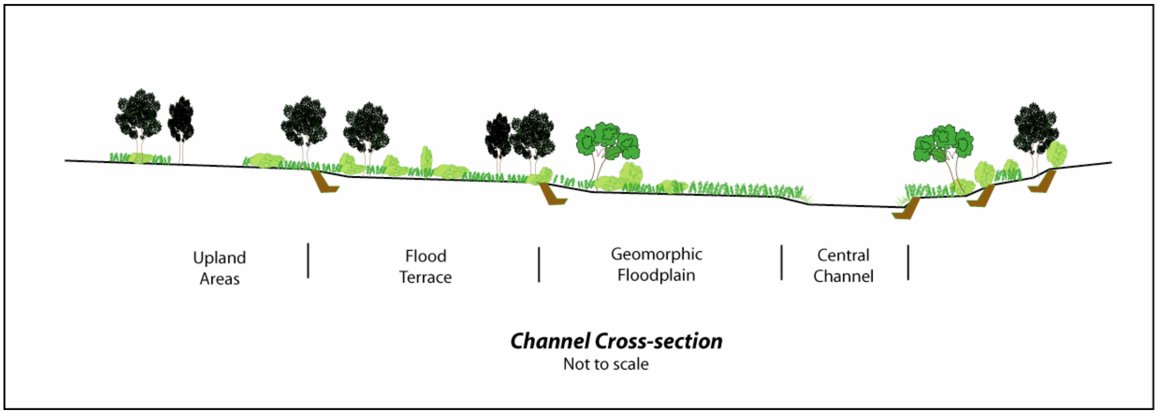


Figure 26 Bank stabilization strategies

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

Fort Pearce Wash is naturally an ephemeral stream with flows occurring only in response to storm events. However, small discharges from industrial, domestic, or agricultural sources are 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.

Nuisance Flows

If flows are large enough to increase soil moistures and timed to the growing season, they can support a native riparian plant community that will increase stream stability. Agricultural returns often meet these criteria. However, if flows are insufficient to maintain sufficient soil moisture levels, they may simply encourage salt cedar thickets that increase instability the channel. Small, inconsistent flows generated by industrial and domestic sources often meet these criteria.

Reaches 1 & 2 don’t currently have sufficient flows to maintain a healthy, stable riparian community. Industrial and other minor discharges should not be allowed to flow through the channel as they will only encourage stands of tamarisk to develop. A current exception is the ponded flows located immediately above River Road Bridge. Here the water is too permanent and deep to support dense salt cedar and instead provides valuable habitat and aesthetics. In the drier reaches (1 & 2), locally generated nuisance flows should be utilized in the flood terrace areas in plantings or constructed wetlands (see stormwater) and minimized in the channel proper unless the flows are in sufficient quantity to support native vegetation.

Reach 3 receives sufficient agricultural return flows to support a native riparian community of willow, cottonwood, quailbush and mesquite. Additional nuisance flows in this reach should be encouraged

Stormwater

Stormwater is collected in developed areas and conveyed to Ft. Pearce wash at designated points. These flows are unpredictable and often large. 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 stormwater 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 this water at this time but as the area evolves to urban, flow timing will be altered.

Long-term Riparian Corridor 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 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 125 foot wide central channel and adjacent geomorphic floodplain by cutting all stems with a diameter at breast height (DBH) greater than 2 inches (Figure 27). The vegetation should not be removed mechanically to minimize damage to the other stabilizing native species. Large woody stems should be removed manually with chainsaws and can be implemented by volunteer labor.

Local aggradation and incision should be monitored periodically and maintenance performed to maintain channel capacity especially in the active mining reaches. This may include excavation or other mechanical treatments. See the Fort Pearce Mining Plan for additional guidance. Vegetation should be replaced if impacted by the maintenance.

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.

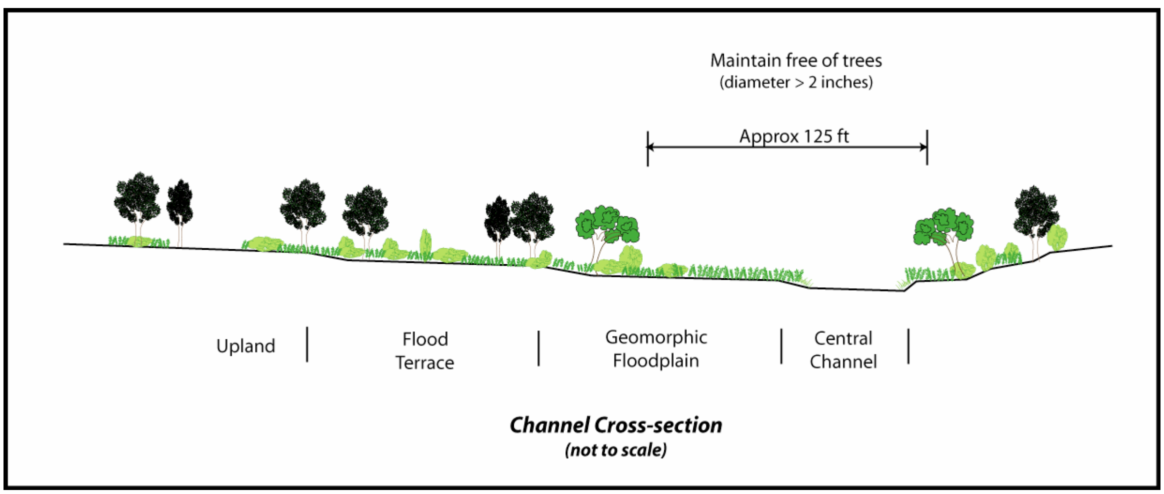


Figure 27 Channel maintenance

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.

