FINAL REPORT

Feasibility Evaluation of Restoration Options to Improve Habitat for Young Colorado Pikeminnow on the San Juan River

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1. INTRODUCTION

1.1 Purpose and Need

One component of the San Juan River Recovery Implementation Program's (SJRIP) efforts to recover populations of the federally endangered Colorado pikeminnow (*Ptychocheilus lucius*) in the San Juan River is the stocking of hatchery-raised young-of-the-year (YOY) Colorado pikeminnow. The SJRIP's Augmentation Plan for Colorado pikeminnow calls for the stocking of 200,000 to 300,000 YOY pikeminnow between 2002 and 2009 (Ryden 2003). The goal of these stockings is to develop an adult population of more than 800 individuals. Studies on the San Juan River and throughout the Colorado River Basin have shown that YOY Colorado pikeminnow prefer low-velocity habitats, such as secondary channels and backwaters (Tyus and Haines 1991, Propst and Hobbes 1999, Chart and Lentsch 2000, Trammel and Archer 2000). When the initial results of a YOY Colorado pikeminnow sampling program indicated that the retention of fish stocked in 2002 near Farmington and Shiprock, New Mexico, appeared lower than expected, a lack of good backwater habitats was presented as a potential explanation for the poor retention (Golden et al. 2004). Physical channel monitoring has documented a decline in the quantity and quality of low-velocity backwater habitats since the mid-1990s (Bliesner and Lamarra 2000, Golden et al. 2004). Since backwater areas appear to be crucial in the survival of YOY Colorado pikeminnow, the in-filling and loss of these backwater areas may be contributing to low retention of stocked fish.

Since the 1930s, the San Juan River has generally been narrowing and converting to a more single-threaded, more stable, and less complex channel. With the introduction of non-native riparian vegetation species in the 1930s and 1960s, many of the river's open gravel bars have become densely vegetated islands or floodplain areas. Many historical secondary channels that previously supported backwaters are now disconnected from the active river. Additional channel simplification, vegetation encroachment, and backwater habitat loss occurred during the recent drought period. Because of the existing vegetated, "armored" condition of many of the river's bars and islands, physical habitat manipulation and channel restoration efforts may need to be implemented, in conjunction with the established Navajo Dam flow-release recommendations, in order to restore backwater habitats and overall channel dynamics.

As a first step toward implementing physical habitat improvements, this report provides a list of habitat/channel restoration options, discusses the feasibility of various options, and provides an assessment of the relative costs and benefits of the different options as well as appropriate locations for their implementation.

1.2 Study Area

This project focuses on the stretch of the San Juan River between Hogback Diversion (River Mile [RM] 159) and the Highway 371 bridge in Farmington (RM 180), which is within the area defined as geomorphic Reach 6 (Bliesner and Lamarra 2000) (Figure 1.2.1). This section of river is the upstream-most area designated as critical habitat for the Colorado pikeminnow. The SJRIP is interested in improving backwater habitat within this portion of the river because it contains abundant clean cobble substrate and numerous cobble bars that would potentially provide suitable spawning habitat (Holden and Masslich 1997). Additionally, the adult Colorado pikeminnow Recovery Goals (USFWS 2002) were based on the assumption that adult Colorado pikeminnow could be established in the area above Hogback Diversion and exploit the abundant native fish food base. Because the Recovery Goals rely on establishing Colorado pikeminnow above Hogback Diversion, the SJRIP is using this reach as one of the areas where YOY Colorado pikeminnow are stocked. Improved juvenile habitat in this reach could increase retention of fish in the upper river, allowing them to take advantage of the available food resources and spawning habitat.

Another reason for the focus on the upper river is the recent completion of a selective fishway at the Public Service Company of New Mexico (PNM) Weir (RM 166.7), which is designed to reduce the abundance of non-native fish and associated predation/competition pressure in the upper half of the Study Area. In addition, the hydrologic and sediment regimes within Reach 6 are less influenced by arroyo inputs and summer/fall storm events than the downstream river reaches, which means that habitat conditions tend to be more spatially and temporally stable (Bliesner and Lamarra 2000). This stability would likely improve the longevity of any constructed or restored habitat features.

More detailed descriptions of historical and current channel and habitat conditions within the Study Area are provided below.

1.3 Goals and Objectives

The goal of the proposed study is to provide the restoration concepts and feasibility information needed for the Program to ultimately select and implement effective measures to restore backwater habitats and improve retention of young Colorado pikeminnow in the upper San Juan River. Specific study objectives include the following:

1. Determine whether anthropogenic influences, such as river channelization, water diversion structures, and irrigation return flows, have substantial impacts on backwater habitat conditions.

2. Describe the role of non-native vegetation in the processes, mechanisms, and temporal dynamics of backwater habitat creation, maintenance, and in-filling.

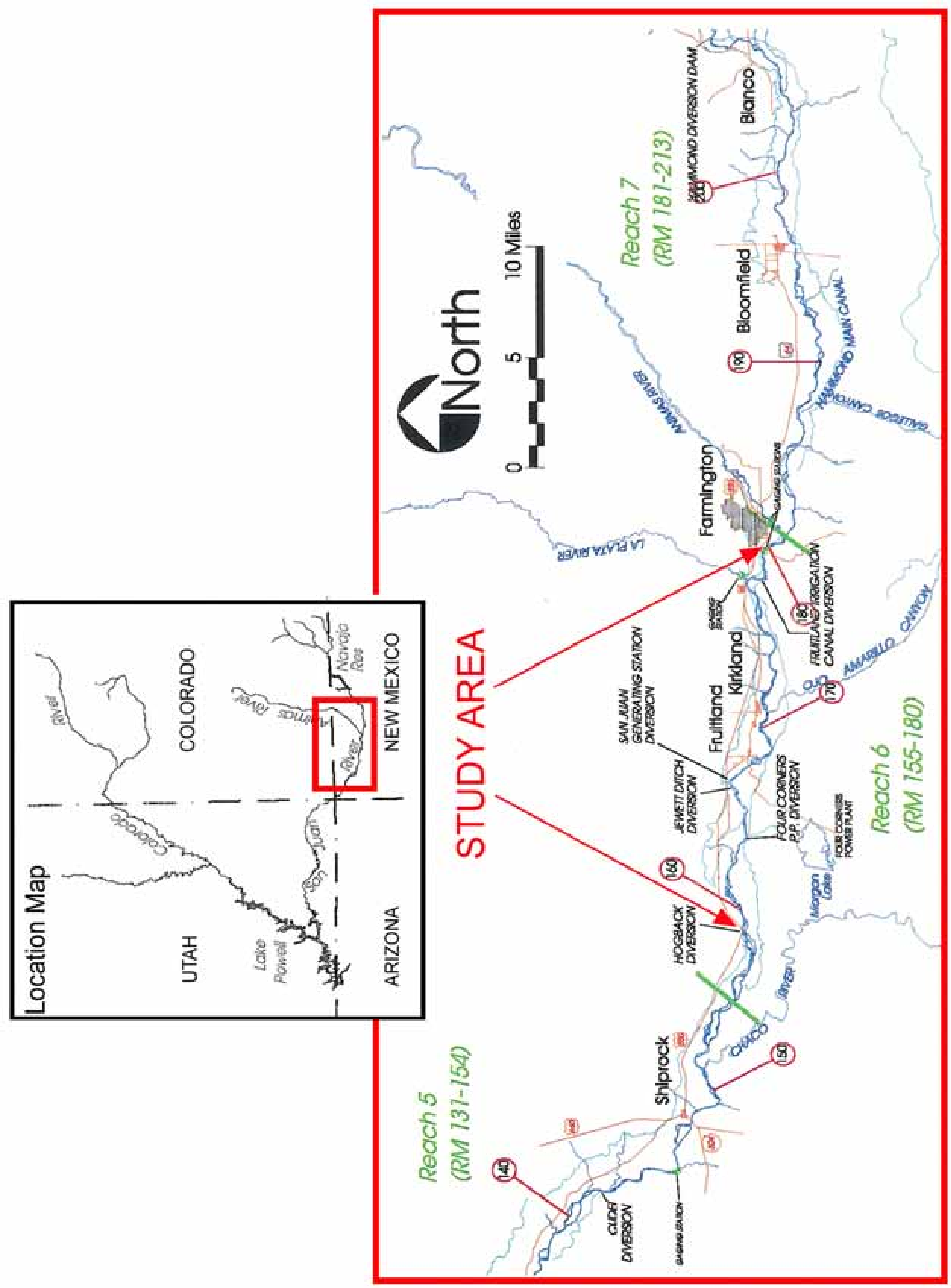

Figure 1.2.1. Location map.

3. Identify specific channel/habitat restoration strategies and appropriate locations for the different strategies.

4. Estimate the costs, benefits, and relative feasibility of different restoration strategies, and rank the various options based on these estimates.

5. Recommend and prioritize specific pilot restoration projects and adaptive management/monitoring strategies.

2. BACKGROUND

2.1 General Description of the Study Area

Geomorphology

At the upstream end of the Study Area, in Farmington, the San Juan River drains an area of 7,240 square miles. Between Farmington and Shiprock, the drainage area increases to 12,900 square miles. Bankfull discharge is approximately 8,000 cfs, and mean bankfull channel width is generally in the range of 200 to 300 feet. Average valley width is about 6,500 feet, and average sinuosity is 1.19 (Bliesner and Lamarra 2000). Channel slope averages about 0.2% in the Study Area (Figure 2.1.1).

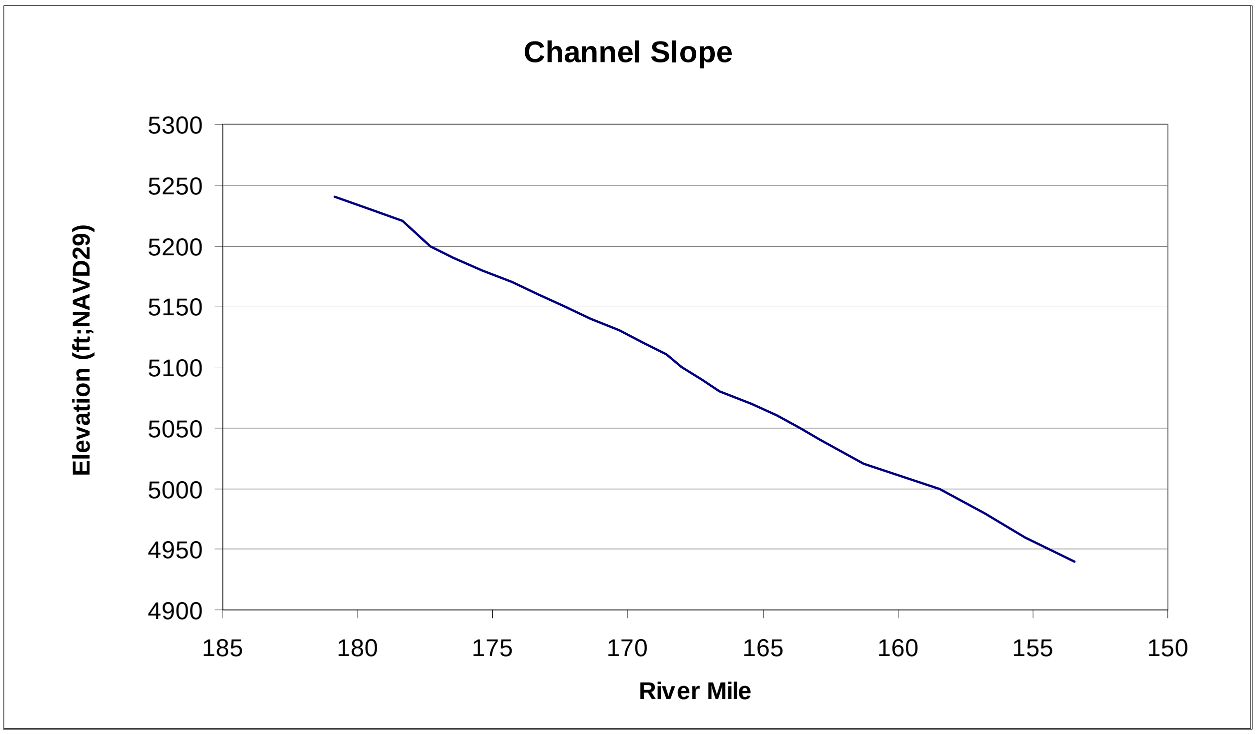

Figure 2.1.1. Channel gradient within the Study Area, as measured from USGS 7.5' topographic maps.

Relative to its bankfull discharge, this reach of the San Juan is somewhat steep and would be expected to exhibit a braided plan form based on empirical plots separating meandering from braided channel types (Figure 2.1.2; Leopold et al. 1964). Within the Study Area, the San Juan River is not entirely braided, but instead alternates between relatively straight single-thread

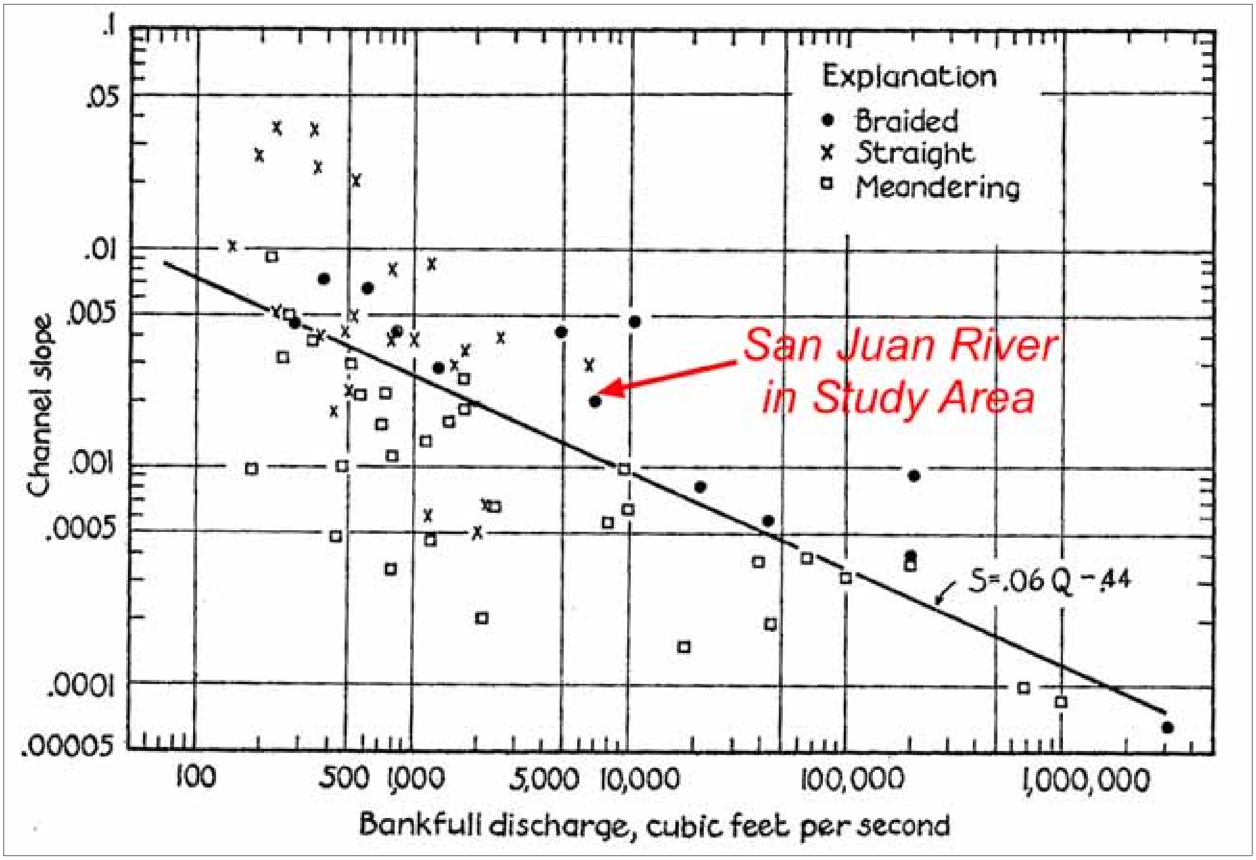

Figure 2.1.2. Plotting position of the San Juan River discharge and slope relative to the line separating meandering and braided channels. Plot taken from Leopold et al. 1964, Figure 7-39B.

channel segments and more complex segments with secondary channels, bars, and islands. Although valley width is typically wide in this reach, the channel occasionally contacts bedrock outcrops which constrain lateral movement along one bank. Channel substrate is dominated by cobble and gravel, and clean cobble bars are abundant in this reach (Bliesner and Lamarra 2000).

The Animas River, a large perennial tributary with a drainage area of 1,360 square miles, enters the San Juan River just upstream of the Study Area. The La Plata River, a much smaller tributary, enters the San Juan River at RM 177.7. Ojo Amarillo, which was naturally an ephemeral tributary but now flows perennially due to irrigation return flows, enters the San Juan River from the south at RM 170.8. Several other ephemeral arroyos also enter the San Juan River within the Study Area.

Land Use and Riparian Vegetation

Riparian vegetation on the San Juan River was mapped in 1994 based on November 1994 videography. Vegetation polygons were ground-truthed in the field and classified based on vegetation type and percent cover (1-25%, 26-75%, 76-100%). The main vegetation categories used were cottonwood (*Populus fremonti*), Russian olive (*Elaeagnus angustifolia*), tamarisk (*Tamarix* sp.), willow (predominantly *Salix exigua*), and wetland herbaceous. Within Reach 6, Russian olive is dominant, generally comprising more than 35% of the riparian vegetation. Tamarisk comprises about 15% of the vegetation between RM 165-180, but becomes more prevalent within the lower part of Reach 6, comprising between 20-40% of the vegetation. Throughout Reach 6, willows are a fairly minor component of the vegetation community, comprising only about 5% of the vegetation. Cottonwoods occupy between about 10-20% of the vegetation in Reach 6, and are at their greatest density between RM 155-170 (Bliesner and Lamarra 2000). Based on available historical information and air photos, tamarisk became well established within the San Juan River basin between 1930 and 1950. Russian olive became established between 1960 and 1988 (Bliesner and Lamarra 2000).

No comprehensive riparian vegetation mapping effort has been undertaken on the San Juan River since 1994. Therefore, quantitative data on recent trends are not available. However, several general vegetation patterns were observed during field visits to the Study Area in November 2004 and August 2005. Dense stands of Russian olive are the most dominant vegetation type present on undisturbed streambanks and floodplain/terrace areas. Mature cottonwood trees are occasionally mixed with the Russian olive in these areas, but rarely dominate the distribution. Dense Russian olive stands are also typically present within the central portions of islands in the Study Area. Along channel margins and around the outer fringe of islands, between the Russian olive stands and the wetted channel, vegetation is dominated by willows or willows mixed with young tamarisk. Relatively sparse patches of both young and older tamarisk are present on some otherwise bare cobble bars. Mature tamarisk are also occasionally present in the Russian olive stands on central portions of islands.

Agriculture (most commonly irrigated alfalfa and pasture) and associated low-density rural development (farmhouses) is the dominant land use within the Study Area. In a few locations (RM 178.9, RM 174.3, RM 173.1, RM 171.3, RM 167), higher-density residential development is present close to the river. Some industrial/commercial development is present on the north side of the river in Farmington, primarily between RM 179 and RM 180. Ponds associated with a gravel operation are present on the south side of the river near RM 179.

Land ownership information for the Study Area was obtained from San Juan County property identification maps (San Juan County 2005). Downstream from the La Plata River confluence, the south side of the river is entirely Navajo Nation land. The City of Farmington owns a 40-acre parcel on the south side of the river between RM 179.4 and RM 179.7, and a smaller parcel on the south side between RM 177.8 and RM 178; otherwise, the south side of the river upstream of the La Plata confluence is privately owned. The north side of the river within the Study Area is predominantly in private ownership, with some exceptions. A Farmington City Park is located between RM 177.8 and RM 178.5. San Juan County owns the land at the Lower Valley Lion's Club boat landing, between RM 172.6 and RM 173.1. The State of New Mexico owns the land on the north side of the river just upstream of the Lion's Club, between RM 173.1 and RM 174.1. Several parcels on the north side of the river, near RM 165, RM 162.2, RM 161.5, and RM 159.7, are listed as "Federal" in the County property identification maps.

Although some specific land parcels have been protected with dikes and/or bank rip-rap, these areas are not extensive or continuous within the Study Area. To date, residential and commercial development has for the most part avoided encroaching into the most flood-prone areas along the San Juan River in the Study Area.

Three significant diversion structures are present within the Study Area: the Arizona Public Service Company (APS) Weir at RM 163.7 (also known as the Four Corners Power Plant Diversion); the PNM Weir at RM 166.7 (also known as the San Juan Generating Station Diversion); and the Fruitland Diversion at RM 178.4. Two additional minor diversions, the Farmer's Mutual Ditch and the Jewett Valley Ditch, withdraw water from the San Juan River at RM 179.7 and RM 166.2, respectively.

Numerous irrigation return flows enter the San Juan River within the Study Area. In many cases, return flows drain into natural ephemeral arroyo channels that convey the flows to the river. Abandoned historical overbank channels also commonly collect and deliver irrigation return flows. In some locations, arroyos conveying return flows have been straightened and channelized through agricultural fields prior to entering the river.

Hydrology and Sediment Load

Like many western rivers, the San Juan River has a hydrologic regime dominated by a springtime snowmelt runoff peak and lower base flows during the winter, summer, and fall. At the Farmington U.S. Geological Survey (USGS) gage (gage #09365000), average monthly flows are greatest in June, and the annual peak flow most commonly occurs in June. However, flows on the San Juan River can also be strongly affected by high-intensity summer and fall rainstorm events that create short-duration flow spikes and contribute high sediment loads. Although springtime snowmelt contributes the greatest overall volume of water to the San Juan River, about 30% of the time the highest annual peak flow occurs in conjunction with a summer or fall storm event. The frequency and overall influence of storm events is greatest in the lower reaches of the San Juan River below Four Corners, and is less significant in the upper reaches near Farmington (Bliesner and Lamarra 2000).

Navajo Dam, located upstream of our Study Area at RM 224, began storing water and regulating flows on the San Juan River in 1962 (Figure 2.1.3). The most significant effects of the dam were a substantial reduction in the magnitude of springtime peak flows, an increase in summer and winter base flows, and a shift in the timing of the springtime peak to earlier in the year (Bliesner

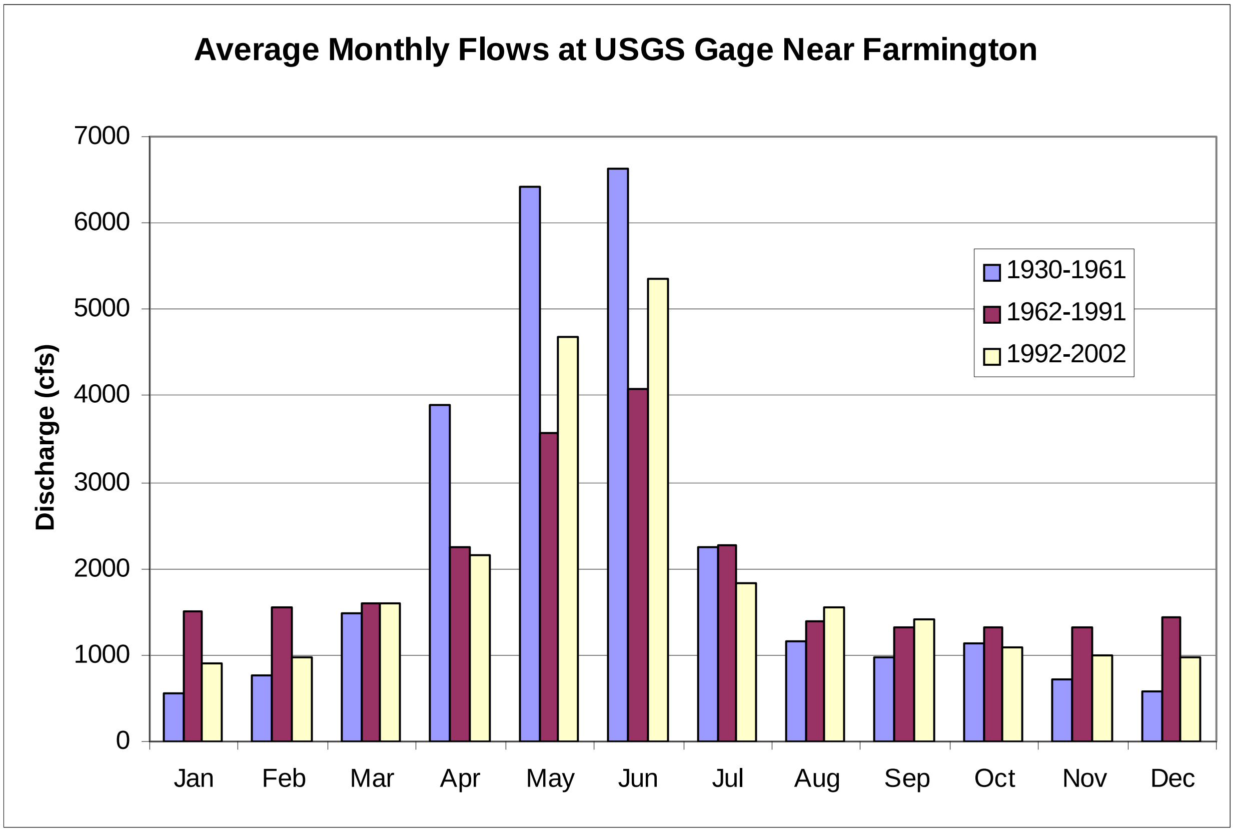

Figure 2.1.3. Average monthly flows at USGS gage near Farmington for pre-dam (1930-1961), post-dam (1962-1991), and research (1991-2002) periods.

and Lamarra 2000). Starting in 1992, the SJRIP began coordinating with the Bureau of Reclamation (BOR) to re-regulate Navajo Dam releases to more closely mimic a natural hydrograph pattern. These efforts have moderated some of the effects of Navajo Dam by increasing May and June peak flows and reducing October through February base flows relative to the 1962-1991 post-dam period (Figure 2.1.3). Specific ecologically based flow recommendations and reservoir operating rules have been developed for the river, and coordination between the SJRIP and Navajo Dam operators is ongoing (Holden 1999).

Relative to flow volume, sediment loads on the San Juan River are generally high compared to other Upper Colorado Basin rivers. However, there is significant spatial and temporal variability in sediment loads and concentrations on the San Juan River. Because Navajo Dam traps sediment, loads immediately below the dam are very low. Loads increase in a downstream direction as perennial and ephemeral tributaries contribute sediment to the system. The frequency of ephemeral tributaries with high sediment loads also increases downstream, increasing the amount of sediment relative to flow volume and resulting in very high sediment concentrations in the lower reaches of the river below Four Corners. Suspended sediment loads measured near Bluff, Utah, averaged 47.2 million tons/year from 1930-1942, but decreased to an average of 20.1 million tons/year between 1943-1973. Loads decreased further, to 10.1 million tons/year, between 1974-1980 (Holden 1999). Variability and range of suspended sediment concentrations measured during 1992-1998 are similar to historic data (Bliesner and Lamarra 2000). Results from this more recent sampling effort also indicate that sediment concentrations greater than 1,000 mg/L are relatively rare at the sampling site near Farmington, but are recorded more frequently at sampling sites downstream (Bliesner and Lamarra 2000).

2.2 Historical Channel Changes

The earliest available air photos of the San Juan River were taken in the mid-1930s. In these photos, the river within Reach 6 is highly complex, with a multi-threaded pattern and numerous secondary channels, overbank channels, and unvegetated bars (Figure 2.2.1). This condition was likely a function of extremely high sediment inputs to the river during the arroyo downcutting period that began around the turn of the century (Bliesner and Lamarra 2000). The arroyo downcutting period has been documented throughout much of the southwest, and has been attributed to widespread overgrazing as well as a climate period characterized by very intense summer rainstorms (Leopold 1994). Unfortunately, information on the channel condition of the San Juan River prior to the 1930s is very limited, making it difficult to know what the “natural,” pre-disturbance condition of the channel would have been.

Bliesner and Lamarra (2000) analyzed available historical air photo sets of the river to determine bankfull channel area, island area, and island count as indicators of temporal changes in channel conditions. They found that since the 1930s, the San Juan River has generally been narrowing and converting to a more single-threaded, less complex channel pattern, and many open bar areas have become vegetated islands or floodplain areas (Bliesner and Lamarra 2000). Considerable vegetation establishment was evident between the 1935 and 1950 air photo sets. This is the time when tamarisk was introduced into the basin, and was also a period of reduced sediment loads. Additional simplification occurred between 1950 and 1962, which was a dry period with small flood magnitudes. Russian olive was introduced to the basin sometime after 1962, and Navajo Dam began regulating downstream flow in 1962. Between the 1962 and 1986 air photos analyzed by Bliesner and Lamarra (2000), bankfull channel area and mean bankfull width in Reach 6 decreased significantly. In contrast, island count and island area increased significantly during this time, although they did not recover to the 1935 level. This increase in the number and size of islands has been attributed to the process of Russian olive trees dislodging during large floods and forming debris piles that capture sediment and eventually grow into new islands (Bliesner and Lamarra 2000). Changes in hydrology have most likely also played a role. During the post-dam period between 1962-1991, the average peak runoff value at the Farmington gage decreased by 45%, and the frequency of peak flows greater than 10,000 cfs dropped from 53% to 33%.

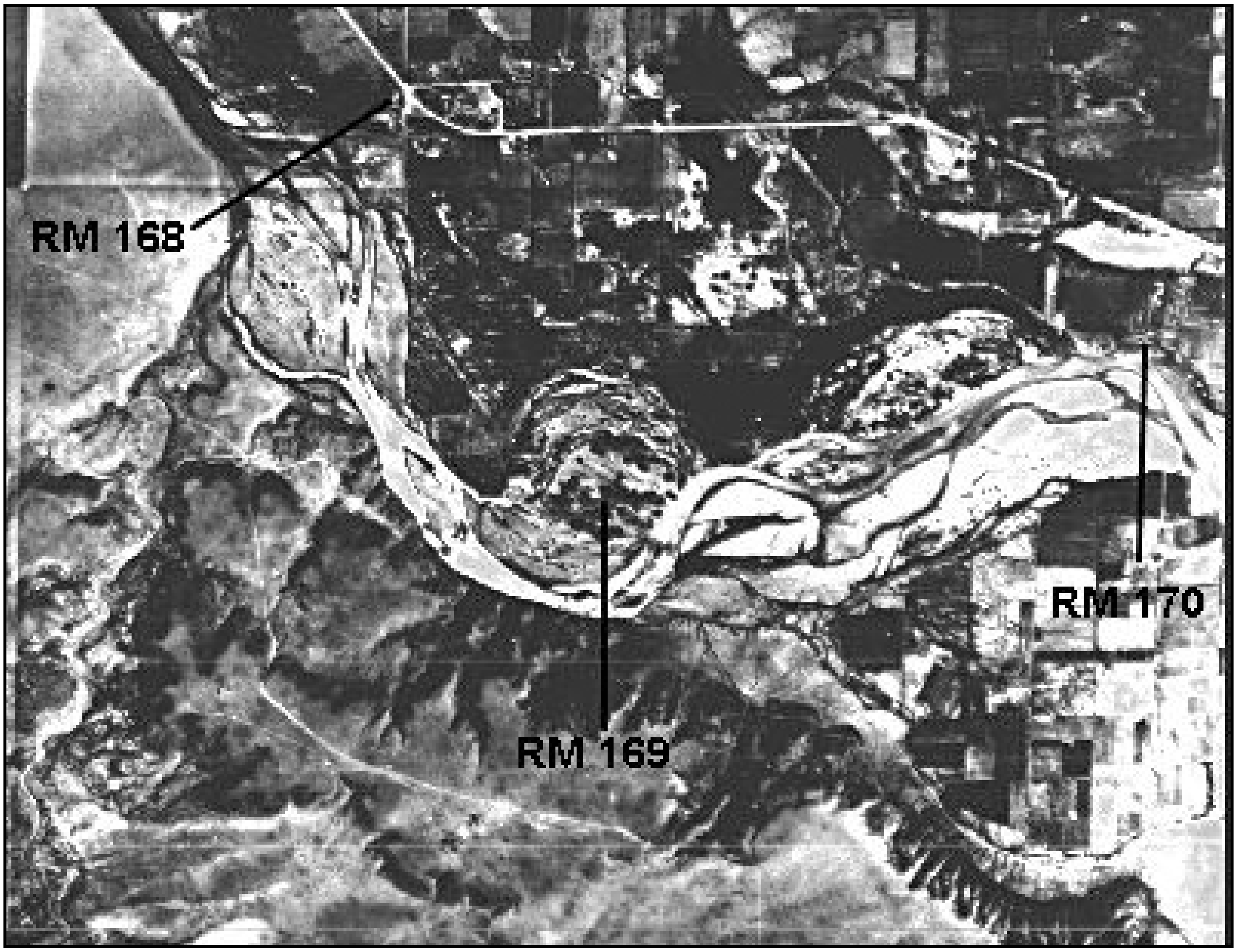

Figure 2.2.1. Air photo from 1935 of middle portion of Study Area (RM 170-168).

