Virgin River

Stability Study Update

Washington County, Utah

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1 PREFACE

The Virgin River experienced a large-magnitude flood in January 2005. Several U.S. Geological Survey (USGS) gages within the vicinity of St. George Utah recorded the event as the highest natural peak flow in the gage record[1]. Within the City of St. George, UT the event resulted in flooding damage to numerous homes along the Virgin River and caused the loss of a significant volume of channel bank due to lateral channel erosion. The flood also damaged three highway bridges and several golf courses. In response to this event, Washington County, the City of Santa Clara, and the City of St. George initiated a Virgin River Master Plan study to document what occurred during the flood, to establish guidelines to manage development within the river corridors, and to prevent future flood damage. In addition to recommending specific protocols for reestablishing stream channel, floodplain and terrace features, the Master Plan evaluates potential future erosion hazards and defines a corridor within which special development practices are required.

In September 2005 JE Fuller/Hydrology & Geomorphology, Inc. (JEF) completed the *River Stability Study – Santa Clara and Virgin Rivers* (hereafter referred to as the 2005 study) which was initiated by the Washington County Water Conservancy District (WCWCD) in response to the 2005 flood. The 2005 study was a geomorphic assessment of the Virgin River from the Santa Clara River confluence downstream to the southern limits of Bloomington, UT, and a portion of the Santa Clara River. The objectives of the 2005 study were to compare the magnitude of channel change that occurred during the 2005 with historical channel change, evaluate the potential causes of channel change, identify areas of channel aggradation and degradation, and update the erosion hazard zone. Following the completion of the 2005 study, the WCWCD initiated an additional study for the Virgin River extending from the Santa Clara River confluence upstream to the Washington Fields diversion. The additional study, represented by this report, is essentially a continuation of the 2005 study. Although the documents are independent, their analyses and results apply to the Virgin River throughout the entire reach (Bloomington to Washing Fields diversion). The 2005 study report is included in this document as Appendix E. The erosion hazard zone delineations from the 2005 study are included with the erosion hazard zone delineations for this study and are shown in entirety in Appendix B.

2 INTRODUCTION

2.1 Purpose

The *Virgin River Stability Study Update* portion of the Master Plan consisted of a geomorphic evaluation of the Virgin River from the confluence of the Santa Clara River to the Washington Fields Diversion dam. This report is intended to serve as an update to the *River Stability Study: Virgin River, Santa Clara River, and Ft. Pierce Wash* (CH2M Hill et. al, 1997) study described in Section 2.2.1 The objectives of the update study were the following:

- Extend the erosion hazard delineations from the 1997 study to the Washington Fields Diversion.
- Quantify areas of sedimentation caused by the 2005 flood.

[1] Gage # 09408150 near Hurricane, UT (39 years of record), Gage # 09413200 near Bloomington, UT (27 years of record), and Gage # 09413500 near St. George, UT (21 years of record).

- Quantify long-term sedimentation trends based on historical information.
- Evaluate the effect of tamarisk growth on the floodplain.

The *Virgin River Stability Study Update* extends from the Santa Clara River confluence to the Washington Fields Diversion, approximately 12 river miles (Figure 1).

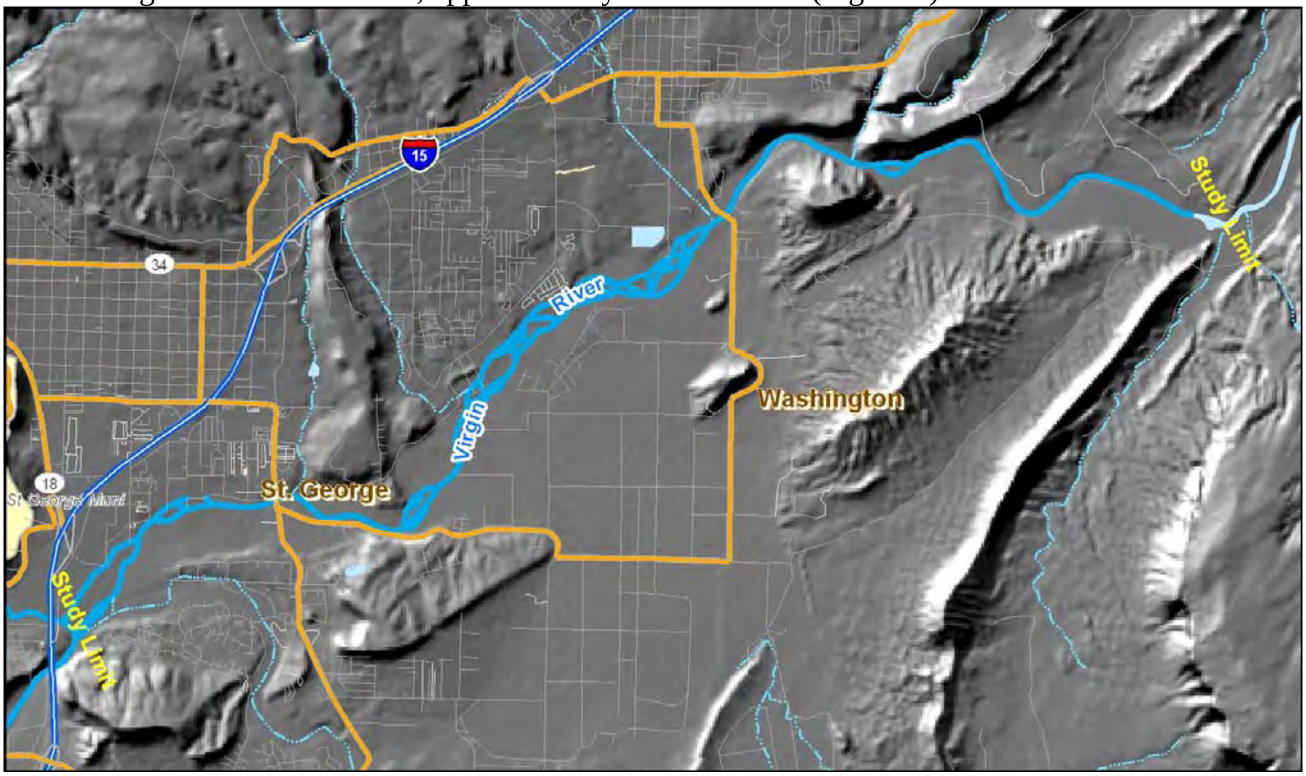

Figure 1. Vicinity map

2.2 Previous Studies

2.2.1 CH2M Hill 1997 Study

In 1996, the City of St.George completed a river stability study addressing the erosion hazards along the Virgin River, Santa Clara River, and Ft. Pierce Wash. Prior to 1996, the City managed development along river corridors using the 1986 Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) maps. City staff recognized that the flood inundation hazards shown on the FEMA maps reflected the river geometry in 1986 and did not address potential lateral erosion hazards. To address these issues, the City initiated the *River Stability Study: Virgin River, Santa Clara River, and Ft. Pierce Wash* (CH2M Hill et. al, 1997) (hereafter referred to as the "1997 study"). The 1997 study was a comprehensive evaluation of historical, climatic, hydrologic, anthropogenic, and geomorphic information compiled and analyzed to provide an overall summary of the erosion hazard potential for each of the three watercourses. Below are portions of the Conclusion section from the 1997 study for the Virgin River:

> *…Since prehistoric times, the Virgin River's perennial flow and fertile floodplains have supported an agricultural economy. However, the variability and volatility of runoff as well as the erosive nature of the river have created problems for the local residents as long as the area has been inhabited.*

- *Archaeological, soils, and geomorphic information indicate that the Virgin River has been subject to large, erosive floods for at least the past 1,000 years. These erosive floods have caused the active channel to frequently shift location within its geologic floodplain. Numerous floods much larger than the largest floods experienced in the historical period have occurred in the past 1,000 years.*
- *The period of extensive flooding that occurred after the Virgin River Valley was first settled in the 1850s was concurrent with a period of extensive channel erosion that deepened by up to 15 feet and significantly widened the river.*
- *The appearance and character of the Virgin River was substantially changed during the historical period. The first pioneers (ca. 1860) described a narrower river, with grassy banks and lined by tall trees and swampy grassland. The river seen in the earliest photographs (ca. 1900) is wide and braided with a barren, active floodplain and vertical cut banks.*
- *Lateral channel movement and/or bank erosion of 800 to 2,000 feet was not uncommon on the Virgin River during the 7- to 14-year periods between the dates of the historical aerial photographs. It is likely that most of the lateral erosion and channel migration occurred during floods, when erosive powers were significantly increased.*
- *The Virgin River has degraded by up to 10 to 15 feet within the study reach in the past 140 years, but may now experience alternating periods of scour and fill. Historical channel deepening created unstable vertical cut banks throughout the study reach.*
- *During the past 35 years, the main channel of the Virgin River has become narrower and deeper, and the active floodplain has become densely vegetated with brushy plants such as tamarisk and willow. The existing channel pattern is less braided and more sinuous, with wide irregular point bars and coarse bed sediments.*
- *In general, structures built in the floodplain have not been adequately designed. Most of them have been destroyed by channel erosion and/or scour. Bedrock appears to have been the only effective and permanent barrier to erosion.*
- *The bank stability criteria considered indicate that the hazard of bank erosion and lateral channel movement is extreme. None of the criteria considered indicate that the banks are stable. Permissible velocity criteria are exceeded, indicating that the banks of the study reach will erode during even moderate flooding.*
- *There are no adequate grade control structures in the study reach that will prevent long-term degradation, except for the reach immediately adjacent to the turf farm diversion dam.*
- *Tamarisk and willow growth in the floodplain has not altered the ability of the Virgin River to erode its banks, although it may have contributed to an overall narrowing of the active channel.* *(CH2MHill et. al, 1997).*

The analysis results, conclusions, and recommendations from the 1997 study formed the foundation for the analyses and results presented herein, which effectively represent an update to the 1997 study.

2.2.2 River Stability Study – Santa Clara River and Virgin River (2005 Study)

Following the 2005 flood the Washington County Water Conservancy District, the City of St. George, and the City of Santa Clara prepared an interagency agreement and initiated a Master Plan study. One component of the Master Plan was the *River Stability Study – Santa Clara River and*

Virgin River (JEF, 2005) developed to evaluate the geomorphic response of the Santa Clara and Virgin Rivers to the flood, specifically:

- Compare the magnitude of channel change from the 2005 flood with historical (1870-2004) channel changes.
- Evaluate and identify potential causes of channel change.
- Quantify the changes in channel width/lateral migration.
- Identify areas of channel aggradation and/or degradation.
- Quantify changes in river sinuosity.
- Identify geologically young surfaces susceptible to potential erosion hazards.
- Evaluate and update the erosion hazard zone limits (CH2MHill et. al, 1997) to reflect lessons learned from the 2005 flood.

The *River Stability Study* included the Santa Clara River from the Virgin River confluence to upstream of the City of Santa Clara. It also included the Virgin River from the southern limits of Bloomington to the Santa Clara River confluence. The following recommendations were derived from the study:

- *Adopt the recommended erosion hazard zone delineations for floodplain management and regulation purposes. Proposed development within the erosion hazard zone should be allowed only if it is protected from erosion by structural measures and can be shown to have no adverse impact on adjacent properties.*

- *Amend existing flood control ordinances and policies to include river management policies that support preservation of the natural river systems, promote land uses that are compatible with a natural river system, and limit construction of structural improvements inside the erosion hazard zone, except to protect existing structures needed of public safety such as bridges and existing buildings, or where the channel threatens to move outside of the established erosion hazard corridor.*

- *Regulate all development within the erosion hazard zones by requiring a special use permit that meets the following:*
  - *Meet NFIP requirements for development within a floodway or floodplain.*
  - *Provide and engineering and geomorphic study prepared by a professional engineer licensed to practice in the State of Utah certifying that the proposed development will not be affected by erosion over a 100-year planning period.*
  - *Demonstrate that proposed bank stabilization, if any, will not adversely impact adjacent property.*
  - *Demonstrate the stability of proposed bank stabilization. Local scour, long-term degradation, channel movement, and bank erosion shall be explicitly addressed in the proposed bank protection design.*
  - *Hold the City harmless from any and all claims resulting from erosion or any other flood related damage to development within the erosion hazard corridor.*
  - *Provide for perpetual maintenance of the bank stabilization that protects private property at no cost to the City or any other public agency.*
  - *Obtain necessary floodplain, wetlands (404), water quality (401), and stream alteration permits or approvals for any construction activities at no cost to the City.*

- *Add additional bank protection structures in areas of discontinuous NRCS dikes. Areas located within the breaks in the current NRCS dikes are potentially subject to a greater erosion hazard.*

- *Development of a river management plan for the low-flow channel corridor from the Hilton Drive Bridge downstream to the I-15 Bridge. The plan should include vegetation management within the low-flow channel corridor to allow sufficient flood conveyance. The plan should also include monitoring of lateral erosion of the channel banks and intervention measures if such erosion occurs.*

- *Require that any development adjacent to the NRCS structures be required to adhere to specific guidelines in analysis and design to comply with the Master Plan.*

The *Virgin River Master Plan* is essentially an extension of the original Master Plan to include the Virgin River upstream of the Santa Clara River confluence.

2.3 2005 Flood Impacts

The January 2005 flood contained the largest natural peak flood within the gage record at many sites along the Virgin River. At USGS gage # 09413200 located near Bloomington, Utah the peak discharge estimate for the 2005 flood was 19,600 cfs. Prior to the 2005 flood, the largest natural event in the 27-year record of the gage was 17,000 cfs in 1978. The largest event (unnatural) in the gage record was the 1989 Quail Creek Dam failure which resulted in a discharge estimate of 60,000 cfs at the Bloomington gage. Figure 2 is a plot of USGS peak discharge estimates for the Bloomington gage.

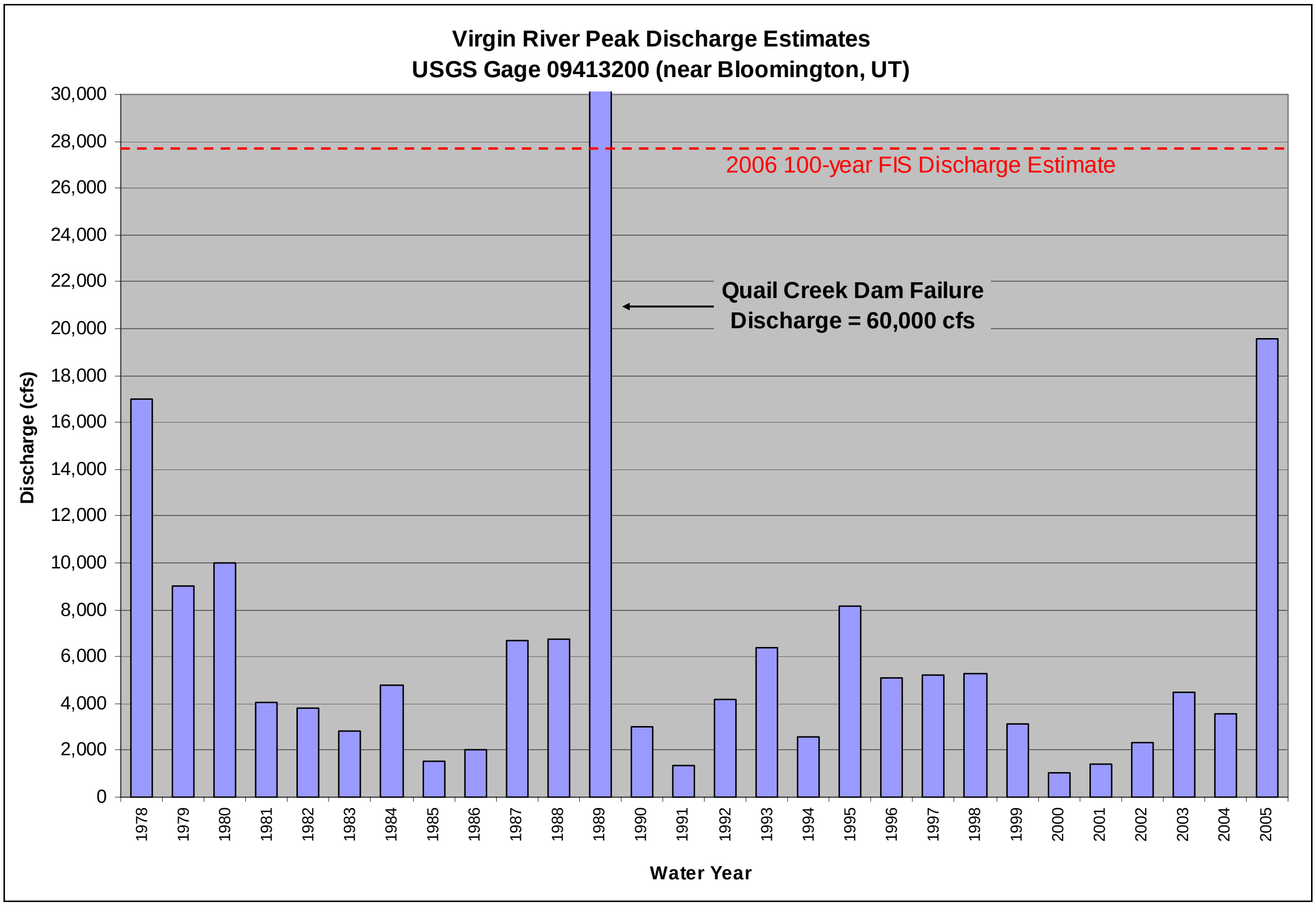

Figure 2. Peak discharge estimates at USGS gage 09413200 near Bloomington, Utah

Following the 2005 flood, a re-evaluation of the regulatory one percent recurrence interval discharge estimate was conducted. The result of the analysis was a 100-year peak discharge estimate of 27,500 cfs. Prior to the 2005 flood, the FEMA regulatory 100-year estimate near the Bloomington gage site was 33,000 cfs[2].

Following the Quail Creek Dam flood, a paleoflood study of the Virgin River (Enzel et al., 1993) was conducted to determine the flood's historical context within the geologic record. The study concluded that within the past 1,000 years, multiple natural floods within the Virgin River gorge have equaled or exceeded the magnitude of the 1989 Quail Creek Dam event. Flood frequency analysis results of the study concluded that the 1989 flood had a 250-year recurrence interval, and that the 100-year flood estimate (combining paleoflood data with the gage record) was equal to 45,555 cfs. These results suggest that the present 100-year estimate of 27,500 cfs may be too low.

The 2005 flood was not as devastating on the Virgin River as it was on the Santa Clara River, however significant changes to the active channel corridor and floodplain did occur.

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[2] Rollins, Brown & Gunnell FIS study (1981)

2.3.1 Tamarisk Impacts

The presence of dense, deeply rooted channel bank vegetation can enhance bank stability and reduce rates of lateral erosion. Root material binds soil material and can increase resistance to stream erosion. Vegetative litter produces a mat that can reduce the degree of water to soil contact. Plant stems, branches, and leaves increase roughness, resulting in decreased flow velocities, all of which can contribute to reduced lateral erosion potential. Vegetation characteristics generally vary by geomorphic surface, soil substrate, water availability, frequency of flood inundation, and human influence.

The vegetation variability along the Virgin River active channel within the study reach was relatively low. Both the active channel and floodplain vegetation were dominated by tamarisk of varying maturity and density. As with many watercourses in the western United States, tamarisk has become the dominant plant species and influences geomorphic behavior and channel stability of the Virgin River. Tamarisk was thought to have first been introduced into the United States by nurserymen in the early 1800s and used as a landscape ornamental, wind barrier, and for stabilization of channel banks (Robinson, 1965). Where tamarisk has invaded watercourses within the southwest United States it has generally been characterized as fast growing and rapidly encroaching on channel floodplains. The high density growth patterns often result in sedimentation and aggradation of floodplains. Additionally, it often competes with and replaces lower density, native vegetation. Encroachment of dense vegetation such as tamarisk can influence channel behavior (Graf, 1978; Kunzmann et al., 1987, and others). For example, during the low-flow years of 2000-2004 (see Figure 2), tamarisk encroached on the Virgin River active channel within the study reach resulting in an overly-narrow conveyance corridor. This corridor was insufficient to convey the discharge from the 2005 flood resulting in channel widening, floodplain sediment deposition, and lateral erosion of channel banks.

A significant amount of bank and floodplain vegetation was lost during the 2005 flood as a result of channel widening and overbank flows. Although pre-flood aerial photography indicated dense bank vegetation throughout much of the study reach, this vegetation appeared to provide moderate to no protection from lateral erosion. This was likely due to highly erosive flow velocities confined to the narrow conveyance corridor which resulted in scour below the tamarisk rooting layer. The encroachment of vegetation on the low-flow channel was likely caused by persistent years of drought, combined with a lower frequency of moderate to large flood events. The result was a narrow channel that was densely vegetated along both the banks and the floodplain. The active channel width in 2004 was narrower than any other time in the period of record, a direct result of repeated low-flow years and tamarisk encroachment.

The 2005 flood demonstrated that when a large-magnitude, low frequency flood occurs during this condition, the narrow channel is insufficient to convey the flow, thus must create a wider conveyance corridor. This process removes bank vegetation and creates vertical, unstable cutbanks. These processes occurred during the 2005 flood. The plot of USGS peak flow values shown in Figure 2 indicates a series of low-flow years from 2000 to 2004. This resulted in a narrow, over-grown channel insufficient for conveying a discharge of 19,600 cfs (peak 2005 flood). Figure 3 shows typical examples of pre- and post-flood channel and bank vegetation conditions within the study reach. The presence of tamarisk generally does not prevent lateral erosion, and may actually result in higher susceptibility of erosion during some types of channel avulsions.

Figure 3. Examples of changes in floodplain vegetation from the 2005 flood

3 GEOMORPHIC EVALUATION

3.1 Data Collection

Historical data including aerial photographs and maps collected for the 1997 study were re-assembled for the present study. Additional data collected for the present study included more recent, post 1997 aerial photography, digital soils mapping, geologic mapping, digital topographic mapping, and other miscellaneous spatial data.

3.1.1 Topographic Data

Digital topography was collected for the geomorphic assessment. The historical topography was the primary source of data for the aggradation assessment (Section 5). Table 1 lists the topography collected.

Table 1. Digital mapping data sources

Data Year	Source	Data Type	Resolution	Vertical Datum	Comment
1993	USGS NAPP DEM	DEM	10 meter	NGVD29	NAVD88 conversion factor of 2.7 applied
1999	City of St. George	DTM	1:2,400	NAVD88	
2003	City of St. George	DTM	1:2,400	NAVD88	Update of 1999 DTM
2006	City of St. George	DTM	1:2,400	NAVD88	Update of 2003 DTM

3.1.2 Aerial Photography

Aerial photography spanning much of the 20th Century served as a foundation of the historical analysis. Table 2 lists the series of photographs collected. A historical aerial photography comparison exhibit book is attached in Appendix D (separate volume).

Table 2. Historical aerial photos

Photo Year	Source	Description
1938	NRCS	Black & white, stereo
1952	USDA	Black & white, stereo
1960	USDA	Black & white, stereo
1967	USDA	Black & white, stereo
1976	USDA	Black & white, stereo
1977	USDA	Black & white, stereo
1984	UDSA	Black & white, stereo
1993	USDA	Black & white, stereo
1994	City of St.George	Black & white, stereo
1995	USDA	Black & white, stereo
1999	City of St.George	Black & white, orthophotography
2003	City of St.George	Color, digital orthophotography
2004	State of Utah, SGID	Color, digital orthophotography
2005	City of St.George	Color, digital orthophotography
2006	City of St.George	Color, digital orthophotography

3.1.3 Geology

Understanding the regional geology of a river valley is fundamental to predicting the types and magnitude of channel processes. Identification of geologic units and their extent within the study reach provides valuable information on where the river has been in the past and, more importantly, the relative time frame of channel movement. To date, the Utah Geological Survey (UTGS) has completed a series of geologic maps covering the study reach. The UTGS map information was compiled and analyzed for this study. Geologically old surfaces that experienced significant erosion or inundation during the 2005 flood suggest that it was a low frequency event. In contrast, if impacts were constrained within geologically young surfaces, it suggests that the 2005 flood had a more frequent return period. The 2005 flood was generally constrained within the younger geologic surfaces. Additional information derived from analysis of the geologic mapping included:

- Areas of geologic control on lateral river movement.
- Limits of active river processes within recent geologic time.

Table 3 lists the UTGS geologic maps used in this study.

Table 3. UTGS geologic maps

UTGS Map	Author	Year	Scale
Interim geologic Map of the St. George Quadrangle, Washington County, Utah	J.M. Higgins and G.C. Willis	1995	1:24,000
Interim geologic map of the Washington Quadrangle, Washington County, Utah	G.C. Willis and J.M. Higgins	1995	1:24,000
Geologic map of the 7.5' Harrisburg Junction Quadrangle, Washington County, Utah	R.F. Biek	2003	1:24,000
Geologic Map of the Washington Dome Quadrangle, Washington County, Utah	J.M. Hayden	2005	1:24,000

Analysis of the study reach indicated the Virgin River has been constrained within the Holocene floodplain throughout the historical record. Table 4 lists the geologic units generally within the Holocene floodplain.

Table 4. UTGS surficial geology

Map Unit ID	Name	Age	Description
Qal_1, Qal_2	Alluvial stream deposits	Quaternary	Moderately to well-sorted clay to gravel deposits in and adjacent to active drainages
$Qat_{3\text{-}5}$	Stream-terrace deposits	Quaternary	Gravel to cobble clasts in muddy to coarse sand matrix forming indurated pedogenic carbonate-cemented conglomerate. Level 3 deposits are 40'-90' above active drainage, level 4 are 90'-140', level 5 are 140'-190'.
Qao	Older alluvial deposits	Quaternary	Remnants of older, locally derived alluvial deposits.
Qap	Pediment-mantle deposits	Quaternary	Poorly sorted, sub-angular to rounded clasts that range in size from gravel to small boulders.
Qaow	Older alluvial deposits near Washington	Quaternary	Poorly to moderately well-sorted clay to small boulder-sized deposits that cap an older surface in the NE part of the quadrangle.
Qe	Eolian sand	Quaternary	Well to very well sorted fine to very fine quartz sand.

3.1.4 Soils

Analysis of soil data can provide information about the evolution and future behavior of river systems. Soil Conservation Service (SCS)[3] soil data (Mortensen et. al, 1977) were collected and analyzed for this study. Like geologic data, soils data can provide valuable information regarding old and young geomorphic surfaces, in addition to information about the relative frequency of flood inundation and lateral erosion. Soils described by the SCS are often grouped into Soil Associations for regional context. A Soil Association is a landscape that has a distinctive proportional pattern of soils and normally consists of one or more major soils and at least one minor soil. Seven soil associations were identified within the study reach as shown in Figure 4. A general description of each soil association is listed in Table 5, in addition to the landform interpretation made for this study to facilitate the use of soils mapping for assessing river stability and to estimate potential lateral erosion.

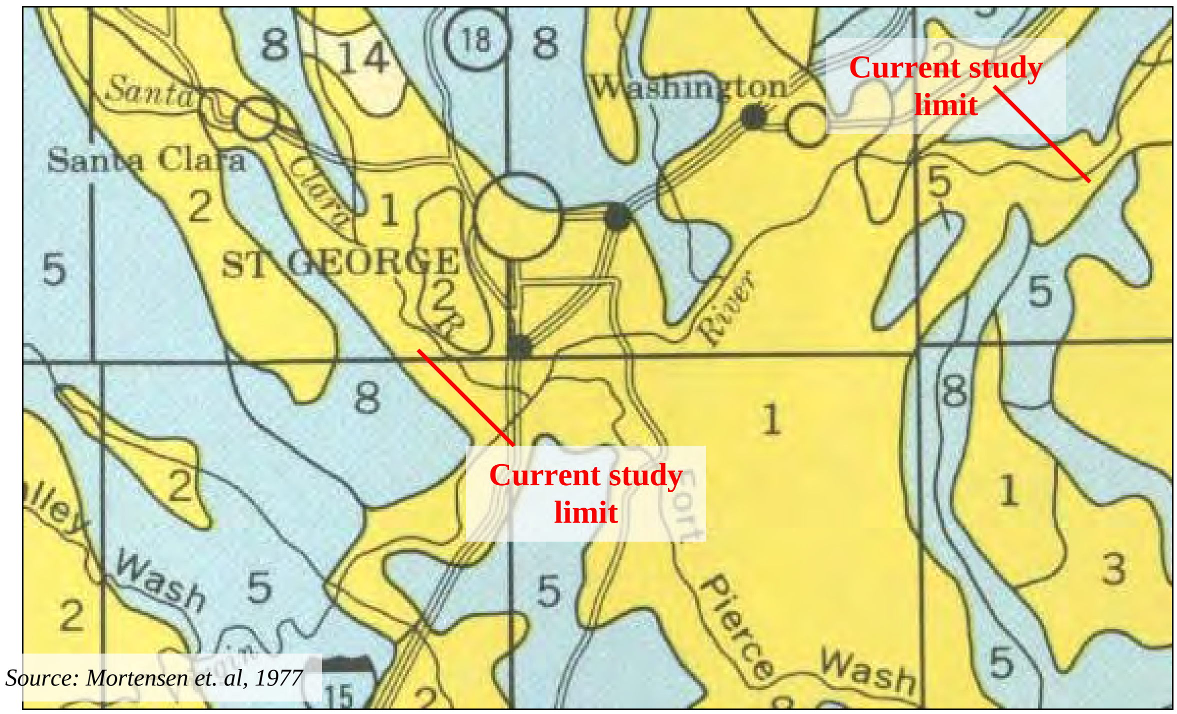


Figure 4. SCS General Soils Map

[3] The SCS was renamed the Natural Resources Conservation Service (NRCS).

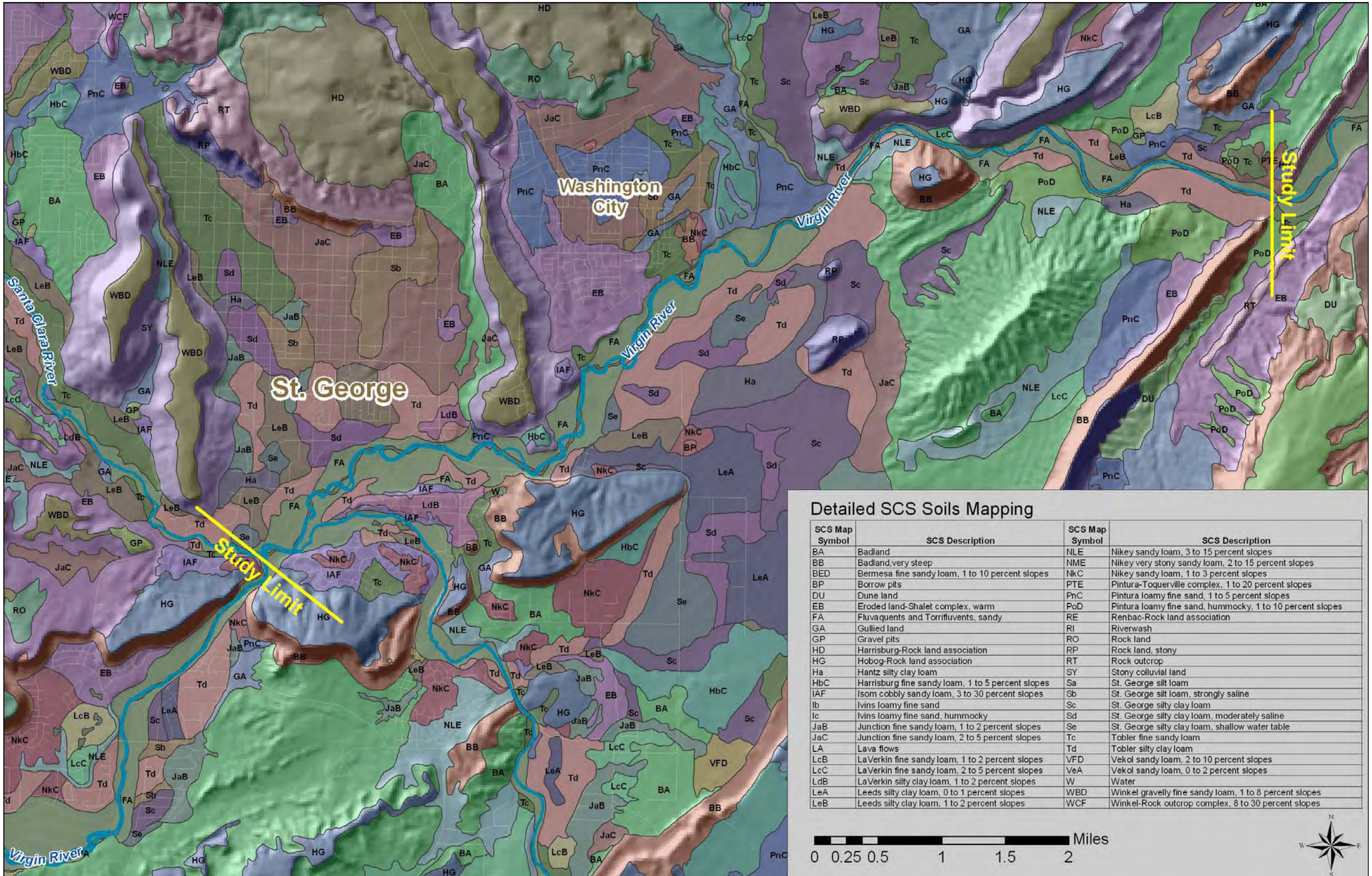
Table 5. SCS Soil Association Descriptions			
Unit ID	SCS Soil Association	Description	Landform Interpretation
1	Tobler-Harrisburg-Junction	Well-drained, nearly level to moderately steep, moderately deep and deep fine sandy loams and silty clay loams.	Active channels and floodplains
2	Winkel-Rock land	Well-drained, gently sloping to steep, shallow gravelly fine sandy loams and Rock land.	Piedmonts and bedrock
3	Pintura-Toquerville-Dune land	Somewhat excessively drained, gently sloping to moderately steep, shallow to deep loamy fine sands and fine sands and Dune land.	Mountain slopes and piedmonts
5	Badland-Eroded land	Rolling to very steep Badland and Eroded land. Active erosion with rapid runoff and high sediment loads.	Piedmonts and mountain slopes
8	Rock outcrop-Rock land	Exposed bedrock.	Bedrock
14	Collbran-Tacan-Nehar	Well-drained, gently sloping to very steep, deep very cobbly clay loams and very stony sandy loams.	Piedmonts

The primary use of the SCS soils mapping was to identify geomorphic surfaces (based on their soil characteristics) that have been subject to active fluvial processes (flood inundation and lateral erosion) in recent geologic time, thus at risk for future lateral erosion. The Tobler-Harrisburg-Junction Association represents the active channel and floodplain corridor of the Virgin River. The Winkel-Rock land and Pintura-Toquerville-Dune land soils comprise the transition from riverine processes to piedmont/ slope processes. The remaining soils represent upper piedmont and hillslope processes and exposed bedrock.

Each SCS soil association is comprised of multiple soil units, mapped and described in detail in Mortensen et. al, 1977. Table 6 lists each SCS soil identified within the study reach and its SCS description. Figure 5 shows the detailed SCS soils mapping. Based on our interpretations of the SCS descriptions, a landform type was assigned to each soil. These landform categories were then combined and mapped to illustrate their geomorphic relationships within the study reach. Figure 6 is a detailed SCS soils map showing the landform interpretations.

Table 6. SCS Detailed Mapped Soils Units		
SCS Soil Symbol	SCS Soil Description	Landform Interpretation
BA	Badland	Hills
BB	Badland,very steep	Hills
BED	Bermesa fine sandy loam, 1 to 10 percent slopes	Lava Flows
BP	Borrow pits	Borrow Pit
DU	Dune land	Eolian dunes
EB	Eroded land-Shalet complex, warm	Erosion Remnants
FA	Fluvaquents and Torrifluvents, sandy	Floodplain
GA	Gullied land	Gullied land
GP	Gravel pits	Gravel Pit
HD	Harrisburg-Rock land association	Mesas

Table 6 cont.		
SCS Soil Symbol	SCS Soil Description	Landform Interpretation
HG	Hobog-Rock land association	Mesas
Ha	Hantz silty clay loam	Alluvial Fans
HbC	Harrisburg fine sandy loam, 1 to 5 percent slopes	Mesas
IAF	Isom cobbly sandy loam, 3 to 30 percent slopes	Alluvial Fans
Ib	Ivins loamy fine sand	Terraces
Ic	Ivins loamy fine sand, hummocky	Terraces
JaB	Junction fine sandy loam, 1 to 2 percent slopes	Alluvial Fans
JaC	Junction fine sandy loam, 2 to 5 percent slopes	Hills
LA	Lava flows	Lava Flows
LcB	LaVerkin fine sandy loam, 1 to 2 percent slopes	Floodplain
LcC	LaVerkin fine sandy loam, 2 to 5 percent slopes	Stream Terraces
LdB	LaVerkin silty clay loam, 1 to 2 percent slopes	Stream Terraces
LeA	Leeds silty clay loam, 0 to 1 percent slopes	Alluvial Flats
LeB	Leeds silty clay loam, 1 to 2 percent slopes	Floodplain
NLE	Nikey sandy loam, 3 to 15 percent slopes	Alluvial Fans
NME	Nikey very stony sandy loam, 2 to 15 percent slopes	Hills
NkC	Nikey sandy loam, 1 to 3 percent slopes	Alluvial Fans
PTE	Pintura-Toquerville complex, 1 to 20 percent slopes	Mountain Slopes
PnC	Pintura loamy fine sand, 1 to 5 percent slopes	Mountain Slopes
PoD	Pintura loamy fine sand, hummocky, 1 to 10 percent slopes	Mountain Slopes
RE	Renbac-Rock land association	Mountain Slopes
RI	Riverwash	Floodplain
RO	Rock land	Mountain Slopes
RP	Rock land, stony	Mountain Slopes
RT	Rock outcrop	Bedrock
SY	Stony colluvial land	Colluvium
Sa	St. George silt loam	Floodplain
Sb	St. George silt loam, strongly saline	Alluvial Fans
Sc	St. George silty clay loam	Floodplain
Sd	St. George silty clay loam, moderately saline	Floodplain
Se	St. George silty clay loam, shallow water table	Floodplain
Tc	Tobler fine sandy loam	Hills
Td	Tobler silty clay loam	Floodplain
VFD	Vekol sandy loam, 2 to 10 percent slopes	Alluvial Fans
VeA	Vekol sandy loam, 0 to 2 percent slopes	Valley Floors
W	Water	Water
WBD	Winkel gravelly fine sandy loam, 1 to 8 percent slopes	Mesas
WCF	Winkel-Rock outcrop complex, 8 to 30 percent slopes	Mesas



SCS Map Symbol	SCS Description	SCS Map Symbol	SCS Description
BA	Badland	NLE	Nikey sandy loam, 3 to 15 percent slopes
BB	Badland,very steep	NME	Nikey very stony sandy loam, 2 to 15 percent slopes
BED	Bermesa fine sandy loam, 1 to 10 percent slopes	NkC	Nikey sandy loam, 1 to 3 percent slopes
BP	Borrow pits	PTE	Pintura-Toquerville complex, 1 to 20 percent slopes
DU	Dune land	PnC	Pintura loamy fine sand, 1 to 5 percent slopes
EB	Eroded land-Shalet complex, warm	PoD	Pintura loamy fine sand, hummocky, 1 to 10 percent slopes
FA	Fluvaquents and Torrifluvents, sandy	RE	Renbac-Rock land association
GA	Gullied land	RI	Riverwash
GP	Gravel pits	RO	Rock land
HD	Harrisburg-Rock land association	RP	Rock land, stony
HG	Hobog-Rock land association	RT	Rock outcrop
Ha	Hantz silty clay loam	SY	Stony colluvial land
HbC	Harrisburg fine sandy loam, 1 to 5 percent slopes	Sa	St. George silt loam
IAF	Isom cobbly sandy loam, 3 to 30 percent slopes	Sb	St. George silt loam, strongly saline
Ib	Ivins loamy fine sand	Sc	St. George silty clay loam
Ic	Ivins loamy fine sand, hummocky	Sd	St. George silty clay loam, moderately saline
JaB	Junction fine sandy loam, 1 to 2 percent slopes	Se	St. George silty clay loam, shallow water table
JaC	Junction fine sandy loam, 2 to 5 percent slopes	Tc	Tobler fine sandy loam
LA	Lava flows	Td	Tobler silty clay loam
LcB	LaVerkin fine sandy loam, 1 to 2 percent slopes	VFD	Vekol sandy loam, 2 to 10 percent slopes
LcC	LaVerkin fine sandy loam, 2 to 5 percent slopes	VeA	Vekol sandy loam, 0 to 2 percent slopes
LdB	LaVerkin silty clay loam, 1 to 2 percent slopes	W	Water
LeA	Leeds silty clay loam, 0 to 1 percent slopes	WBD	Winkel gravelly fine sandy loam, 1 to 8 percent slopes
LeB	Leeds silty clay loam, 1 to 2 percent slopes	WCF	Winkel-Rock outcrop complex, 8 to 30 percent slopes

Figure 5. Detailed SCS Soils Mapping

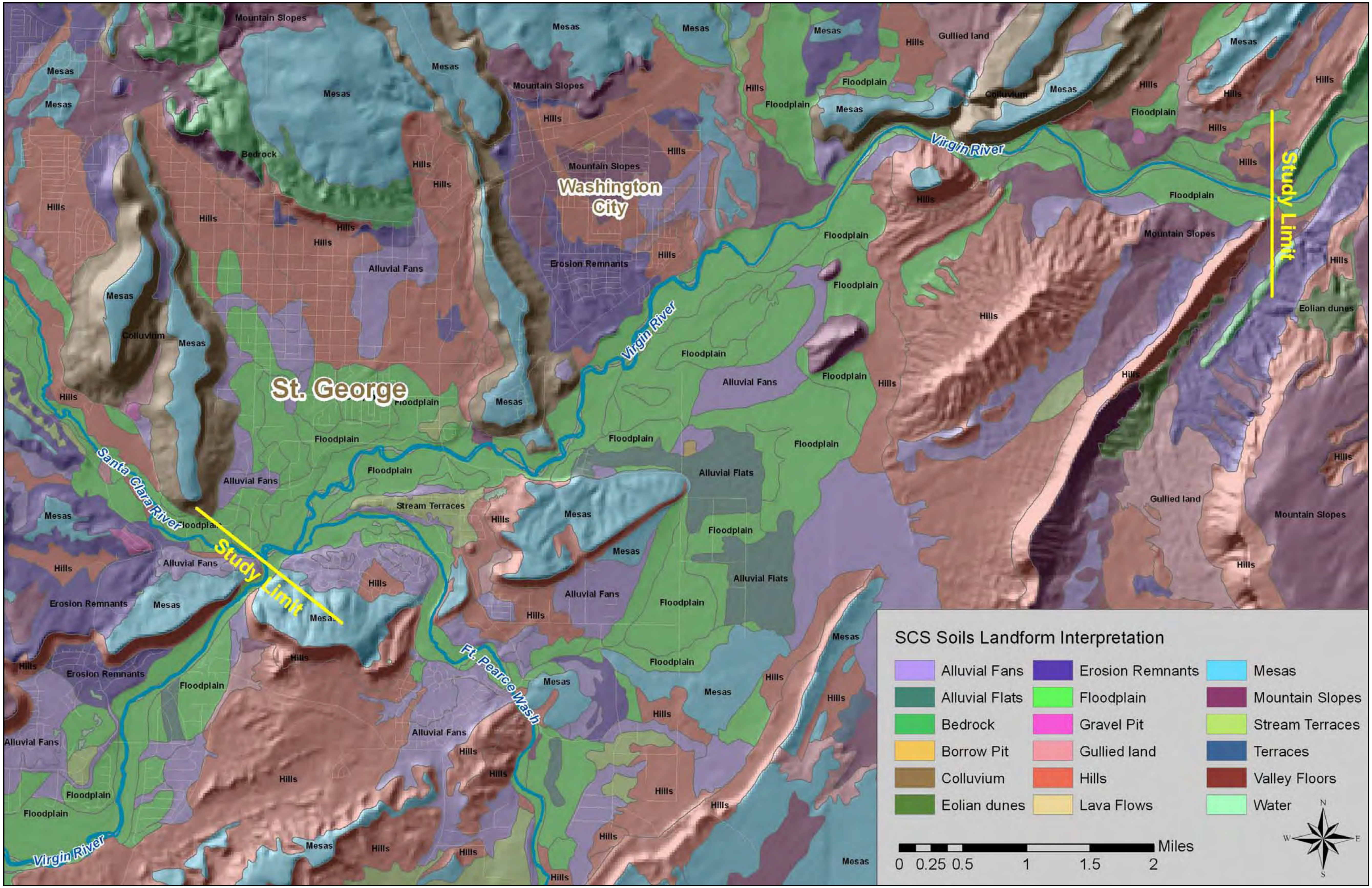


Figure 6. SCS Soils Mapping with Landform Interpretation

4 DETAILED FIELD INVESTIGATION

A detailed field visit to the study reach was conducted over a three-day period from August 30 through September 1, 2006[4]. JEF staff walked the entire study reach of the Virgin River photographing and mapping key features and general post-flood channel conditions. Every effort was made to observe and record the changes to the channel and floodplain caused by the 2005 flood. Additionally, bridges and other significant structures including NRCS levees and bank protection located within the river corridor were visited and documented. Field photos taken during the August/September field visit are presented throughout this report. Each photo is labeled with a Photo ID which can be referenced to the field photo location exhibits in Appendix A.

