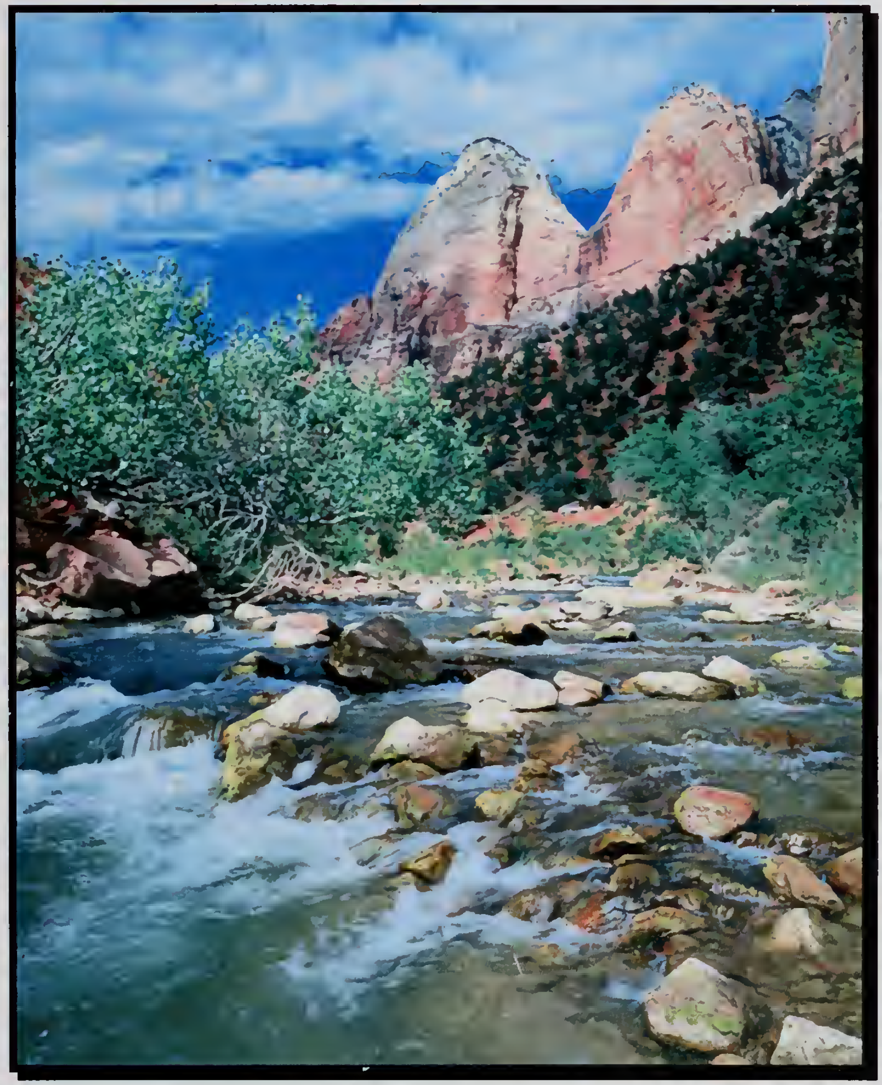
THE POTENTIAL FOR RESTORATION ALONG THE VIRGIN RIVER IN ZION NATIONAL PARK



Virgin River, Zion National Park, Photo by Dave Pettit

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September 2001

FINAL REPORT

THE POTENTIAL FOR RESTORATION ALONG THE VIRGIN RIVER IN ZION NATIONAL PARK

An evaluation of restoration alternatives with focus on the potential to regenerate cottonwood (*Populus fremontii*) along the North Fork of the Virgin River in Zion National Park

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EXECUTIVE SUMMARY

Without active intervention the magnificent canopy of cottonwood trees, part of the historic landscape within Zion Canyon, will vanish in the next few decades. Pioneer accounts describe a canyon filled with many mature trees as early as 1860 but today there is insufficient successful reproduction to replace those aging trees. Cottonwood reproduction is reduced throughout the Canyon, the lack of young trees is especially apparent in the areas near Zion Lodge where virtually none are present. Previous studies suggest that the reduction in cottonwood recruitment is greatest in areas where man-made rock and wire revetments were constructed in the 1930's. These aging revetments along the Virgin River will soon have to be replaced or removed as their deterioration creates an increasing public safety hazard.

Cottonwood reproduction is dependent on bare, moist soils commonly created during flooding. It is apparent in the areas lined with revetments that cottonwood trees are not being replaced due to the separation of the river from the floodplain. Concern over the loss of the historic cottonwood forest and the need to address the deteriorating revetments caused the National Park Service to explore options including the possible restoration of a naturally functioning river channel and floodplain. The purpose of this study was to provide the park with an assessment of existing conditions and potential for restoring riparian function with its associated benefits to the river and the cottonwood community.

FIGURE 1. Mature cottonwood trees in Zion Canyon are nearing the end of their biological life. Lack of suitable conditions limits the recruitment of young cottonwoods to take their place. Note lack of young or middle age trees.

In the 1920's and 1930's, shortly after establishment of Zion National Park, the National Park Service channelized and armored the Virgin River in Zion Canyon from the Temple of Sinawava to Birch Creek. These efforts were initiated due to flooding and channel migration that had been troublesome to settlers and threatened new constructed park facilities. While successful in controlling bank erosion and flooding, the revetments separated the river from its floodplain and effectively eliminated the reproduction of cottonwood trees, willows, and other native plants. Over the years, more than half of the revetments have been eroded away by the river. The channelization and armoring remain most apparent in the area of the Grotto Picnic Area and Zion Lodge.

FIGURE 2. Rock and wire revetments channelize the Virgin River in Zion National Park.

This report analyzes the potential for restoring a broad, functioning floodplain to the channelized reaches of the Virgin River through Zion Canyon. A set of alternatives ranging from maintaining the current conditions to complete reconstruction of a channel and floodplain were assessed. Two approaches, differing in cost and risk, were identified that met the multiple Park objectives of infrastructure protection, public safety, flood control, and riparian enhancement. Each alternative

contains elements to protect the historic park road, Zion Lodge and public safety. Two approaches, differing in cost and risk, were identified that met the multiple Park objectives of infrastructure protection, public safety, flood control, and riparian enhancement. Each approach restores channel meander and an adjacent broad floodplain. The increase in channel meander more accurately reflects conditions in areas without revetments. The reestablishment of a functioning floodplain promotes the recruitment of young cottonwood trees and other riparian plants along the river corridor as well as lowering reducing flood risk from high flow events.

It must also be recognized that the existing valley-wide canopy of cottonwoods is a result of particular conditions early in the last century. Future cottonwood recruitment can improve significantly but will be limited to the width of the active floodplains along the Virgin River.

<u>Conclusions</u>

- *Many trees, including cottonwoods, were common in Zion Canyon as early as the 1860's.* Pioneer accounts state that there were "many more trees" in the canyon and along the Virgin River in the 1860's than in 1930. These accounts describe thick forests of cottonwood, ash, and box elder and an abundant supply of willows.

- *Changes over the past century in the North Fork of the Virgin River influenced the extent and quantity of cottonwood recruitment in Zion Canyon.*
Between 1880 and 1930, climatic changes and deteriorating watershed condition resulted in large amounts of sediment to be eroded from the watershed and deposited in Zion Canyon by the North Fork of the Virgin River. As sediments filled the river valley, the Virgin River channel became wide, shallow, and braided. This channel morphology exacerbated flooding of the canyon floor threatening the new road and Zion Lodge but also greatly enhanced conditions for cottonwood reproduction across the floor of Zion Canyon (Figure 3a). In a logical reaction, revetments were constructed along the river to protect infrastructure. Sediment concentrations were subsequently reduced by improved watershed condition and changing climate. The result was a natural narrowing and deepening of the river channel and narrowing of floodplains (Figure 3b). Today the channel and floodplain in areas without revetments utilizes about half the width of the floor of Zion Canyon (Figure 3c). In the areas near Zion Lodge, removal of revetments and reestablishment of a floodplain would

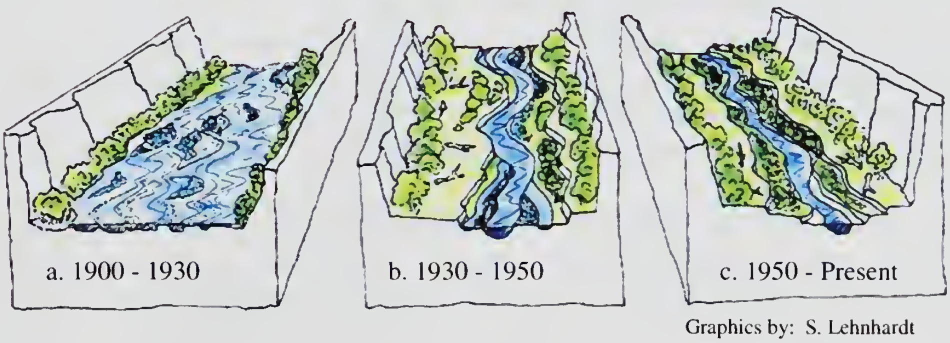


FIGURE 3. Geomorphic evolution of the Virgin River. Changes in climate and watershed condition resulted in the evolution from a wide braided channel to the current narrower channel. Man-made revetments exacerbated the process.

significantly increase the riparian corridor width.

- *The recruitment of cottonwood is eliminated by wire and rock revetments that currently constrain the North Fork of the Virgin River in Zion Canyon.*
  Cottonwood trees and many other riparian plants require specific environmental conditions to reproduce. These include disturbed, moist soil during and after seed dispersal, and protection from subsequent stream scour. These conditions are commonly created by moderate, frequent floods across low floodplain areas. The wire and rock revetments in lower Zion Canyon reduce or eliminate these floodplain areas. In many areas exotic grass species and dominance of Emory baccharis (*Baccharis emoryi*) along the stream banks also reduce successful recruitment.

- *The existing valley floor cottonwood forest will reach their natural lifespan and die over the next 30 years.*

- *There is significant potential for increasing cottonwood reproduction and riparian function by removing rock and wire revetments and/or restoring channel dimension, pattern, and profile.* Evaluation of several potential restoration alternatives suggest that there are considerable costs involved in maintaining the existing revetments and that significant restoration of riparian function can be provided by their removal.

- *Actions described in Alternatives 5 and 6 within this report would result in increased general riparian function and specifically, cottonwood recruitment along the North Fork of the Virgin River between the Grotto Campground and Birch Creek.* Both of these alternatives provide the conditions necessary to increase riparian function through these reaches. They differ in terms of degree of restoration, time of recovery, and implementation cost. The benefits and costs associated with each alternative is described in this report.

<u>Assessing Management Alternatives</u>
A set of alternatives for managing the channelized stream corridor was evaluated based on Park objectives. The alternatives ranged from benign neglect (current management) to complete active restoration of the channel and floodplain. The report suggests that two alternatives (5 and 6) would meet the resource objectives described in this project. Both alternatives include complete removal of the existing wire and rock revetments, the lengthening of the footbridges to accommodate eventual floodplain width and the lowering of terraces in the Birch Creek reach. Both alternatives rely on the road as protection for the lodge and other facilities, and will result in increased riparian function along the project reach. However, there are significant differences between the actions as well.

The hydrologic and geomorphic analyses in this report suggest that current conditions for cottonwood recruitment differ dramatically from historic conditions. Expectations for restoration must be tempered accordingly. Cottonwood regeneration in the channelized reaches of Zion Canyon is dependent upon the restoration of river's depositional processes including the reconnection to floodplain features. Once these steps are completed, however, it may be a period of years before the right set of conditions occurs (i.e. an extended moderate flood followed by a series of drier years) to result in significant successful cottonwood recruitment.

Alternative 5, Remove Levees.

This alternative proposes to actively remove wire and rock revetments, lengthen existing footbridges and widen floodplain features in the vicinity of those bridges, and lower elevations of low terraces in the Birch Creek reach. With the removal of the revetments, natural erosional and depositional processes will widen the channel and create a floodplain. Trees, willows, sedges, and grasses will naturally colonize the evolving system. This alternative achieves the majority of Park objectives at a reasonable cost. However, there are tradeoffs in terms of on-going maintenance, an increase in bank erosion and sediment added to the river during floods, delayed resource benefits, and greater planning uncertainty. As the stream widens, erosion will create steep cut-banks and undermine mature trees increasing threats to the public and the need for additional maintenance. It will take several decades for the river to create new wide floodplain that will provide improved riparian function and cottonwood reproduction. Benefits to riparian and aquatic resources will be small initially and increase over time. As the stream channel widens towards the road, unknown costs will be incurred for bioengineering or structural protection. This alternative will require several decades to achieve.

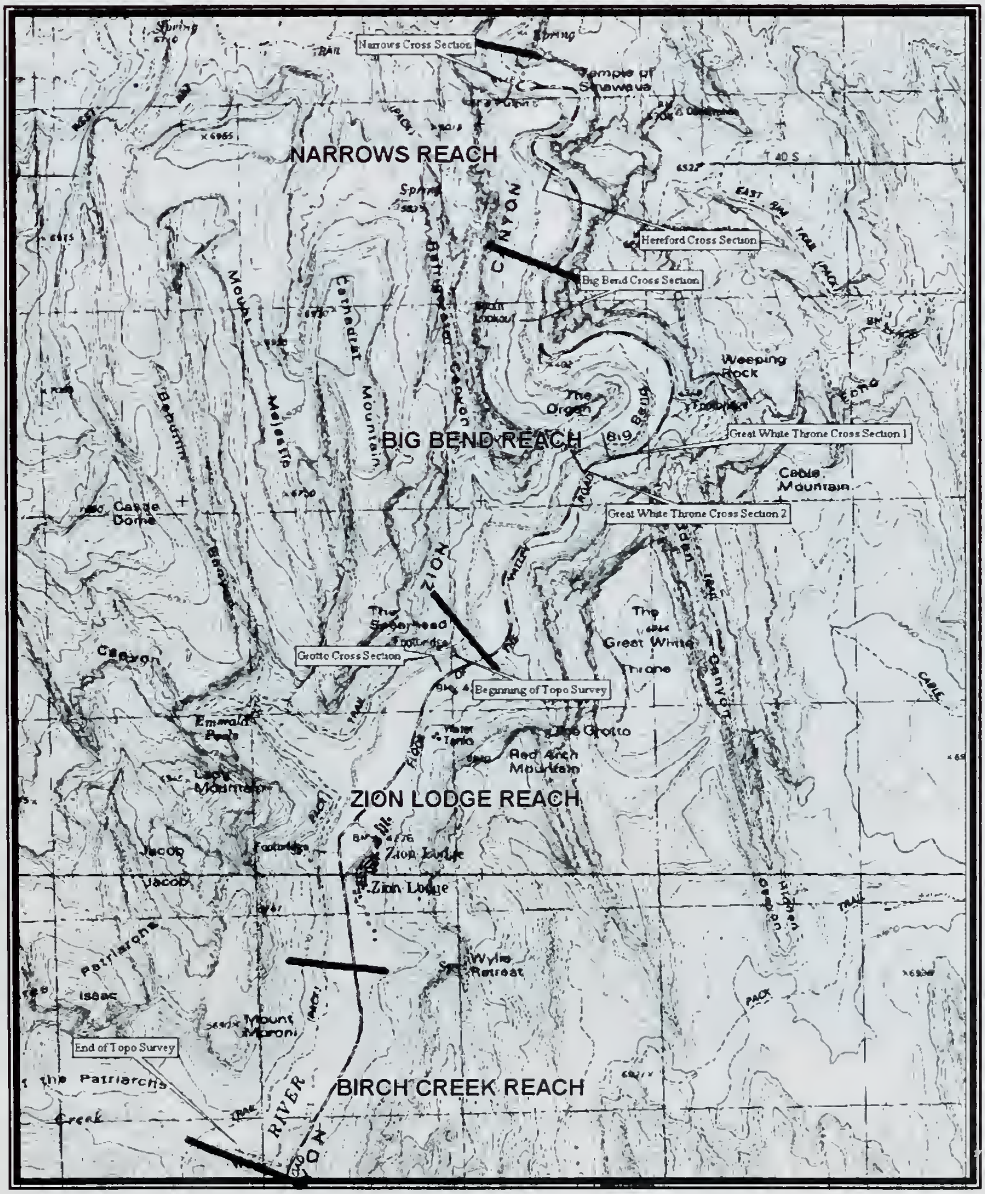
Alternative 6, Remove Levees and Construct Channel with Natural Characteristics

This alternative proposes to actively remove wire and rock revetments, lengthen existing footbridges, widen floodplain to reference conditions, and lower elevations of low terraces in the Birch Creek reach. The removal of revetments and construction of an appropriate channel and floodplain will reestablish conditions for riparian function immediately. The rapid return to an equilibrium state will benefit both riparian and aquatic resources. A new crop of cottonwood groves could be maturing along the Virgin River corridor as the current forest ages and dies over the next 30 years. Bioengineering and structural protection can be designed and installed during the initial construction. The cost for this alternative is higher due to the removal of greater quantities of terrace. But these costs are offset by a more rapid restoration of riparian and aquatic habitats and a decrease in the amount of material that will erode into the river.

INTRODUCTION

This project was initiated because of the concern by Zion National Park over the level of riparian function of the Virgin River within Zion National Park (Figure 4). Previous studies have documented that the number and distribution of cottonwood trees, a key indicator of riparian function, appear to be declining in Zion Canyon. The concern for this and other potential changes in woody plants stems from their important role in the ecological system, and because they contribute to the aesthetics and experience of the 2.3 million annual visitors to the park. The Park objectives to maintain the natural function of the riparian system within the natural fluvial processes of the stream system led to this project.

FIGURE 4. Map of Zion Canyon and project reaches



BACKGROUND

The North Fork of the Virgin River was aggressively channelized in the 1920's and with the intent to protect the newly constructed Zion Lodge and Zion Canyon Scenic Drive. The stream was confined to the western-most portion of the 1,000-foot wide floodplain by excavating the channel deeper and by building a levee along the eastern side of the channel for about 4 miles. Over the years, the upstream half of the channelization has been washed out by the river, leaving the better-constructed and maintained levees in the vicinity of the lodge. These are armored with gabions (heavy wire baskets filled with rock) for much of their length. Though the wires along the bottom of many of the gabions have rusted away, the levees have been periodically repaired, and remain effective in isolating the river from the floodplain, even when large floods have occurred (a 100-year event of 9,100 cfs).

The negative consequences of this channelization are that the channel no longer maintains natural patterns of flooding and channel migration. As the greatest mechanism of natural change in the valley, disruption of river processes sent ripples through all of the physical and biological processes there. One of the most apparent is the lack of reproduction among cottonwoods and other riparian trees. Little if any reproduction of these species is occurring, and the older overstory is decadent and rapidly dying out. Some channels of ephemeral tributaries are blocked from direct discharge into the river by the levees, so their more indirect pathways create sediment traps that require frequent cleaning.

FIGURE 5. Lack of young cottonwood trees along valley floor in Zion Canyon. These areas now lie more than 12 feet above the river and no longer contain conditions favorable to cottonwood recruitment.

One of the most compelling reasons for restoring the channel is that the levees are no longer the only, or even best, source of flood protection for the lodge. The park road, with improvements done to it over the years, is at a higher elevation than the levees, so will provide protection for the lodge and other facilities during larger flood events.

NATIONAL PARK SERVICE OBJECTIVE

The National Park Service objective for the North Fork of the Virgin River is to restore its function and appearance to natural conditions, consistent with the principles of fluvial geomorphology, without causing undue resource impacts, or increases in safety hazards and flood hazards. Each of the alternatives developed and evaluated in this project are judged against this objective.