Studies below dams on various rivers have documented a trend of streambed degradation and channel incision following dam closure (Petts 1984, Williams and Wolman 1984, Richard 2001, Massong 2004). This process occurs due to the reduced sediment supply below dams. The magnitude and extent of the channel degradation response vary depending on the specific type of flow and sediment regulation and the individual river characteristics. On rivers such as the Rio Grande below Cochiti Dam, this process has resulted in a lack of overbank flooding and reduced channel complexity due to the entrenched condition of the channel (Richard 2001). Within our Study Area on the San Juan River, there is no evidence of long-term channel degradation due to Navajo Dam. Historical analysis of relative mean bed elevations at the USGS gages near Farmington and Shiprock does not show any long-term trend toward channel incision (Bliesner and Lamarra 2000). The most significant change evident after closure of Navajo Dam is a reduction in the short-term variability in streambed elevation (i.e., reduced annual magnitude of scour and fill). Therefore, post-dam channel incision does not appear to be a cause of reduced channel complexity on the San Juan River, at least within the Study Area. This is likely due, at least in part, to the fact that the Study Area is more than 40 miles downstream from Navajo Dam, and also downstream from the Animas River. It is possible that channel incision may be more of an issue immediately below the dam; however, historical bed analysis at the Archuleta USGS gage (located 4 miles below the dam) has not been possible due to shifts in gage datum and location (Bliesner and Lamarra 2000).

2.3 Recent Trends

Changes Since 1986

Although post-1986 changes in bankfull width, bankfull channel area, island count, and island area have not been comprehensively analyzed, available information suggests that channel narrowing and simplification trends have continued. Based on a comparison of low flow habitat mapping results from August 1994 with results from October 2003, at least eight areas mapped as cobble bars or shoals in 1994 converted to vegetated islands by 2003 within the Study Area. In addition, in nine locations in the Study Area, individual islands grew larger in size and/or merged between 1994 and 2003. Mapping results also provide evidence of vegetation encroachment along channel margins and associated narrowing of secondary channels during this time period within the Study Area. Many of these changes appear to have occurred during the recent drought period and are evident when comparing the 1998 aerial photography with the 2004 video imagery. Between 1997-2005, there were no sustained, high overbank springtime flows within the Study Area.

Effects of Spring 2005 Flood

In 2005, a large snowpack resulted in some of the highest flows on the San Juan River since Navajo Dam began operation (Figure 2.3.1). At the Farmington USGS gage (gage #09365000), the 2005 maximum average flow was 13,700 cfs, and occurred in late May. This is the largest average daily flow recorded at the gage since Navajo Dam began operating in 1962. However, 2005 flow data are currently only available in provisional form and may be subject to adjustment. Nevertheless, the spring 2005 flows were among the highest recorded in the post-dam time period. Flows at the Farmington gage remained above bankfull stage (8,000 cfs) for 18 days in a row and exceeded 10,000 cfs for 12 consecutive days (Figure 2.3.1). At the Shiprock USGS gage (gage #09368000), the maximum 2005 daily flow was 13,000 cfs. Since 1962, this value was only exceeded once at this gage, in 1979.

We completed a qualitative comparison of channel conditions in the Study Area before and after the 2005 spring flood. Specifically, photos taken during a November 2004 reconnaissance visit were compared to matched photos taken during August 2005 field surveys. When the November 2004 photos were taken, flows in the Study Area ranged from 750 to 780 cfs. Flows were

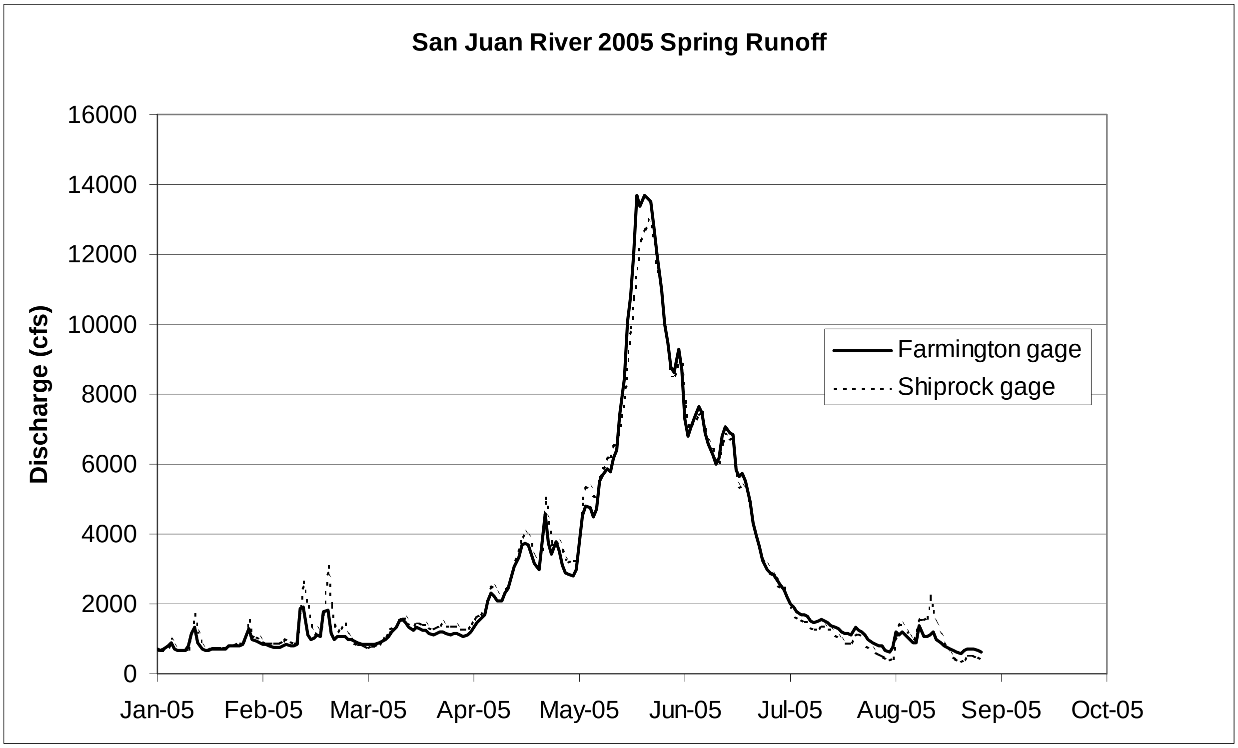

Figure 2.3.1. San Juan River 2005 spring flood. Data based on provisional USGS flows downloaded on 9/29/05.

approximately 1,000 cfs when the August 2005 photos were taken. In addition, aerial videography images from September 2004 were compared with images flown in September 2005.

One post-flood trend evident throughout the Study Area was the presence of large sand deposits at the mouths of tributaries and irrigation return channels. These deposits most likely formed due to slow velocity/backwater conditions that developed when the high stage in the main river inundated the tributary mouths. Immediately after the flood peak, these sand deposits most likely spanned the entire width of the tributary mouth, but at the time of our August 2005 field work the tributaries had cut new channels through the deposits and were connected to the main river (Figure A1).

The 2005 flood also scoured away vegetation and widened the mouths of several secondary channels and overbank channels within the Study Area. At RM 170.9, cattails (*Typha* spp.) as well as some young willows and tamarisk that were growing in the overbank channel mouth in 2004 are gone in the August 2005 photos (Figure A2). The change at this site can also be seen in the comparison of the 2004 versus 2005 videography (Figure A3). Similarly, it appears that some of the vegetation that had encroached into the secondary channel mouth at RM 162.7 was removed by the 2005 flood (Figure A4). At another secondary channel near RM 170.4, the channel entrance had silted in and become vegetated with cattails and young willows and tamarisk between 1998 and 2004. The 2005 flood scoured and reactivated this channel entrance, and the channel now carries flow even at low discharge (Figure A5).

Although these examples demonstrate that the 2005 flood was effective at reversing the 1998-2004 vegetation encroachment trends in certain parts of the river, other areas remained vegetated following the flood. For example, a channel across an island at RM 170.1 that had become inactive and vegetated between 1998 and 2004 remained thickly vegetated with young willows after the spring 2005 flood (Figure A6). At this location, fresh sand deposits were evident following the flood, and there was no evidence of scour. In general, fresh sand deposits about 3-6 inches thick were observed within young willow and tamarisk stands on islands throughout the Study Area during our August 2005 field work trip.

There was also evidence of considerable mobilization of cobble-sized bed material within the Study Area during the 2005 spring flood. Fresh deposits of cobbles were evident on existing cobble bars throughout the Study Area, and a brand new mid-channel cobble bar was deposited at RM 168. At RM 160.7, the cobble bar on river left expanded horizontally during the spring 2005 flood, substantially reducing the width of the main channel (Figure A7). Just upstream, at RM 161.1, a fresh cobble deposit formed at the entrance to a secondary channel, disconnecting it from the main channel at its upstream end (Figure A8). Cobble movement was also evident within a secondary channel at RM 162.5, where tamarisk seedlings observed in the channel during the November 2004 reconnaissance visit appeared to have been “battered” to death by moving rocks during the spring 2005 flood (Figure A9).

Another general observation following the spring 2005 flood was that the river appears more active downstream from RM 162 relative to the upstream portion of the Study Area. Evidence of active bank erosion was very minimal upstream of RM 162, while significant areas of bank erosion were observed below RM 162, especially between RM 161 and RM 160. Across from the expanded cobble bar at RM 160.7, mature cottonwood and Russian olive trees had toppled into the river due to recent bank erosion. Evidence of this process was not observed upstream. It is not readily apparent why the channel becomes more active in this part of the Study Area, although the change may be related to gradient. Channel slope between RM 162.9 and RM 161.25 is 0.23% (about average for the Study Area), but then flattens to 0.14% between RM 161.25 and RM 158.45. Other factors, such as valley width, bank material, geology, or the geologic control at “The Hogback” may also play a role.

In general, our qualitative observations after the 2005 flood indicate that sustained flows above 10,000 cfs are capable of reactivating secondary channels, building bars, and improving overall channel complexity, at least to some extent. This result supports the results of the 1992-1997 research studies, which documented increases in channel complexity in years where springtime flows exceed 10,000 cfs (Bliesner and Lamarra 2000).

3. BACKWATER CHARACTERISTICS AND PROCESSES

3.1 Definitions and Types of Backwaters

For habitat monitoring purposes, backwaters on the San Juan River have been defined as aquatic habitat units with no perceptible flow and depths from <10 cm to >1.5 m at higher flows (Bliesner and Lamarra 2000). Within the category of backwaters, three subtypes have been defined: backwater, backwater pool, and embayment (Bliesner and Lamarra 2000). Backwaters are typically associated with channel indentations or obstructions, or are located at the mouths of secondary channels or tributaries. A backwater pool is a particularly deep backwater, with depth >2 m. An embayment has the same hydraulic characteristics as a backwater, but forms at the upstream end (entrance) to a secondary channel rather than at its mouth (Holden 1999). Because these definitions are based on water velocity and depth, they are flow-dependent. For example, a secondary channel mouth that forms a backwater at moderate flow may become a run at high flow, and a shoal or sand bar at low flow even though the physical topography of the site remains unchanged. Because this report is concerned with physical habitat restoration rather than flow manipulation, we focus on the flow-independent geomorphic channel features and processes that create the physical template for backwater habitats.

Within the Study Area, the geomorphic features that typically form backwater habitats are bars, secondary channels, overbank channels, and the mouths of tributaries and irrigation return flows. For the purposes of this report, we define bars as predominantly unvegetated areas of exposed sand, gravel, or cobble substrate found within the active river channel. We define secondary channels as companion channels to the main channel that flow at discharges less than bankfull. Secondary channels are separated from the main channel by bars or vegetated islands. For the purposes of this report, overbank channels are defined as features that carry flow at discharges greater than bankfull, and are separated from the main channel by vegetated islands or floodplain areas. Overbank channels are generally narrower than secondary channels and carry less flow. We also define a third type of companion channel: the “cross channel”. A cross channel is defined as a feature that flows in a direction lateral to the main downstream flow direction and connects an overbank or secondary channel to the main channel. Cross channels may flow at discharges either less than or greater than bankfull, and may dissect either bars or islands (Figure 3.1.1). As with secondary and overbank channels, cross channels may form backwaters at either their entrance or mouth, depending on discharge and the specific site topography. In this report, the term “secondary channel” is sometimes used as a broad term referring collectively to any combination of the three companion channel subtypes: secondary, overbank, and cross channels. This nomenclature is comparable to the usage of the broad term “backwater” to collectively refer to backwaters, backwater pools, or embayments. A photo of a backwater formed at the mouth of an irrigation return channel can be seen in Figure A1, and a photo of a backwater formed at an overbank channel mouth can be seen in Figure A2.

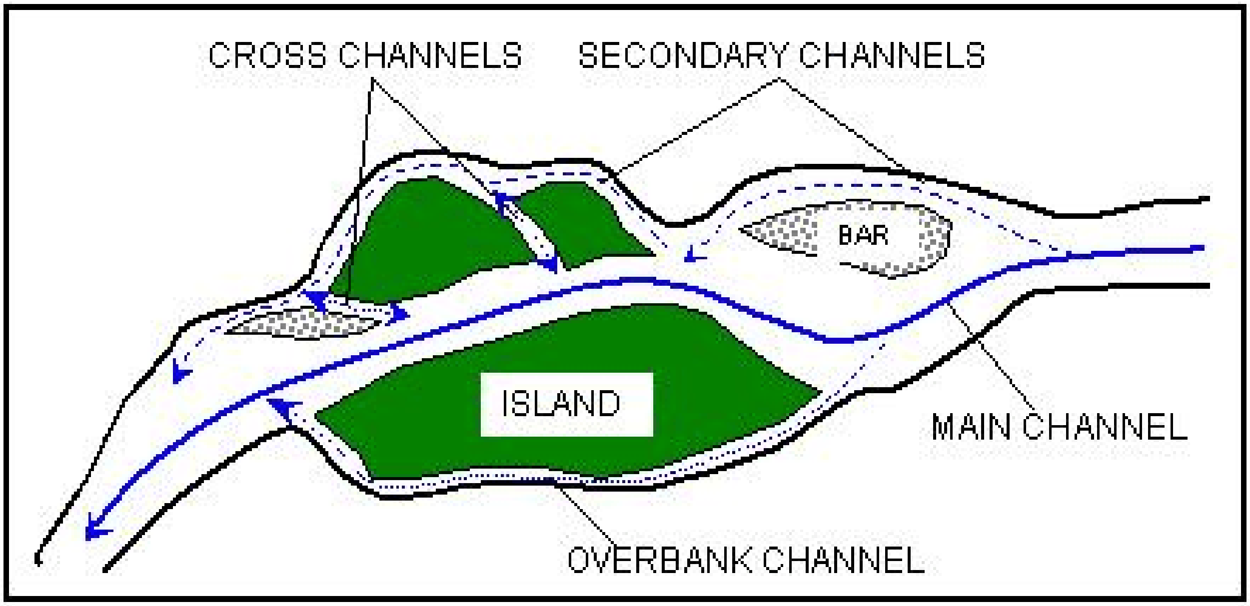

Figure 3.1.1. Illustration of different channel types in the Study Area.

3.2 Habitat Benefits of Backwaters

Low-velocity habitats, and backwaters in particular, have been shown to be critical to the survival of young-of-year (YOY) Colorado pikeminnow (Holden 1977, McAda and Tyus 1984, Tyus and Haines 1991). Studies of habitat use following the 1996 and 1997 stocking efforts in the San Juan River indicated that young Colorado pikeminnow tend to select for backwaters and other low-velocity habitats (Holden 1999, Trammel and Archer 2000). Studies of retention after the more recent Colorado pikeminnow stocking efforts in the San Juan River indicate that backwaters are important habitats for the stocked fish, especially during the initial months after stocking (Golden et al. 2004, Golden and Holden 2005, Golden et al. forthcoming.). Winter sampling after YOY Colorado pikeminnow were stocked in 2002-2005 showed that Colorado pikeminnow used backwater habitats significantly more often than expected. Additionally, catch rates for YOY Colorado pikeminnow in backwaters were found to be significantly higher from 0-1.5 months after stocking until at least 5 months after stocking. The stocked YOY Colorado pikeminnow have also been found to use side channel habitats significantly more often than expected. During certain low-flow conditions, secondary channels provide the majority of low-velocity habitats in the system (Holden 1999).

Studies to date demonstrate that low-velocity habitats in general are critical for YOY Colorado pikeminnow survival; however, the relative benefits of specific characteristics of low-velocity habitats (size, turbidity, depth, temperature, vegetative cover) are less well known. Some studies have suggested that deeper backwaters contain a higher abundance of YOY Colorado pikeminnow than shallower backwaters, while other studies have not found a correlation between depth and abundance (Tyus and Haines 1991, Holden 1999, Trammell and Chart 1999). Recent monitoring studies in the San Juan River suggest that high turbidity and cover may be at least as important habitat qualities as depth (Golden et al. forthcoming; M. Golden 2006, personal observation). The average and maximum depth of samples where Colorado pikeminnow were found versus samples where they were not found showed no clear trend, but YOY Colorado pikeminnow have been found significantly more often than expected in habitats with some kind of overhead cover (e.g., woody debris, overhanging vegetation, boulders, tires) during winter sampling. Catch rates for YOY Colorado pikeminnow during winter sampling were also significantly higher in areas with cover. Monitoring in November 2005 and March 2006, under high-clarity conditions, indicated that Colorado pikeminnow were even more clumped in deeper areas and areas with cover to avoid high water clarity. Tyus and Haines (1991) also showed that Colorado pikeminnow preferred more turbid areas.

Carrying capacities (i.e., potential number of YOY Colorado pikeminnow per unit area or volume) for different types and sizes of backwaters have not been calculated or specifically examined by research to date. Within the Study Area, recent retention monitoring work has found that the overall abundance of low-velocity habitats (of any type) appears to be very sensitive to small changes in streamflow (M. Golden, personal observation). Therefore, under existing river conditions, streamflow and availability of low-velocity habitat in general may be the most important factors affecting retention, rather than the carrying capacity or depth of any individual backwater. In terms of potential restoration efforts, it may be most important to focus on providing a large number of backwater features that provide low-velocity habitat at a range of flows, rather than emphasizing specific depth and turbidity parameters that would only be available at a single flow level. Monitoring results also suggest that providing cover as part of backwater habitat restoration efforts would be beneficial.

3.3 Formation and Maintenance Processes

Maintenance Processes

Maintenance of existing secondary and overbank channel-associated backwater habitats is largely dependent on the process of flushing of accumulated fine sediments. Research and monitoring studies on the San Juan River have found that the main channel streambed tends to scour during springtime runoff events and aggrade with fine sediment in between runoff events (Bliesner and Lamarra 2000, Bliesner and Lamarra 2003). Measurements at transect RT-1 (now called CS6-02), located in the Study Area at RM 168.3, indicate that the proportion of cobble material on the streambed typically increases following spring runoff, and then declines during the low-flow period as fine material is deposited (Bliesner and Lamarra 2000, Bliesner and Lamarra 2003). The overall magnitude of annual bed scour and cobble movement has been correlated to the number of days with flows >5,000 cfs, suggesting that relatively long-duration, moderately high magnitude flows will be the most effective in flushing accumulated fine sediment (Bliesner and Lamarra 2000).

No geomorphic studies of secondary or overbank channel-associated backwaters have been conducted within the Study Area. However, suspended sediment transport was modeled for two secondary channels in Reach 3, downstream from the Study Area, to determine conditions required for backwater flushing and maintenance. Although geomorphic conditions in the sand-dominated Reach 3 differ from the more stable, cobble-dominated channel in the Study Area, the Reach 3 study results confirm the conclusion that extended-duration flows of >5,000 cfs are effective at flushing accumulated fine sediments and maintaining associated backwaters (Bliesner and Lamarra 2000). Reach 3 modeling results also suggest that a steep hydrograph receding limb may limit the amount of backwater in-filling that occurs as flows drop. However, additional studies would be needed to confirm whether this pattern holds true upstream within the Study Area. In any case, the long-term effectiveness of a given springtime runoff hydrograph will be affected by the summer and fall climatic conditions following the spring runoff. Specifically, the effectiveness of a high-runoff year can be negated if it is followed by numerous sediment-producing storm events that refill backwaters with fine sediment.

Studies of topographic changes on individual cobble bars on the San Juan River indicate that the relationship between runoff and localized scour/deposition patterns may not be so straightforward. Average elevations of two bars within the Study Area (at RM 173.7 and RM 168.4) responded inconsistently to runoff events based on surveys completed between 1996-2002 (Bliesner and Lamarra 2000, Bliesner and Lamarra 2003). Predictable trends toward overall erosion or deposition could not be discerned. Each year, portions of each bar scoured while other parts of the bar aggraded. Because of the dynamic nature of cobble bar topography, local depressions or cross channels that form backwaters in one year may disappear the next year. However, if flows are adequate to mobilize the bar material, new depressions and backwaters may form in different locations within the bar, thereby maintaining bar-associated backwater habitat. In general, bar-associated backwater habitats constitute a fairly small proportion of backwaters relative to secondary channel-associated backwaters within the Study Area. Therefore, secondary channel maintenance processes are probably more critical to overall backwater availability than bar maintenance processes.

Formation Processes

Within the Study Area on the San Juan River, backwater habitats are formed by the processes that create cobble bars, islands, and various types of secondary channels. As on most dynamic river systems, bars and islands on the San Juan River undergo various stages of development through time. Bars initially form when more sediment is delivered into a given stream segment than that segment is capable of transporting, resulting in a net deposition of bed material. These bars form in areas where local stream power is decreased due to reductions in gradient, depth, or velocity. In locations where multiple channels are already present, bars tend to form in the lower-velocity areas between the channels where eddies or slackwaters form during high flow. Within the Study Area, cobble-sized material typically comprises the main, central portion of bars rather than sand, and initially the bars are devoid of vegetation. Various types of bars are present within the Study Area including mid-channel bars, channel margin bars, and tributary-associated bars that form where tributaries deposit sediment as they enter the main channel. Because the San Juan River exhibits more of a multi-threaded pattern rather than a meandering plan form typical of lower-gradient rivers, well-developed, inside-bend point bars are rare within the Study Area. Bars may also initially develop in the lee of woody debris piles that obstruct flow and promote deposition. Studies on the San Juan River have identified flows of 8,000 cfs (bankfull discharge) as necessary for cobble bar construction (Holden 1999).

If initial bar formation is followed by a sequence of relatively dry years with non-erosive flows, the bar may begin to stabilize via a process of fine sediment accretion and vegetation establishment. The newly established vegetation promotes further sediment deposition, and as vegetation grows and the bar continues to aggrade, the feature becomes protected from scour by high flows. Ultimately the bar may develop into a stable, mature, island. If vertical accretion and further vegetation growth occur at the entrance to the secondary channel that surrounds the island, it may become a less-active overbank channel and eventually be abandoned altogether. Thus, the full sequence is one of bars becoming islands and then islands becoming part of the vegetated floodplain (Hooke 1986, Osterkamp1998). Cross channels through bars and islands may also become abandoned through this process.

As discussed above in Sections 2.2 and 2.3, this process of sediment accretion and vegetation encroachment has been documented on the San Juan River both historically and during the recent drought period, and has resulted in the loss of channel features that often support backwater habitats. However, as discussed in Section 2.3 above, large floods that fully mobilize cobble bed material are still capable of creating new cobble bars and adding new areas of bare cobble to existing bars.

Islands, overbank channels, and secondary channels may also form via the process of channel avulsion. This is a high-energy, erosional process by which a new channel carves through an existing floodplain area, and the river takes a new path. Avulsions can be initiated when flow is deflected into an erodible bank area by a log jam, large debris pile, or large bar deposit within the main channel. The main channel may avulse and move, leaving behind the abandoned main channel as a secondary channel, or an avulsion can create a new secondary or overbank channel while the main channel remains in place. Another common process is for an existing secondary channel to capture more of the flow and become the main channel, leaving the original main channel as a secondary channel. Channel avulsions usually occur during very high magnitude, erosive flood events (Osterkamp 1998). Although the avulsion process has not been studied in detail on the San Juan River, review of Reach 3, 4, and 5 (RM 68-154, downstream of the Study Area) island count data collected as part of habitat mapping efforts suggests that multi day flows of >10,000 cfs can be effective at creating new islands (Holden 1999).

3.4 Anthropogenic Influences

As discussed in Section 2.1 of this report, land development within the Study Area appears to have generally had little direct negative impact on available backwater habitat. Although some areas that were islands or secondary channels in the 1930s are now being used for agriculture, these areas were not directly diked off or drained; rather, changes in hydrology, sediment supply, and riparian vegetation encroachment initially caused channel simplification and made the areas available for agricultural development. We did identify three specific sites where development appears to have directly impacted channel complexity. One location is in the vicinity of RM 179, where historical secondary and overbank channels have been converted to ponds as part of gravel mining operations. The entrance to one of these secondary channels was mapped as a backwater in 1993, 1997, and 1998, before it was converted to a pond. The pond at Hatch Trading Post, at RM 168.4, is another location where there have been direct anthropogenic impacts. This pond used to be a secondary channel in the 1930s, but it is currently diked off from the river. The third site is on the north side of the river at RM 165.55, where the entrance to a secondary channel has been disconnected from the main channel by rip rap placed on the Jewett Valley Ditch embankment.

Water diversion structures do not appear to have had a significant or extensive negative impact on backwater habitat availability within the Study Area. The Fruitland, APS, and PNM structures were all constructed within the main-stem channel, and do not directly impact any secondary channels. Although the structures alter local bed and water surface gradients for some distance upstream and downstream, any indirect backwater effects that this may have are overwhelmed by the more-significant, larger-scale historical processes of vegetation encroachment and accretion. Rather than having a negative effect on backwaters, the Fruitland Diversion structure has actually “created” backwaters that have been mapped at the sluiceway channel mouth and where water backs up above the sluiceway gates. Similarly, parts of the Jewett Valley Ditch rock dam structure and ditch entrance have been previously mapped as backwaters.

The anthropogenic influence that appears to have most substantially affected backwaters within the Study Area is irrigation return flows. During field visits in November 2004 and August 2005, we noted that many of the secondary and overbank channel mouths that remained clear of vegetation during the 1998-2004 drought period are used to convey irrigation return flows. Apparently, the presence of irrigation water in these areas during the growing season can limit the extent of vegetation establishment and help flush fine sediments, even in the absence of high spring flows. In this manner, irrigation return flows appear to be playing a role in the maintenance of secondary and overbank channel mouths that can form backwaters under specific flow conditions. Similarly, irrigation flows returned to the river via ephemeral arroyo channels can help erode through high-flow sand deposits at the arroyo mouth that might otherwise block off the tributary from the river (see Figure A1). Increased soil moisture caused by seepage from irrigated lands also supports increased growth of grass and vegetation on the banks of tributaries and secondary channels that would otherwise be more susceptible to erosion.

However, irrigation return flows can also reduce backwater availability during the summer irrigation season. Depending on the relative gradients and bed elevations of the main channel and irrigation return channel, flow velocities at the confluence may be too high to meet the "no perceptible flow" definition of a backwater. Irrigation returns also affect water quality in ways that can reduce the habitat quality of a given backwater. Irrigation water has lower turbidity and sediment concentrations than the main channel river water, and the influx of water may reduce the temperature of the backwater relative to truly stagnant conditions. Trammell and Chart (1999) and Trammell and Archer (2000) showed that Colorado pikeminnow preferred deeper and more turbid backwaters in the Green River and the San Juan River, respectively. Depth and turbidity provide more cover from predators. Higher temperatures in backwaters may lead to increased growth for Colorado pikeminnow. The potential negative effects of irrigation return flows, however, are limited to the summer irrigation season. From November through March, some backwaters are available that would most likely have become silted in and vegetated in the absence of irrigation return flows.

4. ROLE OF NON-NATIVE RIPARIAN VEGETATION

4.1 General Influences of Riparian Vegetation

As alluded to in the above discussions, riparian vegetation plays a significant role in the formation and maintenance of backwater habitats. In-channel woody debris piles and log jams create localized scour holes and low-velocity habitats with good protective cover. At a larger scale, the effects of woody debris accumulations on channel hydraulics can promote bar formation, sediment deposition, and channel avulsion, leading to increased overall channel and habitat complexity.

As discussed above, riparian vegetation can also contribute to reduced channel complexity through the process of vegetation encroachment. Vegetation that becomes established on bars or in secondary channels during dry periods promotes deposition of fine sediment through its effect on flow resistance. This, in turn, can accelerate the processes of vertical and lateral accretion, protecting the vegetation and its associated geomorphic surface from future scour. Riparian vegetation also increases bank strength, making floodplain areas and islands less susceptible to erosion or scour. This can increase overall channel stability and reduce the frequency of processes such as channel avulsion and cobble bar-reworking that can create new channels and backwaters.

Although the influence of vegetation on the process of vertical sediment accretion has not been extensively studied on the San Juan River, observations and measurements made during fieldwork completed for this project indicate that significant depths of sediment can be captured by vegetation, often within a short period of time. At the cobble bar/island located at RM 172, we observed elevated “levees” of sand that had been captured by tamarisk shrubs that are colonizing the bar (Figure 4.1.1). In one part of the bar, we measured a 1.39' difference between the sand surface surrounding a tamarisk shrub and the lower, unvegetated surface found when conducting fieldwork in August 2005. Similarly, we found that a depositional sand surface adjacent to a tamarisk tree at the RM 173 cobble bar was 2 feet higher than the surrounding bar surface. As seen in Figure 4.1.2, the extensive root and stem network of tamarisk is also very effective at stabilizing banks and protecting captured sediment from lateral erosion.

In August 2005, we excavated and sampled a tamarisk tree located within the more densely vegetated island portion of the RM 172 bar/island. The tree had multiple stems/ trunks, and we sampled the main trunk as well as two smaller stems. Stems were cleanly cut and sanded so that tree rings could be counted. The largest (main) stem was aged at 15 years and had a diameter of 3.2 inches, and the two smaller stems were each aged at 6 years. The establishment surface (lateral root crown) of the 15-year-old stem is 1.5' below the present ground surface, and the 6-year-old stems are each buried by 0.25' of sand (Figure 4.1.3). This translates to an average accretion rate of 0.14' (1.7 inches) per year between 1990-1999, and a rate of 0.04' (0.5 inches) per year between 1999-2005. We also excavated and sampled a Russian olive tree growing

Figure 4.1.1. **Elevated "levee" surface (indicated by red dashed line) created by tamarisk capturing sediment at RM 172 bar. Photo taken November, 2004.**

about 60 feet downstream from the sampled tamarisk on the RM 172 island. The Russian olive was 6 years old, with a diameter of 2.75 inches, and its root crown was buried by 2.1 feet of sand (Figure 4.1.4). These results indicate that accretion rates can be spatially and temporally variable, even within the same island. Two young tamarisk saplings growing along the right bank of the secondary channel at RM 176.2 were also excavated and sampled in August 2005. The stems were sanded so that the tree rings could be counted, and both saplings were found to be 2 years old. Since initial establishment, the saplings have been buried by 0.65' and 1.1' of medium-grained sand, respectively (Figure 4.1.5).

Willows also appear to be effective at capturing fine sediment. At four islands within the Study Area, relative elevations were surveyed in different vegetation communities during our August 2005 fieldwork. We found that the outer fringe areas of these islands, where young willows are the dominant vegetation, had elevations 0.03, 0.07, 0.235 and 0.24 feet higher than the central portions of the islands, where older Russian olive trees are the dominant vegetation. We also

Figure 4.1.2. **Photo of tamarisk growing on streambank near RM 171. Note how the extensive root and stem network protects deposited sediment from erosion. Photo taken November, 2004.**

surveyed an abandoned cross channel at RM 170.2, where willows have established and sand deposition has occurred. The elevation of the sand deposit at the entrance to the abandoned cross channel is an average of 2.84 feet higher than the adjacent main channel thalweg elevation. The original bed elevation of the cross channel is not known, but in the 1998 orthophotos the channel is open, unvegetated, and flowing. This suggests that a considerable volume of sand has deposited at this location since 1998, coincident with willow establishment.

Although the above results are not comprehensive, they do indicate that vertical accumulations of as much as 1 to 2 feet of sediment within a period of several years are not uncommon within the Study Area on the San Juan River. Increases in height of this magnitude greatly alter the hydraulic position of a given bar or island, and much higher flows become necessary to overtop the feature. In this way, riparian vegetation can lead to stabilization and "armoring" of a given bar or island, ultimately reducing channel complexity and associated backwater habitats.