4.1 Types of Data Collected

Below is the list and description of observed physical characteristics of the Virgin River from the 1997 study. For comparison purposes, the same characteristics were identified for this stability study update. Following each 1997 description are photographs of the characteristic taken during the 2006 field visit to illustrate the continuing evidence of lateral instability of the Virgin River.

<u>Failed/failing rip-rap bank protection</u>. Riprap bank protection has been placed in several locations along the study reach, and is beginning to fail upstream of River Road along 1450 South and near the Interstate 15 bridges.

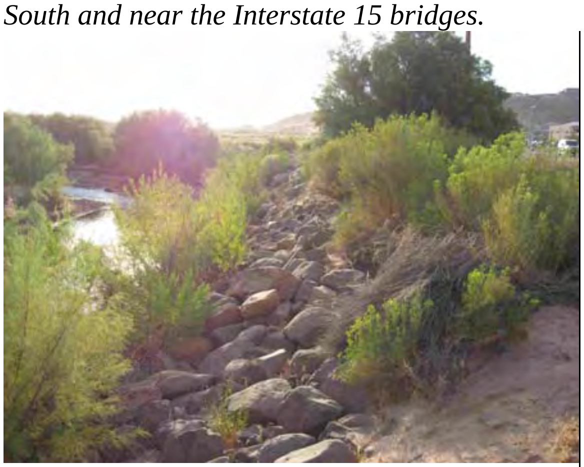


Photo ID: 8-31-2006-64
Bank protection along River Road near 1450 South

Photo ID: 8-31-2006-67
Newly placed bank protection along River Road near 1450 South

[4] Several additional regional field visits were conducted between January 2005 and February 2007.

Vertical cut banks. Vertical cut banks were the dominant bank condition observed throughout the study reach. Vertical cut banks are indicative of rapid lateral channel movement, long-term scour, and unstable channels.

Photo ID: 8-31-2006-207

Photo ID: 8-31-2006-80

Photo ID: 8-31-2006-110

Photo ID: 8-31-2006-180

Undercut banks. Undercut banks were observed where tamarisk or other brushy vegetation was growing in dense thickets above vertical banks. The root network of the vegetation provides a limited degree of stability to the tops of the sandy bank soils and temporarily prevents its collapse. Undercut banks are indicative of rapid lateral channel movement and unstable channels.

Photo ID: 8-30-2006-60

Photo ID: 8-30-2006-56

<u>Tipped bank vegetation</u>. Tipped bank vegetation is indicative of lateral erosion undercutting the banks, and was observed in numerous places throughout the study reach.

Photo ID: 8-30-2006-17

Photo ID: 9-1-2006-240

<u>Perched bank vegetation</u>. In general, where bank vegetation was present, it was perched above vertical or very steep banks. Vegetation becomes perched after long-term scours lower the bed elevation or when lateral channel movement erodes into elevated floodplain terraces. Because the vegetation is perched above the bankfull water surface elevation, its root mass and canopy do not protect the bank from the hydraulic forces that cause bank erosion.

Photo ID: 9-1-2006-233

Photo ID: 8-31-2006-137

<u>Stratified bank sediment</u>. In general, the channel banks in the study reach are composed of stratified sand and gravel alluvium. Stratified bank sediments are generally less resistant to erosion than banks composed of uniform fine-grained sediments.

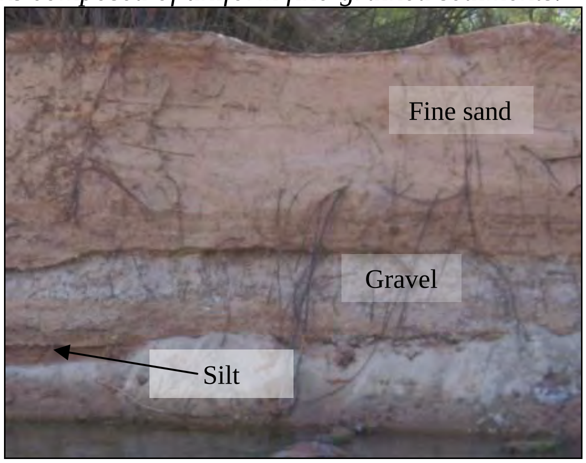


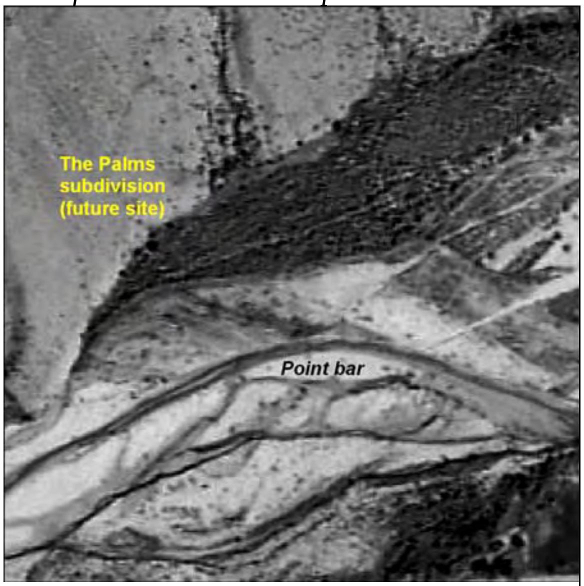
Photo ID: 8-30-2006-60

<u>Coarse bed sediments</u>. Bed sediment much larger than the normal bed load of the river forms small riffles and gravel bars throughout the study reach. Coarsening of bed sediment is indicative of long-term scour and incipient channel armoring.

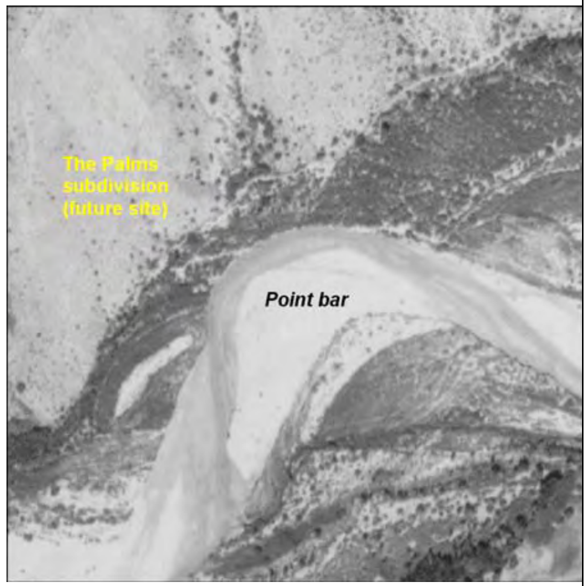
Photo ID: 8-31-2006-124
Normal bed sediments

Photo ID: 9-1-2006-258
Coarse bed sediments

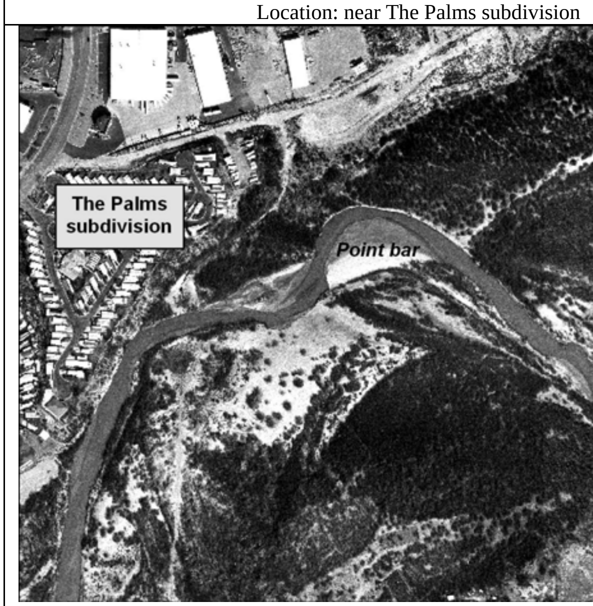
<u>Wide point bars</u>. Wide point bars are found along most channel bends in the study reach. Wide point bars usually indicate rapid lateral channel movement and high bed load transport. Wide point bars form where bank erosion rates exceed the rate of re-vegetation by floodplain species. Given that the dominant form of floodplain vegetation is tamarisk, a very fast-growing plant, the rate of lateral erosion is rapid.



Aerial photo year: 1952
Location: near The Palms subdivision



Aerial photo year: 1967
Location: near The Palms subdivision



Aerial photo year: 1994
Location: near The Palms subdivision

Aerial photo year: 2005
Location: near The Palms subdivision

<u>Tamarisk growth</u>. Most of the active floodplain terraces and some of the medium height bars are densely vegetated with tamarisk that range in height from several feet (on topographically lower surfaces) to tens of feet (on older surfaces). Very few large deciduous trees such as cottonwood, ash, or willow were observed except where planted near homes. The tamarisk observed above vertical cut banks did not appear to provide any significant protection from bank erosion. The tamarisk on the floodplain terraces appeared to have survived recent flood inundation without substantial damage.

Aerial photo year: 2004 (pre-flood)
Location: near Industrial Drive and 100 E.

Aerial photo year: 2005 (post-flood) – loss of floodplain tamarisk
Location: near Industrial Drive and 100 E.

Aerial photo year: 2004 (pre-flood)
Location: near Sunrise Valley Bridge

Aerial photo year: 2005 (post-flood) – loss of floodplain tamarisk
Location: Sunrise Valley Bridge

<u>Hanging tributaries.</u> Some small tributaries join the Virgin River in the study area. Several of these tributaries cascade into the main channel from an elevation well above the floodplain, indicating that long-term degradation of the Virgin River occurred relatively recently.

No post flood-field photo available

<u>Abandoned perched channels.</u> At several locations in the study reach, cross-sections of abandoned channels were visible in the vertical cut bank stratigraphy, indicating that the active channel bed elevation is significantly lower than in the past and that the channel alignment is significantly different. That is, the river has been subject to vertical and lateral scour.

No post flood-field photo available

<u>Exposed bridge pile caps</u>. The pile caps at the Interstate 15 and Man of War bridges have had 4 to 12 feet of soil removed from around their base, according to soil lines and other features observed on the bridge foundation.

No field evidence of significant post-flood scour at River Road bridge or Washington Fields bridge.

<u>Quicksand</u>. At many places upstream of River Road, the channel bed and bars are unable to support the weight of the field crew, who sank up to 2.4 feet into the channel in a matter of seconds. The presence of quicksand indicates saturated bed sediments and poorly graded sediment material.

Quicksand was encountered throughout the study reach. No field photos available.

5 EROSION HAZARD ANALYSIS

5.1 Methodology

The following types of information were considered in defining the erosion hazard zones for the Virgin River within the study reach:

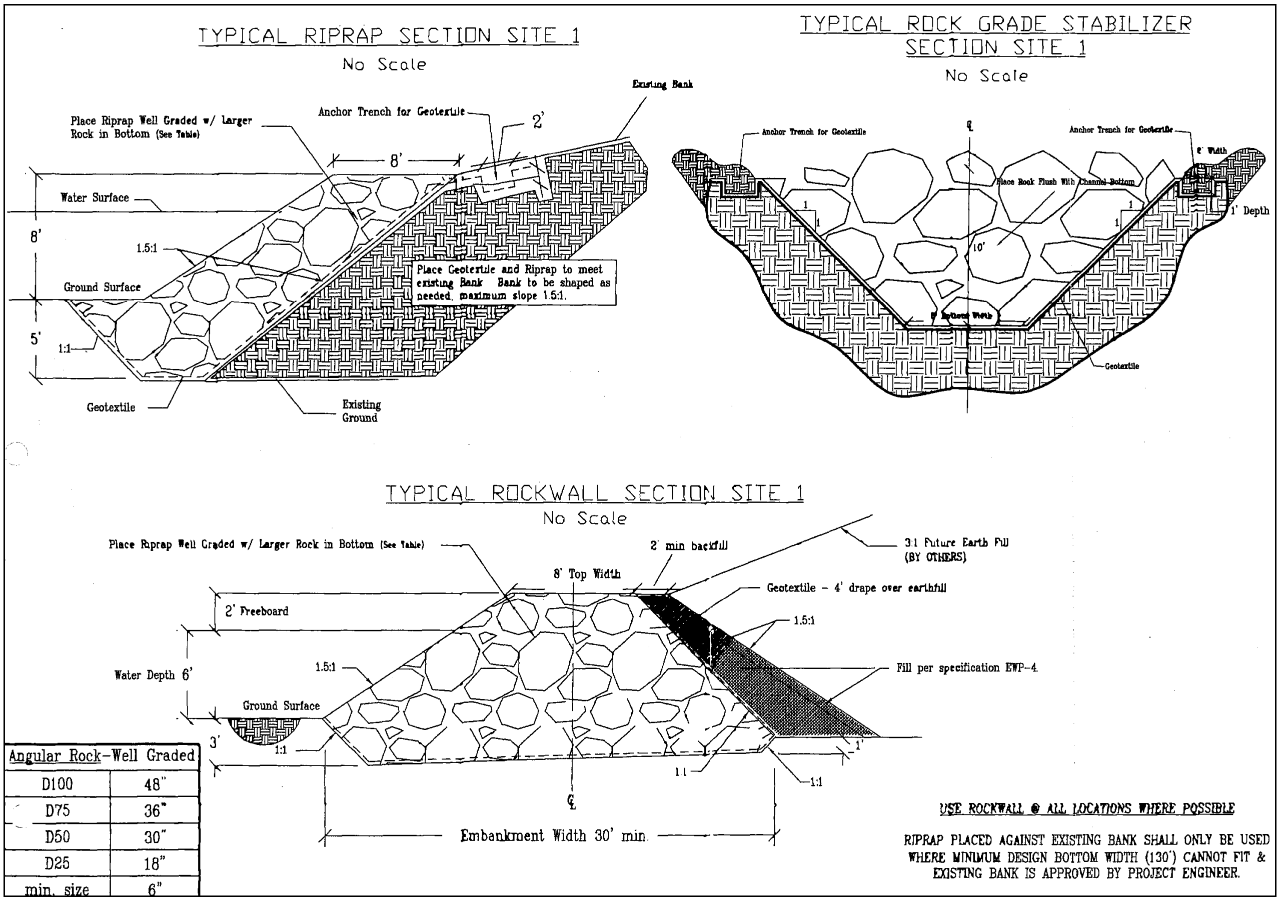
- 1997 River Stability Study results, conclusions and recommendations
- Location and design of NRCS channel stabilization structures
- Field observations (Section 4.1)
- Historical channel changes
- Geology/soils mapping
- Observed and measured channel changes from the 2005 flood
- Expected future channel behavior

5.1.1 1997 River Stability Study

The conclusions and recommendations from the 1997 study are considered the foundation of this update study. The 1997 study conclusions listed in Section 2.2.1of this report accurately predicted the behavior of the Virgin River observed during the 2005 flood. With few exceptions, the 1997 erosion hazard zone delineations proved adequate and were considered in this analysis. As noted in the 1997 study, the potential for future bank erosion increased dramatically once bank vegetation was lost. Therefore, the hazard of future lateral erosion on the Virgin River significantly increased after the 2005 floods because of the change in channel and bank conditions. Without stabilization measures and consistent river management, lateral erosion such as experienced in the winter of 2005 will become more common during moderate to large floods.

5.1.2 Engineered Structures

Immediately following the 2005 flood, the NRCS enacted an *Emergency Watershed Project* (EWP) for the Virgin River in portions of the study reach. The NRCS project consisted of debris removal and construction of streambank protection. The NRCS design consisted of rock wall levees and rip-rap bank protection. Under the guidelines of the EWP Program, the NRCS stabilization was designed for the peak discharge of the 2005 event, rather than the 100-year (or larger) discharge that is used for most river engineering projects. Figure 7 shows the typical design detail for each type of erosion protection structure built by the NRCS, as well as a rock sizing table. Figure 8 shows the locations of the NRCS structures that were observed during the field investigation. Several attempts were made to obtain official as-built surveys of the structures from the NRCS. The as-built information was not available at the time of this report; therefore the structures shown in Figure 8 are only those that were visible during the field investigation. It is entirely possible that additional buried structures exist which were not readily identifiable in the field. Figure 9 shows ground photos examples of the structures.



Angular Rock–Well Graded	
D100	48"
D75	36"
D50	30"
D25	18"
min. size	6"

Figure 7. Typical design of NRCS structures within the study reach

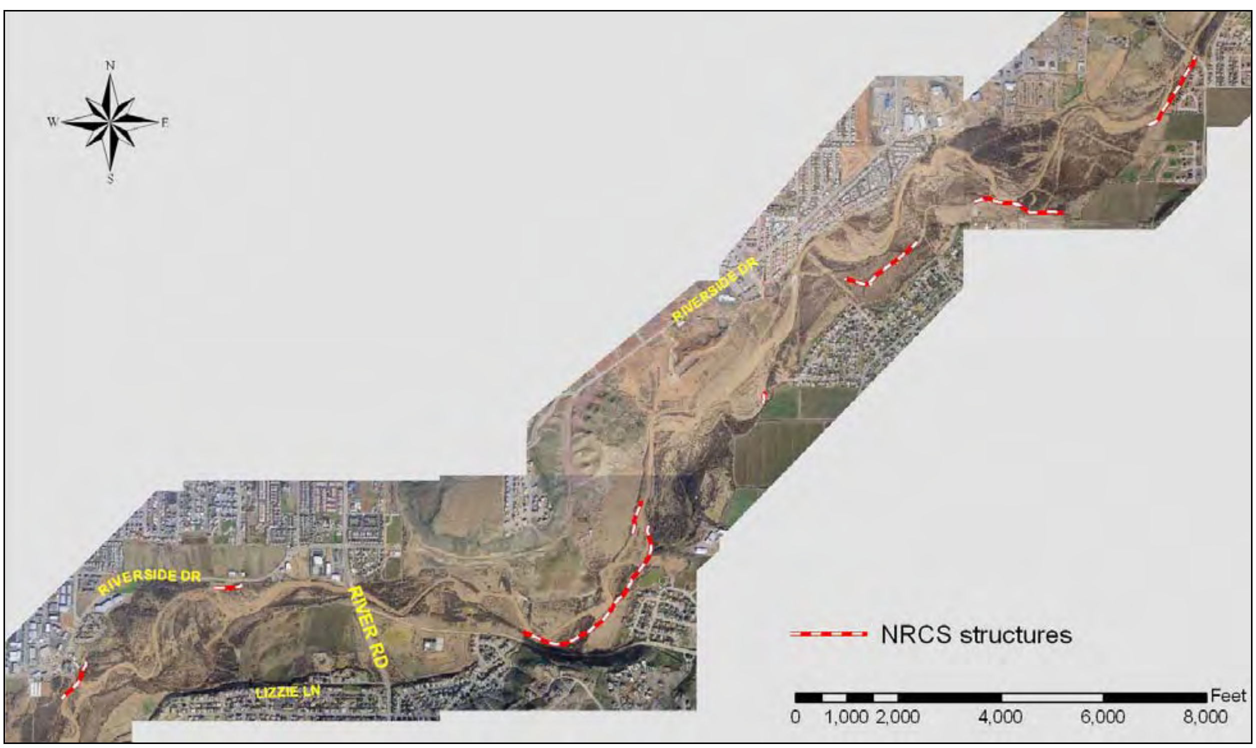


Figure 8. Location of NRCS structures within the study reach

Photo ID: 8-30-2006-32

Photo ID: 8-31-2006-85

Photo ID: 8-31-2006-128
(structure is buried)

Photo ID: 8-31-2006-149

Figure 9. Photos of NRCS structures within the study reach

While construction of the NRCS erosion control measures may reduce potential future lateral migration and bank erosion in portions of the study reach, it does not eliminate erosion hazards in those reaches. Because the NRCS structures were designed for a flood less than the 100-year event, the potential for high stage flows to overtop the structures and erode behind the levees or above bank protection still exists. All of these factors were considered when delineating the erosion hazard zone. Additionally, discontinuous placement of the NRCS structures and the lack of structural tie-in to resistant bank material may provide significantly less protection from erosion than initially intended. Examples of a few of these situations are discussed below.

<u>NRCS Structure Consideration Examples</u>

1. <u>Levee at Riverside Drive</u> – an approximate 540 foot section of rock levee was constructed by the NRCS along Riverside Drive downstream of the River Road bridge (Figure 10). During the 2005 flood, a small meander

developed and began migrating toward Riverside Drive. The levee was placed to protect the roadway from erosion. The following evidence for this location was used in determining the location of the erosion hazard zone:

a. Field inspection of the structure suggested that there is a potential for the river to erode behind the structure due to its relatively short lateral extent in combination with the lack of lateral tie-in to resistant bank material.
b. Historical aerial photos indicate the active channel corridor has been behind the levee within the past 54 years.
c. The floodplain sediments both adjacent to and behind the levee are highly erodible as evidenced during the 2005 flood.

When considering the above described evidence, it was determined that a potential existed for the levee to be flanked during a large flood event, thus the structure was not considered to provide adequate erosion protection when determining the placement of the erosion hazard zone.

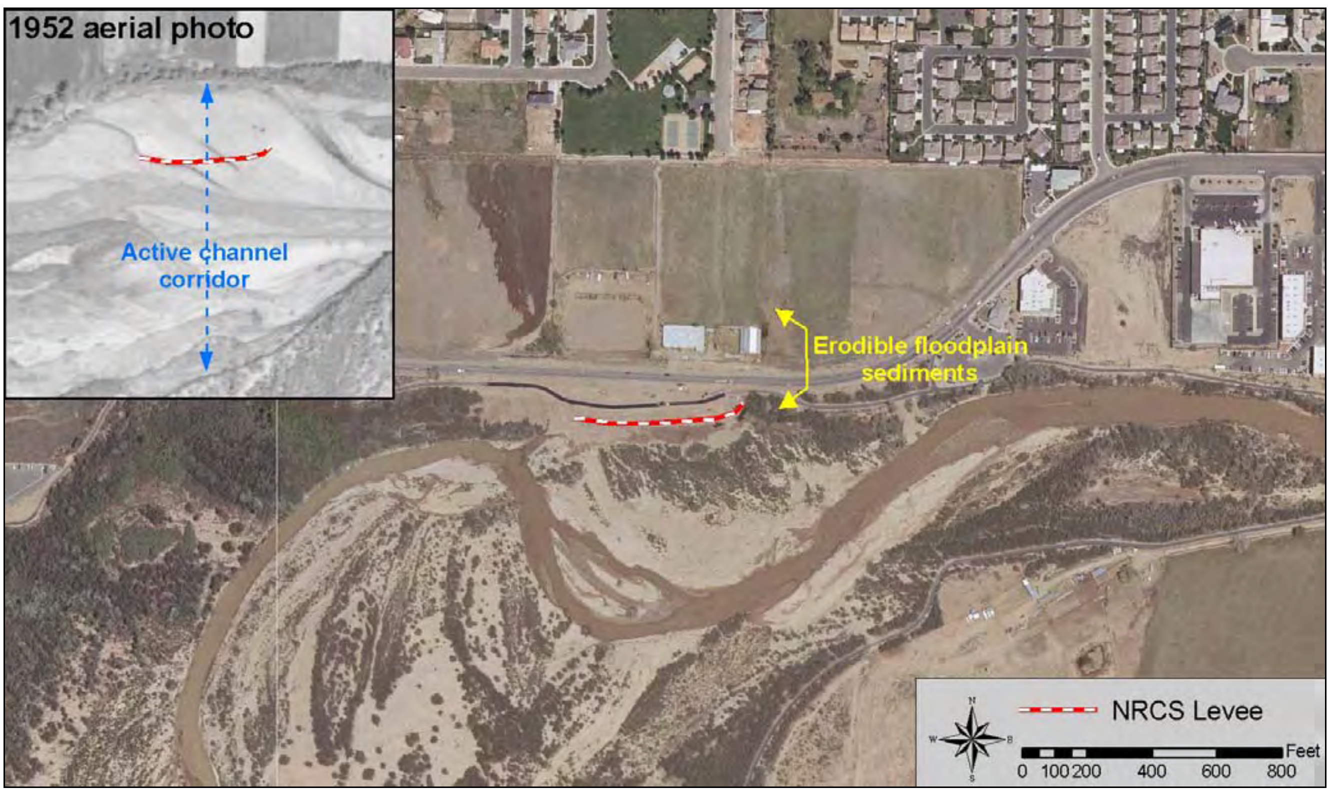


Figure 10. NRCS structure example 1

2. <u>Levees near the intersection of W. Mariposa Dr. and S. Alondra Dr.</u> – two sections of levee were constructed in the left-overbank floodplain near the intersection of W. Mariposa Dr. and S. Alondra Dr. (Figure 11). The upstream levee is approximately 1,800 feet in length and the downstream approximately 2,560 feet in length. The primary concern at this location is the 1,400 foot gap between levee sections. The following evidence for

this location was used in determining the location of the erosion hazard zone:

a. Aerial photography from 1967 shows the active channel within 200 feet of the location of the downstream levee (Figure 11).
b. Analysis of aerial photography in this area from 1952 through 2006 indicates the active channel has been very dynamic and has migrated laterally over 1,000 feet within the past 54 years. This suggests that there is a potential for the active channel to migrate through the gap in the levee structures. If this were to occur, the channel would essentially become trapped behind the levee and could likely cause significant erosion and flood inundation damage to homes and other structures in the vicinity.
c. The revised floodplain and floodway mapping indicate flow overtops the structure and flanks the levee.

This scenario was considered when placing the erosion hazard zone in this area. To reduce to potential for this situation, it is recommended that an additional levee section be constructed to close the 1,400 foot gap.

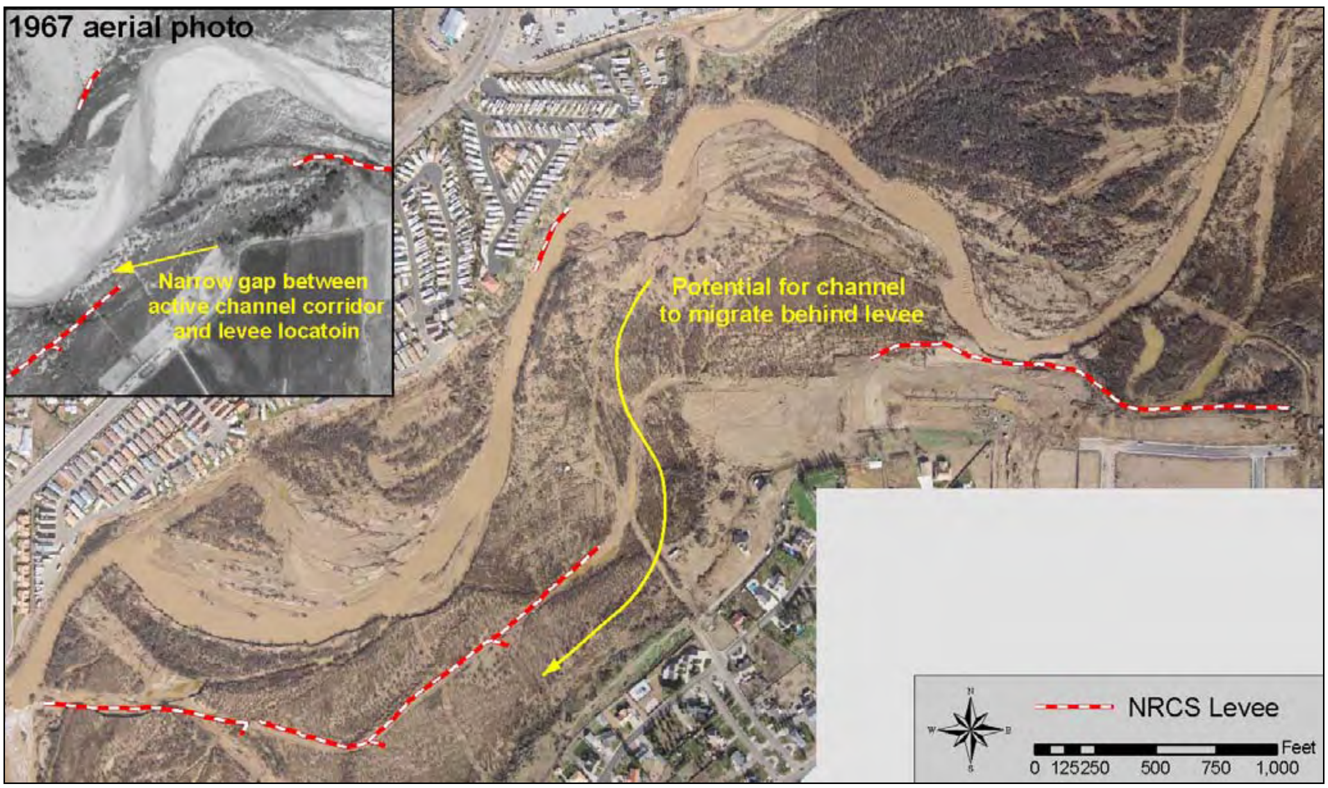


Figure 11. NRCS structure example 2

5.2 Results

One key component of both the 1997 and 2006 river stability studies was the development of regulatory erosion hazard zones and recommendations for river management within the zones. Those recommendations are listed previously in Section 0 The same recommendations are applicable to this stability study update.

5.2.1 Modification of the 1997 Erosion Hazard Zone

As discussed in Section 5.1.1, the 1997 erosion hazard zones within the study reach proved adequate during the 2005 flood. Although some flood inundation occurred outside the 1997 erosion hazard zone, lateral migration and erosion from the main channel was constrained within the zone. Therefore, minimal modification was made to the 1997 delineations. The few modifications that were made were primarily the result of higher resolution data and the advancement of mapping technology since the 1997 study. For example, the base map for the 1997 study field analysis was USGS quadrangle maps at a scale of 1:24,000 and a contour interval of 20 feet. The base map for this stability study update was digital aerial photography at a resolution of 0.5 foot/pixel and digital topography with a contour interval of 2 feet. Figure 12 shows an example of modifications to the 1997 erosion hazard zone as a result of higher resolution topographic information. The erosion hazard zone also incorporates updates made at the Tuscany Shores and The Springs subdivision previously submitted and approved by St. George City.

Figure 12. Example of changes to EHZ using higher resolution information

5.2.2 Extension of 1997 Erosion Hazard Zone

The 1997 upstream study limit was located approximately one mile downstream from the Washington Fields bridge. One of the primary tasks of this stability study update was to extend the erosion hazard zone upstream to the Washington Fields Diversion. All the factors listed at the beginning of Section 4 were considered in determining the location of the erosion hazard zone. The exhibit plates in Appendix B illustrate the erosion hazard zone for the entire study reach, including the extension to the Washington Fields Diversion.

5.3 Definition of the Erosion Hazard Zone

The erosion hazard zone is defined as a land area adjoining a body of water or adjacent to or located partially or wholly within a delineated floodplain which due to the soil instability, is likely to suffer flood-related erosion damage. The erosion hazard zones consist of the channel margin area likely to be eroded by a “typical” series of floods over a sixty year period, plus the erosion that would be caused by a 100-year flood. It also includes the natural channel movement due to geomorphic processes such as meander migration or channel avulsion.

The erosion hazard zones are a distinct management tool intended to help protect the health, safety and welfare of landowners and users of the river corridors in the study reach. The erosion hazard zones are independent of the FEMA 100-year floodplain and floodway limits. The FEMA floodplain boundaries are primarily intended to prevent damage from flood inundation. The erosion hazard zones are intended to prevent damage from erosion during flooding, whether or not the property is located within the 100-year floodplain.

It is important to recognize that the erosion hazard zone is not a “no-build” zone. The erosion hazard zone depicts areas that deserved special design consideration to account for some risk of being affected by lateral erosion during the design life of any structure or the tenure of land ownership. The erosion hazard zones also serve as notice to landowners that development of the property carries inherent risk that should be adequately addressed through engineering design, insurance, appropriate land uses, or avoidance. As delineated, the erosion hazard zones depict the long-term potential for river movement should no river management plan be adopted and enforced, and the river is allowed to migrate naturally within the river valley.

The use of erosion hazard zones rather than erosion hazard lines reflects the inherent uncertainty in predicting future channel changes such as lateral migration. Stream morphology and behavior are governed by a large number of variables, few of which can be predicted with certainty. Therefore, prediction of future channel change and future lateral movement is subject to similar uncertainty. Even if the uncertainties associated with the methodologies used, and the variables that impact lateral erosion were eliminated, the sequence, timing, and magnitude of future floods cannot be predicted with precision. Therefore, future erosion cannot be known with a high degree of certainty.

The erosion hazard zone delineation for the *Virgin River Stability Study Update* was based on the following assumptions and methodologies:

- Conservative. The erosion hazard zone delineation is conservative with respect to public safety and prevention of flood damages. It is possible that more detailed, site-specific erosion hazard analyses could be conducted to modify the erosion hazard zone limits in some areas if additional site information were considered.

- Defensible. The erosion hazard zones were delineated using techniques that have been applied and accepted by local, state, and federal floodplain management agencies elsewhere in the Southwest. The methodologies have been calibrated by comparison of historical channel behavior, compared favorably to mathematical modeling techniques, and verified by comparison of pre- and post-flood channel movement.

- Advisory. The erosion hazard zones are intended to be used to advise the public of potential risk of future damage by flood-related erosion. There are numerous means to protect properties from erosion. Therefore, with proper engineering, development within the erosion hazard zone is feasible.

- Existing Conditions. The erosion hazard zone was delineated for conditions documented during the August 2006 field visit and by the most recent aerial photography used (2006). It is necessary to periodically update the erosion hazard zones to reflect channel changes caused by flooding and human activities like channelization or mining.

- The erosion hazard zone was delineated to be wide enough to contain all of the known historical active channel limits. That is, the erosion hazard zone limit was set back from the existing bank at least as far as the maximum historical channel movement within the entire study reach.

- Regulatory Floodplain. The erosion hazard zone is not coincident with the 100-year floodplain, and may be wider or narrower than the regulatory floodplain mapped for FEMA floodplain studies. Where available, hydraulic modeling developed for the FEMA floodplain delineations was considered when delineating the erosion hazard zone. In general, the erosion hazard zone encompasses the regulatory floodway.

- Sand and Gravel Excavations. Sand and gravel excavations were included within the erosion hazard zone due to the potential for breach and capture of off-line pits, or channel movement within on-line pits. It would be possible to remove the sand and gravel mines from the erosion hazard zone if engineered structures were constructed to isolate the pits from the floodplain or from the potential for breaching the pits. A narrow buffer was applied to the outside of the excavation limits to account for collapse of pit walls if the pits were to be captured and filled by flood waters. If excavations are expanded beyond the limits shown on the 2006 aerial photographs, the erosion hazard zone should be moved proportionately.

- Geology. Alluvial surfaces such as stream terraces were considered to be erodible. Older surfaces were considered to be less erodible due to increased induration, calcification, and clay accumulation. Older surfaces also tend to erode laterally at slower rates because they tend to be higher and thus deliver greater volumes of eroded material per unit of lateral movement. Bedrock was considered non-erodible within the time scales considered for the delineation.

- Channel Pattern. The erosion hazard zones tend to be wider on the outside of bends compared to the inside of bends to account for likely channel pattern evolution. The active corridor width within channel bends, as described above, was used as an indication of long-term potential lateral movement.

- Tamarisk. Dense tamarisk can slow flood velocities and induce sediment deposition on floodplains. However, due to long-term scour that undercuts the banks and root zones, tamarisk provides only marginal increases in bank stability along the main channel. Furthermore, dense tamarisk has been shown to block flood conveyance and cause erosive flood waters to be diverted along the outside of the tamarisk forest. Finally, tamarisk eroded from the floodplain and channel banks can accumulate on bridge piers and hydraulic structures, resulting in flow diversions and channel avulsions. Therefore, in general, tamarisk was considered to be a destabilizing force with respect to channel stability.

- Smoothing. Rivers tend to form smooth curvilinear patterns, rather than follow rectilinear or orthogonal lines typical of property and jurisdictional boundaries. In some places, the erosion hazard zone boundary was smoothed to better reflect a more riverine appearance.

6 AGGRADATION ASSESSMENT

A spatial analysis to determine the change in elevation for the channel and floodplain within the study reach was conducted using historical and recent elevation data and GIS tools. The purpose of this analysis was to attempt to determine if long-term trends (either aggradation or degradation) could be established for the active channel and floodplain, and if such trends directly influenced the behavior of the river during the 2005 flood. Two primary data types were used in the analysis: 1) digital mapping and 2) individual cross-sections. Table 7 lists the digital mapping data sets used in the analysis.

Table 7. Digital mapping data sources

Data Year	Source	Data Type	Resolution	Vertical Datum	Comment
1993	USGS NAPP	DEM	10 meter	NGVD29	NAVD88 conversion factor of 2.7 applied
1999	City of St. George	DTM	1:2,400	NAVD88	
2003	City of St. George	DTM	1:2,400	NAVD88	Update of 1999 DTM
2006	City of St. George	DTM	1:2,400	NAVD88	Update of 2003 DTM

6.1 Digital Mapping Data

The analysis was conducted using 1993, 1999, 2003, and 2006 mapping grid data. The 2006 data had the most limited spatial extent; therefore any data set used in comparison with the 2006 data was clipped to the 2006 extent. Each grid data set was converted to a triangular irregular network (TIN) model using GIS, and the TIN models were then converted to raster data sets. Using advanced geoprocessing tools within the GIS software, the raster data sets were then subtracted from one another resulting in new raster data representing the difference. The difference, either positive or negative, represented a raising (aggradation) or lowering (degradation) of the ground surface. Figure 13 and Figure 14 show the results from the 1993-2003 and 2003-2006 elevation change comparisons. A general interpretation of the figures can be described by the warmer colors representing degradation between data sets and the cooler colors representing aggradation. The purpose of the 1993-2003 analysis was to determine if any long-term trends in aggradation/degradation was occurring within the Virgin River corridor prior to the 2005 flood. The purpose of the 2003-2006 analysis was to obtain a quantitative estimate of aggradation and degradation resulting from the 2005 flood.

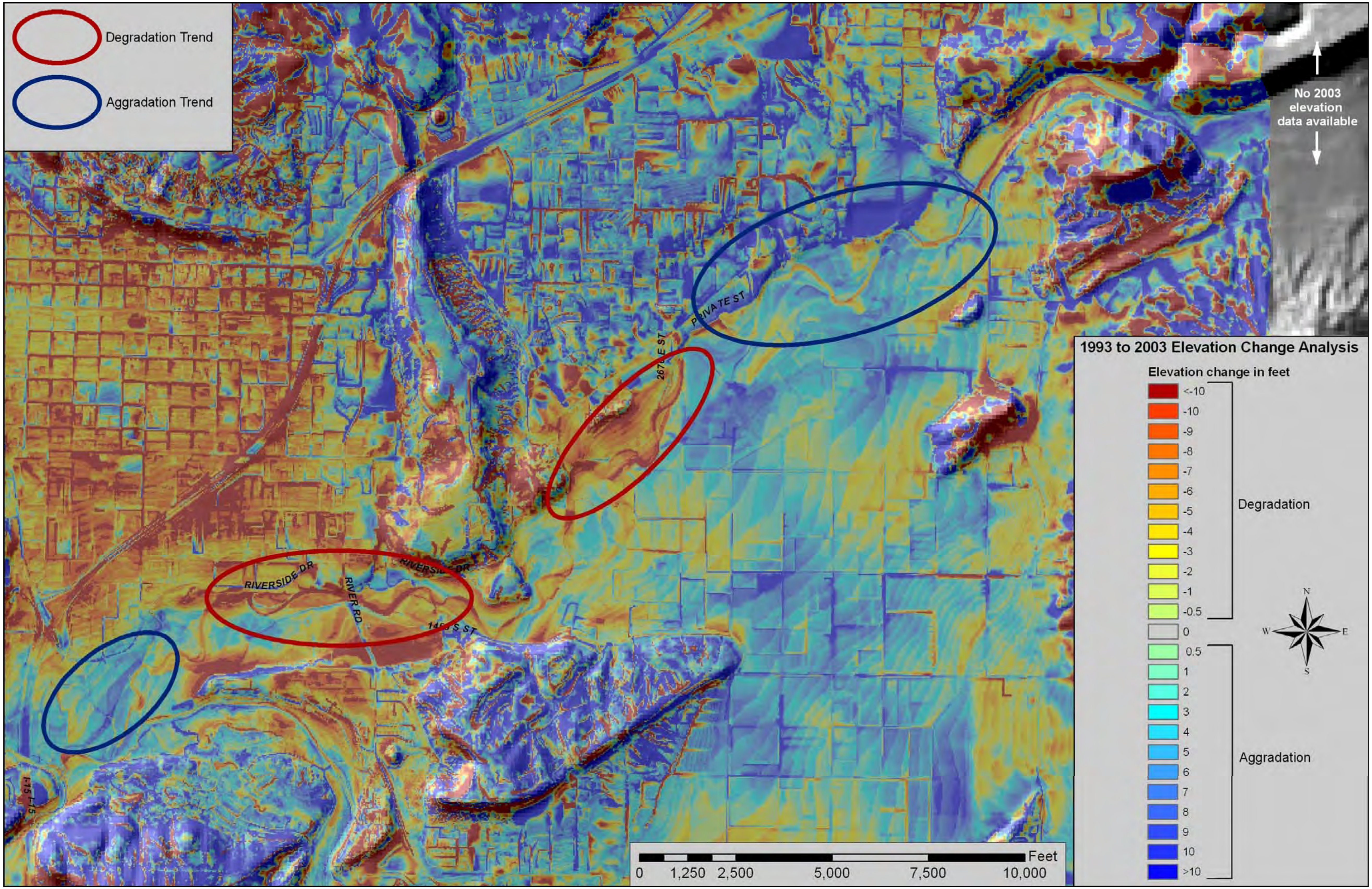


Figure 13. 1993-2003 elevation change analysis results

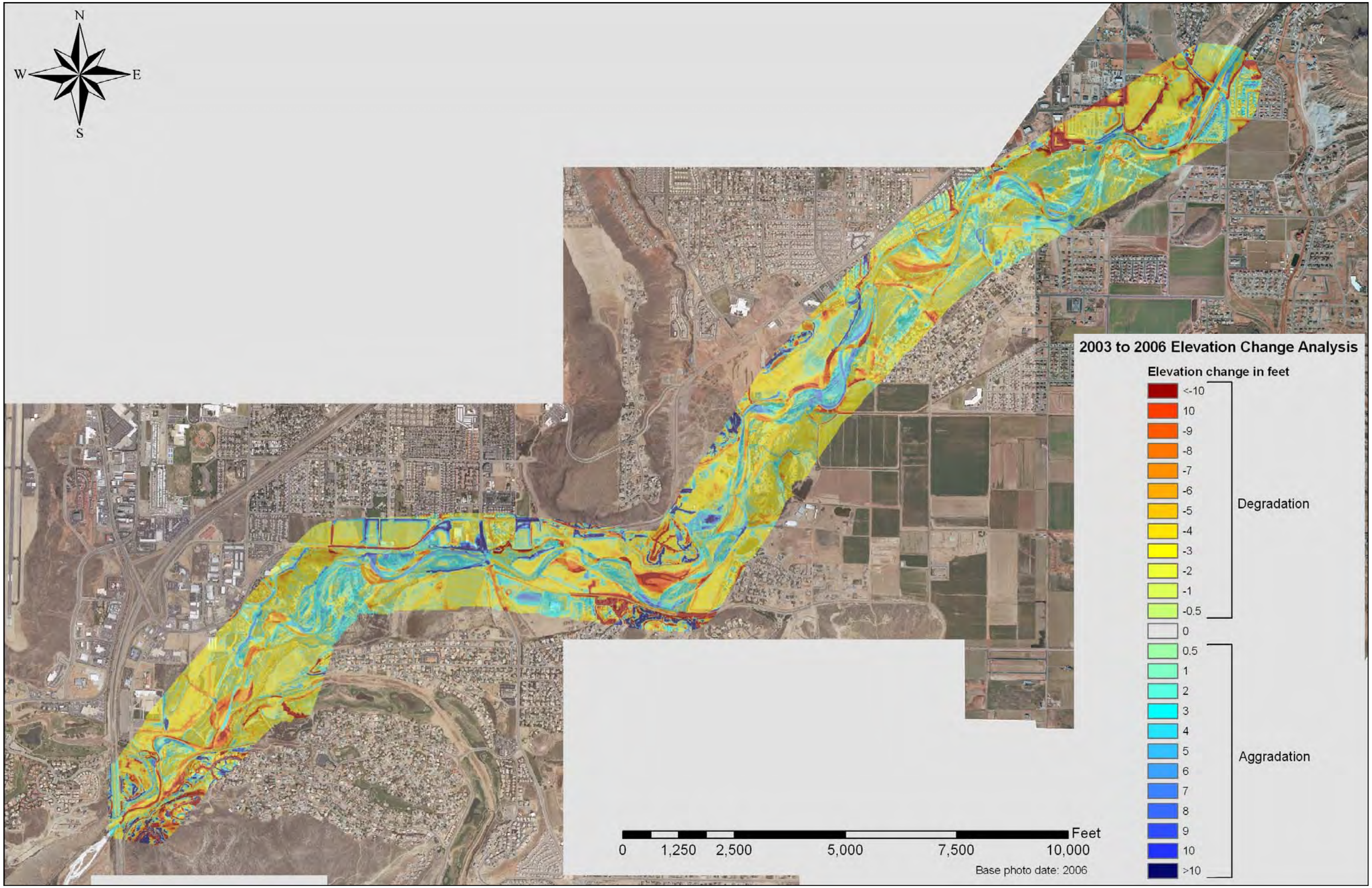


Figure 14. 2003 to 2006 elevation change analysis results

6.1.1 Interpretation

1993-2003 Comparison Results

The results suggest large-scale trends in both aggradation and degradation within the data set limits. To verify the accuracy of these results, site-specific comparisons were made between the 1993 and 2003 data sets at locations where vertical changes did not occur (e.g. developed/stable areas outside the Virgin River floodplain). Table 8 lists the site-specific locations and the comparison results.