SECTION 5: SPECIFIC REACH RECOMMENDATIONS

This section describes areas of concern and provides specific recommendations for each project reach.

Reach 1

This reach is largely undeveloped and in a natural condition (Figure 28). The stream channel is well defined and stable with relatively minor historic lateral migration (see Fort Pearce Wash Stream Stability Study). As the reach is developed, alterations to the channel should be consistent with the recommendations in the Fort Pearce Wash Master Plan, Stream Stability Study, and Mining Plan. Changes in alignment should reflect the cross-section and meander pattern templates presented in this Master Plan.

Reach 2

This reach is currently dominated by active sand and gravel mining operations (Figures 29 & 30). As the properties surrounding Fort Pearce Wash are developed, reclamation efforts should be consistent with recommendations presented in the Fort Pearce Wash Master Plan, Stream Stability Study, and Mining Plan.

There are two specific areas of concern within the reach.

A. In general the existing stream alignment and meander pattern are within the natural, stable ranges. However, a relatively sharp meander upstream of River Road creates the potential for increased instability. If channel alignments are altered during reclamation, the radius of curvature should be increased.

B. Immediately above River Road the riparian corridor narrows primarily due to the naturally narrowing geology. The geology reduces the lateral migration hazard but will increase the potential flood risk and increase velocities during extreme flow events. The impacts of these increased flow velocities should be considered in protection of the bridge and downstream properties.

Reach 3:

Fort Pearce Wash is most constrained in this reach (Figure 31). Properties adjacent to the stream channel are largely developed. The use of golf courses adjacent to the active stream channel is appropriate and it is assumed that the golf course areas lie within the 100-year floodplain providing an outlet for overbank flows.

However, the topography of the golf courses still provide the potential for damage from flooding. Along most of the reach, berms have been installed to separate public areas from Fort Pearce Wash. Golf course areas are generally lower in elevation behind the berms. The berms will protect the areas from some flood events but once overtopped will trap flows away from the river. Either the water will pond in low areas or find a channel to reconnect with the river. Large volumes of sediment will be deposited in the ponded areas as occurred at Sun River during the 2005 Virgin River flood. The relatively smooth golf courses will allow high velocities behind the berms and result in local scour and erosion damage. In order to minimize the potential for flood damage, it is recommended that the areas adjacent to Fort Pearce Wash be recontoured with slopes and vegetation consistent with the Guiding Principles described in this document.

A number of potential problem areas were identified in Reach 3.

C. The narrowing of the riparian corridor at River Road will produce higher flow velocities. Flood and lateral migration protection for the adjacent neighborhood should be evaluated and reengineered if necessary.

D. Dense salt cedar thickets in this relatively wide portion of the corridor are currently being removed. Once that is completed the corridor should be recontoured consistent with the Cross-section Template and revegetated as recommended in the Master Plan. Supplimental irrigation may be necessary to establish plantings in the higher and drier areas away from the channel. It is critical that a native plant community be established or salt cedar and other exotics will simply recolonize the cleared areas.

E. The berms protecting the golf course in this area and downstream should be recontoured to provide a gentle upslope away from the stream channel and geomorphic floodplain as described in the Cross-section Template and Guiding Principles.

F. The extreme narrowness of this section will increase velocities and increase the risk of lateral migration. The banks on the western side of the channel should be recontoured consistent with the Cross-section Template and Guiding Principles. Golf course areas can be incorporated into the recontoured areas without loss of land.

G. The berms protecting the golf course here are similar to “E” and should be recontoured to be consistent with the Cross-section Template and Guiding Principles. If flows can escape into the golf course during extreme events paths should be created to return it to the river to minimize the potential for flooding neighboring homesites.

H. The berms protecting the golf course here are similar to “E” and should be recontoured to be consistent with the Cross-section Template and Guiding Principles.

I. The confluence with the Virgin River will remain a highly dynamic area due to the complex interactions between the two streams. Salt cedar removal and revegetation should be continued here but the channel cross-section template will naturally vary over time. A higher groundwater level may ease revegetation efforts.