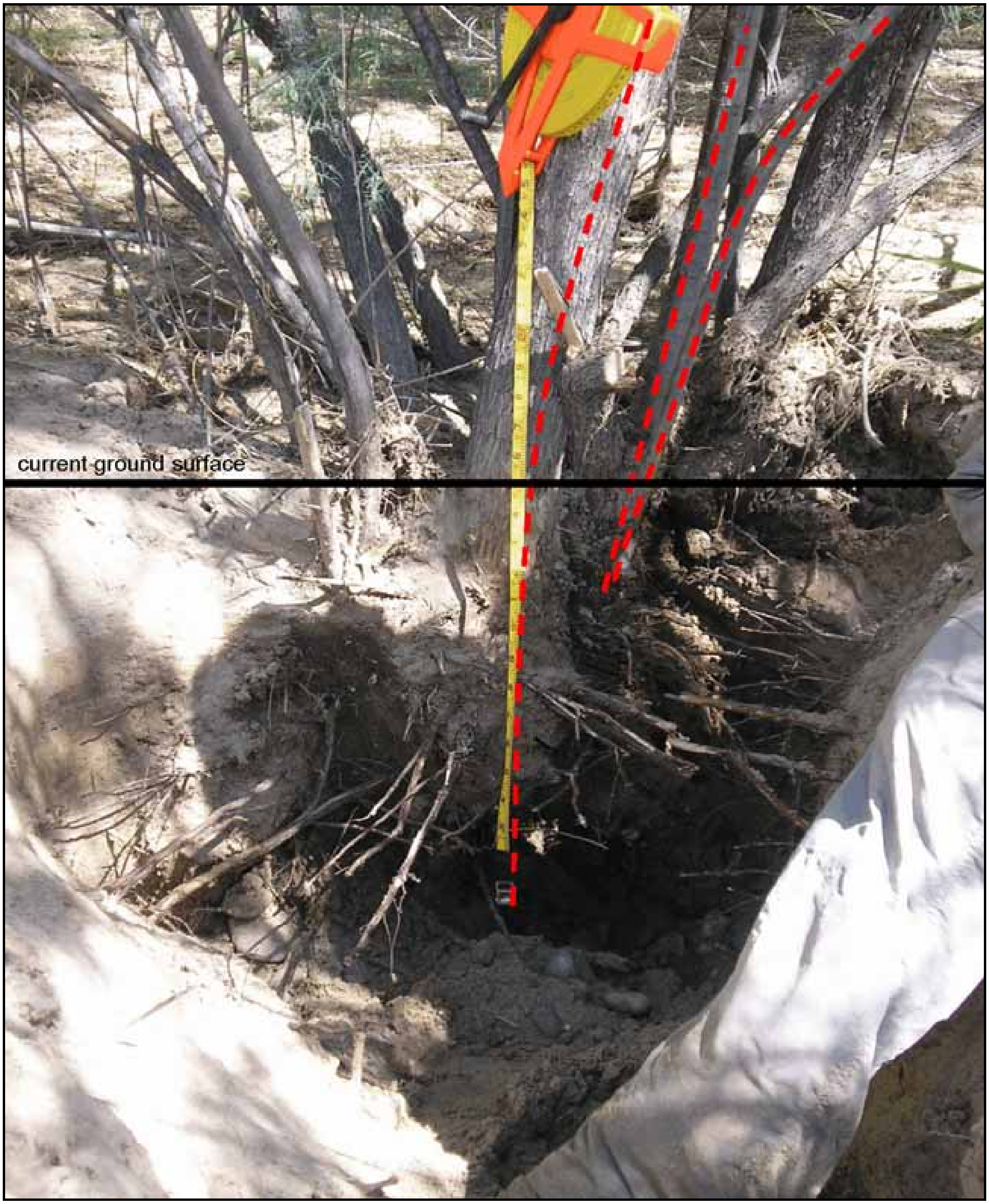

Figure 4.1.3. **Excavated tamarisk growing on RM 172 island. Dashed red lines indicate stems that were sampled and aged; black line indicates the level of the current ground surface. Photo taken 8/17/05.**

Figure 4.1.4. Excavated Russian olive growing on RM 172 island. Photo taken 8/17/05.

Figure 4.1.5. **Photos of vegetation growing along bank of secondary channel near RM 176. Top: view of young tamarisk and willows growing on bank; Bottom: close-up of excavated tamarisk sapling. Photos taken 8/16/05.**

4.2 Characteristics of Russian Olive

Russian olive is a deciduous perennial tree or large, multi-stemmed shrub that is native to Europe and Western Asia. Russian olive was initially introduced to North America as a horticultural plant in the late 1800s and has been planted for shade, hedges, windbreaks, soil stabilization, wildlife habitat, and landscaping. By the mid-1900s it became prominent outside cultivated areas and is now extensively naturalized in 17 western states (TNC 2003). Russian olive can invade and negatively impact riparian plant communities by creating dense, monotypic stands, that out-compete native vegetation such as cottonwoods and willows. This displacement typically occurs as a result of disturbance such as flooding or river regulation.

Plant Structure

Russian olive grows from 16 to 30 feet in height, with trunks from 4 to 20 inches thick. Without pruning, the tree typically grows 5 to 6 main stems starting near the ground. The branches are flexible and covered with coarse thorns. Fruits are berry-type, oval, and 1-2cm in length and contain a single seed. The plant typically bears fruit in 3 to 5 years.

There is little information available about the root structure of Russian olive, but it is generally described to be extensive or deep, with many well-developed laterals (Zouhar 2005). Yeager (1935) described a 25-year-old, 26-foot tall Russian olive with roots as long as 39 feet where the water table depth was below 15 feet.

Regeneration

Russian olive propagates both sexually and vegetatively. After a Russian olive tree or shrub is cut down, the stump readily produces suckers that sprout new growth. The stems have also been shown to propagate new plants (Stannard et. al. 2002).

Russian olive flowers early in the growing season from June to July. The seeds are dispersed most typically by birds, with some seeds transported by water. Fluvial transport of Russian olive seeds occurs after seeds have been loosened from trees by wind or birds with ripe seeds floating for up to 48 hours (Lesica and Miles 2004). The seeds can remain viable for up to 3 years.

Russian olive seeds can germinate in many soil types and under a broad range of conditions (DiTomaso and Healy 2003). Seedling establishment can occur on disturbed sites in full sun, shade, or within vegetative groundcover. This broad range of establishment conditions allows Russian olive to outcompete native cottonwoods and willows that have more specific germination requirements. The Russian olive's longer seed viability relative to native cottonwood and willow further adds to this competitive edge (Katz and Shafroth 2003). This allows the Russian olive to take advantage of favorable germination conditions over a longer period of time.

Habitat and Stand Structure

Russian olive can form dense, monotypic stands of vegetative cover on invaded riparian sites. This cover often has no clear over-story and forms a continuous closed canopy. Often, dense dead branches form a tangle of vegetation in the lower portion of the stand. Plants appear to prefer sandy floodplains but do occur in a variety of soil and moisture conditions. It grows in moderate salt and alkali soil conditions. Russian olive tolerates some shade which allows it to grow under a cottonwood overstory and eventually out-compete the native trees. Russian olive is classified as a facultative phreatophyte and shows higher tolerance to drought stress relative to competing native species.

4.3 Characteristics of Tamarisk

Tamarisk is a deciduous, loosely branched shrub or small tree. It is native to the Mediterranean region and the deserts of central Asia and north Africa. Thought to have been originally introduced to North America by the Spaniards, tamarisk was sold as a nursery plant for ornamental landscaping and windbreaks from the early 1900s through the 1960s. By the 1960s it had became invasive primarily in the southwestern U.S., Texas, and Mexico and is now found in many areas throughout the western U.S. and northern Mexico (Zouhar 2003). The invasion of tamarisk is due, in part, to the construction of large dams and water diversions that regulate streamflow and change the shape of the hydrograph, giving tamarisk a reproductive advantage over native species. This invasion has now spread to unregulated rivers (Larsen 2004).

Plant Structure

Tamarisk is described as a shrub, shrub-like tree, or small tree. It has numerous large basal branches that are usually less than 13 to 20 feet in height, but can extend to 26 feet. The deciduous leaves are scale like and have salt-secreting glands. Tamarisk has flowering raceme branches. With a deep and extensive root system, tamarisk has a primary root that extends to the water table. It is classified as a facultative phreatophyte, which means that its roots can extract water from unsaturated soil layers.

Regeneration

Tamarisk reproduces both by seed and vegetatively. Typically the plants reach maturity and begin to produce seeds in their third year. Once mature, they produce seeds throughout the entire growing season. Tamarisk is prolific in seed production with large mature plants capable of producing several hundred thousand seeds in a growing season (Merkel and Hopkins 1957). The seeds are dispersed by wind and water. Under ideal conditions of humidity and shade, the seeds can remain viable for up to 45 days or for 24 days if conditions are hot and dry. Rarely do seeds produced in one summer germinate during the following spring.

Tamarisk seeds can germinate immediately after dispersal. They require a moist and fine grained silt, or smaller particle substrate for germination (Stevens 1989). These conditions are common in southwestern riparian areas after spring floods recede. Under appropriate conditions germination occurs within 24 hours and is not impacted by salinity.

Tamarisk seedlings require saturated soils, are sensitive to drying during the first weeks of growth, and grow somewhat more slowly than native riparian species. The seedlings can survive some submergence, but long term submergence (4 to 6 weeks) has been shown to kill most seedlings. Small river current can dislodge and carry away small seedlings (Horton et al. 1960).

Tamarisk also reproduces vegetatively. Lateral shoots are produced from mature plants and can grow up to 10 feet in one growing season. Root crowns sprout following disturbance (i.e., fire, flood, and cutting). The stems are also capable of producing adventitious roots when placed in warm, moist soil. This allows stems that are broken off during a flood to reproduce new plants after being buried in moist sediment.

Habitat and Stand Structure

Once established, tamarisk grows in dense thickets and tolerates a wide variety of environmental conditions. It is primarily found in wet areas such as riparian floodplains, lakeshores, and wetland margins. It has a stress-tolerant plant physiology that allows it to survive high stress conditions that exist on regulated rivers (Glenn and Nagler 2005). Tamarisk establishes and grows in saline soil. As a facultative phreatophyte, tamarisk can extract water and survive in unsaturated soils. This physiology gives tamarisk the ability to tolerate drought stress and survive in very dry conditions for multiple years.

Evapotranspiration

Early estimates showed tamarisk to have a high evapotranspiration (ET) rate, and this information has been used as a primary argument for tamarisk removal. Reports state that eliminating tamarisk would reclaim large amounts of water lost to tamarisk ET (Glenn and Nagler 2005). More recent measurements of tamarisk ET in the natural stand environment using different techniques (sap-flow, Bowen Ratio, eddy covariance flux towers) show annual rates similar to that of cottonwoods (Glenn and Nagler 2005).

Nagler et al. (2004) measured the leaf area index (LAI) on tamarisk, cottonwood, willow, and arrowweed (*Pluchea sericea*) plants growing along the Little Colorado River. This study showed that, although some tamarisk stands had very high LAI values, on average it has a lower LAI than cottonwood, willow, and arrowweed.

4.4 Comparison with Native Species

Tamarisk / Native Riparian Vegetation Differences

Available literature shows that tamarisk tolerates salinity, drought, and fire better than native cottonwoods and willows, but that under natural flow conditions natives are competitive with tamarisk during flood years (Glenn and Nagler 2005). It is thought that tamarisk generally has a germination advantage over native cottonwood and willow. Like tamarisk, the native trees can be abundant seed producers but their period of seed production is shorter. Tamarisk produces seeds throughout the growing season whereas cottonwood produces seeds from April through June and willow produces seeds from March through June (Table 4.4.1). Cottonwood and willow seeds can germinate rapidly and the seedlings can grow quickly under natural spring flooding conditions. Altered flow regimes (draw-downs occurring later in the growing season) and saline soils give tamarisk a germination advantage over native trees and shrubs, which can not establish in saline soils (Table 4.4.1).

Tamarisk does not tolerate inundation in comparison to native cottonwoods and willows. Tamarisk, cottonwood, and willow nursery plants showed great differences in their response to inundation (Vandersandae et al. 2001). The tamarisk plants did not grow after one week inundation and had rotting roots after 70 days. The cottonwood and willow plants had doubled or tripled in size after 70 days.

Russian Olive / Native Riparian Vegetation Differences

Russian olive has several competitive advantages over native cottonwoods and willows. One major advantage is the long duration of seed viability, and the ability of seeds to germinate in shade, saline soil, or within established vegetative ground cover (Table 4.4.1). This allows Russian olive to establish under the canopy of existing mature cottonwood stands. The seeds of native cottonwoods, on the other hand, only remain viable for a relatively short time, and successful seed-based recruitment requires a specific combination and sequence of fluvial surfaces and hydrologic patterns (Scott et al. 1993). The general conditions that must be met for successful cottonwood recruitment include:

1. Presence of a bare surface with freshly deposited sediments at the time of seed dispersal.

2. Transport and deposition of seeds onto the surface.

3. Post-germination decline in water levels at a rate slow enough that seedlings do not dessicate.

4. Absence of post-germination floods that would scour seedlings.

Table 4.4.1. Summary of differences between native and non-native riparian vegetation species.

CHARACTERISTIC	RUSSIAN OLIVE *(E. angustifolia)*	TAMARISK (*Tamarix* sp.)	WILLOW *(S. exigua)*	COTTONWOOD *(P. fremonti)*
Stand Density	high	high	high	low for mature stands
Near-ground Stem/Branch Density	high	high	high	low for mature stands
Root System	deep and extensive	deep and extensive	extensive	9.8-16.4' deep for mature stands
Seed Viability	3 years	24-45 days	1 week	1-5 weeks
Timing of Seed Production	June-July	throughout entire growing season	March-June	April-June
Ability to Germinate in Shade or Within Ground Cover	yes	no	no	no
Require Sunny, Bare, Moist Flood Deposits for Germination	no	yes	yes	yes
Age to Maturity/Initial Seed Production	3-5 years	3 years		5-10 years
Relative Salinity Tolerance	moderate to high	high	low	low
Relative Drought Tolerance	high	high	low	low
Relative Inundation Tolerance of Seedlings	no data found	low	high	high

Once Russian olive becomes well-established in a given location, it is unlikely that the first requirement for cottonwood recruitment – the presence of a bare, sunny surface with fresh sediment – will be met at that location. In this manner, Russian olive is able to invade floodplain areas and prevent recruitment of new cottonwoods that otherwise might replace historically established but now-senescent, mature cottonwood stands.

Relative Influences of Native and Non-Native Vegetation

It is challenging to distinguish the role that non-native vegetation has played in the loss of channel complexity on the San Juan River from the general influences of riparian vegetation described in Section 4.1. Studies have found that tamarisk can be effective at trapping sediment and stabilizing bars and streambanks. Cooper et al. (2003) describe that tamarisk stems reduce near bed flows and increase the shear stress required to remobilize the channel bed. This causes the armoring of gravel and cobble islands and bars, leading to bar enlargement and subsequent channel narrowing. These changes have been observed on both the regulated Green River and the unregulated Yampa River (Larsen 2004). In addition to these empirical observations, the effects of tamarisk on flow resistance have been quantitatively documented in flume experiments examining the effects of vegetation on flow resistance. Results from flume runs planted with tamarisk had bed roughness (Manning's "n") values of 0.067 to 0.119, as opposed to values of 0.02 to 0.022 in unvegetated flume runs (Freeman et al. 2000).

However, our observations on the San Juan River demonstrate that willows are also highly effective at capturing sediment and promoting vertical accretion of bar and island surfaces. As with tamarisk, these observations are supported by the results of flume experiments. Flume runs planted with mountain willow (*Salix monticola*) had bed roughness (n) values of 0.064 to 0.143, compared to values of 0.02 to 0.022 in unvegetated flume runs (Freeman et al. 2000). These increases in hydraulic roughness are similar to the increases measured in the flume runs planted with tamarisk. Sandbar (coyote) willow (*Salix exigua*) is the most common willow type on the San Juan River. Although roughness calculations were not completed for flume runs planted with sandbar willow, a normalized index (modulus) of plant stiffness was determined based on flume experiments. A higher plant stiffness value is correlated with a higher hydraulic roughness. Sandbar willow was found to have a plant stiffness of 104,000 lbf/ft^2, while tamarisk was found to have a stiffness of 82,070 lbf/ft^2 (Freeman et al. 2000).

No flow resistance experiments were performed with cottonwoods or with Russian olive, so the effects of these plants on roughness can not be quantitatively compared with tamarisk and sandbar willow. However, observations by researchers on the San Juan River indicate that Russian olive plants have stiffer stems and branches relative to the other riparian species, leading to a higher hydraulic roughness for Russian olive stands (R. Bliesner 2006, pers. comm.). Because of this higher stiffness, Russian olive trees occupying streambanks have a tendency to be completely scoured away and fall into the river during high flows, whereas the other riparian species would be more likely to flatten or bend and then recover following a high-flow event (R. Bliesner 2006, pers. comm.).

Additional inferences about Russian olive and cottonwood can be made based on differences in plant structure. Like tamarisk and willow, Russian olive tends to grow from multiple stems, and forms a dense "thicket" of branches, stems, and leaves near the ground (Figure 4.4.1). In contrast, mature cottonwoods on the San Juan River typically have only one or two main stems, and branching occurs higher above the ground to form a broad high canopy (Figure 4.4.1). In

Figure 4.4.1. **Comparison photos of plant structure for four major riparian plant types within the Study Area. Note low stem and near-ground branch density of cottonwood relative to other plant types. Note that the tamarisk photo is of a mature plant; young tamarisk stands are more similar to willow (see Figure 4.1.5).**

addition, mature cottonwood trees tend to be less densely spaced than Russian olive, tamarisk, or sandbar willow. Because of these plant structure differences, a cottonwood forest would likely have a lower hydraulic roughness than the other three plant types. A young cottonwood stand, however, grows more densely and would have hydraulic properties more similar to willow, Russian olive, or tamarisk stands.

This difference means that, prior to the arrival of tamarisk and Russian olive, floodplain and island areas on the San Juan River vegetated by cottonwoods would likely have been more susceptible to channel avulsion or the scouring of secondary channels, overbank channels, and cross channels. During overbank flows, scour would have been possible in the bare, unprotected areas between individual cottonwood trunks, whereas Russian olive now forms a dense, complete, and highly scour resistant thicket on floodplain surfaces. Thus, the present dominance of Russian olive on the San Juan River has reduced the effectiveness of floods in creating channel complexity, and is most likely contributing to the decline of backwater habitat availability in the Study Area. On bars and lower bank areas where willows would have historically been the dominant vegetation type, the addition of tamarisk and Russian olive to the vegetation mix may not be as significant in terms of altering flow resistance, since the structure of willow is more similar to the non-natives.

In addition to increasing the scour resistance of areas historically occupied by cottonwoods, the introduction of non-native riparian species into the Study Area has also most likely increased the overall areal extent of riparian vegetation. The higher drought tolerance and salinity tolerance of both non-native species allows them to grow in saline soils and relatively dry areas that would not support cottonwood or willow. Because it has a longer seed production window and less stringent establishment requirements, tamarisk can germinate and grow whenever bare, moist soil is available, while the native plants can only become established during the spring runoff period. Historically, in a year with low spring runoff, the higher-elevation portions of bars and streambanks would remain unvegetated and susceptible to future mobilization. With tamarisk in the mix, however, these areas could become vegetated if inundated by high flows earlier or later in the growing season. Similarly, the multi-year seed viability, shade tolerance, and lower dependence on disturbance of Russian olive allows it to establish more frequently and under a broader range of hydrologic conditions than the native plants. In summary, the presence of non-native riparian species in the San Juan watershed means that woody vegetation can become established more often and on more fluvial surfaces. Over time, this results in a smaller area of active, unvegetated channel susceptible to mobilization. In turn, this may limit the development of new channels and bars, and reduce the number of channel features that can form backwater habitats.

5. RESTORATION CONCEPTS

5.1 Introduction

River restoration projects are being implemented throughout the United States at a rapidly increasing rate (Bernhardt et al. 2005). Since 1990 an average of more than $1 billion per year has been spent on river restoration efforts (Bernhardt et al. 2005). Unfortunately, many restoration efforts have not been entirely successful. Typical reasons for failure include: a lack of understanding of the ecological and geomorphic history of the area, treatment of the symptoms of degradation rather than the underlying causes, failure to approach the project at the appropriate scale, lack of adequate understanding of scientific ecological principles, and failure to identify specific goals and adaptively monitor and manage to achieve those goals (Williams et al. 1997). Researchers involved with restoration science have proposed that projects will be most effective if they are pursued within a watershed context and if they emphasize restoration of critical ecosystem processes (Wohl et al. 2005).

Within the context of this particular study, the goal of implementing restoration efforts on the San Juan River is to improve retention of young Colorado pikeminnow and help recover the Colorado pikeminnow population by improving the availability and/or quality of backwater habitat within the Study Area. However, under the broad umbrella of this overall goal, there are a range of specific objectives and "levels" of restoration that can be pursued for any particular individual project. The habitat creation concepts described in Section 5.3 are relatively small-scale approaches that specifically focus on "form" (backwaters) without necessarily addressing larger-scale geomorphic processes. As alluded to in the discussion above, local-scale habitat creation efforts will tend to have a lower likelihood of long-term success and are unlikely to be self-sustaining.

At the other end of the spectrum are the destabilization concepts described in Section 5.5. These restoration activities focus on restoring a larger active channel area and promoting dynamic channel processes that create and maintain the desired "form" (backwaters). The vegetation management and removal concepts described in Section 5.2 also fall within the category of larger-scale, process-focused restoration techniques. Determining which type of techniques are most appropriate depends on specific restoration objectives. Small-scale habitat creation projects may be appropriate if they are implemented with the understanding that their effectiveness will be short lived unless they are regularly maintained. Habitat creation projects can also be appropriate when there is a need for rapid results and when societal, logistical, and economic realities constrain the ability to fully restore natural processes at a watershed scale. On the San Juan River, complete restoration of natural hydrologic and sediment regimes is not feasible because of the presence of Navajo Dam and residential and agricultural water needs. In addition, the widespread presence of tamarisk and Russian olive throughout the southwestern United States (i.e., at a scale even larger than the San Juan watershed), combined with the fact that much of the watershed is within private ownership, means that complete watershed-scale eradication of non-native vegetation and full restoration of natural riparian processes is not realistic. However, restoration efforts on the San Juan River should ideally strive to incorporate natural process restoration to the extent possible or at least should be implemented with the recognition of the importance of these underlying processes.

Specific questions that the SJRIP should consider when defining restoration objectives and selecting specific restoration techniques include:

- What is the target number of bars, islands, and secondary channels for the Study Area?

- At what range of flows is it most important to maximize backwater habitat?

- At what time of year is it most important to maximize backwater habitat?

- Is it more beneficial to create/restore many smaller backwater habitats, or fewer but larger backwater habitats?

The answers to these questions as well as specific restoration objectives may change with time. Focusing on small-scale habitat creation to maximize backwater availability during the fall stocking period may be the most appropriate objective in the short term. As Colorado pikeminnow populations begin to increase, focusing on larger-scale, more holistic restoration of dynamic channel processes that would also benefit spawning habitat and native vegetation recruitment may become a more important objective. Regardless of the particular restoration project or technique selected, it is important to explicitly define the project objective(s) so that success and effectiveness can be evaluated.

5.2 Vegetation Removal / Management Concepts

Vegetation removal is an integral component of many of the restoration activities described below, particularly secondary channel entrance reestablishment, bank and island destabilization, and floodplain lowering. In addition to clearing vegetation when a restoration activity is initially implemented, vegetation management/control will be an important long-term technique for maintaining backwaters within the Study Area. As described above in Section 2.3, considerable vegetation encroachment occurred on islands, bars, and in secondary channels during the dry climate conditions between 1998-2004. Droughts will occur again in the future, and will not always be followed by flows as high as the 2005 spring runoff. Because flows alone will not always be effective in controlling vegetation encroachment and maintaining open bars and secondary channels, active annual or biannual control may be needed to remove young tamarisk, Russian olive, or willows from important backwater-supporting channel features. Climate and hydrology patterns will largely define the needed control frequency.

A variety of different vegetation removal/control techniques can be used, and selection of appropriate technique(s) will depend primarily on the size and composition of the vegetation stand and the accessibility of the site. The Tamarisk Coalition (2005) has developed a report providing detailed descriptions and photographs of various control techniques for tamarisk, and we have summarized this information in Table 5.2.1. The complete report can be found on-line at: http://nmdaweb.nmsu.edu/DIVISIONS/APR/TAMARISK/NM%20Options%20for%20 Control%203-31-05.pdf.

Although the specific focus of these techniques is tamarisk control, the methods would also be applicable to removal of Russian olive or willows. Because cottonwoods are relatively rare in the Study Area and do not tend to armor banks and islands to the same extent as the non-native species, cottonwood removal is not recommended as a technique for restoring backwaters. In some cases, it may be beneficial to promote cottonwood establishment on a site as means of limiting tamarisk or Russian olive establishment.

Additional information on the effectiveness of specific control strategies for Russian olive and tamarisk is provided below.

Russian Olive Control Strategies

Once Russian olive is established in a watershed it is very difficult to eradicate. Successful control of small patches is possible by using multiple eradication strategies, though costly and labor intensive (TNC 2003). Treatment strategies to remove Russian olive stands have included mowing, cutting, burning, excavation, spraying, girdling, and bulldozing. Combining control treatments on small, isolated stands of Russian olive has been most effective.

When the soil is moist, Russian olive seedlings and saplings can be pulled out of the ground by hand or with a weed wrench. A weed wrench can successfully pull out a Russian olive with a diameter less than 3.5 inches (Deiter 2000). Larger plants can be cut or girdled, but stumps and roots sprout vigorously in response to cutting and therefore need to be treated with herbicide immediately.

Prescribed burning of Russian olive stands can control seedlings but it stimulates root growth in larger trees. This method can be used in combination with other methods such as herbicide application following burning.

All sizes of Russian olive trees (seedlings, saplings and mature trees) can be successfully killed using herbicides. Young trees, seedlings, and saplings can be foliar or basal sprayed. Older trees need to first be cut as low to the ground as possible before immediately (within 5 minutes) spraying the stump (TNC 2003). Herbicides used to successfully kill Russian olive include glyphosate (e.g., Rodeo, RoundUp) and triclopyr ester (e.g., Garlon 4).

Table 5.2.1. Summary of different non-native vegetation control strategies.

TREATMENT TYPE	DESCRIPTION	EFFECTIVENESS	STAND TYPE/ APPLICABILITY	COST	PROS/CONS
Hand cutting with herbicide application	Individual tree removal using chainsaws. Herbicide application to stump within 15 minutes.	85% effective. Requires herbicide treatment of re-growth.	Difficult access areas – canyons, washes, irrigation ditches, and steep banks. Use in mixed vegetation to protect native plants.	Very expensive. $1500 - $5000 per acre	• Effective in mixed vegetation. • Expensive, best for difficult access areas. • Spot herbicide treatment for re-growth.
Mechanical removal – bulldozer/root plow	Bulldozer followed by root plow used for root crown removal. Removal of all vegetation.	80-95% effective.	Easy access, monotypic stands. No steep slopes.	$800 per acre	• Requires level, accessible terrain. • Severe soil disturbance. • Flood irrigation water for revegation. • No initial herbicide treatment. • Spot herbicide treatment for re-growth.
Mechanical removal – excavator	Large excavator plucks individual trees from ground.	80-95% effective.	Use in mixed stands. Use where equipment can access steep slopes and river banks.	$150-$600 per acre, depending on stand density; cost may exceed this range for dense stands along riverbank.	• Removes only target species. • No initial herbicide treatment. • Minimal soil disturbance. • Best if tree form.
Mechanical removal – mulcher	Large mulching equipment mows through vegetation. Herbicide application to stumps.	85% effective.	Easy access, mixed stands. No steep slopes.	$220 - $800 per acre.	• Removes only target species. • Minimal soil disturbance. • Stems in moist soils can sprout into new plant. • Spot herbicide treatment for re-growth.

TREATMENT TYPE	DESCRIPTION	EFFECTIVENESS	STAND TYPE/ APPLICABILITY	COST	PROS/CONS
Hand herbicide application	Herbicide is sprayed on foliage or the basal bark of target species using backpack, horseback, or vehicle-mounted sprayers.	85% effective.	Light density infestations with access to all leaf surfaces or basal bark.	$5 per plant (general, depending on plant size).	• Inexpensive for light infestations. • Allows removal in remote and difficult access areas. • Spot herbicide treatment for re-growth.
Aerial herbicide application	Herbicide, typically imazapyr (approved for use near water in New Mexico), application using helicopter or fixed- wing aircraft.	95% effective.	High density, monotypic, large area stands.	$200 - $250 per acre This price requires a 1,000 acre minimum and does not include cost of removal of dead trees.	• Kills almost all vegetation. • Not recommended for areas with significant native vegetation component. • Potential negative impacts to wildlife habitat. • Spot herbicide treatment for re-growth.
Biological control – goats	Control tamarisk by defoliation.	Unknown, preliminary tests show a 3-year goat presence requirement.	Goats have been used in fenced, monotypic, young stands of tamarisk.	$1,100 per acre in one test area.	• Unknown, large study underway on Rio Grande in New Mexico.
Biological control – Chinese leaf beetle	Control tamarisk by defoliation.	Unknown, within tented research cages, tamarisk plants died after 3 successive years of defoliation.	Could be used in any stand type.	Inexpensive; less than $10 per acre This does not include removal of dead trees.	• Negative impact to endangered southwestern willow flycatcher. • Risk of impacts to other plant species.
Dead tamarisk removal	Removal of dead trees by fire or mulching after successful treatment.	NA	Necessary in moderate and heavy infestations for revegetation and establishment of native species. May not be necessary in light infestations.	Fire=$50 - $100 per acre. Mulching= $400 per acre.	NA

Source: New Mexico Options for Non-Native Phreatophyte Control (Tamarisk Coalition 2005).

The most effective method for removing Russian olive has been to combine mechanical vegetation removal with herbicide treatment. Caplan (2002) reported success with cutting the tree and treating the stump with a 50% solution of Garlon 4 within 5 minutes. This method proved most successful on trees sized 4 inches in diameter and smaller. This treatment was followed up with a 25% solution of Garlon 4 application to the root sprouts for two years. Caplan (2002) reports that after two years of treatment he found less than 3 sprouts per acre. This method requires significant labor, monitoring, and maintenance for long-term success, but would be useful for removal of small, isolated stands of Russian olive. Most herbicides are restricted in areas where water is present. Care must be taken when working in areas where water is present. Rodeo (glyphosate) is an approved herbicide for use in aquatic areas.

Tamarisk Control Strategies

The Bosque del Apache National Wildlife Refuge (located on the Rio Grande in central New Mexico) uses bulldozing and root plowing (mechanical) and aerial herbicide spraying (chemical) for tamarisk control (Zouhar 2003). These methods, combined with late summer floods, were compared by Sprenger and others (2001). Areas where mechanical removal methods were used showed more success and had better cottonwood recruitment than areas where chemical removal methods were used. Almost all tamarisk seedlings less than 5 weeks old were killed by the late summer floods, but most older seedlings (10 weeks old) withstood the flooding.

Other tamarisk removal research at the Bosque del Apache National Wildlife Refuge has been conducted by Taylor and McDaniel (2004). They use integrated control techniques that include chemical, mechanical, burning, revegetation, and flooding. Plant densities determine which removal method is used. Mechanical techniques removed all portions of the plants, including the roots. Aerial herbicide (glyphosate and imazapyr) application on large stands was followed by prescribed burning after two to three years. They found the treatment of root sprouts was required for two to three years. Removal was followed by revegetation with cottonwoods and willows and flooding to mimic natural Rio Grande flows. Cottonwood and willow germinated in response to flooding and this appears to be as successful as planting plants and more cost effective. The above treatments have reduced plant densities from about 7000 plants/ha (2,800 plants/acre) to about 50 plants/ha (20 plants/acre) in 4 to 6 years.

Tamarisk has been successfully removed from a 25 acre wetland in the Coachella Valley Preserve in Southern California (TNC 2001). Removal began in spring of 1986 and took 5 years. Trees were removed by cutting close to the ground and then treating the stumps immediately with triclophyr. A 7.5-acre heavy infestation area was treated with a bulldozer. Hand removal left native vegetation intact and cut debris was piled around the preserve to provide habitat for birds. Root sprouts were sprayed with triclophyr on a yearly basis with the best effectiveness appearing to be during the months from November through January. The springs began flowing almost immediately after initial removal efforts. Revegetation was accomplished by spreading seeds collected from nearby vegetation with the bulldozed areas revegetating at a much slower rate than the hand cleared areas. After nine years native vegetation is present at the site at natural levels and there is almost no sign of tamarisk.

Successful tamarisk removal requires continued maintenance. Augmenting flow regimes with pulse floods will aid in preventing re-establishment. On Green River test removal plots in Dinosaur National Monument (UT), removal of tamarisk without altering the fluvial component appears to result in either tamarisk re-establishment or site invasion with other noxious weed species (e.g.. Thistle [*Cirsium* spp.], Whitetop [*Cardaria* spp.]) (M Scott 2005, pers. comm.).

5.3 Habitat Creation Concepts

The focus of restoration concepts within this category is the targeted creation of relatively small-scale, managed backwater habitats that do not necessarily correspond to a natural, historical channel template. Specific types of "creation" activities are described below, and appropriate locations for these activities are listed in Section 6 of this report.

Constructed Bank Indentations/Crenulated Shoreline

This restoration activity involves digging out a series of indentations, or "scallops" into the river bank to create a shoreline with a "crenulated" appearance (Figure 5.3.1). The irregular bankline would create eddies or slackwater areas that would serve as low-velocity habitats similar to backwaters. Individual bank indentations could be varied in size, shape, position, elevation, and alignment to provide a variety of habitats (Figure 5.3.2).