PROJECT TASKS AND OBJECTIVES

Formal tasks within this project include:

1) Collection of essential baseline information about the resources and structures in the Virgin River floodplain,
2) Preparation of a concept restoration plan including evaluation of the preliminary alternatives, and
3) Conducting a workshop with Park staff, interested agencies, and knowledgeable professionals to discuss and critique the concept plan.

The primary goal of the project was to collect data necessary to prepare a concept plan for restoration of the natural form and function of the North Fork of the Virgin River within Zion National Park. The project site includes approximately 4 miles of the North Virgin River between the mouth of the Virgin River Narrows and a prehistoric landslide downstream of Birch Creek. The concept plan is based on an assessment of the current channel and identifies design restoration criteria. Based on these criteria, an evaluation of 6 preliminary alternatives developed by Zion National Park will provide the basis for a concept restoration plan. The plan provides some of the data necessary to develop an Environmental Assessment and to seek funding for construction of the project.

At least two evaluations of the prospects for restoring this reach of the river have been conducted, Weiner and Smillie (1997) and Smillie et. al. (1997). From these, and evaluations by park staff, six options were identified for restoring the river channel.

1) **Retain Levees** - The levees would be maintained for the foreseeable future. This would require repair and some replacement of gabions.
2) **Benign Neglect** - Allow the gabions to deteriorate and the river to slowly remove the levees.
3) **Remove Wire Only** - The wire would be removed from the gabions to hasten the river's actions and reduce hazards.
4) **Breach Levees and Construct Selected Meanders** - Wire would be entirely removed, the levees physically breached in a few places and 2-4 meanders constructed outside of the levees to hasten lateral movement of the channel.
5) **Remove Levees** - The levee material and rock filling the gabions would be removed and deposited in the channel to raise the streambed or disposed of elsewhere.

6) **Remove Levees and Construct Channel with Natural Characteristics** - The levees would be removed and a channel would be physically constructed for the entire 1.5-mile reach, with dimensions and patterns similar to natural conditions and consistent with a channel in equilibrium.

METHODS

This study was initiated to understand the following questions and attempt to understand if the following goals can be achieved:

- Is the evidence available and do the data suggest that cottonwood is declining in the park.
- Is a shift in woody vegetation occurring that would further exacerbate any decline in cottonwood that may be occurring in the park?
- What appear to be the causative agents that may be contributing to a cottonwood decline and other woody vegetation shifts?
- What causative agents, if any, can be influenced through restoration and management to address changes that may be occurring?
- What types of ecological restoration strategies could be used for both regenerating cottonwood and for reversing vegetation shifts that may also be discouraging the regeneration of cottonwood?
- Is the current riparian and valley bottom vegetation community representative current hydrologic and geomorphic conditions, and is this landscape a practical objective without repeated plantings and other manipulation?
- Identify data gaps and additional data needs to understand the above issues.
- Identify potential testing, demonstration projects, and research and monitoring needs to understand restoration potentials.

This report was generated using limited literature review, limited field reconnaissance, and discussion with other project team members present during the field reconnaissance.
As a team we reconnoitered the cottonwood and fluvial systems within the park. Cross-section and longitudinal profile surveys were conducted at 6 sites along the North and East Forks of the Virgin River to characterize the physical character of the channel, floodplain and terraces. Bed and bank material was characterized using the Wolman pebble count. At these and other sites we visually examined the existing cottonwoods and did reconnaissance examinations for seedlings, sapling, and mature canopy trees. In addition, we increment cored some representative trees within some of the cross-sectioned areas. These increment core specimens were then mounted, sanded, and ages of the trees were determined.

This information was used to draw preliminary interpretations of the conditions within the riverine environment that were conducive to cottonwood regeneration, non-supportive of regeneration, and settings conducive to regeneration of other woody plant species. General notes and photographs about the field conditions were also taken.

A set of basic assumptions and information derived from information gathered previously and in this study was used to develop a preliminary model to help understand cottonwood regeneration and fluvial processes in the park. That work on the STELLA model is contained in Attachment 1.

SUMMARY OF PREVIOUS STUDIES

Much relevant study has been conducted within the park. This report does not provide a critical review or detail summary of the large body of literature on this subject, but instead attempts to briefly and pointedly summarize relevant points from some key research projects.

STEEN, 1999

This thesis has documented the following:

- Manipulation of the stream environment, including the installation of stream bank revetments, land-filling, stream channelization, and other localized drainage and routing of perimeter waters to the stream have occurred since at least the period of National Park Service occupancy and stewardship of the Park, a situation aggravated by confinement of portions of the channel in levees.

- Manipulation of the uplands, the stream, and drainage infrastructure, and vegetation – especially woody vegetation reduction for fuel wood and other uses, occurred at the time of settlement and probably up and to the period of National Park Service occupancy. Denudation of woody vegetation was believed to have occurred during this period from approximately 1860's to the turn of the century. During this period, larger terrace areas were used extensively for agricultural production and, at a point(s) in time, these fields were fallowed and have been invaded by woody and herbaceous vegetation.

- Planting and landscaping of the park and restructuring of the stream environment occurred, yet little or no records are available on actually what and where plantings occurred.

- Prehistory of the site suggested Native American occupancy, and this likely had significant influence on vegetation, including conversion of some terraces to agricultural land-uses and other uses.

- Late 1800's settlement and potential associated significant erosion and depositional processes that were regional in scale and may have been caused by overgrazing, climate change, deforestation, and perhaps other variables.

HEREFORD, JACOBY, AND MCCORD, 1995

- The floor of Zion Canyon can be divided into a series of alluvial features representing different periods of the fluvial system. These terraces are Prehistoric (pre-900 -1200 AD), Settlement (>1200-1883), Historic (1892--~1926), Early Modern (1930-1940), Modern (1940-1970), and the active channel/floodplain.

- Erosion and deposition were largely contemporaneous with variations in streamflow. Erosion was during unusually high streamflow and deposition during relatively low

streamflow.

- Precipitation and runoff immediately before and during the historic arroyo cutting period in the decades before and after the turn of the 20th Century were the most unusual in 300 years.

- Tree ages are reported from the Historic and Modern Terraces using estimated dates of establishment based on tree ring methods. Trees from the Historic Terrace are dated from 1893, 1895, 1900, 1904, 1907, 1909, and >1909. Trees from the Modern terrace are dated from 1940, 1947, 1951, 1953, 1957, and 1963.

Other documents have speculated on the effects of A) deer browse and B) beaver herbivory on cottonwood seedlings and saplings, and larger trees as having profound influence on cottonwoods ability to maintain populations of varying size and age classes within the park.

FIGURE 6. Summary of general relationships with fluvial aggradation and erosion processes (Hereford, et al, 1995).

Aggradation:
- Builds up channel and adjacent floodplains
- Channel widens and meander increases
- Sediment comes from upstream sources and eroding stream banks.

Erosion:
- Channel bed lowers
- Channel widens and forms new floodplain at lower elevation
- Active floodplains become terraces removed from subsequent scour

Triggered and maintained by regional factors:
- Climate (long term)
- Landuse (historic period)
- Individual events or series of events

Mainstem deposits:
- Transported by Virgin River from upstream sources

←Interbedding→

Tributary deposits:
- Transported to alluvial valley by fluvial activity of tributary streams, gullies, rills, and debris and landslide

Channel, floodplain, terrace materials
- Yellowish-gray
- Poorly to moderate well sorted
- Fine to medium-grained sand and minor subrounded to rounded gravel
- Well bedded

RESULTS AND DISCUSSIONS

The widespread distribution of cottonwood trees throughout the western U.S. obscures the fact that successful recruitment requires a very special set of conditions. Seeds must be dispersed onto bare fine-grained substrates that have adequate moisture throughout the spring and summer for germination, but is not subsequently scoured by floods. In Zion Canyon cottonwood seeds are dispersed in very large numbers during April and May each year, typically corresponding with the subsidence of the spring flood. Seed viability is measured in days rather than weeks or months and the vast majority of seeds never find moist soils in which to germinate. Of those that do sprout a large number do so in the wet substrate of the active channel and are subsequently scoured away in the next flow event.

Channel fluvial processes and morphology play important roles in providing successful recruitment environments. In this paper the alluvial system is divided into 1) an active or bankfull channel, 2) an associated floodplain, and 3) assorted terrace features. The bankfull channel is defined as carrying moderate, frequent flow events (Leopold, 1994). The geomorphic floodplain is defined as a level feature, adjacent to and created by the stream in the current climate, and overtopped by moderate, frequent flow events. These moderate, frequent flow events generally have 1 to 2 year return intervals (Leopold, 1978; Moody, et.al., 1999). For this reach of the Virgin River bankfull discharge is estimated to be ~1100 cfs. Terraces are defined as abandoned floodplains. Bankfull stage was identified at several sites within Zion Canyon and provides a common reference point for assessing floodplain processes along the Virgin River.

Generally the floodplains and their associated features such as secondary channels and depressions create conditions for successful cottonwood recruitment. Sprouts in the active channel are scoured by subsequent flows while the terraces do not contain adequate soil moisture through the dry summer season. Suitable bare, moist substrate is generally created through floodplain scour, floodplain deposition, and/or channel meander.

Several delineative criteria were used to describe the physical channel characteristics. Bankfull width, mean depth, and maximum depth refer to dimensions of the channel at bankfull stage. Floodprone width is defined as the width of the floodplain at an elevation equal to twice maximum bankfull depth. Width-depth ratio is bankfull width divided by bankfull mean depth and is a dimensionless measure of channel shape. Because sediment transport is largely dependent on channel shape, width-depth ratio is also an indicator of this fluvial process. Entrenchment ratio is floodprone width divided by bankfull width and is a measure of the stream's ability to utilize an adjacent floodplain.

Stream Reaches within Zion Canyon

The North Fork of the Virgin River through Zion Canyon was divided into 4 reaches based on differing stream channel morphologies (Figure 4). These reaches are:

- Narrows Reach; geologically controlled upper reaches
- Big Bend Reach; unconstrained alluvial upper reaches
- Zion Lodge Reach; channelized revetment reaches
- Birch Creek Reach; lower meandering reaches

In addition, a site along the East Fork Virgin River was surveyed to compare with the North Fork sites.

The following section briefly summarizes key observations in these surveys. This information was then correlated with hydraulic data and tree age data to begin to formulate hypotheses on how cottonwood regeneration has occurred and currently occurs in the park with an eye toward what restoration strategies and recommendations may be useful in the future management of cottonwood and the fluvial environments in Zion National Park.

SUMMARY OF REACH OBSERVATIONS

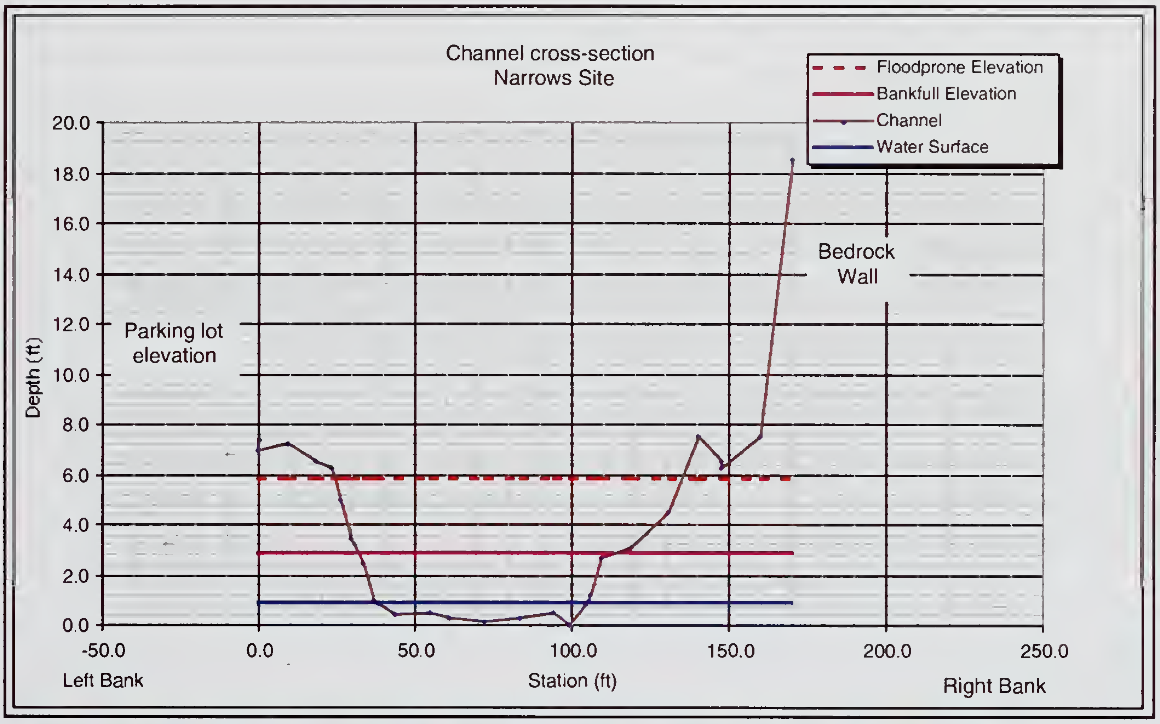
1. NARROWS REACH

This reach extends from the Narrows parking lot to a point just upstream of the viewpoint above Big Bend. The valley floor is relatively narrow within these reaches and the shape of the surrounding canyon controls the channel meander pattern. Revetments are common along the eastern bank where the channel is adjacent to the road. The channel is dominated by riffle sections, a low width-depth ratio, and has limited access to an adjacent floodplain. The channel bed is gravel/cobble with clay veneer, with sand common between cobbles. The channel bed appears to be partially cemented by fine clay particles. Banks consist of cohesive soils with sand veneer. There is little evidence of active bank erosion or deposition and bare substrate is at a minimum.

Relatively even-aged 100-year-old cottonwood isochrones dominate the outside and upper margins of the highest terraces. Only occasional scattered young cottonwood trees are found in other locations and all were on mid to lower terraces, growing on the side slopes and tops of the depositional strands that were located between the location of the bank full stage and the upper-most terrace. The high terraces are covered with grass and mature cottonwood, ash, and box elder. Low point-bars are all well vegetated with grasses, sedge/rush, baccharis, and other woody seedlings.

The *Narrows survey site* lies just above the Temple of Sinawava parking area at the mouth of the Virgin Narrows (Figure 7). The channel is constrained by revetments along the left (road) bank and by stable terraces along the right bank. There is little or no floodplain. Stream banks are stable except along the constructed fill of the parking area. Most successful woody plants near the river appear to be in areas partially protected by geologic (boulders/bedrock) or geomorphic (point bars) features. There are numerous cottonwood and ash seedlings in the moist fine sediments of the bankfull channel and within 6-10 inches of the waterline. Several 10 – 20 foot cottonwoods and ash individuals are found on lower terraces. Baccharis (*Baccharis emoryi*) are dominant along bankfull stage; coyote willows (*Salix exigua*) are very sparse. Non-native, cool season grasses proliferate leaving little bare substrate.

FIGURE 7a. Cross-section at Narrows survey site.



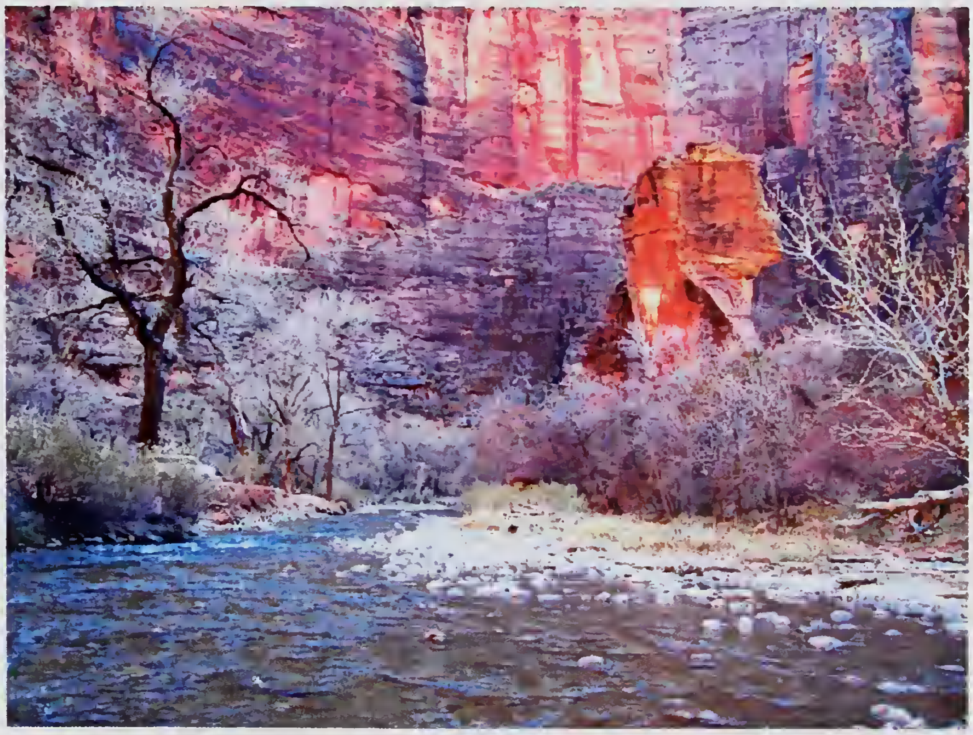


Figure 7b. Narrows site. Parking area on left and geologic control on right constrain stream channels ability to spread across a floodplain.

The *Hereford survey site* lies approximately 0.23 miles below the Narrows site and is within the Hereford, et.al. study area. This reach is a straight, continuous run/riffle. The surveyed cross-section traverses several of Herefords terraces. The channel is relatively flat bottomed with a uniform trapezoidal shape. The left bank below road is armored with wire baskets of the newer vintage. Baccharis (*Baccharis emoryi*) is thick along ripraped left bank and only slightly less robust along right bank. Numerous ash seedlings occur along waterline and within bankfull channel; few cottonwoods are present and no willows. Scattered 10–20 feet ash trees near bankfull stage on both banks. Bankfull features include a narrow depositional bar running along right bank composed of sand and stabilized by thick baccharis community. Sedge-rush community is continuous from water's edge to bankfull. Three terrace features described by Hereford (1995) lie within this cross-section. Descriptions of these features are described below and shown in Figure 8.

<u>Modern Terrace</u> (~1940 – 1970) lies approximately 1.5 feet above the current channel bed elevation. It has a sandy substrate and appears to be an abandoned or secondary channel. Cobbles are sometimes evident within channel and along margins. Young Ash trees (6-10 feet tall) growing along margins. A single young juniper was also located within channel. This secondary channel becomes active at about bankfull stage and the vegetation suggests moister soil conditions as it approaches the river downstream.

<u>Early modern terrace</u> (~1930 – 1940) lies approximately 7 feet above and adjacent to the present channel. It is composed of sand and colonized by grasses, occasional prickly pear cactus and various annuals. Cryptogamic soils lie over much of the surface. There are scattered ash and cottonwood trees 20 – 30 feet tall.

<u>Settlement Terrace</u> (~1860 – 1890) lies approximately 10 feet above current channel bed elevation. Sands with bunch grasses and mature cottonwoods dominate the substrate. No young cottonwoods were observed on this terrace.