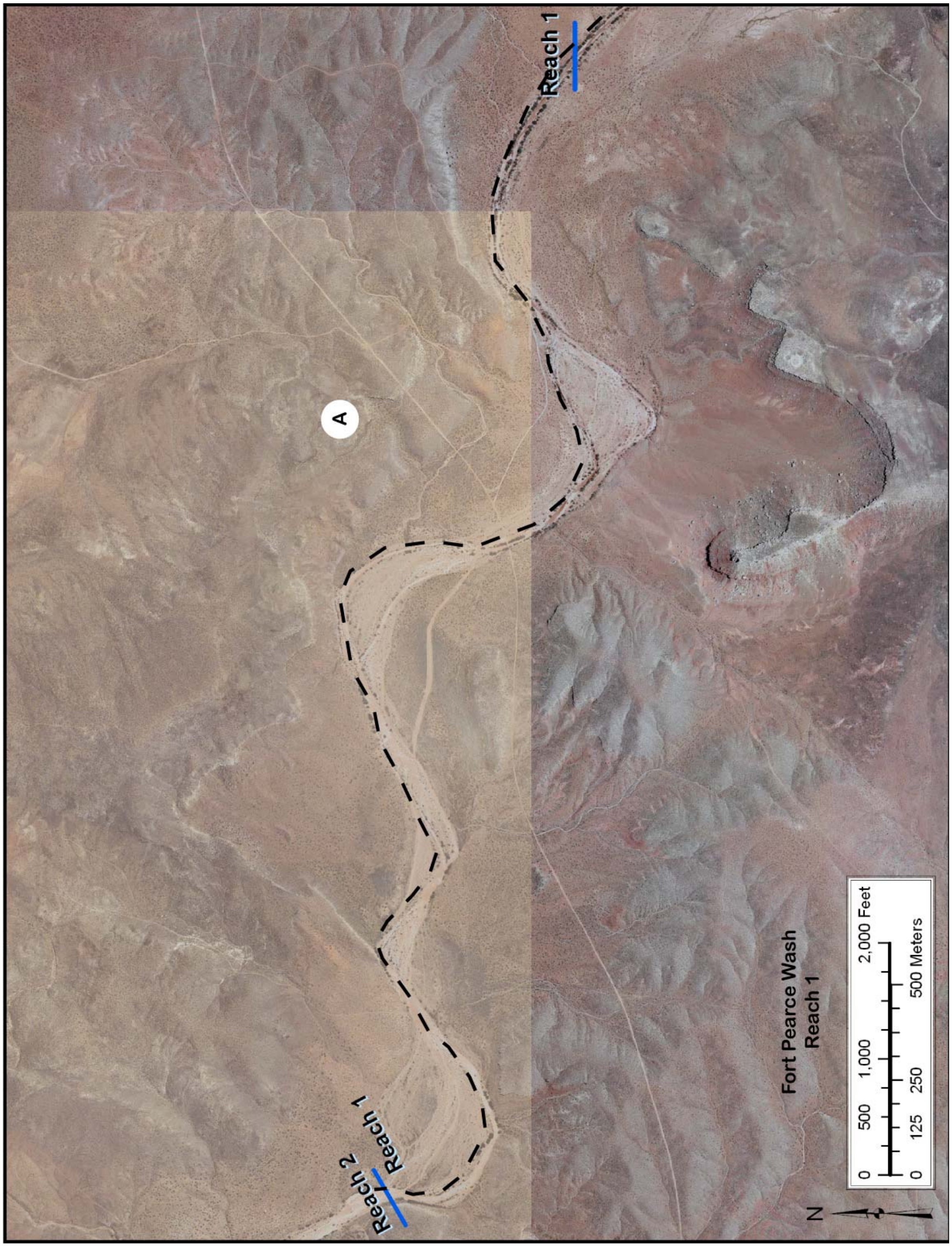


Figure 28 Reach 1 map

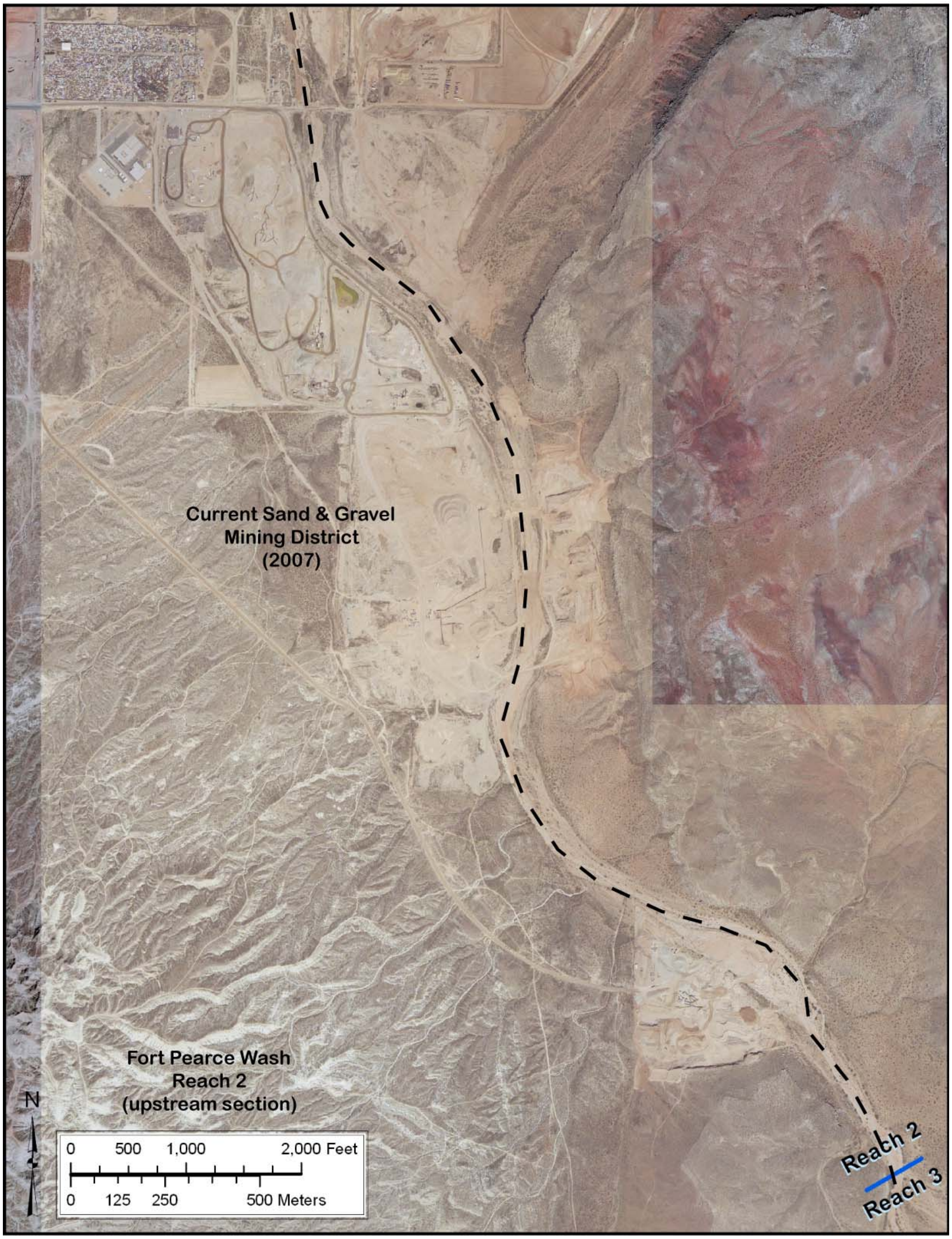


Figure 29 Reach 2 map (upstream section)

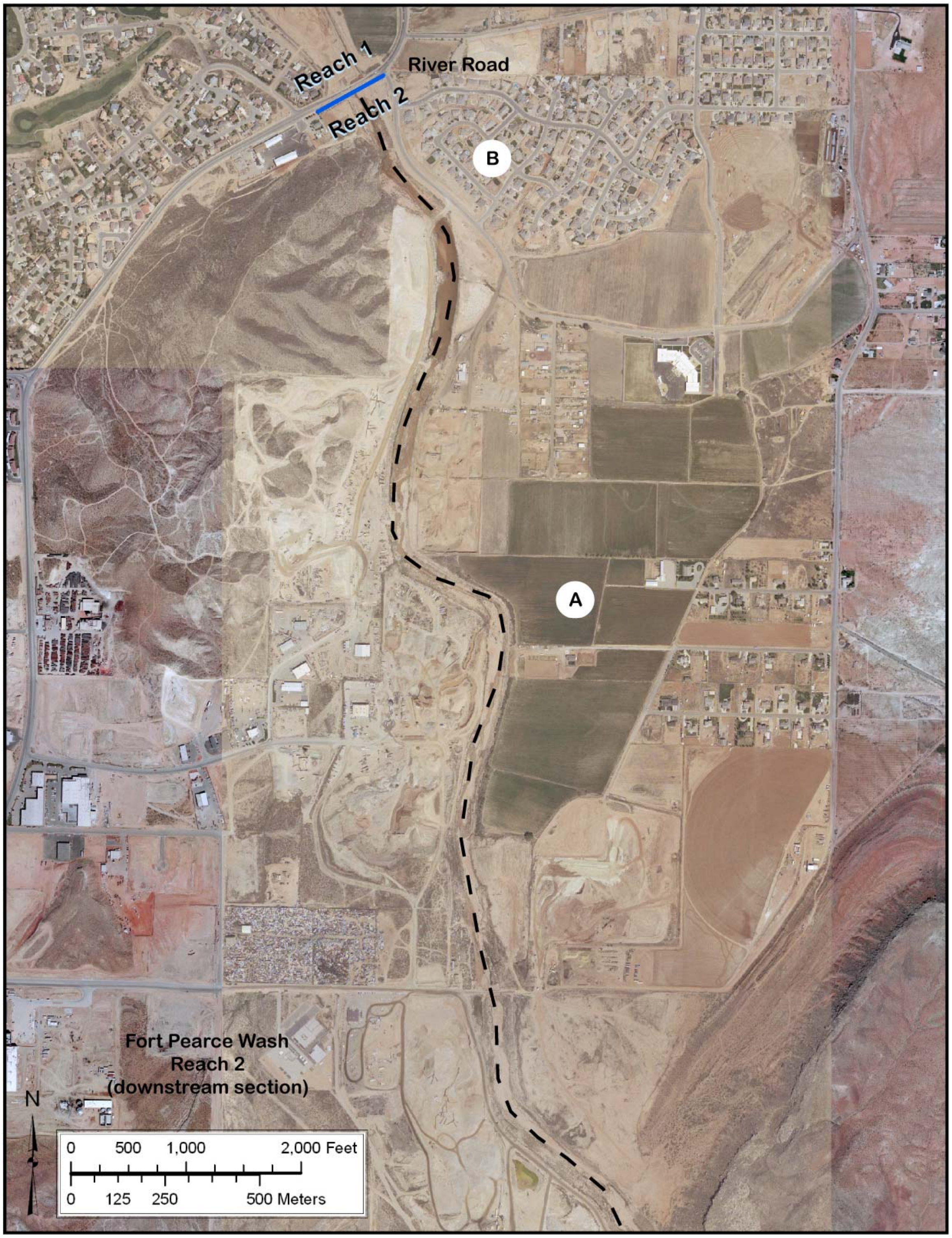


Figure 30 Reach 2 map (downstream section)

Figure 31 Reach 3 map

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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 32).