Low bank areas with convenient heavy equipment access would be the most appropriate locations to create bank indentations. Because "construction" would simply entail straightforward excavation of relatively small volumes of material, bank indentations would be relatively cheap to implement. However, because the indentations would not be flow-through systems, they would be subject to sediment in-filling over time. This process would limit the long-term effectiveness of this restoration activity. Regular maintenance to remove accumulated sediment would most likely be needed. Topographic surveys and hydrodynamics models could be used to help design indentation shapes, alignments (angle relative to bankline), and positions (i.e., straight bank vs. inside or outside of bend) that would promote scour and reduce the rate of sediment in-filling. Monitoring different types of constructed indentations would also be useful in identifying the most effective designs.

A variation on the bank indentation restoration technique could be implemented in order to help prevent sediment in-filling and reduce maintenance needs. This variation would involve installing a headgate along the river bank at the entrance to the indentation. The headgate could be kept closed during the spring runoff period, when the river carries high sediment loads that would be likely to deposit in the indentation. During the lower flow periods in the summer, fall, and winter, the headgate could be kept open to allow young fish to access the indentation habitat.

Figure 5.3.1. Photo of constructed bank indentations (area within red circle) installed as part of the Los Lunas Habitat Restoration Project on the Rio Grande.

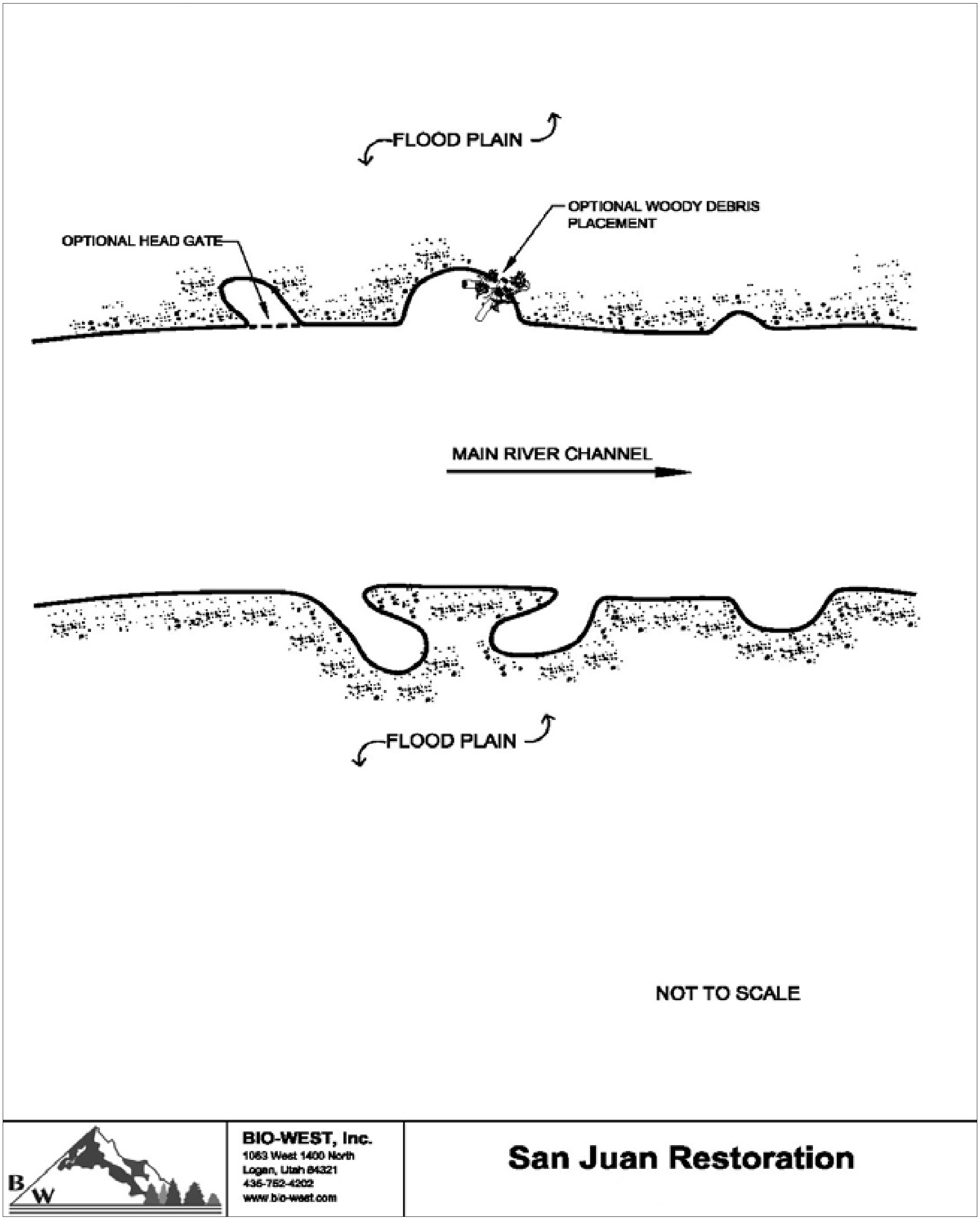

Figure 5.3.2. Conceptual sketch of different shapes, alignments, and types of constructed bank indentations.

If operated in this manner, the bank indentation would still be subject to sediment in-filling during summer and fall storm events. The “bank indentation with headgate” restoration technique would be more expensive to initially install than bank indentations alone, but may be less expensive in the long run depending on needed maintenance frequency. In addition, the “headgates” could be something as simple as slots that would hold stacked boards, which would still keep installation costs relatively low compared to other types of restoration activities. However, the benefits of a headgate may not outweigh the increased installation, management, and maintenance costs. Regular cleaning of accumulated sediments would probably still be required, and the presence of a headgate may reduce the accessibility of the habitat for juvenile fish.

Another variation on this restoration activity would involve placing woody debris within the bank indentation feature. Tree trunks could be embedded in the banks around the indentation and backfilled or anchored/cabled in place. The woody material would add diversity to the habitat and provide protective cover and shading.

Irrigation Return Channel Enhancement

This restoration activity involves relocating or reconfiguring the downstream portions of irrigation return channels where they enter the San Juan River. As previously discussed in this report, irrigation returns appear to help maintain existing backwaters in the Study Area by flushing accumulated sediment and minimizing the extent of vegetation encroachment. Currently, in some locations, existing irrigation returns enter the river via straightened ditches or steep, narrow channels that do not have any backwater habitat potential. In these locations, enhancements could be implemented to realign and reshape the return channel such that it would provide backwater habitat under certain flow conditions.

Enhancements could involve simply widening and deepening the mouth of the irrigation return channel so that river water would back up into the channel mouth. The return channel could also be realigned through the floodplain to reduce its gradient, and its banks could be widened and laid back to create a larger area of wetted habitat and a larger potential backwater (Figure 5.3.3).

Irrigation return channel enhancements could be completed as stand-alone restoration projects, or implemented in conjunction with other activities such as secondary channel creation/restoration or installation of constructed bank indentations. If implemented in this way, the irrigation return flows could be used to help flush accumulated sediments and limit vegetation growth, ultimately improving the long-term effectiveness of the overall restoration project. An irrigation return could even be split into two outlet channels connected to two separate features, and a headgate could be used to alternately direct flow into one or the other of the outlets (Figure 5.3.4). Under this scenario, the irrigation return would essentially be used as a management device to help maintain backwaters. Creating “two outlet” irrigation returns would also improve backwater habitat quality during the irrigation season by limiting the less-desirable cool, clear irrigation water to just one of the outlets.

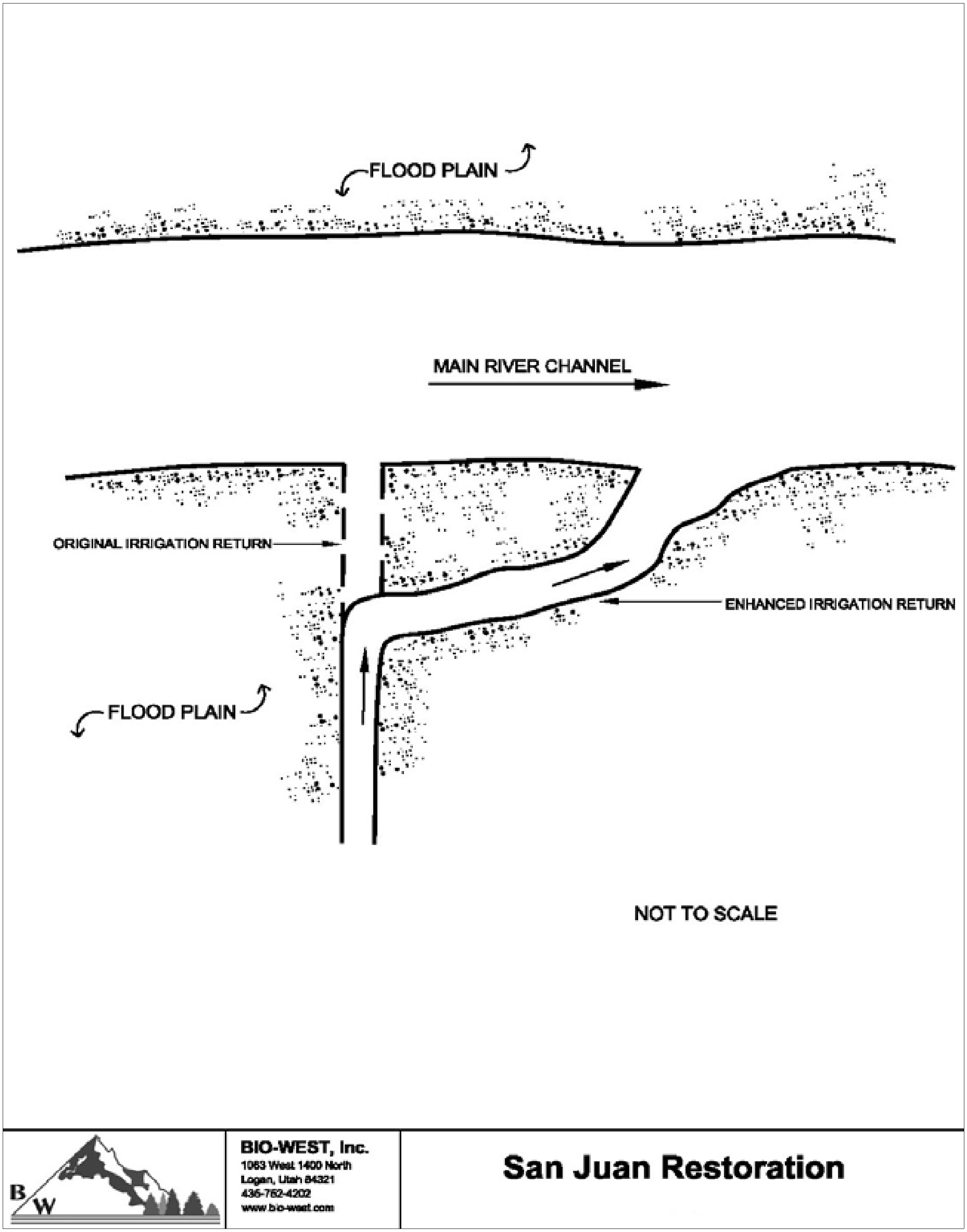

Figure 5.3.3. Conceptual sketch of enhanced irrigation return channel.

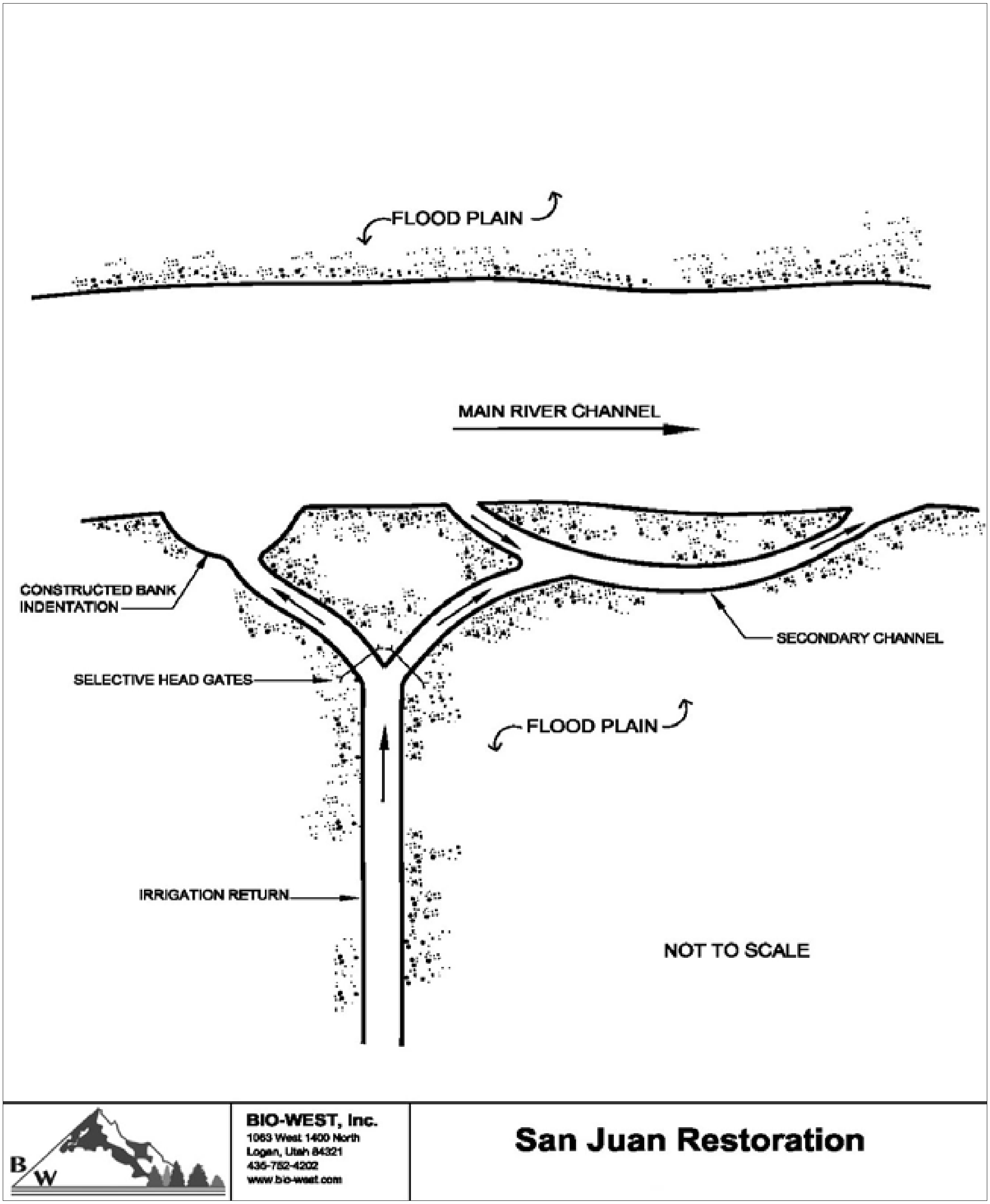

Figure 5.3.4. **Conceptual sketch of enhanced irrigation return channel installed with two outlets and combined with secondary channel and bank indentation features.**

Another variation on this restoration activity would involve placing woody debris at the mouth of the enhanced irrigation return channel and/or along its banks to provide protective cover and shading.

In terms of cost, irrigation return channel enhancements would be relatively low cost to implement. As with constructed bank indentations, excavation expenses would be the primary costs. In floodplain areas with dense, mature stands of Russian olive, vegetation removal costs to allow for heavy equipment access would also be incurred. If the “two outlet” option were selected, there would be additional costs associated with headgate installation. However, the headgate could be a very simple, low-cost structure such as an open-top concrete box with slots in the sidewalls to hold stacked boards. For smaller irrigation returns, it may even be possible to simply use piled sandbags to block off one of the outlet channels.

Woody Debris Placement

This restoration activity involves placing or embedding large woody debris (tree trunks or large branches) along the river bank, within the river channel, or within constructed or restored habitat features. Logs could be placed in piles along the edges of mid-channel bars to create small slackwater habitats and provide cover. Individual logs or piles could be placed along the river bank to promote scour or localized bank erosion that would create a bank indentation and low-velocity habitat.

Woody debris could either be placed freely or anchored in place using cable and rebar. Placement of unanchored debris would not be appropriate in areas just upstream of diversion structures or bridges, where floating logs could accumulate and cause damage or require removal. Debris placement may be particularly suitable in secondary or overbank channels, where stream power would typically be lower than in the main channel and logs would be more likely to remain in place. Woody debris placement could be done as a stand-alone restoration project, or as a component of any of the other activities described in this report.

Costs for woody debris placement would be relatively low. The dense forests of Russian olive that line the banks within the Study Area provide a convenient, on-site source of logs. Therefore, equipment and labor costs for harvesting and placing logs would be the primary expense. Additional costs for rebar, cable, boulders, or excavation would be incurred for anchored or buried woody debris installations.

As discussed in Section 3.2, monitoring studies of stocked YOY Colorado pikeminnow indicate that the young fish exhibit a preference for low-velocity habitats with cover (Golden et al. forthcoming). Therefore, incorporating woody debris placement into a restoration project could provide improved habitat quality for relatively little cost. However, pre-installation surveys and proper installation design will be important to ensure that the debris structure provides cover at an appropriate range of flows and that it will not be susceptible to rapid siltation or wash-out. Debris pile studies conducted as part of stocked YOY Colorado pikeminnow monitoring efforts have found that small changes in flow can lead to stranding, siltation, or wash-out of placed debris piles, or conversion of the habitat from a backwater to a higher velocity flow-through condition (Golden et al. forthcoming). If not installed properly, the habitat benefit of a woody debris placement will likely be short-lived.

5.4 Secondary Channel Restoration/Creation Concepts

The focus of restoration concepts within this category is to restore or create secondary channels, overbank channels, and cross channels within the Study Area. Creation or enhancement of these types of features increases overall channel complexity and diversity, increasing the potential for formation of low-velocity/backwater habitats. However, creating habitat complexity does not necessarily guarantee that a backwater will be present at the desired flow level or time of year, and secondary channels do not always form backwaters. Therefore, the restoration concepts described in this section have somewhat lower “outcome certainty” than the habitat creation concepts described above.

Depending on the desired result and the individual site conditions, the level of effort involved in secondary channel restoration/creation can range from minor to major. Specific activities are described below, and appropriate locations for these activities are listed in Section 6 of this report. Any of the secondary channel restoration/creation concepts described below could be implemented in conjunction with woody debris placement, irrigation return enhancement, or bank indentation construction. The use of combined techniques would serve to enhance the overall complexity and habitat value of the created or restored secondary channel.

Secondary Channel Entrance Re-establishment

This restoration activity involves removing encroached vegetation and accumulated sediment “plugs” from the entrances to previously active secondary, overbank, or cross channels. This technique is appropriate in locations where a fairly well-defined secondary channel is still present, but has been disconnected from the main river by a localized accumulation of sediment blocking its entrance.

Costs for this activity would be relatively low, since the volume of material that would need to be removed would be fairly small. Costs would be limited to equipment and labor costs to clear vegetation and excavate the material. Depending on the site, additional vegetation clearing may be needed to provide heavy equipment access. Overall, secondary channel entrance reestablishment represents a minor level of effort relative to the range of specific secondary channel restoration/creation concepts.

Specific project costs would depend on the amount of accumulated material and desired depth of excavation at a particular site. During our August 2005 field visit, we used a total station to survey the entrance to the overbank channel at RM 171.8 (south side of river) and calculate the approximate volume of sediment that would need to be removed to reestablish this channel. At this site, a sand deposit approximately 30 feet wide, 20 feet long, and 1 to 2 feet thick has accumulated at the channel entrance (Figure 5.4.1). Presently this sand deposit does not completely block all flow from entering the channel, but it reduces the volume of flow into the channel, and has increased the river stage at which flow enters the overbank channel. Removal of the approximate 33 cubic yards of accumulated material would increase the frequency and amount of flow entering the overbank channel, which could help maintain the size of the backwater at its mouth.

Pilot Channel Excavation

This restoration activity involves excavating the upstream portion of a secondary channel or overbank channel. When flow is introduced, the river would “self-excavate” the remainder of the channel. Relative to complete secondary channel excavation, this technique minimizes disturbance to the floodplain and reduces costs associated with excavating and hauling material.

Pilot channels could be used to reactivate historical secondary and overbank channels (secondary channel restoration), or to establish channels in new areas (secondary channel creation). The amount of excavation required to create an effective pilot channel would vary depending on the site conditions and the desired final channel size. In locations where secondary channels have been active more recently (i.e., where open channels are visible in 1988 air photos, or have been mapped during 1990s habitat mapping), a pilot channel may require only slightly more excavation than the secondary channel entrance reestablishment technique described above. In areas where woody vegetation has become established within the inactive historical channel, vegetation removal may be required along the entire channel corridor in order for the pilot channel to successfully self-excavate. Specific vegetation removal techniques are described below in Section 5.5.

Larger pilot channel excavations would be required for creation of secondary channels in new locations, and for restoration of historical secondary channels that have been inactive for longer periods of time and are poorly defined. In these cases, rather than simply excavating the upstream portion of the channel, a small “footprint” channel (i.e., an undersized version of the secondary channel) may need to be excavated along the entire secondary channel corridor. Specific pilot channel dimensions (gradient, width, etc.) would need to be tailored to the specific site, taking into account the tie-in elevations at the entrance and exit of the secondary channel as well as the composition (susceptibility to erosion) of the substrate materials. Two key factors in designing pilot channels would be insuring that adequate flow enters the channel and designing the pilot channel slope (knickpoints, etc.) such that it promotes scour in desired locations.

Costs for pilot channel excavation would range from relatively low to high depending on the scale of the pilot channel. Equipment and labor costs for excavation and vegetation removal would be the primary expenses. Additional costs would be incurred where site access requires additional vegetation removal, and where site conditions would require off-site hauling of excavated material. Costs would be lowest in areas with low banks, and in areas where well-

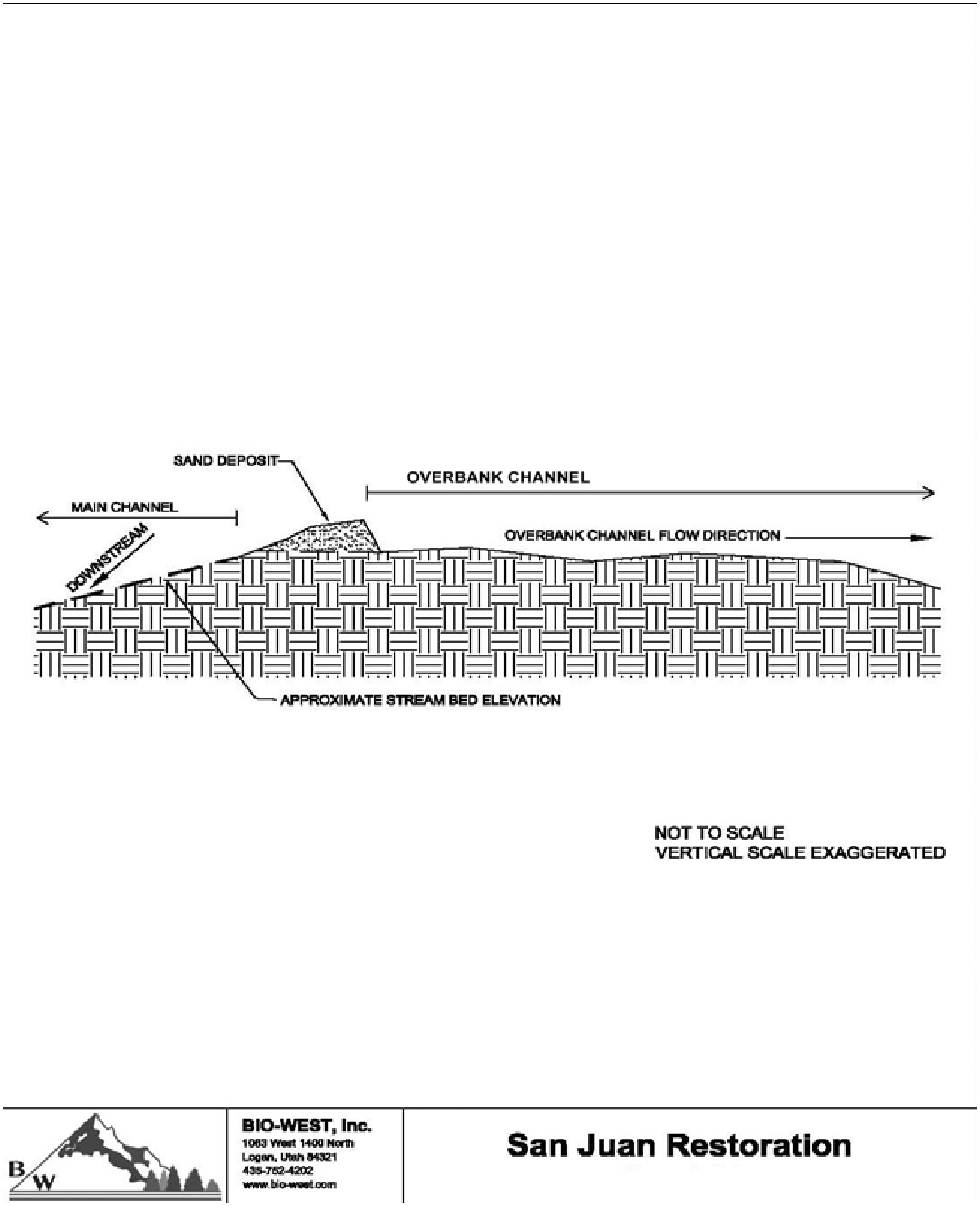

Figure 5.4.1. Plot of surveyed sand deposit at entrance to overbank channel at RM 171.8.

defined, low-elevation historical channels are present. Pilot channels to create secondary channels would generally be more costly than piloting overbank channels, since excavation to a lower elevation would probably be required.

Pilot channels are most appropriate in relatively large, undeveloped floodplain areas where the instabilities associated with active channel erosion would not pose a risk to infrastructure. Pilot channels would be most cost effective when used to restore historical secondary, cross, and overbank channels, or to create relatively small new channels. If the entrance to a historical cross-channel departs at a sharp angle to the main flow and is not subject to high flow velocities, realignment of the entrance or redirection of the main flow may be needed to ensure that entrance flow velocities are adequate to initiate erosion. Hydraulic modeling of the site should be performed prior to any excavation to determine whether or not these additional efforts are needed.

Complete Secondary Channel Excavation

This restoration activity involves excavating an entire secondary, overbank, or cross channel to its desired final dimensions. This technique could be used to either create an entirely new secondary channel, or to restore an inactive historical channel. Secondary channel excavation would generally be most cost effective if used to restore historical channels that have only partially filled in with sediment, since these areas are typically topographic low spots and less material would need to be removed. For the same reason, low bank areas would be preferred locations for this restoration activity.

Costs for secondary channel excavation would range from moderate to high depending on the size of the excavated channel. Equipment and labor costs for vegetation removal, excavation, and grading would be the primary expenses. Additional costs would be incurred where site access requires additional vegetation removal, and where site conditions would require off-site hauling of excavated material.

To provide an example of how much material may need to be removed for a particular channel restoration project, we used a total station to survey a vegetated, accreted cross channel at RM 170.2 during our August 2005 field visit and calculated the approximate volume of sediment that would need to be removed to restore flow through the cross channel (see Figure A6 for photo of site). Figure 5.4.2 shows a profile view of the existing channel and a possible restored bed profile. Approximately 2 feet of accumulated sediment would need to be removed along the length and width of the channel, for a total volume of about 300 cubic yards. At an estimated unit cost of $8 per cubic yard, total excavation cost would be $2,400. At an estimated clearing and grubbing cost of $436/acre, it would cost an additional $45 to remove this amount of vegetation (UDOT 2006). Unless additional access costs were very high, this would therefore be a relatively inexpensive project to implement.

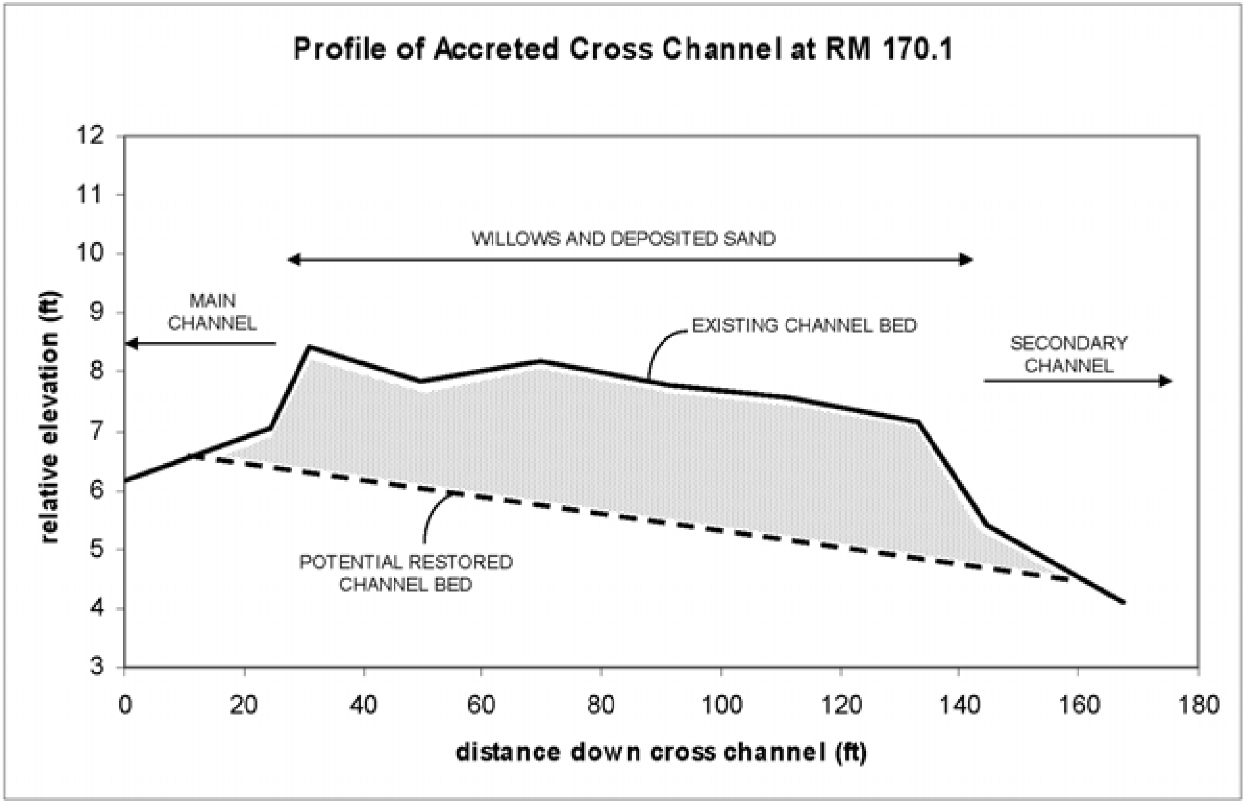

Figure 5.4.2. Profile plot of accreted cross channel at RM 170.1. The shaded area represents the amount of material that would need to be removed to restore the channel to a lower bed elevation and a more active condition.

Specific channel designs (size, cross-sectional shape, alignment, gradient) would depend on individual site conditions. Because the primary purpose of the excavation would be to create backwater conditions at the exit (and/or entrance) of the secondary channel, care would need to be taken to ensure that the design promotes scour rather than deposition in these target areas. The dimensions and slope of existing natural secondary channels that have consistently maintained backwaters at their mouths could be surveyed and used as design templates. Field observations suggest that secondary channels with steep entrance slopes and flatter outlet slopes tend to be more effective at creating backwaters.

Headgate-Controlled Secondary Channels

This restoration activity involves installing headgates at the entrances and/or exits to excavated secondary or overbank channels. Incorporating headgates into a secondary channel creation or restoration project would add flexibility in terms of controlling sediment in-filling and managing flow depths and velocities to maximize backwater conditions. As described for the headgate-controlled constructed bank indentation option, gates could be closed during the spring runoff period to limit high-flow sediment deposition. If sediment in-filling does occur, an entrance headgate could be operated to sluice accumulated material out of the secondary channel mouth. Headgates would also provide a convenient means of isolating the secondary channel from the main river to assist in fish sampling or non-native fish control efforts, or with acclimation experiments with stocked hatchery fish.

Headgate installation would be most appropriate in secondary channels (rather than overbank channels), where the headgates would be functional at both low and high flows. Convenient access to the site would also be important. Because headgates would provide greater control over potential erosion or channel instability, they may also be particularly appropriate to use in project sites located near developed infrastructure.

Construction costs would be greater for headgate-controlled secondary channels than for projects installed without headgates. Headgate costs would vary depending on size and type. Selection of the appropriate headgate type would depend on the desired opening style (i.e., gates that open from the bottom versus from the top) and security needs. The benefits of a headgate may not outweigh the increased installation, management, and maintenance costs. Periodic cleaning of accumulated sediments would likely still be required, and the presence of a headgate may reduce the accessibility of the habitat for juvenile fish.