FIGURE 8a. Cross-section at Hereford survey site

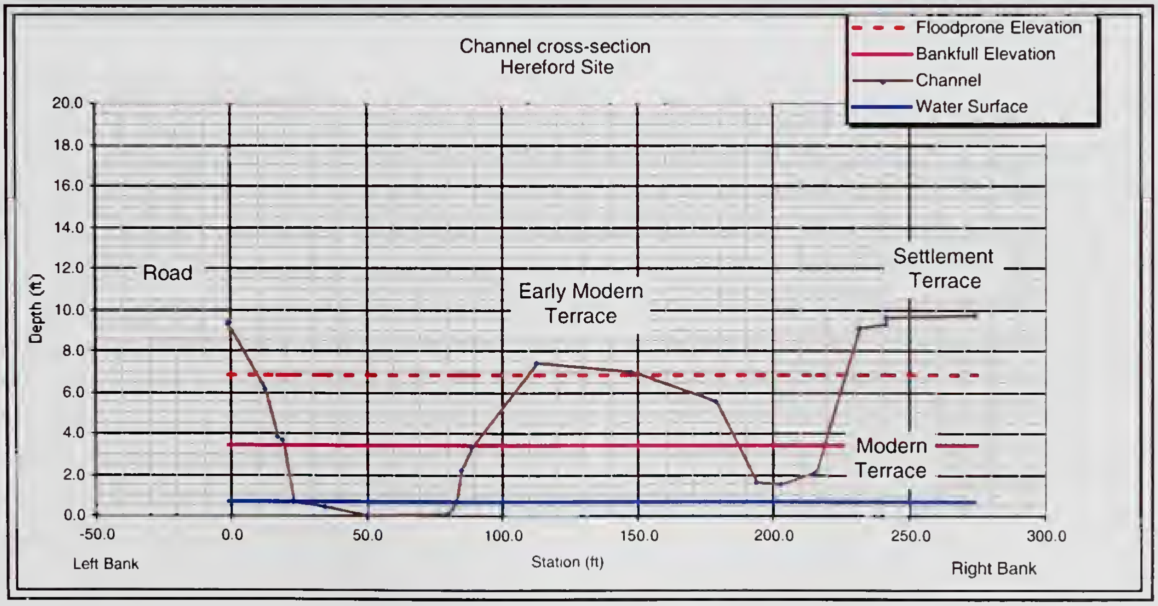
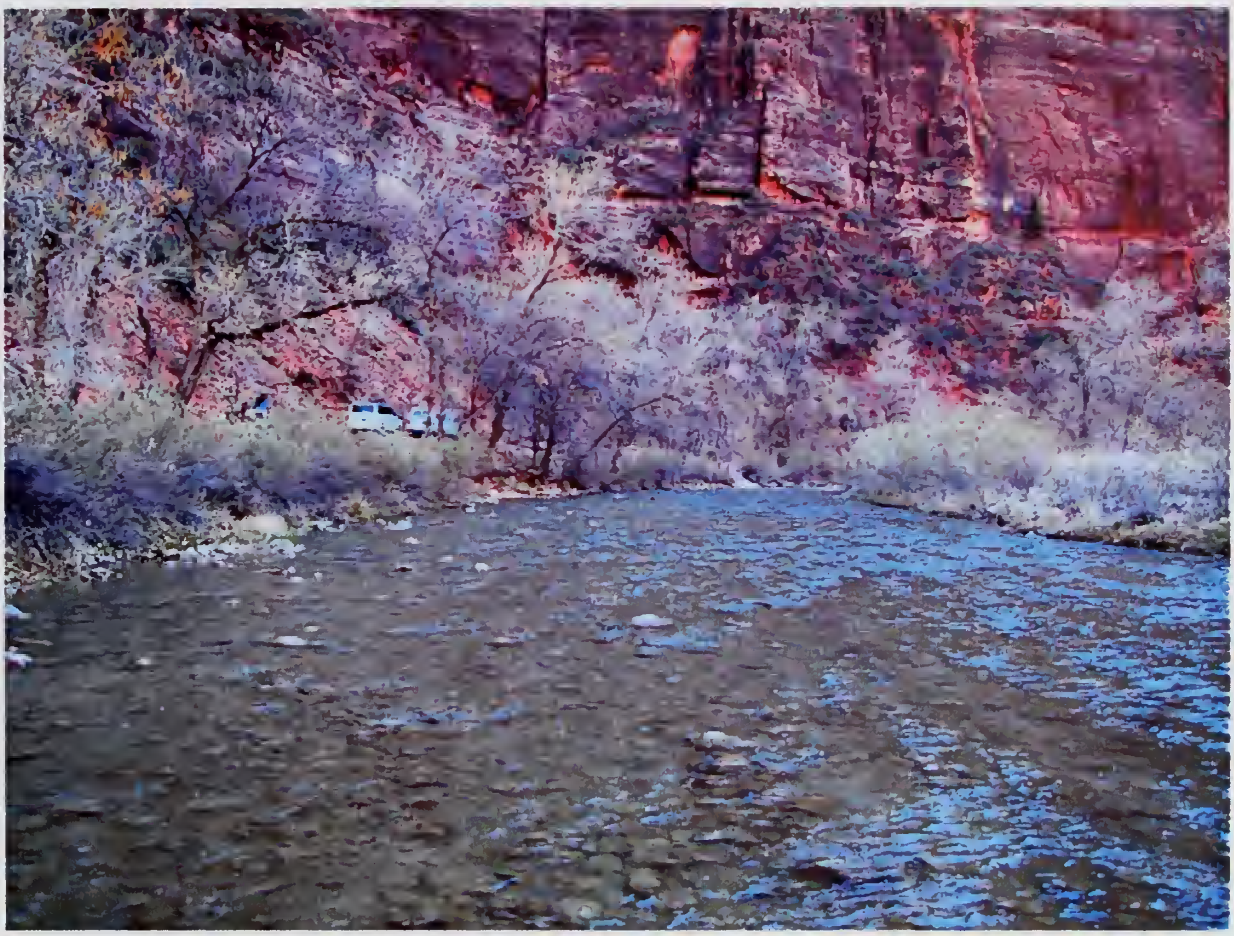


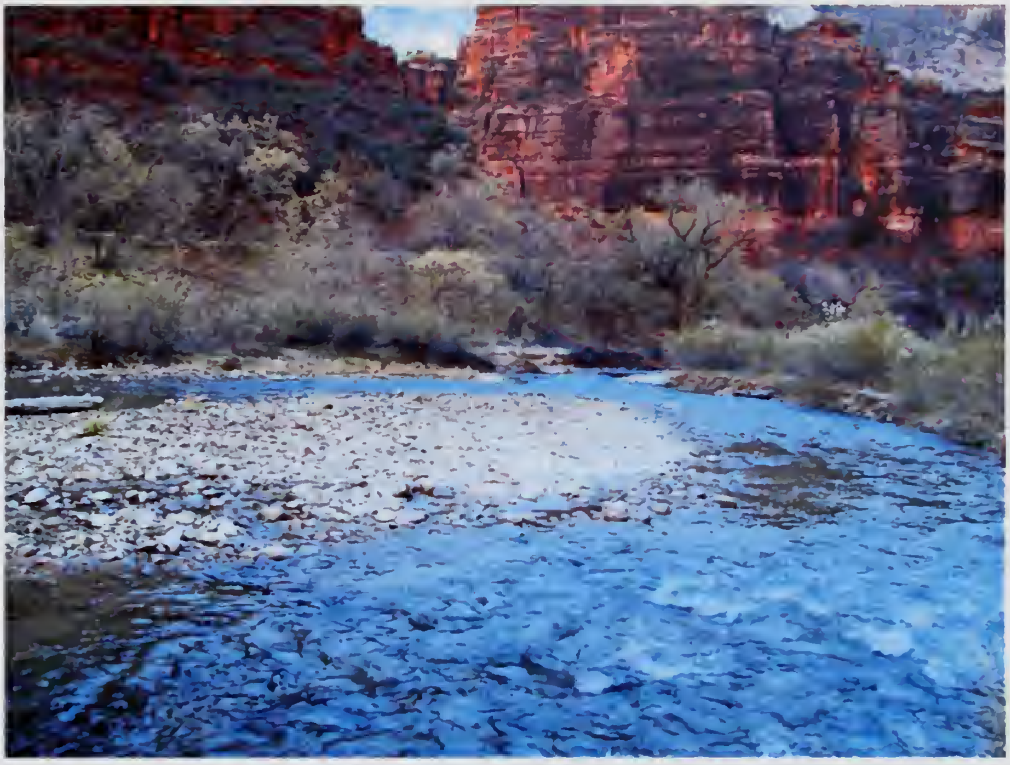
FIGURE 8b. Hereford Site. Stream channel is constrained by roadway on river left and well-vegetated low terraces along river right. Note dense vegetation along both banks and absence of disturbed soils suitable for cottonwood recruitment. Whether mature cottonwoods along road were the result of natural recruitment or planting is unknown.



2. <u>BIG BEND REACH</u>

This reach begins below the Hereford Site and extends to the Grotto Campground footbridge. Although much of this reach was once channelized most of the revetments are gone or no longer constrain channel movement. The valley floor is relatively wide and the channel has some degree of movement. The reach is dominated by a series of riffle/run sections and has significantly more complex morphology than in other reaches. The stream is actively forming meanders and low cutbanks lie along both banks especially at outside of meanders. High terraces are restricted to valley margins. There is evidence of recently abandoned meanders that now serve as cut-off channels. At least some of these cutoff channels are active below bankfull creating mid-channel islands. Because the splits appear to be limited to two channels, the system is not considered braided. The bankfull channel is relatively wide with a high width-depth ratio. Mid-channel bars and secondary channels are common. Two sites were surveyed in this reach.

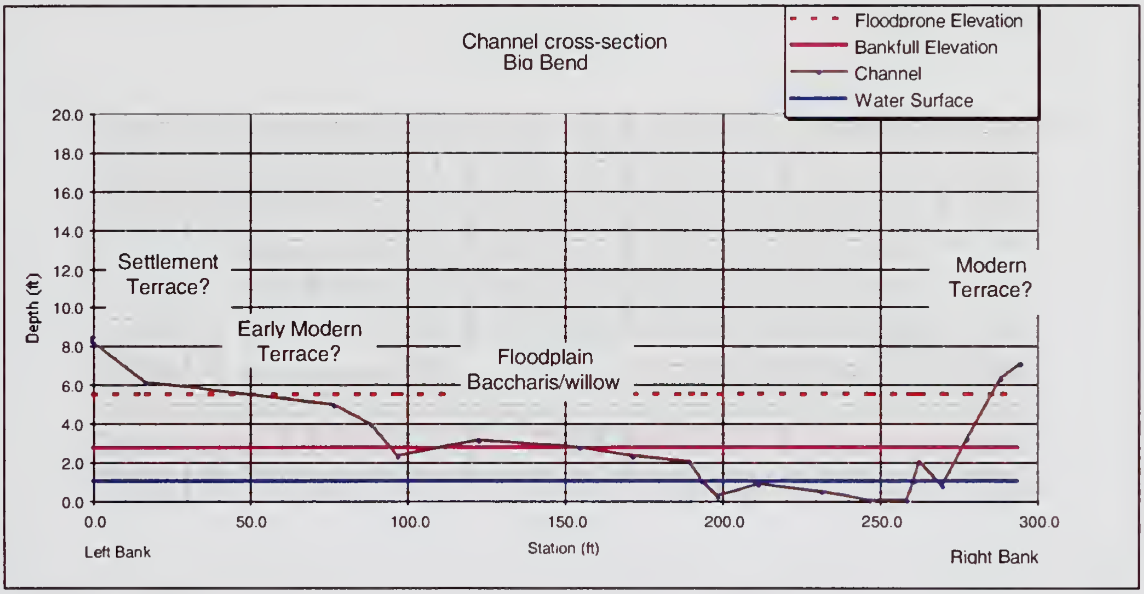
FIGURE 9a. Photo of Big Bend survey site. Note active deposition in central channel bar and low floodplain features along both banks. Numerous young cottonwood, ash, and box elder trees were found in floodplain and cutoff channel areas.



Big Bend survey site lies just upstream of the high viewpoint along the road just above Big Bend (Figure 9). The channel has a meandering riffle-run morphology with numerous low islands and cut-off channels. The combination of added sediment from eroding banks and split flow has formed a number of low unvegetated mid-channel bars.

There are several 10 - 20 feet tall ash and cottonwood trees established within the floodplains or in the abandoned or cutoff channels. Ash are usually more common. Hundreds of small seedlings (ash and cottonwood) were observed on low, moist sandbars located within the bankfull channel. However these have very little chance for survival. Baccharis dominated the low terraces or floodplains but willow as well as tamarisk was much more common in this reach. Several Cottonwood individuals 10 – 20 feet tall were observed along the floodplain and in abandoned channels.

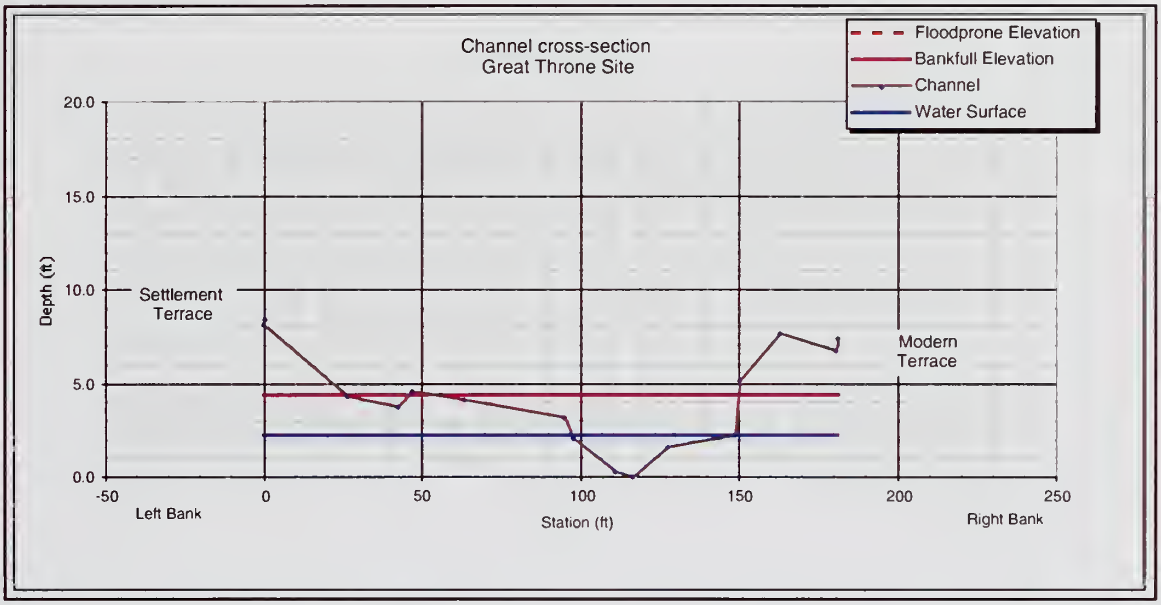
FIGURE 9b. Cross-section at Big Bend survey site



Great White Throne Site is located just downstream of Big Bend. This reach has considerable width to meander. There is very little incision with high terraces only 6 feet above streambed (Figure 10). Below the upstream revetments the channel makes a series of low flow meanders with low alternating point bars. The bars are freshly disturbed with a surface of sand over gravel/cobble. Young 1-year seedlings are very numerous within the active channel; cottonwoods, baccharis, tamarisk, and ash are present but obviously few survive. It appears that the river may not mender much at bankfull or above.

Low terraces on both sides of river contain a reasonable number of 10 – 25 feet tall ash, cottonwood, and tree willow. Coyote willow is also more abundant than at other sites. Low bars are often very wet and colonized by equisitum and sedges/rush. Arroyo willow (*Salix exigua*) is also more common. A survey of a single floodplain bar resulted in a count of 8-10 cottonwood, 25-30 ash, and 3-4 black willow. These individuals appear to be 5 – 10 years old. Recent beaver herbivory on cottonwoods and willows was observed at this site. Mature cottonwoods were abundant on the settlement terrace near the road.

FIGURE 10. Cross-section at Great White Throne survey site



3. <u>ZION LODGE REACH</u>

This reach begins just above the Grotto Campground footbridge and extends through the stream section below the Lodge footbridge. The entire reach had been channelized and constrained by levees armored with wire covered rock riprap. In many areas the wire had deteriorated and the rock was falling into the channel. Channel is narrow with a uniform trapezoidal shape and no floodplain access. These reaches were zones of apparent and conspicuous regular scour and both the potential presence of moist and fine substrates for potential cottonwood invasion and cottonwood invasion were not observed.

The reach is stable in that there are no cutbanks, however it is deeply incised below high terrace. Both banks thickly vegetated primarily with *Baccharis emoryi* with a few *Salix exigua* and tamarisk. A sedge/rush community exists along water's edge. Cottonwood seedlings are numerous on very low bars well below bankfull but are unlikely to survive subsequent flows. Scattered juniper grow at the elevation of the right cross-section marker pin on upland slope. No riparian tree species were observed along either bank.

Riprap baskets are reinforced around bridge but in other places rotted at the bottom with rock spilling out. High terrace is very flat and sandy with a widely scattered mature cottonwood forest. These were once leveled and utilized as cultivated and irrigated fields. A single representative cross-section was surveyed in this reach just below the Grotto Campground footbridge (Figure 11).

FIGURE 11a. Cross-section at Grotto footbridge survey site

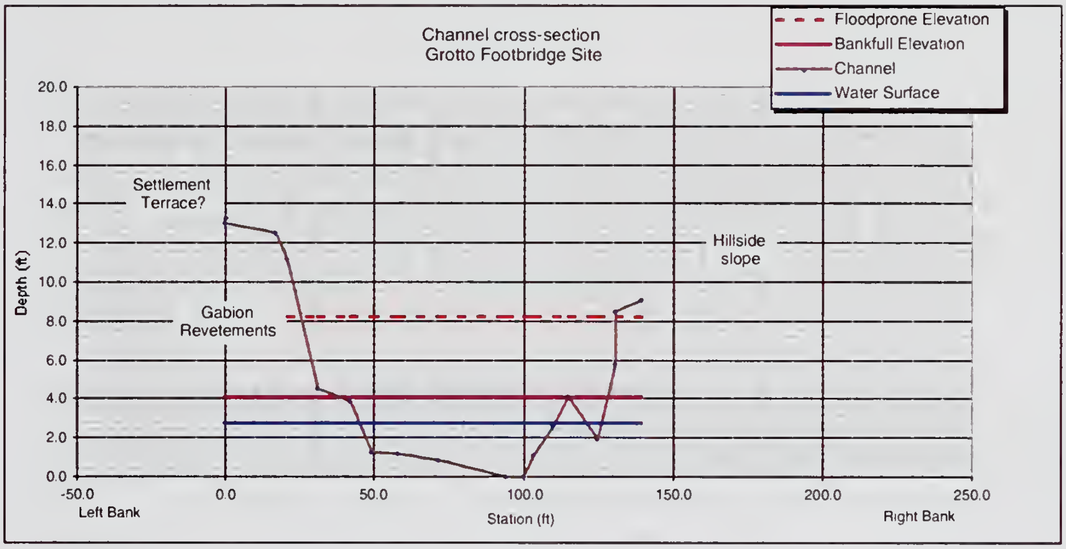


FIGURE 11b. Photo of Grotto footbridge site. Channel is severely channelized by rock and wire revetment on river left and by canyon walls on river right. Lack of floodplain features limits riparian vegetation including cottonwoods.