Table 8. Site-specific discrepancies in 1993 and 2003 elevation data

Location Description	Elevation Difference from 1993 to 2006
House on Vermillion Ave. near San Rafael Circle	+12 feet
House on South 1280 E Street	+2 feet
Building in The Palms subdivision	+11 feet
Building on East 965 South	+2 foot
Bedrock outcrop near Riverside Drive	-1 foot
Building near South 400 East and Riverside Drive	+7 feet
MEAN DIFFERENCE	+5.5 feet

The results shown in Figure 13 also suggest that significant changes in elevation occurred on the large bedrock mesas such as Webt Hill near Interstate 15 and Nichols Peak near Washington Fields. The results suggest elevation changes greater than 100 feet in these areas, when in fact no such changes occurred between 1993 and 2003 as evidenced in aerial photography. One likely explanation for this discrepancy is a slight lateral shift between the two data sets. This shift would result in significant changes in elevation in areas with high relief (such as Webt Hill and Nichols Peak), but the effects would be dampened in areas of low relief (such as the Virgin River floodplain). Another possible explanation for the discrepancies shown in Figure 13 and listed in Table 8 is the significantly lower resolution of the 1993 USGS data (10 meter (32.8 ft)). The results suggest that a quantitative, site-specific estimate of elevation change should not be made with this data set. Large-scale interpretations should be made with caution. In addition to the spatial elevation change analysis, a cross-section profile comparison analysis was also conduced for the topographic data sets (described below in Section 6.1.2). The results of this analysis also suggest there are discrepancies in the accuracy of the 1993 data.

The outlined areas on Figure 13 illustrate general trends in elevation change between the two data sets. The two reaches identified as aggradation trends correspond to the densest areas of tamarisk within the study reach. These dense vegetation zones within the floodplain result in extremely high roughness values and low hydraulic energy environments which accumulate floodplain sediment over time. The result of the elevation change analysis indicates general aggradation values between one and eight feet in these areas. The discrepancy in the 1993 data discussed previously suggests that the quantitative values represented in Figure 13 should not be interpreted precisely. However, the overall trends toward aggradation and degradation shown in the figure are likely valid.

2003-2006 Data Sets

Quantification of elevation change from the 2005 flood was conducted utilizing the 2003 and 2006 mapping data (Figure 14). The plot clearly identifies the changes in both width and depth of the active channel, and when compared with the pre-flood channel position, shows locations of significant lateral channel migration. The plot also shows the extent of aggradation in the floodplain outside the active channel meander corridor. Sedimentation in the inundated portions of the floodplain was generally between two and six feet and was concentrated in the most dense tamarisk areas such as downstream of the Washington Fields Bridge to the Rio Virgin RV and trailer park, and downstream of the River Road Bridge to the Ft. Pearce Wash confluence. Degradation within the inundation portion of the floodplain was generally between two and three feet

The analysis shows several, site-specific areas that appeared to have experienced between 12 and 14 feet of degradation (shown in dark red on Figure 14). The figure can be somewhat misleading with respect to the active channel by suggesting that some areas experienced significant scour, when the process was actually lateral migration. Since the elevation data is a snapshot in time, changes in the lateral position of the channel between data sets will result in apparent aggradation, when in reality the channel migrated laterally and the former location of the channel subsequently became floodplain, likely filling-in with flood deposits and vegetation (shown as aggradation). The new location of the channel is expressed as degradation in Figure 14 when in reality the active channel migrated through the former floodplain, eroding the bank and removing floodplain sediment which gives the appearance of floodplain degradation.

6.1.2 Comparison of Survey Cross-Sections

Historical cross-section comparisons can be highly informative about the vertical and lateral changes of an active channel and floodplain over time. Like most historical analyses, the further back in time the data extends, the better the understanding of long-term processes. Potential limitations that frequently exist in historical cross-section comparisons are data accuracy and the variability in topographic resolution. A cross-section comparison analysis was conducted for the topographic data sets. The 2006 FIS study cross-sections were used as the base information for the analysis. Cross-section profiles were generated for each digital elevation data set using GIS tools. As discussed previously, there appears to be discrepancies in the 1993 data. Areas that did not experience any measurable change in elevation between 1993 and 2006 show minor, and in many cases, major elevation differences in the cross-section plots. Figure 15 shows an example of a cross-section profile comparison plot. The entire set of cross-section comparisons are attached in Appendix C.

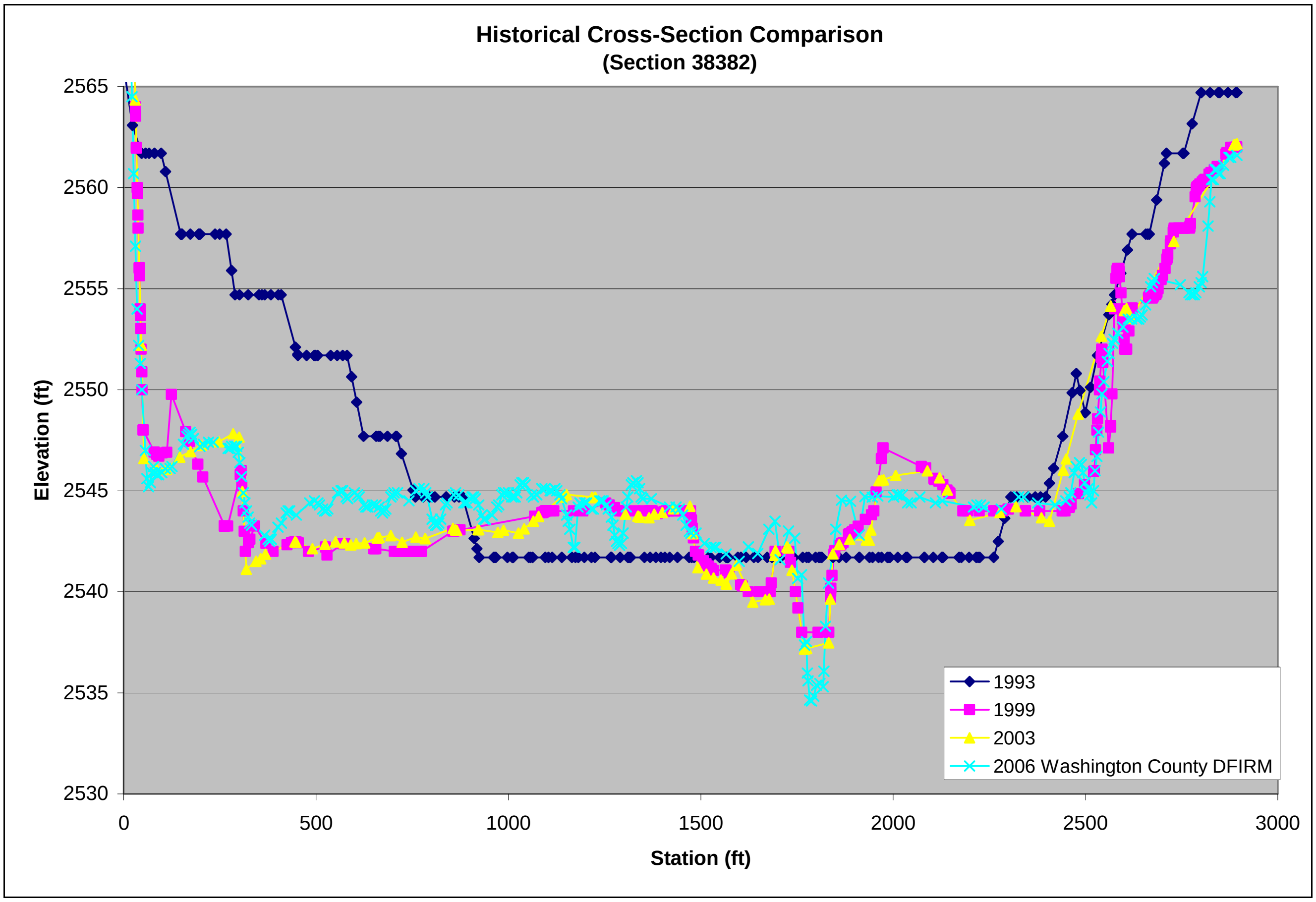


Figure 15. Example of cross-section profile comparison plot

6.2 Longitudinal Profile

A longitudinal profile is a plot of the channel elevation versus distance along the stream bed. Analysis of the longitudinal profile can be used to identify slope irregularities, over-steepened or flat reaches, headcuts, areas of natural grade control, and historical changes in bed elevation. Interpretation of the longitudinal profile also provides information on the expected lateral stability of the stream. Reaches with lower slopes than upstream reaches will tend to experience net deposition (aggradation) and bank erosion associated with braiding and avulsions. Reaches with steeper slopes than upstream reaches will tend to experience net degradation and bank erosion associated with undercutting and scour. Comparison of historical profiles with modern profiles can be used to indicate where degradation and aggradation have occurred in the recent past, and where future adjustments of channel geometry are most likely to occur. A longitudinal profile analysis was performed on the Virgin River within the study reach.

6.2.1 Interpretation

Figure 16 shoes the results of the longitudinal profile analysis comparison for the data sets discussed in Section 6.1 in addition to HEC-2 cross-section data derived from a 1981 Virgin River FIS study conducted by Rollins Brown & Gunnell (RBG). The RBG HEC-2 data was available only in hard copy format. FIS workmaps illustrating the location of the cross-sections were not available at time of this report, thus several assumptions were made when translating the hard copy HEC-2 data into a spatial GIS format:

- Descriptions of bridge locations in the hard copy HEC-2 were used as starting locations for locating the spatial position of cross-sections.
- Reach lengths were measured using 1984 aerial photography (the nearest photos available to 1981) and assuming they were measured along the thalweg.
- The 1981 FIS cross-section elevation values were surveyed in NGVD29 datum. A factor of 2.7 was applied to convert the vertical datum to NAVD88 for comparison with the remainder data sets in this analysis.

The 1993 USGS DEM data plotted in Figure 16 is significantly different than the remainder of the data. These inconsistencies suggest that the data is suspect and is unlikely to be an accurate representation of the channel profile in 1993.

The plot shows that from 2003 to 2006 the Virgin River experienced a consistent degradation of the low-flow channel between two and three feet. The majority, if not all the degradation likely occurred during the 2005 flood. Given the size of the Virgin River watershed and the magnitude of the 2005 flood, it is remarkable that such minimal degradation occurred during the event.

The 1981 FIS data plots indicate the Virgin River has not experienced significant changes in bed elevation in the past 24 years. Within that 24-year period, the river experienced an unprecedented flood (60,000+ cfs) following the Quail Creek Dam failure, and the largest natural flood in the gage record in 2005 (19,600 cfs). These large magnitude events appear to have had little impact on the bed elevation. However, the 1981 data does show aggradation has occurred downstream of the Ft. Pearce Wash confluence. This is potentially caused by the influx of sediment from Ft. Pearce Wash over time.

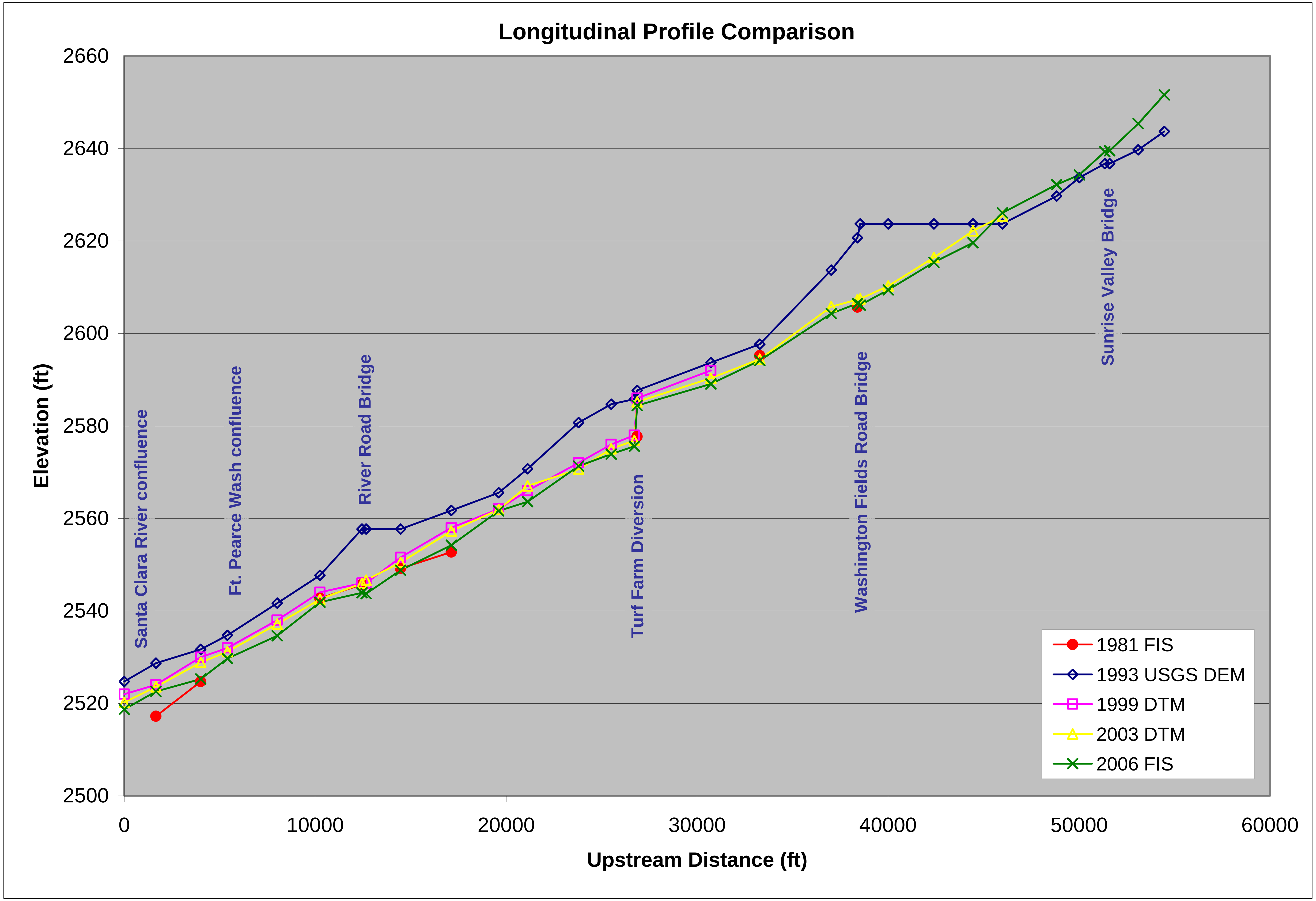


Figure 16. Longitudinal profile comparison plot

Slope Analysis

Changes in plotted channel profiles indicate changes in channel slope. Slope changes over time may suggest disequilibrium conditions. Channel slope is a function of several factors including sediment load and discharge. If sediment influx is greater than the river's transport capacity, excess sediment will be deposited (aggradation) resulting in an overall steeper slope. If sediment influx is less than transport capacity, the river will pick-up excess sediment from the bed and banks (degradation) resulting in an overall flatter slope and vertical, unstable banks. The Turf Farm diversion structure is located in the central portion of the study reach and has been in place since at least 1993. The structure is constructed on bedrock which has served as grade control within geologic time. Due to this grade control, slope comparisons were made with the reach upstream of the structure independent of the reach downstream. Table 9 summarizes the results of the slope analysis.

Table 9. Results of historical channel slope analysis

Upstream of Turf Farm Diversion			
1993 USGS DEM	1999 DTM	2003 DTM	2006 FIS
Slope = 0.0022 R2 = 0.8533	-	Slope = 0.0022 R2 = 0.9892	Slope = 0.0022 R2 = 0.987
Downstream of Turf Farm Diversion			
1993 USGS DEM	1999 DTM	2003 DTM	2006 FIS
Slope = 0.0023 R2 = 0.9879	Slope = 0.0022 R2 = 0.99	Slope = 0.0022 R2 = 0.9917	Slope = 0.0023 R2 = 0.9892

The results in Table 9 indicate an equilibrium slope both upstream of downstream of the diversion. This suggests that no significant trends in aggradation or degradation should be expected based on the results of the historical slope analysis.

6.3 Summary

The aggradation assessment of the Virgin River within the study reach was conducted using digital topographic data spanning the past 13 years, and survey data which extended the record an additional 12 years. The following conclusions were derived from the results of the analysis:

- The 1993 USGS DEM data contained significant inconsistencies that suggest site-specific interpretations of elevation change should not be made using the data set.
- The 2005 flood resulted in a consistent two to three foot degradation of the channel thalweg within the study reach. Considering the 2005 flood was the largest natural event in the gage record, it is significant that the channel experienced such minimal bed elevation change.
- The 1989 Quail Creek Dam failure event appears to have had little impact on the channel bed elevation. Although no credible elevation data between 1989 and 1999 was analyzed, comparing these two data sets suggests that if the Quail Creek event scoured the channel, it had completely recovered by 1999.

- The portion of the reach between the Ft. Pearce Wash confluence and the Santa Clara River confluence experienced a trend of aggradation between 1981 and 1999.
- The remainder of the study reach has not exhibited a trend toward aggradation or degradation within the past 25 years.

7 RECOMMENDATIONS

The updated Virgin River Stability Study erosion hazard zone is recommended for adoption by the City of St. George and Washington County. General river management alternatives are discussed elsewhere in the Master Plan Report as well as in the 1997 study report.

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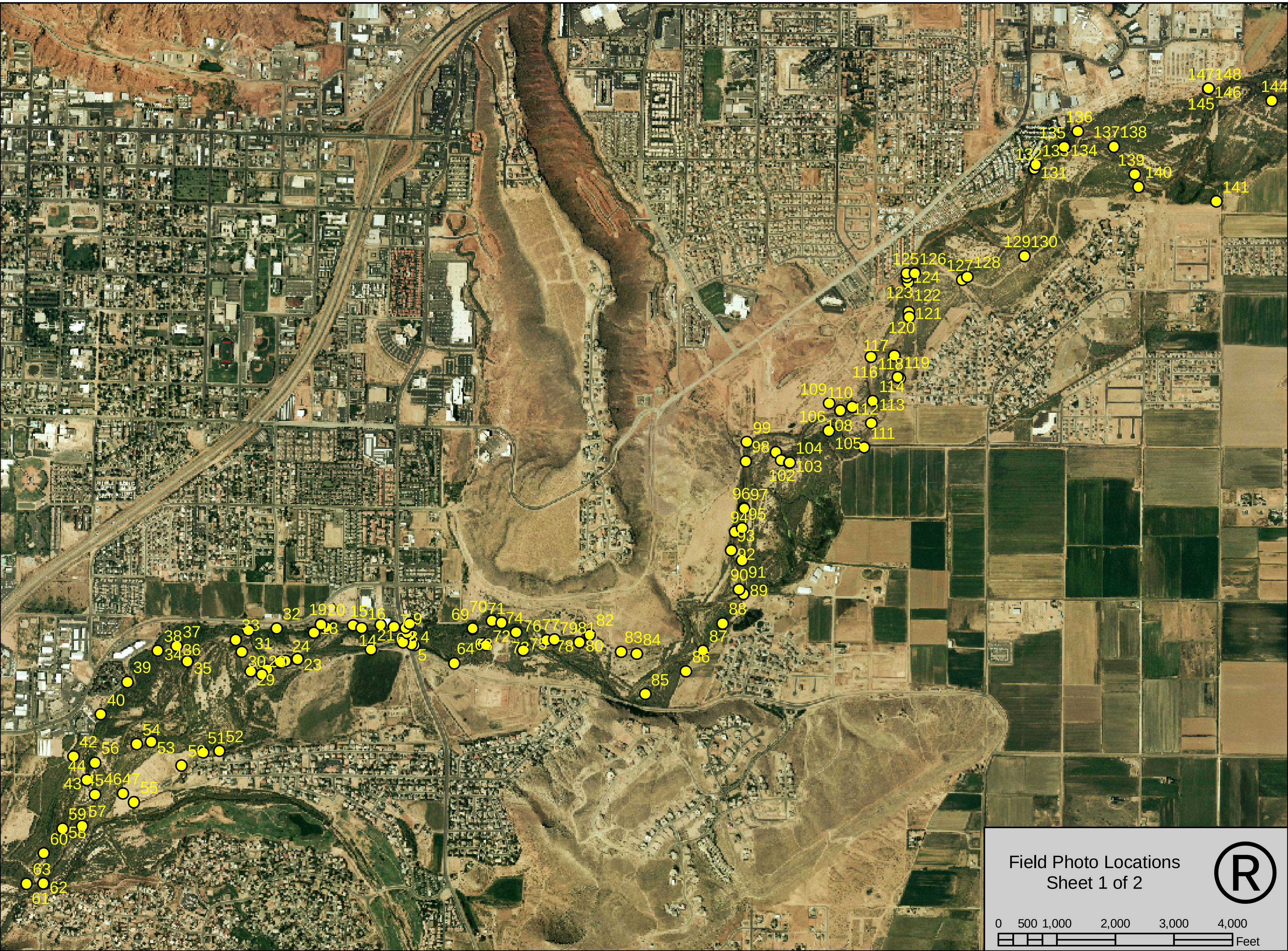
APPENDIX A

Field Photos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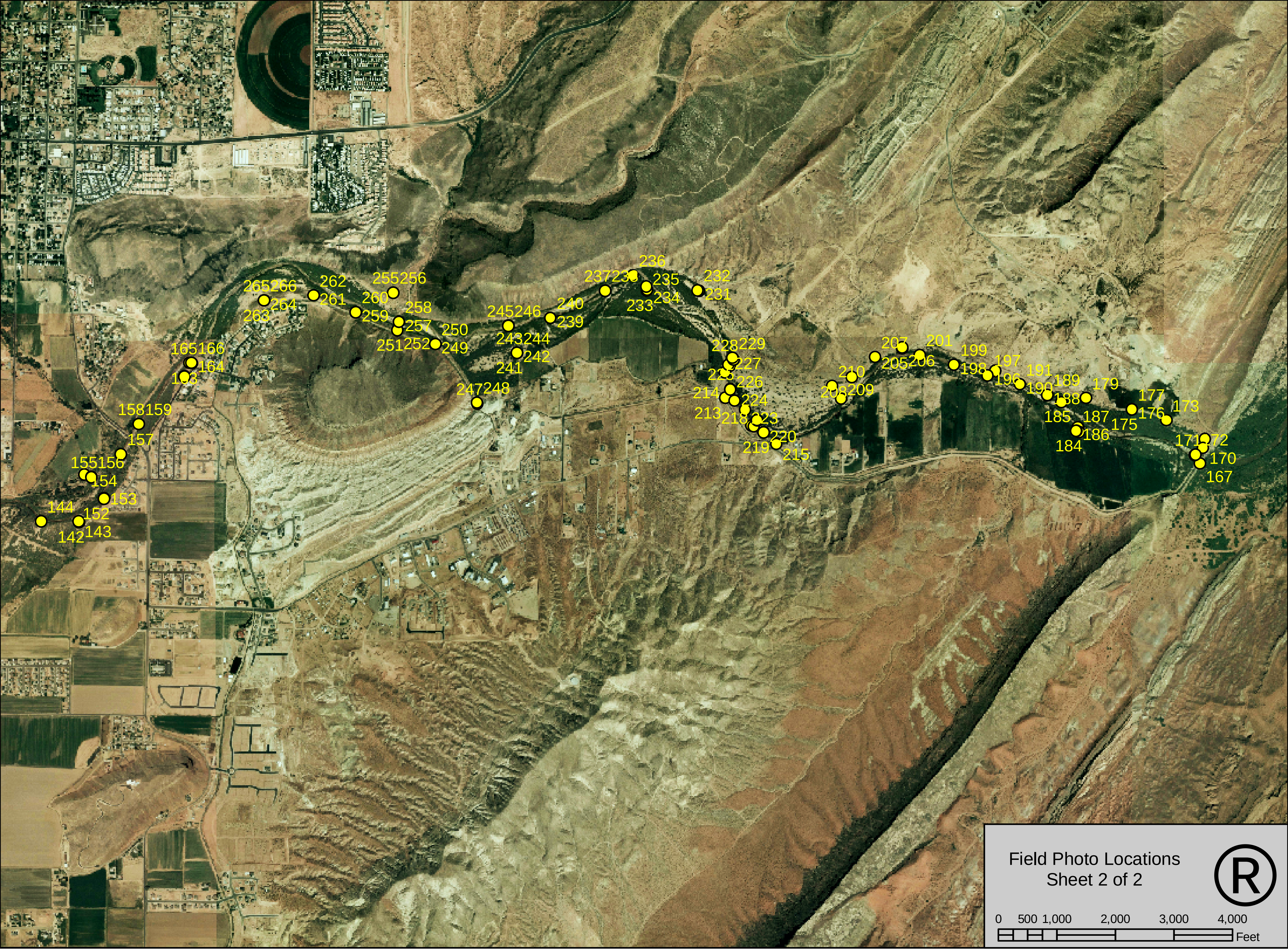

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The fieldphotos on the proceeding pages are labeled with the image filename. Contained within the filename is the date the photo was taken in addition to the photo number.

Example: 08-30-2006-004
The photo date is August 30, 2006.
The photo number is 4.

The photo number vaules correspond to the photo numbers on the preceeding index maps.


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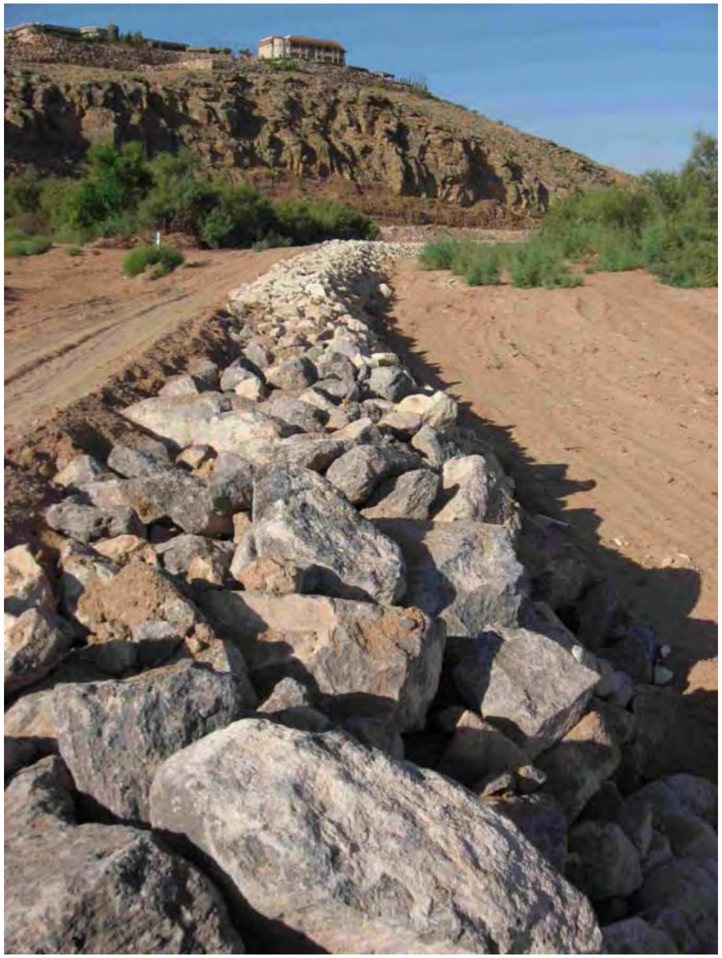

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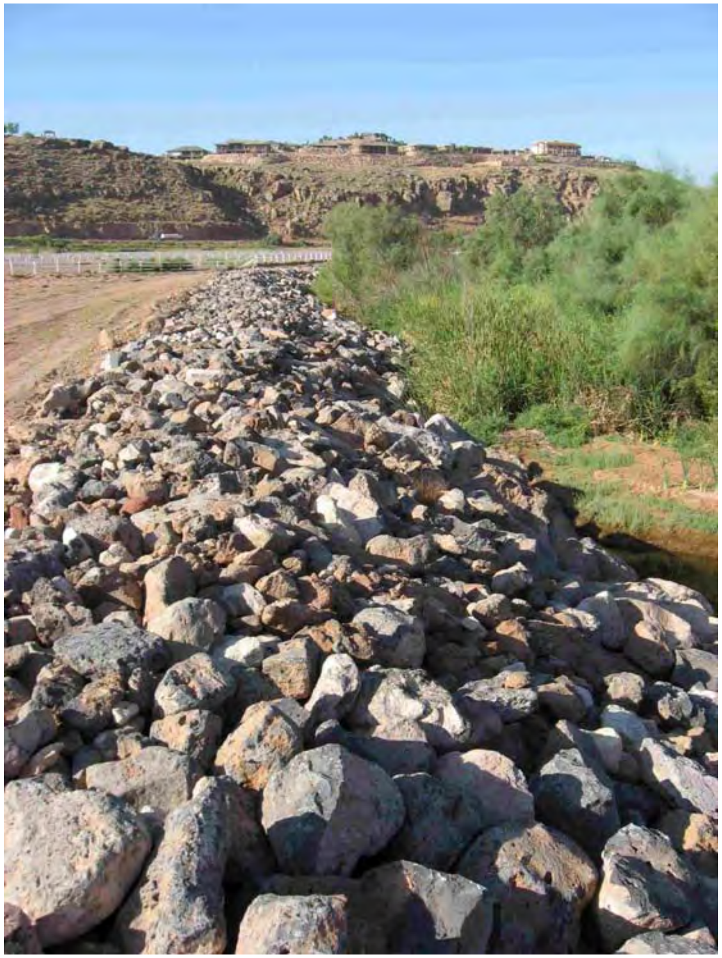
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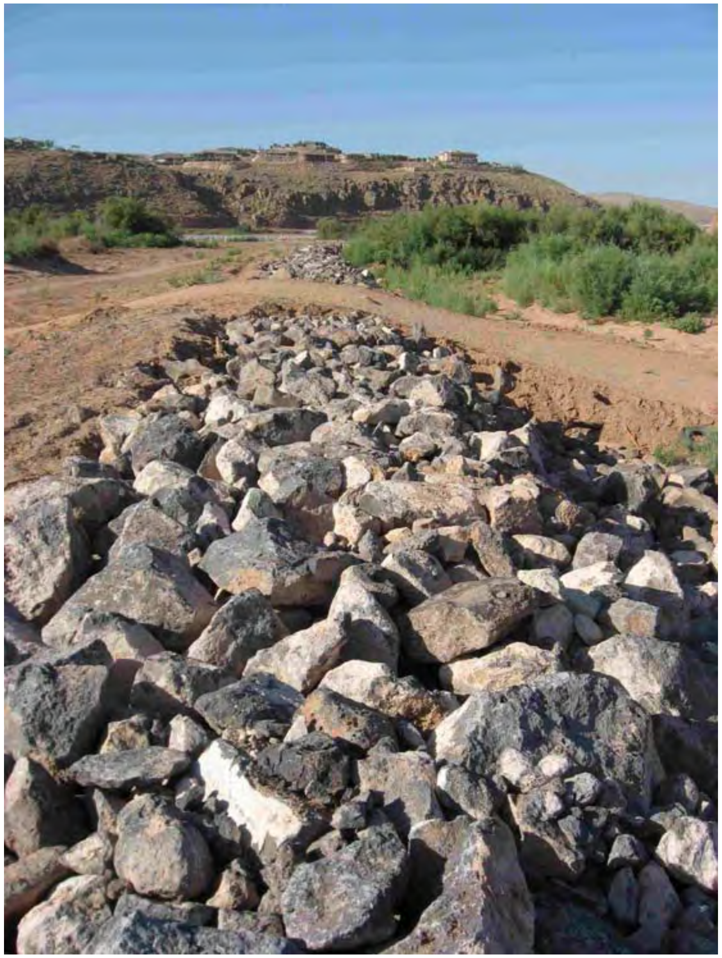
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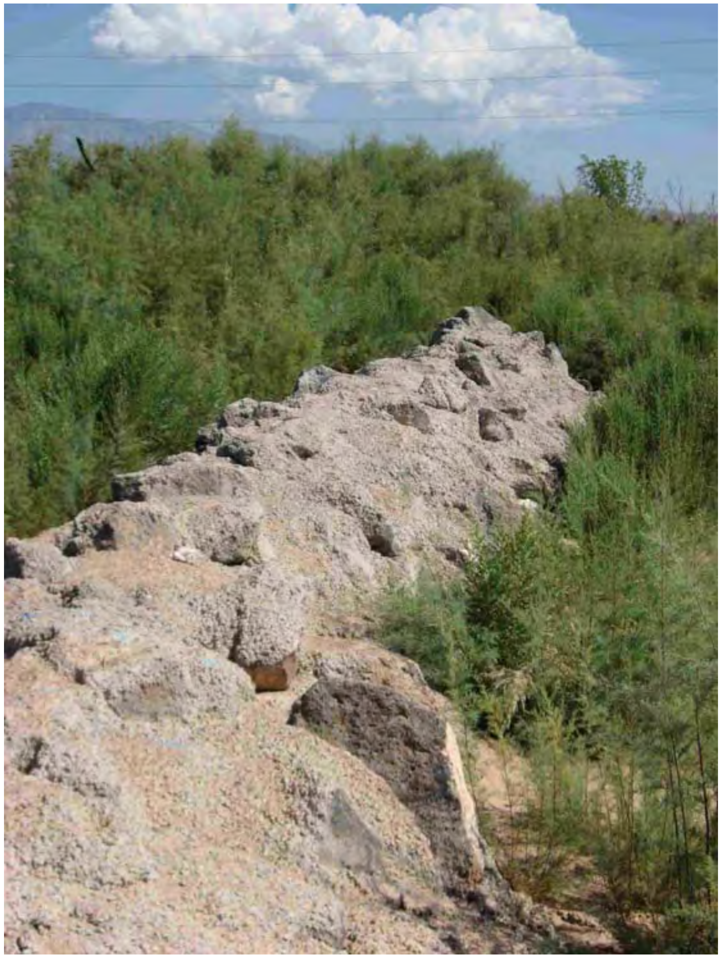
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pano12.jpg

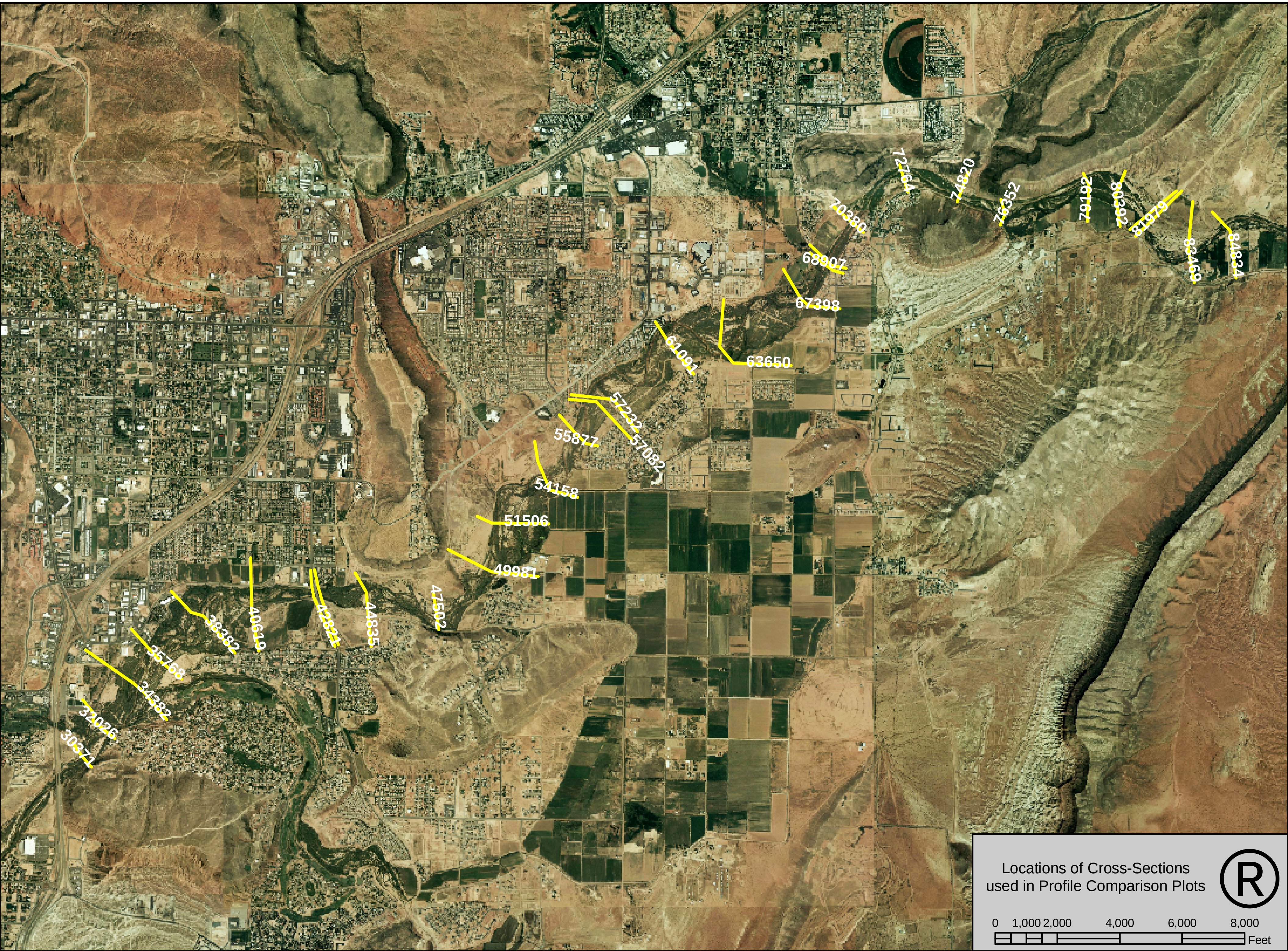
APPENDIX B

Erosion Hazard Zone


Santa Clara
St. George
Washington
Erosion Hazard Zone (Current Study)
Erosion Hazard Zone (2005 Study)
O
Electronic copy of final document. Original, sealed document with the Washington County Water Conservancy District.
Michael J. Kellogg, P.G. #6111914-2250
Jonathan E. Fuller, P.E. #319476
0
0.25
0.5
1
1.5
2
Miles
Base photo date: 2004