5.5 Destabilization Concepts

The focus of restoration concepts within this category is to restore a larger active channel area and promote dynamic channel processes and channel change. Restoration of dynamic channel processes will increase overall channel complexity and diversity, increasing the potential for formation of low-velocity/backwater habitats. However, promotion of channel change will not necessarily translate directly into increased backwater availability at the desired flow level or time of year. Therefore, the destabilization concepts described in this section have a lower initial "outcome certainty" than the other restoration concepts described above. However, destabilization techniques come the closest to "true restoration," in that they attempt to address some of the root causes and processes (vegetation encroachment, bank and floodplain accretion/armoring) responsible for the currently simplified condition of the San Juan River. Specific destabilization activities are described below, and appropriate locations for these activities are listed in Section 6 of this report.

Island Destabilization

This restoration activity involves converting vegetated, armored islands to more active, unvegetated bars. Depending on the height of a given island, destabilization may require sediment removal/island lowering in addition to vegetation removal. The objective of this technique is to restore processes of bar erosion, bank erosion, and channel movement that can increase channel complexity and promote formation of new backwater habitats. Island destabilization could also be implemented selectively along island margins to prevent islands from merging with each other or from accreting onto the river bank. Island destabilization could also be implemented in conjunction with bank destabilization and/or floodplain lowering as part of a more comprehensive “reach destabilization” effort.

Island destabilization projects would not be appropriate in areas located near/just upstream of diversion structures, bridges, or other developed infrastructure that could be damaged by increased sediment loads or erosion resulting from destabilization efforts. Islands that are separated from the riverbank by relatively shallow, narrow channels would be more appropriate candidates for destabilization than sites surrounded by deep, wide channels that would limit equipment access.

Costs for island destabilization would vary based on the age and density of vegetation and the size and height of the island. Information on relative costs and effectiveness of different vegetation removal techniques is provided in Section 5.2 . The need for sediment removal/island lowering will depend on the current height of a given island and the desired height after destabilization. During our August, 2005 field visit, we used a rod and engineer’s level to spot-measure heights above the water surface at eight vegetated islands and 5 bare cobble bars in the Study Area (Table 5.5.1 and Table 5.5.2). Although these spot measurements are by no means a complete or comprehensive survey of all islands within the Study Area, the results do provide some indication of how much material might need to be removed to convert stable islands to active bars. The active cobble bars we surveyed were between 2.3 and 4 feet higher than the adjacent water surface, while the vegetated portions of islands were between 3 and 6 feet above the water surface. On average, a thickness of 1 to 2 feet of material would need to be removed from islands to reduce their elevation to a level where flooding frequency and flow depths would be adequate to maintain a more active condition.

Table 5.5.1. Heights of bare cobble bars surveyed in August 2005.

LOCATION	LATERAL POSITION	SITE CHARACTERISTICS	SURVEYED HEIGHT ABOVE ADJACENT WATER SURFACE (FEET)	FLOW AT TIME OF SURVEY (CUBIC FEET PER SECOND)
RM 173	near south bank	bare cobble	3.89	1,150
RM 172.3	near south bank	bare cobble/sand	2.32	1,130
RM 172	mid-channel	bare cobble	2.33	1,130
RM 160.6	near north bank	bare cobble near upstream tip of bar	2.83	1,000
RM 160.6	near north bank	bare cobble at high point of bar	4.01	1,000

Table 5.5.2. Heights of vegetated islands surveyed in August 2005.

LOCATION	LATERAL POSITION	SITE CHARACTERISTICS	SURVEYED HEIGHT ABOVE ADJACENT WATER SURFACE (FEET)	FLOW AT TIME OF SURVEY (CUBIC FEET PER SECOND)
RM 173	near south bank	vegetated with tamarisk	5.91	1,150
RM 172.5	near south bank	vegetated with Russian olive	3.11	1,140
RM 172.4	near north bank	vegetated with Russian olive	3.94	1,130
RM 172.3	near south bank	vegetated with Russian olive	4.29	1,130
RM 171.95	mid-channel	vegetated with tamarisk	4.89	1,130
RM 170.5	near south bank	vegetated with Russian olive	3.04	1,270
RM 168.6	mid-channel	vegetated with willows	3.9	1,010
RM 162.4	near north bank	vegetated with Russian olive	4.96	1,000

If vegetation were removed from a relatively high elevation island without also lowering its elevation, it is unlikely that the feature would be destabilized. Based on observations during our August 2005 field visit, flows during the 2005 spring runoff were able to overtop most islands in the Study Area and deposit fresh layers of sandy material. However, we did not observe any evidence of significant scour within vegetated portions of islands. Despite the fact that the 2005 spring flood was one of the highest magnitude events since Navajo Dam was installed, the inundation depths over islands appear to have been inadequate to cause scour. Given the current flow regime within the Study Area, lowering of island elevations will be needed in order to provide adequate inundation frequencies and depths for destabilization. On relatively narrow islands, vegetation removal alone may be able to effect destabilization via progressive bank erosion.

In most cases, some type of long-term vegetation management would be needed to maintain destabilized islands in an active, unvegetated condition. Russian olive and tamarisk seedlings that invade the area may need to be treated with herbicides or mechanically removed to prevent the redevelopment of dense, mature stands that would re-armor the island. The needed frequency of treatments would depend on flooding and climatic conditions. Promoting revegetation with native cottonwoods, which are not as effective at armoring islands (see discussion in Section 4.4 of this report) and can be competitive with the less desirable species under certain conditions, may also be useful in limiting the reestablishment of Russian olive and tamarisk (Glenn and Nagler 2005). This approach would initially require intensive management to plant cottonwood seedlings or promote growth of naturally established cottonwoods while selectively removing Russian olive and tamarisk seedlings. However, once a cottonwood stand becomes established, its presence can help reduce the needed amount/frequency of long-term exotic vegetation management.

Without additional research or pilot studies, it is unclear how effective large scale island destabilization efforts would be in creating and maintaining backwaters on the San Juan River. On the Platte River in Nebraska, where vegetation encroachment has also armored islands and caused channel simplification, various island destabilization projects have been implemented since the 1980s to increase open sand bar habitat for birds. The effectiveness of these projects has varied depending on climate and hydrology/flooding conditions following implementation (Currier 2001). Experience on the Platte River has shown that mechanical vegetation removal and island leveling efforts are most effective if implemented shortly before high river flows that scour and rework the river bed (Currier 2001). However, some research on the Platte River suggests that while vegetation clearing/destabilization may be locally effective, the technique may have negative effects on habitat at downstream sites. Sediment that is mobilized as a result of island destabilization activities may cause downstream aggradation, channel narrowing, and provide new establishment sites for addition vegetation encroachment (Johnson 1997). These downstream repercussions could be a concern on the San Juan River, where increased sediment loads could potentially cause additional in-filling of existing backwaters. Therefore, relatively small-scale destabilization projects may be most appropriate on the San Juan. Avoiding such destabilization projects immediately upstream of high quality backwaters would also be advisable to avoid any in-filling of the backwaters by liberated sediment. Destabilization projects should also be implemented with the recognition that regular, even annual, vegetation management may be needed to prevent re-armoring of the surface by woody riparian species (J. Jenniges 2006, pers. comm.).

Bank Destabilization

This restoration technique involves removing a strip of vegetation from the river bank to promote bank erosion and channel migration processes, which can increase active channel width and complexity, and promote backwater formation. Many of the river banks within the Study Area have been armored in place by the extensive root systems of Russian olive and tamarisk, and as a result are highly stable. Removal of a 50 foot minimum width of vegetation would be needed to effectively cause destabilization. Bank destabilization could also be implemented in conjunction with island destabilization and/or floodplain lowering as part of a more comprehensive “reach destabilization” effort.

Mechanical techniques using an excavator or a bulldozer/root plow would probably be the most appropriate vegetation removal methods for streambank vegetation in the Study Area. Additional information on the costs and effectiveness of different vegetation removal techniques is provided in Section 5.2. Depending on the size and height of the existing trees along the bank, cutting trees with a chainsaw may be required before a bulldozer and root plow can be used. Regardless of the specific technique selected, removal of a considerable portion of the tree roots as well as the aboveground stems will be needed to effectively destabilize the river bank.

Bank destabilization could be implemented in conjunction with floodplain lowering efforts, or could be implemented along the banks of islands to assist with island destabilization. As with island destabilization, bank destabilization is not an appropriate technique for use in developed areas or immediately upstream of infrastructure. Bank destabilization would also be incompatible with restoration activities such as constructed bank indentations or headgate-controlled secondary channels, which require stable bank conditions. Woody debris placement would be an obvious choice as a restoration technique to compliment bank destabilization efforts.

Floodplain Lowering

This activity involves excavating floodplain areas to a lower elevation in order to increase overbank flooding frequency and promote channel change. Floodplain lowering could be implemented in conjunction with non-native vegetation removal or cottonwood restoration projects, or in conjunction with bank and island destabilization efforts. Floodplain lowering could also be implemented in areas between the main river channel and constructed or restored secondary channels to increase overbank flooding and microhabitat diversity.

Because floodplain lowering entails extensive excavation using heavy equipment, it is only appropriate in areas with good access. Care would need to be taken to ensure that floodplain lowering would not create an increased flooding risk for adjacent properties or infrastructure. Excavation equipment and labor expenses would be the primary costs for this activity. Costs would vary depending on the total area and depth of excavation. Additional costs would be incurred if off-site hauling is required to dispose of the excavated material.

On the Rio Grande, floodplain lowering was recently implemented by the BOR as part of the Albuquerque Overbank Project at a cost of $5,000/acre. For this project, about 2.4 acres of floodplain was lowered by about 2 feet, for a total removal of approximately 6,100 cubic meters of material (Muldavin et al. 2004). The site was graded to create small channels and diverse, uneven floodplain topography to increase microhabitat diversity. To date, the project has resulted in localized channel widening/bank erosion and highly successful cottonwood establishment relative to portions of the floodplain that were not lowered (Muldavin et al. 2004). As with the other destabilization techniques described in this section, additional studies and pilot projects would be needed to better assess the effectiveness of floodplain lowering as a technique to increase backwater habitats on the San Juan River. Implementing a combination of bank destabilization, floodplain lowering, and island destabilization throughout a reach may be the most effective way to initiate active channel reworking and other dynamic processes. Figure 5.5.1 shows before and after photos of a recently completed floodplain lowering/destabilization project completed in the Hocker Flat area of the Trinity River near Junction City, California.

Figure 5.5.1. **Photos of the Hocker Flat channel rehabilitation site on the Trinity River before and after implementation of floodplain lowering/bank destabilization. Photos obtained from http://www.tcrcd.net/almanac/current/article04.htm.**

Channel Realignment

This restoration activity involves actively relocating the main river channel to simulate the natural channel avulsion process. The new channel could be fully excavated to the desired shape and location, or flow could be redirected into an excavated pilot channel. Flow from the main channel could also be redirected into an existing secondary channel. Regardless of the specific technique employed, the abandoned main channel could be left largely intact to function as a secondary or overbank channel that could create new backwaters. Channel realignment could be combined with floodplain lowering, bank destabilization, constructed bank indentations, or woody debris placement to create even greater habitat complexity.

Various structures, such as bendway weirs, rock barbs, or large woody debris placements could be installed to redirect flow toward the new channel location. Fill material could also be placed across the original main channel to force flow into the new location. Selection of an appropriate flow redirection technique will depend on local hydraulic conditions, channel width, and aesthetic considerations.

Because channel realignment would have a major effect on the location of flood-prone and erosion-prone areas, areas adjacent to active agricultural fields, residential or commercial development, canals, diversions, or bridges would not be appropriate locations for this activity. If a pilot channel is used, sites immediately upstream of high quality backwaters should be avoided so that they would not be subject to in-filling by liberated sediment. Areas with wide undeveloped floodplains and resistant terraces or bedrock outcrops to contain any potential erosion or flooding would be the most appropriate sites for channel realignment.

Costs of channel realignment would depend on the specific technique used. Costs would be lowest if the main channel were realigned into an existing secondary channel, because required excavation would be relatively minimal. In this case, expenses would consist of equipment, labor, and materials costs for the bendway weirs, rock barbs, woody debris structures, or fill material used to redirect flows. Additional costs would be incurred for excavation and grading of pilot channels or complete channel excavation. In general, channel realignment would be a relatively large-scale, expensive restoration activity compared to habitat creation-type activities or secondary channel creation/restoration.

5.6 Comparison of Different Restoration Activities

Table 5.6.1 provides a comparison of the different restoration activities presented. Pros and cons of individual techniques are described in terms of relative cost, maintenance needs, and certainty of outcome (i.e., the likelihood a given activity will create a usable backwater habitat in the short term). Figures 5.6.1 and 5.6.2 visually illustrate the differences among the different techniques with respect to relative implementation cost, anticipated maintenance needs, relative certainty of outcome, and focus on habitat form versus channel processes.

Table 5.6.1. Comparison of different restoration activities.

RESTORATION ACTIVITY	MOST APPROPRIATE LOCATION(S)	RELATIVE COST OF IMPLEMENTATION	LONG-TERM MAINTENANCE/ MANAGEMENT NEEDS	PROS/CONS
Constructed bank indentations	Low bank areas with convenient access.	Low; higher if installed with headgates.	High; anticipate need for frequent removal of accumulated sediment.	• Simple and cheap to construct. • High certainty of creating usable backwater in short-term. • High anticipated maintenance costs.
Irrigation return channel enhancement	Relatively wide, undeveloped floodplain areas with low banks and existing irrigation return flow.	Low; higher if installed with headgates.	Low; higher if headgates are installed that require management and maintenance.	• Irrigation flows help "self-maintain" backwaters. • High certainty of creating usable backwater in short-term. • Irrigation water reduces habitat quality during irrigation season.
Woody debris placement	Not appropriate near bridges or diversion structures; well-suited for use in secondary or overbank channels.	Low.	Low.	• Simple and cheap to construct. • Habitat benefit relatively small unless installed as part of other restoration activities.
Secondary channel entrance reestablishment	Sites where sediment deposits block main channel from well-defined relict secondary channel.	Low, but variable based on volume of material excavated.	Moderate; would likely require periodic vegetation control.	• Lowest cost option for restoration of secondary channels. • High certainty of creating usable backwater when implemented where backwaters previously existed.

RESTORATION ACTIVITY	MOST APPROPRIATE LOCATION(S)	RELATIVE COST OF IMPLEMENTATION	LONG-TERM MAINTENANCE/ MANAGEMENT NEEDS	PROS/CONS
Pilot channel excavation	Large, undeveloped floodplain areas away from infrastructure; areas immediately upstream of high quality backwaters should be avoided.	Moderate, but variable based on amount of material excavated.	Moderate; would likely require periodic vegetation control.	• Lower certainty of creating usable backwater than other secondary channel creation/restoration techniques. • Lower cost than complete channel excavation. • Resulting channel would have natural, self-formed size/shape. • Risk of sediment in-filling of downstream backwaters.
Complete secondary channel excavation	Most cost effective in low bank areas or inactive historical secondary channels.	Moderate to high, but variable based on amount of material excavated.	Moderate; would likely require periodic vegetation control.	• High certainty of creating functional secondary channel; moderate certainty of creating usable backwater in short-term.
Headgate-controlled secondary channels	Low-flow secondary channels with convenient access; can be used in areas near developed infrastructure.	High relative to secondary channel creation/restoration without headgates.	Moderate; management of headgates could reduce need for vegetation control/sediment dredging.	• High certainty of creating functional secondary channel; moderate certainty of creating usable backwater in short-term. • Management flexibility can maximize habitat benefits at range of flows. • Headgates provide convenient tool for biological monitoring. • Benefits of headgates may not outweigh increased installation and management costs.

RESTORATION ACTIVITY	MOST APPROPRIATE LOCATION(S)	RELATIVE COST OF IMPLEMENTATION	LONG-TERM MAINTENANCE/ MANAGEMENT NEEDS	PROS/CONS
Island destabilization	Not appropriate near developed areas or infrastructure, immediately upstream of high quality backwaters, or where deep, wide channels would prevent equipment access.	Moderate, but variable based on age and density of vegetation and size/ height of island.	Moderate; would likely require periodic vegetation control to prevent accretion and re-armoring.	• Low certainty of creating usable backwater in short-term. • Risk of sediment in-filling of downstream backwaters. • Promotes dynamic channel processes that can create multiple backwaters over long-term.
Bank destabilization	Not appropriate near developed areas or infrastructure or immediately upstream of high quality backwaters; most appropriate along straight, thickly vegetated banks that lack habitat	Low to moderate, but variable based on size of project and vegetation size/density.	Moderate; would likely require periodic vegetation control.	• Low certainty of creating usable backwater in short-term. • Risk of sediment in-filling of downstream backwaters. • Promotes dynamic channel processes that can create multiple backwaters over long-term.
Floodplain lowering	Not appropriate where it would increase flood risk for developed areas/ infrastructure; convenient equipment access required	Moderate to high, but variable based on volume of material removed.	Moderate; would require control of non-native vegetation in order to maximize habitat benefit.	• Promotes overbank flooding and dynamic channel processes that can create multiple backwaters over long-term. • Low certainty of creating usable backwater in short-term.
Channel realignment	Wide, undeveloped floodplains confined by resistant terraces; not appropriate where it would increase flooding/erosion risks for developed areas or infrastructure.	Moderate to high, but variable based on specific technique(s) used and size of project.	Low to moderate- periodic vegetation control in old channel location may be required to maximize habitat benefit.	• High potential habitat benefit; old main channel location could provide very large, complex backwater habitat. • Risk of sediment in-filling of downstream backwaters if pilot channel used.

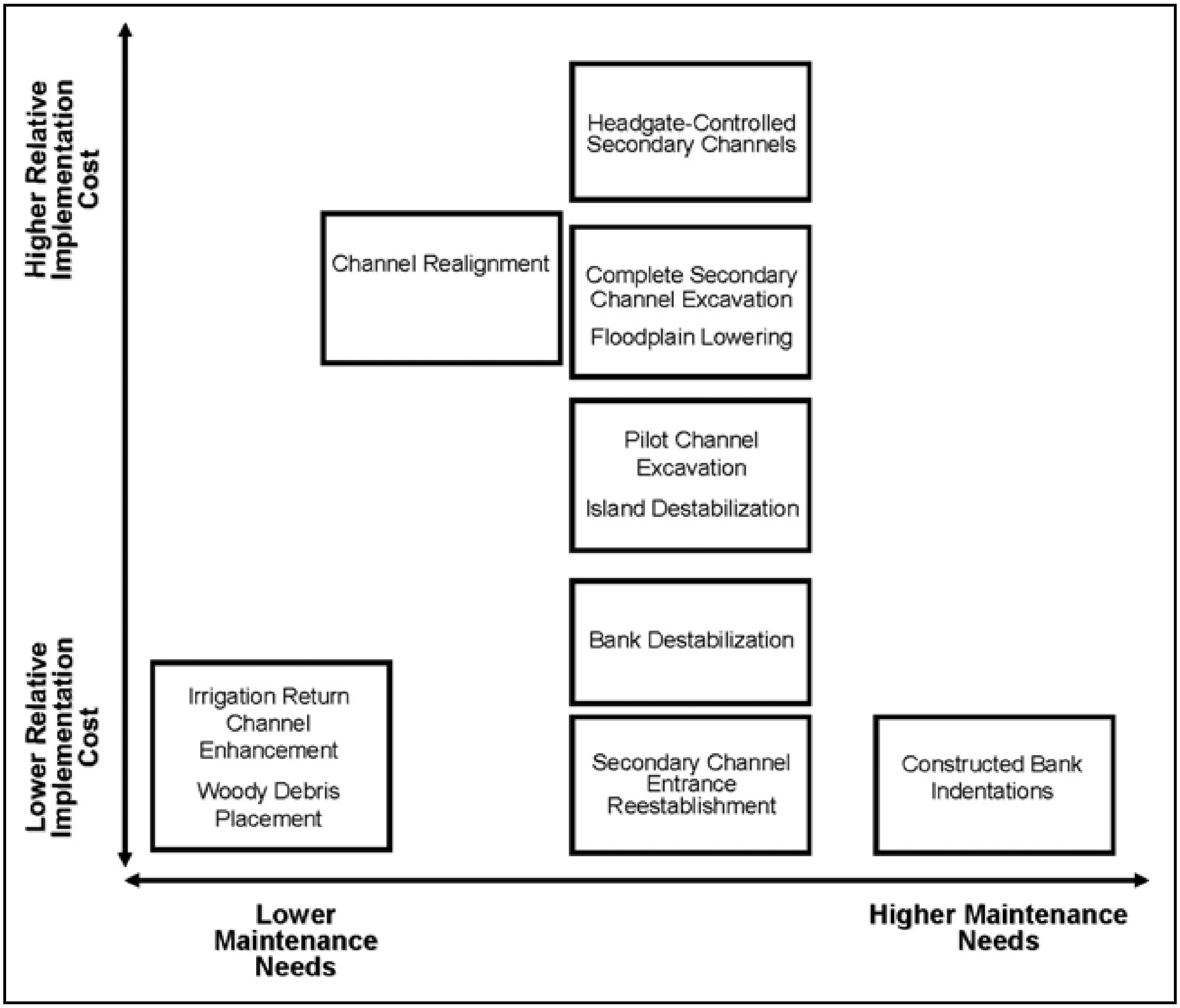

Figure 5.6.1. Comparison of different restoration concepts in terms of maintenance needs relative to implementation cost.

It is important to keep in mind that the comparisons presented are very general; actual implementation costs of a specific technique will vary widely depending on site access and project scale (i.e., installation of a single constructed bank indentation versus a sequence of indentations over a long length of streambank). Therefore, although a technique such as constructed bank indentations is listed as having a low implementation cost relative to other techniques, an extensive installation of multiple bank indentations in an area with difficult access could actually cost more than installation of a single, small-scale headgate-controlled secondary channel in an area with convenient access.

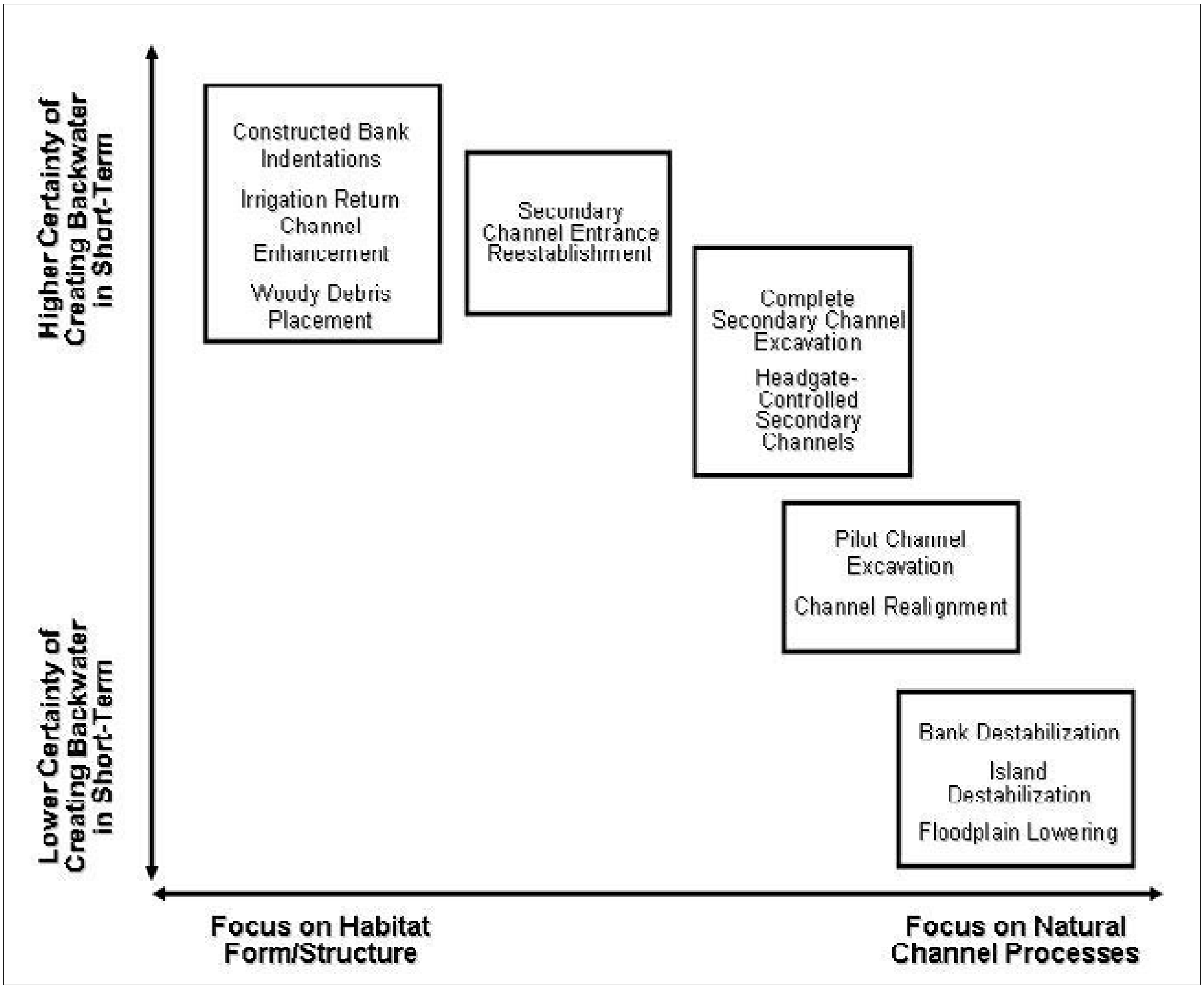

Figure 5.6.2. **Comparison of different restoration concepts in terms of outcome certainty relative to focus on habitat form versus channel processes.**

Anticipated maintenance needs are also evaluated in a highly general manner in Table 5.6.1 and Figures 5.6.1 and 5.6.2. Actual maintenance needs and required maintenance frequency at a specific site will vary depending on the final project design and location as well as climate conditions/storm event frequency. The type of maintenance needed for a specific project will also vary. Constructed bank indentations may require periodic sediment removal/dredging, while maintenance of other types of projects will primarily involve vegetation control/removal. Projects that include headgates may not require direct dredging or vegetation control, but will need regular management of the headgates. In this case, maintenance costs would entail paying someone to periodically inspect and adjust the headgate settings, as opposed to heavy equipment costs for direct sediment removal or labor/herbicide costs for vegetation control. Funding availability may vary for these different types of maintenance activities; therefore, the specific type of maintenance required should be considered when selecting and implementing a particular restoration project.

Relative certainty of outcome is also an important factor to consider when selecting a specific restoration technique or set of techniques for a project. Techniques such as constructed bank indentations and woody debris placement create “instant” habitat, although the total habitat area may be relatively small or short-lived unless actively maintained. In contrast, restoration techniques such as pilot channel excavation or bank destabilization will require time and flooding to create habitat, and their outcome is less certain than techniques that directly create and shape habitat. However, the techniques that focus more on channel processes have the potential to create greater overall habitat complexity, more total habitat area, and are also more likely to be self-maintaining over time. The acceptable amount of uncertainty will vary depending on specific restoration objectives. During a critical drought period when natural habitat availability is low, creation of “instant” habitat using techniques with high outcome certainty may be the most appropriate choice, even if no maintenance is planned and the habitats are short-lived. The implementation of techniques with less outcome certainty may be more appropriate during wet periods when flooding is anticipated.

5.7 Cost Information

Developing a specific cost estimate for implementing any of the above restoration techniques in a particular location on the San Juan River would require detailed information on site topography, access, and irrigation return channel characteristics (timing and volume of flow, etc.). Because detailed site information was not obtained as part of this study, it was not possible to develop accurate, project-based cost estimates because of the uncertainty in construction mobilization costs, access costs, and potential land purchase/easement costs. Therefore, we instead provide general information on the unit costs of different restoration activities as well as some example construction costs for restoration projects completed elsewhere.

Unit Costs

Unit cost information compiled from a variety of sources is provided in Table 5.7.1. Approximate costs for different vegetation removal/management techniques, excavation, grading, and various instream structures (debris piles, headgates, etc.) are provided. As seen in Table 5.7.1, reported costs for vegetation removal (clearing and grubbing, etc.) vary widely. This variability is most likely a function of the specific removal technique employed (see Table 5.2.1), the density and size (trunk diameter) of the existing vegetation, and differences in site accessibility. Removal costs will be relatively cheap for easily-accessed areas with less dense vegetation, while remote areas occupied by numerous large-trunked trees will be relatively expensive.

Table 5.7.1. Unit cost information.

ITEM	UNIT	UNIT PRICE	SOURCE OF COST INFORMATION	COMMENTS
Clearing and grubbing	Acre	$436	UDOT 2006	2005 average bid price for UDOT projects.
Clearing and grubbing	Acre	$4,000	J. Reiss 2006, pers. comm.	Cost for vegetation removal along Trinity River floodplain in 2005.
Remove/pile/burn vegetation	Acre	$500 to $800	J. Jenniges 2006, pers. comm.	Cost range for Platte River vegetation removal projects completed over the last 4 or more years.
Medium brush clearing with dozer and rake	Acre	$281	RS Means 2006	2006 heavy construction cost data.
Grub stumps and remove	Acre	$1,500	RS Means 2006	2006 heavy construction cost data.
Annual vegetation maintenance/weed control	Acre	$100 to $500	J. Jenniges 2006, pers. comm.	Cost range for Platte River vegetation removal/ management projects completed in the last 4 or more years.
Excavation	Cubic yard	$8.59 (roadway) $18.27 (small ditch)	UDOT 2006	2005 average bid price for UDOT projects.
Excavation	Cubic yard	$6.74	J. Reiss 2006, pers. comm.	Cost for Hocker Flat (Trinity River) floodplain excavation in 2005.
Excavation	Cubic yard	$6.00	BIO-WEST 2004	Cost estimate for Bernalillo and Sandia Priority Sites (Rio Grande).
Island lowering	Cubic yard	$1.20	J. Jenniges 2006, pers. comm	Cost for bulldozing island material into Platte River (no loading or hauling).
Landscape grading	Square yard	$1.50	BIO-WEST 2004	Cost estimate for Bernalillo and Sandia Priority Sites (Rio Grande).
Russian olive removal/ bank lowering/ revegetation with native plants	Acre	$5,000	Muldavin et al. 2004	Total cost per acre for Albuquerque Overbank Project (Rio-Grande).
Bendway weir	Each	$2,500	BIO-WEST 2004	Cost estimate for Bernalillo and Sandia Priority Sites (Rio Grande).
Debris pile	Each	$500	BIO-WEST	Preliminary cost estimate for Bernalillo and Sandia Priority Sites (Rio Grande).
Rootwads	Each	$2,000	BIO-WEST	Preliminary cost estimate for Bernalillo and Sandia Priority Sites (Rio Grande).
Loose riprap	Cubic yard	$44	UDOT 2006	2005 average bid price for UDOT projects.
Hand-slide gate 24 inch	Each	$595	UDOT 2006	2005 average bid price for UDOT projects.
Screw gate and frame 36 inch	Each	$2,200	UDOT 2006	2005 average bid price for UDOT projects.

Costs of Restoration Projects Elsewhere

Trinity River-Hocker Flat Rehabilitation

The Hocker Flat Rehabilitation project, located near Junction City, California, was constructed in 2005 as a pilot project of the Trinity River Restoration Program. The project involved the following: selective removal of fossilized berms (berms that have been anchored by extensive woody vegetation root systems and consolidated sand deposits); revegetation and provision of conditions for regrowth/sustenance of native riparian vegetation; and creation of alternate point bars and complex fish habitat similar in form to the conditions that existed prior to the construction of the Trinity River Diversion. Specific activities included lowering of the floodplain by approximately 4 feet and removing more than 93,000 cubic yards of material within a 17-acre project area along a 1.1 mile segment of the Trinity River. Total project cost was approximately $915,000. Excavation accounted for about two thirds of the total cost ($629,000), with clearing/grubbing and revegetation expenditures each totaling approximately $65,000. The remaining costs were associated with mobilization and preparation ($38,000), surveying ($25,000), erosion control and dust abatement ($69,000), and final site preparation ($22,000) (J. Reiss 2006, pers. comm.). To date, the project appears to have been successful in restoring some alluvial processes and channel dynamics. Shortly after construction was completed, winter flood flows resulted in the creation of high-flow channels, caused sediment deposition and scour, and deposition of large woody debris on floodplain surfaces. More information about the Hocker Flat project can be found online at:

http://www.trrp.net/RestorationProgram/MechChannel.htm

Platte River Vegetation Removal/Island Destabilization

Various vegetation removal and island lowering projects have been implemented on the Platte River to provide open river channels and bare sandbars to improve habitat for cranes and other avian species. These efforts have been implemented to help offset the impacts of water diversion and hydroelectric projects to endangered species. The Nebraska Public Power District is implementing a multi-year, multi-phased habitat development plan at a total cost of $1.3 million. To date, more than 200 acres of forest have been cleared from island and floodplain areas, two bare sand islands have been constructed, and various wetland and grassland habitats have been built. Although the areas cleared of vegetation have successfully been used by target species such as whooping cranes, the projects have not been self-sustaining due to a continued lack of flood flows adequate to mobilize the available sediment. Annual vegetation maintenance (spraying and disking) has been needed to prevent regrowth of vegetation (J. Jenniges 2006, pers. comm.). More information about Platte River implementation and monitoring efforts can be found online at:

http://www.nppd.com/our_community/environment/additional_files/wetlands.asp

Rio Grande – Bernalillo and Sandia Priority Sites

The BOR is pursuing river maintenance and habitat improvement activities for the Bernalillo and Sandia Priority Sites on the Rio Grande near Bernalillo, NM. These activities are needed to ensure the integrity of the existing levee system along the river and to improve conditions for the endangered silvery minnow and other species of concern. Although this project has not been built yet, appraisal-level cost estimates have been developed for the different alternatives. The preferred alternative will involve creation of a secondary channel, realignment of the existing main channel, creation of floodplain shelf features, installation of debris piles and a silvery minnow nursery habitat feature, installation of bendway weirs and rootwads to prevent bank erosion, and extensive revegetation with seed and native plantings. The project spans approximately 1,700 linear feet of river, includes an area of more than 5 acres, and will entail excavation of about 36,000 cubic yards of material. The estimated total construction cost is in the range of $700,000- $800,000, with about half of this amount going toward revegetation costs (BIO-WEST 2004).