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.

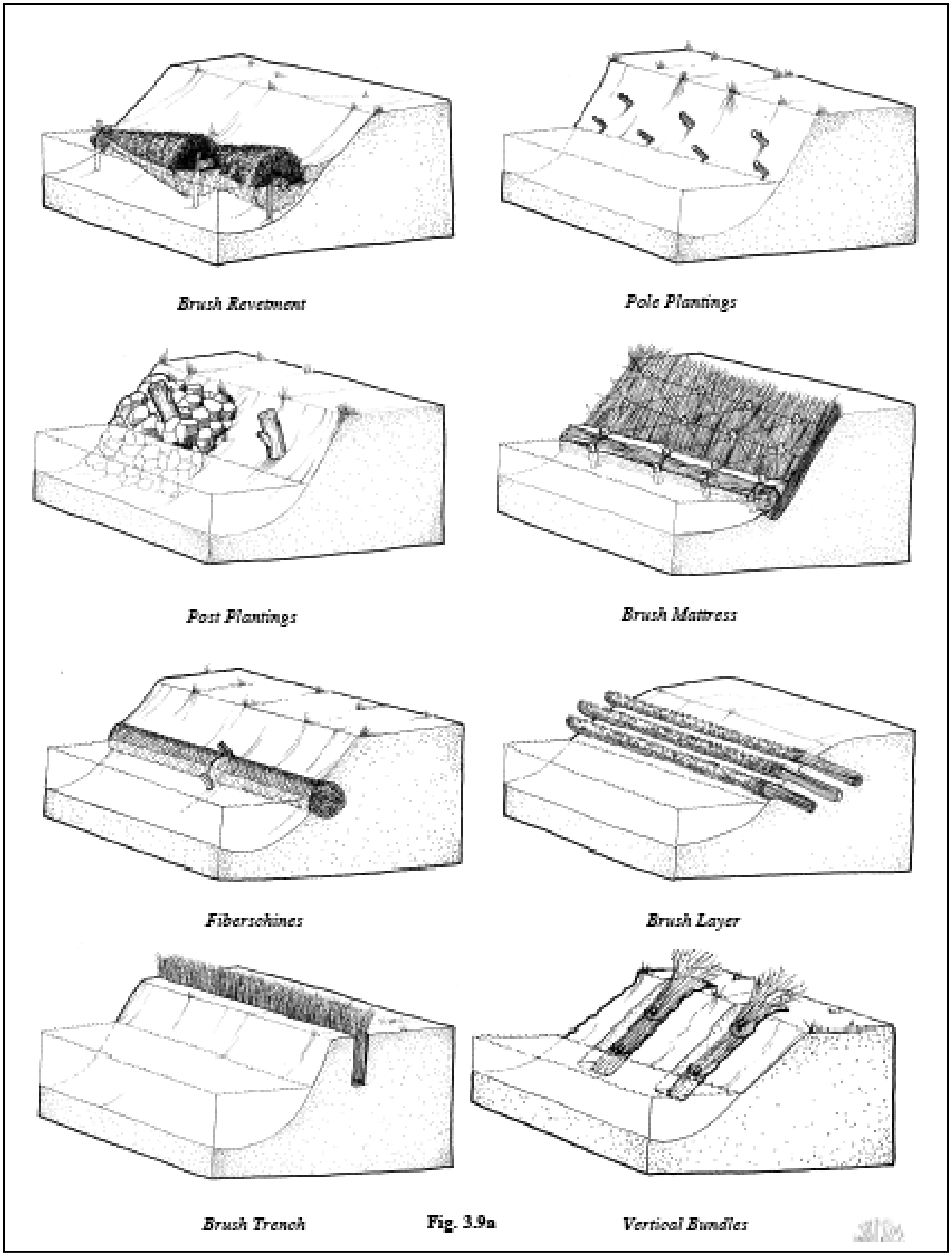

Figure 32 Bioengineering Practices.

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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- Hoag, J.C. and J. Fripp. 2002. Streambank Soil Bioengineering Field Guide for Low Precipitation Areas. USDA-NRCS Aberdeen Plant Materials Center and the USDA-NRCS National Design, Construction and Soil Mechanics Center, Aberdeen, ID. December, 2002. 64p. (6.65 MB) (ID# 3883)

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- Ogle, D., J.C. Hoag, and J. Scianna. 2000. Technical Note 32: Users guide to description, propagation and establishment of native shrubs and trees for Riparian Areas in the Intermountain West. USDA-NRCS, Boise, ID and Bozeman, MT. ID-TN32, Feb. 2000. 22p. (573 KB) (ID# 2251)

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 Ft. Pearce Wash Stability Study. . 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 33).