APPENDIX C

Historical Cross-Section Profile Comparison Plots



Locations of Cross-Sections
used in Profile Comparison Plots
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2,000
4,000
6,000
8,000
Feet
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76352
79192
80392
70330
68907
67398
63650
61091
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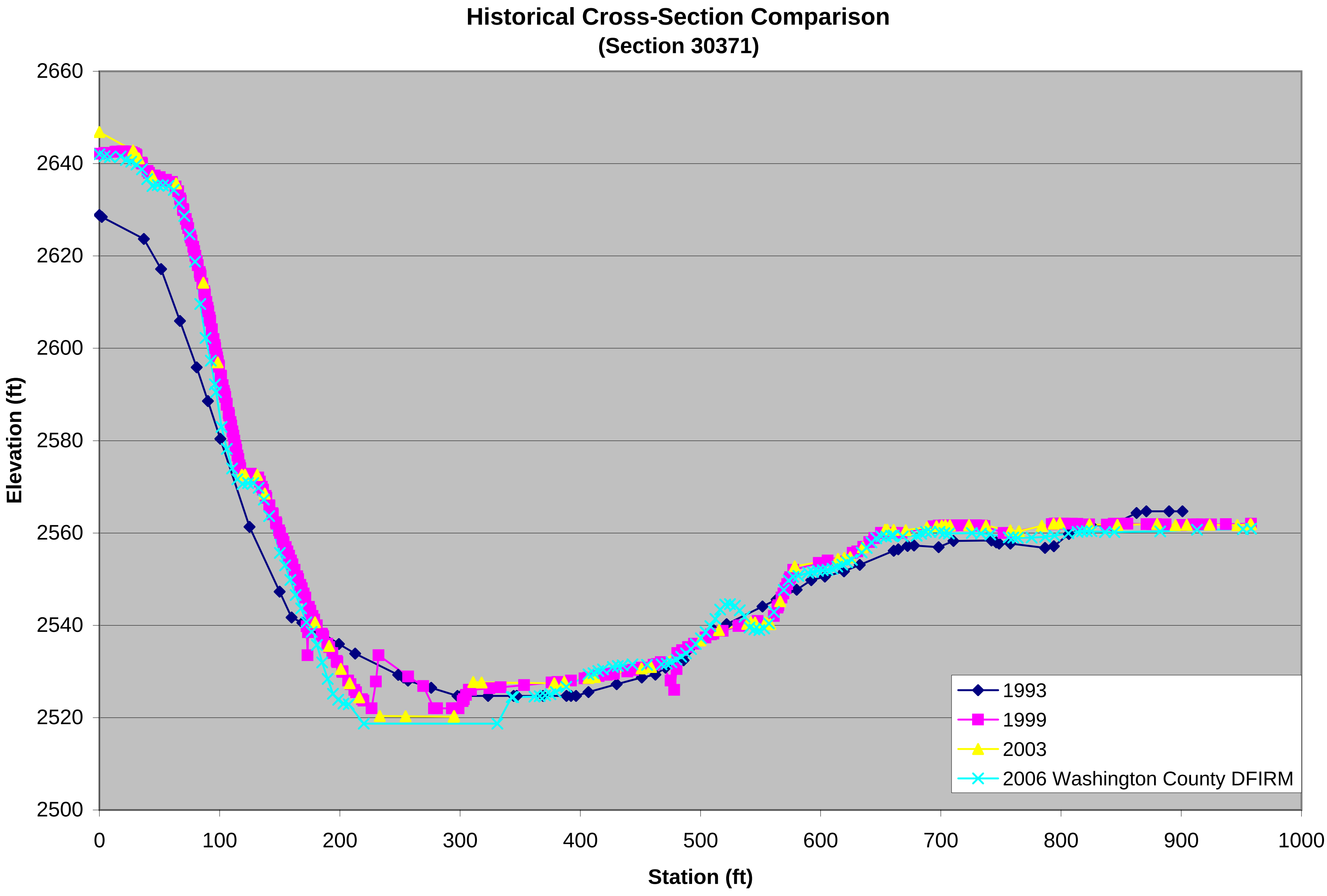
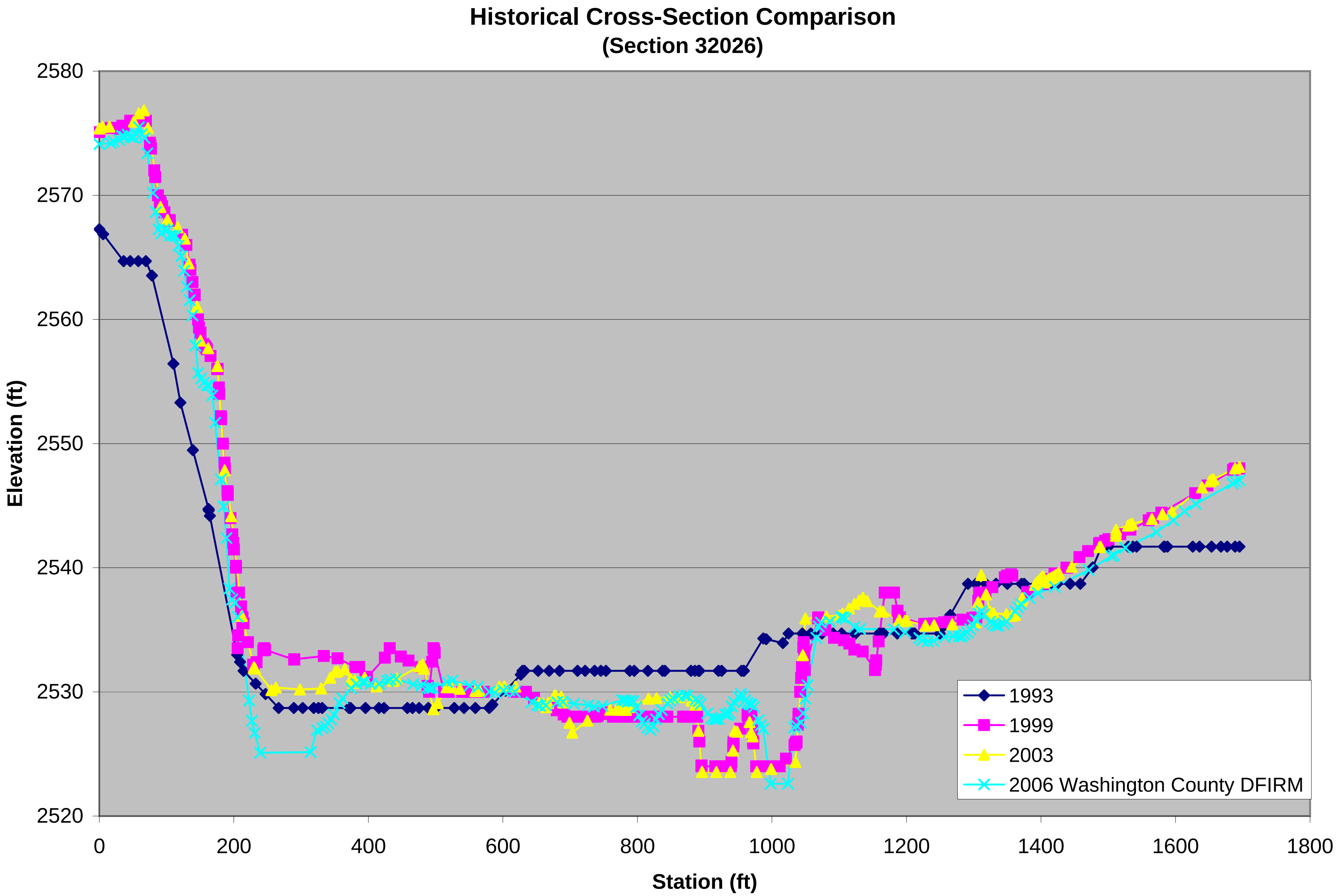
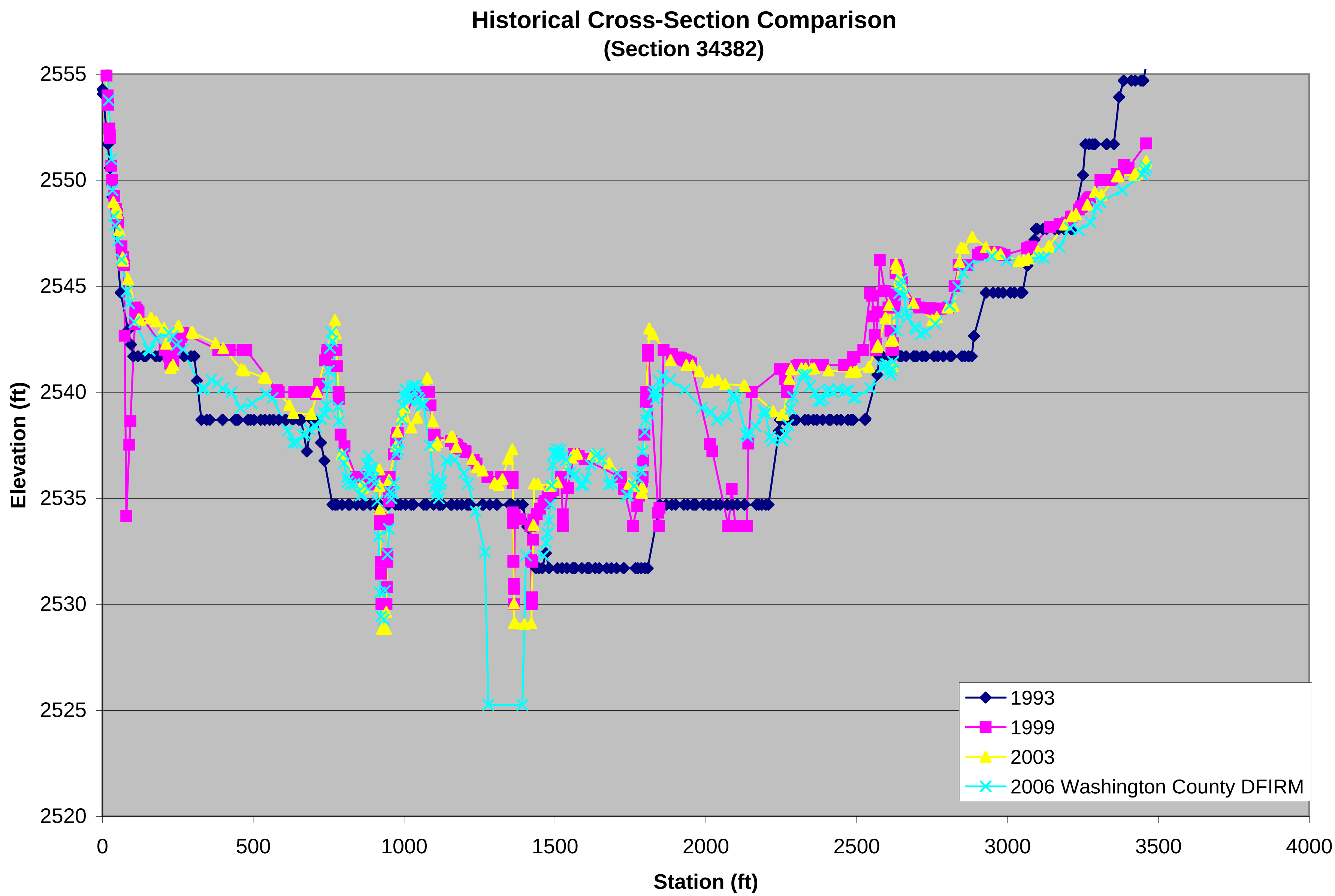
32026
30371



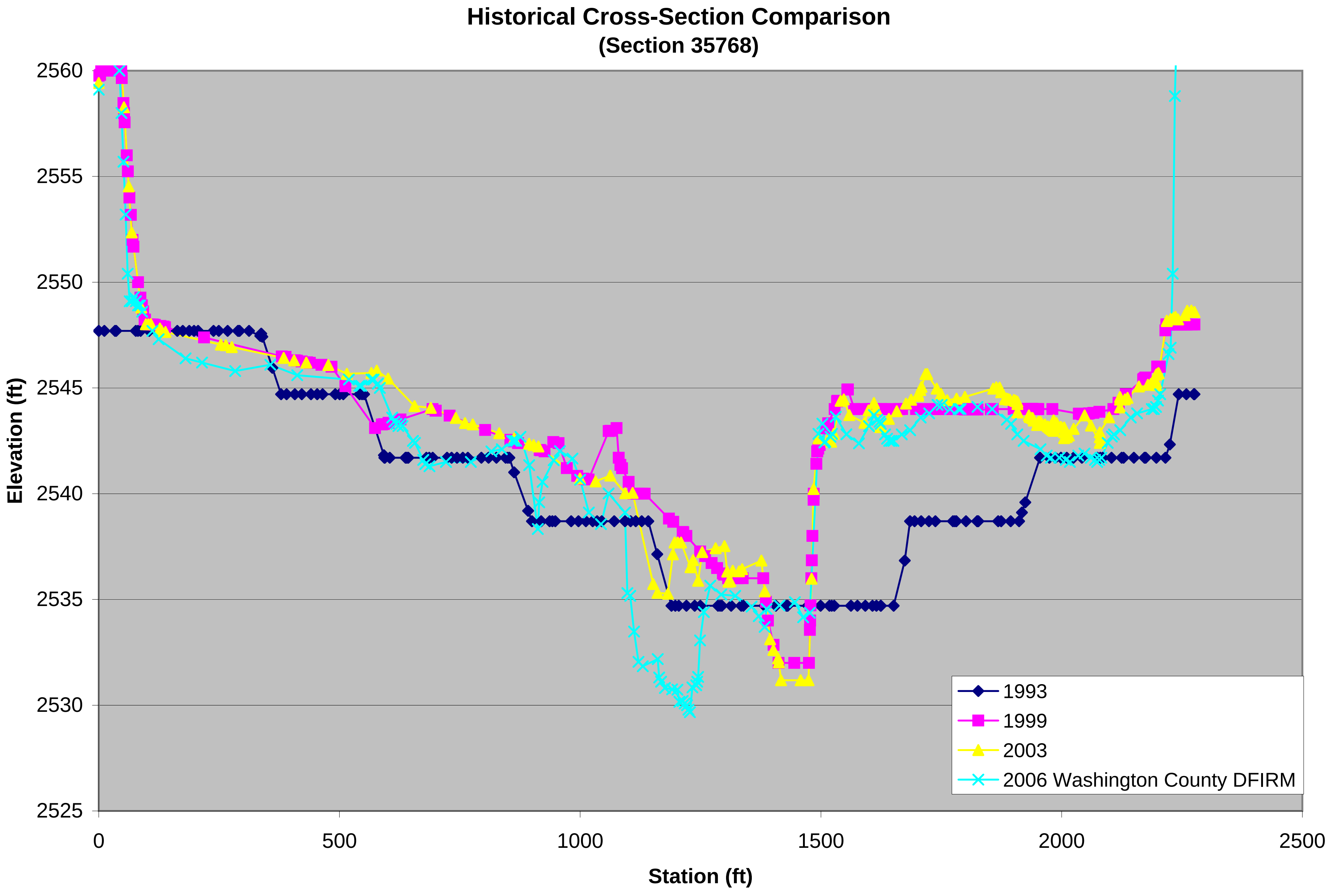
Historical Cross-Section Comparison
(Section 30371)
Elevation (ft)
2660
2640
2620
2600
2580
2560
2540
2520
2500
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)
1993
1999
2003
2006 Washington County DFIRM



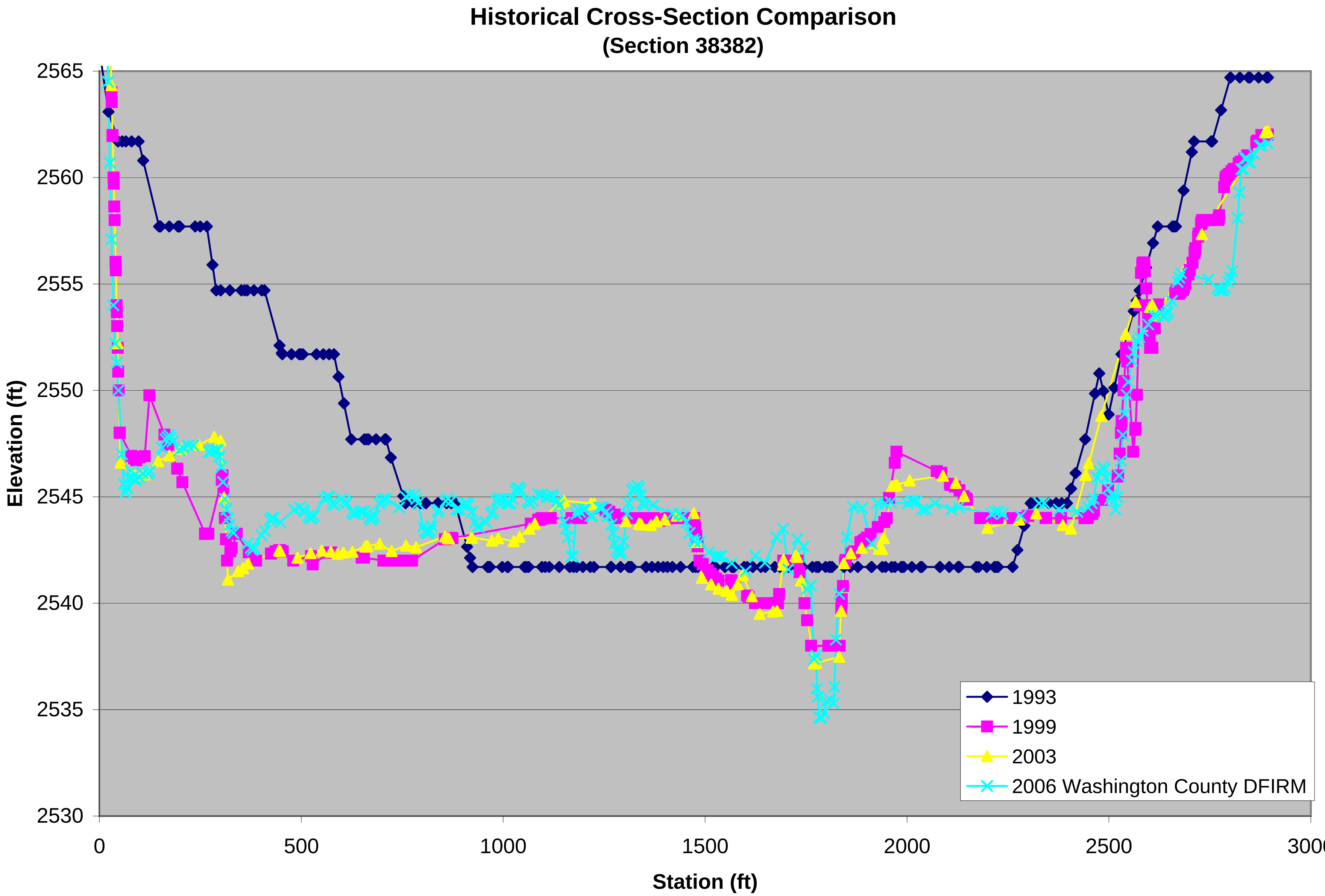
Historical Cross-Section Comparison
(Section 32026)
Elevation (ft)
2580
2570
2560
2550
2540
2530
2520
Station (ft)
0
200
400
600
800
1000
1200
1400
1600
1800
1993
1999
2003
2006 Washington County DFIRM



Historical Cross-Section Comparison
(Section 34382)
Elevation (ft)
Station (ft)
2555
2550
2545
2540
2535
2530
2525
2520
0
500
1000
1500
2000
2500
3000
3500
4000
1993
1999
2003
2006 Washington County DFIRM



Historical Cross-Section Comparison
(Section 35768)
Elevation (ft)
2560
2555
2550
2545
2540
2535
2530
2525
0
500
1000
1500
2000
2500
Station (ft)
1993
1999
2003
2006 Washington County DFIRM



Historical Cross-Section Comparison
(Section 38382)
Elevation (ft)
2565
2560
2555
2550
2545
2540
2535
2530
0
500
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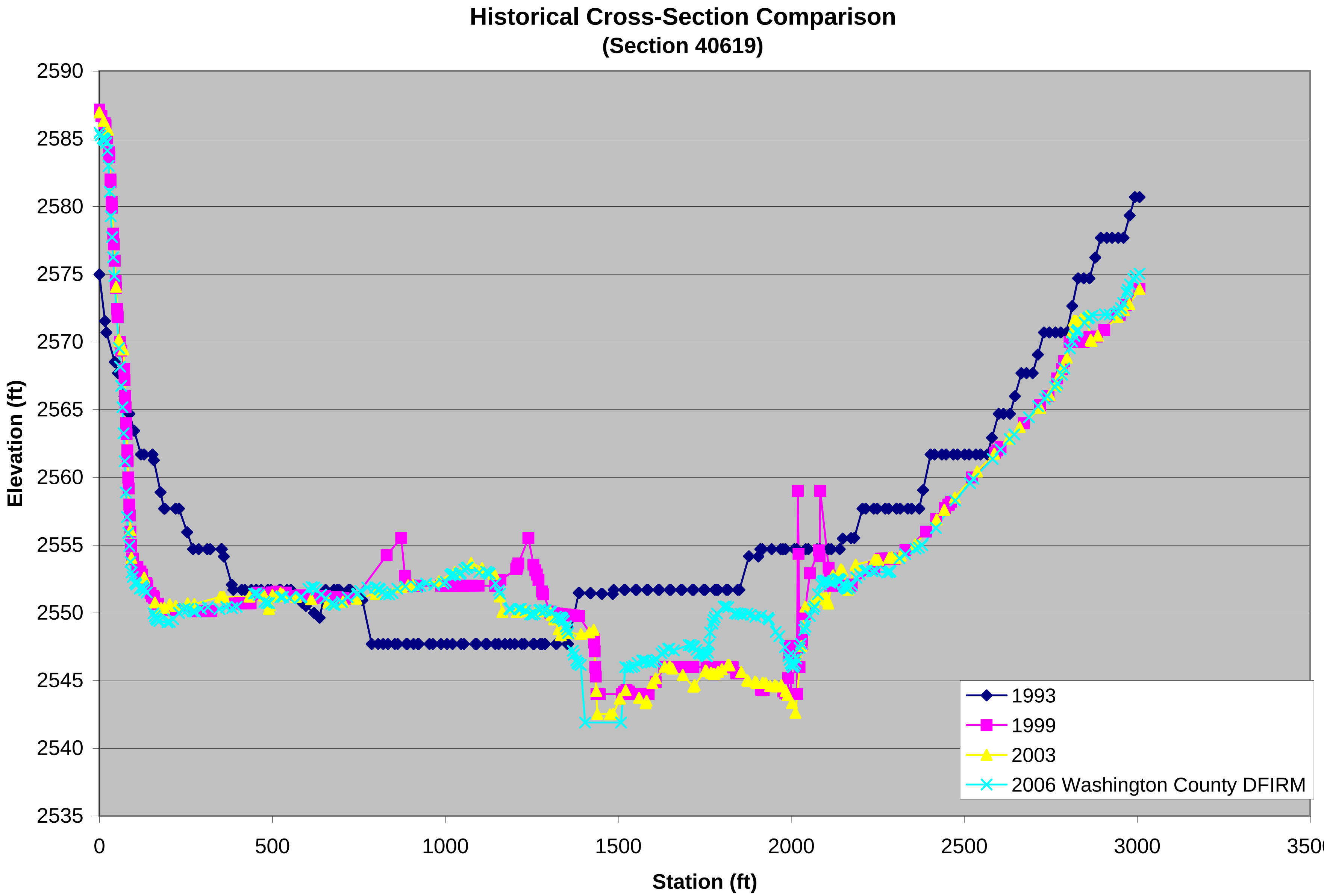
1999
2003
2006 Washington County DFIRM



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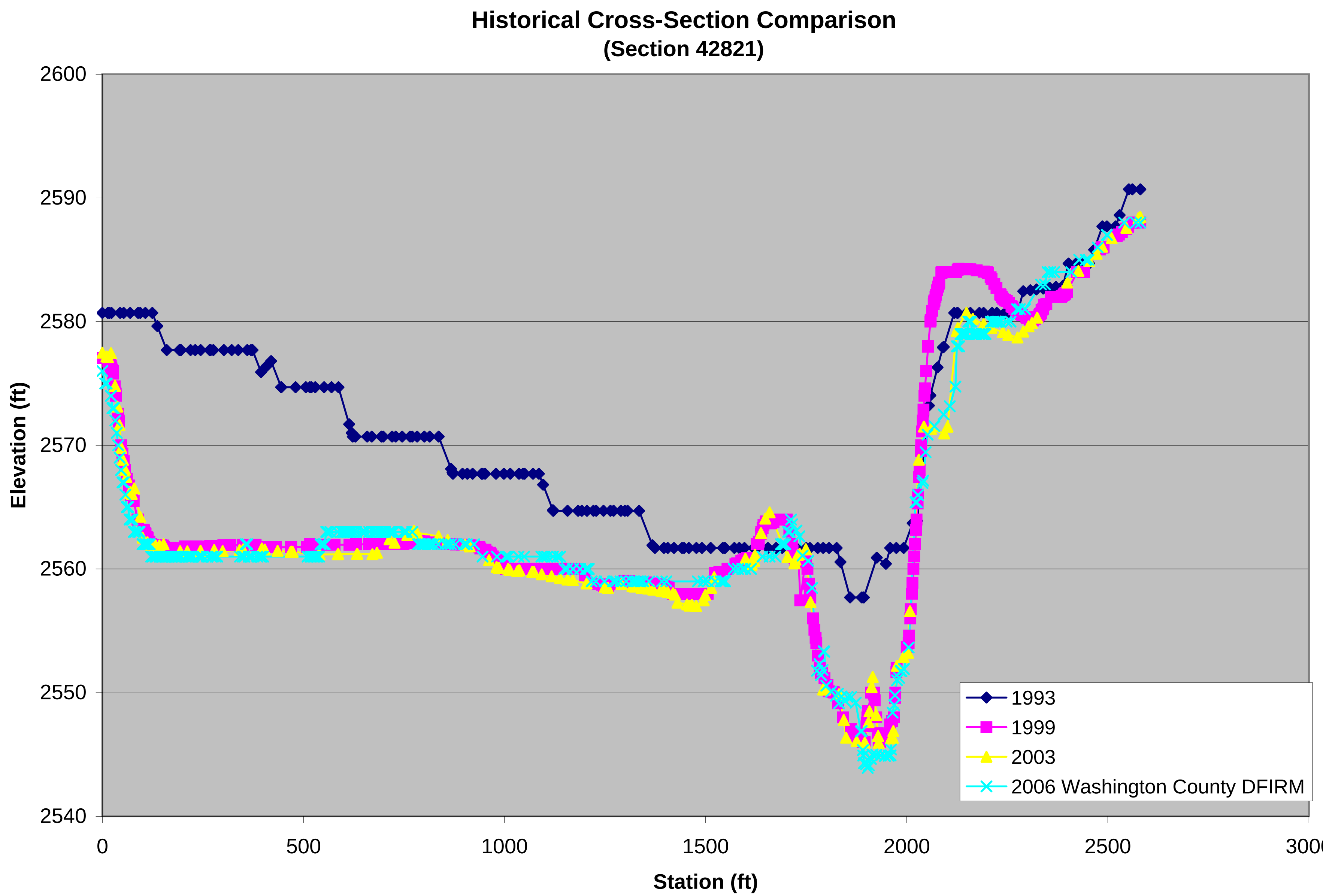

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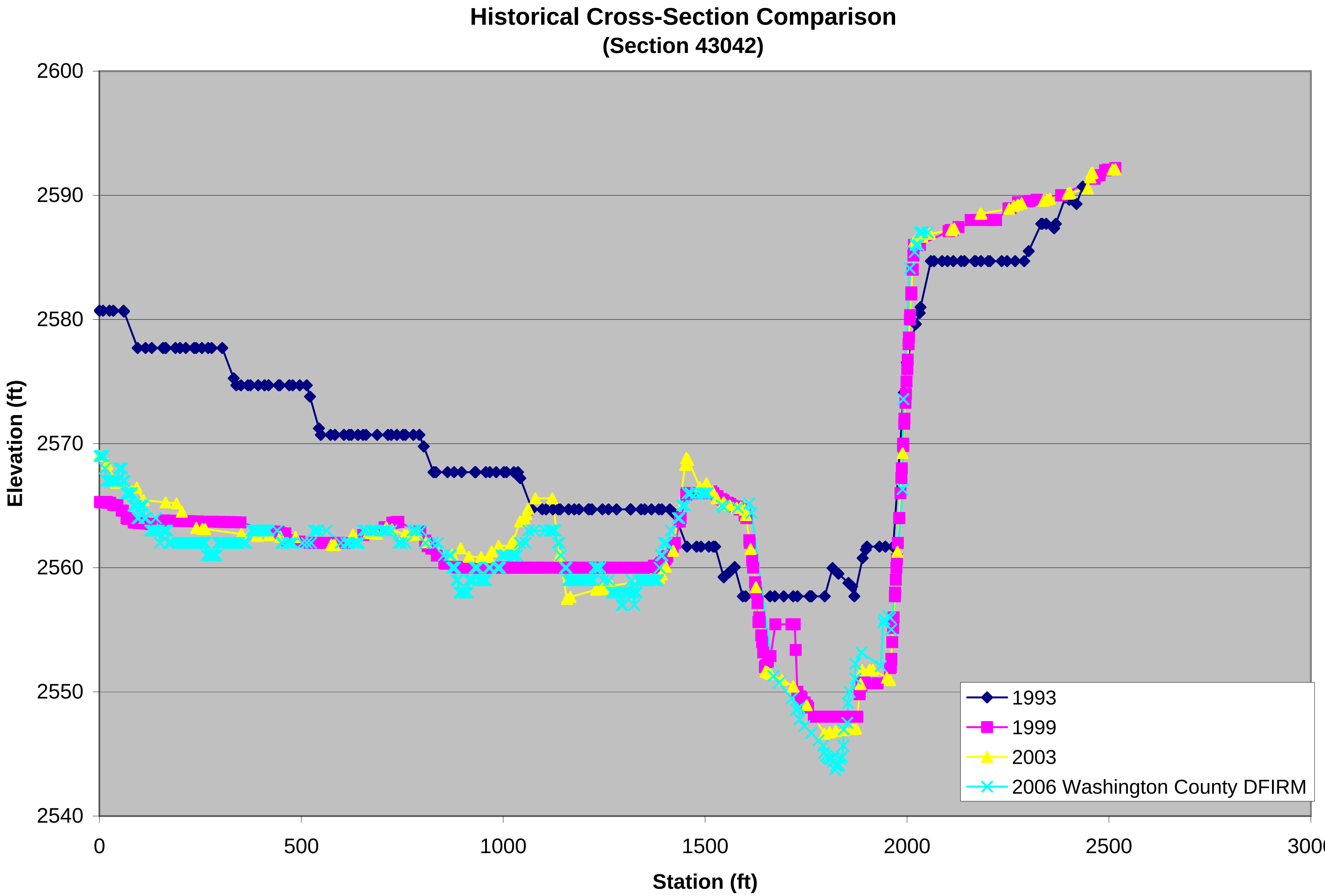

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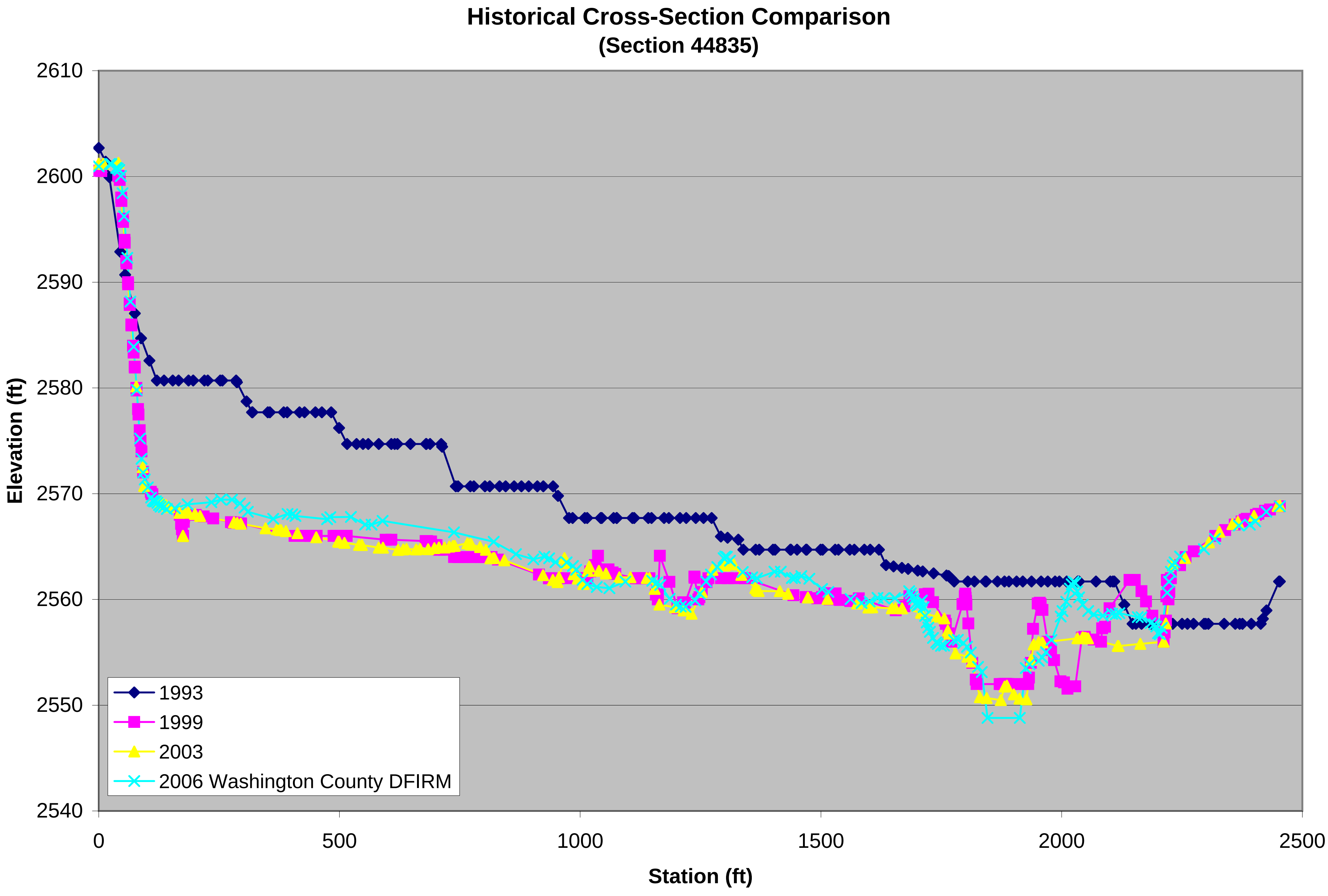

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2003
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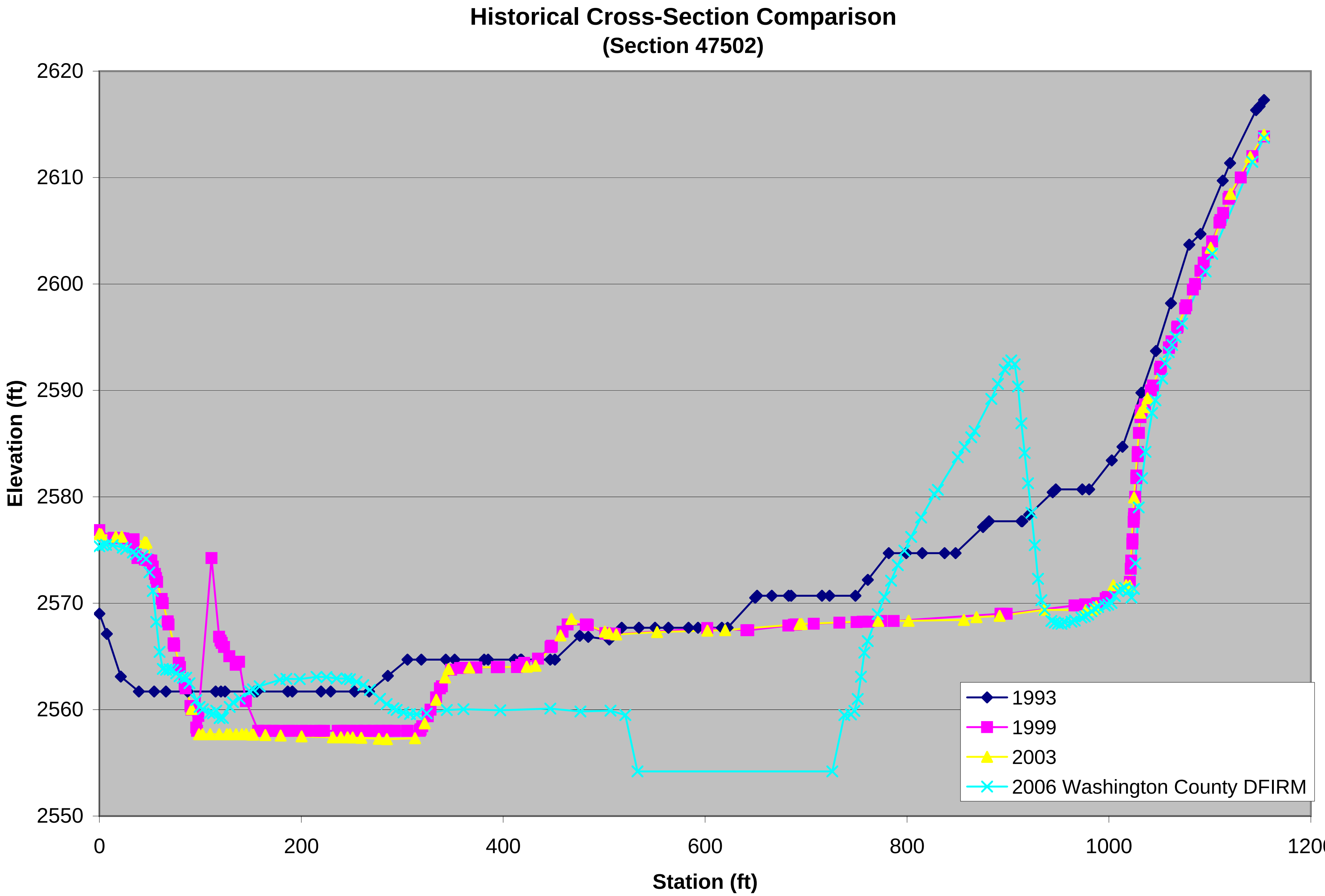

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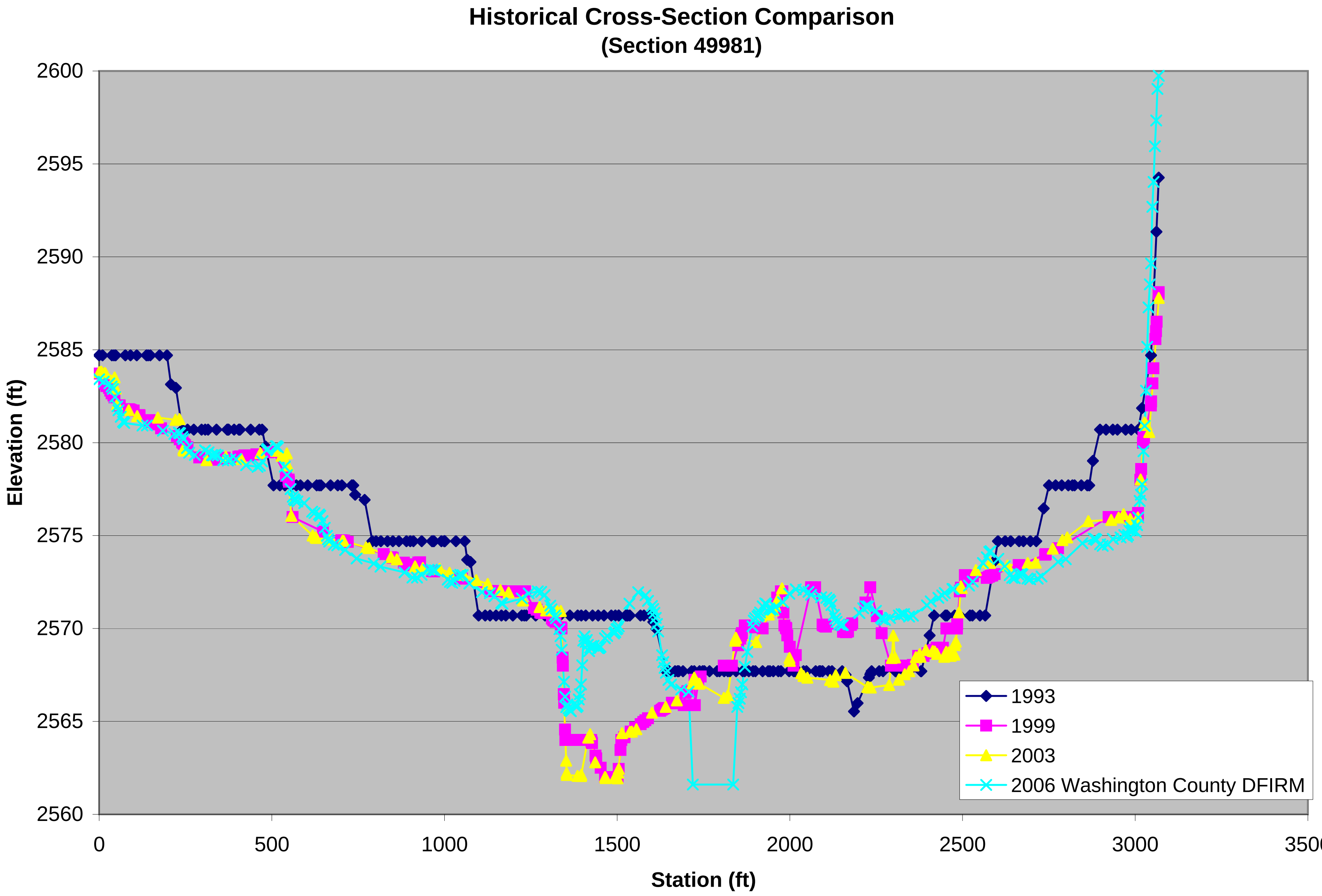
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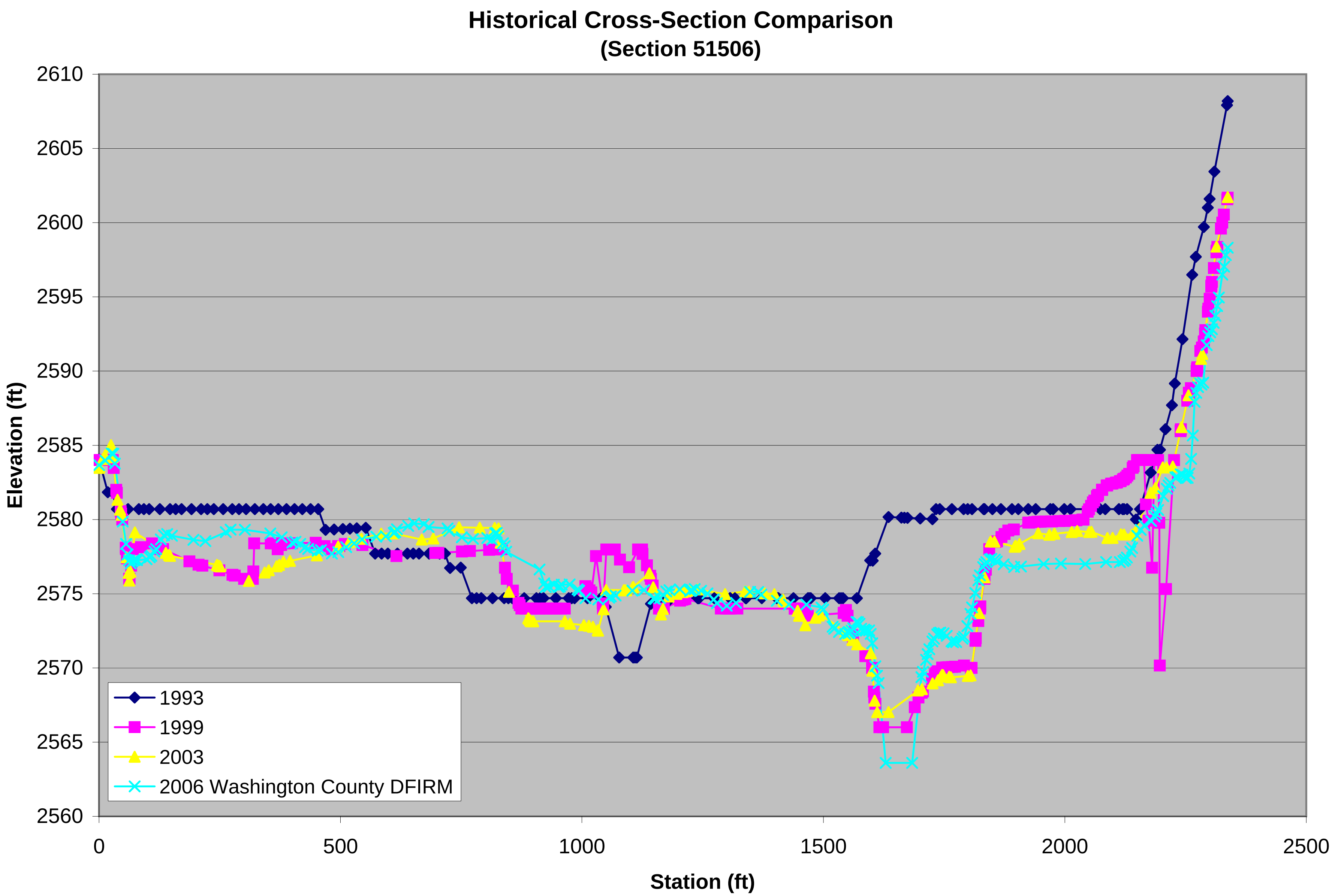