5.8 General Considerations

Timing of Restoration Activities

Proper timing of restoration activity implementation with regards to streamflow will have a large influence on the success of the activity. Ideally, island destabilization, bank destabilization, pilot channel excavation, and floodplain lowering projects should be constructed in early spring in a year with high snowpack conditions. Prompt flooding will maximize the amount of channel change and habitat creation that can result from these activities. If destabilized areas are not flooded shortly after excavation, vegetation encroachment is likely to occur, and will reduce the effectiveness of any future flooding.

As discussed in Section 5.2, flooding and flow management can be useful tools for non-native vegetation control. Timing non-native vegetation removal projects to be followed by flow releases designed to meet cottonwood recruitment requirements can help prevent rapid reestablishment of undesirable tamarisk and Russian olive.

Minimization of Water Quality Impacts

For any of the restoration activities that involve excavation, it will be important to use construction best management practices (BMPs) to minimize adverse water quality impacts. Where possible, excavation work should be done “in the dry” by leaving a berm of intact material between the river and the work area until all downstream excavation work is complete. Specific storm water management plans will need to be developed in conjunction with individual restoration project designs. Coordination will be needed with the various permitting and regulatory agencies, including the U.S. Army Corps of Engineers (404 permit), U.S. Environmental Protection Agency (NPDES stormwater permit), New Mexico Environment

Department (NMED) (401 certification, stream alteration permit), Navajo Nation, and U.S. Fish and Wildlife Service (Section 7 consultation). Support and approval by these permitting agencies will be important to ensure that restoration activities are feasible. Coordination will be particularly important for some of the "less traditional" potential restoration activities, such as island destabilization, where it may not be possible to dispose of all excavated material in upland areas or to completely avoid working "in the wet" because of access needs. It would also be beneficial to explore the possibility of setting up a general permit with the NMED to cover a range of different restoration activities and lessen the permitting burden for individual restoration projects.

Landowner Cooperation and Partnering Opportunities

Implementation of any restoration activity will require cooperation and buy-in by the relevant landowner and/or land management agency. Early contact with property owners to explore their willingness to "host" a restoration project will be an important first step in identifying feasible and infeasible restoration sites. Opportunities for partnering with the Navajo Nation, the State of New Mexico, San Juan County, and the City of Farmington should also be explored. It may be possible to combine backwater restoration activities with other ongoing initiatives such as native forest restoration/tamarisk removal, trail/interpretive facility construction, firewood harvesting, prescribed burns, etc. This may be a way to leverage funds or obtain grant money to implement multi-purpose, cooperative projects. One potentially promising partner is the recently formed San Juan Basin Russian Olive Salt Cedar Task Force. This group has been working to pull together various tribal, State, Federal, and local interests, identify funding sources, and begin implementing a basin-wide strategy to control and remove exotic riparian vegetation.

6. SUBREACH ASSESSMENTS

6.1 Assessment Criteria and Methods

The Study Area was divided into 3-mile-long subreaches for assessment purposes. In some cases, subreach boundaries were extended slightly so as not to divide channel features such as secondary or overbank channels. Within each subreach, the following items were assessed and identified for the north and south banks of the river:

- Presence of Publicly Owned Land
- Relative Intensity of Development
- Presence of Low Banks
- Presence of High Banks
- Presence of Named Tributaries
- Presence of Diversions
- Presence Irrigation Returns
- Presence of Previously Mapped Backwaters
- Areas of Vegetation Encroachment Since 1998

Areas of publicly owned land were identified from the San Juan County property identification maps (San Juan County 2005). When available, the tax ID number for the publicly owned parcel was also noted. For the purposes of this report, land parcels are considered "publicly owned" when the County maps identify the parcel owner as Farmington City, San Juan County, the State of New Mexico, U.S.A., or Federal. Information on publicly owned land is helpful in identifying areas where restoration projects would be feasible, because public entities may be more willing to allow project implementation than private land owners.

The relative intensity of land development was qualitatively assessed for each subreach. Development intensity is considered "high" where buildings, paved roads, and/or commercial or residential developments are present along the river bank. Intensity is considered "moderate" where active agricultural fields or canals are present along the river bank. Intensity is considered "low" where primarily natural vegetation is present along the river bank. Information on land development intensity is useful in identifying feasible locations for potential restoration projects. Where development intensity is high, large-scale restoration projects that might lead to bank instability or substantial channel shifts would not be feasible since they could pose risks to infrastructure.

The locations of low and high bank areas were determined based on a field assessment completed on August 18, 2005. BIO-WEST staff floated the river from RM 178 to RM 159.4 and noted areas of low and high river banks on a laminated map set (rectified 1998 color orthophotos). Average streamflow on August 18, 2005, was 1,000 cfs at the Farmington USGS gage. A bank was considered "low" if its height was less than 4 feet above the water surface. A bank was considered “high” if its height was more than 6 feet above the water surface, or if the bank abutted a tall terrace or bedrock outcrop. Banks with heights between 4 and 6 feet above the water surface were considered “medium,” but were not specifically noted on the map set. We determined approximate bank height by “calibrating” the height of our eye level relative to the water surface using a stadia rod, and then viewing the river banks using a clinometer as a level. When this technique was not accurate enough to identify the bank height category, a “spot check” was performed by placing a stadia rod at a vertical edge of the bank to more accurately measure its height above the water surface. The bank mapping effort was a relatively rapid visual assessment, and should not be considered quantitative or entirely complete. In sections of the river with multiple channels around bars or islands, it was not possible to see both channel banks.

Identification of areas with particularly low or high banks is helpful in assessing the suitability of different sites for potential restoration projects. Areas with low banks may be the most appropriate locations for restoration projects that involve excavation, since less material would need to be removed relative to areas with taller banks. On the other end of the spectrum, areas with high banks would generally not be suitable for restoration projects due to the large amounts of material that would need to be excavated, and/or because their height prohibits safe access by equipment and people.

The locations of named tributaries and diversions were identified using USGS 7.5' topographic maps. Irrigation return points were identified during the same August 18, 2005, field assessment used to identify low and high bank areas. Points where clear, flowing water was entering the river were noted as irrigation returns on the laminated map set. As with the bank assessment, the irrigation return point mapping is somewhat incomplete because it was not possible to see both channel banks in sections of the river with multiple channels around bars or islands. In addition, some smaller return points may have been missed because they were obscured by vegetation. Areas coded as irrigation returns in any of the 1992-2003 habitat maps (GIS coverages obtained from Keller-Bliesner Engineering in October 2004) were also noted as part of the subreach assessment, even if the sites were not noted during the August 2005 field assessment. Knowing the locations of irrigation return points is helpful in identifying and evaluating restoration opportunities because the return flows can help flush backwaters and prevent vegetation encroachment (see description of this process in Section 3.3 of this report).

Sites that were identified as backwaters (i.e., coded as backwater, backwater pool, or embayment) in any of the 1992-2003 habitat mapping efforts were noted as part of the subreach assessment. Sites that have frequently supported backwaters in the past, but have become silted in or vegetated could be high priority candidates for vegetation removal and restoration activities. To simplify the subreach assessment, minor backwaters associated with sand or cobble bars or minor bank indentations were not listed.

The 1998 orthophotos were compared with the 2005 videography images to identify areas where substantial vegetation encroachment has occurred on bars or at the entrances/mouths of secondary channels. Photographs and notes taken on the laminated map set during the November 2004 and August 2005 field visits were used as supplemental information to help identify these sites. Because the process of vegetation encroachment tends to reduce channel complexity, sites where the 2005 flood was unable to remove young vegetation could be candidate sites for vegetation removal-focused restoration activities.

6.2 Potential Restoration Site Assessment

Potential sites for implementation of restoration activities were identified based on the results of the subreach assessments. All publicly owned areas were identified as potential sites, unless high bank conditions made the site infeasible. Low bank areas were also identified as potential sites, unless they were inaccessible, very short in length, or too close to residential or commercial development or infrastructure. Irrigation returns that flow through or adjacent to substantial areas of undeveloped floodplain were also identified as potential restoration sites. Sites where recent vegetation encroachment has occurred and could lead to channel simplification were identified as potential sites for vegetation removal activities.

For each potential restoration site, specific types of appropriate restoration activities were identified. Sites meeting criteria but located near diversions, bridges, or residential/commercial development were generally considered appropriate for activities within the "habitat creation concepts" and "vegetation removal" categories, but not for activities within the other categories. The uncertainties and potential channel instabilities that could result from secondary channel creation/restoration or destabilization activities make these types of activities inappropriate in areas with developed infrastructure. Developed areas are most appropriate for more managed, controlled activities. Proximity to infrastructure (e.g., paved roads and services) can actually be an advantage for habitat creation activities, which can require more frequent monitoring and maintenance than other types of activities.

Undeveloped areas where active secondary channels were historically present were considered the most appropriate locations for activities within the "secondary channel creation/restoration concepts" category. Areas that have historically functioned as secondary channels are likely to be relatively low in elevation, thus requiring less excavation than surrounding areas. Historical channels also provide a convenient template for designing an appropriate secondary channel size, shape, and length. Undeveloped floodplain areas mapped as having low banks were also considered appropriate sites for possible secondary channel creation activities.

6.3 Results

The results of the subreach assessments are shown in Tables 6.3.1 through 6.3.7. Information on potential restoration sites is provided for each subreach in Tables 6.3.8 through 6.3.14. Maps showing the locations of irrigation returns, low bank and high bank areas, and potential restoration sites are included in Appendix B.

It is important to keep in mind that the subreach assessment and potential restoration site identification results should not be considered entirely comprehensive or perfectly accurate. The results are based on remote information from maps, air photos, and video imagery, and relatively rapid/broad scale field evaluations. More detailed investigations and site visits would be needed to thoroughly assess access requirements, confirm irrigation return pathways/water rights, and definitively identify property ownership. Sites other than those listed in Tables 6.3.8-6.3.14 may also prove to have good restoration potential upon further investigation.

Table 6.3.1. Subreach 1 assessment results.

EVALUATION ITEM	SUBREACH 1 (RM 180-177)	
	North Side of River	South Side of River
Public Land	• RM 178.5-177.7 City of Farmington Parcel #34925, #32175, #51642	• RM 179.6-179.4 City of Farmington Parcel #50294 • RM 178.1-177.7 City of Farmington Parcel #52801
Development Intensity	• RM 180-179.4 high • RM 179.4-179 moderate • RM 179-178.5 high • RM 178.5-177.9 low • RM 177.9-177 moderate	• RM 180-179.15 low • RM 179.15-178.3 high • RM 178.3-177 low
Low Banks[a]	• RM 177.1-176.3	• RM 178-177.4
High Banks[a]	• RM 177.95-177.8 • RM 177.65-177.25	--
Named Tributaries	• RM 179.9 Farmington Glade • RM 177.7 La Plata River	--
Diversions	• RM 179.6 Farmer's Mutual Ditch	• RM 178.4 Fruitland Diversion

EVALUATION ITEM	SUBREACH 1 (RM 180-177)	
	North Side of River	South Side of River
Irrigation Returns[a]	• RM 177.95 • RM 177.45 • RM 177.1	--
Previously Mapped Backwaters (month/year mapped)	• RM 178.9 (8/94) • RM 178.7 secondary channel (8/94, 11/94) • RM 178.4 areas around Fruitland Diversion (1/96) • RM 178 island complex (4/95, 1/96, 10/96) • RM 177.1 irrigation return (11/97)	• RM 179 bar/secondary channel (10/93, 11/97, 11/98) • RM 178.4 areas around Fruitland Diversion (10/93, 11/94, 4/95) • RM 178.25 small secondary channel (1/96)
Vegetation Encroachment Since 1998	--	• RM 178.3 cobble bar/island
Potential Restoration Sites	• RM 178.7 inactive secondary channel • RM 178.5-177.7 - floodplain area within City of Farmington Parcel	• RM 179.6-179.4 - floodplain area within City of Farmington Parcel • RM 178.3 - vegetated cobble bar • RM 177.9 - floodplain area

[a] not mapped upstream of RM 178.

Table 6.3.2. Subreach 2 assessment results.

EVALUATION ITEM	SUBREACH 2 (RM 177-174)	
	North Side of River	South Side of River
Public Land	--	• RM 174.7-174.2 USA
Development Intensity	• RM 177-176.3 high • RM 176.3-175.4 low • RM 175.4 - 174.9 high • RM 174.9-174.6 moderate/low • 174.6-174 high	• RM 177-175.6 low • RM 175.6-175.2 moderate • RM 175.2-174.7 low • RM 174.7-174.3 high • RM 174.3-174 moderate

EVALUATION ITEM	SUBREACH 2 (RM 177-174)	
	North Side of River	**South Side of River**
Low Banks	• RM 177.1-176.3 • RM 175.85-175.8 • RM 174.1-173.7	• RM 176.65-176.2 • RM 175.9-175.8 • RM 174.75-174.65
High Banks	• RM 176.25-176.2 • RM 176.1-175.95 • RM 175.8-174.7	• RM 176.9-176.65 • RM 174.6-174.4
Named Tributaries	• RM 174.9 Locke Arroyo	--
Diversions	--	--
Irrigation Returns	• RM 176.35 • RM 176.1 • RM 175.3 • RM 174.9 • RM 174.6	• RM 176.95 • RM 176.65 • RM 174.25
Previously Mapped Backwaters (month/year mapped)	• RM 176.6 sec. channel/island (7/02)0	• RM 176.95 irrigation return (11/94) • RM 176.4 bar/ secondary channel entrance (10/93) • RM 176.1 bar in secondary channel (10/93) • RM 175.9 bar in secondary channel (10/93) • RM 175.8 secondary channel exit (8/94)
Vegetation Encroachment Since 1998	--	• RM 176.6 secondary channel entrance
Potential Restoration Sites	• RM 174.6 irrigation return	• RM 174.7-174.6 low bank/USA land • RM 176.6 island/secondary channel entrance • RM 176.6-175.6 island, secondary channel, floodplain area

Table 6.3.3. Subreach 3 assessment results.

EVALUATION ITEM	SUBREACH 3 (RM 174-170.9)	
	North Side of River	**South Side of River**
Public Land	• RM 174.2-173.1 State of New Mexico • RM 173.1-172.5 San Juan County Parcel #81711	--
Development Intensity	• RM 174-173.1 low • RM 173.1-172.7 moderate • RM 172.7-172.4 low • RM 172.4-171.9 moderate • RM 171.9-171.6 low • RM 171.6-170.9 moderate/high	• RM 174-173.6 moderate • RM 173.6- 172.8 low • RM 172.8-172.6 moderate • RM 172.6-170.9 low
Low Banks	• RM 174.1-173.7 • RM 172.8-172.6 • RM 171.1-171	• RM 172.2-172 • RM 171.9-171.7 • RM 171.2-170.9
High Banks	• RM 171.55-171.2	• RM 172.85-172.6
Named Tributaries	• RM 173.6 Dain Arroyo • RM 171.6 Coolidge Arroyo	--
Diversions	--	--
Irrigation Returns	• RM 171.75 • RM 171.7	• RM 173.6 • RM 170.9
Previously Mapped Backwaters (month/year mapped)	• RM 173.6 secondary channel entrance (10/03) • RM 172.4 secondary channel/island (1/96, 6/96) • RM 171.9 secondary channel exit (10/93, 1/96) • RM 171.7 tributary/irrigation return (11/94)	• RM 173 secondary channel /bar/island (8/94, 1/96, 10/96, 10/03) • RM 172.05 overbank channel entrance (7/02) • RM 170.9 overbank channel exit (8/94, 11/94, 1/96, 11/99, 10/00, 11/01)
Vegetation Encroachment Since 1998	--	• RM 173.8 bar/island
Potential Restoration Sites	• RM 174.2-173.1 floodplain area in State ownership • RM 173.1-172.5 floodplain area in County ownership • RM 171.75-171.7 tributary/irrigation returns	• RM 173.6-172.9 floodplain area/irrigation return • RM 172.2-170.9 floodplain area/overbank channels

Table 6.3.4. Subreach 4 assessment results.

EVALUATION ITEM	SUBREACH 4 (RM 170.9-167.7)	
	North Side of River	**South Side of River**
Public Land	--	--
Development Intensity	• RM 170.9-170.4 low • RM 170.4-169.4 moderate • RM 169.4-168.6 low • RM 168.6-167.7 moderate	• RM 170.9-170.3 moderate • RM 170.3-169.1 low • RM 169.1-167.7 high (road on bluff)
Low Banks	• RM 169.3-169.1 • RM 168.6-167.7	• RM 170.65-170.6 • RM 169.3-169
High Banks	--	• RM 169-168.4 • RM 168.3-167.7
Named Tributaries	--	• RM 170.8 Ojo Amarillo Canyon
Diversions	--	--
Irrigation Returns	• RM 170.2 • RM 169.9 • RM 169.1	• RM 169.25
Previously Mapped Backwaters (month/year mapped)	• RM 170.4 secondary channel entrance (1/96) • RM 170.25 cross channel exit (1/96) • RM 170.1-169.9 cross channels/secondary channel exit (10/93, 8/94, 11/94, 4/95, 1/96, 11/97) • RM 169.1 overbank channel exit (8/94, 1/96) • RM 168.4 secondary channel entrance (9/95)	• RM 169.5 bar/secondary channel exit (10/93, 8/94, 1/96, 7/02) • RM 169.25 irrigation return/overbank channel exit (6/94, 6/96) • RM 169.15 overbank channel (8/94, 1/96, 11/97) • RM 168.25 secondary channel entrance (11/01)
Vegetation Encroachment Since 1998	• RM 170.1 and 169.9 cross channels through island • RM 168.4 bars (tamarisk)	• RM 169.5 bar/island • RM 169.15 small secondary channel • RM 169 bar • RM 167.8 bar/tip of island
Potential Restoration Sites	• RM 169.3-169.1 floodplain area/irrigation return • RM 170.1 and 169.9 cross channels	• RM 169.3-169 floodplain area/ irrigation return • RM 168 multiple channel area

Table 6.3.5. Subreach 5 assessment results.

EVALUATION ITEM	SUBREACH 5 (RM 167.7-164.8)	
	North Side of River	**South Side of River**
Public Land	• RM 165.3- 164.6 "Federal"	--
Development Intensity	• RM 167.7-167.2 moderate • RM 167.2-166.8 low • RM 166.8-166.3 high • RM 166.3-165.8 low/moderate • RM 165.8-165.2 high • RM 165.2-164.8 low	• RM 167.7-167.3 moderate • RM 167.3-166.6 high • RM 166.6-166.2 low • RM 166.2-164.8 low/moderate
Low Banks	• RM 167.35-167.15 • RM 166.2-165.85 • RM 165.15-164.9	• RM 167.5-167.4 • RM 166.85-166.75 • RM 166.65-166.55 • RM 166.4-166.2 • RM 165.55-165.5 • RM 165.1-165.05
High Banks	• RM 166.55-166.3 • RM 165.8-165.6 • RM 165.5-165.2	• RM 167.1-166.9 • RM 166.2-166.1
Named Tributaries	• RM 167.4 Stevens Arroyo	--
Diversions	• RM 166.7 PNM Weir • RM 166.3 Jewett Valley Ditch	--
Irrigation Returns	• RM 167.4 (Stevens Arroyo) • RM 165.8 • RM 165.1	• RM 166.85 • RM 165.4 • RM 165.3 • RM 165.15 • RM 165.1

EVALUATION ITEM	SUBREACH 5 (RM 167.7-164.8)	
	North Side of River	**South Side of River**
Previously Mapped Backwaters (month/year mapped)	• RM 167.4 tributary/irrigation return (6/94, 4/95, 6/96) • RM 167.3 secondary channel/bar (1/96) • RM 166.3 Jewett Valley Diversion rock dam/ditch entrance (10/93, 8/94) • RM 165.55 secondary channel (1/96)	• RM 167.45 secondary channel/bar/island (10/93, 8/94, 9/95, 1/96, 11/99) • RM 166.85 irrigation return (11/94) • RM 166.8 secondary channel/island (10/93, 1/96) • RM 165.4 irrigation return (1/96, 6/96) • RM 165.15 irrigation return (6/96) • RM 165.1 irrigation return (11/94)
Vegetation Encroachment Since 1998	• RM 167.15 bar • RM 166.2-166 channel margin bar (tamarisk)	• RM 167.45 bar/island
Potential Restoration Sites	• RM 166.2-165.8 floodplain/irrigation return • RM 165.2-164.8 floodplain/irrigation return	• RM 166.4-166.2 floodplain • RM 166-165.05 floodplain/irrigation returns

Table 6.3.6. Subreach 6 assessment results.

EVALUATION ITEM	SUBREACH 6 (RM 164.8-162)	
	North Side of River	**South Side of River**
Public Land	• RM 164.8-164.6 “Federal” • RM 162.4-162.2 “USA”	--
Development Intensity	• RM 164.8-164.25 low • RM 164.25-163.85 moderate • RM 163.85-163.3 low • RM 163.3-162.6 moderate • RM 162.2-162 low	• RM 164.8-163.7 low/moderate • RM 163.7-163.65 high • RM 163.65-163 low • RM 163-162 moderate/low
Low Banks	• RM 163.9-163.85 • RM 162.7-162.5	• RM 164.4-164.2 • RM 164-163.9 • RM 163.15-163.05 • RM 162.1-162.05

EVALUATION ITEM	SUBREACH 6 (RM 164.8-162)	
	North Side of River	**South Side of River**
High Banks	• RM 164.8-164.55 • RM 163.3-163.2	• RM 163.8-163.6 • RM 163.05-162.9 • RM 162.55-162.4
Named Tributaries	• RM 162.3 Shumway Arroyo	--
Diversions	--	• RM 163.7 APS Weir
Irrigation Returns	• RM 164.8 • RM 164.25 • RM 163.3 • RM 163.2 • RM 162.8 • RM 162.3 (Shumway Arroyo)	• RM 164.4 • RM 164.2 • RM 163.8
Previously Mapped Backwaters (month/year mapped)	• RM 164.55 secondary channel ent. (10/93) • RM 163.3 irrigation return (11/94, 6/96) • RM 162.4 secondary channel exit (10/93, 8/94, 11/94, 9/95, 1/96, 11/97, 11/99, 11/01) • RM 162.3 tributary/irrigation return (10/93, 6/94, 9/96)	• RM 162.7 secondary channel exit/entrance (10/93, 8/94, 11/94, 9/95, 1/96, 11/98, 11/99)
Vegetation Encroachment Since 1998	• RM 164.55 secondary channel entrance • RM 163 mid-channel bar (tamarisk)	• RM 162.7 secondary channel entrance • RM 162.4 bar
Potential Restoration Sites	• RM 164.55 -164.25 secondary channel/ irrigation return • RM 162.4-162.2 floodplain	• RM 164.4-164.2 floodplain/irrigation returns • RM 164-163.8 floodplain area/irrigation return • RM 162.7 secondary channel

Table 6.3.7. Subreach 7 assessment results.

EVALUATION ITEM	SUBREACH 7 (RM 162-159)	
	North Side of River	**South Side of River**
Public Land	• RM 161.8-161 "Federal" • RM 159.8-159.5 "Federal"	• RM 162-161.5 "Federal"
Development Intensity	• RM 162-161.3 moderate/low • RM 161.3-159.7 low • RM 159.7-159 moderate	• RM 162-161.5 moderate • RM 161.5-159.9 low • RM 159.9-159.4 moderate • RM 159.4-159 low
Low Banks[a]	• RM 161.9-161.75 • RM 161.25-161.2 • RM 161-160.9 • RM 160.45-160.4 • RM 159.9-159.8	• RM 161.75-161.7 • RM 161.6-161.55 • RM 161.3-161.2 • RM 160.9-160.6 • RM 160.55-160.4 • RM 160-159.9
High Banks[a]	• RM 162-161.95	• RM 162-161.8 • RM 159.9-159.45
Named Tributaries	• RM 161.45 Waughan Arroyo	--
Diversions	--	--
Irrigation Returns	• RM 161.45 • RM 160.95 • RM 160.4 • RM 159.65	• RM 161.25 • RM 160.6 • RM 159.9
Previously Mapped Backwaters (month/year mapped)	• RM 161.45 tributary/irrigation return (9/95, 1/96, 6/96, 11/98, 11/99) • RM 160.95 irrigation return/secondary channel exit (10/93, 8/94, 11/94, 9/95) • RM 160.9 secondary/cross channel (10/93, 9/95, 1/96) • RM 160.6 bar/secondary channel (9/95, 1/96, 11/01)	• RM 161.7 overbank channel entrance (10/93) • RM 160.6 irrigation return (11/94, 6/96) • RM 160 bar complex (10/93, 8/94, 11/94, 1/96, 11/01) • RM 159.4 bar/ secondary channel 8/94, 9/95, 1/96)

EVALUATION ITEM	SUBREACH 7 (RM 162-159)	
	North Side of River	**South Side of River**
Vegetation Encroachment Since 1998	• RM 161.25 overbank channel entrance • RM 160.9 cross channel	• RM 161.7 overbank channel entrance • RM 159.4 bar/island
Potential Restoration Sites	• RM 161.8-161 floodplain area in Federal ownership • RM 161.25 vegetated overbank channel entrance • RM 160.9 inactive cross channel • RM 160.45-160.4 low bank/irrigation return • RM 159.65 irrigation return	• RM 161.8-161.2 floodplain in Federal ownership/irrigation return/overbank channel entrance • RM 160.6 irrigation return • RM 160.55-160.4 low bank area • RM 160.3-159.9 inactive overbank channel/irrigation return • RM 159.4 vegetated bar/island

[a] Not mapped downstream of RM 159.4.

Table 6.3.8. Potential restoration sites in subreach 1 (RM 180-177).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
1.1	RM 179.6-179.4 (S) floodplain area	City of Farmington	• constructed bank indentations • woody debris placement	• public ownership • convenient access	• near Farmer's Mutual diversion
1.2	RM 178.7 (N) inactive secondary channel	private (ID#51522)	• vegetation removal/ • secondary channel reactivation		• near residential development
1.3	RM 178.5-177.7 (N) floodplain area	City of Farmington Park (Westland Park boat launch site)	• constructed bank indentations • woody debris placement • irrigation return channel enhancement	• public ownership • convenient access • park setting offers educational/ interpretive opportunities	
1.4	RM 178.3 (S) bar/island	Navajo Nation	• vegetation removal to prevent merging of islands/loss of potential backwater		• poor access for large heavy equipment

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
1.5	RM 177.9 (S) floodplain area	City of Farmington (site), Navajo Nation (access roads)	• secondary channel creation	• public ownership • good access via dirt roads • low bank height	• no historical secondary channel

Table 6.3.9. Potential restoration sites in subreach 2 (RM 177-174).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
2.1	RM 176.6 (S) inactive secondary channel/ accreted island	Navajo Nation	• vegetation removal • pilot channel excavation • secondary channel restoration • irrigation return enhancement	• irrigation return present • good access via dirt road/ canal crossing • low bank • no adjacent development	
2.2	RM 176.6-175.6 (S) island/secondary channel area	Navajo Nation	• pilot channels or complete excavation of cross channel(s) through island • secondary channel reactivation (RM 175.6)	• large undeveloped area • good access via dirt roads/ farm fields • one of largest secondary channels/islands in Study Area	
2.3	RM 174.7-174.6 (S) low bank/USA land	U.S.A.	• constructed bank indentations • woody debris placement	• publicly owned • good access via dirt roads	• small area
2.4	RM 174.6 (N) irrigation return	private (ID#82938)	• irrigation return enhancement	• good access via dirt roads/ farm fields	• small amount of flow • near residential development
2.5	RM 174.25 (S) irrigation return	Navajo Nation	• irrigation return enhancement	• good access via dirt roads/ farm fields	• small amount of flow • narrow floodplain

Table 6.3.10. Potential restoration sites in subreach 3 (RM 174-170.9).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
3.1	RM 174.2-173.1 (N) floodplain area	State of New Mexico	• pilot channel excavation • secondary channel restoration • constructed bank indentations • woody debris placement	• large publicly owned area • historical secondary channel location • good access via dirt roads/farm fields • low to medium bank height	• area was recently burned/cleared of vegetation; may be planned for other use
3.2	RM 173.8 mid-channel bar	access via State of New Mexico or Navajo Nation land	• cross channel excavation • vegetation removal	• access possible via public land • no nearby infrastructure/development	
3.3	RM 173.6-172.9 (S) floodplain area/ irrigation return	Navajo Nation	• pilot channel excavation • secondary channel restoration • irrigation return channel enhancement	• historical secondary channel location • large undeveloped area	• existing ponds within floodplain may need to be preserved
3.4	RM 173.1-172.5 (N) floodplain area	San Juan County (parcel tax ID #81711; Lower Valley Lion's Club boat launch site)	• constructed bank indentations • woody debris placement	• publicly owned • convenient access • areas of low bank present • boat launch site creates educational/interpretive opportunities	• near residential development

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
3.5	RM 172.2-170.9 (S) floodplain area/irrigation return	Navajo Nation	• pilot channel excavation/vegetation removal • secondary channel restoration	• location of various historical side channels • one of longest active overbank channels in Study Area • irrigation return present • areas of low bank present • good access via dirt roads/farm fields	
3.6	RM 171.75-171.7 (N) irrigation return/tributary	private (ID#80213)	• irrigation return channel enhancement	• good access via dirt roads/farm fields	

Table 6.3.11. Potential restoration sites in subreach 4 (RM 170.9- 167.7).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
4.1	RM 170.1 and 169.9 (N) cross channels	private (ID#80761)	• restoration/reactivation of accreted, vegetated cross channels	• good access via dirt roads/farm fields • irrigation returns present • area previously mapped as backwater	

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
4.2	RM 169.3-169.1 (N) floodplain area/irrigation return	private (ID#81596)	• secondary channel restoration • irrigation return channel enhancement	• good access via dirt roads/farm fields • irrigation return present • area previously mapped as backwater • low bank height	
4.3	RM 169.3-169 (S) floodplain area/ irrigation return	Navajo Nation	• secondary channel restoration • irrigation return channel enhancement	• good access via dirt roads/farm fields • irrigation return present • area previously mapped as backwater • low bank height	
4.4	RM 168 (mid-river) multiple channel area	• private access on north side (ID#80979 & #80976; Hatch Trading Post boat takeout) • Navajo Nation access on south side	• cross channel excavation across island(s) between existing secondary channels • realignment of main channel toward west/into secondary channel	• low bank height across islands • presence of high, resistant bluff along south side of river would provide stability if main channel were realigned	• access from north side would require crossing main river channel • access from south side could be challenging due to steep slope

Table 6.3.12. Potential restoration sites in subreach 5 (RM 167.7-164.8).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
5.1	RM 166.4-166.2 (S) floodplain	Navajo Nation	• constructed bank indentations • woody debris placement	• convenient access from PNM weir area • low bank height	• small workable area due to proximity to Jewett Valley Ditch diversion structure
5.2	RM 166.2-165.8 (N) floodplain/ irrigation return	private (ID#80844)	• irrigation return channel enhancement • secondary channel creation • constructed bank indentations • woody debris placement	• low bank height • good access via dirt roads/farm field/established canal crossing • irrigation return present	• relatively narrow floodplain area between river and agricultural field • no historical secondary channel
5.3	RM 166-165.05 (S) floodplain/ irrigation returns	Navajo Nation	• secondary channel restoration • pilot channel excavation • irrigation return channel enhancement • floodplain lowering • vegetation removal/bank de-stabilization	• large undeveloped area • irrigation returns present • low to medium bank height • historical secondary channels present • good access via dirt roads/farm fields	
5.4	RM 165.2-164.8 (N) floodplain/ irrigation returns	listed as "Federal" on County maps	• irrigation return channel enhancement • secondary channel creation	• good access via dirt roads/farm fields • irrigation return present • publicly owned • low bank height	• access would require crossing Jewett Valley Ditch • no historical secondary channel

Table 6.3.13. Potential restoration sites in subreach 6 (RM 164.8-162).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
6.1	RM 164.55 - 164.25 (N) secondary channel/ irrigation return	private (ID #4000104 and #4001995)	• secondary channel restoration • irrigation return channel enhancement	• good access via dirt roads/farm fields • irrigation return present • secondary channel was active as recently as 1990s	
6.2	RM 164.4-164.2 (S) floodplain/ irrigation returns	Navajo Nation	• irrigation return channel enhancement • woody debris placement • constructed bank indentations	• low bank height • irrigation returns present • convenient road access	• power lines at site may limit excavation options • narrow undeveloped floodplain width
6.3	RM 164-163.8 (S) floodplain area/irrigation return	Navajo Nation	• irrigation return channel enhancement • secondary channel restoration	• convenient road access • low to medium bank height • irrigation return present	
6.4	RM 162.7 (S) secondary channel	Navajo Nation	• vegetation removal • secondary channel entrance reestablishment	• convenient road access • exit of secondary channel frequently mapped as backwater	
6.5	RM 162.4-162.2 (N) floodplain	listed as “USA” on County maps; access may be through private land (ID# 80772)	• constructed bank indentations • irrigation return channel enhancement • woody debris placement.	• public ownership • good access via dirt roads • irrigation return/tributary present	• medium (not low) bank height • existing tributary/irrigation return and secondary channel already provide backwaters

Table 6.3.14. Potential restoration sites in subreach 7 (RM 162-159).