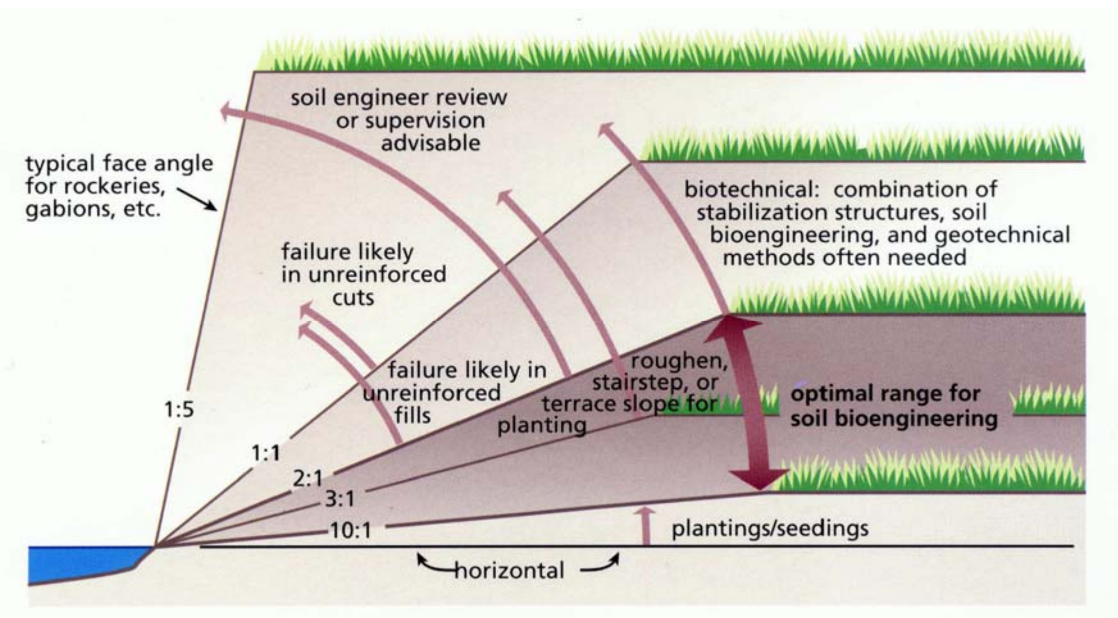


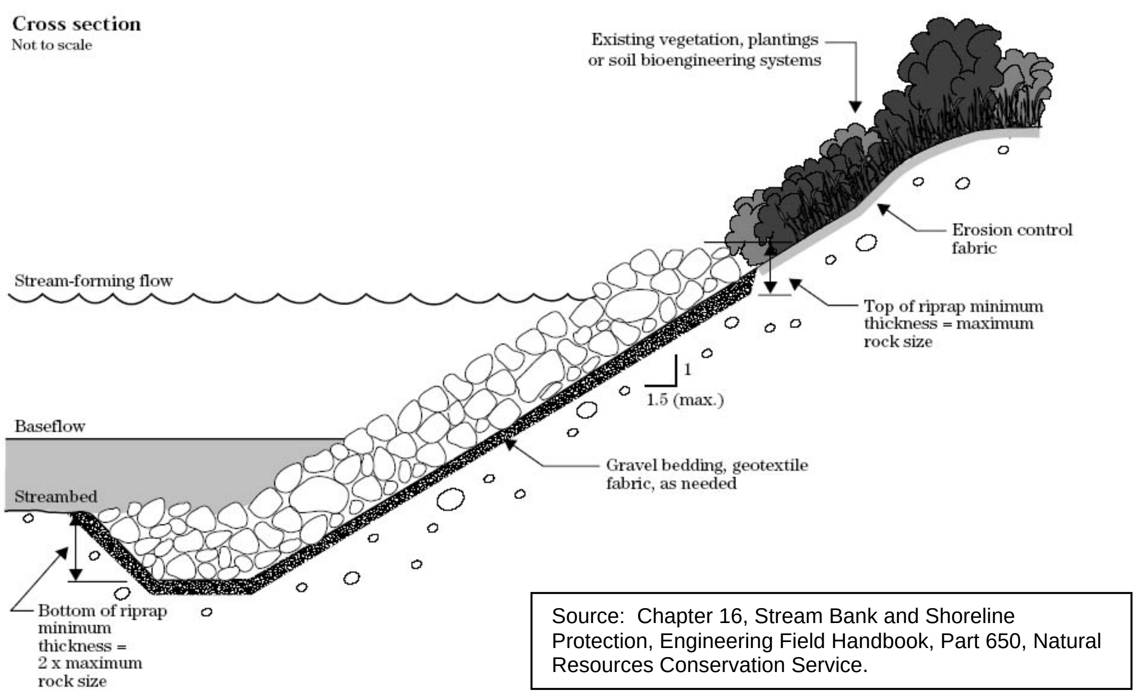
Figure 33 Stream bank slope stability

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 34). 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 34 Toe Rock.