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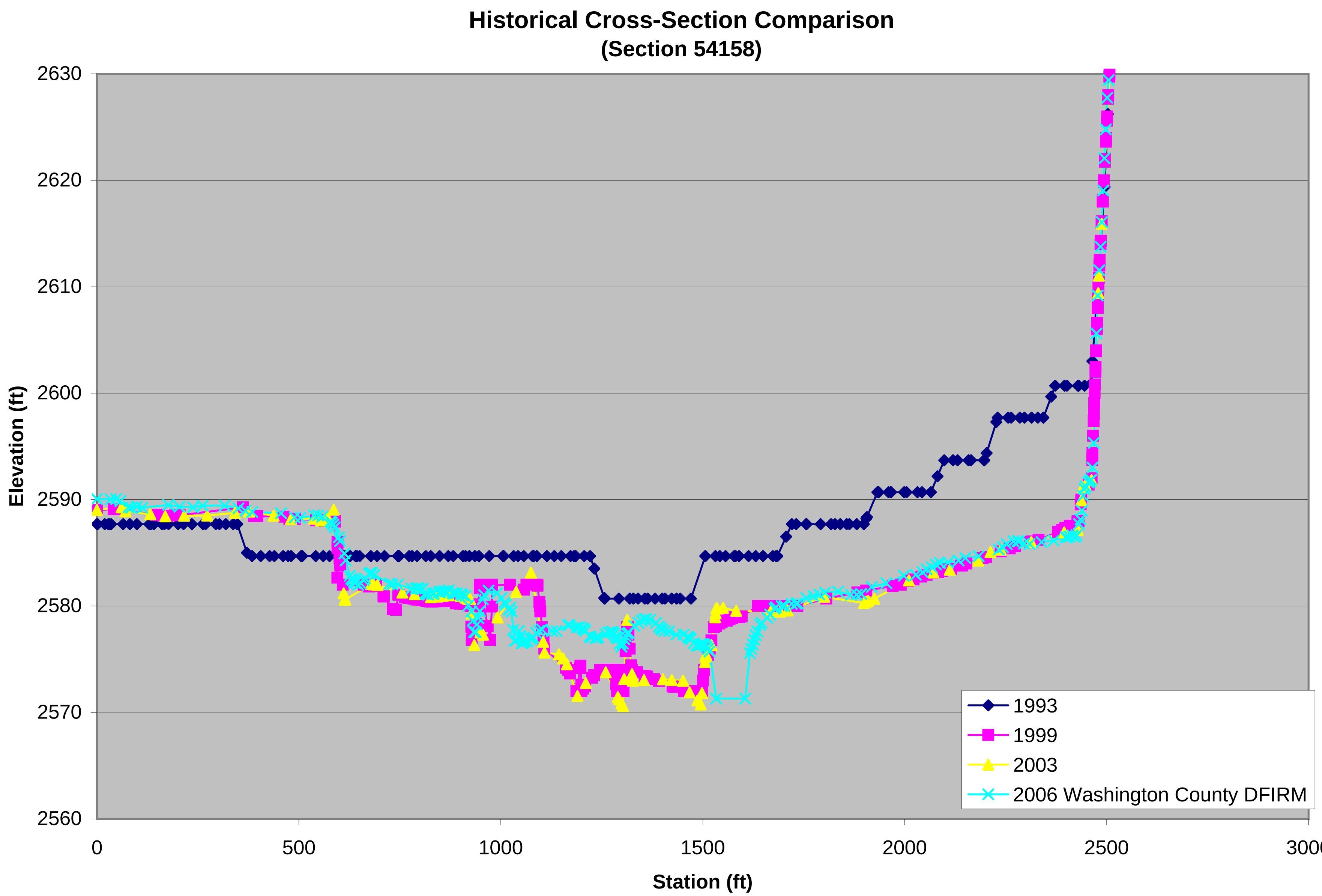

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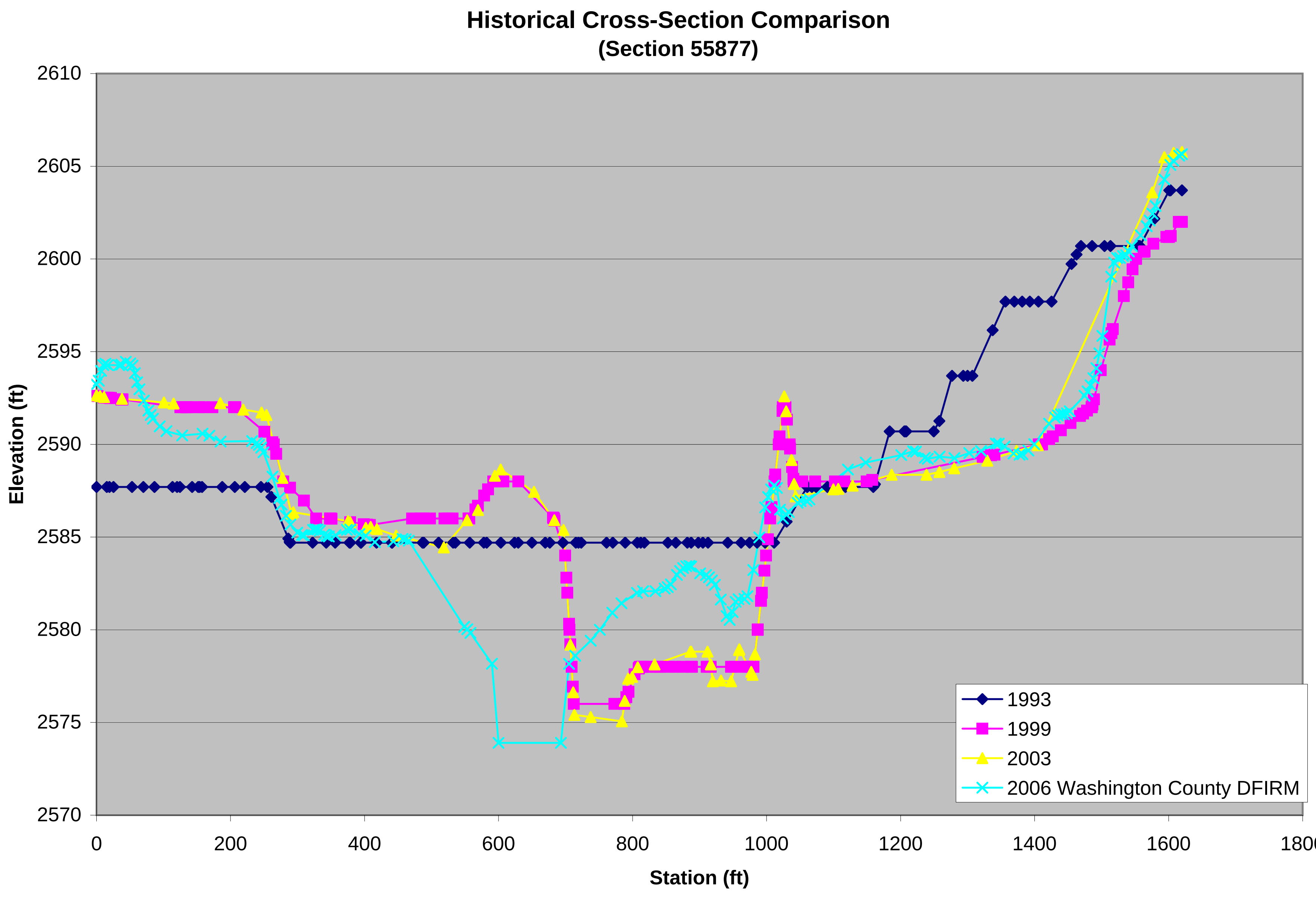

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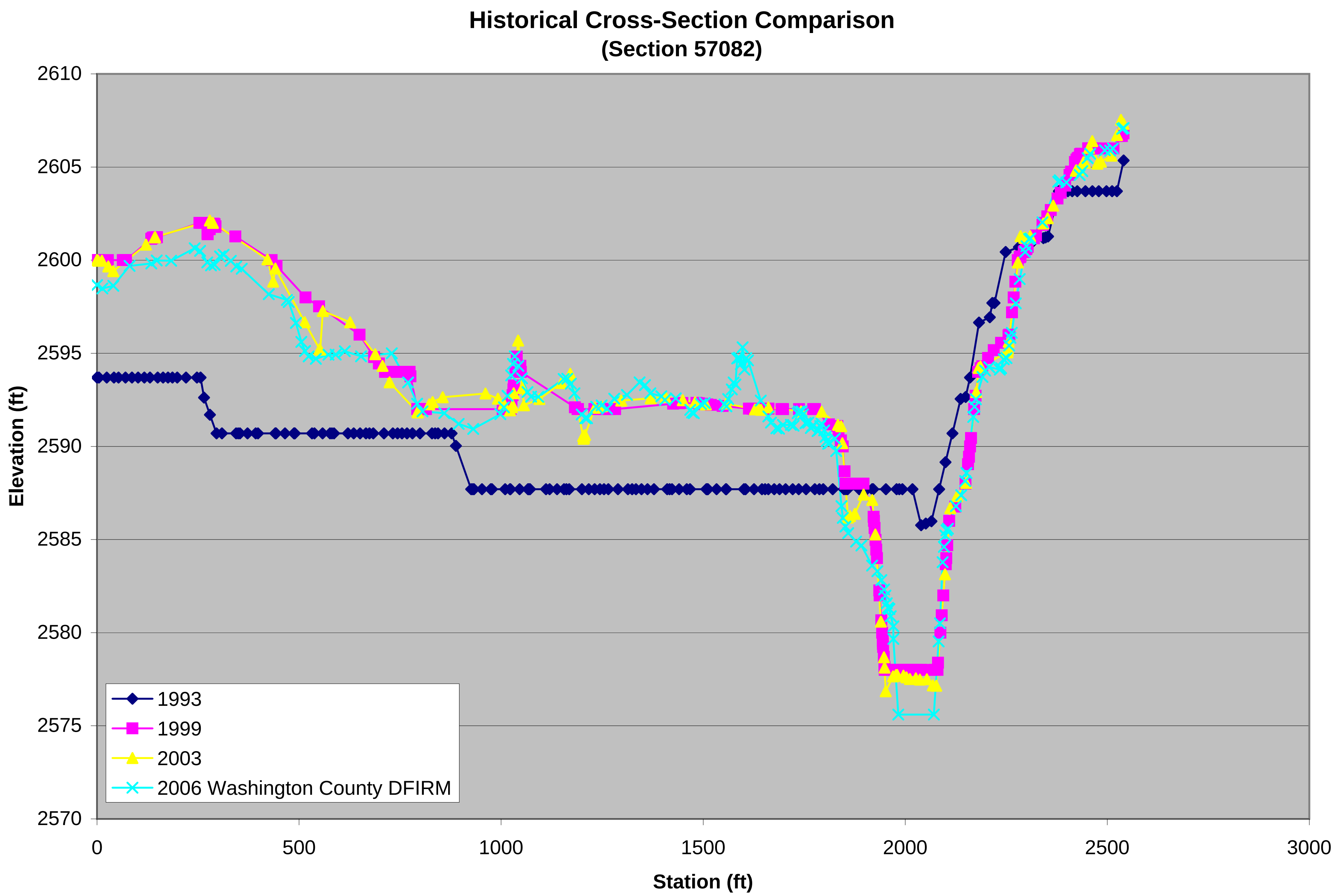

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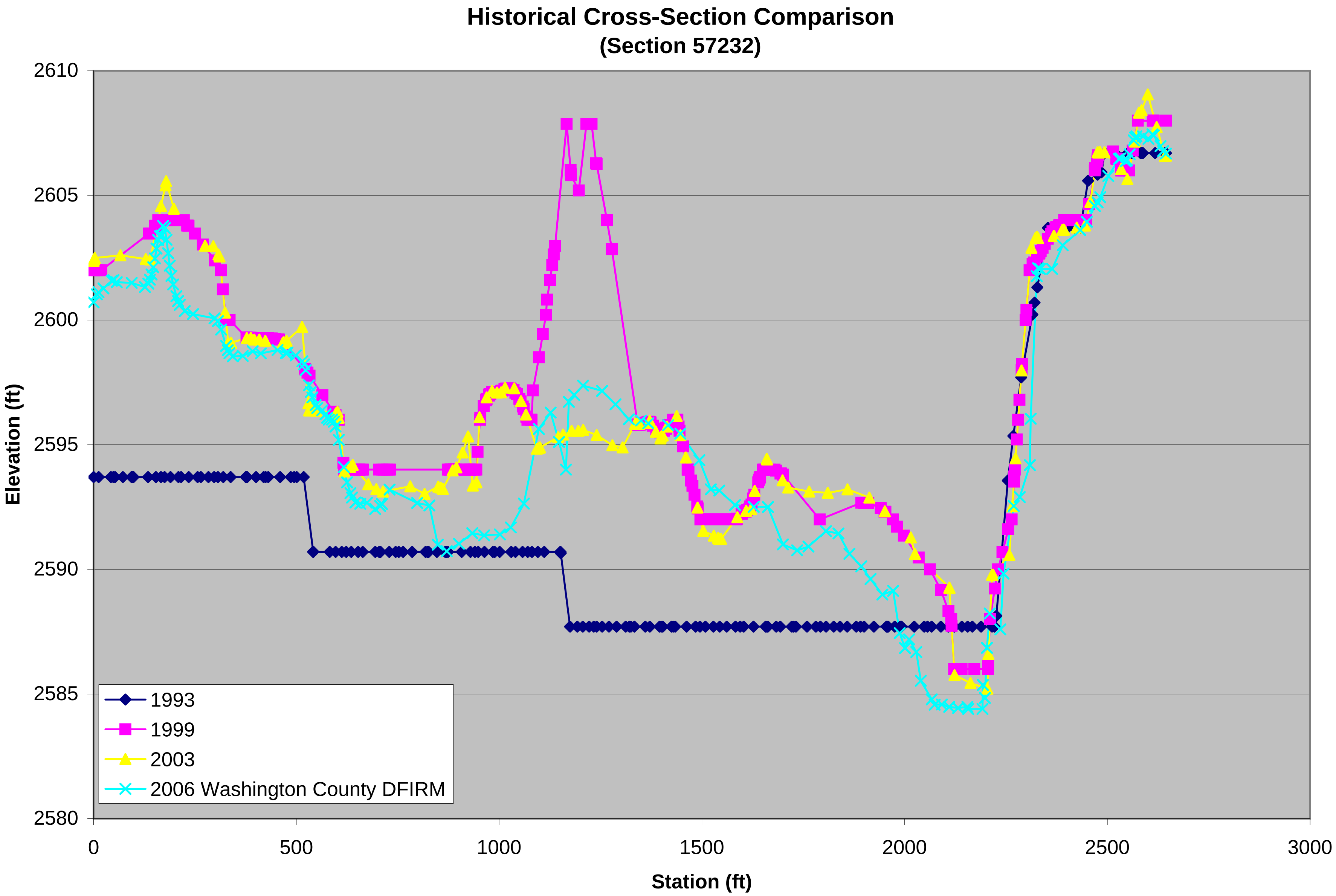
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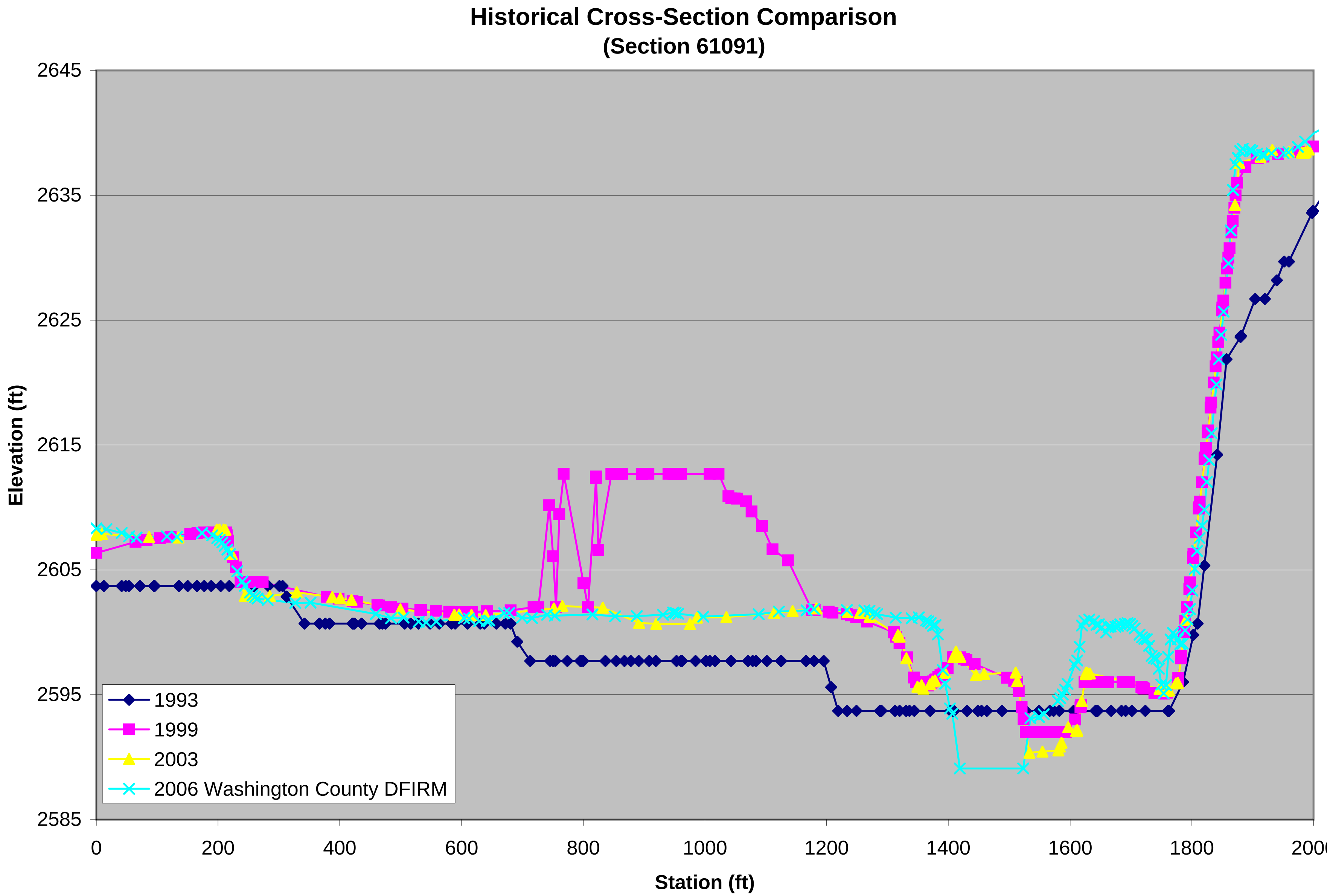
2006 Washington County DFIRM



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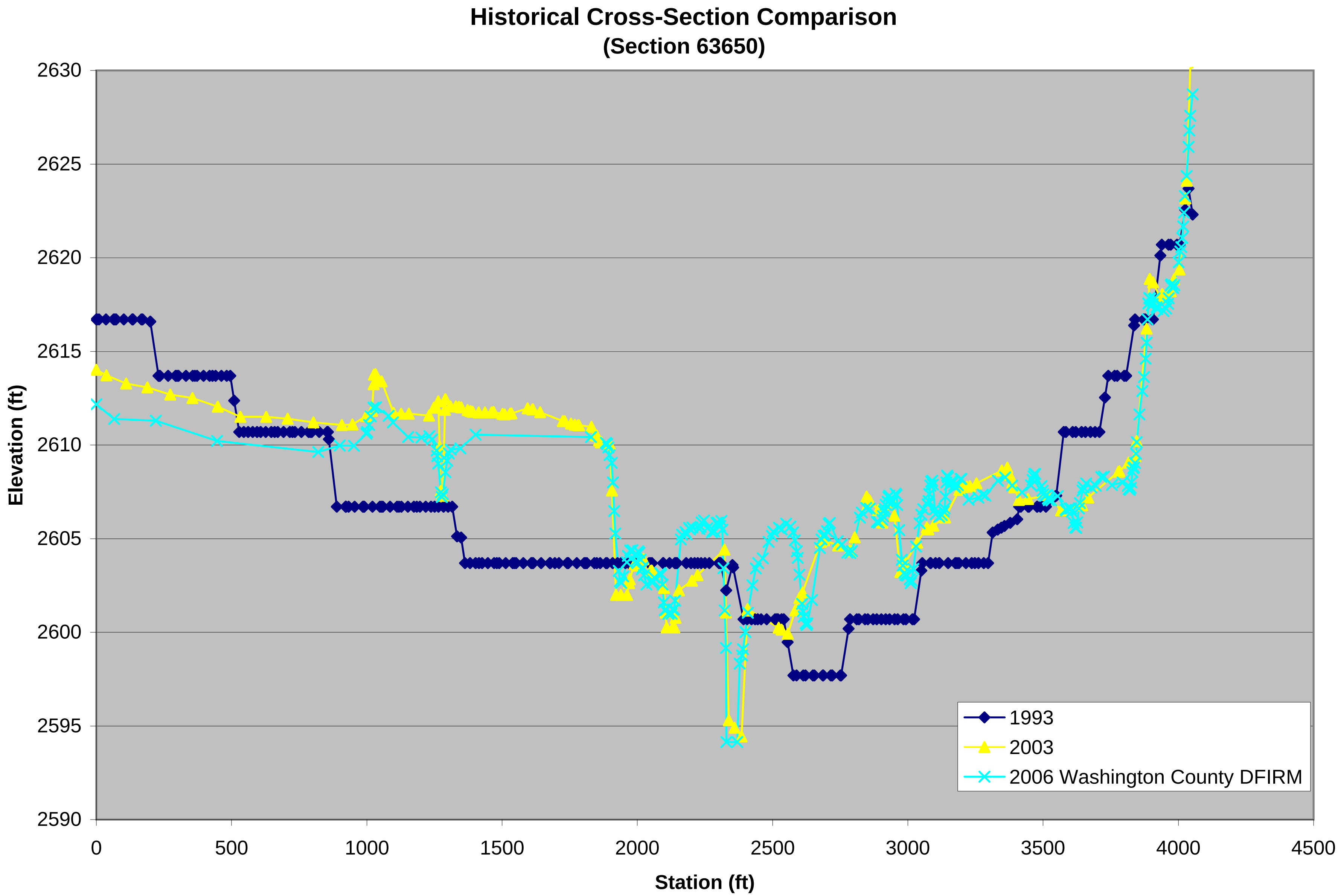

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Station (ft)
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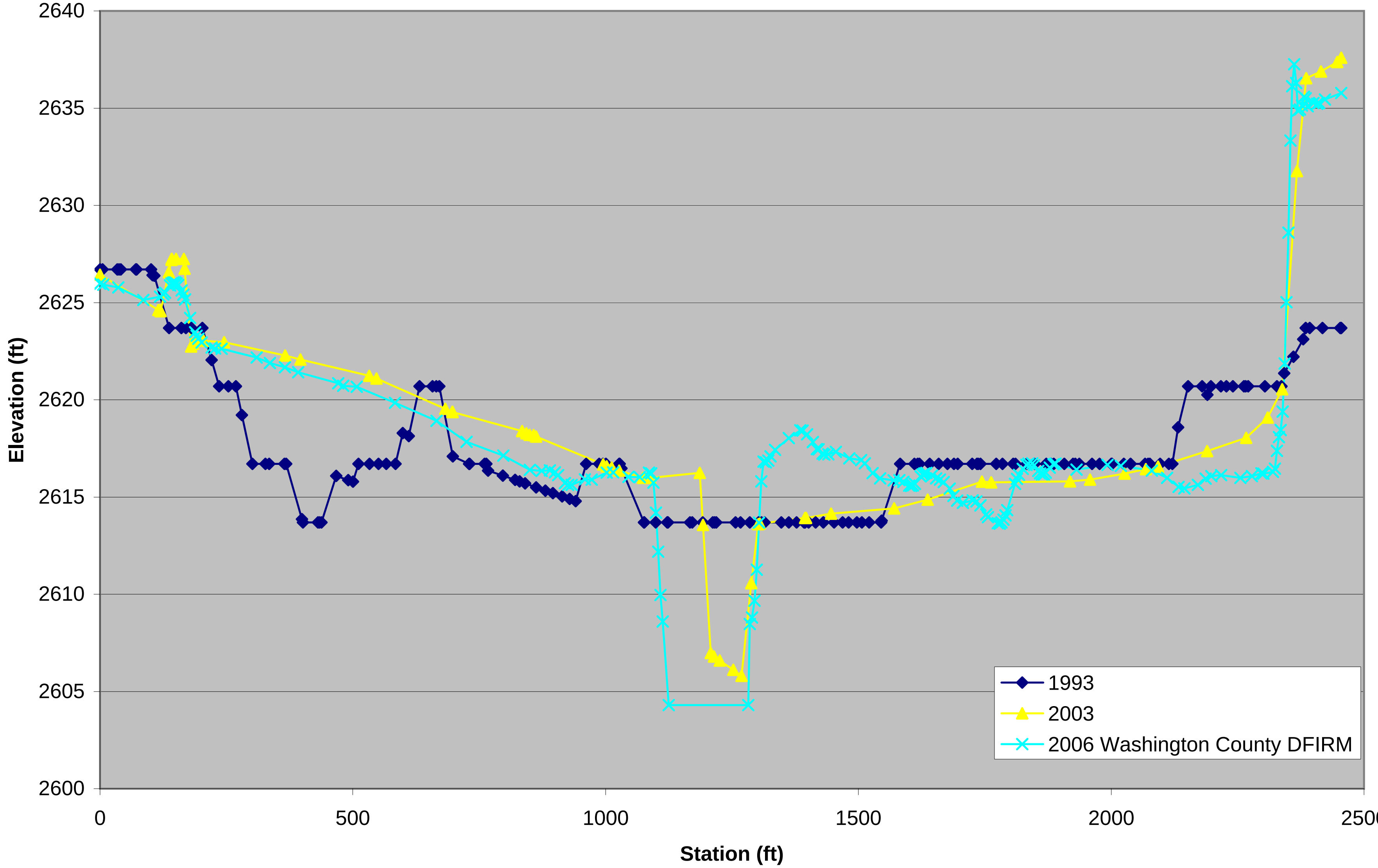

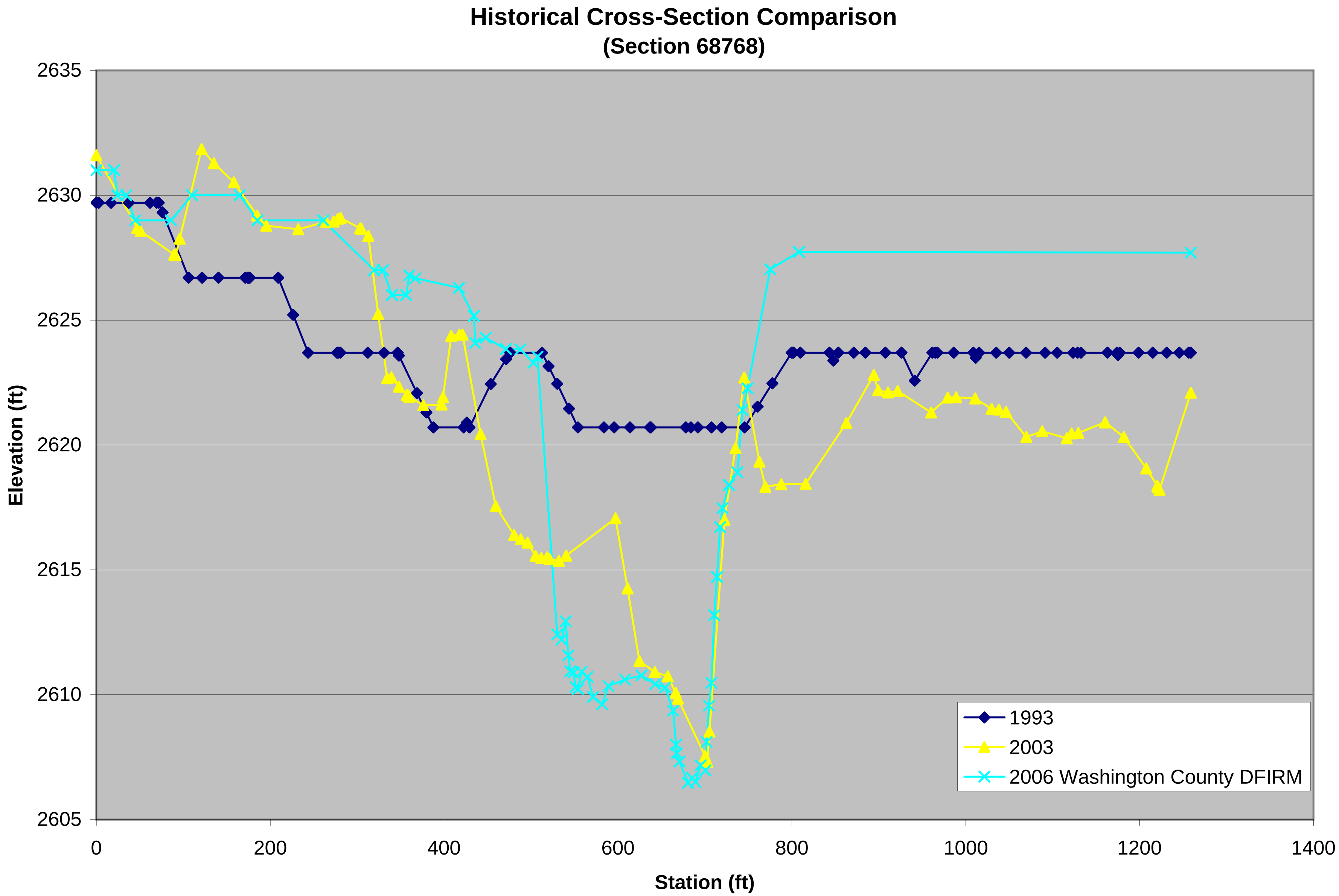

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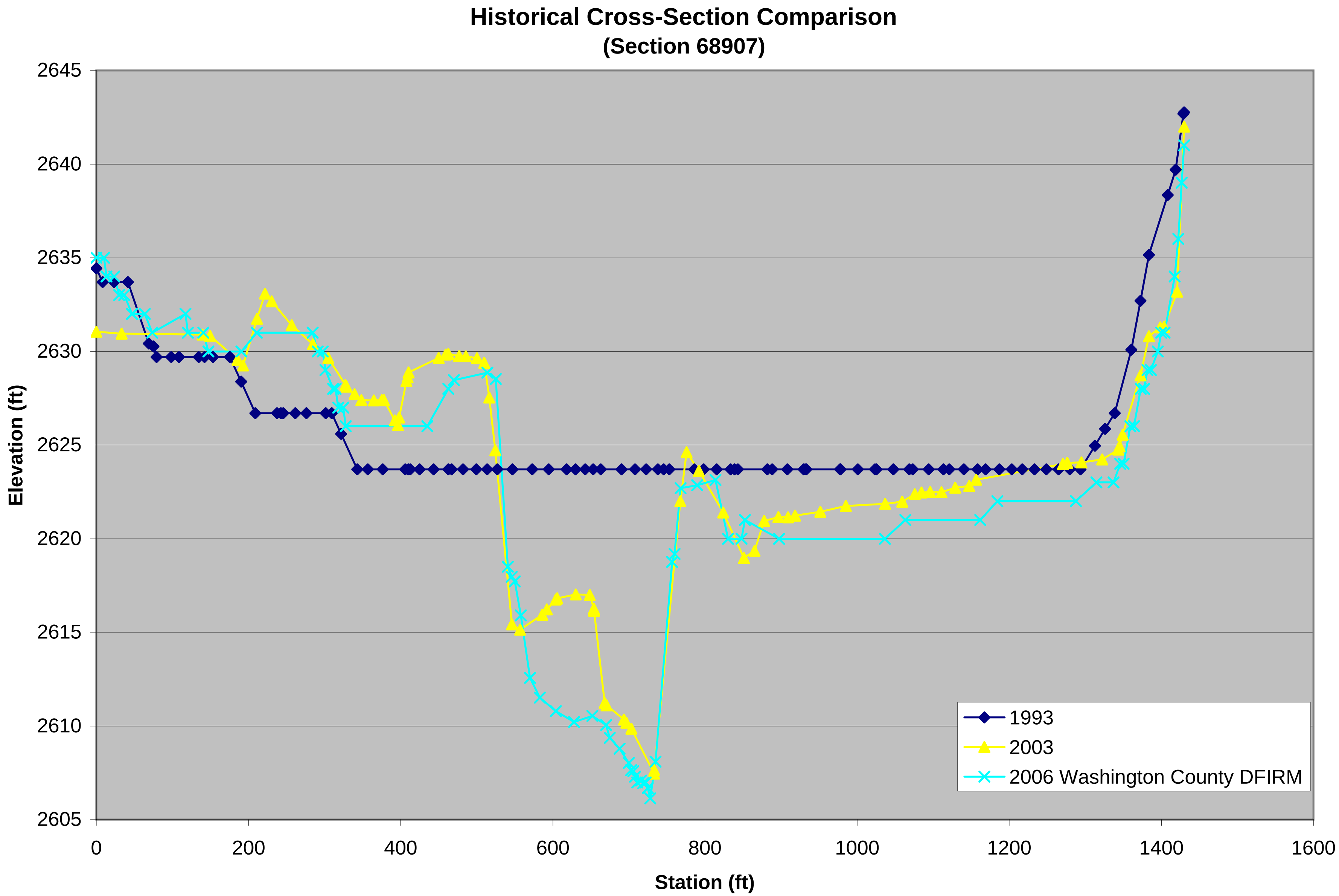
2006 Washington County DFIRM



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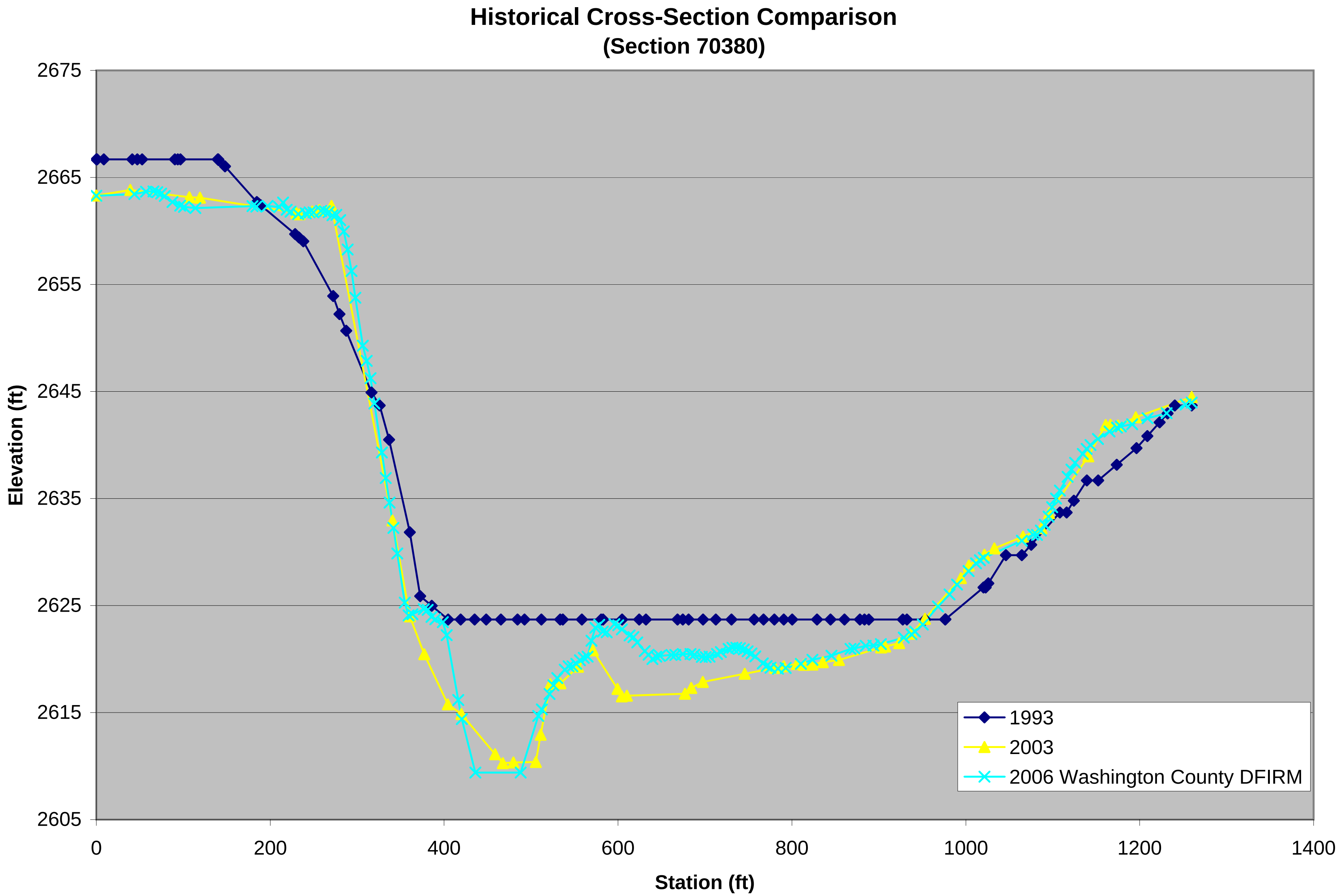
2006 Washington County DFIRM



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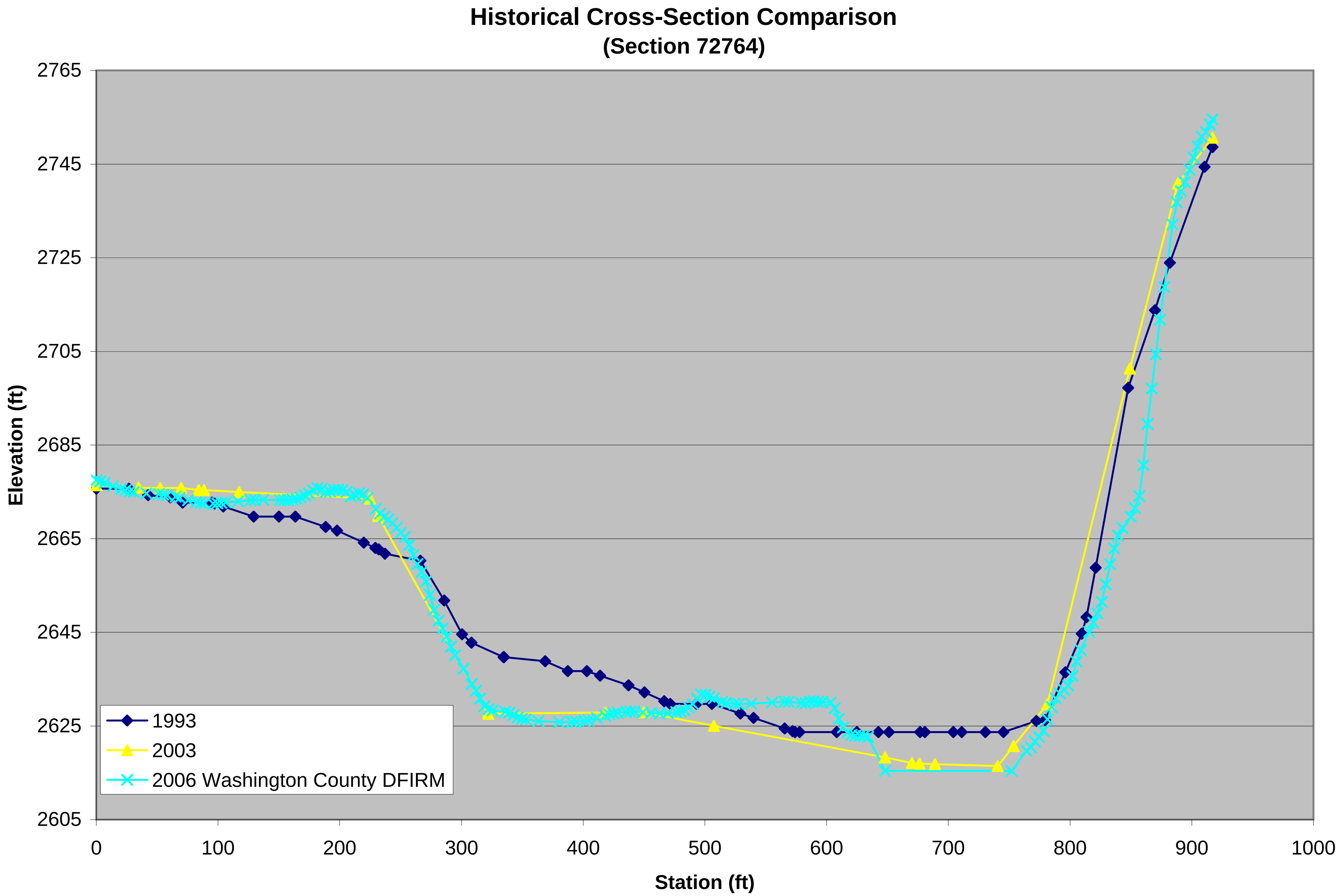

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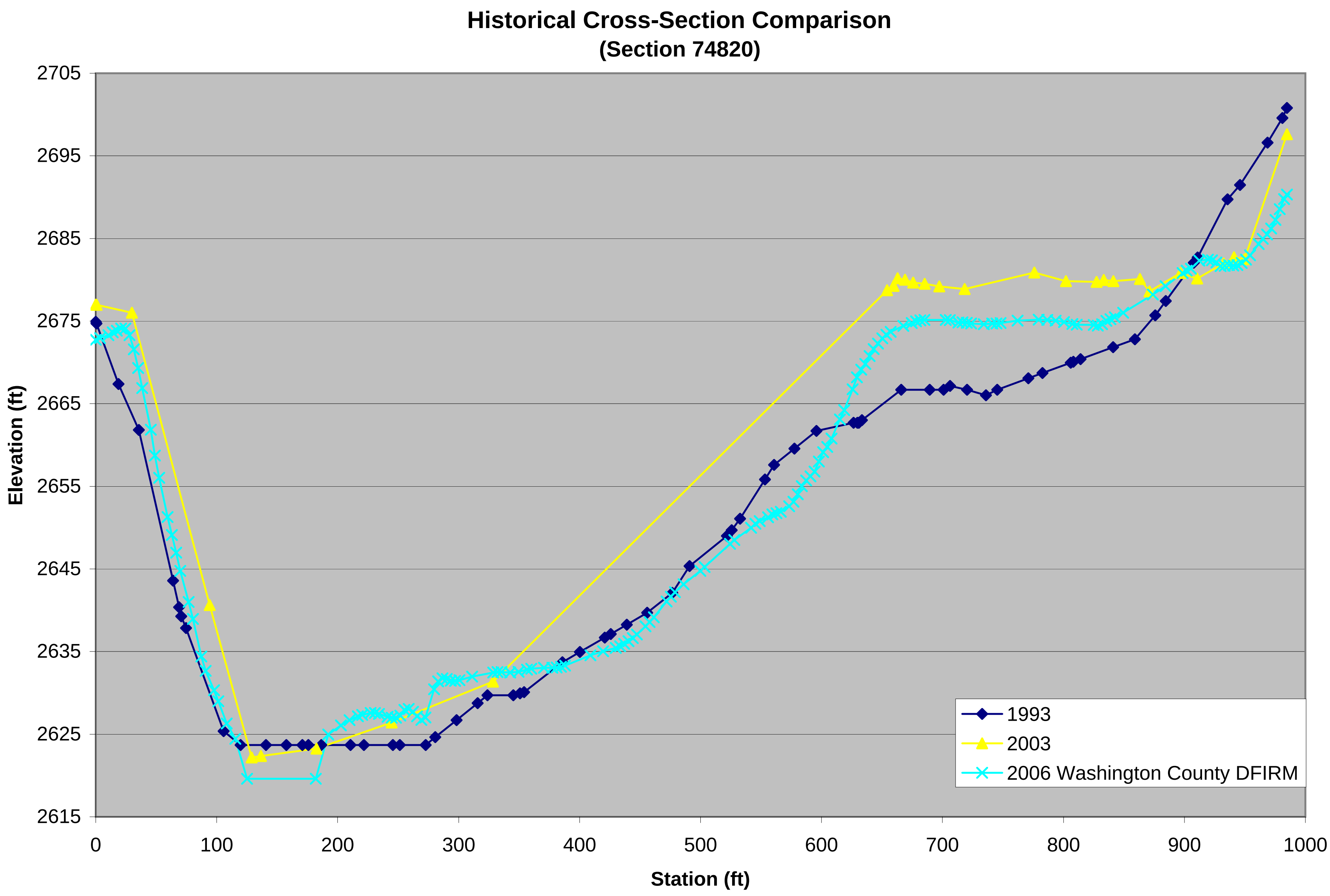