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
7.1	RM 161.8-161.2 (S) floodplain area	"Federal" and Navajo Nation	• secondary/overbank channel entrance reestablishment • irrigation return channel enhancement • cross channel creation • pilot channel excavation	• public ownership • good access via dirt roads/farm fields • irrigation return present • low bank height at entrance/exit to secondary channel • channel entrance previously mapped as backwater	
7.2	RM 161.8-161 (N) floodplain area	listed as "Federal" on County maps; access via private land (ID#80950)	• constructed bank indentations	• public ownership • good access via dirt roads/farm fields	• portions of area are heavily grazed • narrow undeveloped floodplain • mostly medium (not low) bank height
7.3	RM 161.25 (N) overbank channel entrance	listed as "Federal" on County maps; access via private land (ID#81045)	• secondary/over-bank channel entrance reestablishment	• low bank height • public ownership • good access via dirt roads/ farm fields	
7.4	RM 160.9 (N) inactive cross channel	access via private land (ID#81855)	• cross channel restoration	• cross channel active as recently as 1996 • previously mapped as backwater	
7.5	RM 160.6 (S) irrigation return	Navajo Nation	• irrigation return channel enhancement	• wide undeveloped floodplain • previously mapped as backwater	• thick vegetation may hinder access

SITE NUMBER	LOCATION	OWNERSHIP OF SITE AND/OR ACCESS TO SITE	POTENTIAL RESTORATION ACTIVITIES	SITE ADVANTAGES	SITE DISADVANTAGES
7.6	RM 160.55-160.4 (S) low bank area	Navajo Nation	• floodplain lowering • bank destabilization	• wide undeveloped floodplain • portions of bank already eroding • low bank height	• thick vegetation may hinder access
7.7	RM 160.45-160.4 (N) low bank/irrigation return	private (ID#81880)	• irrigation return channel enhancement • constructed bank indentations	• good access via dirt roads/farm fields • low bank height/existing depression	
7.8	RM 160.3-159.9 (S) inactive overbank channel/irrigation return	Navajo Nation	• irrigation return channel enhancement • overbank channel restoration	• channel mapped as active as recently as 1994 • irrigation return present • low bank height at mouth	• high terrace may prevent access
7.9	RM 159.65 (N) irrigation return	listed as “Federal” on County maps; access via private land (ID#82081)	• irrigation return channel enhancement	• public ownership • good access via dirt roads/farm fields	• narrow undeveloped floodplain width • medium (not low) bank height
7.10	RM 159.4 (S) vegetated bar/island	Navajo Nation	• vegetation removal • secondary channel restoration	• previously mapped as backwater	• high terrace may hinder access

7. RECOMMENDATIONS

7.1 Pilot Projects

A wide variety of pilot projects could be selected for implementation within the Study Area. Because the SJRIP does not own land within the Study Area, identifying a cooperative, interested property owner or land management agency will be a primary consideration in selecting a pilot project site. The ability to conveniently monitor an installed pilot project will also be an important consideration. Although some information on the effectiveness of different restoration techniques is available for projects on the Platte River and the Rio Grande (Currier 2001, Muldavin et al. 2004, J. Jenniges 2006, pers. comm.), detailed results are limited and are not necessarily applicable to the San Juan River. Because the San Juan River within the Study Area has unique characteristics in terms of sediment load, hydrology/storm influence, slope, and bed material, San Juan-specific monitoring will be essential to ensure that restoration efforts produce the greatest habitat benefit possible. Identifying an easily accessed, large-sized pilot project site that is appropriate for implementing a variety of restoration techniques will allow for efficient monitoring and will help minimize the logistics involved with coordinating with multiple landowners. Table 7.1.1 identifies a subset of the potential restoration sites previously listed in Tables 6.3.8-6.3.14 that would be suitable locations for pilot project implementation. We recommend that the SJRIP begin the process of contacting the owners or management agencies for these sites in order to assess the feasibility of working in these locations. It is important to keep in mind that the list of sites in Table 7.1.1 is not necessarily comprehensive; additional sites within the Study Area may prove to be suitable for pilot project implementation upon further investigation.

Table 7.1.1. Characteristics of potential pilot project sites.

POTENTIAL RESTORATION SITE NUMBER (*FROM TABLES 6.3.8 - 6.3.14*)	CONVENIENT ACCESS (WITHIN 1 MILE OF IMPROVED ROAD)	LARGE WORKABLE AREA	SUITABLE FOR IMPLEMENTATION OF VARIOUS TECHNIQUES	IRRIGATION RETURN PRESENT	HISTORIC SECONDARY CHANNEL PRESENT
1.3	X	X	X	X	
2.1/2.2		X	X	X	X
3.1	X	X	X		X
3.4	X	X	X		
5.3	X	X	X	X	X
7.1	X	X	X	X	X

Once a feasible pilot project site is identified, we recommend that a variety of restoration techniques be experimentally installed and monitored. Results from these pilot project activities could then be used to maximize the effectiveness of future restoration efforts within the Study Area. Some specific activities/experiments could include:

- installing constructed bank indentations of varied size, shape, and orientation and monitoring rates of sediment in-filling;

- installing and managing a headgate-controlled bank indentation and comparing its sediment in-filling rate to that of a "paired" indentation (same size, shape, orientation) installed with no headgate;

- installing streambank woody debris placements of various sizes and orientations and monitoring to see which style of structure creates the largest/highest quality habitat;

- installing and experimenting with a simple irrigation return channel enhancement as well as a multi-outlet, headgate-controlled irrigation return channel enhancement to better determine the magnitude/duration/depth of water needed to prevent vegetation encroachment;

- installing a small-scale pilot channel and monitoring post-flood change/"self-excavation" effectiveness;

- installing a small headgate-controlled secondary channel and experimenting with different headgate management techniques to determine how to most effectively minimize sediment in-filling; and

- experimental removal of Russian olive from streambank/small-scale floodplain lowering to promote streambank cottonwood establishment.

Although implementing and monitoring any of the above activities (or combination thereof) would provide useful information and habitat, we recommend pursuing irrigation return channel enhancement as the highest priority habitat creation-type pilot project. This restoration activity has a relatively low cost to implement, is expected to have lower, long-term maintenance costs than other habitat creation concepts, and has a high certainty of creating a usable backwater within a short time frame. We also recommend that woody debris placements of different types be incorporated into the pilot irrigation return channel enhancement project. As discussed in Section 3.2, young Colorado pikeminnow appear to exhibit a preference for habitats with overhead cover such as woody debris.

Because they include irrigation returns as well as historic secondary channels, potential pilot project site numbers 2.1/2.2, 5.3, and 7.1 may be the most promising project locations (Table 7.1.1). However, detailed information on irrigation return characteristics (i.e., amount and timing of flow) should be obtained from the appropriate ditch companies as part of initial feasibility studies prior to selecting a project location. Because of the uncertainty in access feasibility, project size, and mobilization/access costs, we have not ranked these potential pilot project sites in terms of cost. However, the unit cost information provided in Section 5.7 can be used to estimate the cost of implementing a specific project in a specific location.

Prior to implementing any type of habitat enhancement project, a detailed survey of site topography and water surface elevations at different discharge levels should be completed. This information should be used to develop stage-discharge and other hydraulic information for the entire area that would be affected by the project. Anticipated changes to hydraulic conditions after restoration project implementation should be analyzed, and the design should be adjusted as necessary to ensure that the habitat created has suitable depth and velocity conditions and sediment transport characteristics. We recommend that any project implemented with the objective of improving retention of stocked young Colorado pikeminnow include features designed to provide backwater conditions throughout the range of flows anticipated during the fall stocking season.

In addition to pursuing implementation of a pilot habitat creation project such as irrigation return channel enhancement, we also recommend that the SJRIP begin to explore partnering opportunities and potential sites for implementation of a larger-scale non-native vegetation removal/channel destabilization project. Because of infrastructure constraints within the Study Area, the most appropriate site for a large-scale destabilization project may be in the less-developed river reaches downstream from the Study Area. We recommend that the SJRIP contact the San Juan Basin Russian Olive Salt Cedar Task Force, the Navajo Nation, and other potential partners to identify possible project locations and opportunities to leverage funding from various sources.

7.2 Secondary Channel Recommendations

A number of the potential restoration sites listed in Tables 6.3.8-6.3.14 involve restoration/reactivation of secondary, overbank, or cross channels that have become silted in and/or vegetated relatively recently. In most cases, these sites have previously been mapped as supporting backwaters, often in more than one year. Implementing these projects would be relatively low cost, and would have a high probability of restoring or increasing the size and quality of backwater habitats within the Study Area. Therefore, we recommend that SJRIP take steps to contact the relevant land owners/managers to explore the feasibility of accessing and doing work at these sites. Pursuing restoration efforts at these sites will help ensure that channel features that consistently provided high quality habitat prior to the recent drought period are restored and maintained. The specific site numbers we recommend for implementation are: 4.1, 4.2, 4.3, 6.1, 6.4, 7.4, 7.8, and 7.10.

7.3 Monitoring

Restoration Project Monitoring

Once a pilot restoration project is implemented, regular (i.e., annual) monitoring of the project site should be conducted in order to assess changes in site topography, bed material, and vegetation characteristics. Monitoring tools could include surveys of monumented cross-sections, substrate mapping, pebble counts, bed material sampling, water quality sampling (temperature and turbidity), vegetation mapping/transect surveys, and repeat photography. Biological monitoring should also be conducted to document habitat use by Colorado pikeminnow and other native aquatic species. Ideally, at least 1 year of baseline biological data should be collected prior to restoration project implementation. Biological monitoring of restoration site(s) should be coordinated with ongoing monitoring studies examining the retention of stocked young Colorado pikeminnow within the Study Area (Golden et al. forthcoming). This will allow for assessment of the degree of improvement in retention (i.e., habitat benefit) associated with the restoration project relative to the cost of implementing the project.

Geomorphic and Riparian Monitoring

Previous and ongoing geomorphic and habitat monitoring efforts on the San Juan River have been well thought-out and provide a spatially extensive, rich data set. However, some specific adjustments and additions to monitoring of the Study Area are recommended in order to better track and understand backwater habitat creation and maintenance processes.

The results of annual aquatic habitat monitoring efforts are used to track the number and total surface area of backwater habitats and islands on the San Juan River between RM 180 and RM 3. While this monitoring provides a wealth of useful information, its usefulness in tracking the evolution of complex secondary channel areas is limited by the fact that the mapping results are flow-dependent and the extent of the mapping is sometimes limited to just the wetted portions of the channel. For example, a secondary channel mouth that forms a backwater at moderate flow may be mapped as a run at higher flow, a shoal at lower flow, or not be mapped at all at the low flow when the channel is dry/disconnected, even though the physical topography of the site remains unchanged. One way to help resolve this problem would be to map at the same flow level every year. Current monitoring protocol is to map at low flows, between 500 and 1,000 cfs. Although consistency within this flow range is adequate for general comparisons, an individual secondary channel mouth may vary between dry and inundated within this flow range, making it difficult to determine whether a backwater was truly “lost” or simply was dry or unmapped. Because flows on the San Juan River can respond significantly to rain events, and because of the logistics involved in planning multiple-day, raft-based mapping trips, it is simply not possible to complete habitat mapping at exactly the same flow level in every reach every year.

As an alternative, we recommend that the total areal extent of habitat mapping be standardized to the full bankfull channel area, at least within the Study Area. This would ensure that secondary channels are mapped, even if they are dry. Mapping codes are already set up for “dry channel” (code 27) and “island with dry channel” (code 51); an additional code could be added for “dry channel with encroaching vegetation” to help track secondary channels that are becoming vegetated. Standardizing the overall habitat mapping extent and ensuring that the codes for “dry channel”, etc., are consistently used will make it easier to track temporal changes in channel features that could impact backwater availability. This would increase the utility of ongoing monitoring efforts with relatively little cost increase, particularly if the protocol change were only implemented within the Study Area/Reach 6 (rather than the entire river between RM 180 and RM 3). If it is cost-prohibitive to implement this change throughout the Study Area, we recommend that, at a minimum, the protocol change be implemented within any specific river segment selected for a pilot restoration project. The use of standardized, flow-independent habitat monitoring will be particularly important for tracking long-term channel changes in any location where a vegetation removal/channel destabilization project is implemented. Without this standardization, it will be difficult to accurately track the habitat benefits of restoration projects and to determine the highest-priority locations for backwater restoration (i.e., river reaches experiencing the most significant loss of backwaters).

Because non-native riparian vegetation exerts an influence on channel/backwater processes, we also recommend that riparian vegetation be comprehensively mapped within the Study Area so that trends over the last decade can be evaluated. A protocol similar to that used to develop the 1994 riparian vegetation maps (Bliesner and Lamarra 2000) should be used so that quantitative comparisons can be made. Understanding where and to what degree Russian olive and tamarisk have become more prevalent (or not) within the Study Area will be useful in identifying and prioritizing restoration efforts that involve vegetation removal or management.

Finally, we also recommend that detailed topographic monitoring be completed in a complex channel area. Cross-section monitoring in the Study Area has been limited to just two locations, RM 175 (cross section CS6-01) and RM 168.3 (cross section CS6-02). Both of these cross sections are located in fairly straight, single-thread channel sections. Therefore, they do not provide information on scour/aggradation processes in secondary channel areas relative to the main channel, or on stage-inundation relationships in complex portions of the river. It is our understanding that a new (fiscal year 2005), detailed channel morphology monitoring effort is planned for two complex channel sites located downstream from the Study Area. It is our understanding that detailed topographic surveys/multiple cross sections will be surveyed within each detailed monitoring site, capturing both main channel and secondary channel features. Regularly collecting this data will provide invaluable information on the processes and flow regimes that create and maintain complex channel habitats and backwaters. We also recommend that generalized riparian vegetation categories be mapped within each detailed monitoring site to allow for tracking of vegetation encroachment processes. Characterizing vegetation in addition to the planned substrate characterization effort will also be useful in determining roughness values for input into the planned two-dimensional hydrodynamics models of the detailed sites.

Although the planned detailed/complex-channel monitoring sites are not located within the Study Area, implementing a pilot restoration project within one of these monitoring sites could be a cost-effective, coordinated way to track the channel changes and habitat benefits resulting from restoration project construction.

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APPENDIX A: FIGURES COMPARING 2004 AND 2005 PHOTOS AND VIDEO IMAGES

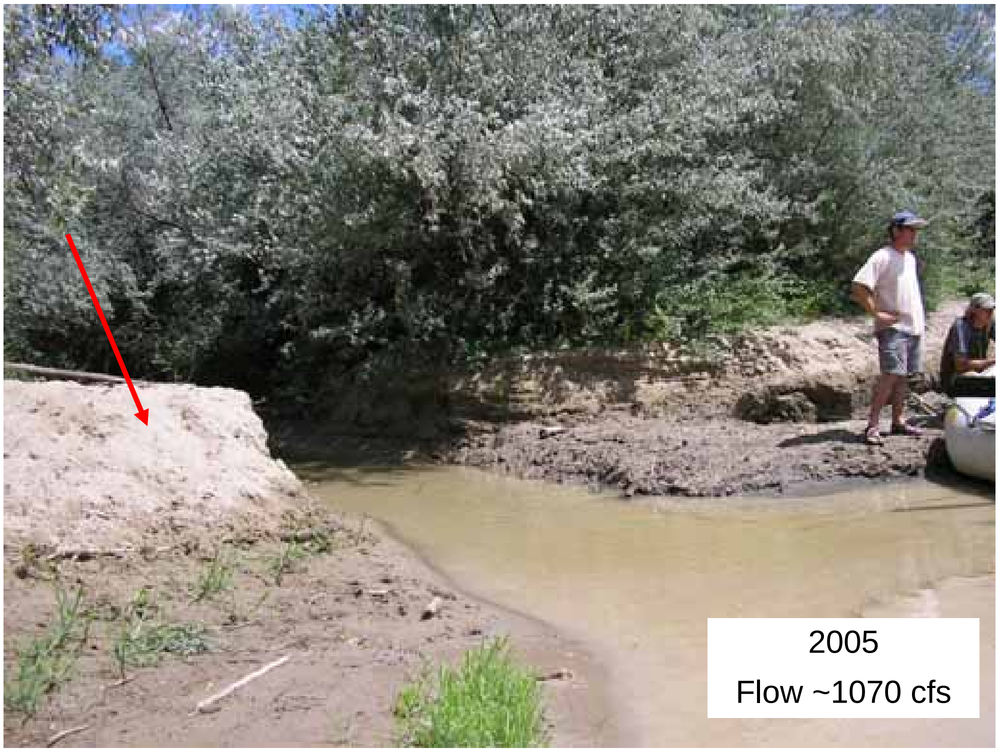


Figure A1. Mouth of irrigation return channel at RM 163.3 before and after the spring 2005 flood. Note fresh sand deposit indicated by red arrow.

Figure A2. Backwater at exit to secondary channel at RM 170.9 in 2004 versus 2005.

Figure A3. Comparison of 2004 and 2005 aerial videography images of RM 170.9 side channel mouth.

Figure A4. Comparison of RM 162.7 side channel mouth in 2004 versus 2005.

Figure A5. Entrance to secondary channel at RM 170.4 in 2004 versus 2005. Note re-activation of previously vegetated channel entrance following the 2005 spring flood.

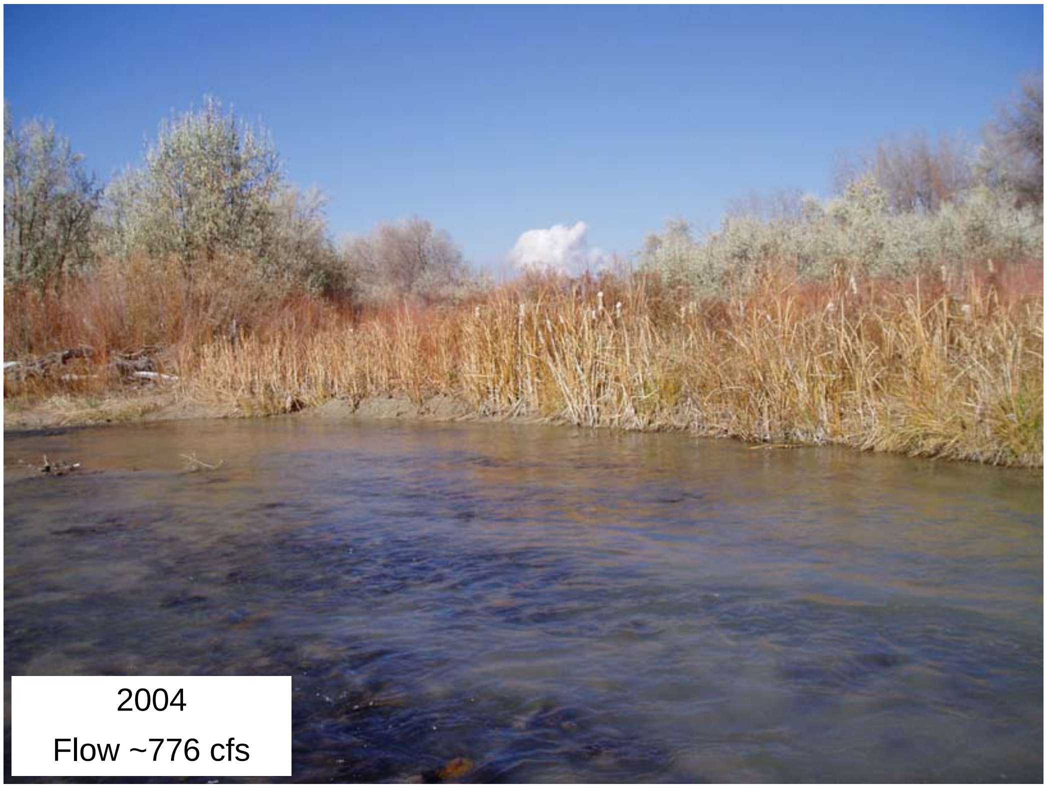


Figure A6. Entrance to inactive channel at RM 170.1 in 2004 versus 2005. Note persistence of vegetation following the 2005 spring flood.

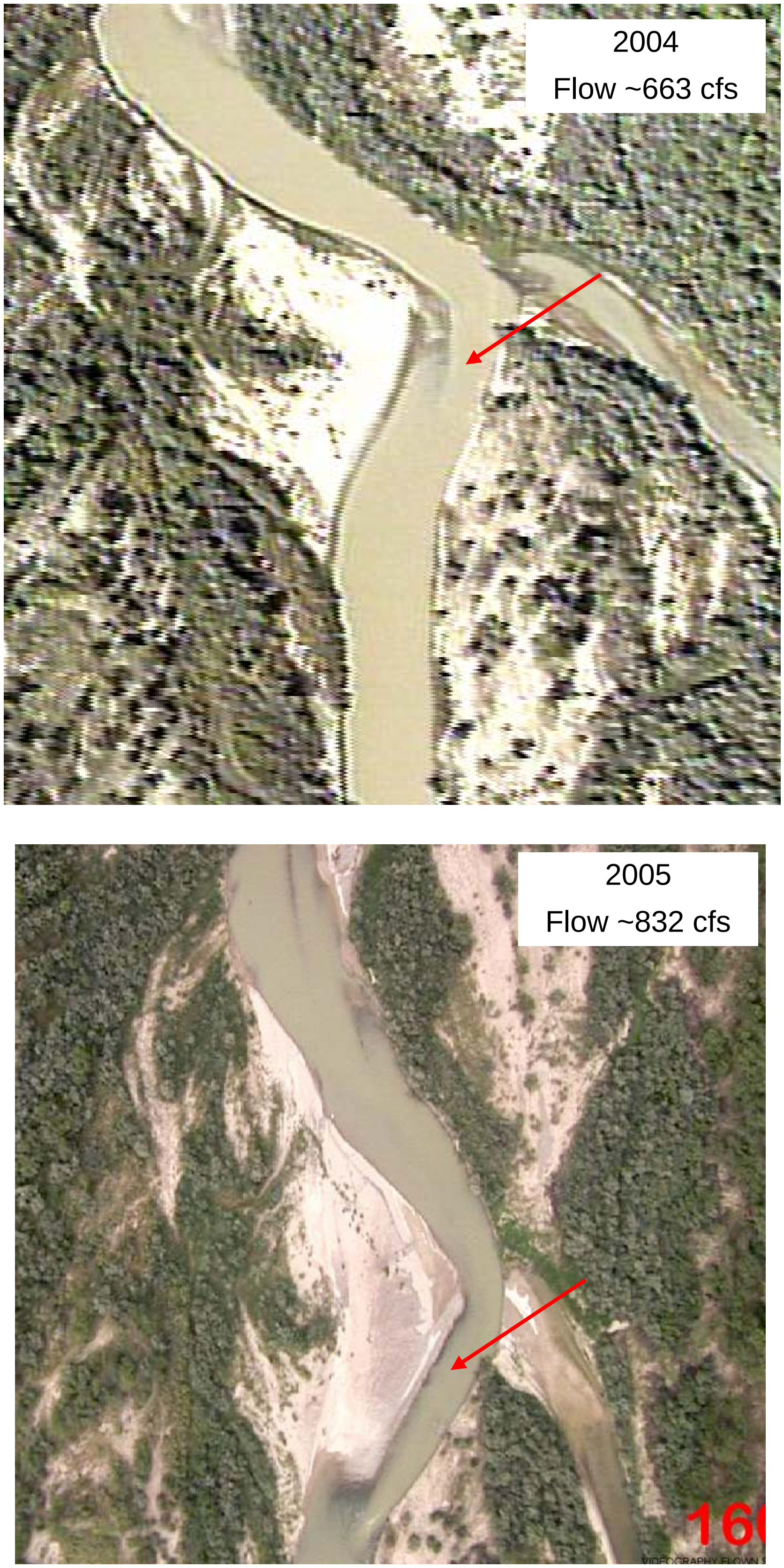


Figure A7. Comparison of 2004 and 2005 aerial videography images of cobble bar at RM 160.7. Note associated channel narrowing at location indicated by arrows.

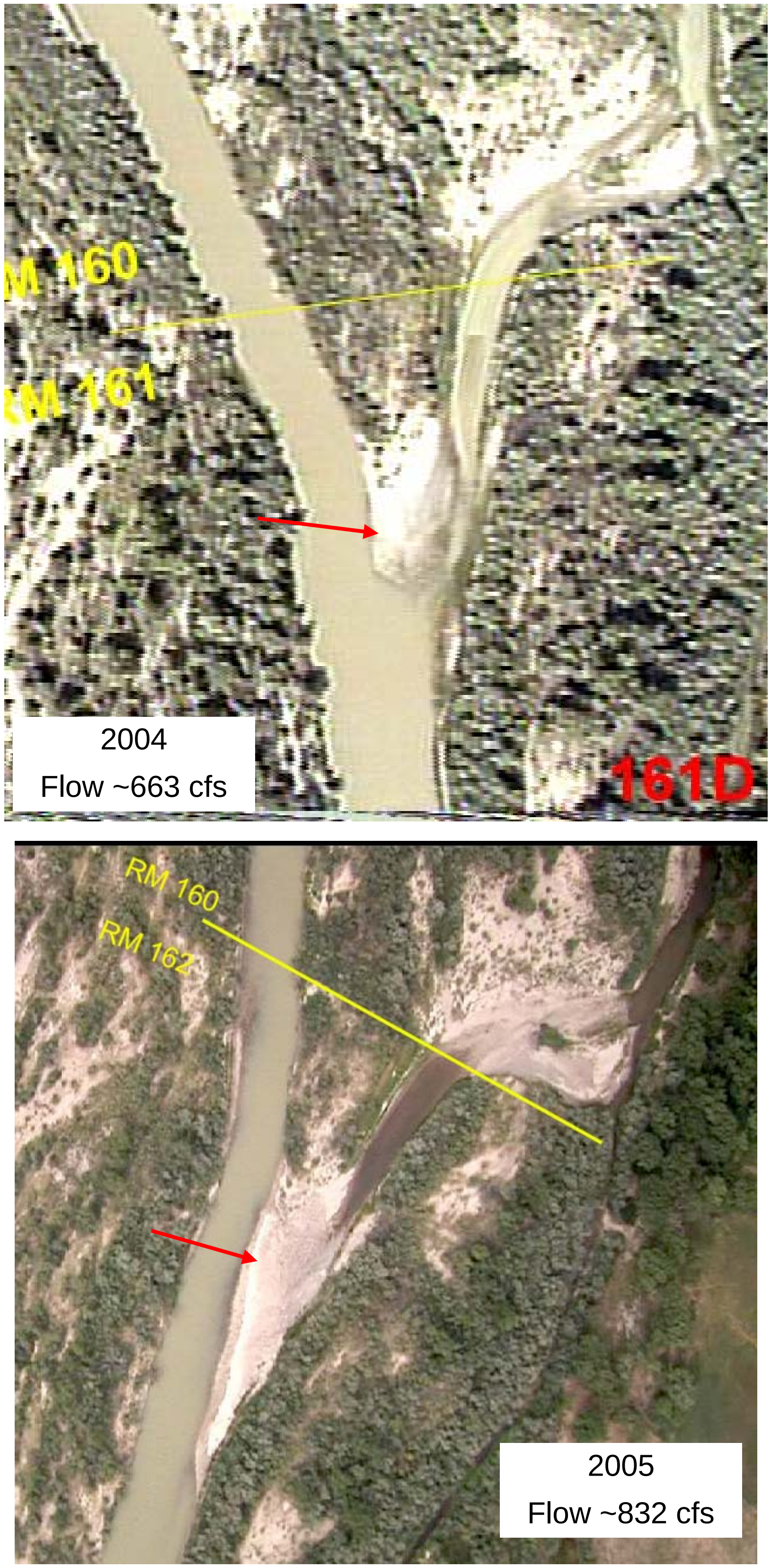
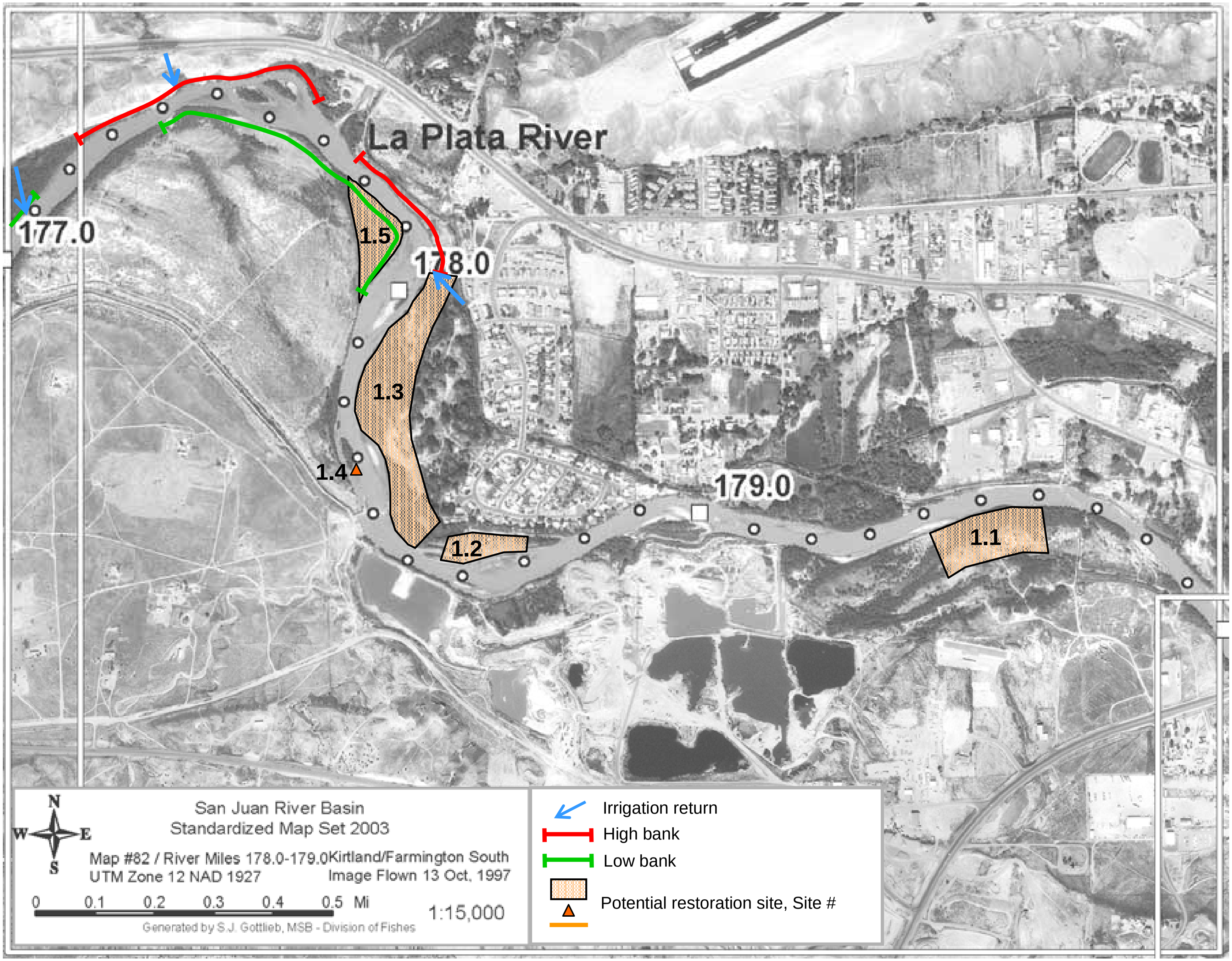
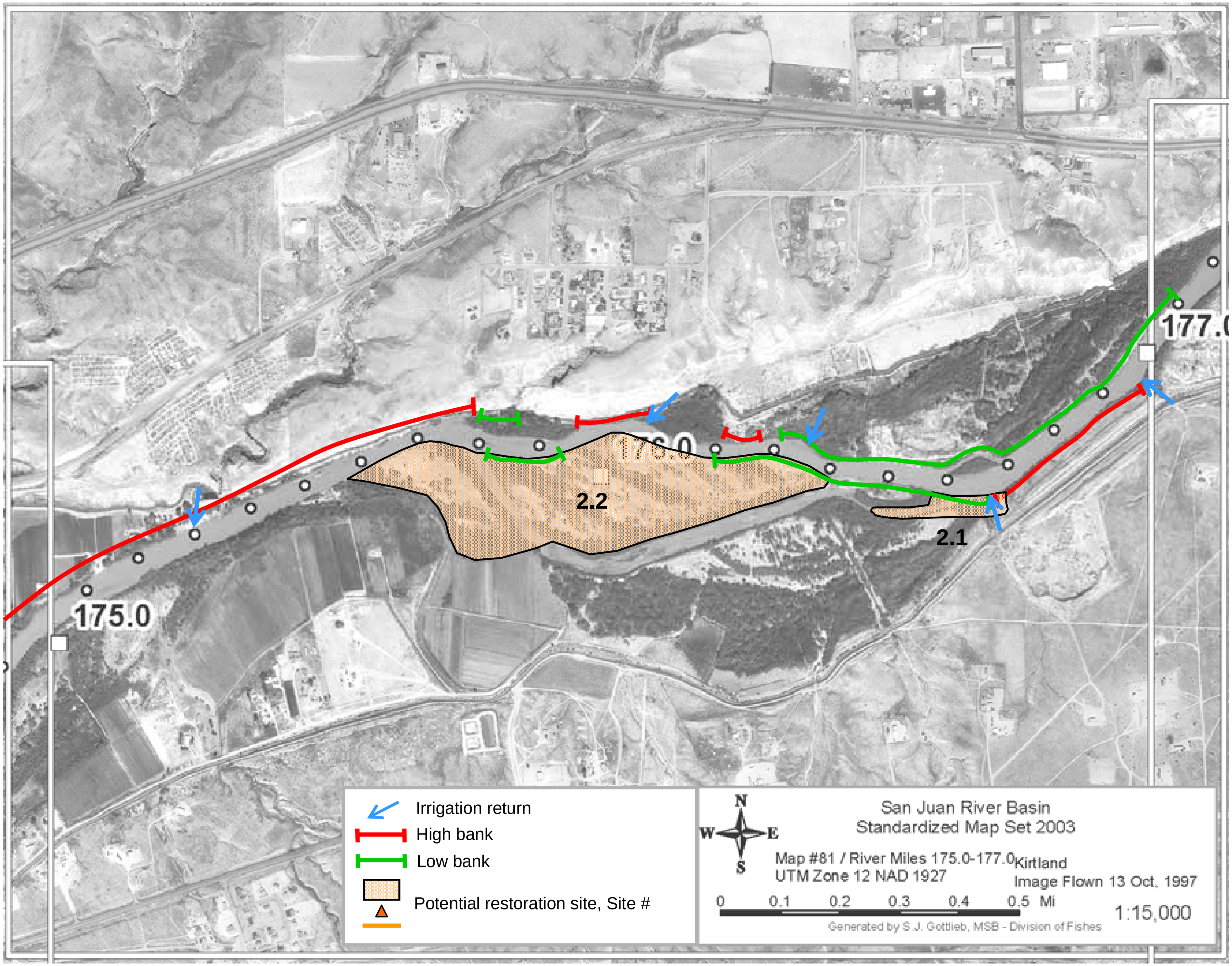