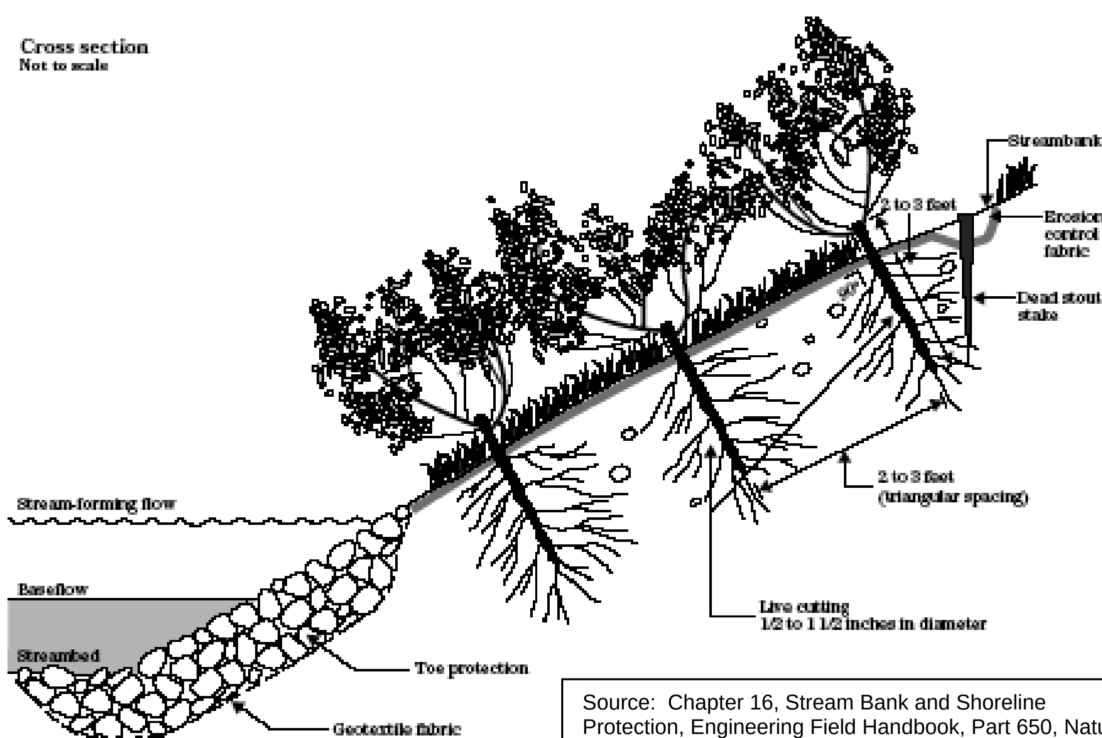
This structural practice is generally installed along the outside of a meander bend to reduce the risk of lateral erosion.

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 35).

Figure 16–4 Live stake details



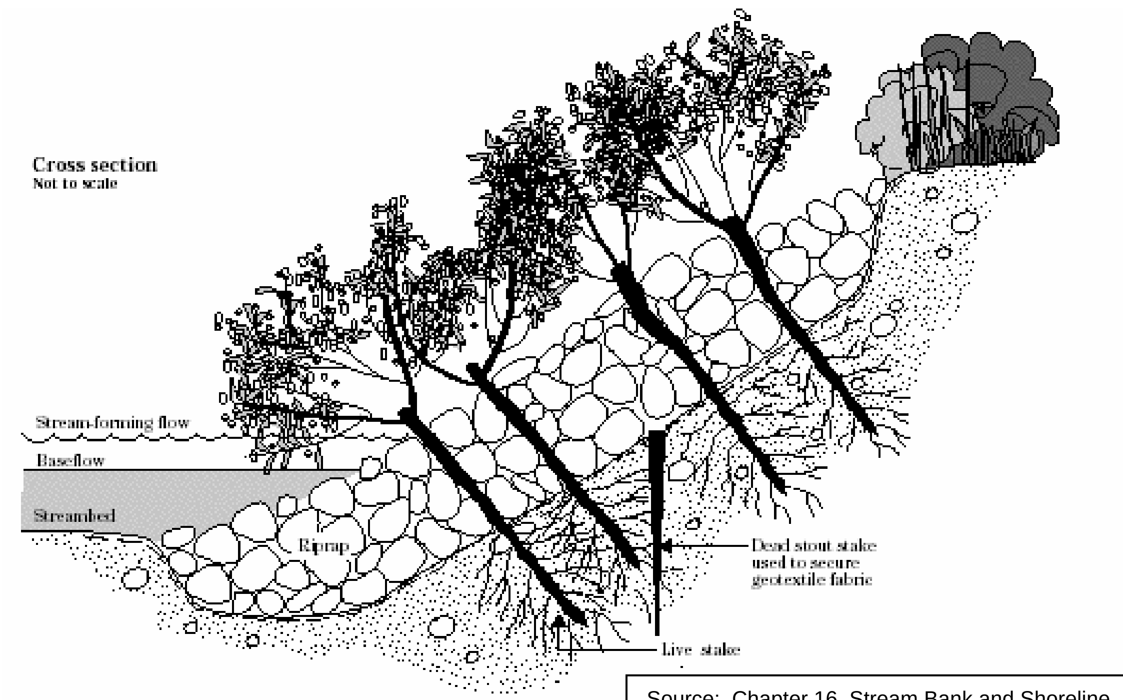
Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 35 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 36). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.