4. BIRCH CREEK REACH:

This reach begins at the end of the straightened stream section about 1,500 feet below the Lodge foot bridges and extends to Birch Creek. Revetments are limited to the outside of those meanders that may impinge in the road or a parallel utility easement. From aerial photos it appears the stream has maintained it historic pattern, however it may have been channelized in the past. Channel and floodprone widths are similar to the sites Big Bend reach (Table 1). The width-depth ratios are somewhat lower and as a result sediment transport is greater. Point bars are well formed on the inside of each meander though most are 1 – 4 feet above bankfull stage (Figures 12b & 13). Active cutbanks are common along the outside of meanders and there is moderate disturbance on the outer edges of the point bars.

The high point bars are dominated by *Baccharis emoryi*. Some *Salix exigua* is present along the outer faces of these point bars. No cottonwood sprouts or young trees were observed within the reach. Mature cottonwoods and other trees are limited to the upper terraces. A topographic survey was completed on the Zion Lodge and Birch Creek reaches and two representative cross-sections were created.

FIGURE 12a. Photo of Birch Creek site. Stream channel is constrained by high terraces along both banks. Mature cottonwoods and grasses cover high terraces.

FIGURE 12b. Cross-section #1 in Birch Creek reach

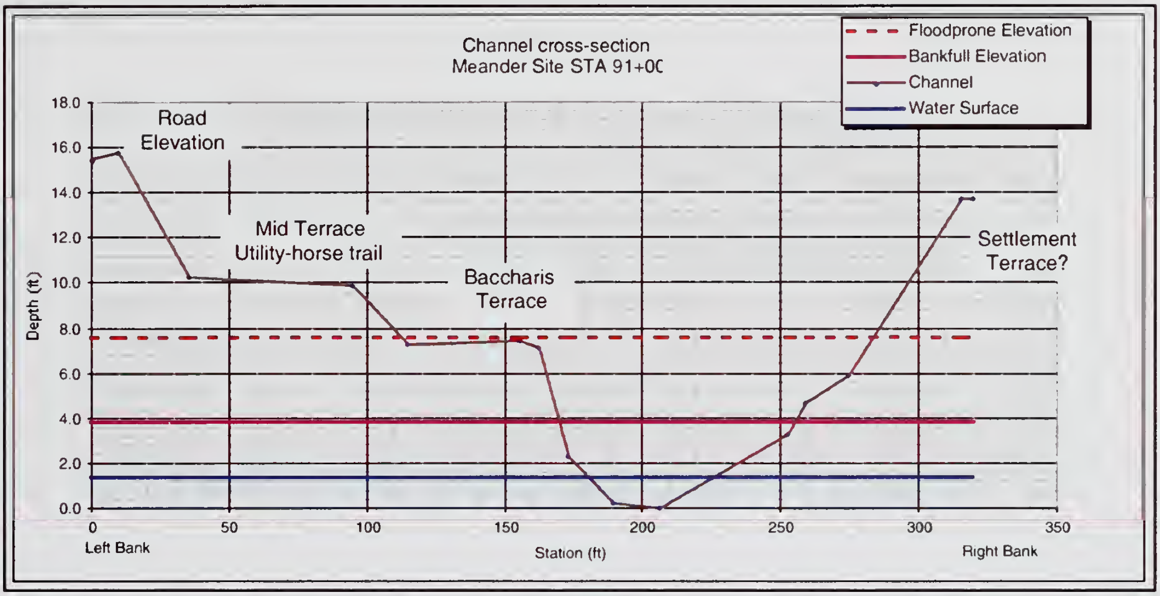
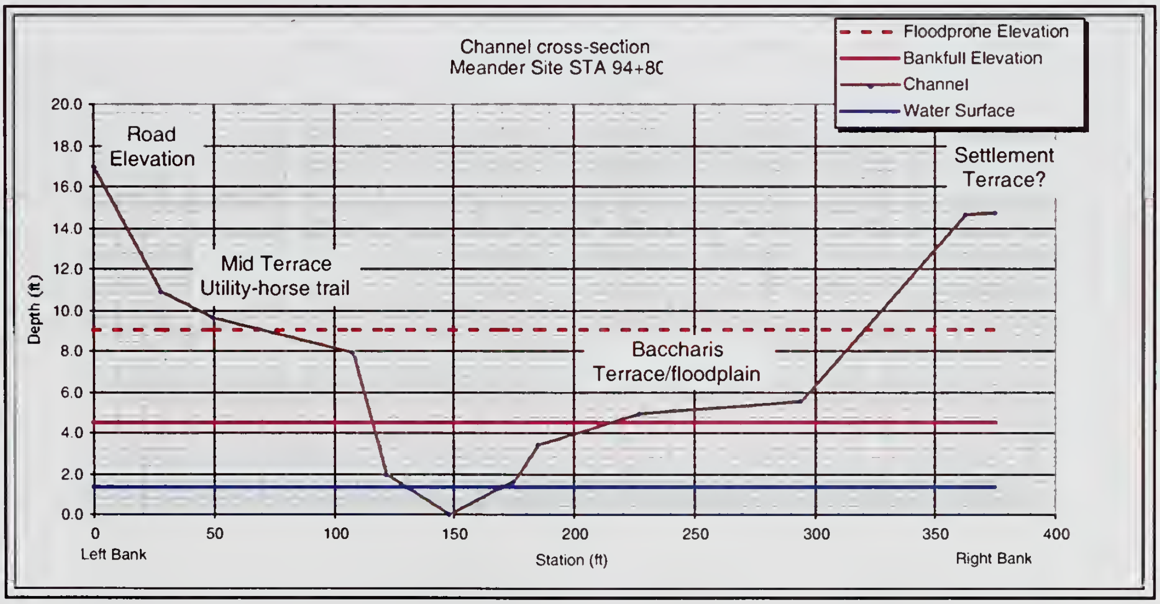


FIGURE 13. Surveyed cross-section #2 in Birch Creek reach



<u>SENTINEL SLIDE AREA:</u>

Major and minor regular slope failures along the Sentinel Slide showed cottonwood invasion, including young age classes occurring along the margins of the toe of slumped lands. In virtually all locations, cottonwood survival was not apparent along the high scour stream within bankfull stage. However, survival appears to be occurring several feet above bankfull stage where disturbance is created by the slumps. These zones of germination are comprised of a mix of fine silts, sands, and rock fragments and appear to receive moisture from upslope locations

rather than requiring a direct connection to the stream hydraulics. This reach was included to illustrate that conditions exist for successful cottonwood recruitment away from the fluvial environment. No cross-sections were surveyed in this reach.

Table 1. Summary of channel and floodplain dimensions for survey sites

NAME	WS Area (mi2)	XS Area (ft2)	Width (ft)	Mean Depth (ft)	Max Depth (ft)	Floodprone Width (ft)	Channel Type
Narrows Site	290	181.9	75.0	2.4	2.9	112.0	B4c
Hereford Site	291	198.4	70.0	2.8	3.4	100.0	B4c
Big Bend Site	291	189.4	120.0	1.6	2.8	245.0	C4
Great White Throne Site	300	198.5	100.0	2.0	4.4	240.0	C4
Grotto bridge Site	320	229.6	72.0	3.2	4.1	105.0	B4c
Meander Site STA 91+00	320	210.9	90.0	2.3	4.5	250.0	C4
Meander Site STA 94+80	320	203.4	85.0	2.4	3.8	140.0	B4c
East Fork Virgin River	340	130.5	42.0	3.1	4.2	260.0	C5

Table 2. Summary of dimension, pattern, and profile data for survey sites.

NAME	Width/depth Ratio	Entrenchment Ratio	Slope (ft/ft)	Sinuosity	D50 (mm)	Median Material	Channel Type
Narrows Site	30.9	1.5	0.007	1.3	18	Coarse Gravel	B4c
Hereford Site	24.7	1.4	0.005	1.2	34	Coarse Gravel	B4c
Big Bend Site	76.0	2.0	0.009	1.2	40	Coarse Gravel	C4
Great White Throne Site	50.4	2.4	0.007	1.3	30	Coarse Gravel	C4
Grotto Site	22.6	1.5	0.006	1.0	38	Coarse Gravel	B4c
Meander Site STA91+00	38.4	2.8	0.004	1.3	-	Coarse Gravel	C4
Meander Site STA94+80	35.5	1.6	0.004	1.3	-	Coarse Gravel	B4c
East Fork Virgin River	13.5	6.2	0.002	1.3	-	Sand	C5

Table 3. Relationship of floodprone stage to related discharges and return intervals

NAME	Floodprone Stage (ft)	Related Discharge* (cfs)	Return Interval (yrs)
Narrows Site	5.8	8500	50
Hereford Site	6.8	9100	100
Big Bend Site	5.5	8000	50
Great White Throne Site	8.8	19,000	100+
Grotto bridge Site	8.2	9200	100
Meander Site STA 91+00	9.0	22,000	100+
Meander Site STA 94+80	8.4	22,000	100+

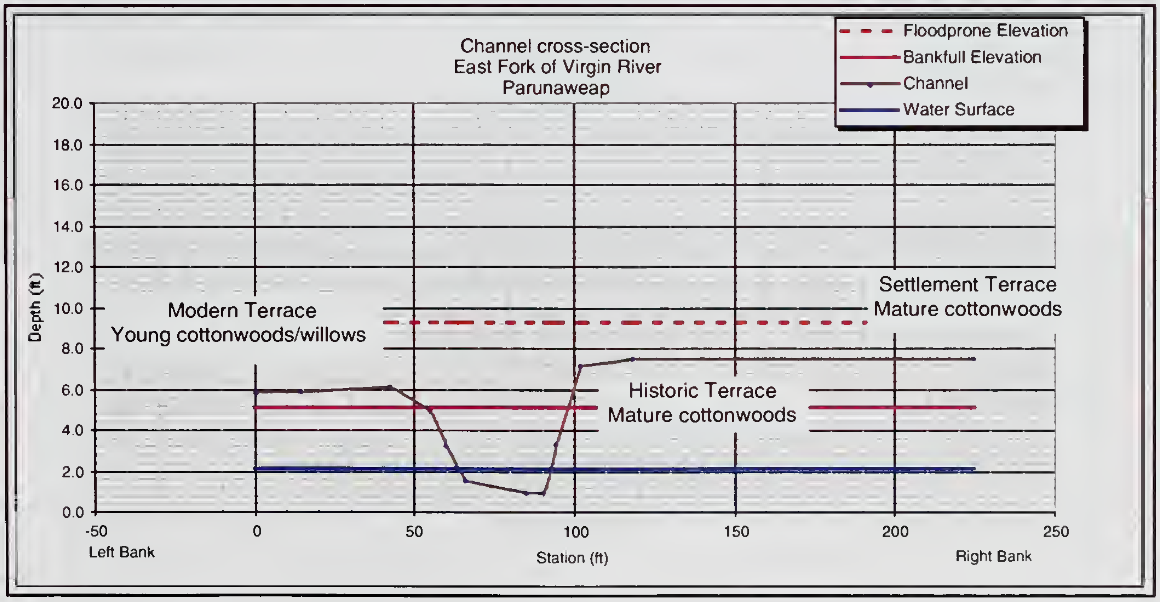
* Discharge necessary to achieve floodprone stage.

ZION CANYON AND EAST FORK (PARUNAWEAP CANYON) COTTONWOOD CONDITIONS

The East Fork is a northeast-southwest trending tributary to the Virgin River and joins the North Fork in the town of Springdale, UT, just outside the Park boundary. The watershed area is approximately 340 sq. miles, a value similar to that of the North Fork. A single cross-section was surveyed on the East Fork at a site located a short distance above the Park boundary approximately 1.6 miles above Shunesburg townsite. The survey is located within the site described by Hereford (1995) and the cross-section intercepts 3 historic terraces. The stream is a low gradient, single thread, meandering channel with a riffle/run morphology and broad adjacent floodplains. Despite a watershed of similar size to the North Fork, bankfull channel dimensions are considerably smaller. The channel is much less incised and a wide accessible floodplain produces a very high entrenchment ratio. It appears that much less channel incision has taken place in recent times in the East Fork than the North Fork. Channel, floodplain, and terrace features are dominated by a sand substrate and it appears that some of the older cottonwood and mesquite trees have been substantially buried over time. It is evident that considerably more sand is carried by the East Fork than the North Fork.

As in the North Fork, spare bunch grasses and very old cottonwood trees dominate high terraces. Mesquite occupies the terrace margins on south facing slopes. The Modern Terrace lies only slightly above floodplain elevation and contains a rich community of Arroyo or coyote willow (*Salix exigua)* and young Fremont cottonwood (*Populus fremontii).*

FIGURE 14. Cross-section at East Fork survey site



As a part of this review, we also investigated cottonwood and related environmental conditions along the East Fork of the Virgin River in Parunaweap Canyon. Table 4 summarizes and highlights conditions we observed in each canyon.

Based on these observations, cottonwood has more recently regenerated in the East Fork than the North as indicated by the presence of young isochrone growths in a variety of age classes. The East Fork also has very conspicuous recent depositional and scour areas capable of, and that do, support cottonwood regeneration. This is occurring in both gap phase opportunities and continuous strand areas within the riverine environment. Shrub-form willow is a dominant shrub in the East Fork and *Baccharis* is absent to sparse. The reverse is true in the North Fork where *Baccharis* dominates to the exclusion of willow. The presence of mesquite and some other plant species within the East fork suggests either localized environmental conditions, a difference in history that may have eliminated species such as mesquite within the North Fork Canyon, or that the distribution is related to historic gradients, such as fire gradients. Mesquite is very cold sensitive and grows at the upper elevations of its range in the East Fork area. The wide, east-west trending East Fork receives sunlight even in winter while the north-south oriented North Fork provides a considerably cooler environment. The cooler temperatures and/or fire gradients may explain the presence and abundance of ash and boxelder within Zion Canyon and their absence or low abundance along East Fork. These observations are consistent with earlier studies (Steen, 1999, Taylor, 1989).

Table 4. Cottonwood regeneration comparison between the North Fork in Zion Canyon and East Fork (Parunaweap) Virgin River, in Zion National Park.

	Cottonwood Regeneration	**North fork in Park**	**East Fork**
1.	Ages classes of isochrones	15-20 years	X <20 years
	Age classes	70-90 years old	40-60 years
		100+ years	90-100 years
2.	Dominance by *Chrysanthamnus*		X
3.	Dominance by *Baccharis*	X	
4.	Presence of mesquite		X
5.	Depositional vs. eroding	Primarily Erosional	Primarily Depositional
6.	Willow invasion	Rare and scattered	Widespread
7.	Possible fire history differences, fire gradient differences	Closed, tight canyon; cool, moist; lightening ineffective,human caused likely	Wide; open aspect; warm-dry; lightening effective with higher fire probability
8.	Human history	Early occupancy	Early occupancy
9.	Gap phase opportunities	Heavy brush covered and native cool season grass cover throughout canyon; little exposed substrates	Sporadic rabbit brush, much exposed substrates
10.	Substrate character in floodplain	Sands, cobbles	Sands, fine sands and silts

Evidence of cottonwood in archeological sites in Parunaweap offer good evidence of long-term cottonwood presence in that area. However, no similar archeological evidence has been found on the North Fork. This may be related to the lack of sites rather than the lack of cottonwood. Experts caution that the lack of human evidence along the North Fork may be due to deep burial

or washing away of sites in the narrow confines of Zion Canyon rather than complete absence of use. In the historic period, there was substantial human use in both canyons for irrigated farming and livestock grazing (Dave Sharrow, personal communication).

COMPETING VEGETATION

Cottonwood is a species that invades and establishes in locations with low competition by other vegetation. It generally invades into semi-open to completely open high light environments with temporally adequate moisture on fine substrates. It seldom and only sporadically invades into dense shrub, dense herbaceous vegetation, or in or beneath woody vegetation.

Based on these life history strategies and observations along the Virgin River in Zion National Park, the following points are provided.

A). In general, the historic prime habitats for potential cottonwood invasion are now occupied by other larger cottonwoods and other woody vegetation. This vegetation, along with other factors, prevents cottonwoods invasion and growth.

B). Areas that would appear to be prime habitat are now dominated by Baccharis (*Baccharis emoryi)* that appear to maintain an aggressive root and canopy presence over depositional areas, including abandoned channel areas, within the riverine systems. Baccharis appears to resprout up through fresh deposition as well as promptly reinvade into deeply scoured areas through seedling recruitment. In addition, based on observations, the first year seedlings of Baccharis appear to easily grow larger than cottonwood seedlings, and they also appear to be evergreen, thus showing continued growth before and after cottonwood's growing season. It appears that Baccharis not only invades into fines, but also readily expands into coarser sediments, including in the interstices between cobbles.

C). Non-native, cool-season grasses.

It is our understanding from reading Steen (1999) and other documentation that bunch grasses historically occupied the upland terraces within the park. Now, bunch grasses are rare and a prevailing assemblage of non-native, cool-season grasses cover the ground in all but the driest sandiest depositional areas on higher terraces. This cool-season grass reduces soil-seed contact for cottonwood establishment over a large area of Zion Canyon. Principal species appear to be bromes (*Bromus tectorum, Bromus spp.*), which are winter annuals (e.g., germinate in fall and cover the ground during the winter, spring, and early summer, when they flower and seed) and which effectively reduce cottonwood's seedbed, it's soil-seed contact, and thus it's germination potential.

It apparently would require a higher flood event or lower flood events that are fortuitously timed to reduce this cool-season grass component. The shallow rooted nature of these grasses makes them vulnerable to scour and deposition. However, the prolific seed production and high viability also allows them to easily and promptly reinvade areas where

scour or sand deposition has reduced or removed them. They may be managed by intentional fire.

D). Boxelder and velvet ash regeneration.
Conspicuous and apparent regeneration of both of these trees species is occurring substantially more successfully than cottonwood. Both species were observed to invade into all terrace locations including the higher driest terraces. The species appear in some locations to have isochronal patterns reflecting strand depositional developments, and in other locations are scattered in and amongst *Baccharis*, growing in the understory of cottonwoods, invading into seep and wetland areas, and invading into maintained uplands landscapes around the Zion Park Lodge. Seeds of both have blown up into cliff areas, hanging gardens, and have become generally well distributed throughout the canyon. Even gambles oak zones on talus above the highest stream terraces are occupied by both species.

Some interesting notes, taken during the field observations and which may be useful to help understand likely woody vegetation changes that appear to be occurring in the park, are as follows:

<u>Ash and boxelder seed rain period:</u>
These species appear to have a prolonged seed dispersal period. They hold and partially release seeds into the fall and winter, and perhaps into spring of the year following the growing season of seed set. This makes seed available for dispersal over a longer time period and would increase the probability of both reaching more locations and being exposed to greater range of conditions. This strategy for seed retention and partial release would be expected to increase the success of these species. In contrast, cottonwood has a relatively short time period of seed dispersal, and the release is usually a single event over a few weeks with no retention or partial release.

<u>Large endosperms and cotyledons:</u>
Both ash and boxelder seeds have large carbohydrate reserves, which provide for greater germination success, and allow for seedlings to establish in less desirable (more competitive) environments, where a species with less reserve would be suppressed before successful establishment occurred. These strategies favor germination and establishment within a greater range of environmental settings. In contrast cottonwood has very small seeds and disproportionately small metabolic reserves. It does not compete with other vegetation, nor does it invade into dense vegetation cover.