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Station (ft)
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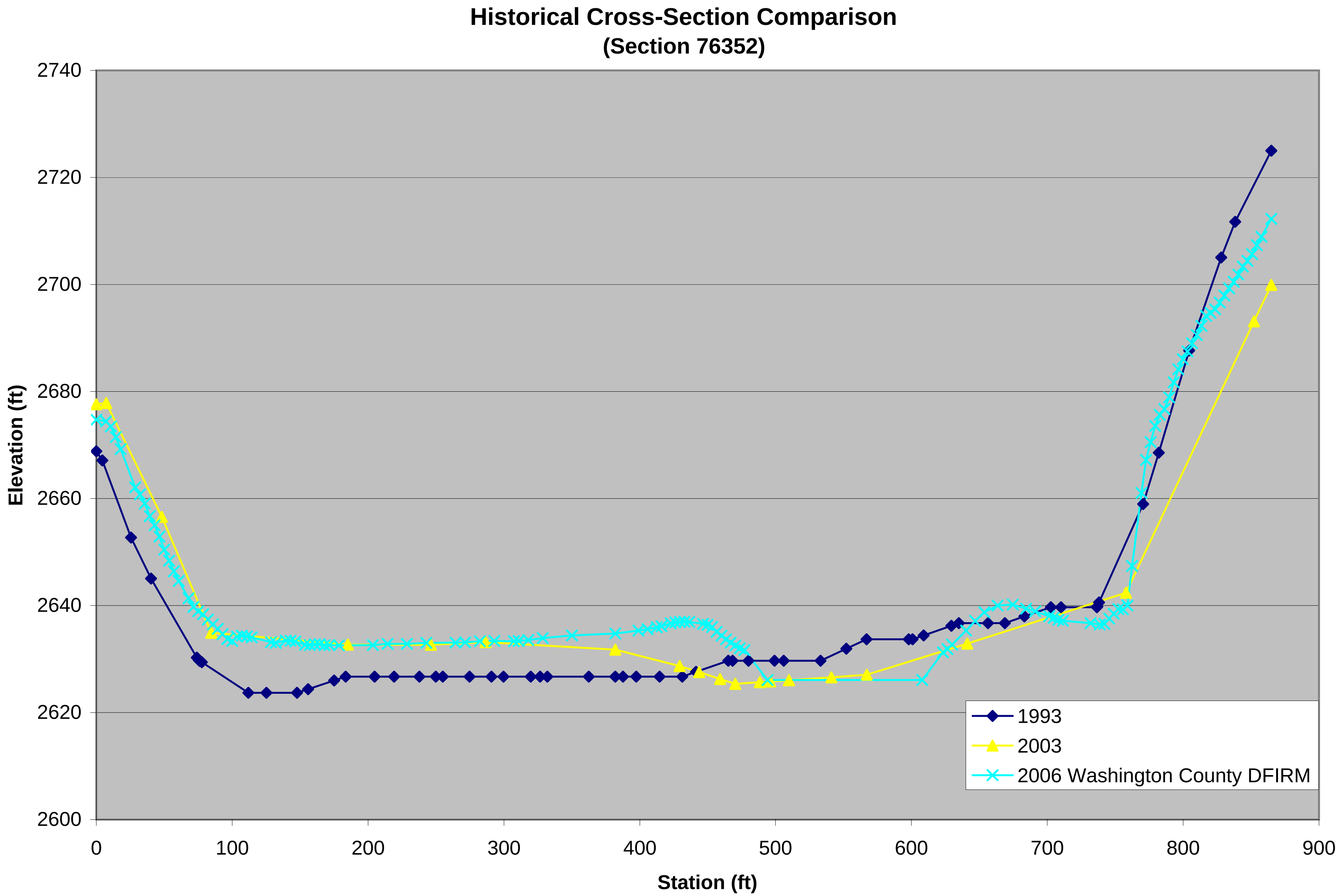
2006 Washington County DFIRM



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Station (ft)
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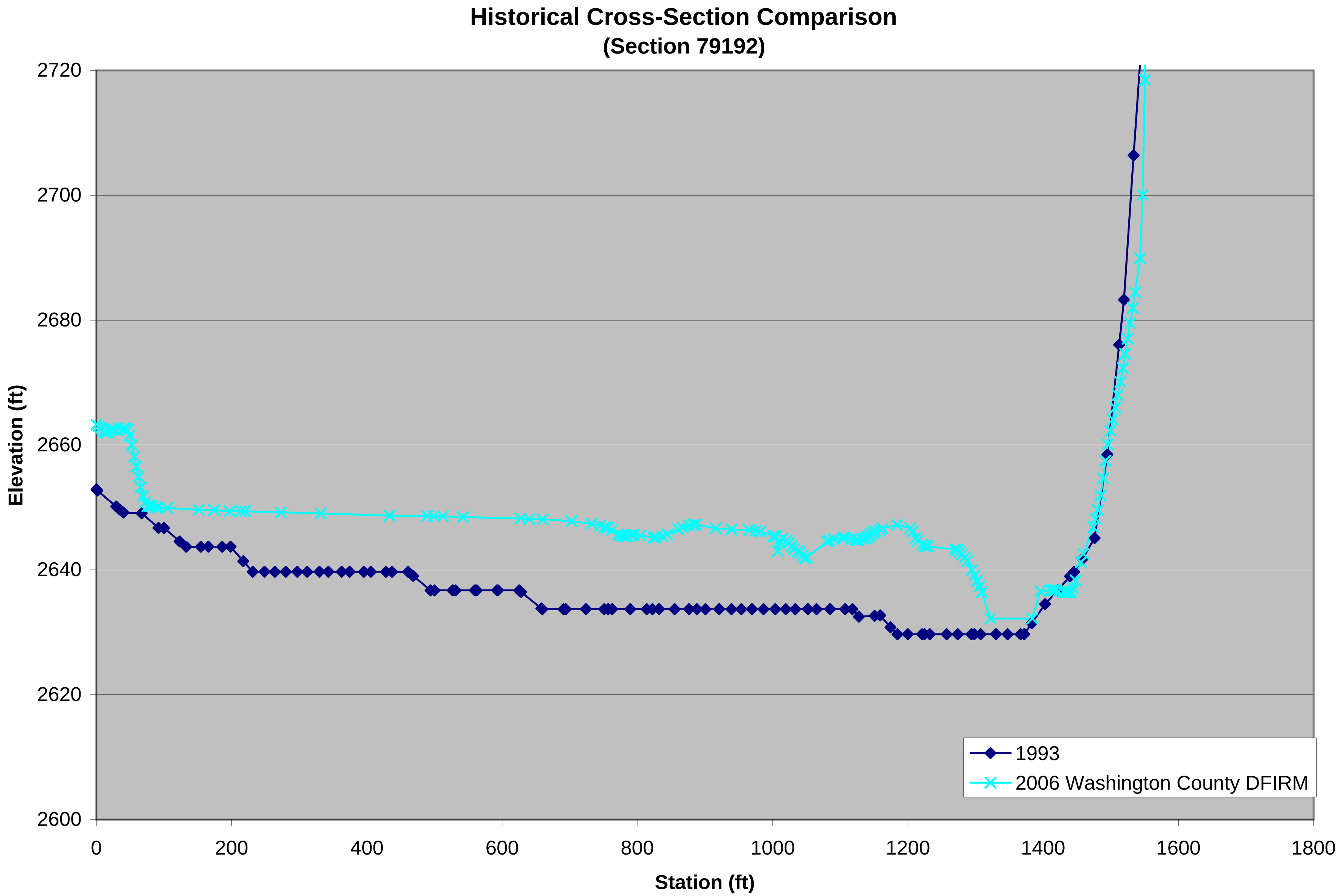
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Station (ft)
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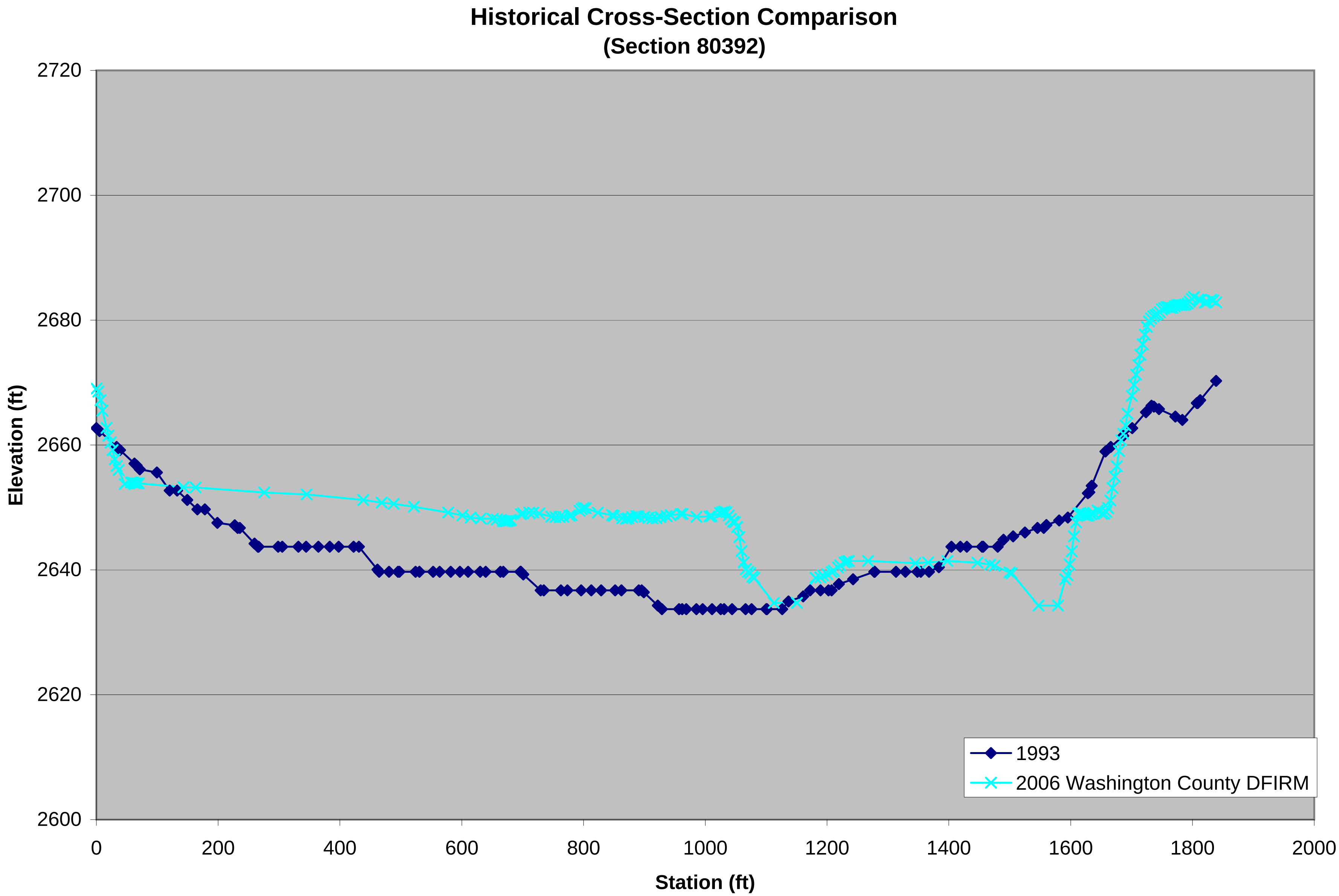
2006 Washington County DFIRM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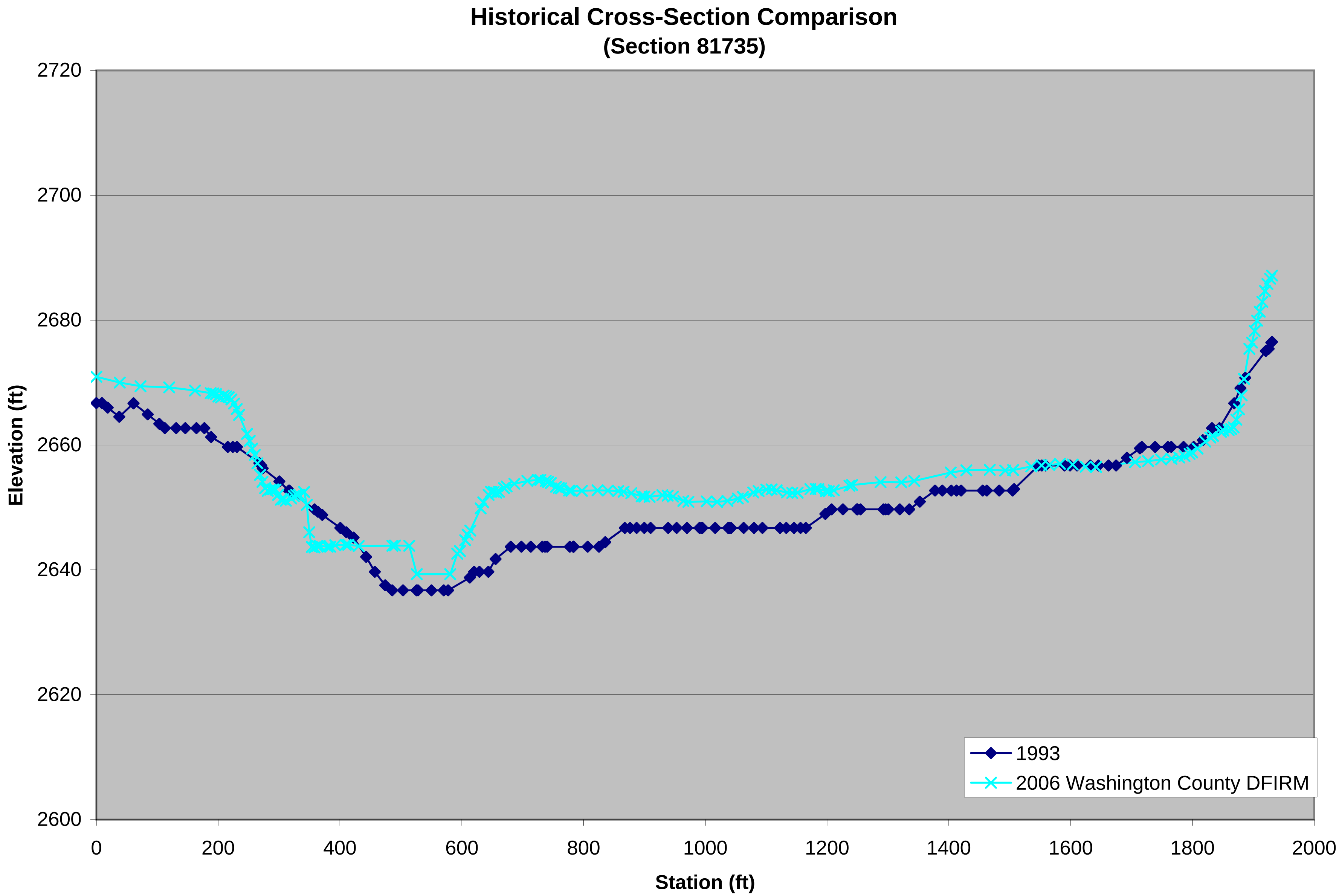
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Station (ft)
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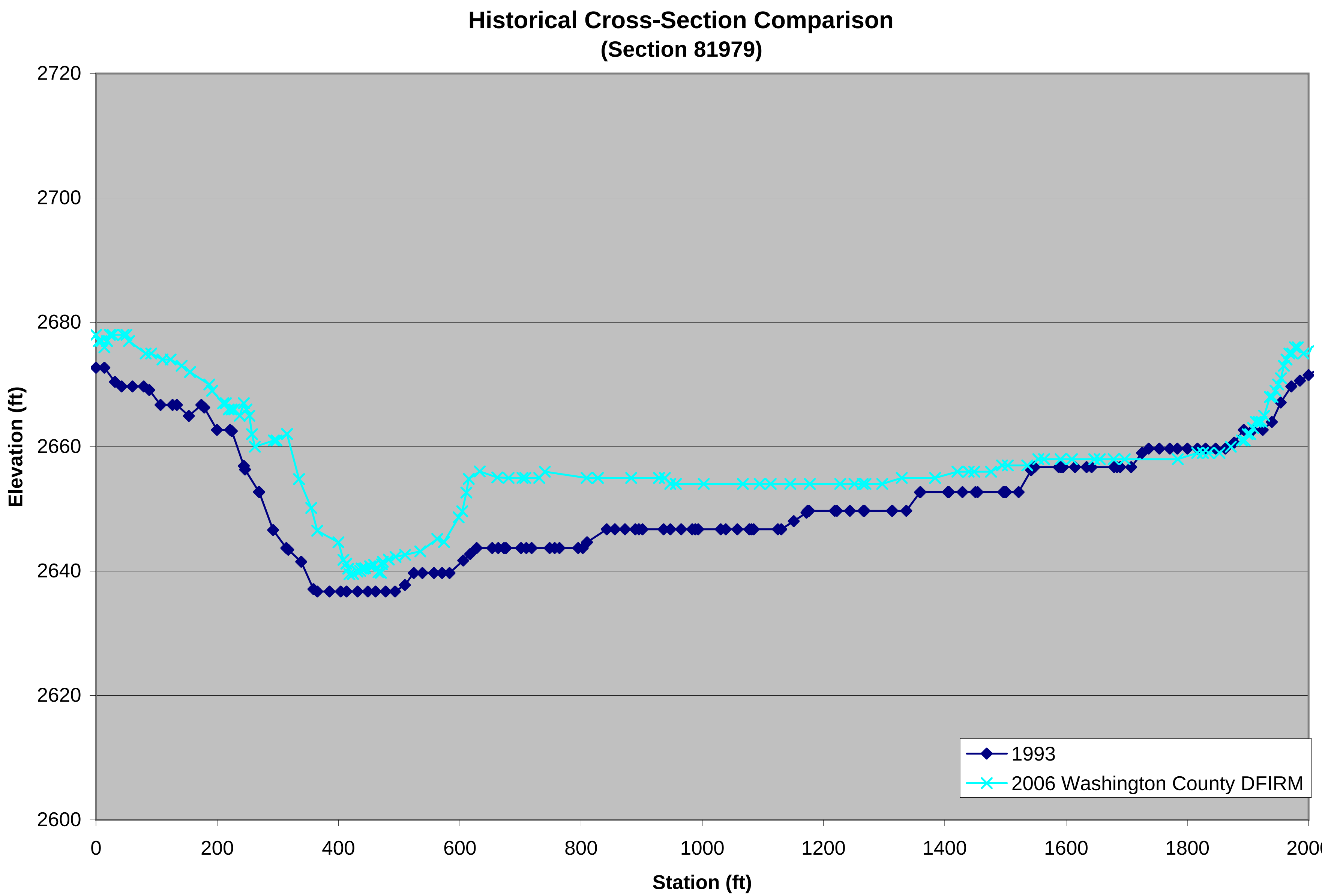
2006 Washington County DFIRM



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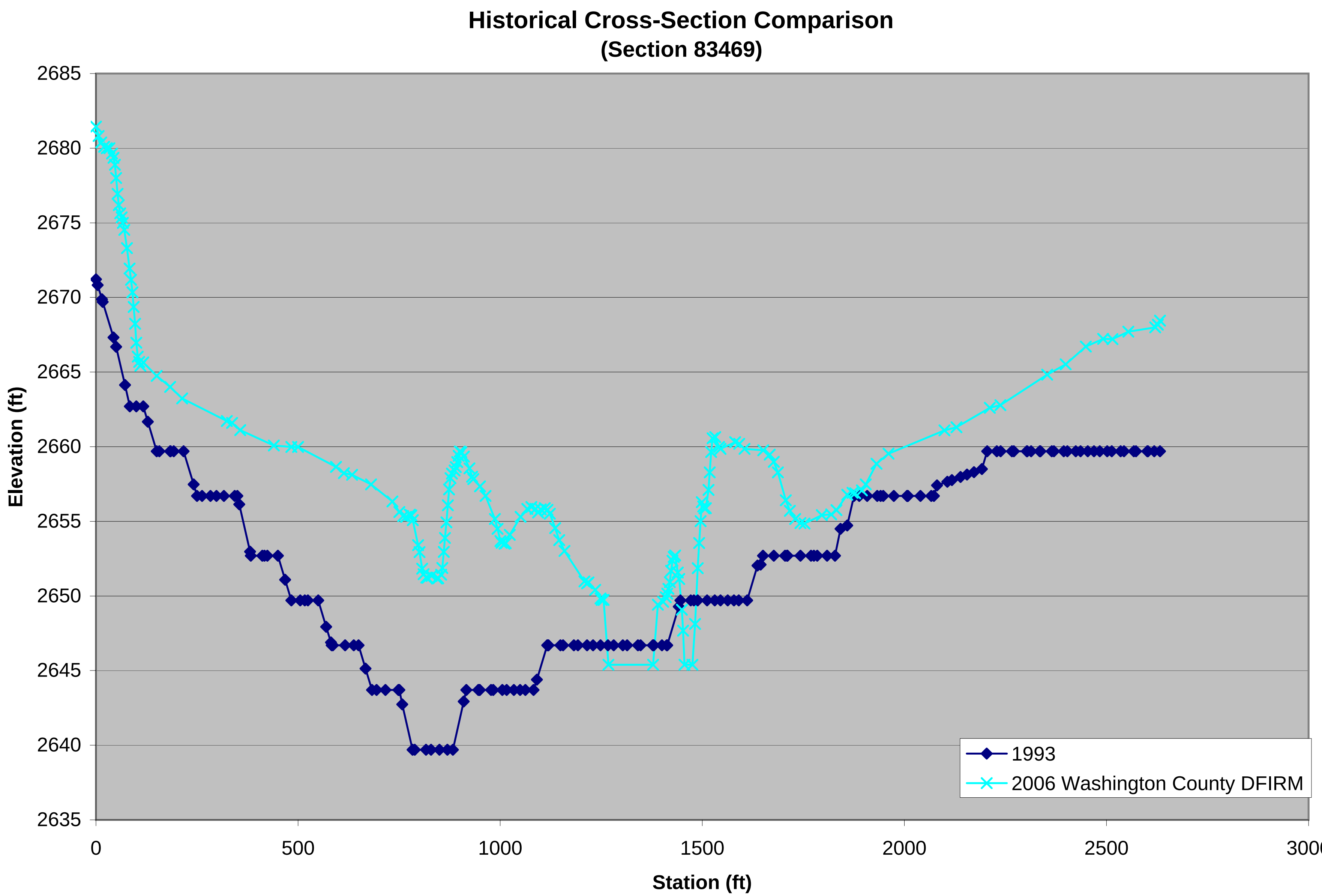

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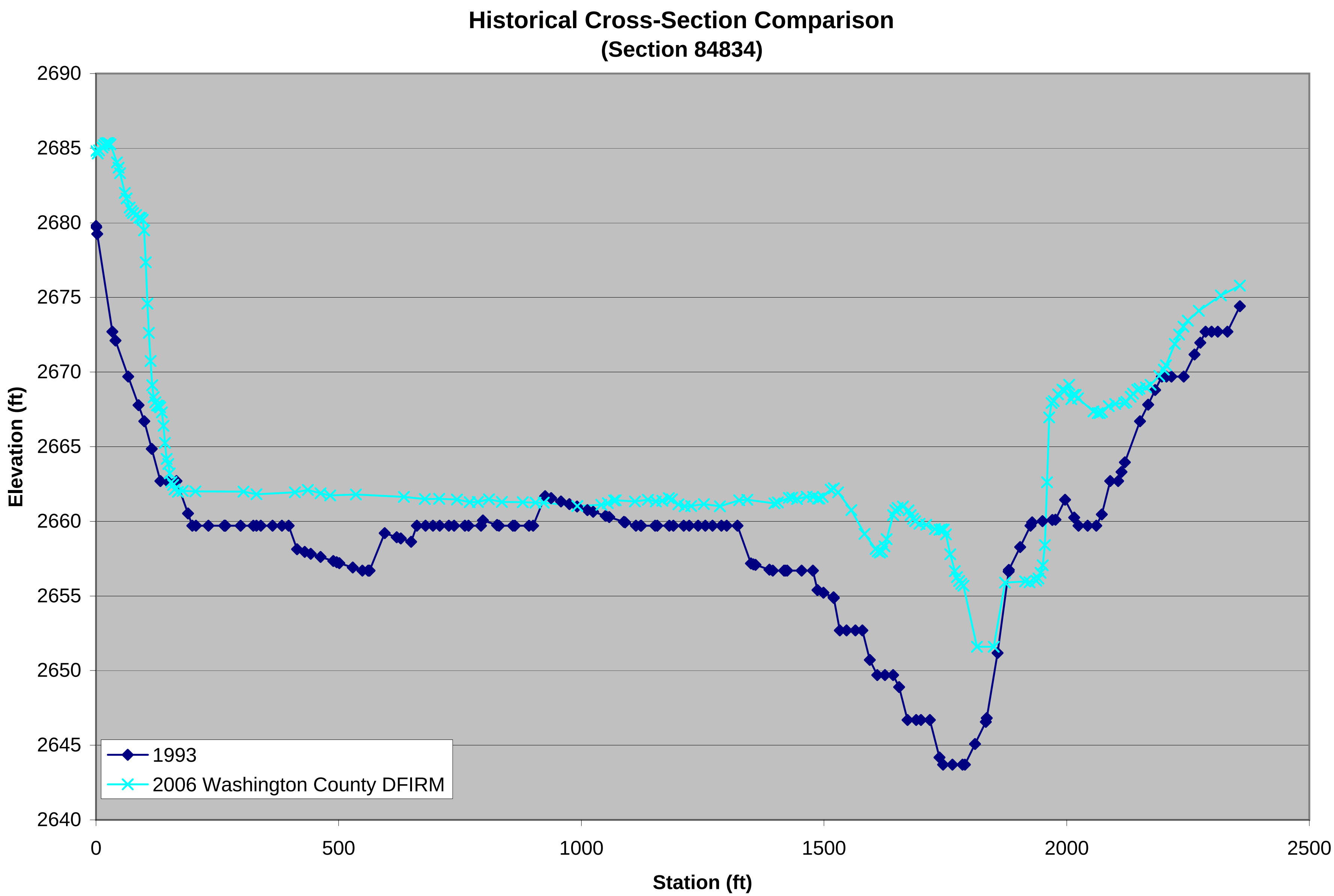
2006 Washington County DFIRM



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0
500
1000
1500
2000
2500
Station (ft)
1993
2006 Washington County DFIRM

APPENDIX D

Historical Aerial Photo Exhibit Book
(SEPARATE VOLUME)

APPENDIX E

River Stability Study – Santa Clara & Virgin Rivers (JEF, 2005)

River Stability Study

Santa Clara & Virgin Rivers

Washington County, UT

Digital copy of final document.
Original sealed document with
Washington County Water Conservancy District.

Jonathan Edward Fuller, P.E.
Registered Professional Engineer
#319476-2202, State of Utah

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September 2005

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Appendix A – Erosion Hazard Zone Map Sheets (Separate Volume)
Appendix B – Historical Photo Comparison Sheets (Separate Volume)
Appendix C – Development Scope of Service Examples & Erosion Hazard Identification Guidelines

1. INTRODUCTION

The Santa Clara and Virgin Rivers experienced large floods in January 2005. Lateral channel erosion resulted in damage to or complete loss of 17 homes, with an additional nine homes classified as “unsafe” following the floods. Four bridges were completely destroyed by the floods, and eleven more were substantially damaged. In response to these events, Washington County, the City of Santa Clara, and the City of St. George initiated a Master Plan to document what occurred during the floods, to establish guidelines to manage development within the river corridors, and to prevent future flood damage. In addition to recommending specific protocols for reestablishing stream channel, floodplain and terrace features, the Master Plan evaluates potential future erosion hazards and defines a corridor within which special development practices are required.

The river stability portion of the Master Plan consisted of a geomorphic evaluation of the Santa Clara and Virgin Rivers. The study limits for the river stability study extended along the Virgin River from the southern limits of Bloomington upstream to the Santa Clara River-Virgin River confluence, and upstream along the Santa Clara River to the Section 17/18 boundary upstream of Santa Clara City, a total distance of approximately 12 river miles (Figure 1). This river stability report is intended to be a companion document to the Master Plan report, prepared by Natural Channel Design, Inc. (NCD).

Figure 1. Vicinity map

1.1. Study Objectives

The primary objectives of the river stability analysis were to evaluate the geomorphic response of the Santa Clara and Virgin Rivers to the flood of January 2005, specifically:

- Compare the magnitude of channel change from the 2005 flood with historical (1870-2004) channel changes
- Evaluate and identify potential causes of channel change
- Quantify the changes in channel width/lateral migration
- Identify areas of channel aggradation and/or degradation
- Quantify changes in river sinuosity
- Identify geologically young surfaces susceptible to potential erosion hazards
- Evaluate and update the erosion hazard zone limits (CH2MHill et. al, 1997) to reflect lessons learned from the 2005 flood

1.2. Previous River Stability Study

In 1996, the City of St.George completed a river stability study addressing the erosion hazards along the Virgin River, Santa Clara River, and Ft. Pierce Wash. Prior to 1996, the City managed development along river corridors using the 1986 Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) maps. City staff recognized that the flood inundation hazards shown on the FEMA maps reflected the river geometry in 1986 and did not address potential lateral erosion hazards. To address these issues, the City initiated the *River Stability Study: Virgin River, Santa Clara River, and Ft. Pierce Wash* (CH2MHill et. al, 1997) (hereafter referred to as the "1997 study"). The 1997 study was a comprehensive evaluation of historical, climatic, hydrologic, anthropogenic, and geomorphic information compiled and analyzed to provide an overall summary of the erosion hazard potential for each of the three watercourses. Below are portions of the Conclusion section from the 1997 study for the Santa Clara and Virgin Rivers:

> *Santa Clara River*
> *…Although floods and flood-related channel changes have occurred during the past 140 years, the lateral position of the channel of the Santa Clara River within its floodplain has been relatively stable, unlike the Virgin River. <u>Recently, however, flood-related channel instability has caused problems for land owners along the banks of the Santa Clara River.</u>*
>
> *Based on the historical and geomorphic data considered, the following conclusions can be drawn regarding the stability of the Santa Clara River in St. George:*
>
> - *The Santa Clara River experienced a period of channel bed degradation during the late 1800s that caused the main channel to become entrenched. Despite entrenchment of up to 10 feet, the channel pattern apparently did not change significantly. <u>Historical channel degradation has over-steepened banks in portions of the study area.</u>*
> - *The channel was relatively stable from 1938 to 1984, a period which included extended drought, the peak flood of record, and many other large floods. <u>Historical data indicate that the banks of the study reach have been relatively stable, except where bank vegetation has been disturbed by human activities.</u>*

- *Recent channel instability on the Santa Clara River is concurrent with a period of human disturbances of the floodplain and channel and is generally located near the areas of human modifications. However, adequately engineered floodplain improvements such as bridges have generally been stable.*
- *Undisturbed reaches of the Santa Clara River have been stable since at least 1938.*
- *Recent channel instability includes relatively small-scale bank failures whereby the channel has recovered some of the pre-1952 sinuosity but generally has not eroded beyond the limits of the entrenched channel.*
- *The bank stability criteria considered indicate that the hazard of bank erosion and lateral channel movement is high were bank vegetation has been removed and moderate elsewhere.*
- *Permissible velocity criteria are exceeded, indicating that the banks of the study reach will erode if not protected. Historically, bank vegetation has provided adequate protection from erosion.*
- *Application of stream classification systems indicate that the study reach is subject to lateral erosion and degradation where bank vegetation is disturbed.* *(CH2MHill et. al, 1997)*

Virgin River
…Since prehistoric times, the Virgin River's perennial flow and fertile floodplains have supported an agricultural economy. However, the variability and volatility of runoff as well as the erosive nature of the river have created problems for the local residents as long as the area has been inhabited.

- *Archaeological, soils, and geomorphic information indicate that the Virgin River has been subject to large, erosive floods for at least the past 1,000 years. These erosive floods have caused the active channel to frequently shift location within its geologic floodplain. Numerous floods much larger than the largest floods experienced in the historical period have occurred in the past 1,000 years.*
- *The period of extensive flooding that occurred after the Virgin River Valley was first settled in the 1850s was concurrent with a period of extensive channel erosion that deepened by up to 15 feet and significantly widened the river.*
- *The appearance and character of the Virgin River was substantially changed during the historical period. The first pioneers (ca. 1860) described a narrower river, with grassy banks and lined by tall trees and swampy grassland. The river seen in the earliest photographs (ca. 1900) is wide and braided with a barren, active floodplain and vertical cut banks.*
- *Lateral channel movement and/or bank erosion of 800 to 2,000 feet was not uncommon on the Virgin River during the 7- to 14-year periods between the dates of the historical aerial photographs. It is likely that most of the lateral erosion and channel migration occurred during floods, when erosive powers were significantly increased.*
- *The Virgin River has degraded by up to 10 to 15 feet within the study reach in the past 140 years, but may now experience alternating periods of scour and fill. Historical channel deepening created unstable vertical cut banks throughout the study reach.*

- *During the past 35 years, the main channel of the Virgin River has become narrower and deeper, and the active floodplain has become densely vegetated with brushy plants such as tamarix and willow. The existing channel pattern is less braided and more sinuous, with wide irregular point bars and coarse bed sediments.*
- *In general, structures built in the floodplain have not been adequately designed. Most of them have been destroyed by channel erosion and/or scour. Bedrock appears to have been the only effective and permanent barrier to erosion.*
- *The bank stability criteria considered indicate that the hazard of bank erosion and lateral channel movement is extreme. None of the criteria considered indicate that the banks are stable. Permissible velocity criteria are exceeded, indicating that the banks of the study reach will erode during even moderate flooding.*
- *There are no adequate grade control structures in the study reach what will prevent long-term degradation, except for the reach immediately adjacent to the turf farm diversion dam.*
- *Tamarix and willow growth in the floodplain has not altered the ability of the Virgin River to erode its banks, although it may have contributed to an overall narrowing of the active channel.*
  (CH2MHill et. al, 1997)

The analysis results, conclusions, and recommendations from the 1997 study formed the foundation for the present river stability study. This study is effectively a temporal continuation of the 1997 study through the 2005 flood.

2. GEOMORPHIC EVALUATION

2.1. Previous Study

The 1997 study included a comprehensive geomorphic evaluation for the purpose of characterizing the stability of both the Santa Clara River and Virgin Rivers, in addition to estimating where future aggradation, degradation, and lateral channel migration were likely to occur. Methodologies employed for that study included the following analyses:

- Field observations
- Hydraulic data
- Channel profile
- River classification
- Permissible velocity
- Bank stability
- River geometry
- Sediment transport

The results from the geomorphic evaluation are reflected in the study conclusions listed in Section 1.2.

The purpose of the geomorphic evaluation for the current study was to observe and document the Santa Clara River's and Virgin River's responses to the 2005 flood and compare the changes in channel morphology to those predicted by the 1997 study. Although some of the geomorphic methodologies employed in the 1997 study were repeated for the current study (e.g., field evaluation and longitudinal profile), it was not the goal of the current study to re-evaluate the previous analysis in entirety.

2.2. Data Collection

Historical data including aerial photographs and maps collected for the 1997 study were re-assembled for the present study. Additional data collected for the present study included recent aerial photography, digital soils mapping, geologic mapping, digital topographic mapping, and other miscellaneous spatial data.

2.2.1. Aerial Photographs

Aerial photography spanning much of the 20^{th} Century served as a foundation of the historical analysis. Table 1 lists the series of photographs collected. Historical aerial photograph comparison exhibits are attached in Appendix B (separate volume).

Table 1. Historical Aerial Photos		
Photo Year	Source	Description
1938	NRCS	Black & white, stereo
1952	USDA	Black & white, stereo
1960	USDA	Black & white, stereo
1967	USDA	Black & white, stereo
1976	USDA	Black & white, stereo
1984	UDSA	Black & white, stereo
1993	USDA	Black & white, stereo
1994	City of St.George	Black & white, stereo
1995	USDA	Black & white, stereo
1999	City of St.George	Black & white, orthophoto
2004	City of St.George	Color, digital orthophoto
2005	City of St.George	Color, digital orthophoto

2.2.2. Geology

Understanding the regional geology of a river valley is fundamental to predicting the types and magnitude of channel processes. Identification of geologic units and their extent within the study area provides valuable information on where the river has been in the past and, more importantly, the relative time frame of channel movement. In 1997, the Utah Geological Survey (UTGS) completed a series of geologic maps of the study area at a scale of 1:24,000 (Higgins et. al, 1995; Willis et. al, 1996; and Higgins, 1997). This UTGS map information was compiled and digitized for the river stability study, and landform interpretations were made based on the UTGS geologic unit descriptions. Figure 2 shows the UTGS geology map units and landform interpretations. The landform interpretation map in Figure 2 was used to identify geologically old and young surfaces impacted by the 2005 flood (either by flood inundation or erosion) which aided in determining the magnitude of the flood in a geologic context. Geologically old surfaces that experienced significant erosion or inundation during the 2005 flood might suggest that it was a low frequency event. In contrast, if impacts were constrained within geologically young surfaces, it suggests that the 2005 flood had a more frequent return period. The 2005 flood was generally constrained within the younger geologic surfaces.

Additional information derived from analysis of the geologic mapping included:

- Areas of geologic control on lateral river movement.
- Limits of active river processes within recent geologic time.

2.2.2.1. Summary

Surfaces identified on the UTGS geology map as active channel, active floodplain, and (low to high) river terraces were considered to be subject to lateral erosion or flood inundation hazards. That is, the geologic record indicates that these surfaces have been part of the active floodplain in recent geologic time, or are close enough to the river channel to be captured by lateral erosion. Further, geologically young materials tend to be less resistant to erosion due to lower clay and carbonate content. Medium and high terraces were considered to be more resistant to erosion than lower terraces and active floodplain, although some erosion of the margins of these surfaces was observed during the 2005 flood.

Figure 2. UTGS Geology

Riverine Deposits

- Active Channel
- Tributary Channel
- Active Floodplain
- Low River Terrace (10-20ft)
- Medium River Terrace (30-90ft)
- High River Terrace (90-240ft)
- Older Terrace
- Older High Terrace (up to 350ft)
- Mixed Deposit Terrace

Colluvial Deposits

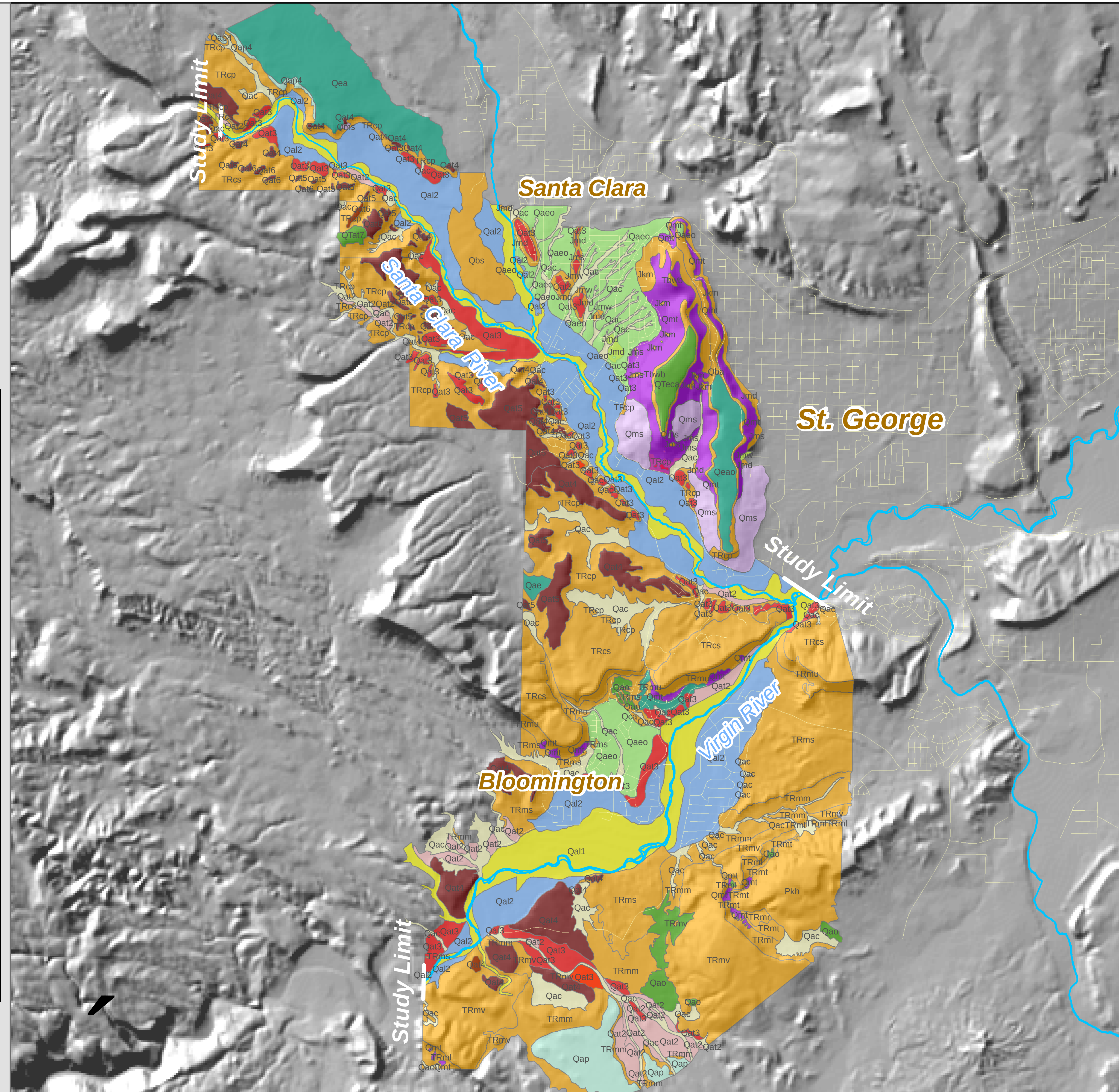
- Debris Flow
- Talus

Pediments and Bedrock

- Pediment
- Bedrock

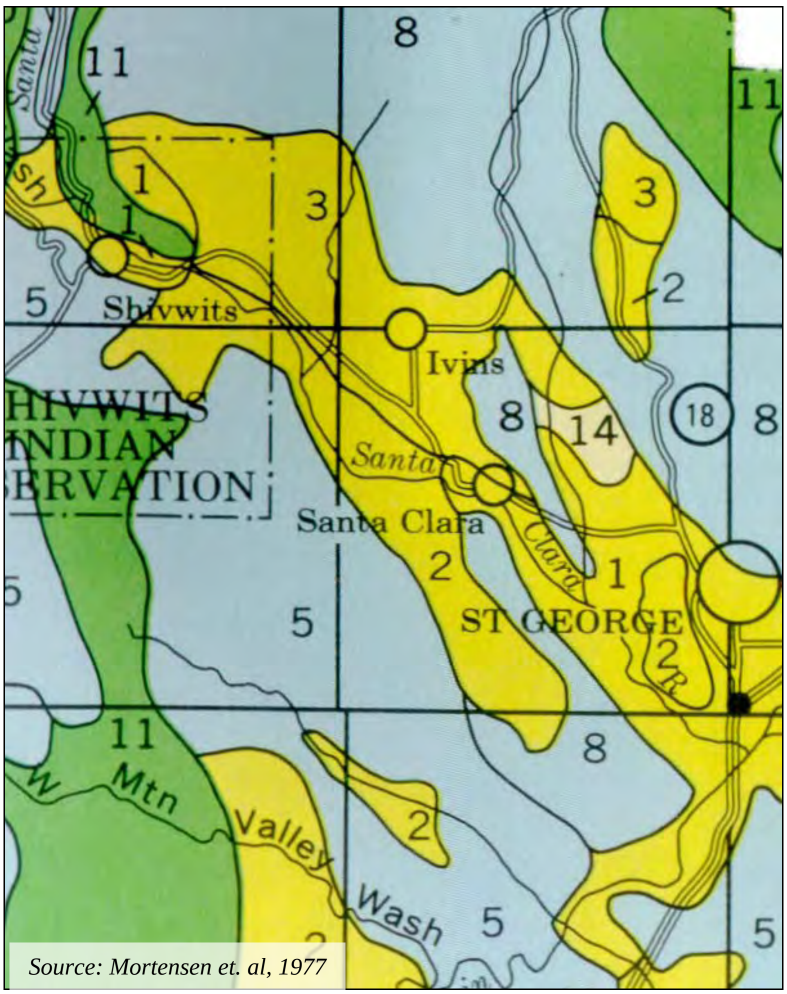
UNIT	GEOLOGIC AGE	UNIT NAME & DESCRIPTION	COLOR ID
Riverine Deposits			
Qal1	Quaternary	Young alluvial stream deposit (0-20ft)	
Qac	Quaternary	Mixed alluvial/colluvial deposit	
Qal2	Quaternary	Young alluvial stream deposit (0-40ft)	
Qat2	Quaternary	Stream terrace deposit (10-30ft)	
Qat3	Quaternary	Stream terrace deposit (30-90ft)	
Qat4	Quaternary	Stream terrace deposit (90-140ft)	
Qat5	Quaternary	Stream terrace deposit (140-190ft)	
Qat6	Quaternary	Stream terrace deposit (190-240ft)	
QTat7	Quaternary	Stream terrace deposit (350ft)	
Qaeo	Quaternary	Mixed alluvial/eolian deposit	
Qao	Quaternary	Alluvial deposit (older)	
QTeca	Quaternary	Alluvial deposit (older with thick carbonate)	
Qae	Quaternary	Mixed alluvial/eolian deposit	
Qca	Quaternary	Mixed colluvial/alluvial deposit	
Qea	Quaternary	Mixed eolian/alluvial deposits	
Qeao	Quaternary	Mixed eolian/alluvial deposit	
Colluvium Deposits			
Qmt	Quaternary	Mass-movement deposit (talus)	
Qms	Quaternary	Mass-movement deposit (landslide)	
Pediment Deposits			
Qap	Quaternary	Pediment-mantle deposit	
Qap4	Quaternary	Pediment-mantle deposit (4ft)	
Basalts			
Qba	Quaternary	Basalt (Airport flow)	
Qbs	Quaternary	Basalt (Santa Clara flow)	
Bedrock			
Jkm	Jurassic	Kayenta Formation (Middle member)	
Jms	Jurassic	Moenave Formation (Springdale Sandstone Member)	
Jmw	Jurassic	Moenave Formation (Whitmore Point Member)	
Jmd	Jurassic	Moenave Formation (Dinosaur Canyon Member)	
TRcp	Triassic	Chinle (Petrified Forest Member)	
TRcs	Triassic	Chinle (Shinarump Conglomerate)	
TRmu	Triassic	Moenkopi Formation (Upper red member)	
TRms	Triassic	Moenkopi Formation (Shnabkaib Member)	
TRmm	Triassic	Moenkopi Formation (Middle red member)	
TRmv	Triassic	Moenkopi Formation (Virgin Limestone Member)	
TRml	Triassic	Moenkopi Formation (Lower red member)	
TRmr	Triassic	Moenkopi Formation (Rock Canyon Conglomerate)	
TRmt	Triassic	Moenkopi Formation (Timpoweap Member)	
Pkh	Permian	Kaibab Formation (Harrisburg Member)	
Tbwb	Tertiary	Basalt (West Black Ridge flow)	

0 0.5 1 2 3 4 Miles



2.2.3. *Soils*

Analysis of soil data can provide information about the evolution and future behavior of river systems. Soil Conservation Service (SCS)[1] soil data were collected and analyzed for the river stability study (Mortensen et. al, 1977). Like geologic data, soils data can provide valuable information regarding old and young geomorphic surfaces, in addition to information about the relative frequency of flood inundation and lateral erosion. Soils described by the SCS are often grouped into Soil Associations for regional context. A Soil Association is a landscape that has a distinctive proportional pattern of soils and normally consists of one or more major soils and at least one minor soil. Seven soil associations were identified within the study area as shown in Figure 3. A general description of each soil association is listed in Table 2, in addition to the landform interpretation made for this study to facilitate the use of soils mapping for assessing river stability and estimate potential lateral erosion.