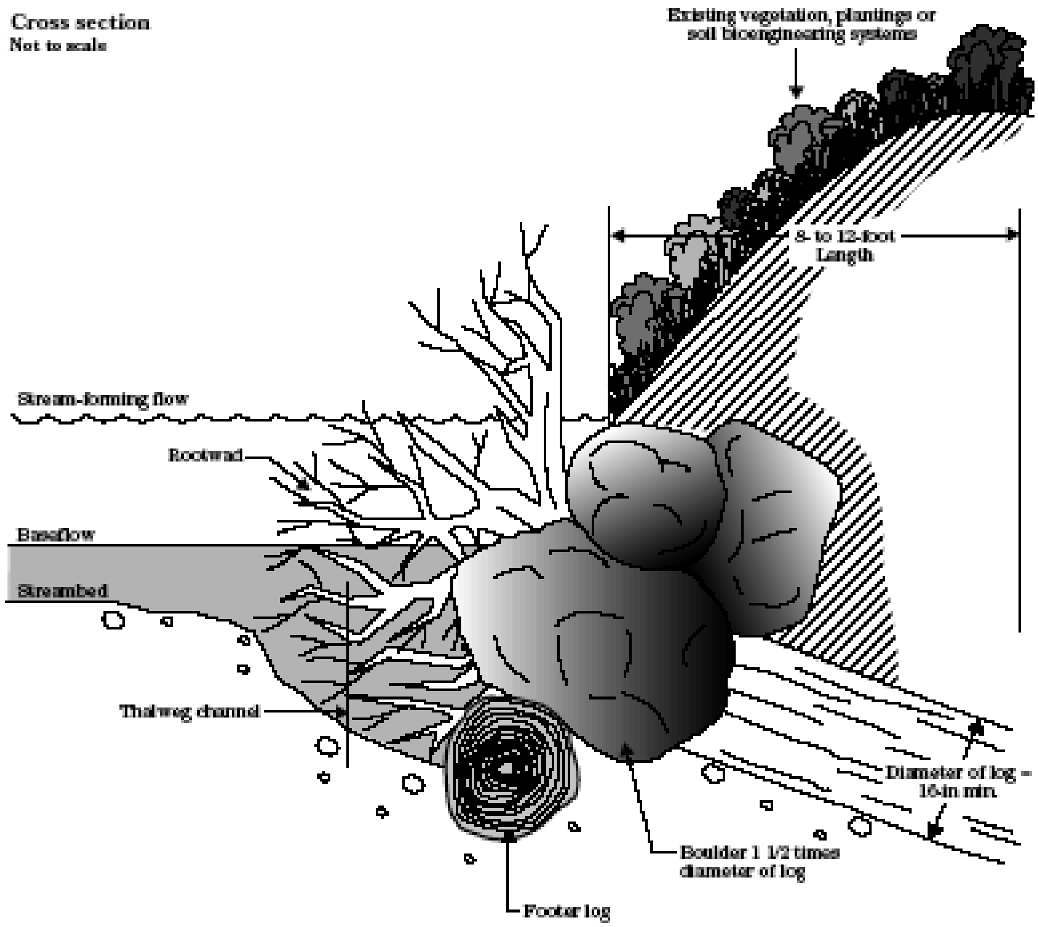
Source: Chapter 16, Stream Bank and Shoreline Protection, Engineering Field Handbook, Part 650, Natural Resources Conservation Service.

Figure 36 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 37). 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 37 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 38). 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.

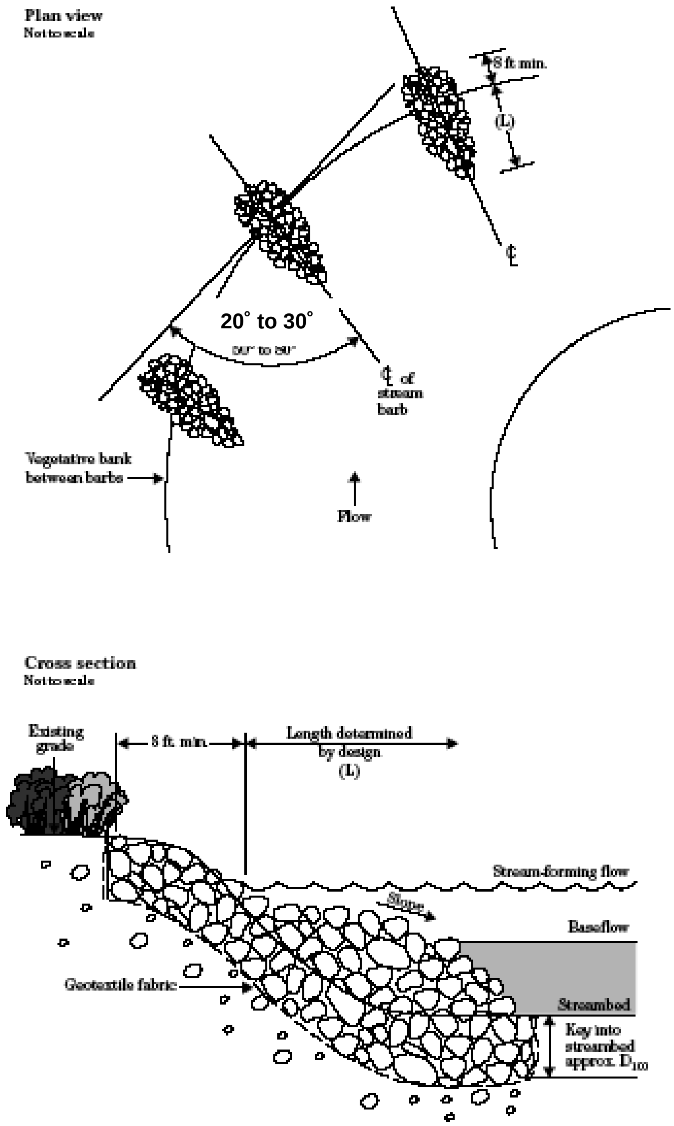


Figure 38 Stream barbs/rock vanes.

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