<u>Establishment is not tied to stream dynamic:</u>
Ash and boxelder species were found invading high dry terraces, gambles oak clones, lawns around the Zion Lodge, hanging from cracks in rock overhangs and seeps, and many other locations. The plasticity in their establishment contrasts with cottonwood, which establishes only in moist, competition-less sites, which are mostly along the stream course in suitably moist substrates.

Boxelder and ash are vigorous resprouters and cottonwood is not:
In a stream environment, scour damage that leaves even only a partial root system intact for box elder and ash will likely stimulate resprouting and additional root development. Top damage stimulates vigorous resprouting by these species. Cottonwood on the other hand is less resilient to top and scour damage. Cottonwood is also more sensitive to browse damage and may not survive repeated browse events while ash and boxelder appear very capable of survival and continued growth under heavy browsing.

Beaver and cottonwood:
In Zion National Park, it appears that beaver preferentially harvest cottonwood over ash and boxelder. What few cottonwoods in recent times have survived to a sapling stage appear very vulnerable to beaver herbivory. Little to no evidence of beaver herbivory on either ash or boxelder was apparent during field observations in the park.

Cottonwood Success
Cottonwood becomes the dominate canopy in the riparian vegetation by producing an abundant seed crop that can take advantage of the right conditions when they occur. It can then use its capacity for rapid growth and larger overall size to dominate all other riparian trees in this area.

Notable absence of *Salix* in the park.
In contrast to many other stream courses in the region, few coyote or black willows are found along the North Fork in Zion Canyon. We do not understand the reasons, as conditions would seem to be conducive for their growth here. What was apparent during the site reconnaissance, was that a few coyote willows are invading along the bankfull stage, but are not spreading beyond this zone. In all cases where willow was observed, *Baccharis* was found dominating the adjacent terraces, and no seeding or rhizomateous spreading willows were found in *Baccharis* stands. It appears that *Baccharis* aggressively holds the point bars and strands against willow invasion and establishment. We also observed differential beaver and deer herbivory on the few willows and little to none on *Baccharis.* It is possible that extensive planting of *Baccharis* by the Civilian Conservation Corps (CCC) for revegetation during its channelization work accounts for the unusual dominance of this plant. CCC records available refer to "planting," but provide no details as to species, locations or numbers.

EXPLAINING THE CHANGING WOODY VEGETATION CONDITIONS IN ZION NATIONAL PARK

Cottonwood has been documented to be primarily regenerated after floods that reduce competitive vegetation or in newly deposited fine and moist substrate settings. The literature on cottonwood regeneration (*Populus deltoids, P. fremontii*, and perhaps *P. angustifolium*) suggests that synchronized regeneration occurs and cohort recruitment occurs often in spatial patterns reflecting zones of deposition (strands) and that the cohorts are very even aged (isochrones). There is no reason to believe that these patterns and life history strategies would not presently nor historically have occurred in Zion National Park. A variety of factors may come into play. Cottonwood establishment may be inhibited due to woody vegetation competition from *Baccharis.* If healthy regeneration of cottonwood was occurring, herbivory would not be

significant, nor would it likely represent a measurable threat to cottonwoods. However, with limited invadable habitats for cottonwood in recent years, the few successful cottonwood saplings are a target for herbivory, and a significant and measurable impact on cohort recruitment appears to occur in the park.

Given this information, observations, and trends, the following preliminary explanations and testable hypotheses are offered for consideration and discussions.

In the past, cottonwood recruitment in the park seems to have occurred in three ways as follows:

1. **Event triggered synchronized cohort recruitment** that has lead to isochrones, made up of even-aged stands.

These would occur in areas triggered by flood depositional strands and scour areas where cottonwood seed dispersal, seedling establishment, and saplings temporally and spatially escape (by growth to a less vulnerable larger (taller) size, or by spatial separation from the active channel locations with deposition and scour) subsequent flood events, or where survival of many of the trees occurs even in the face of subsequent high flood events. This process was probably most common and widespread during periods with high flow and sediment conditions and dominated during the establishment of the Settlement, Early Modern, and Modern terraces. During stable periods cottonwood seedlings and saplings establish in secondary channels and margins of slow water velocities and strand development occurs thus offering protection to the developing plants.

We also saw event triggered synchronized growth and recruitment in the toe of slumped slopes, such as described above. The seemingly largely even-aged cohorts of cottonwood growing along the side slopes of the Sentinel Slide opposite the entrance road to the park may be explained in this way.

The abandonment of old agricultural fields also may have been responsible for the establishment of many cottonwoods. Based on observations, it appeared that historic irrigation ditching and field edges are where the larger cottonwoods grow in the park. It also appears that relatively even aged individuals are now growing dispersed across the areas that we believe were historic farm fields.

A series of sub-hypotheses are also provided that could be tested to better understand historic regeneration of cottonwood in Zion Canyon. These are as follows:

- Cottonwood is regenerated after big scour events on strands within 1-2 feet vertically of the bankfull stage.
- Cottonwood regeneration occurs after big flood events on higher terraces only during above average regional moisture or with appropriately timed follow-up storms that maintain seed/soil moisture and contact.
- Cessation from farming may also be able to explain apparent even-aged stands on larger upper terraces that may have been historic farm fields.

- Slumps at the mouth of the canyon created valley plugs that every 30-100 years have surcharged Virgin River waters over the valley bottom, including the higher terraces, which could have resulted in suppression and mortality of competing vegetation and reinvasion opportunities for cottonwood.

2. **Opportunistic and minor flood event** invasion that leads to scattered individual tree recruitment and sporadic numbers of recruited trees.

It appears that scattered individual cottonwood trees are present in higher terraces and other locations within the fluvial environment. Scattered trees rather than development of isochrones can be explained by the random presence of successful seedling and sapling recruitment. This gap phase invasion would only occur in locations with appropriate patch size, substrates, and moisture conditions. We observed this to occur in locations on dredge or deposited spoils along old drainage ditches, in seepage locations at the toe of the cliff faces, and perhaps in locations on strand lines, where gaps in *Baccharis* were present.

3. **Planting and landscaping introduction** may account for a large number of trees in areas that simply cannot be explained by stream fluvial processes.

Plantings can occur most anywhere, and it's likely, although we cannot support this with planting records, that they did occur in locations where stream revetments were installed, in locations in association with the lodge and other facilities in the park. Records of landscape architecture plantings in the park would be worth reviewing to better understand the woody vegetation systems in the park.

Of particular interest would be the determination if such plants as *Baccharis* were extensively utilized in the park as a part of the planting programs of yesteryear. Although native to the region, the density and extent of the Baccharis communities to the exclusion of willow seem out of balance. Our preliminary review of the behavior of this plant in the park, suggests strongly that it may in fact been extensively used by the CCC in streamside plantings.

In addition, advertent and inadvertent plantings of non-native, cool-season grasses (*Bromus spp.*, etc.), that were identified to have been conducted during the 1930's (Steen 1999), have also had unforeseen ecological effects on the recruitment of native species, including trees such as cottonwood. Some of these grasses establish very quickly on scoured areas and, in essence, reduce the window for gap phase or isochrone invasion to occur, because of the dense vegetation cover they create quickly. These grasses could have colonized extensively on fallowed fields providing a rich seed source during stream channelization activities.

In the uplands terraces around the Zion Lodge there appear to be older trees mixed with mid-aged trees in a pastoral landscape setting. It is very confusing and difficult to explain the presence and establishment of these trees in any other way, but having been planted as a part of a cultivated landscape. Conversely, the lack of mixed-age stands in Zion Canyon away from the lodge would indicate a lesser likelihood of widespread cottonwood planting

Recent colonization theory.

Observations within the canyon suggested little to no buried historic logs within the terraces and fluvial deposits within the park. This is very unusual not to find buried logs that were covered by historic flood events and terraces. The absence of all but recent dead trees (which is located on the surface of the terraces) may also be explained in part, if the following factors prevailed in the park in historic times.

- Wood use during presettlement and post settlement times utilized all the woody debris found within the canyon, including the excavation of larger buried and perhaps partially exposed historic trees/logs. There is evidence of post settlement land clearing, and wood utilization, but no mention of exhuming buried logs. Also, it would be unlikely that all larger logs would be exhumed, there should be ample evidence of historic larger trees.
- Perhaps increased wood-use, and fires, which are typically associated (and have been documented elsewhere to occur) with human occupancy before and after Indo-European settlement, simply restricted woody vegetation system establishment within the park until after initial post-settlement Indo-Europeans departed the canyon.
- Perhaps, buried woody debris is not present because it simply decomposed. This would include buried historic and recent surficial debris.
- Because Fremont's cottonwood is at the upper end of its elevation range within the park, it may simply be that this species has truly only recently invaded. It could also be that it (perhaps along with velvet ash and boxelder) was introduced into the park for wood production and shade and perhaps other amenities it may offer.
- This can also be explained if the hydrology at the turn of the century that produced terrace features also temporarily provided the necessary conditions for widespread cottonwood recruitment. As the hydrology shifted from depositional to erosional the terraces were abandoned and cottonwood forest preserved. Since cottonwoods and terraces would be of similar ages, few if any older remnants would be buried.
- Finally, some of the absence of buried logs could be attributed to especially zealous "landscaping" by the CCC during the channelization period or by rigorous maintenance since that time.

FIGURE 15a,b,c. Outline of the relationships between flood events, scour, deposition, moisture substrate conditions, and cottonwood recruitment and survival.

Figure 15a. Spring flooding period (April – May) inundates alluvial features. Cottonwoods release seeds that remain viable only a few weeks.

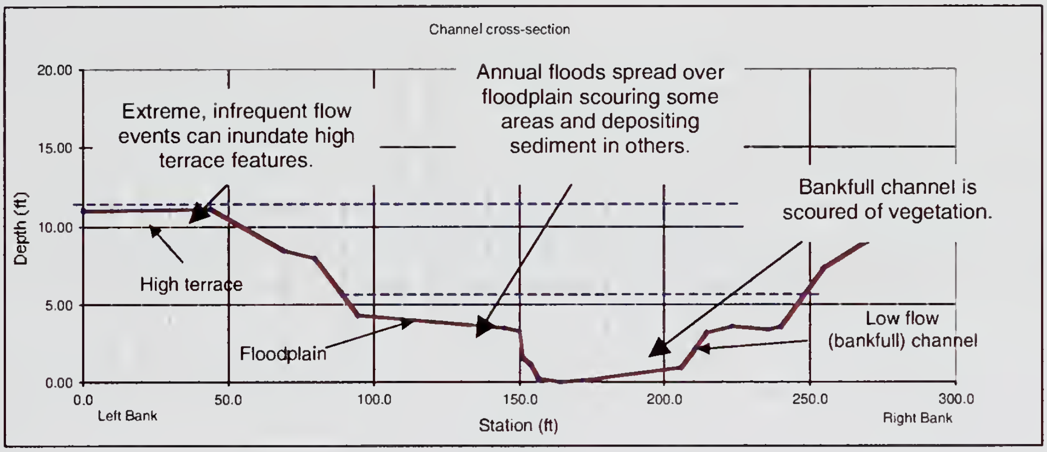


Figure 15b. Summer season; little rain, low stream flows. Soils dry out except near the level of stream flow. Sprout mortality high in dry soils.

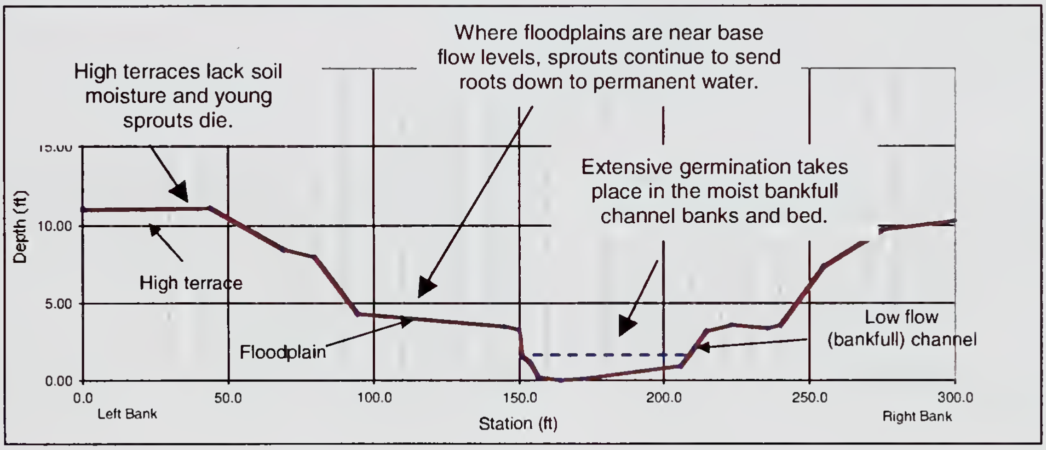
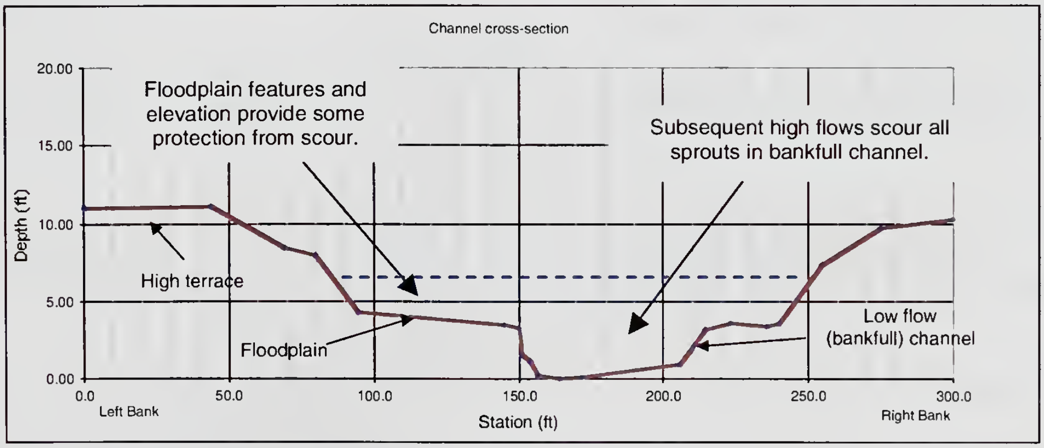


Figure 15c. Late summer or winter flood flows often remove young saplings through scour and channel migration.



CHANNEL GEOMORPHOLOGY

The regeneration of cottonwood trees along the Virgin River within Zion Canyon is interdependent with the stream's fluvial processes. Seeds depend on stream flows for dispersal and adequate soil moisture. In addition, the ultimate survival of seedlings is dependent on protection from subsequent scouring events. The history of stream morphology has been well described by Hereford and others (1995). Periods of erosion and deposition over the past 500 years have alternately created and eroded a variety of alluvial features within the canyon (Table 5). A number of cottonwood trees were cored during this study to date depositional terraces. Tree ring and other data suggests that the majority of mature cottonwoods are linked to terrace features created in three distinct periods; 1867 – 1883, 1892 – 1906, and 1926 - 1937. Other studies suggest that regional climatic variation combined with watershed management created periods of alluvial deposition alternating with periods of stream cutting (Hereford and Webb, 1992).

Table 5. Terrace features along North Fork Virgin River (Hereford, et al, 1995)

	Depositional Periods	Channel Deepening	Description
Prehistoric Terrace	~800 - ~1100		Fine-grained sands with a very thin coating of calcium carbonate. Probably correlates with prehistoric terraces in East Fork. 3-4 m (10-13 ft)* above active channel.
		1100 - 1200	
Settlement Terrace	> 1200 - 1883		Vegetation is a woodland of Gambel oak with subordinate boxelder. Agricultural use is probable. 3 m (10 ft)* above active channel and 1-2 m (3-7 ft)* above Historic Terrace. Oldest cottonwood trees found on this feature.
Historic Terrace		1883 - 1926	This terrace was the stream channel beginning in the 1890's and abandoned by 1926. Cottonwood trees present. 2 m (7 ft)* above active channel.
Early Modern Terrace	1926 - 1937		This terrace was originally a floodplain formed below the historic terrace. 2 m (7 ft*) above active channel.
		1937 - 1940	
Modern Terrace	1940 - 1980		Primarily created by record flood of 1966 (9,150 cfs). 1 m (3 ft) above active channel*.
		1980 - 1983	
Active channel/floodplain			Includes active stream channel and floodplain. Floodplain elevation is approximately 0.5 (1.5 ft)* above active channel.

*All elevations measured at Hereford Site.

The age of the existing cottonwood forest within Zion Canyon appears to date to these depositional periods suggesting that cottonwood recruitment has been historically timed with above average regional moisture periods, which contribute higher sediment yields as well as higher flood events. Natural channels are created and maintained by the forces of water and sediment from their watersheds. Stream channels like the Virgin River may be as sensitive to changes in sediment loading as they are to flood magnitude, frequency, and duration. Increasing sediment supply forces the channel to adjust creating wide and shallow channels. As the channel widens, bank erosion contributes additional sediment, enhancing the process. The wide shallow channel morphology results in a relatively high ground water table and extensive overbank flows during even minor flood events. Historic photographs show a broad, braided channel during at the turn of the last century and for at least three decades thereafter. These conditions would exacerbate flooding of adjacent farmland and destroy in-stream structures. Accounts of the period describe extensive flooding and destruction of farmland, homes, and diversion structures. With such river behavior, it is not surprising that settlers and park managers desired some sort of structural flood control measures. But these conditions would be excellent for widespread and successful cottonwood reproduction.

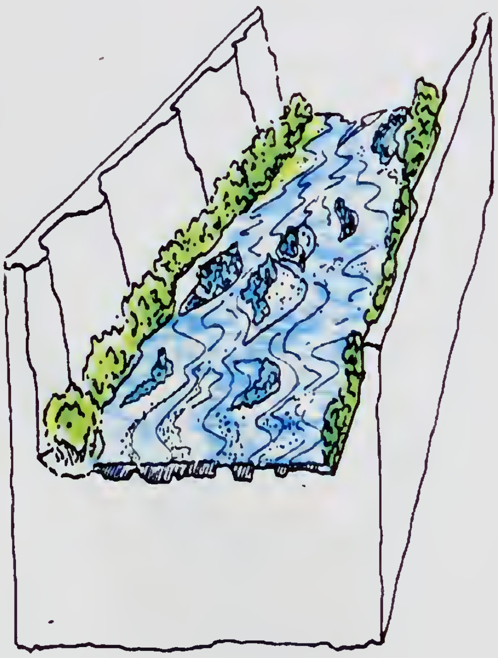


FIGURE 16a.
~ 1880 – 1930. Poor watershed condition due to grazing and regional climate changes combine to increase the sediment inputs to the North Fork of the Virgin River. The stream channel widens and shallows in response increasing the flooding and bank erosion in the canyon. The broad overbank flows create prime conditions for cottonwood recruitment across the floor of Zion Canyon.

Graphics by: S. Lehnhardt

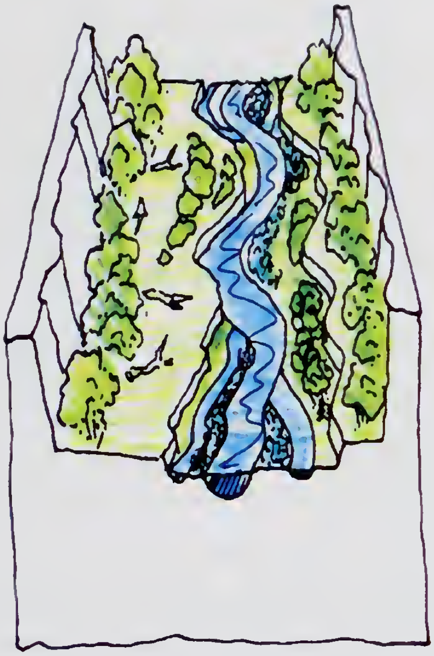


FIGURE 16b. ~ 1930 – 1950. Park officials installed channel revetments to control flooding and bank erosion. At the same time changing watershed and climate conditions reduced the sediment inputs to the Virgin River and the stream channel narrowed and deepened. Minor periods of high sediment and stream flow create new floodplain features. New trees sprout in lesser numbers on narrower floodplain features along the stream. Floods rarely spread across the terraces that supported the cottonwood forest protecting the trees from subsequent scour.