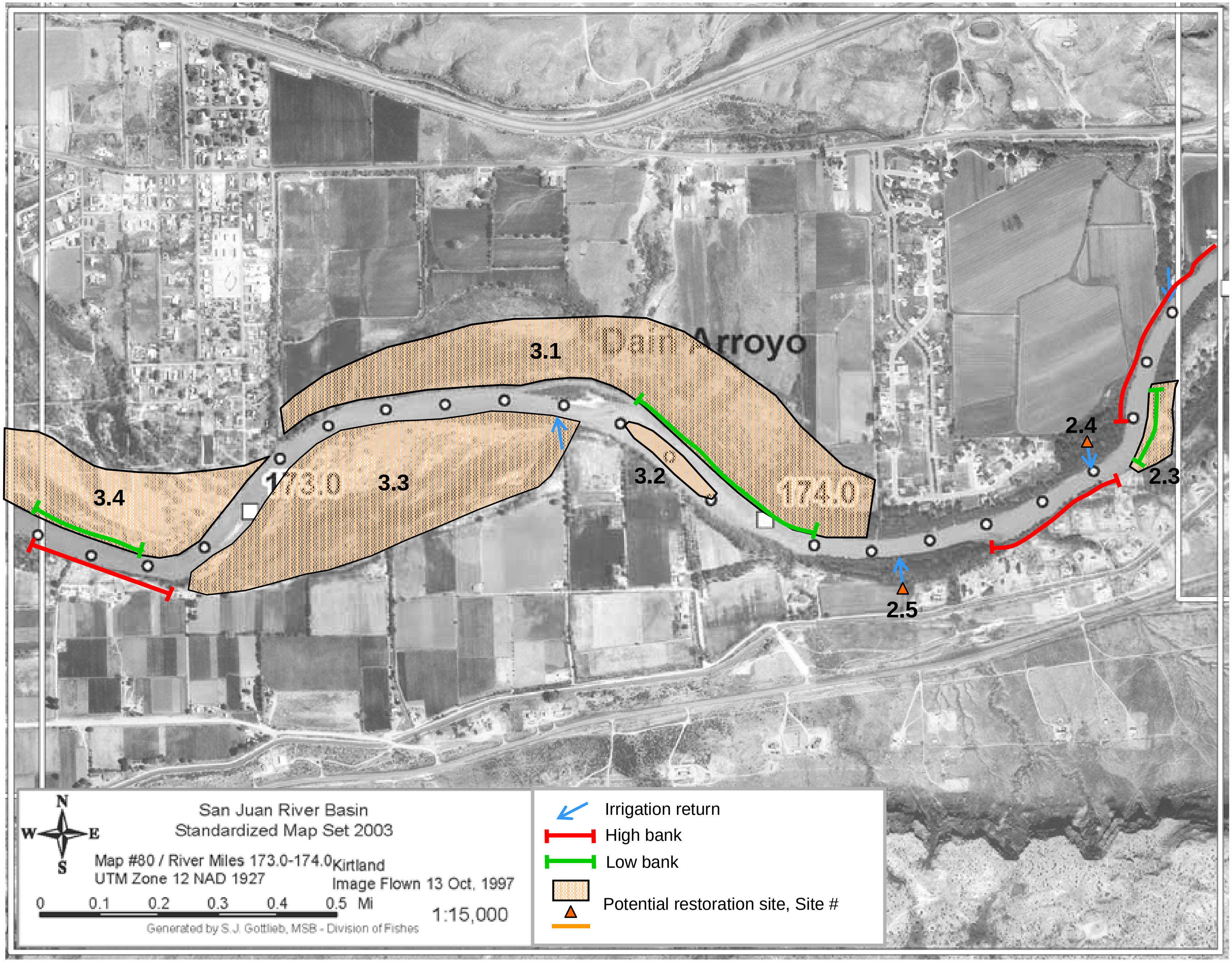
Figure A8. Comparison of 2004 and 2005 aerial videography images of entrance to secondary channel at RM 161.1. Note fresh cobble deposit in area indicated by arrows.

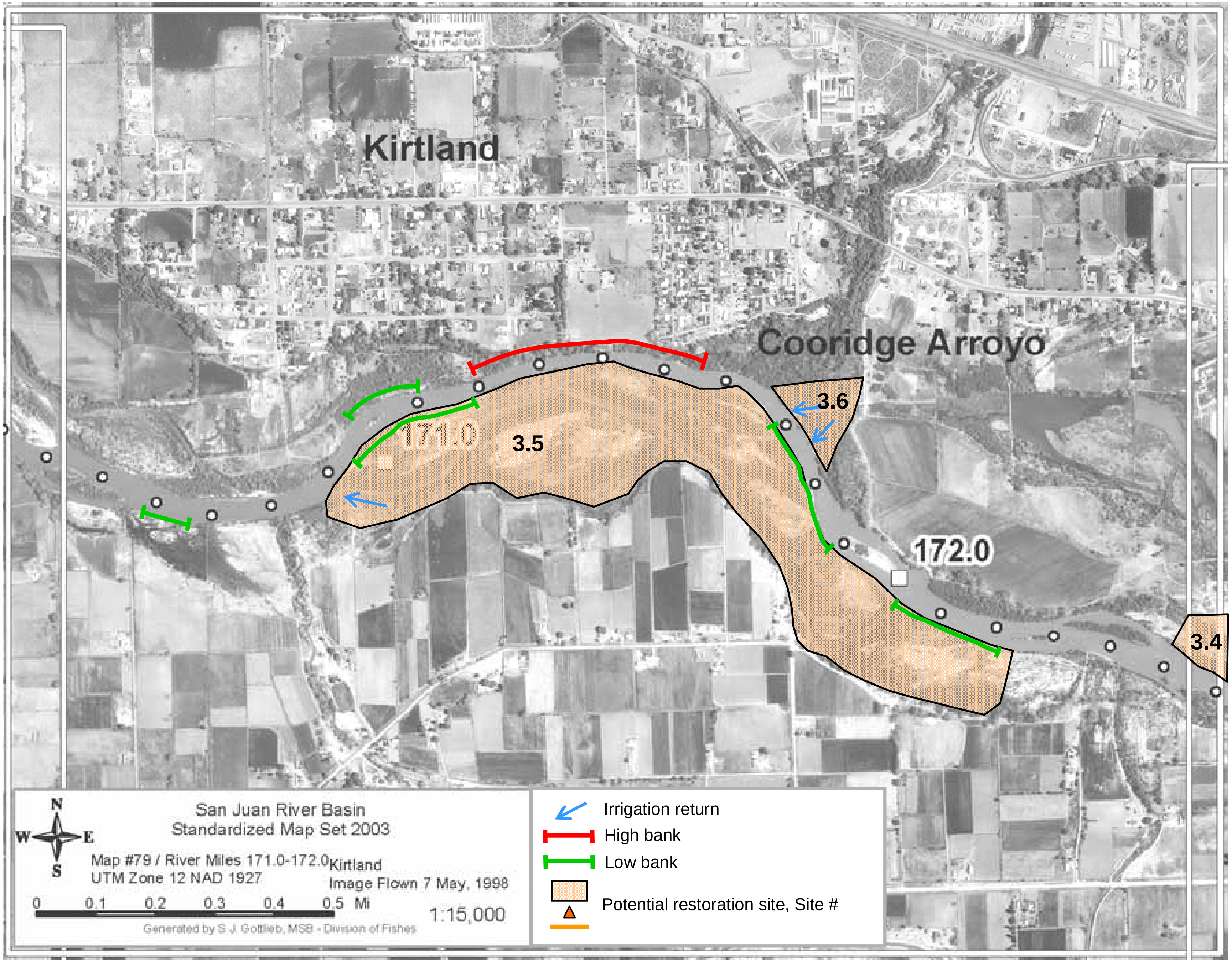
Figure A9. Entrance to secondary channel at RM 162.5 in 2004 versus 2005. Note fresh cobble and loss of some young tamarisk.

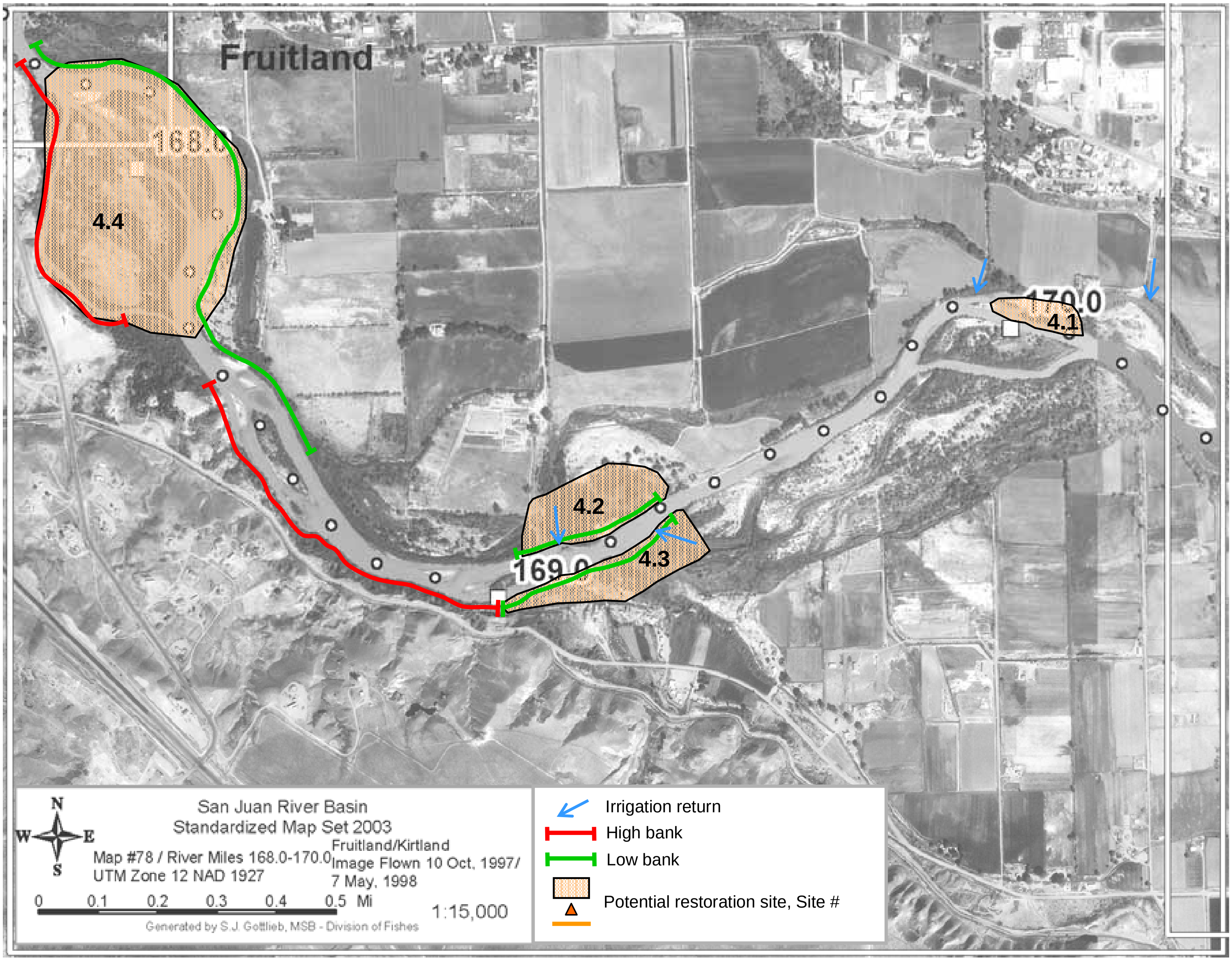
APPENDIX B: MAPS OF IRRIGATION RETURNS, BANK HEIGHTS, AND POTENTIAL RESTORATION SITES IN THE STUDY AREA

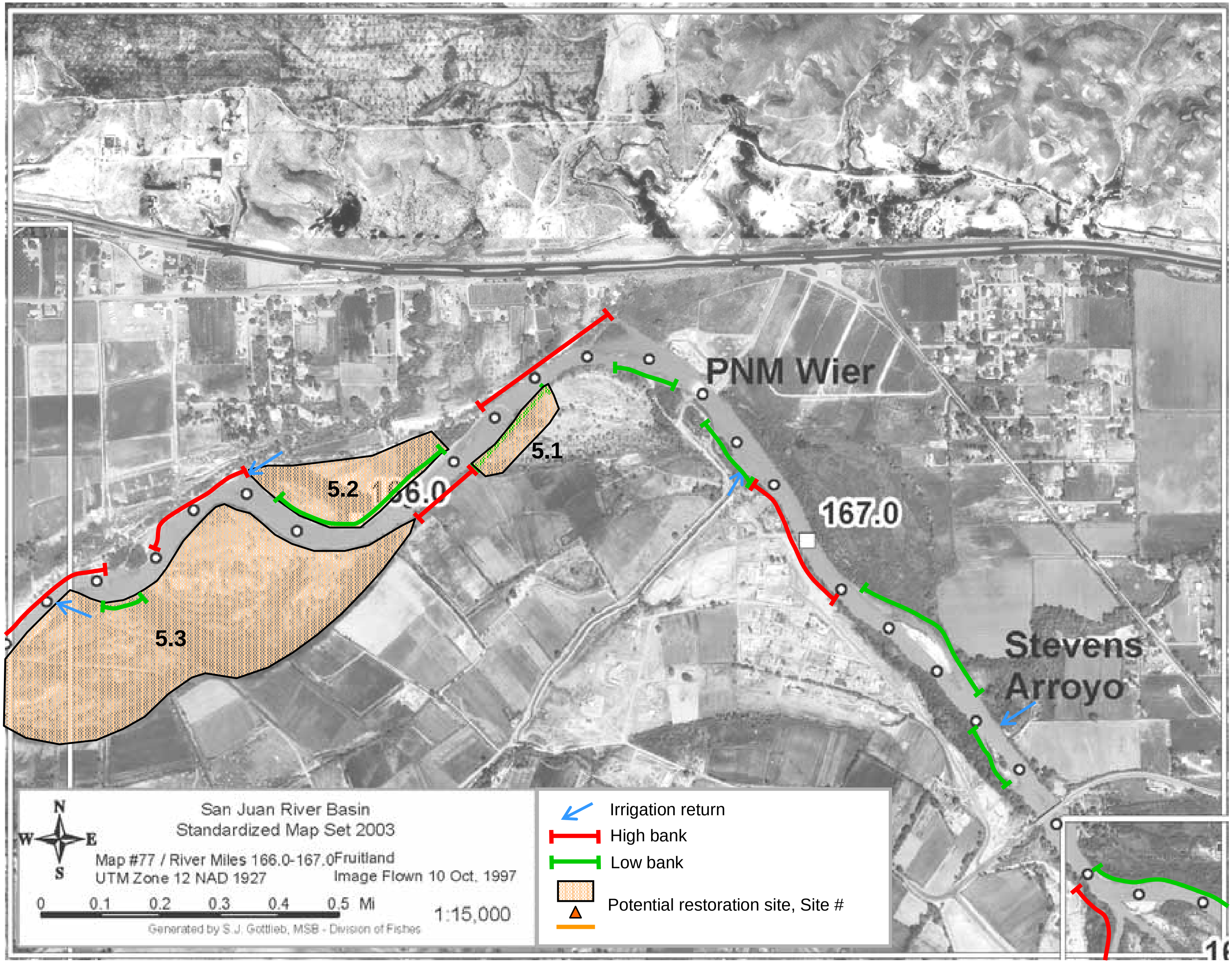

La Plata River
177.0
178.0
179.0
1.1
1.2
1.3
1.4
1.5
N
W
E
S
San Juan River Basin
Standardized Map Set 2003
Map #82 / River Miles 178.0-179.0
Kirtland/Farmington South
UTM Zone 12 NAD 1927
Image Flown 13 Oct, 1997
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #

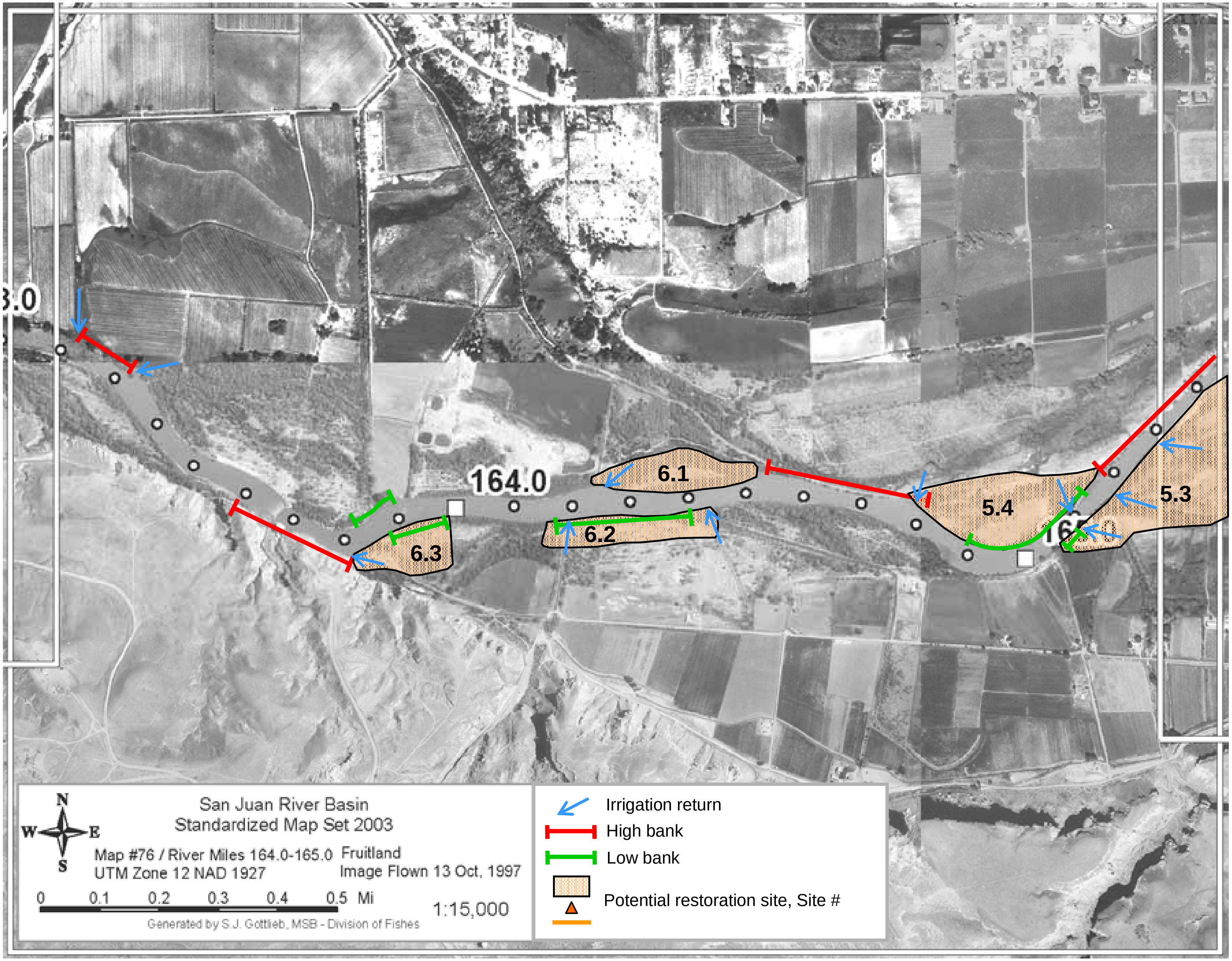

175.0
176.0
177.0
2.1
2.2
Irrigation return
High bank
Low bank
Potential restoration site, Site #
San Juan River Basin
Standardized Map Set 2003
Map #81 / River Miles 175.0-177.0
Kirtland
UTM Zone 12 NAD 1927
Image Flown 13 Oct. 1997
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
N
W
E
S


Dain Arroyo
3.1
3.2
3.3
3.4
2.3
2.4
2.5
173.0
174.0
San Juan River Basin
Standardized Map Set 2003
Map #80 / River Miles 173.0-174.0
Kirtland
UTM Zone 12 NAD 1927
Image Flown 13 Oct, 1997
1:15,000
0 0.1 0.2 0.3 0.4 0.5 Mi
N E S W
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #

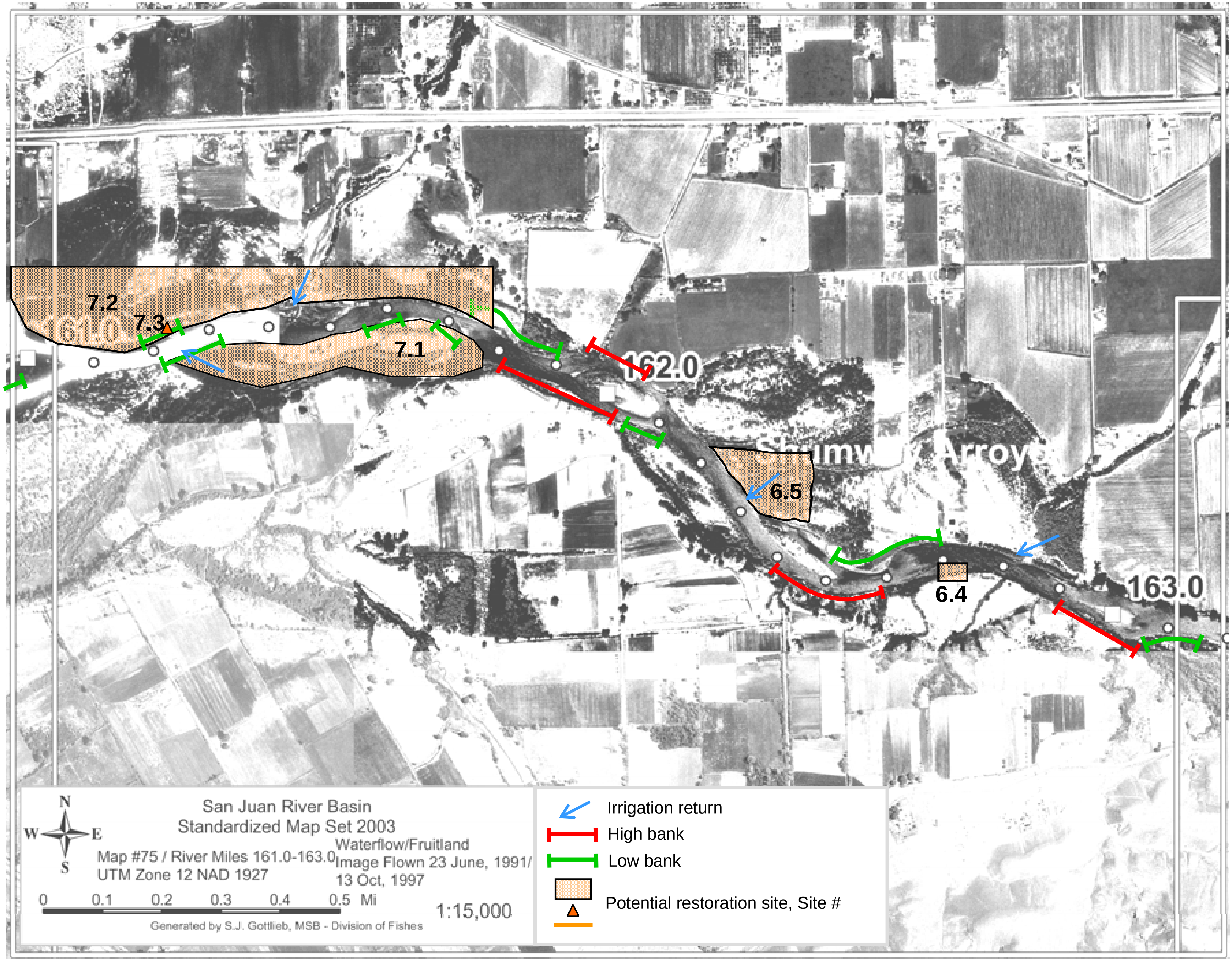

Kirtland
Cooridge Arroyo
171.0
172.0
3.4
3.5
3.6
N
S
E
W
San Juan River Basin
Standardized Map Set 2003
Map #79 / River Miles 171.0-172.0
Kirtland
UTM Zone 12 NAD 1927
Image Flown 7 May, 1998
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #


Fruitland
168.0
169.0
170.0
4.1
4.2
4.3
4.4
N
S
E
W
San Juan River Basin
Standardized Map Set 2003
Map #78 / River Miles 168.0-170.0
UTM Zone 12 NAD 1927
Fruitland/Kirtland
Image Flown 10 Oct, 1997/
7 May, 1998
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #

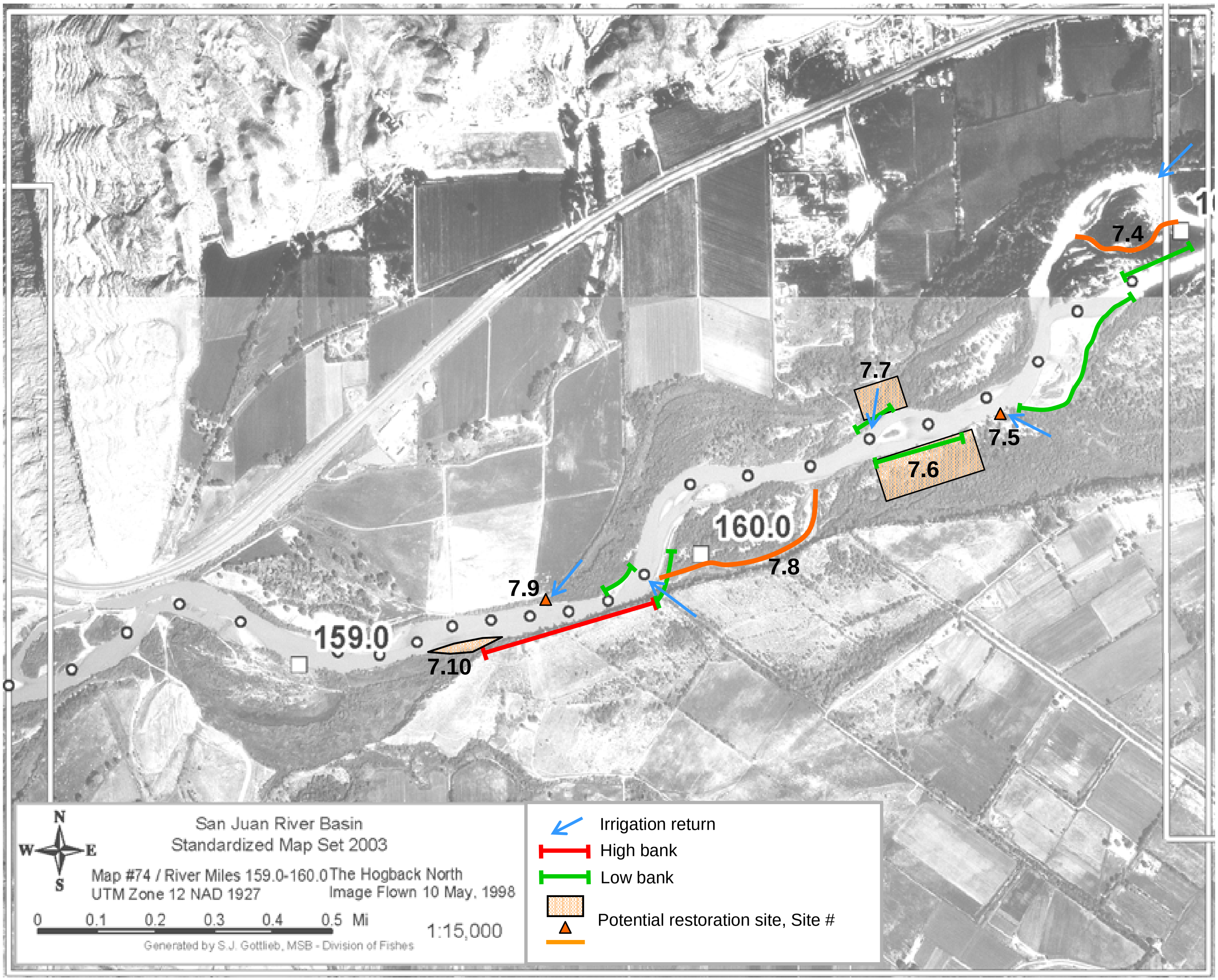

PNM Wier
167.0
166.0
Stevens
Arroyo
5.1
5.2
5.3
N
S
E
W
San Juan River Basin
Standardized Map Set 2003
Map #77 / River Miles 166.0-167.0
Fruitland
UTM Zone 12 NAD 1927
Image Flown 10 Oct. 1997
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #



164.0
6.1
6.2
6.3
5.4
5.3
San Juan River Basin
Standardized Map Set 2003
Map #76 / River Miles 164.0-165.0 Fruitland
UTM Zone 12 NAD 1927
Image Flown 13 Oct, 1997
N
S
E
W
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #



7.2
7.3
161.0
7.1
162.0
6.5
6.4
163.0
N
W
E
S
San Juan River Basin
Standardized Map Set 2003
Waterflow/Fruitland
Map #75 / River Miles 161.0-163.0
Image Flown 23 June, 1991/
13 Oct, 1997
UTM Zone 12 NAD 1927
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #


7.4
7.5
7.6
7.7
7.8
7.9
7.10
160.0
159.0
N
W
E
S
San Juan River Basin
Standardized Map Set 2003
Map #74 / River Miles 159.0-160.0
The Hogback North
UTM Zone 12 NAD 1927
Image Flown 10 May, 1998
0 0.1 0.2 0.3 0.4 0.5 Mi
1:15,000
Generated by S.J. Gottlieb, MSB - Division of Fishes
Irrigation return
High bank
Low bank
Potential restoration site, Site #