Source: Mortensen et. al, 1977

Figure 3. SCS General Soils Map

[1] The SCS was renamed the Natural Resources Conservation Service (NRCS).

Table 2. SCS Soil Association Descriptions			
Unit ID	SCS Soil Association	Description	Landform Interpretation
1	Tobler-Harrisburg-Junction	Well-drained, nearly level to moderately steep, moderately deep and deep fine sandy loams and silty clay loams.	Active channels and floodplains
2	Winkel-Rock land	Well-drained, gently sloping to steep, shallow gravelly fine sandy loams and Rock land.	Piedmonts and bedrock
3	Pintura-Toquerville-Dune land	Somewhat excessively drained, gently sloping to moderately steep, shallow to deep loamy fine sands and fine sands and Dune land.	Mountain slopes and piedmonts
5	Badland-Eroded land	Rolling to very steep Badland and Eroded land. Active erosion with rapid runoff and high sediment loads.	Piedmonts and mountain slopes.
8	Rock outcrop-Rock land	Exposed bedrock.	Bedrock
11	Curhollow-Pastura-Magotsu	Well-drained, gently sloping to steep, shallow gravelly fine sandy loams, gravelly loams, and very cobbly loams. Hardpan at depth 10 inches.	Mountain slopes
14	Collbran-Tacan-Nehar	Well-drained, gently sloping to very steep, deep very cobbly clay loams and very stony sandy loams.	Piedmonts

The primary use of the SCS soils mapping was to identify geomorphic surfaces (based on their soil characteristics) that have been subject to active fluvial processes (flood inundation and lateral erosion) in recent geologic time, and thus could be areas subject to future lateral erosion. The Tobler-Harrisburg-Junction Association represents the active channel and floodplain corridor of the Santa Clara and Virgin Rivers. The Winkel-Rock land and Pintura-Toquerville-Dune land soils comprise the transition from riverine processes to piedmont/ slope processes. The remaining soils represent upper piedmont and hillslope processes and exposed bedrock.

Each SCS soil association is comprised of multiple soil units, mapped and described in detail in Mortensen et. al, 1977. Table 3 lists each SCS soil identified within the study reach and its SCS description. Figure 4 shows the detailed SCS soils mapping. Based on our interpretations of the SCS descriptions, a landform type was assigned to each soil. These landform categories were then combined and mapped to illustrate their geomorphic relationships within the study area. Figure 4 is a detailed SCS soils map showing the landform interpretations.

Table 3. SCS Detailed Soil Units		
SCS Soil Symbol	SCS Soil Description	Landform Interpretation
BA	Badland	Piedmont
BB	Badland,very steep	Piedmont
BED	Bermesa fine sandy loam, 1 to 10 percent slopes	Piedmont
BOD	Bond sandy loam, 1 to 10 percent slopes	Piedmont
BP	Borrow pits	Disturbed Areas
CHF	Chilton gravelly loam, 5 to 30 percent slopes	Alluvial Fan
CI	Cinder land	Rock Outcrop
CUF	Curhollow-Rock outcrop complex, 10 to 30 percent slopes	Rock Outcrop
DU	Dune land	Aeolian Dunes
EA	Eroded land-Shalet complex	Piedmont
EB	Eroded land-Shalet complex, warm	Piedmont
FA	Fluvaquents and Torrifluvents, sandy	Active Floodplain
GA	Gullied land	Fluvial Terrace
GP	Gravel pits	Disturbed Areas
Ha	Hantz silty clay loam	Fluvial Terrace
HbC	Harrisburg fine sandy loam, 1 to 5 percent slopes	Piedmont
HD	Harrisburg-Rock land association	Mountain Slope
HG	Hobog-Rock land association	Mountain Slope
IAF	Isom cobbly sandy loam, 3 to 30 percent slopes	Alluvial Fan
Ib	Ivins loamy fine sand	Piedmont
Ic	Ivins loamy fine sand, hummocky	Piedmont
JaB	Junction fine sandy loam, 1 to 2 percent slopes	Piedmont
JaC	Junction fine sandy loam, 2 to 5 percent slopes	Piedmont
LA	Lava flows	Piedmont
LcB	LaVerkin fine sandy loam, 1 to 2 percent slopes	Fluvial Terrace
LcC	LaVerkin fine sandy loam, 2 to 5 percent slopes	Piedmont
LdB	LaVerkin silty clay loam, 1 to 2 percent slopes	Fluvial Terrace
LeA	Leeds silty clay loam, 0 to 1 percent slopes	Fluvial Terrace
LeB	Leeds silty clay loam, 1 to 2 percent slopes	Fluvial Terrace
NkC	Nikey sandy loam, 1 to 3 percent slopes	Piedmont
NLE	Nikey sandy loam, 3 to 15 percent slopes	Piedmont
PnC	Pintura loamy fine sand, 1 to 5 percent slopes	Piedmont
PoD	Pintura loamy fine sand, hummocky, 1 to 10 percent slopes	Piedmont
PTE	Pintura-Toquerville complex, 1 to 20 percent slopes	Mountain Slope
RE	Renbac-Rock land association	Mountain Slope
RI	Riverwash	Active Floodplain
RI	Riverwash	Piedmont
RO	Rock land	Mountain Slope
RP	Rock land, stony	Mountain Slope
RR	Rock land-Hobog association	Mountain Slope
RT	Rock outcrop	Rock Outcrop
RU	Rough broken land	Rock Outcrop
Sa	St. George silt loam	Piedmont
Sb	St. George silt loam, strongly saline	Fluvial Terrace
Sc	St. George silty clay loam	Fluvial Terrace

Table 3. SCS Detailed Soil Units		
SCS Soil Symbol	SCS Soil Description	Landform Interpretation
Sd	St. George silty clay loam, moderately saline	Fluvial Terrace
Se	St. George silty clay loam, shallow water table	Fluvial Terrace
SH	Schmutz loam	Piedmont
SY	Stony colluvial land	Mountain Slope
TBF	Tobish very cobbly clay loam, 5 to 30 percent slopes	Mountain Slope
Tc	Tobler fine sandy loam	Fluvial Terrace
Td	Tobler silty clay loam	Fluvial Terrace
TG	Tortugas-Rock land association	Mountain Slope
VeA	Vekol sandy loam, 0 to 2 percent slopes	Piedmont
VFD	Vekol sandy loam, 2 to 10 percent slopes	Alluvial Fan
VHD	Veyo-Curhollow complex, 3 to 10 percent slopes	Alluvial Fan
VPD	Veyo-Pastura complex, 1 to 10 percent slopes	Alluvial Fan
W	Water	Water
WBD	Winkel gravelly fine sandy loam, 1 to 8 percent slopes	Mountain Slope
WCF	Winkel-Rock outcrop complex, 8 to 30 percent slopes	Rock Outcrop
YAF	Yaki very cobbly loam, 3 to 35 percent slopes	Mountain Slope
YZE	Yaki-Zukan complex, 1 to 35 pecrent slopes	Piedmont

2.2.3.1. Summary

Surfaces identified in the SCS soils landform map as active floodplain were considered to be subject to lateral erosion and flood inundation hazard. Surfaces flanking the river corridors and identified as fluvial terraces are potentially subject to lateral erosion hazards only along their margins closest to the river corridor.

2.2.4. Topographic Data

Pre-Flood. Pre-2005 flood digital topography was collected for both the Santa Clara and Virgin Rivers. The Santa Clara River pre-flood topography consisted of two data sets:

- 1996: 2-foot contour interval topography extending from the upper study area limit through the City of Santa Clara.
- 1999: 2-foot contour interval topography extending from the City of Santa Clara to the Virgin River confluence.

The Virgin River pre-flood data consisted of 1999 2-foot contour digital topography.

Post-flood. At the time this report was completed, post-flood topography for the Santa Clara River was only available in the vicinity of the Santa Clara City. For the study area downstream of Santa Clara, post-flood surveyed cross sections were the sole source of channel elevation data. No post-flood topography or cross-section data were available for the Virgin River at the time this report was completed. The collected topographic data were employed for the quantitative analyses discussed later in this report.

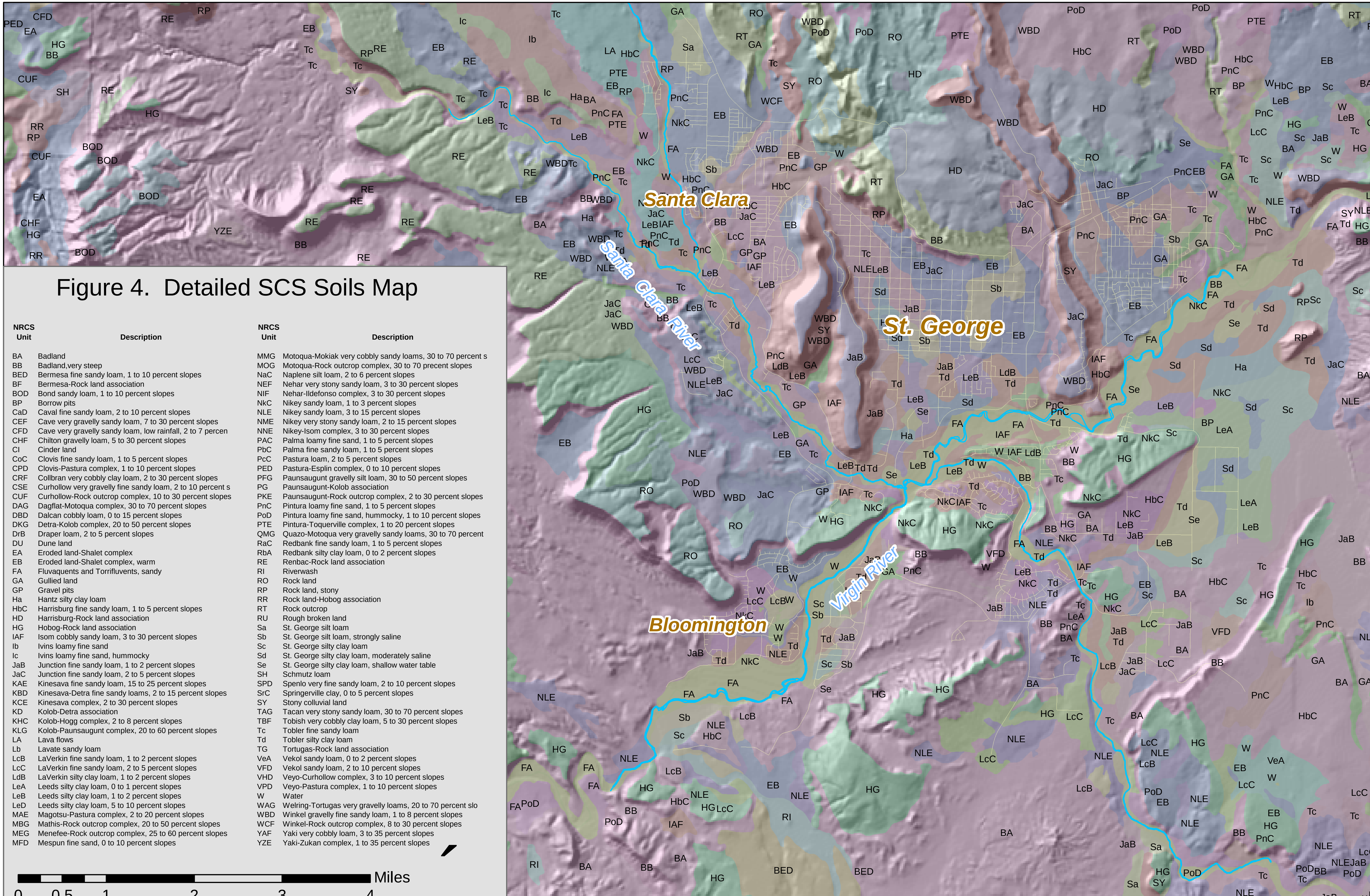


Figure 4. Detailed SCS Soils Map

NRCS Unit	Description	NRCS Unit	Description
BA	Badland	MMG	Motoqua-Mokiak very cobbly sandy loams, 30 to 70 percent s
BB	Badland,very steep	MOG	Motoqua-Rock outcrop complex, 30 to 70 percent slopes
BED	Bermesa fine sandy loam, 1 to 10 percent slopes	NaC	Naplene silt loam, 2 to 6 percent slopes
BF	Bermesa-Rock land association	NEF	Nehar very stony sandy loam, 3 to 30 percent slopes
BOD	Bond sandy loam, 1 to 10 percent slopes	NIF	Nehar-Ildefonso complex, 3 to 30 percent slopes
BP	Borrow pits	NkC	Nikey sandy loam, 1 to 3 percent slopes
CaD	Caval fine sandy loam, 2 to 10 percent slopes	NLE	Nikey sandy loam, 3 to 15 percent slopes
CEF	Cave very gravelly sandy loam, 7 to 30 percent slopes	NME	Nikey very stony sandy loam, 2 to 15 percent slopes
CFD	Cave very gravelly sandy loam, low rainfall, 2 to 7 percen	NNE	Nikey-Isom complex, 3 to 30 percent slopes
CHF	Chilton gravelly loam, 5 to 30 percent slopes	PAC	Palma loamy fine sand, 1 to 5 percent slopes
CI	Cinder land	PbC	Palma fine sandy loam, 1 to 5 percent slopes
CoC	Clovis fine sandy loam, 1 to 5 percent slopes	PcC	Pastura loam, 2 to 5 percent slopes
CPD	Clovis-Pastura complex, 1 to 10 percent slopes	PED	Pastura-Esplin complex, 0 to 10 percent slopes
CRF	Collbran very cobbly clay loam, 2 to 30 percent slopes	PFG	Paunsaugunt gravelly silt loam, 30 to 50 percent slopes
CSE	Curhollow very gravelly fine sandy loam, 2 to 10 percent s	PG	Paunsaugunt-Kolob association
CUF	Curhollow-Rock outcrop complex, 10 to 30 percent slopes	PKE	Paunsaugunt-Rock outcrop complex, 2 to 30 percent slopes
DAG	Dagflat-Motoqua complex, 30 to 70 percent slopes	PnC	Pintura loamy fine sand, 1 to 5 percent slopes
DBD	Dalcan cobbly loam, 0 to 15 percent slopes	PoD	Pintura loamy fine sand, hummocky, 1 to 10 percent slopes
DKG	Detra-Kolob complex, 20 to 50 percent slopes	PTE	Pintura-Toquerville complex, 1 to 20 percent slopes
DrB	Draper loam, 2 to 5 percent slopes	QMG	Quazo-Motoqua very gravelly sandy loams, 30 to 70 percent
DU	Dune land	RaC	Redbank fine sandy loam, 1 to 5 percent slopes
EA	Eroded land-Shalet complex	RbA	Redbank silty clay loam, 0 to 2 percent slopes
EB	Eroded land-Shalet complex, warm	RE	Renbac-Rock land association
FA	Fluvaquents and Torrifluvents, sandy	RI	Riverwash
GA	Gullied land	RO	Rock land
GP	Gravel pits	RP	Rock land, stony
Ha	Hantz silty clay loam	RR	Rock land-Hobog association
HbC	Harrisburg fine sandy loam, 1 to 5 percent slopes	RT	Rock outcrop
HD	Harrisburg-Rock land association	RU	Rough broken land
HG	Hobog-Rock land association	Sa	St. George silt loam
IAF	Isom cobbly sandy loam, 3 to 30 percent slopes	Sb	St. George silt loam, strongly saline
Ib	Ivins loamy fine sand	Sc	St. George silty clay loam
Ic	Ivins loamy fine sand, hummocky	Sd	St. George silty clay loam, moderately saline
JaB	Junction fine sandy loam, 1 to 2 percent slopes	Se	St. George silty clay loam, shallow water table
JaC	Junction fine sandy loam, 2 to 5 percent slopes	SH	Schmutz loam
KAE	Kinesava fine sandy loam, 15 to 25 percent slopes	SPD	Spenlo very fine sandy loam, 2 to 10 percent slopes
KBD	Kinesava-Detra fine sandy loams, 2 to 15 percent slopes	SrC	Springerville clay, 0 to 5 percent slopes
KCE	Kinesava complex, 2 to 30 percent slopes	SY	Stony colluvial land
KD	Kolob-Detra association	TAG	Tacan very stony sandy loam, 30 to 70 percent slopes
KHC	Kolob-Hogg complex, 2 to 8 percent slopes	TBF	Tobish very cobbly clay loam, 5 to 30 percent slopes
KLG	Kolob-Paunsaugunt complex, 20 to 60 percent slopes	Tc	Tobler fine sandy loam
LA	Lava flows	Td	Tobler silty clay loam
Lb	Lavate sandy loam	TG	Tortugas-Rock land association
LcB	LaVerkin fine sandy loam, 1 to 2 percent slopes	VeA	Vekol sandy loam, 0 to 2 percent slopes
LcC	LaVerkin fine sandy loam, 2 to 5 percent slopes	VFD	Vekol sandy loam, 2 to 10 percent slopes
LdB	LaVerkin silty clay loam, 1 to 2 percent slopes	VHD	Veyo-Curhollow complex, 3 to 10 percent slopes
LeA	Leeds silty clay loam, 0 to 1 percent slopes	VPD	Veyo-Pastura complex, 1 to 10 percent slopes
LeB	Leeds silty clay loam, 1 to 2 percent slopes	W	Water
LeD	Leeds silty clay loam, 5 to 10 percent slopes	WAG	Welring-Tortugas very gravelly loams, 20 to 70 percent slo
MAE	Magotsu-Pastura complex, 2 to 20 percent slopes	WBD	Winkel gravelly fine sandy loam, 1 to 8 percent slopes
MBG	Mathis-Rock outcrop complex, 20 to 50 percent slopes	WCF	Winkel-Rock outcrop complex, 8 to 30 percent slopes
MEG	Menefee-Rock outcrop complex, 25 to 60 percent slopes	YAF	Yaki very cobbly loam, 3 to 35 percent slopes
MFD	Mespun fine sand, 0 to 10 percent slopes	YZE	Yaki-Zukan complex, 1 to 35 percent slopes

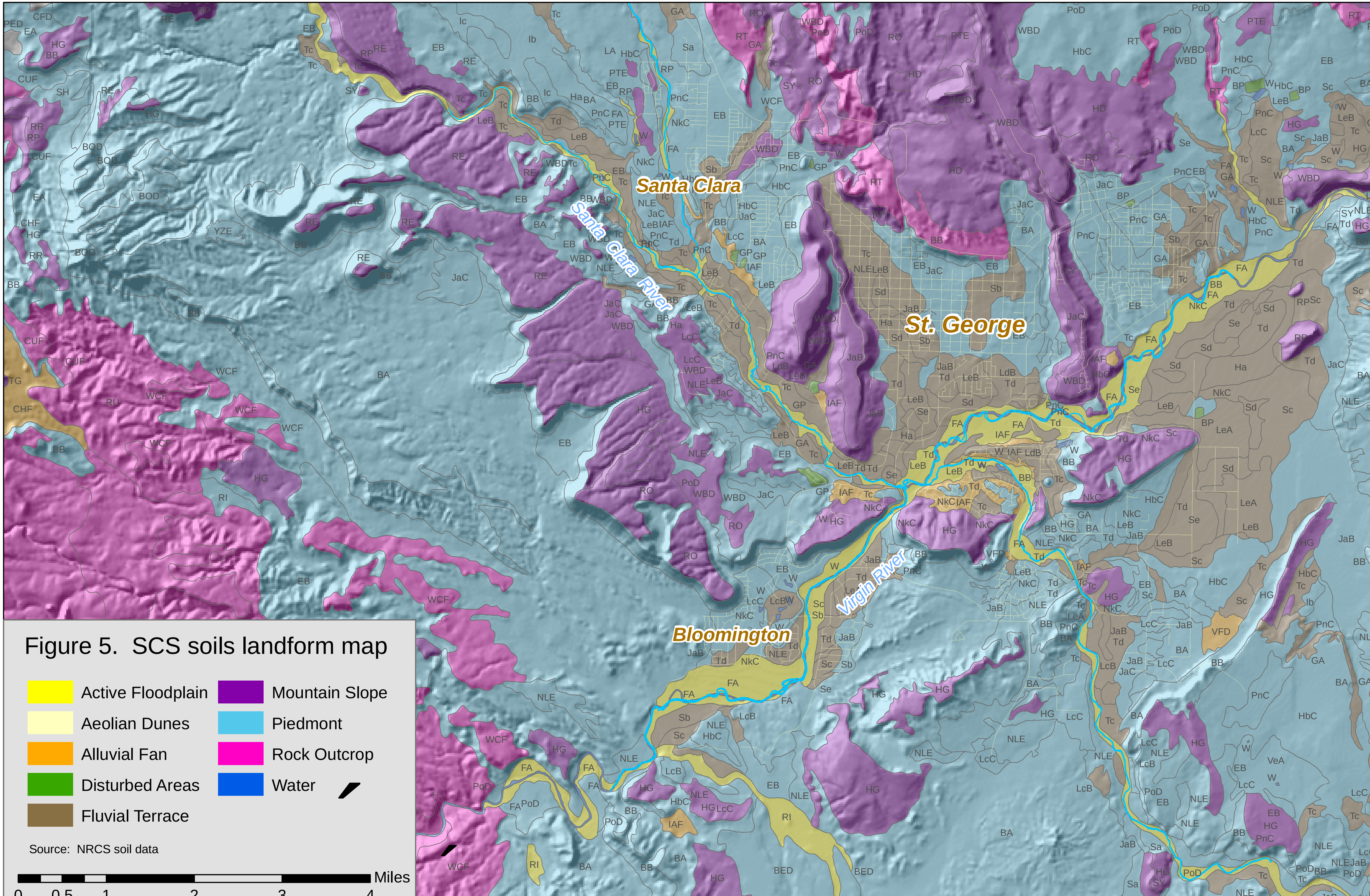


Figure 5. SCS soils landform map

2.3. Historical Analysis

2.3.1. Previous Study (1890-1997)

The historical analysis performed as part of the 1997 study concluded that the Santa Clara River experienced channel degradation in the late 1800s that resulted in oversteepened banks in portions of the study area. Additionally, it was concluded that in areas of minimal human disturbance, the lateral position of the channel had been relatively stable from 1938 to 1997. Conversely, channel instability occurred in areas of channel disturbance, such as removal of bank vegetation.

The 1997 study concluded that the Virgin River had experienced frequent, dramatic changes in the low-flow channel position within the historical record. These changes, although frequent and of great magnitude, were constrained within the geologic floodplain. Lateral channel movements of 800 to 2000 feet were described as common magnitudes of bank position change in the times between aerial photo sets. It was also concluded that the main channel of the Virgin River had degraded by up to 15 feet within the study area resulting in steep, unstable banks. Figure 6 shows the historical thalweg positions for the Santa Clara and Virgin Rivers from 1890 through 2005.

2.3.2. 1995-2004

A comparison of historical channel movement after completion of the 1997 study to the period immediately preceding the January 2005 flood was performed to evaluate river stability within the past eight years. Aerial photographs from 1995 to 2004 were used to quantify channel position changes for both the Santa Clara and Virgin Rivers.

Historical analysis of both the Santa Clara and Virgin Rivers from 1997 to 2004 indicated minimal to no change in the active channel corridor within the eight year period. The low-flow channel of the Santa Clara River experienced minor lateral changes near the Southwood Meadows subdivision, but remained safely within the active channel corridor. Figure 7 is a larger scale meander plot showing the location of the active channel of the Santa Clara River from 1995-2004. Some variation observed in the meander year plots can be attributed to rectification error in the semi-rectified aerial photography of 1995 and 1999 (the 2004 aerial photographs were orthorectified, thus were geospatially correct).

The same result was found in the historical analysis of the Virgin River. No appreciable change in the location of the active channel corridor was observed from 1995 to 2004. Figure 8 illustrates these results. Channel changes during the January 2005 flood are described and quantified in the following sections of this report.

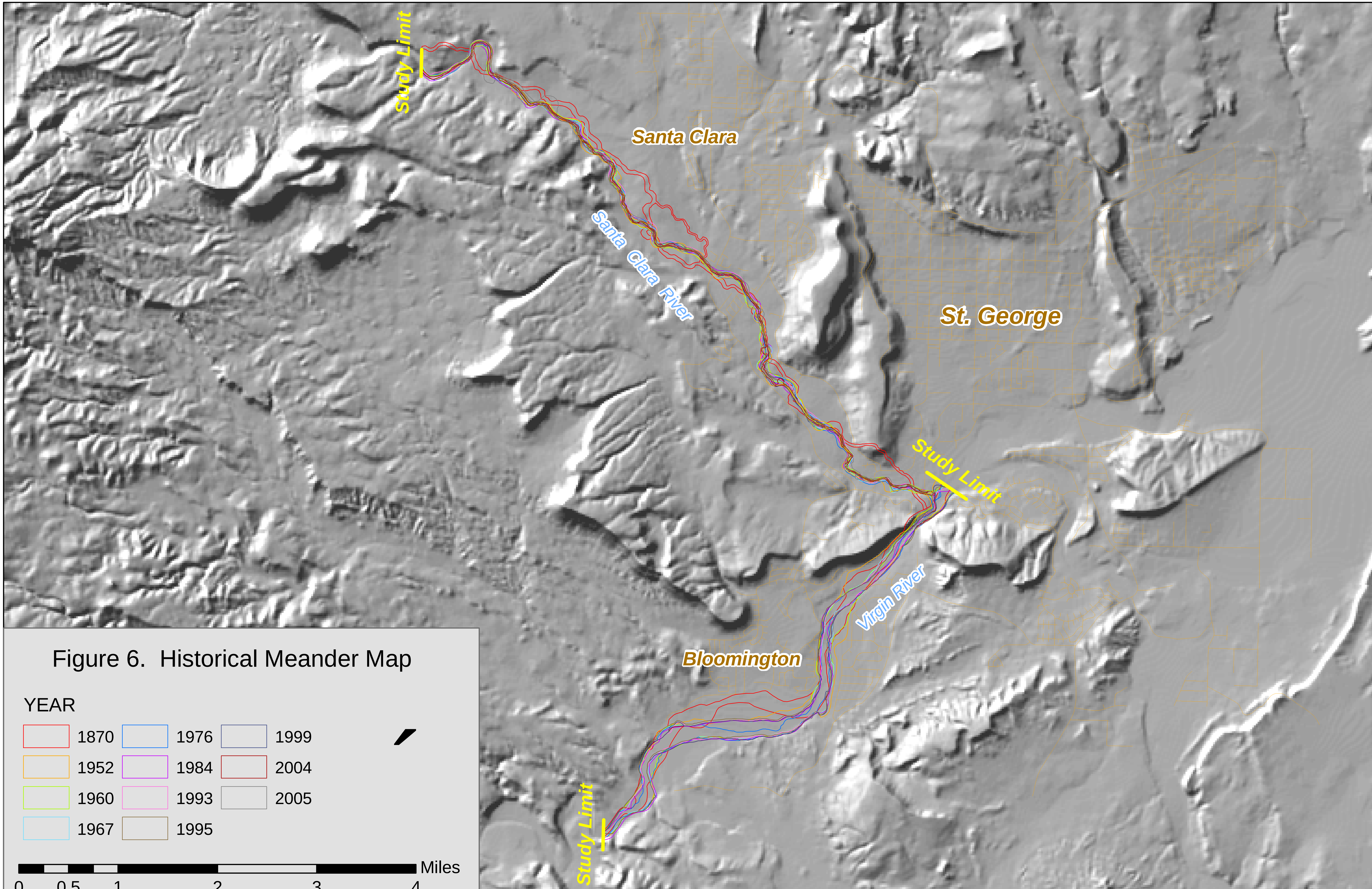


Figure 6. Historical Meander Map

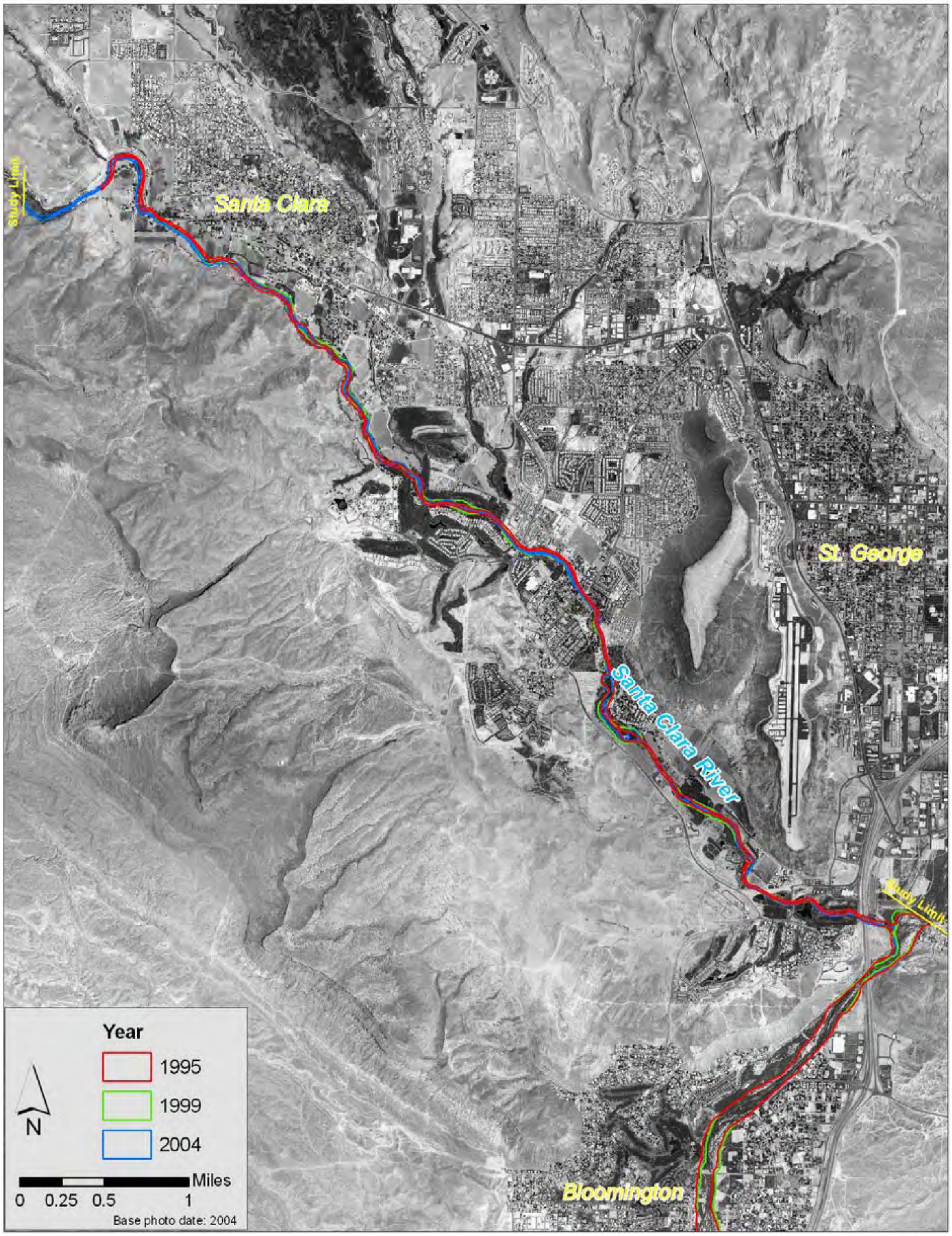


Figure 7. Santa Clara River historical channel position map (1995-2004)

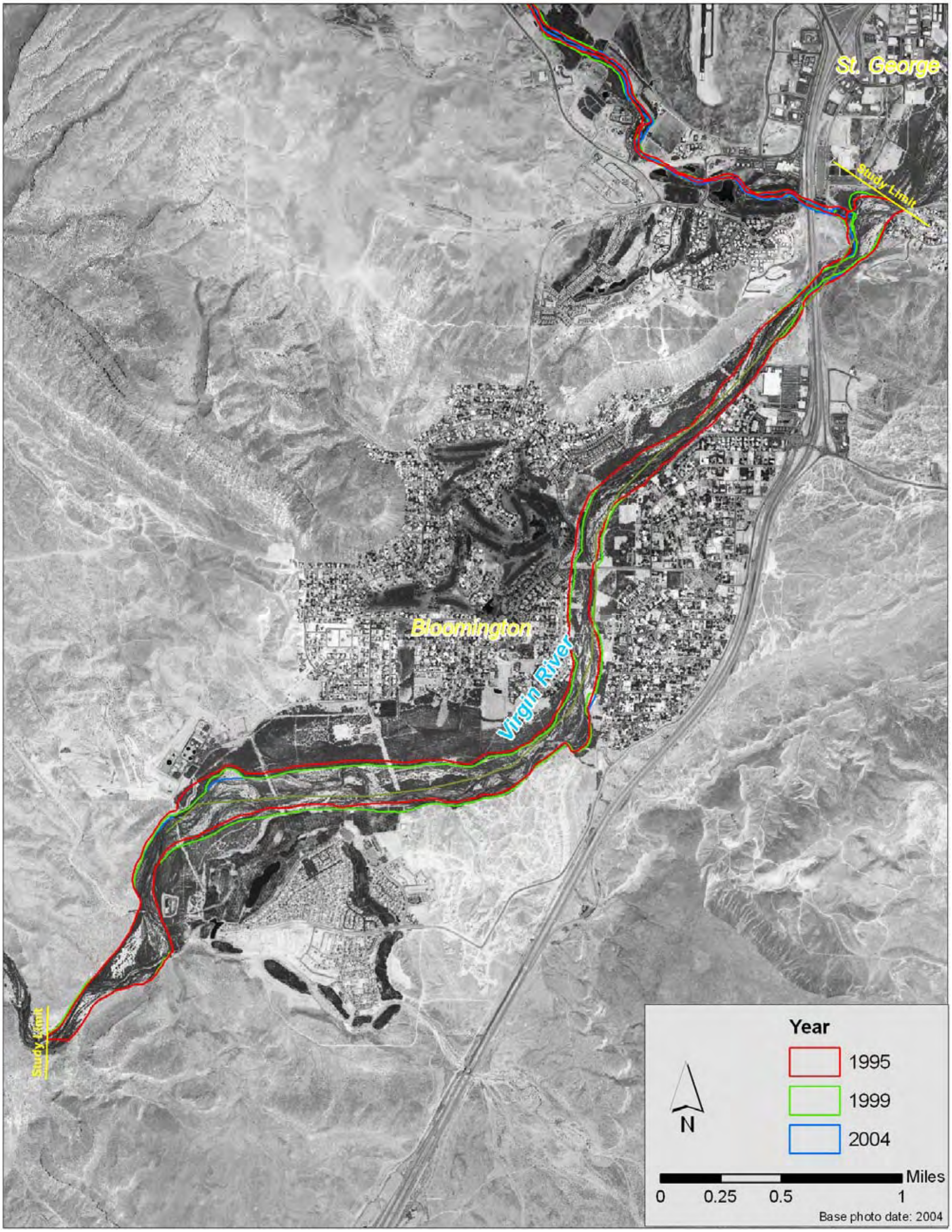


Figure 8. Virgin River historical channel position map (1995-2004)

2.4. Field Observations

Field visits to the study area were conducted over a four day period from March 7th through March 10th, 2005. JE Fuller/Hydrology & Geomorphology, Inc. (JEF) staff walked the entire study reach of the Santa Clara River photographing and mapping key features and general post-flood channel conditions. Every effort was made to observe and record the changes to the channel and floodplain area caused by the 2005 flood. Additionally, all road crossings and other significant structures located in or adjacent to the river were visited and documented. Key areas of the Virgin River were identified for field inspection from post-flood aerial photography. These areas were visited and river conditions were described and photographed.

2.4.1. Types of Data Collected

The following channel characteristics relevant to lateral erosion and channel stability were observed and recorded in the field:

- Fresh cutbanks – locations, heights, characteristics
- Bank sediments – cohesivity, resistance to erosion
- Overbank deposition – depths, lateral extents
- Bedrock – location, lithology
- Carbonate and Clay Soils – location, degree of development
- Vegetation – channel, banks, floodplain, type, density, cover
- Flotsam debris – areas of accumulation, areas lacking accumulation
- Location of structures – bridges, levees, bank protection
- Stable reaches – reaches that experienced minor lateral bank movement
- Human intervention – Areas with stabilized channel banks prior to, during, or after the 2005 flood
- Damaged structures – homes, buildings, bridges, levees, etc.

2.4.2. Mechanisms of Channel Change

Santa Clara River. The 1997 study concluded that the Santa Clara River was characterized by historical channel degradation resulting in oversteepened, unstable banks with a high potential for lateral erosion when no bank stabilization existed. Post-2005 field observations indicated that although the river behaved as predicted, the magnitude of change was greater than could have been anticipated based on historical records.

Without exception, the entire active channel corridor within the study area was modified by the 2005 flood. Observed changes to the low-flow channel included the removal of vegetation from channel banks, widening of channel banks, channel avulsions, areas of local aggradation and degradation, and accumulation of debris. Observed changes to overbank and floodplain areas included development of avulsion channels, removal of vegetation, sediment deposition, scour, and debris accumulation.

Anecdotal information provided by City of St. George officials (J. Sandburg personal communication, 2005) suggested one of the causal mechanisms for abrupt changes in channel bank location was debris blockage of the pre-flood low-flow channel. Evidence of this mechanism was observed during the field investigation. Figure 9 is a photograph of a debris dam that occurred near the upper study area limit. The debris dam caused the channel to avulse, creating a new thalweg alignment through a former floodplain, and resulting in lateral migration of the active channel corridor. Once abandoned, the pre-flood active channel began to function as a floodplain with up to 6 feet of sediment accumulation observed. Figure 10 illustrates another location where a debris dam was likely the cause of significant lateral erosion (debris was not present at the time of the field investigation; however, City officials indicated a debris dam formed during the flood). Debris also accumulated at a concrete irrigation diversion structure, and forced high velocity flows toward the left overbank resulting in substantial lateral erosion and the loss of a section of sewer line. Debris dams tended to occur where structures or where dense woody vegetation narrowed the main channel to a width less than the length of debris (trees, typically) transported by the flood. Stable reaches with less significant lateral erosion tended to be wide enough to reduce the potential for debris blockage.

Another observed cause of channel change was avulsion of the main channel into the floodplain. This process occurred in areas where flows overtopped the main channel or flanked existing bank vegetation, concentrated in the floodplain, and eroded non-resistant floodplain sediments to form a new channel. This process was particularly effective in floodplain areas with sparse vegetation and areas where floodplain vegetation had been removed, creating zones of low roughness which enabled high velocity, erosive flows to concentrate. Figure 11 and Figure 12 illustrate the avulsive erosion process at two locations along the Santa Clara River. The process of flows flanking the main channel vegetation was observed to be most effective in areas where the flows had a clear pathway back to the main channel. In areas where dense vegetation intercepted and blocked flows from returning to the main channel, the flow energy appears to have dissipated and become less erosive. Where overbank flows were able to reach the main channel via a clear pathway, headcuts often formed at the confluence points. Those headcuts migrated up the overbank flowpaths, further accelerating erosion of the overbank soils.

The most common result form of observed channel change in the 2005 flood was simple widening or migration of the low-flow channel banks to accommodate the flood volume. The 1997 study described the bank vegetation as follows:

> *The Channel banks in the upper half of the study reach were vegetated with mature cottonwoods and other deciduous trees, with a health understory of brushy and grassy ground cover. The channel banks in recently developed area in the lower half of the study reach were poorly vegetated or were unvegetated. Tamarix and grass were the dominant type of bank vegetation in the unstable reaches and were typically perched above the vertical cut banks.*

The bank vegetation was inconsistent in providing adequate erosion protection. In some areas the vegetation seemed to prevent lateral erosion of the banks, while in others it appeared to have been undercut or uprooted during the flood, irrespective of vegetation type. This inconsistency makes predicting bank stability by vegetative measures uncertain. Clearly the pre-flood channel contained insufficient capacity to covey the flood peak, thus a wider conveyance corridor was established by the flood.