FIGURE 16c. ~1950 – Present. Surface erosion from the watershed continues to decrease. The Virgin River remains a narrow single-thread channel in areas controlled by geology and man-made revetments. In wider sections of the canyon, revetments are washed away and the channel widens forming new floodplain features providing suitable conditions for cottonwood recruitment.

Graphics by: S. Lehnhardt

GEOMORPHIC CONDITIONS FOR SUCCESSFUL RECRUITMENT

Successful cottonwood recruitment requires four conditions.

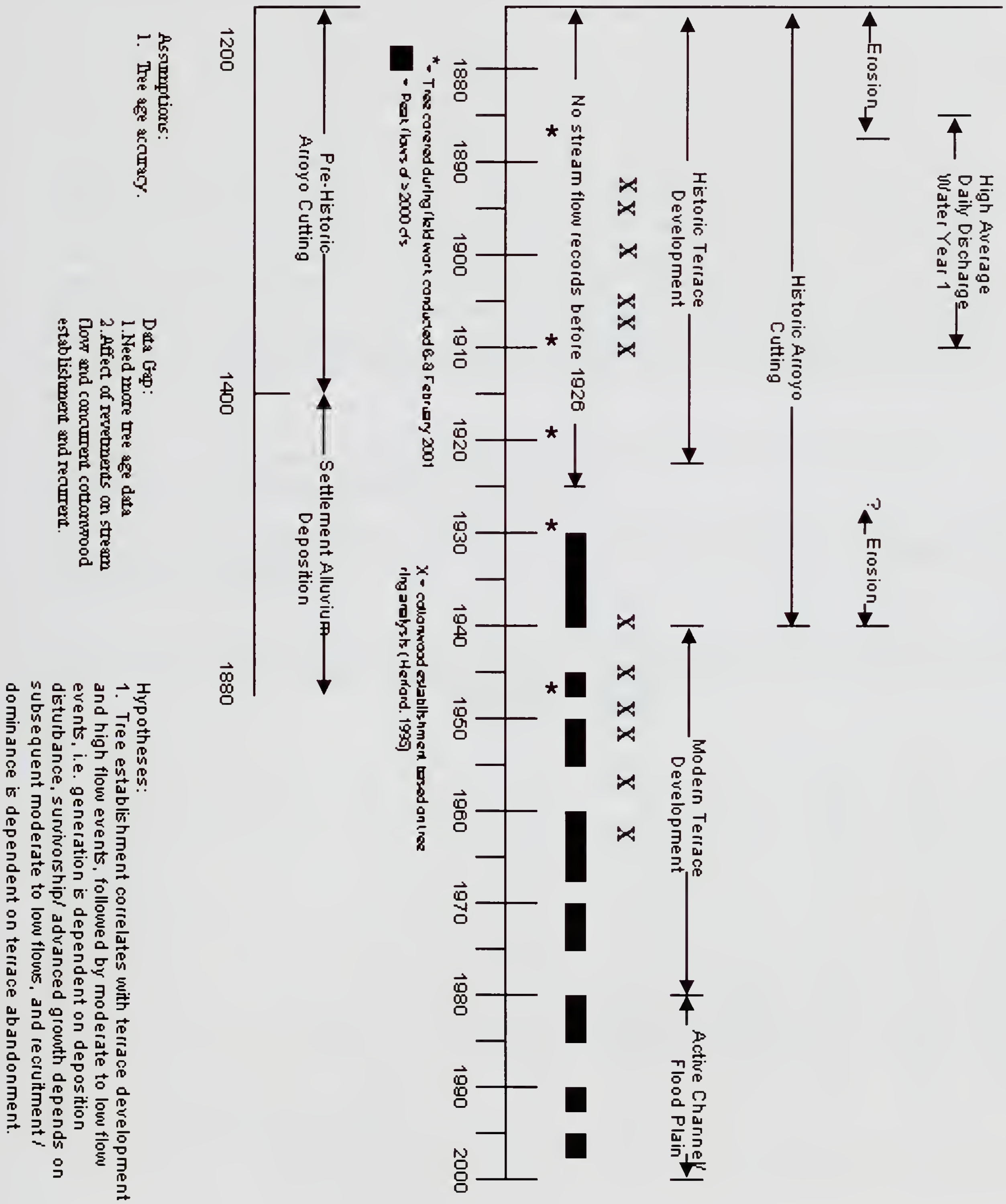
- Stream flows adequate to distribute wet substrate above base flow;
- Fine-grained, bare substrate for germination;
- Adequate ground water though the summer season to establish a root system; and
- Enough distance from stream channel to protect seedling from subsequent scour.

During historic depositional periods high sediment loads created bare ground from overbank deposition. Channels were wide and shallow with low, easily accessed floodplains and overbank flooding was extensive. Shallow channels and relatively high summer flows maintained high ground water tables. Subsequent erosional periods deepened channels protecting vegetated features as elevated terraces removed from stream erosion.

The current climate and channel morphology limits the extent of flooding. The North Fork of the Virgin River has remained relatively stable vertically since the incision events ending in 1983. As a result of incision, the channel is bounded by higher terrace features that limit overbank flow. Geologic control in the Narrows reach and constructed revetments in the Zion Lodge and Birch Creek reaches create relatively narrow, deep channels (width-depth ratios from 25 – 35) and severely limit floodplain width (entrenchment ratios from 1.4 – 1.5).

Narrow channels and narrow floodplains produce high sediment transport conditions, limiting erosion and deposition in these reaches. The resulting stable bank vegetation (baccharis and cool season grasses) also limits available bare ground. In the wider, unconstrained reaches (Big Bend) a shallow, meandering channel (width-depth ratios of 50 to 75) and wider floodplain (entrenchment ratios of 2.0 to 4.0) creates larger areas for potential recruitment. However these same conditions provide limited protection from subsequent scour. While average spring flows have remained relatively constant, summer flows have declined sharply since the turn of the century (Hereford, et al, 1995) lowering ground water levels.

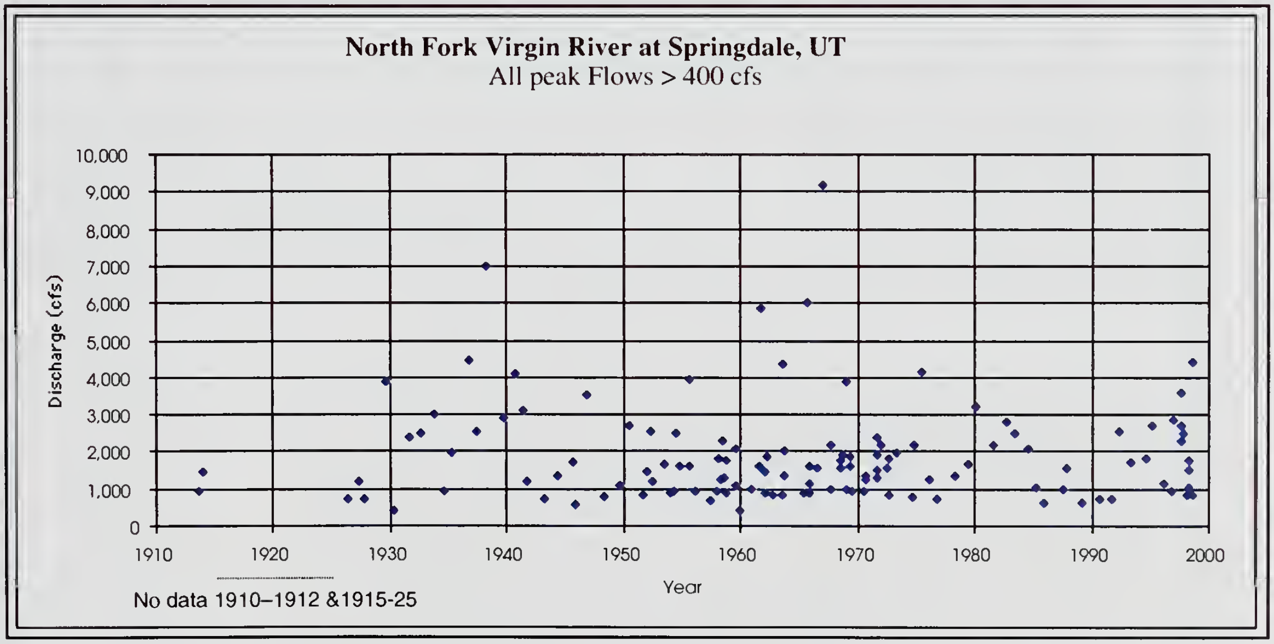
Figure 17. Preliminary Correlation of storm discharge, fluvial features, and cottonwood establishment. Based on Hereford, et al. (1995) and Hereford and Webb (1992).



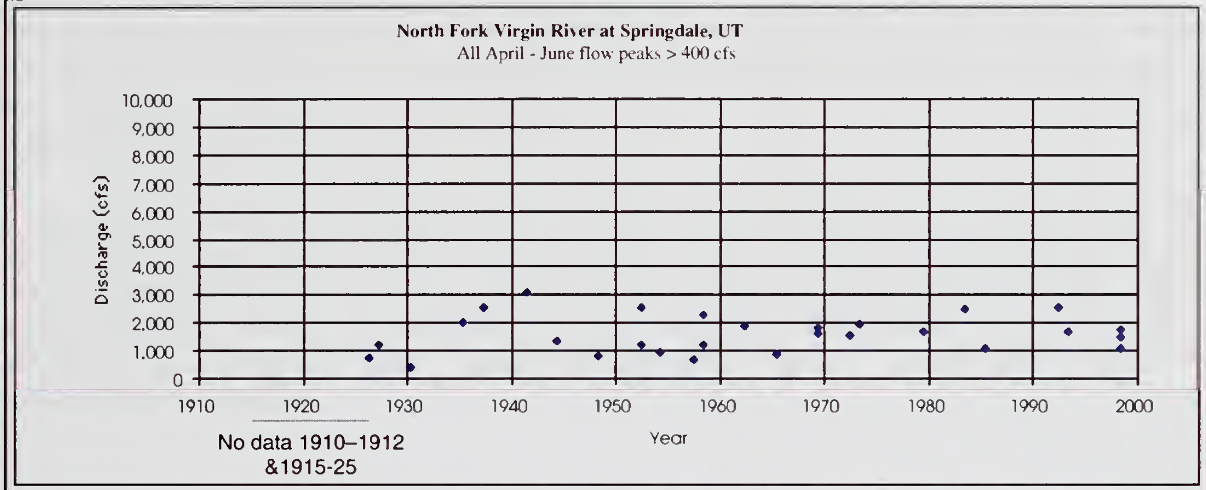
HYDROLOGY:
Cottonwood recruitment requires adequate stream flow to wet seeds on adjacent fine-grained floodplain deposits and sufficient soil moisture through the dry summer season to sustain the sprouts. Cottonwood seed dispersal typically occurs a spring floods gradually subside, leaving wet exposed sediments available for germination. Figure 13 shows the period of high flow events between 1940 and 1970. Since 1970 high flows have been relatively small. As discussed in Hereford, et al (1995), regional hydrology has changed dynamically in the past 150 years. All flow peaks greater than 400 cfs recorded at the USGS gaging station at Springdale, UT are graphed on Figures 14 a, b, & c. It appears that spring flood flows were more frequent during the Modern terrace (1940 – 1980) period and somewhat higher than those of the most recent 20 years (Figure 14a). A similar trend is apparent for summer and fall (Figures 14 b & c). The significance of the relatively few winter peak flows from 1926 through 1958 is not clear. Higher and more frequent spring flow events would have allowed more widespread seed germination. Hereford (1995) reports that average daily summer flows decreased sharply during the past 75 years. This would lower the ground water table during the critical summer months and reduce survival of sprouts.

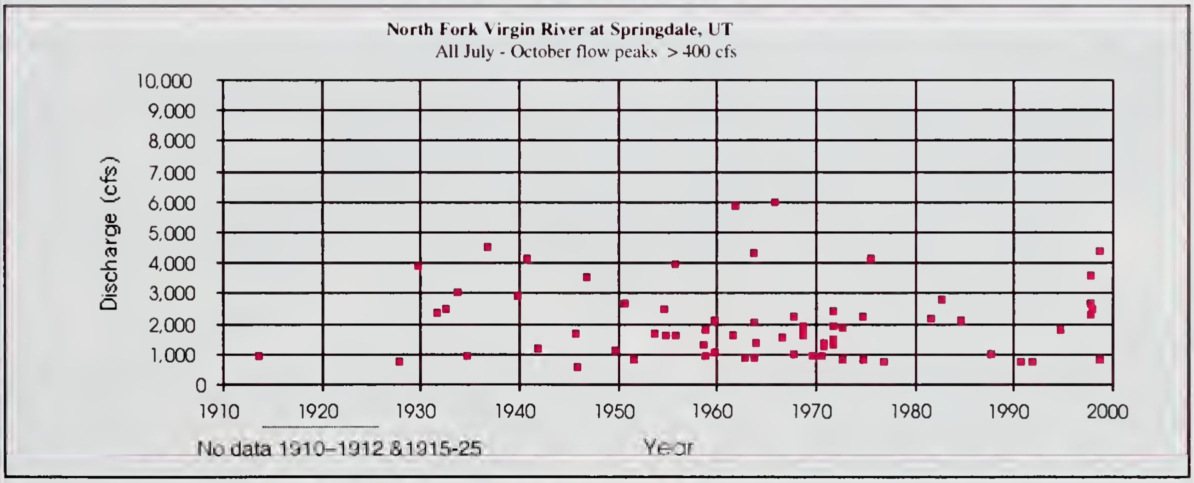
The conclusion of this analysis is that current hydrology limits but does not eliminate the potential for cottonwood regeneration in Zion Canyon.

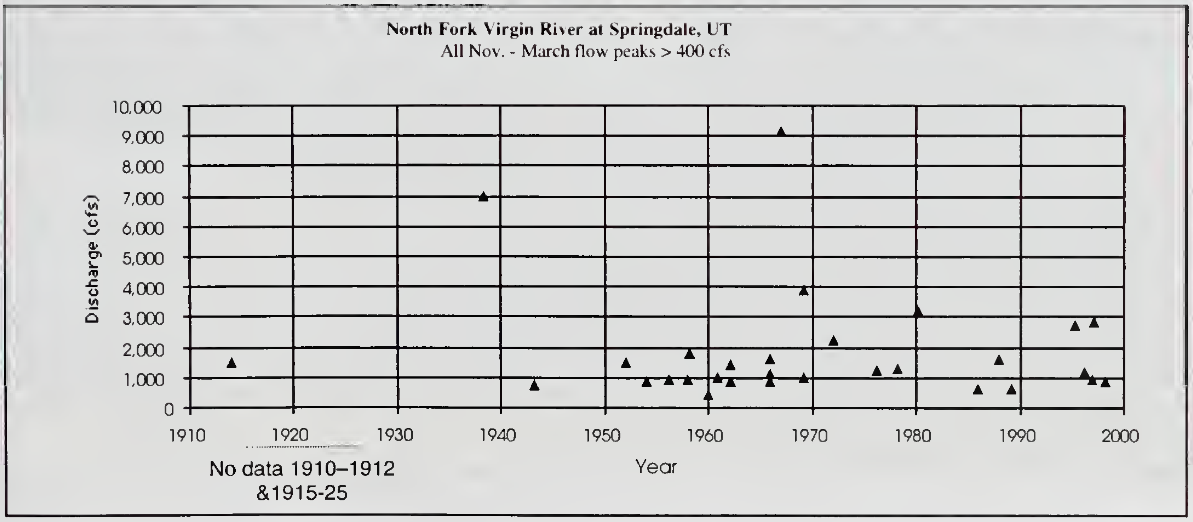
FIGURE 18. All peak flows greater than 400 cfs at North Fork Virgin River at Springdale, UT gage. (1913-14, 1926-98)



FIGURES 19 a, b, c. Peak flow events greater than 400 cfs by season. North Fork Virgin River at Springdale, UT gage station. (1913-14, 1926-98)







CONDITION OF EXISTING REVETMENTS

The location, volume of material, and condition of the revetments in the reaches below the Grotto footbridge were documented for this project. In general, the revetments are constructed of relatively small rock rip –rap (6 – 16 inches) and covered with heavy wire. The gabions line the east bank almost continuously from above the Grotto footbridge to well below the Zion Lodge. The revetments are from 6 – 12 feet in height and 4 – 8 feet thick. They contain an estimated 90,000 square feet of wire and 8,500 cubic yards of rock.

Much of the revetment is in surprisingly good condition considering it was constructed 60 – 70 years ago. However in many places the wire has rusted away and become a safety hazard. In the area near Emerald Pools the river has breached the revetments on both banks and created a sharp meander. In other places the wire has given way and the rock is dropping out the bottom of the basket and into the river. The rock baskets are not generally repairable, and will have to be reconstructed or replaced.

FIGURE 20. Rock revetments in disrepair near Zion Lodge

DESIGN CHANNEL/FLOODPLAIN GEOMETRY

Channel and floodplain geometries are be best determined by identifying a functioning reference reach within the project or nearby watershed. However, preliminary assessment of the East Fork and main Virgin River below Zion National Park suggested that these channels would not provide suitable reference conditions for the North Fork. As a consequence reference conditions for the physical channel were quantified from data taken at the Big Bend and Great White Throne sites in Zion Canyon. In these reaches young cottonwoods and other woody species were observed in depressions and secondary channels in floodplain areas adjacent and only slightly elevated above the stream channel. While this recruitment may appear limited compared to the extent of the cottonwood forest that now occupies the valley floor, it appears to represents the potential under the current climate.

Design Criteria

Component	Average	Range
Drainage Area	~200 sq miles	NA
Bankfull Cross-sectional Area	200 sq feet	175 – 225 sq feet
Width-depth ratio	50	40 – 75
Entrenchment ratio	2.5	2.0 – 3.0
Sinuosity	1.3	1.2 – 1.4
Design channel/floodplain dimensions		
Bankfull Channel width	100 feet	85 – 125 feet
Bankfull mean depth	2.0 feet	1.6 - 2.4 feet
Bankfull maximum depth (1.6 d_{mean})	3.2 feet	2.5 – 3.8 feet
Floodprone width	250 feet	200 – 300 feet
Meander width	230 feet	110 – 390 feet
Meander length	935 feet	775 – 1100 feet
Radius of curvature	315 feet	200 – 600 feet

FIGURE 21. Design cross-section overlaid on existing cross-section near Zion Lodge reach

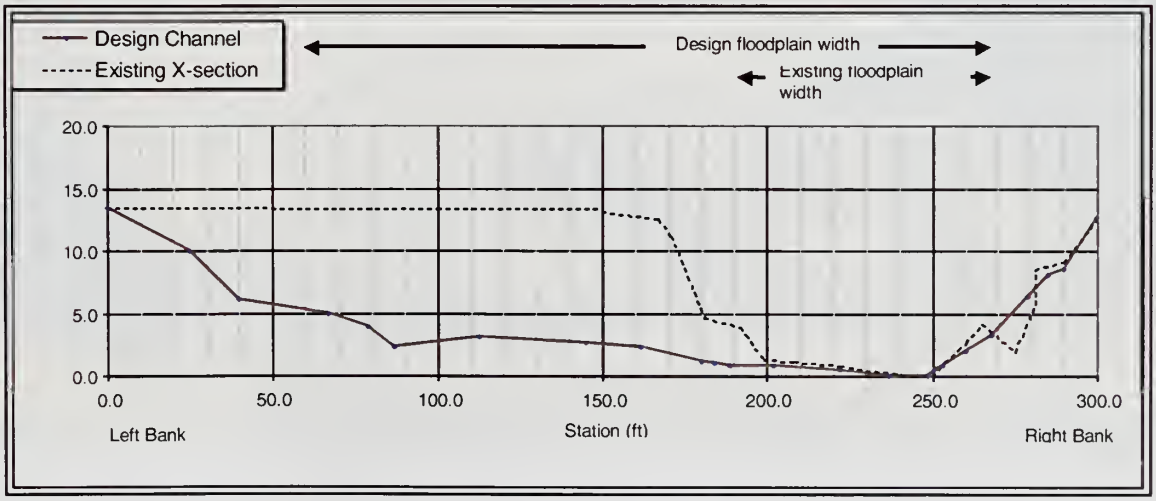


FIGURE 22. Design cross-section overlaid on existing cross-section within Birch Creek reach

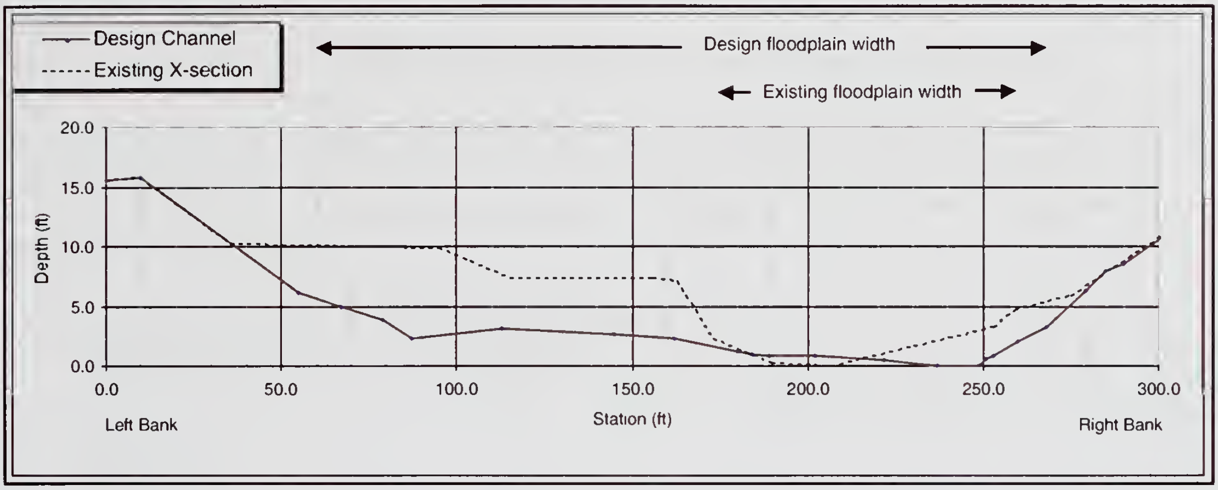


FIGURE 23. Photo of Big Bend reach

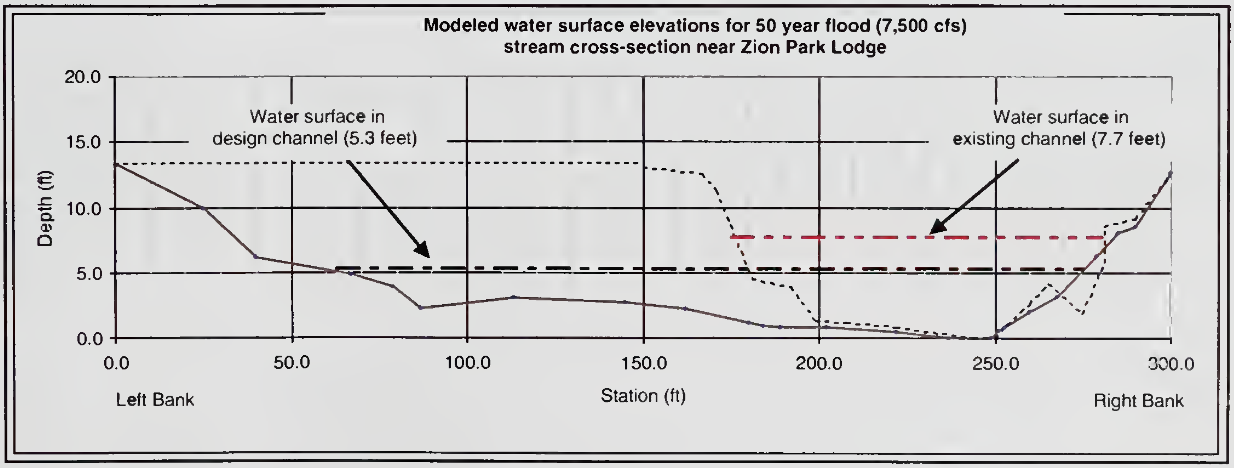
ASSESSING DESIGN FLOOD POTENTIAL:
Flooding potential was evaluated at the surveyed sites using WinXS-Pro, a cross-section analyzer developed by the USDA Forest Service. Flood magnitudes and return intervals were modeled using HEC-FFA, a flood frequency analyzer developed by the Army Corps of Engineers. While the stages should be considered estimates, the values suggest that there will not be additional flood risk in the lodge area as a result of increasing floodplain width in the reveted reaches. The Big Bend Site which exhibits the floodplain width closest to the design cross-section (Table 5). Stage-Discharge relationships are plotted on surveyed and design cross-sections in Attachment 2.

Table 6. Stage-Discharge relationship at survey sites.

Return Interval (years)	1.3 (Bankfull)	2	5	10	25	50	100
Discharge (cfs)	1,150	1,600	3,000	4,000	4,500	7,500	9,000
	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
Narrows reach							
NARROWS	3.0	3.3	4.4	4.5	4.9	5.6	5.9
HEREFORD	3.4	4.0	4.8	5.3	6.2	6.4	6.8
Big Bend Reach							
BIG BEND	2.8	3.2	3.9	4.3	4.4	5.3	5.7
GREAT THRONE XS-1	4.2	4.7	5.5	5.9	6.1	7.0	7.4
GREAT THRONE XS-2	3.4	4.3	5.1	5.5	5.7	6.5	6.9
Zion Lodge Reach							
GROTTO	3.9	4.6	5.6	5.9	6.2	7.7	8.2
Birch Creek Reach							
MEANDER STA 9+00	3.8	4.1	5.1	5.5	5.7	6.3	6.6
MEANDER STA 9+80	4.2	4.5	5.6	5.9	6	6.5	6.7
DESIGN CROSS-SECTION	2.8	3.2	3.9	4.3	4.4	5.3	5.7

Water surface elevation is inversely related to floodplain width. The wider the floodplain, the lower the water surface elevation, particularly during large flood events. The reduction in water surface, and subsequent flood risk, is greatest in the reveted stream sections around Zion Park Lodge (Figure 22).

Figure 24. Modeled water surface elevations for 50-year flood (7,500 cfs) in existing and design cross-sections near Zion Park Lodge.



HISTORIC MEANDER
Alluvial channels slowly migrate across a landscape as erosion on the outside of a meander is offset by deposition on the opposing point bar. In a practical sense, these values represent the expected limits of long-term lateral erosion.

To assess historic belt width (the extent of channel migration), lines were drawn on 1992 aerial photos along each side of the river connecting relatively permanent features. Historic meander describes the total width occupied by the stream channel over time rather than the meander width of the current channel. Mature cottonwoods and canyon walls were used to delineate the extents of channel. Since the age of mature cottonwoods has been identified as 80 – 100 years, these features represent the extent of lateral migration over the past century or a conservative measure of historic beltwidth. Because the majority of the mature trees sit back on higher terrace features, the actual channel meander width is somewhat smaller than the historic meander.

Width measurements were made at regular intervals along the river corridor from the Narrows parking area to the Sentinal slide. The mean and range of values are summarized in Table 6.

Table 7. Meander Widths through Zion Canyon

	Belt Width (feet)	
Section:	Mean	Range
A – Narrows Reach	134	90-220
B – Big Bend Reach	234	110-390
C – Zion Lodge Reach	116	70-290
D – Birch Creek Reach	146	90-250

Conclusions:
The narrow belt widths in the Narrows and Birch Creek Reaches reflect the influence of strong geologic control. The belt width values for the Zion Lodge Reach are limited by the man-made revetments. However, lateral channel migration in the Big Bend Reach has been relatively unrestricted over the past decades and these values represent the beltwidth as a result of natural erosion and depositional processes. The values in this reach suggest 200 – 250 feet provides an adequate width for channel migration over an extended period. Meander width of the current channel in this reach is 150-200 feet based on the representative cross-sections.

This analysis suggests that 150 – 200 feet of width is necessary for floodplain features to handle high flow events, and that the long-term extent of lateral migration if the revetments are removed, is in the order of 200 – 250 feet with occasional widths as high as 400 feet. Widths between the west canyon wall and the Zion Canyon road within the project area are commonly in the 250 – 400 foot range with some values as high as 600 feet. This analysis suggests that the stream can develop its natural meander pattern without the need to relocate the Zion Canyon road.

Table 8. Historic meander width data by transect and reach

Narrows Reach		*Big Bend Reach*		*Zion Lodge Reach*		*Birch Creek Reach*	
Transect	Width (ft)	Transect	Width (ft)	Transect	Width (ft)	Transect	Width (ft)
1	100	21	200	70	110	103	110
2	100	22	210	71	90	104	140
3	170	23	240	72	90	105	250
4	220	24	260	73	100	106	240
5	180	25	250	74	120	107	220
6	130	26	250	75	110	108	180
7	120	27	330	76	150	109	200
8	120	28	320	77	140	110	150
9	150	29	320	78	140	111	130
10	100	30	270	79	120	112	120
11	170	31	290	80	120	113	110
12	190	32	300	81	170	114	130
13	160	33	340	82	100	115	150
14	130	34	240	83	180	116	100
15	100	35	130	84	290	117	110
16	100	36	170	85	250	118	90
17	90	37	340	86	120	119	100
18	110	38	390	87	90	120	100
19	120	39	330	88	80		
20	120	40	330	89	70		
		41	380	90	90		
		42	310	91	100		
		43	230	92	80		
		44	280	93	100		
		45	200	94	100		
		46	200	95	100		
		47	280	96	90		
		48	230	97	90		
		49	170	98	80		
		50	150	99	90		
		51	150	100	90		
		52	120	101	70		
		53	110	102	100		
		54	230				
		55	260				
		56	200				
		57	170				
		58	150				
		59	270				
		60	250				
		61	110				
		62	140				
		63	190				
		64	200				
		65	240				
		66	220				
		67	220				
		68	140				
		69	160				
Average	134	Average	234	Average	116	Average	146
Range	90-220	Range	110-390	Range	70-290	Range	90-250

DESIGN SUMMARY

The analysis of current geomorphic and biological conditions in the Big Bend reach suggests that increased floodplain width is the single most important element to restore the potential for cottonwood recruitment in the reveted section of the North Fork of the Virgin River within Zion Canyon. Due to the channel's deep entrenchment, this will entail the removal of a large volume of material. A set of potential alternatives is evaluated in the next section. In the final discussions a series of options are presented for further consideration.

RESULTS OF PRELIMINARY DESIGN WORKSHOP

Preliminary results of this study were presented to Park staff, interested agencies, and knowledgeable professionals to discuss and critique the concept plan. The purpose of the workshop was to seek expert input on selecting an approach to river restoration, and to inform regulatory and other interested parties of the need for restoration. The workshop discussions were designed to provide a basis for developing a final design, for conducting compliance with NEPA, NHPA, 404 and Endangered Species Act, and for preparing a competitive proposal for the actual restoration.

The workshop took place April 10 – 11, 2001 at Zion Park Lodge in Zion National Park. The results of the field inventory and draft concept designs were presented to all participants and a tour of the field sites along the Virgin River was conducted. Participants included NPS, other agency and independent specialists in river restoration and morphology, park managers, park concessionaires, park and other agency specialists in cultural resources, fisheries, and water quality.

Draft restoration alternatives were discussed in great detail by workshop participants. The following recommendations were made:

- Two alternatives under consideration, "Remove Wire Only" and "Remove Wire; breach levees" were considered to be technically and environmentally unwise and were dropped from further consideration. The complete removal of the wire, much of which appears to be baskets, would require moving most if not all of the rock as well. There would be little or no cost savings to the option of removing wire only. Secondly, disturbing but leaving large quantities of loose rock would create very unstable banks. Over time loose rock would erode into the stream channel at varying rates causing unpredictable and often undesirable channel adjustments. Similarly, selective breaching of the levees could result in unpredictable channel behavior including the channel becoming trapped between the levees and road.
- The "Retain but Neglect" alternative (with appropriate maintenance costs added) should be designated as "No Action Alternative"
- There was considerable discussion regarding the "Remove levees completely" alternative. This alternative was modified to include transporting revetment rock rather than dumping it into the stream channel. Participants described the modified alternative as the natural healing of the system.
- It was suggested that a new "Staged Restoration" alternative be created to address the potential for restoring the project reach in two or more phases.

There was recognition that there were many non-technical factors that needed to be taken into account during the NEPA compliance. These included but were not restricted to: funding, politics, local cultures, roads, lodge, visitors, utilities, and bridges. A summary of the notes and flip charts recorded during the workshop are included in Attachment 3.

The following local construction costs were developed by workshop participants and are used in evaluating potential management alternatives.

Wire removal:	$50,000 seems reasonable
Rock removal:	$15/yd transported to Rockville
Earthwork:	$3/yd moved within site; $10/yd transported to Rockville

The comments and recommendations of workshop participants are incorporated into this final report.

EVALUATION OF MANAGEMENT ALTERNATIVES

The following alternatives were evaluated based on the design criteria and workshop recommendations.

1) RETAIN AND REPAIR EXISTING LEVEES - The levees would be maintained for the foreseeable future. This would require repair and eventual replacement of existing gabions as they deteriorated over time.

Analysis: This alternative would require an increase in the current maintenance costs to the Park as the deterioration of the aging revetments accelerated. Because revetment deterioration and the actions of the river are unpredictable, it would be difficult to plan the resources and budget necessary for maintenance. The costs to repair or reconstruct existing levees are estimated conservatively at several hundred thousand dollars. There would be frequent, unpredictable needs to repair or replace revetments either to protect infrastructure or public safety. The actual costs could be substantially higher if the reconstruction was forced by the destructive forces of a large flooding event. Significant sections of revetments above the Lodge foot bridge that have already been destroyed by the river would have be rebuilt to prevent accelerated destruction of downstream revetments.

This management alternative would retain the status quo which, it is assumed, the general public considers successful. However, there would be no increase in natural riparian function, cottonwood/riparian recruitment, or aquatic habitats. Riparian vegetation would be limited to the species and aerial extent currently existing. If a broader or more diverse band of riparian vegetation was desired, cottonwoods and other tree species would have to be planted on the terraces and irrigated until they become established in order to replace the expected loss of the existing aging tree population.

Basic tasks:

- Periodically repair and maintain deteriorating revetments
- Replace sections of revetment currently destroyed by river processes
- Replace significant sections of revetments as deterioration accelerates

Estimated costs:

- Annual maintenance costs: $10,000
- Replace all revetments over next 20 years: >$300,000
- Total estimated costs over next 20 years: >$500,000

2) BENIGN NEGLECT - Allow the gabions to deteriorate and the river to slowly remove the levees. This alternative best reflects existing management with the addition of periodic maintenance necessary to protect public safety.

Analysis: It is expected that the deterioration of the aging revetments will accelerate over the next decade. The deterioration will be unpredictable and pose increasing public safety concerns from rusty revetment wire and unstable banks. Maintenance costs will increase unpredictably over time. Costs to protect the existing footbridges will increase as the channels upstream and downstream widen. Eventually, the Park will be forced to lengthen these bridges to match the new channel dimension.

These costs and concerns are magnified by the unstable and unpredictable nature of the revetment deterioration. As a result Park management would be reactive rather than proactive. Many revetments are failing and rock is currently falling out of the bottom of the revetments. This is creating differential armoring which will produce unpredictable stream morphological changes. The stone fall would temporarily armor one side of the stream bank, which will send unpredictable and destabilizing oscillations and hydraulic pulses and erosive forces down the stream.

This alternative would also result in no short-term increase in the riparian potential, cottonwood regeneration, aquatic habitats. However, there would be resource benefits in 50 to 100 years. In the interim, while no additional construction or maintenance costs will be incurred, we expect continued failure of the revetments and the exacerbation of the stream morphological changes and problems. Deteriorating wire and rock will be difficult to reconcile with the public perception of managing parklands in a natural state, or of responsible management of park facilities. It would lessen natural aesthetics of the stream and pose increasing public safety risk.

Basic tasks:

- React to public safety concerns from deteriorating revetments.
- Continued need to reinforce revetments around existing foot-bridges and utility corridor.
- Eventual need to replace or lengthen existing foot-bridges as levees deteriorate and channel widens.

Estimated costs:
Maintenance costs would be uncertain and very difficult to estimate. Annual costs would increase over time as revetments age. Based on average annual maintenance costs of $10,000 and a cost of $100,000 + to replace or lengthen each bridge, total costs could exceed $500,000 over the next 20 years.

3) REMOVE WIRE ONLY – ASSESSED BUT REJECTED
The wire would be removed from the gabions to hasten the river's actions and reduce hazards.

Analysis: This alternative was assessed but rejected for the following reasons. From a practical standpoint it would be impossible to remove the wire under the baskets without removing the rock. Removing the wire only will hasten natural deterioration of the revetment structures and remove the public hazard created by the rusting wire baskets. Because the rock riprap is not sized to withstand high stream flow velocities when not contained, flow events will likely undermine the structures and allow the rock to enter the bankfull channel. It is not clear the effect this additional cobble will have on the system. We are concerned about overwhelming the capacity of the stream to transport sediment of this size by simply allowing revetment rock to fall into the stream.

There is no location within the stream with a predominance of sized or shaped rock similar to the revetment rock and there is concern that it would result chaotic and unpredictable stream channel adjustments (Table 7). Large pulses of rock into the stream channel would likely redirect the stream and interrupt the forming meanders. The result would be increased public hazard and great management uncertainty. On-going maintenance would be difficult to predict and costs unknown. This alternative does not meet park objectives.

4) BREACH LEVEES, CONSTRUCT SELECTED MEANDERS – ASSESSED BUT REJECTED
Wire would be entirely removed, the levees physically breached in a few places and 2-4 meanders constructed outside of the levees to hasten lateral movement of the channel.

Analysis: This alternative was assessed but rejected as technically and environmental unacceptable for the following reasons. Since the gabion baskets extend around the revetments, from a practical point of view wire removal necessitates removal of the rock. Analyses within this report suggest that floodplain elevation and width are more critical than simply restoring meander pattern. Since the current revetments are generally only 100 feet apart, the creation a floodprone width of 150 – 250 feet would require the removal of virtually all revetments. Leaving large quantities of loose rock riprap would increase the potential for unpredictable and undesirable channel adjustments. Accelerated deterioration of the remaining revetments would tend to foster uneven and chaotic channel adjustments and increased public safety hazards. The need for unquantified

future maintenance would result in management uncertainty. Finally, loose rock eroding into the river at random points could overwhelm stream hydraulics, creating unpredictable behavior, potentially excessive bank erosion, and flooding threats to infrastructure. This alternative does not meet park objectives.

5) REMOVE LEVEES – The levee material and rock filling the gabions would be removed and transported from the site. Existing footbridges would be replaced or lengthened to the full floodplain width of 150 feet. The river would be allowed to widen naturally over time. High point bars in the downstream meander sections would be lowered and the baccharis dominated vegetative community partially replaced by willow species.

Analysis: This alternative is considerably less expensive and less intrusive than full immediate restoration (alternative 6) but restoration would be measured in decades rather than in years. Complete removal of the levies would allow the stream heal naturally by adjusting its pattern and channel/floodplain geometry through the processes of erosion. Existing footbridges would be replaced or lengthened to span the expected width of both channel and floodplain. The most cost-effective method may be to retain the existing bridges to span the channel and add 1 to 2 additional arches to the east to span the adjacent floodplain. The existing channel would be widened only in the vicinity of the bridges to create an appropriate floodplain. In the meandering sections of channel downstream of the lodge, high bars on the inside of each meander would be lowered and some of the baccharis communities replaced with willow.

Approximately 66 mature cottonwood trees, 36 near the Grotto bridge and 30 near the Lodge, would be mechanically removed. Initially, eroding banks would be common throughout the reach and additional trees would be lost over time through bank failure. Some maintenance would be recommended for public safety concerns and to remove these trees from the river. The downed trees would increase the local rate of channel widening but could create channel adjustments that threaten footbridge supports. Channel widening would decrease over time and riparian vegetation would quickly reestablish. Some selective bank stabilization may be necessary in the future to protect Park infrastructure, though predicted channel widths suggest this will be minimal. Riparian function would begin to improve immediately and full function restored within about 30 to 50 years depending on the occurrence of floods.

Bank erosion will increase sediment supplies to the stream channel especially during high flow events. This additional sediment supply should be beneficial to the restoration process within the project helping to create point bars and potentially raising the level of the channel. Downstream impacts are expected to be minimal though should be more fully quantified. They would occur over many years, would occur during floods when the river already transports large amounts of sediment, and would be less noticeable downstream of the more sediment laden East Fork.

Basic tasks:

- Remove ~ 90,000 square feet of wire mesh and dispose of properly
- Remove ~ 9,000 cubic yards of rock revetment and transport offsite.
- Excavate and remove ~ 33,000 cubic yards of terrace material from site.
- Replace or lengthen footbridges
- Install bioengineering and replant disturbance areas.

Estimated costs:

- Remove wire: $50,000
- Remove rock: $150,000
- Earthwork/ transport of spoils: $350,000
- Replace or lengthen footbridges: $200,000
- Relocate utility line below Lodge: $50,000
- Revegetation of meander reach: $100,000
- Planning/supervision: $50,000
- Permitting/compliance (CWA, NHPA, ESA, others): $50,000
- Monitoring: $50,000

TOTAL ESTIMATED COST: $1,000,000

6) REMOVE LEVEES AND CONSTRUCT CHANNEL WITH NATURAL CHARACTERISTICS - The rock and wire from levees would be removed, the material transported outside the park, and a channel would be physically constructed for the entire 2.0-mile reach, with dimensions and meander patterns similar to natural conditions and consistent with a channel in equilibrium. Existing footbridges would be replaced or lengthened to the full floodplain width of 150 feet. High point bars in the downstream meander sections would be lowered and the baccharis dominated vegetative community partially replaced by willow species.

Analysis: This alternative would potentially provide the channel morphology to optimize cottonwood regeneration and other riparian function. Removal of the rock and wire would increase visitor access to the stream corridor and lower public safety concerns. Design of the channel meander pattern should decrease the risk of unpredictable channel adjustments and unforeseen infrastructure impacts. This alternative would allow all construction to be completed within a single funding cycle. However, economic costs and initial physical disturbance would be greatest under this alternative. There are a number of critical data gaps that could result in a less successful outcome. Approximately 300 mature cottonwood trees would have to be mechanically removed.

Basic tasks:

- Remove ~ 90,000 square feet of wire mesh and dispose of properly
- Remove ~ 9,000 cubic yards of rock. Some material could be used in creating the channel meanders, in channel fill, and in protecting road grades. The remainder must be transported off site.
- Excavate ~ 500,000 cubic yards of terrace material. Approximately 255,000 cubic yards of material would have to be transported away from the site.
- Existing footbridges would be replaced or lengthened.
- The utility line below the lodge would be relocated nearer the road.
- Install structural protection for footbridges, bioengineering in critical areas, and replant disturbance areas.

Estimated costs:

- Remove wire: $50,000
- Remove rock: $150,000
- Earthwork on site: $750,000
- Transporting soil from site: $2,500,000
- Bioengineering and stabilization: $200,000
- Replace or lengthen footbridges: $200,000
- Relocate utility line below Lodge: $50,000
- Planning/supervision: $100,000
- Permitting (CWA, NHPA, ESA, others): $100,000

TOTAL ESTIMATED COST: $4,100,000

7) STAGED RESTORATION – This new alternative includes the tasks described in Alternative 5, REMOVE LEVEES. However, the work would be done in two stages to spread construction costs and allow experience gained in the first stage to be incorporated into the second. Stage 1 would focus on removing the revetments from above the Grotto footbridge to below the Lodge footbridge.

The levee material and rock filling the gabions would be removed and transported from the site. Existing footbridges would be replaced or lengthened to the full floodplain width of 150 feet. The river would be allowed to widen naturally over time. In the meandering sections of channel downstream of the lodge, high bars on the inside of each meander would be lowered and some of the baccharis communities replaced with willow.

Analysis: This alternative would provide similar benefits as Alternative 5, REMOVE LEVEES, but over multiple years. Complete restoration would take decades, a time scale similar to Alternative 5. Costs would be somewhat higher due to the need to mobilize equipment over two construction periods. While this alternative is considerably less expensive and intrusive than full immediate restoration (Alternative 6), it would not deliver the same resource benefits. Complete removal of the levies would allow the stream heal naturally by adjusting its pattern and channel/floodplain geometry through

the processes of erosion. Existing footbridges would be replaced or lengthened to span the expected width of both channel and floodplain. The most cost-effective method may be to retain the existing bridges to span the channel and add an additional arch to span the adjacent floodplain. The existing channel would be widened in the vicinity of the bridges to create an appropriate floodplain

Approximately 66 mature cottonwood trees, 36 near the Grotto bridge and 30 near the Lodge, would be mechanically removed. Initially, eroding banks would be common throughout the reach and additional trees would be lost over time through bank failure. Some maintenance would be recommended for public safety concerns and to remove these trees from the river. The downed trees would increase the local rate of channel widening but could create channel adjustments that threaten footbridge supports. Channel widening would decrease over time and riparian vegetation would quickly reestablish. Some selective bank stabilization may be necessary in the future to protect Park infrastructure, though predicted channel widths suggest this will be minimal. Riparian function would begin to improve gradually and full function restored within about 30 to 50 years depending on the occurrence of floods.

Bank erosion will increase sediment supplies to the stream channel especially during high flow events. This additional sediment supply should be beneficial to the restoration process within the project. The downstream impacts are expected to be minimal though should be more fully quantified.

STAGE 1.

Basic tasks:

- Remove ~ 90,000 square feet of wire mesh and dispose of properly
- Remove ~ 9,000 cubic yards of rock revetment and transport offsite
- Excavate and remove ~ 10,000 cubic yards of material from meander bars.
- Install bioengineering and replant disturbance areas.

Estimated costs:

- Remove wire: $50,000
- Remove rock: $150,000
- Earthwork/ transport of spoils: $100,000
- Revegetation of meander reach: $100,000
- Planning/supervision: $50,000
- Permitting/compliance (CWA, NHPA, ESA, others): $50,000
- Monitoring: $50,000

STAGE 1 COSTS: $550,000

STAGE 2.

Basic tasks:

Excavate and remove ~ 20,000 cubic yards of terrace material from near bridges
Replace or lengthen footbridges
Install bioengineering in critical areas

Estimated costs:

- Remove/transport terrace material near footbridges: $200,000
- Replace or lengthen footbridges: $200,000
- Install bioengineering and bank protection where necessary: $100,000
- Planning/supervision: $50,000
- Permitting/compliance (CWA, NHPA, ESA, others): $50,000
-

STAGE 2 COST: $600,000

TOTAL ESTIMATED PROJECT COST: $1,150,000

Table 9: ALTERNATIVES MATRIX;
Resource Impacts

Alternative	Impacts to Historic Resources *	Riparian Resources Short-term Benefit <10 years	Riparian Resources Long-term Benefit >10 years	Aquatic Resources Short-term Benefit <10 years	Aquatic Resources Long-term Benefit >10 years	Impacts during Construction & Implementation	Downstream Sediment Loading During Adjustment**
1. RETAIN AND REPAIR EXISTING LEVEES	Low	Low	Low	Low	Low	Low	Same as Existing
2. RETAIN BUT NEGLECT	Moderate	Low	Moderate	Low	Moderate	Low	Gradual increase
3. Remove Wire only	high	Low	low	Low	Moderate	Low	Largest Increase
4. Breach levees and Construct Selected Meanders	High	Low	Moderate	Low	Moderate	Moderate	Largest Increase
5. REMOVE LEVEES	High	Low	High	Low	High	High	Increase
6. REMOVE LEVEES – CONSTRUCT CHANNEL	High	High	High	High	High	High	Small Increase
7. STAGED RESTORATION (New Alternative)	High	Low	High	Low	High	High	Increase

* low impact to historic resources if gabions are replaced in kind, high if they are replaced with a different design or materials
** Once the channel reaches equilibrium, the amount of sediment leaving the reach will be essentially the same as that entering it.

1) Retain Levees -	The levees would be maintained for the foreseeable future. This would require repair and some replacement of gabions.
2) Benign Neglect -	Allow the gabions to deteriorate and the river to slowly remove the levees.
3) Remove Wire Only -	The wire would be removed from the gabions to hasten the river's actions and reduce hazards.
4) Breach Levees and Construct Selected Meanders -	Wire would be entirely removed, the levees physically breached in a few places and 2-4 meanders constructed outside of the levees to hasten lateral movement of the channel.
5) Remove Levees -	The levee material and rock filling the gabions would be removed and disposed of elsewhere.
6) Remove Levees and Construct Channel with Natural Characteristics -	The levees would be removed and a channel would be physically constructed for the entire 1.5-mile reach, with dimensions and patterns similar to natural conditions and consistent with a channel in equilibrium.
7. Staged Restoration	Similar to Alt. 5, except restoration activities would take place over a number of years.

Table 10: ALTERNATIVES MATRIX;
Management Considerations

Alternative	Public Safety Hazard	Planning/ Manageme nt	Approximate Recovery Period	Annual Maintenance Costs	Meets Park Objectives	Estimated Construction Costs
1. RETAIN AND REPAIR EXISTING LEVEES	Decreased	Reactive	Never	Moderate	No	$0.3 million (replace revetments)
2. RETAIN BUT NEGLECT	Gradually Increasing	Reactive	>100 years	Moderate	No	$0.3 million (replace bridges)
3. Remove Wire only	Decreased	Reactive	>100 years	Moderate	No	NA
4. Breach levees and Construct Selected Meanders	Decreased	Reactive	>50 years	Moderate	No	NA
5. REMOVE LEVEES	Decreased	Proactive/ reactive	10-30 years	Moderate	Yes	$1 million
6. REMOVE LEVEES – CONSTRUCT CHANNEL	Decreased	Proactive	10 years	Minimal	Yes	$4 million
7. STAGED RESTORATION (New Alternative)	Decreased	Proactive/ reactive	10-30 Years	Moderate	Yes	$1.1 million

NA: These alternatives assessed but rejected, no costs were estimated.

1) Retain Levees -	The levees would be maintained for the foreseeable future. This would require repair and some replacement of gabions.
2) Benign Neglect -	Allow the gabions to deteriorate and the river to slowly remove the levees.
3) Remove Wire Only -	The wire would be removed from the gabions to hasten the river's actions and reduce hazards.
4) Breach Levees and Construct Selected Meanders -	Wire would be entirely removed, the levees physically breached in a few places and 2-4 meanders constructed outside of the levees to hasten lateral movement of the channel.
5) Remove Levees-	The levee material and rock filling the gabions would be removed and disposed of elsewhere.
6) Remove Levees and Construct Channel with Natural Characteristics -	The levees would be removed and a channel would be physically constructed for the entire 1.5-mile reach, with dimensions and patterns similar to natural conditions and consistent with a channel in equilibrium.
7. Staged Restoration	Similar to Alt. 5, except restoration activities would take place over a number of years.

SUMMARY & CONCLUSIONS

- The basic concept of restoring a more natural stream channel shape and function is sound and desirable. Whether achieved quickly or more slowly, permitting some degree of channel movement, connectivity with a floodplain will have benefits in reducing flood peaks, enhancing native fish habitat and supporting the natural recruitment if native riparian plants.

- Of the features that can be incorporated into the design of the river channel, a floodplain of adequate width and elevation relative to the bankfull channel is the most important feature that is currently absent.

- Observations and some additional tree coring made during the project confirmed the conclusions of earlier research that the woody species composition is shifting within Zion Canyon. Fremont cottonwood (Populus fremontii), once the dominant woody species, has limited recruitment and is now co-dominant along with Box elder (*Acer negundo*) and Velvet Ash (*Fraxinus velutina*).

- The mature cottonwood forest that currently exists throughout Zion Canyon is the result of unique climate, land-use, and hydrologic conditions that occurred during the turn of the 20th century and again, to a lesser degree, in the 1940 – 1960's. These conditions resulted in high sediment loads that aggraded the stream channel and caused widespread bank erosion. With a sediment laden channel and a low, broad adjacent floodplain, overbank flows were common and produced optimum conditions for widespread cottonwood regeneration across the Canyon floor. Subsequent channel deepening protected the young cottonwood forest from later stream scour.

- These "unstable" conditions led to a decision by the NPS to channelize the river and the installation of rock and wire revetments throughout the Canyon. This was an understandable response considering the frequent overbank flows, sediment deposition and channel migration occurring at the time, and that channelization was then widely considered to be the remedy of choice.

- The installation of these structures coincided with climatic conditions that deepened and stabilized the channel. The combination led to further incision, especially in the area of Zion Lodge.

- The East Fork Virgin River maintains a much more stable community of cottonwoods with few gaps in age classes. However, although this watershed is adjacent and has nearly the same drainage area, it does not serve as a reference for the North Fork. Aspect (east-west vs. north-south orientation), greater apparent sediment supply, warmer temperatures, less channel incision, lack of lakebed sediments, and smaller channel size differ markedly from the North Fork.

- Current cottonwood recruitment is limited and confined to a relatively narrow strand along the banks and floodplains of the North Fork of the Virgin River. Recruitment is most successful along those reaches that have active channel dynamics, that is some lateral

movement that produces erosion and deposition. The Big Bend Reach typifies these conditions.

- Cottonwood recruitment and other floodplain processes are severely limited in the Zion Lodge and Birch Creek reaches by the channelized nature of the stream and by a competition from other species, primarily baccharis (Baccharis emoryi). This species and a variety of cool season grass species dominate point bars and other low alluvial features leaving little bare ground for cottonwood recruitment. Restoration of cottonwood recruitment may require the active removal and/or control of these plant species.

- The absence of broad, active floodplains inundated by frequent, moderate flow events appears to be the primary missing component in the lower half of the system. Efficient sediment transport through the reveted sections limits erosional and depositional processes which is essential to provide necessary substrate for cottonwood recruitment.

- Restoring a more natural stream morphology and function will not restore the valley wide canopy of cottonwood trees that is currently dying out. These became established under a set of apparently rare circumstances early in the 20th century. Under the current climatic and hydrologic conditions, it is practical to expect cottonwood establishment as individual trees, or groups or strands of trees along floodplain margins, or abandoned channels. They will remain a visually and ecologically important component of the riparian vegetation, but will not form a near complete canopy as they did in the last century.

RECOMMENDATIONS

Future tasks that would provide important information necessary for final planning of comprehensive riparian restoration:

INCREASE KNOWLEDGE BASE OF EXISTING COTTONWOODS IN PARK

- Characterize in terms of numbers and age-class frequency the existing cottonwood recruitment and populations in the Big Bend reference reach. Correlate populations and age-classes to morphological features and flood frequencies. Use this data to identify current level of recruitment and develop a predictive model. Develop a cottonwood age and GPS locations database for park.

- Develop a Cottonwood phenology database for the Park in which date of first flowering, seed release, and measurements of seed rain density, spatial patterns of seed dispersal, spatial disparities in seed production, etc. are recorded.

- Calibrate a model (Stella Model) to help evaluate cost-benefits for various management alternatives to increase cottonwood recruitment.

- Develop an age-class frequency distribution for live and dead trees to determine age-class mortality specific rates for cottonwood. Use this information to develop life-cycle tables to predict the longevity of the extant cottonwood population, the potential public safety hazard involved, and determine the likely # of individual cottonwoods needed to regenerate a healthy age-class distribution in the park.

INCREASE KNOWLEDGE OF CHANNEL MORPHOLOGY

- Annually resurvey a set of cross-sections within the Zion Lodge and Birch Creek Reaches to monitor vertical and lateral channel movements.

- Continue longitudinal survey upstream from Grotto footbridge into Big Bend Reach to determine changes in slope and/or migrating nickpoints.

INCREASE UNDERSTANDING OF AQUATIC SPECIES NEEDS

- Initiate studies of Virgin River spinedace passage opportunities, and determine both the potential for utilization of the park by these and other sensitive species, and a framework and specific details for restoration of the Virgin River reach in the park to create/restore habitat for these species.

- Increase the number and variety of monitoring sites for native fish species within Zion Canyon in order to identify any correlation between channel geometry and fish populations. Sample sites should include each of the geomorphic reaches described in this report.

APPLIED RESEARCH/PILOT PROJECTS

- Complete a detailed literature review and a series of testable hypotheses for cottonwood regeneration to serve in the following experiments, tests, and demonstration projects.

- Further explore opportunities for enhancement of cottonwood regeneration and riparian enhancement where side tributaries empty onto elevated terrace features (above revetment reaches). Create a pilot project to test the ability to create recruitment environments along these tributaries.

- Initiate a pilot project of cottonwood pole plantings in a variety of locations outside the riparian corridor. These sites include high terraces near the existing upstream exclosures, the high terraces within the reveted sections and the areas around lodges and campgrounds. These pilot projects will help determine the practicality and feasibility of replacing the maturing forest within the valley floor.

- Initiate a pilot project to test the feasibility of replacing baccharis thickets with willows. In the meandering river sections below the lodge, remove baccharis from a point bar and lower the bar to the level of the geomorphic floodplain. Replant aggressively with *Salix exigua* pole plantings.

- Conduct experiments to reduce/contain exotic grass species (prescribed burning, removal, etc) on terraces and riparian areas. The successful containment of these species would provide additional open areas for cottonwood recruitment.

DEVELOP RESTORATION PLANS

- Development of detail engineering and ecological specifications for restoration areas where revetments will be removed, modified, and floodplain restoration areas.

- Develop integrated plans for park vegetation system restoration.

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