Virgin River. The Virgin River experienced changes to both the active channel corridor and floodplain areas during the 2005 flood. However, the changes were smaller in scale compared to those on the Santa Clara River. Also, unlike the Santa Clara, the most severe flood effects occurred inside the 100-year floodplain. Those effects included sediment deposition on the floodplain, vegetation removal, debris accumulation, and lateral migration and widening of the low-flow channel.

The most severe changes in the Virgin River study reach occurred in the vicinity of the Man-of-War Bridge. Upstream of the Man-of-War Bridge, the pre-flood low-flow channel was characterized by a gradual, wide radius bend with dense vegetation adjacent to the low-flow channel with vegetation density decreasing outward across the left-overbank floodplain. Vegetation patterns in this overbank area indicated the presence of historical overbank flow channel across the surface. During the 2005 flood, overbank flows were able to concentrate in the overbank corridors where vegetation was sparse to nonexistent. This resulted in a near avulsion of the main flow channel and likely contributed to a larger volume of flow in the floodplain potentially resulting in greater amounts of sediment deposition. Figure 13 shows this location. Bank vegetation in this reach appears to have survived the flood and was moderately affective at stabilizing the low flow channel position.[2]

Similar processes of change occurred downstream of Man-of-War bridge. Prior to the 2005 flood, the vegetation pattern of the right-overbank was characterized by dense thickets of Tamarisk with interwoven areas of no vegetation, and remnants of overbank flow channels. During the 2005 flood, overbank flows were able to exploit the low-roughness areas resulting in concentrated, higher velocity flows in the overbanks. Figure 14 shows the resulting overbank channel formation.

Directly across the river from the area described above is the reach of the Virgin River that experienced the most significant lateral migration within the study area. Approximately 2 acres of pasture land were eroded by the flood. One likely explanation for erosion of the left bank is a flanking of the bank vegetation by overbank flows as occurred in multiple locations along the Santa Clara River (see Figure 11 and Figure 12). Once the flows were outside the rougher vegetation corridor, the smooth pasture land would have enabled high velocity, high energy flows to concentrate and erode the non-resistant soil. Figure 15 illustrates this potential explanation for the lateral migration in this area.

[2] Subsequent to the flood, much of the surviving bank and floodplain vegetation was manually removed near the Man-O-War Bridge, which may contribute to increased low flow channel lateral instability in the reach.

Figure 9. Debris dam in upper study area

Figure 10. Debris dam at irrigation diversion structure

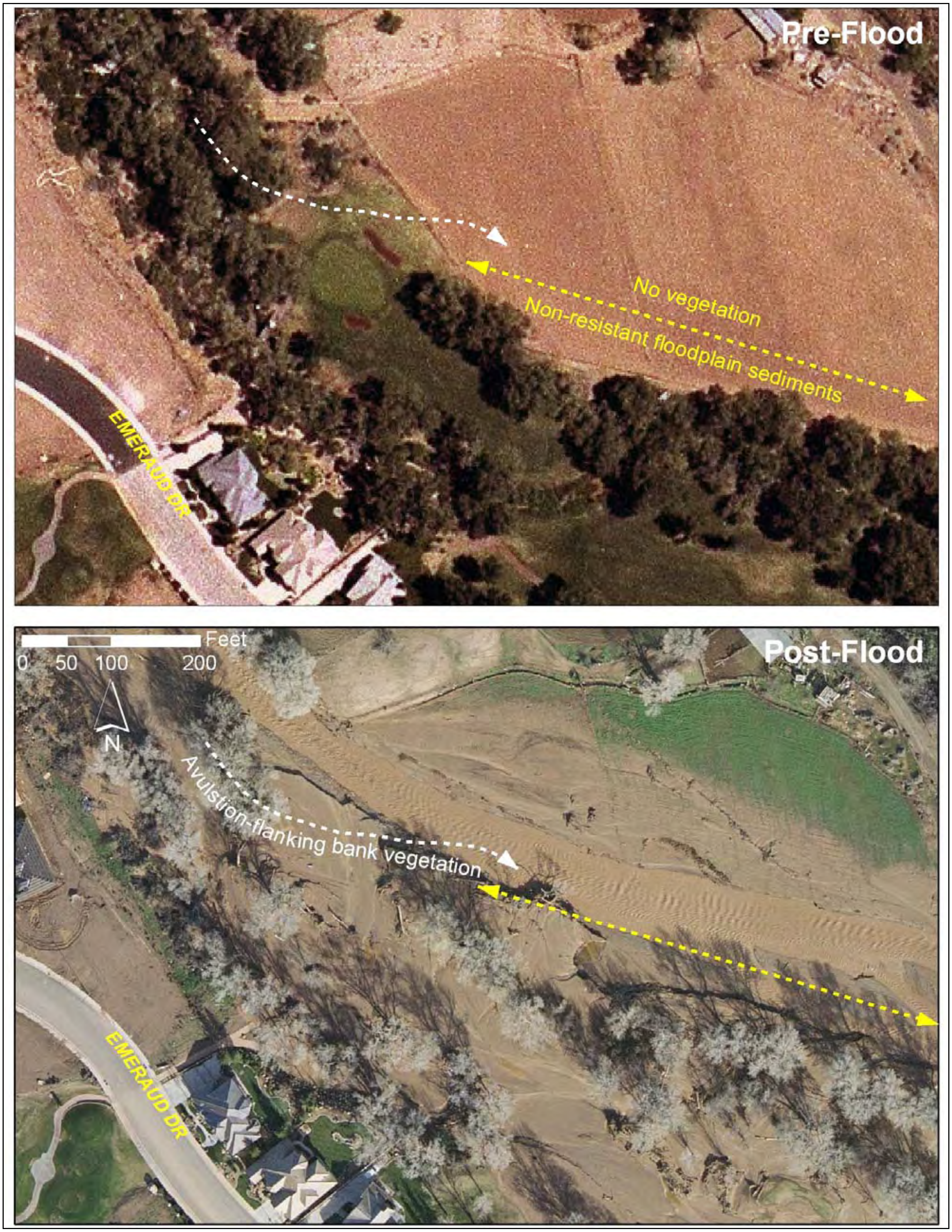


Figure 11. Example 1 - avulsion due to flanking of bank vegetation

Figure 12. Example 2 - avulsion due to flanking of bank vegetation

Figure 13. Virgin River upstream of Man-of-War bridge

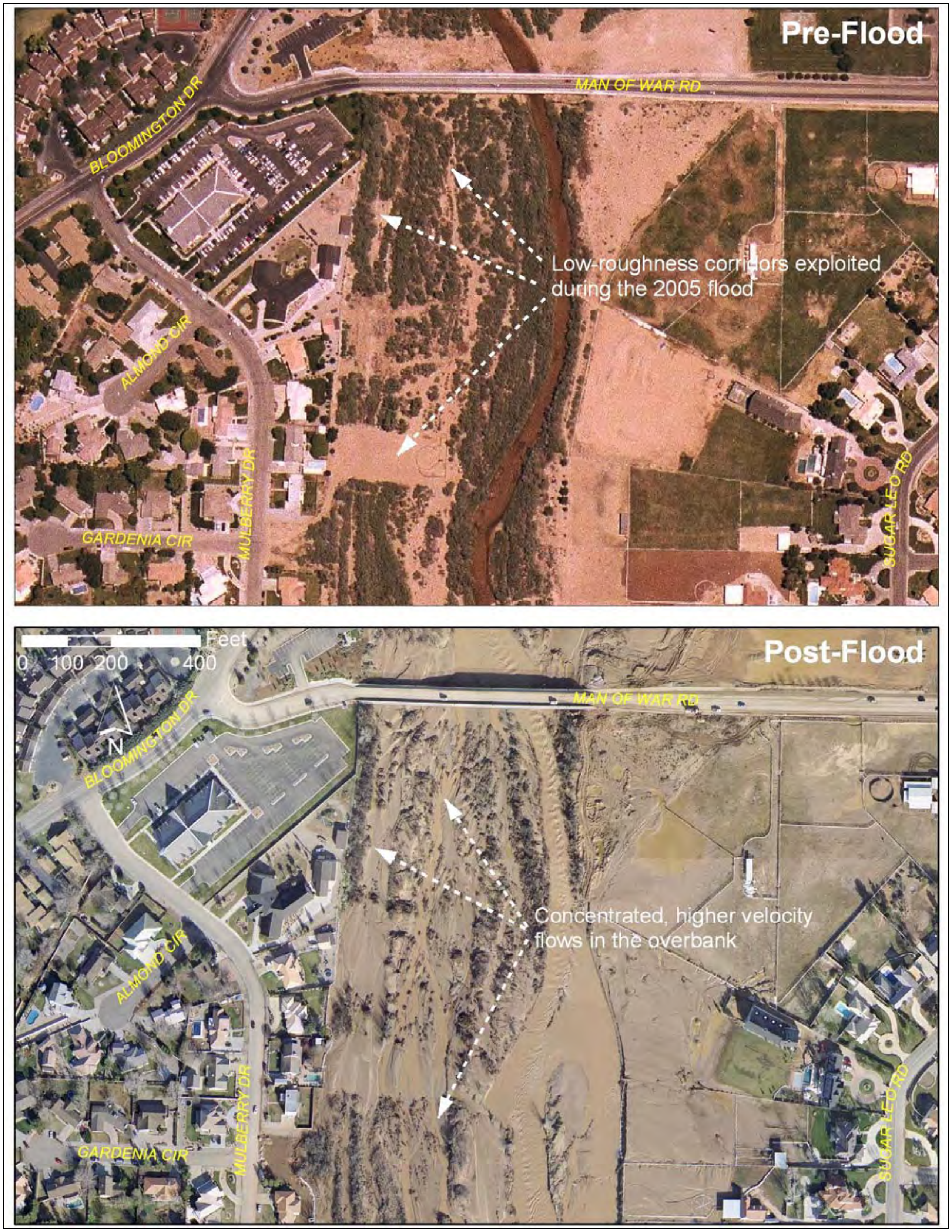


Figure 14. Virgin River downstream of Man-of-War bridge

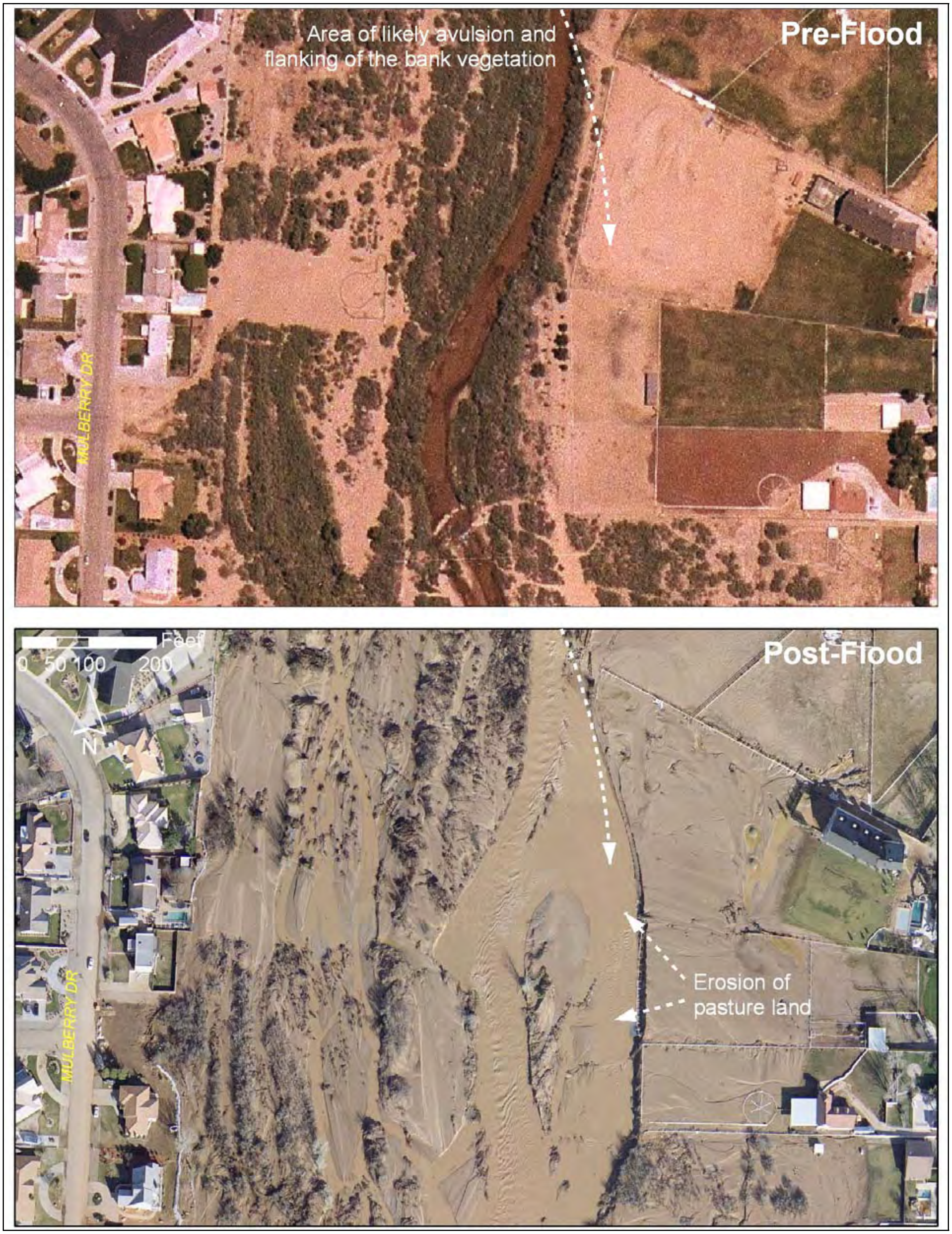


Figure 15. Lateral migration on the Virgin River downstream of Man-of-War bridge

2.4.3. Stable Reaches

Santa Clara. Two reaches of the Santa Clara River within the study area were observed to have weathered the 2005 flood with relatively little impact. Although minor channel widening and floodplain deposition occurred, the active channel corridor remained relatively consistent with pre-flood conditions.

The first of these areas is a 0.3 mile reach located adjacent to the River's Edge and Stonebridge-Monterey subdivisions. The pre-flood condition of the reach was characterized by moderately dense stands of mature cottonwood trees in the overbanks and lining the low-flow channel. The distal margin of the right overbank floodplain was characterized by dense brush and shrubs up to the base of a 3/1, 6 ft high slope. The left overbank floodplain margin was characterized by moderately dense cottonwoods up to the base of a 10 ft high, densely vegetated, 3/1 slope. Figure 16 illustrates the pre- and post-flood condition of the reach. Figure 17 shows multiple ground photos taken during the field investigation (ground photo locations are shown in the post-flood photo in Figure 16). Another significant factor in the stability of this reach may have been the relatively high elevations of the floodplain above the main channel, which forced flood waters to remain over the main channel corridor as opposed to concentrating in low overbanks and creating avulsive or erosive channels. Note the lack of sediment deposition or other high water marks in Figure 16.

The second stable reach is located in the vicinity of the Gubler property and is adjacent to Dixie Drive (Figure 18). The pre-flood characteristics of the 0.8 mile reach included a relatively straight, low sinuosity low-flow channel with densely vegetated bank and overbank areas. The upper reach was defined by a 4:1 sloped right bank approximately 18 ft in height. The upper reach left bank was also at a 4:1 slope extending about 8 ft in height up to the Gubler property. The downstream portion of the reach was defined by a significantly wider and densely vegetated floodplain. Figure 19 shows ground photos taken during the post-flood field investigation. Again, relatively high floodplains forced flow to remain over the main channel.

There are several likely reasons why these reaches remained relatively unaffected by the 2005 flood. Although any one single factor may have been the cause of stability, it was likely a combination of factors. Potential factors identified included:

- Relatively straight, pre-flood low-flow channel alignments
- Densely vegetated banks and floodplain areas that prevent high overbank velocity
- High floodplain surfaces that prevented flanking of the main channel on to non-resistant surfaces and concentrated flooding over the main channel[3]
- In the upper stable reach, the slopes outside the vegetation areas were covered with irrigated turf which resisted erosion better than bare surfaces
- Wide, open flow channel with low potential for debris blockage

[3] At higher flow rates, such as the 100-year discharge of 13,500 cfs, flanking and erosive overbank flow is more likely than during the smaller January 2005 flood.

Figure 16. Stable reach near River's Edge subdivision

Photo 179

Photo 180

Photo 181

Photo 182

Figure 17. Ground photos of the upstream stable reach

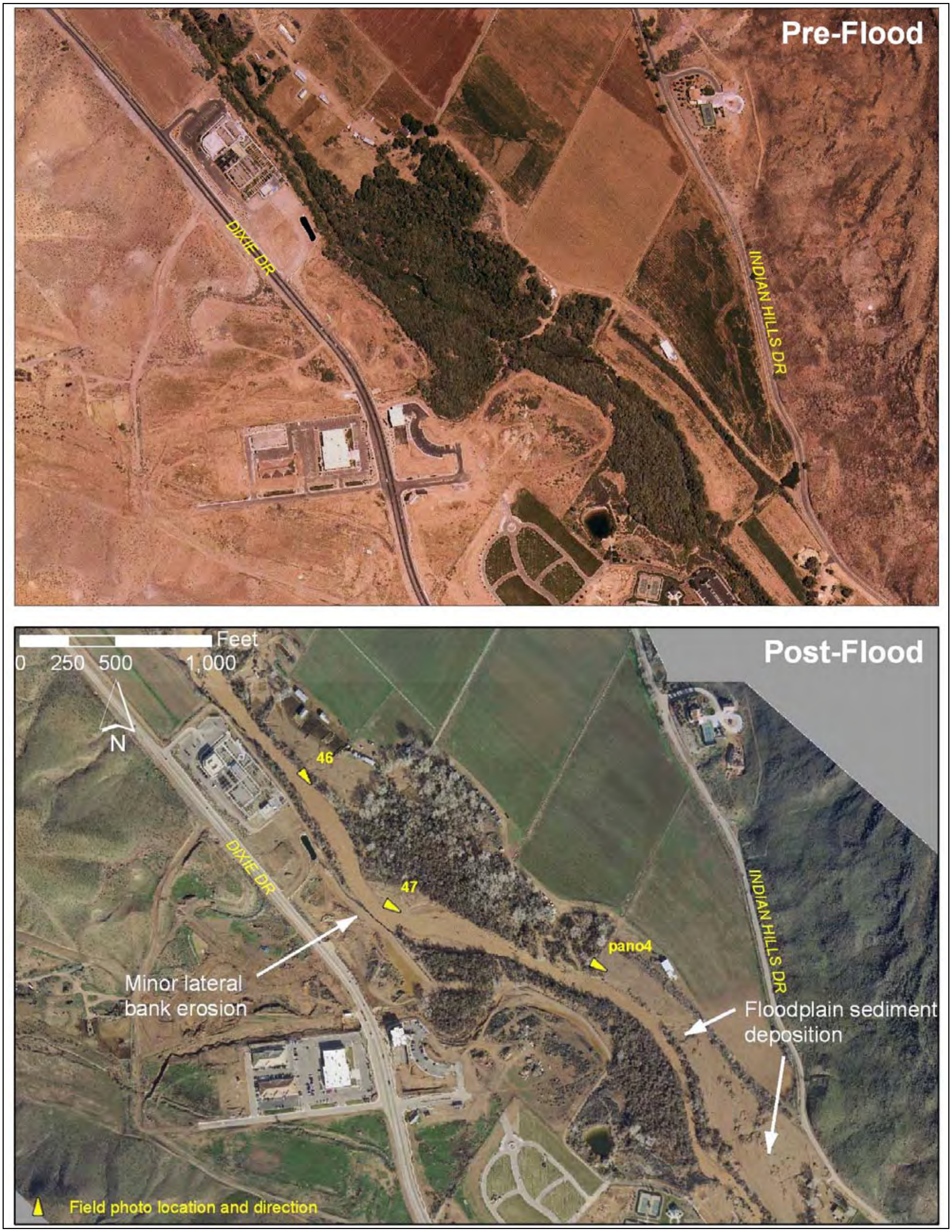


Figure 18. Stable reach near the Gubler property

Figure 19. Ground photos of the downstream stable reach

2.5. Quantitative Historical Analysis

2.5.1. Channel Width/Lateral Migration

Changes in active channel corridor width experienced during the 2005 flood were measured for both the Santa Clara and Virgin Rivers. The width changes were measured by establishing a series of control sections spanning the width of both the pre- and post-flood active channel corridors. These post-flood widths were then subtracted from the pre-flood widths to determine the change. Figure 20 shows the control section locations and ID values. Table 4 and Table 5 list the results of the width change analysis.

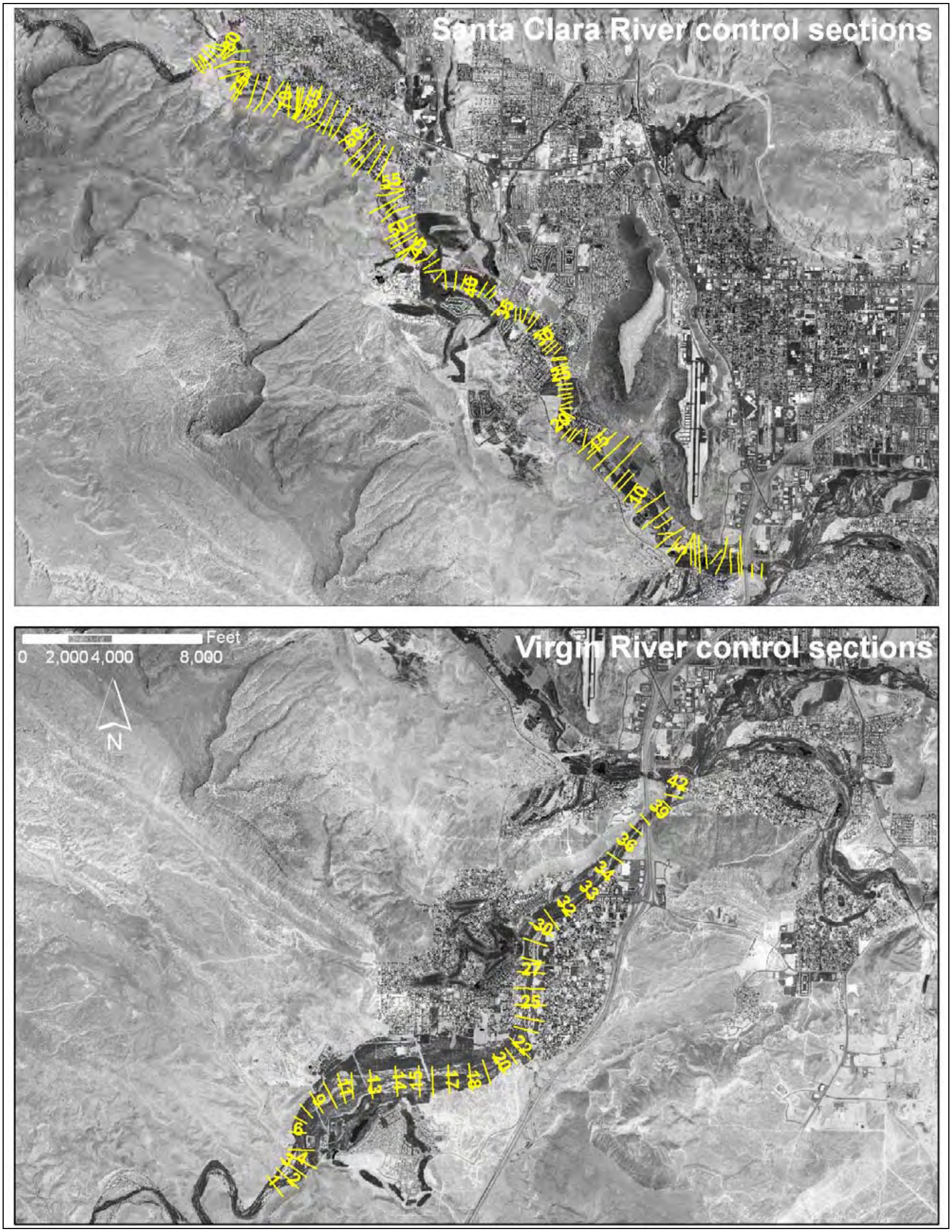


Figure 20. Width change control sections

Table 4. Santa Clara River Width Change Data							
Control Section ID	Width Change (ft)	Control Section ID	Width Change (ft)	Control Section ID	Width Change (ft)	Control Section ID	Width Change (ft)
90	21	64	163	40	167	20	116
89	14	63.1	106	39	81	19	245
88	44	63	100	38.1	84	18.1	289
87	98	62.1	55	38	91	18	350
86	115	62	70	37.1	61	17	123
85.1	107	61.1	220	37	69	16	289
85	141	61	95	36	24	15.1	289
84	82	60	53	35	55	15	256
83.1	98	59	128	34	127	14	38
83	18	58.1	122	33.1	167	13.1	0
82.1	72	58	75	33	170	13	14
82	83	57	204	32.1	143	12.1	35
81.1	68	56	199	32	142	12	142
81	126	55	30	31.1	223	11	98
80.1	83	54.1	83	31	231	10	2
80	114	54	67	30.1	187	9	19
79	25	53	149	30	132	8.1	0
78	20	52.1	138	29	275	8	0
77.1	81	52	30	28.1	302	7	1
77	253	51	219	28	85	6.1	195
76.1	356	50	187	27.1	142	6	304
76	338	49.1	118	27	207	5.2	75
75	361	49	85	26.1	175	5.1	300
74	301	48	44	26	136	5	192
73	333	47	47	25.1	109	4.1	107
72	441	46	35	25	138	4	75
71	398	45	83	24.1	83	3	52
70	270	44	97	24	76	2.2	157
69	140	43.3	41	23.1	163	2.1	108
68	179	43.2	112	23	258	2	228
67	270	43.1	122	22.1	32	1.2	108
66	448	43	182	22	88	1.1	108
65.1	578	42	19	21.1	232	1	33
65	670	41	213	21	172	0.2	17
64.1	608	40.1	166	20.1	209	0.1	16

Table 5. Virgin River Width Change Data					
Control Section ID	Width Change (ft)	Control Section ID	Width Change (ft)	Control Section ID	Width Change (ft)
42	0	27	0	12	0
41	0	26	174	11	0
40	0	25	0	10	0
39	0	24	0	9	0
38	103	23	0	8	0
37	0	22	0	7	0
36	0	21	13	6	0
35	0	20	0	5	0
34	0	19	0	4	0
33	0	18	0	3	0
32	0	17	0	2	0
31	0	16	0	1	0
30	0	15	0	0.5	0
29	15	14	0		
28	0	13	0		

2.5.1.1. Summary

Santa Clara River. The Santa Clara River experienced significant changes in the active channel corridor geometry throughout the entire study area. Pre- and post-flood channel width summary data is listed in Table 6.

Table 6. Santa Clara River Pre- and Post-Flood (2005) Channel Width Changes			
Santa Clara River	Mean Width (feet)	Min Width (feet)	Max Width (feet)
Pre-Flood	83	37	348
Post-Flood	231	81	749
Change During 2005 Flood	147	0	670

Virgin River. The Virgin River experienced little change in the active channel corridor width. Lateral erosion was mostly contained within the active channel corridor. Pre- and post-flood channel width summary data is listed in Table 7:

Table 7. Virgin River Pre- and Post-Flood (2005) Channel Width Changes			
Santa Clara River	Mean Width (feet)	Min Width (feet)	Max Width (feet)
Pre-Flood	608	148	1,035
Post-Flood	615	230	1,035
Change During 2005 Flood	7	0	174

2.5.2. Sinuosity

Changes in the sinuosity of a river system can be an indicator of change in slope or sediment transport regimes. Sinuosity is defined as the ratio of stream length to valley length. A sinuosity of 1 would suggest the stream length is equal to the valley length (i.e., the main channel is parallel to the river valley), while a sinuosity value greater than 1 indicates the stream is exhibiting a sinuous channel pattern. Rivers strive to be in equilibrium by balancing the energy available to perform work (such as erosion) with the water and sediment load. One mechanism for rivers to reduce energy is to form meanders which allow a greater surface area for balancing the water and sediment load (erosion and deposition). Pre- and post-flood sinuosity calculations were made for both the Santa Clara and Virgin Rivers, and are shown in Table 8. Note that at the time this report was prepared, post-flood channel topography was only available for the Santa Clara River upstream of Valley View Drive, thus the post-flood channel length calculation was based on aerial photo interpretation. Additionally, no post-flood topography was available for the Virgin River. Post-flood aerial photography of the Virgin River was only available upstream of Baneberry Drive in Bloomington. Therefore, post-flood channel length was calculated from aerial photography where available, and pre-flood channel length was used post-flood photos where not available. As shown in Table 8, sinuosity on the Santa Clara River increased slightly, while sinuosity decreased slightly on the Virgin River.

Table 8. Sinuosity analysis results

River	Pre or Post Flood	Sinuosity
Santa Clara	Pre	1.07
Santa Clara	Post	1.09
Virgin	Pre	1.11
Virgin	Post	1.10

2.5.2.1. Summary

Santa Clara River. The main channel of the Santa Clara River increased in length within the study area by approximately 830 feet. Post-flood sinuosity measurements were consistent with field observations

Virgin River. Considering the degree of uncertainty in the data, pre-and post sinuosity results indicate little, if any, change in stream length occurred. The results suggest the changes in the low-flow channel width, energy dissipation in the floodplain, and sediment deposition was sufficient to maintain equilibrium within the study area

2.5.3. Longitudinal Profile

Analysis of a pre-and post-flood channel longitudinal profile can provide information regarding areas of likely aggradation or degradation, channel instability, or other future changes in channel slope. A pre- and post-flood channel profile analysis was performed for the Santa Clara River within the study area as shown in Figure 21. The pre-flood profile data were derived from 1999 digital topography. The post-flood profile data were compiled from a combination of digital topography for the City of Santa Clara and surveyed cross-sections. The density of the cross-sections was significantly less than the topographic data, thus the post-flood point density downstream of Dixie Drive is lower than upstream, as shown in Figure 21. Also, post-flood cross-sections were not surveyed for the lower 1.5 miles of river. Neither post-flood topography nor cross-section data for the Virgin River were available at the time this report was drafted. Therefore, a profile analysis was not completed for the Virgin River. As shown in Figure 21, the Santa Clara River appears to have experienced net aggradation, a somewhat surprising result given the historical evidence of net degradation and magnitude of erosion experienced during the flood. Exceptions to net degradation occurred upstream of the diversion dam and Valley View Drive where pre-flood constrictions had caused aggradation observed as breaks in the profile shown in Figure 21.

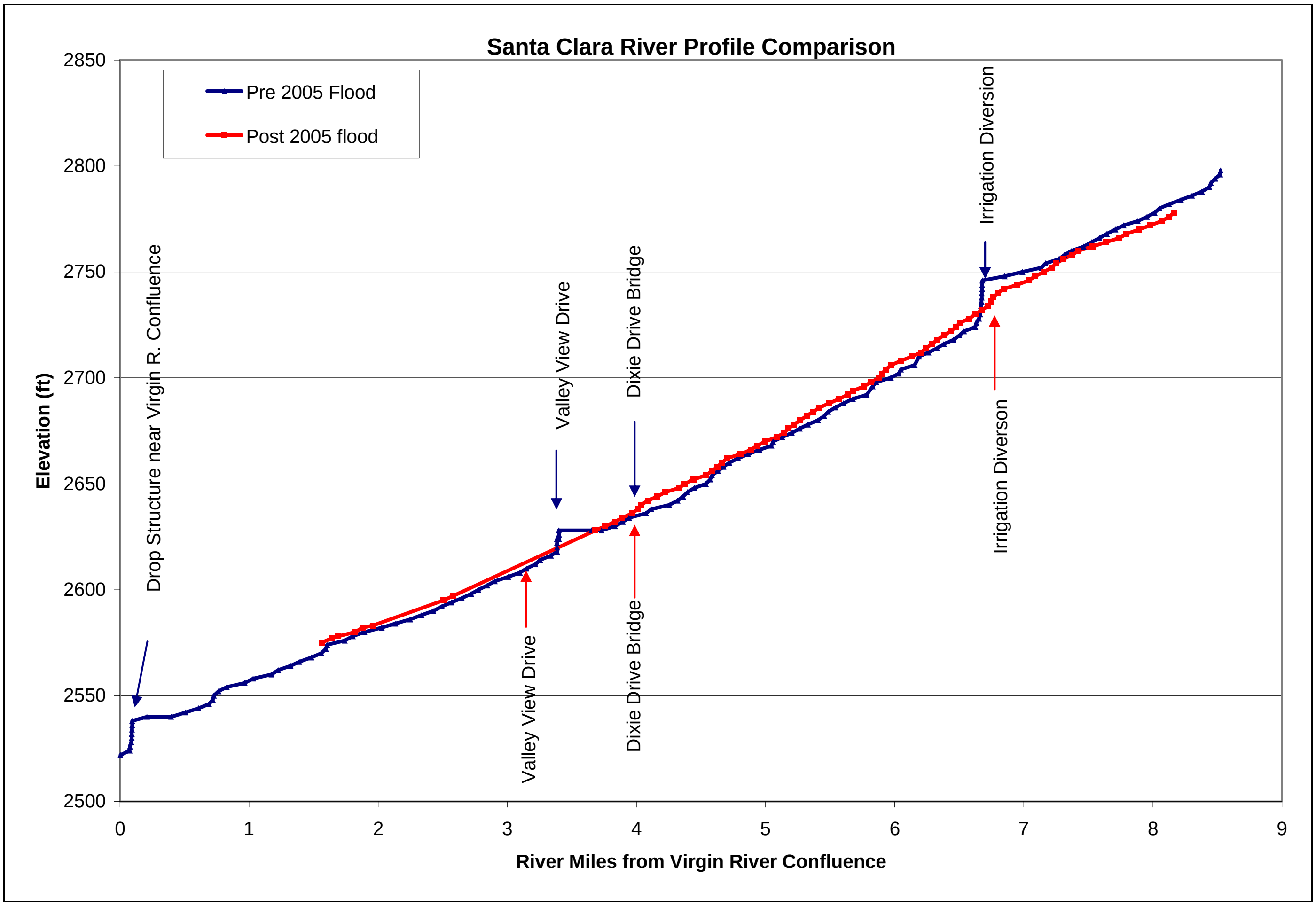


Figure 21. Santa Clara River profile analysis

2.5.3.1. <u>Summary</u>

<u>Santa Clara River</u>. The breach and removal of the irrigation diversion structure resulted in a smoothing of the channel slope immediately upstream and downstream. Erosion and removal of Valley View Drive also resulted in a smoothing of the channel slope. Although the river experienced an overall lengthening as shown in the sinuosity analysis, the channel length decreased from Valley View Drive to the limit of the post-flood cross-sections. Net channel degradation occurred upstream of the irrigation diversion structure in the constricted reach adjacent to Swiss Village. Net channel aggradation occurred downstream of the irrigation diversion structure to downstream of Valley View Drive.

3. EROSION HAZARD ANALYSIS

3.1. Methodology

The following types of information were considered in defining the erosion hazard zones for the Santa Clara and Virgin Rivers:

- 1997 River Stability Study results, conclusions and recommendations
- Location and design of NRCS channel stabilization structures
- Field observations
- Historical channel changes
- Geology/soils mapping
- Results of quantitative geomorphic analyses
- Observed and measured channel changes from the 2005 flood
- Expected future channel behavior

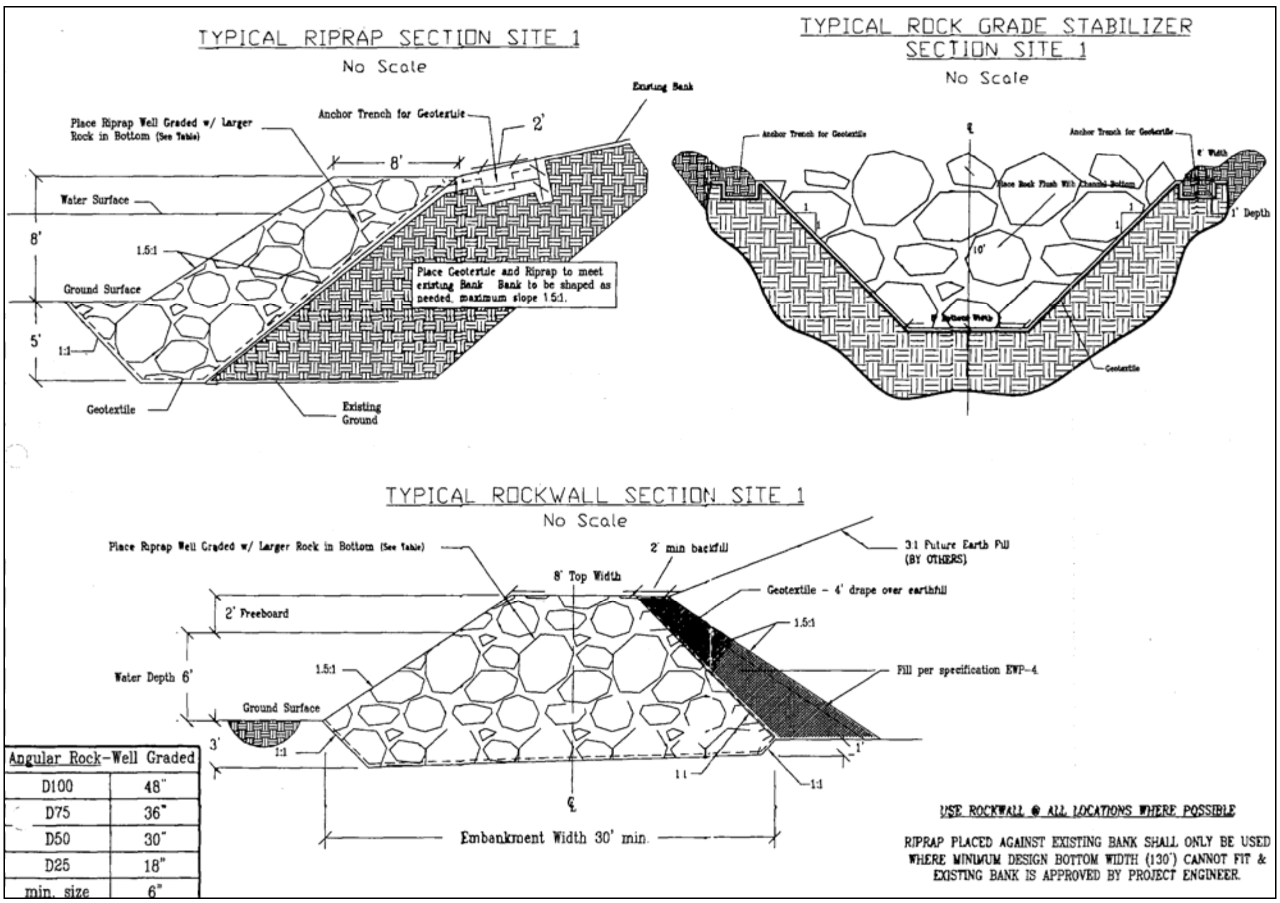
3.1.1. 1997 River Stability Study

The conclusions and recommendations from the 1997 study are considered the foundation of the current study. The 1997 study conclusions listed in Section 1.2 of this report accurately predicted the behavior of the Santa Clara River during the 2005 flood. With few exceptions, the 1997 erosion hazard zone delineations proved adequate and were considered in this analysis. As noted in the 1997 study, the potential for future bank erosion increased dramatically once bank vegetation is lost. Therefore, the hazard of future lateral erosion on the Santa Clara River significantly increased after the 2005 floods because of the change in channel and bank conditions. Without stabilization measures and consistent river management, lateral erosion like that experienced in the winter of 2005 will become more common during moderate to large floods.

3.1.2. Engineered Structures

Immediately following the 2005 flood, the NRCS enacted an *Emergency Watershed Project* (EWP) for the Santa Clara and Virgin Rivers in the study area. The NRCS project consisted of debris removal and construction of over 25,500 linear feet of streambank protection along the Santa Clara River. The NRCS design consisted of rock wall levees, rock grade stabilizers, and rip-rap bank protection. Under the guidelines of the EWP Program, the NRCS stabilization was designed for the peak discharge of the 2005 event, rather than the 100-year (or larger) discharge that is used for most river engineering projects. Figure 22 shows the typical design detail for each type of erosion protection structure built by the NRCS, as well as a rock sizing table. Figure 23 shows the proposed locations of a portion of the NRCS structures on the Santa Clara River. Figure 24 shows ground photos of the construction of the rock levees.

While construction of the NRCS erosion control measures reduces potential future lateral migration and bank erosion in reaches with NRCS structures, it does not eliminate erosion hazards in those reaches, and may increase the potential for erosion in adjacent reaches. Because the NRCS structures were designed for a flood less than the 100-year event, the potential for high stage flows to overtop the structures and erode behind the levees or above bank protection still exists. Therefore, the erosion hazard zone was delineated outside the NRCS structure footprint to acknowledge the potential for erosion and advise developers and landowners that more detailed engineering analysis and design is required. Hydraulic modeling performed for this study indicates that typical overbank velocities during flows that exceed the levee elevations will be near or below the erosive threshold of the local native soils. However, unprotected, unconsolidated fill in these areas would be more susceptible to erosion. In addition, at channel bends, a non-symmetrical velocity distribution could lead to higher, erosive overbank velocities on the outside of the bend. Therefore, the erosion hazard zone was widened slightly on the outside of bends to account for potential overbank erosion during large floods.



Angular Rock-Well Graded	
D100	48"
D75	36"
D50	30"
D25	18"
min. size	6"

Figure 22. NRCS structures typical designs

During the 2005 floods, bank erosion was a significant source of sediment supply for the river. Because the NRCS levees are constructed of erosion-resistant large-diameter rip rap, this source of sediment supply will be unavailable during future floods. Reduced corridor roughness between NRCS levees may lead to increased flood velocities and higher sediment transport capacity. Under some river management scenarios, it is possible that flows exiting levee reaches may be sediment-deprived and more erosive, causing increased bank erosion. Therefore, the erosion hazard zone was widened downstream of long reaches with bank protection.

Local landowners have constructed other stabilization measures ranging from rip rap levees to slope protection to earthen berms and fill. Where these structures were identified on aerials or in the field they were noted and considered in developing the erosion hazard zone boundaries. However, unless designed using sound engineering principles and constructed according to specific plans, it is difficult to assess the probable future performance of such structures. The historical accounts of flood damages reviewed in the 1997 study document failure of many such structures when tested by flooding.

It is important to note that the erosion hazard in the areas outside of and adjacent to the NRCS structures can be mitigated with properly engineered backfill and slope protection measures.

3.1.3. Field Data

Several mechanisms of channel movement were identified during the field investigation, as discussed in Section 2.4.2. This information combined with other field observations such as location of bedrock and resistant soil units were incorporated into placement of the erosion hazard zones. Additional field observations that were considered when placing the EHZ were:

- Areas of imminent bank failure – unstable, vertical or undercut banks
- Areas of stable channel banks and floodplain slopes
- Floodplain elevation – formation of potential avulsions
- Vegetation – density, age, cover, root mass and depth
- Bank material – resistance, cohesion, cementation, and stratification
- Channel pattern – position relative to bends and bend angle
- Channel evolution – like meander migration patterns
- Land management practices – natural areas, agriculture lands, residential zones
- Local stabilization measures – dumped rock, vegetation thickets, earthen berms

Figure 23. Locations of the NRCS dike structures

Rockwall downstream of Valley View Drive

Rockwall with filter fabric (looking downstream)

Rockwall with filter fabric (looking upstream)

Rockwall near Swiss Village

Figure 24. Ground photos of the NRCS rock wall construction

3.1.4. Historical Channel Changes

Measured historical channel movement was described in Section 2.3. The 1997 Study concluded that where undisturbed the active channel corridor of the Santa Clara River was relatively stable. It also concluded that although the Virgin River low-flow channel had experienced relatively frequent lateral changes in the historical record, those changes were confined to the geologic floodplain. The 2005 flood on the Santa Clara River resulted in channel changes greater than the cumulative channel change measured over the past 67 years. Although the direction and magnitude of future erosion cannot be predicted with 100 percent certainty, the lateral erosion distances that occurred during the 2005 floods serve as an indication of the potential magnitude of future erosion, and were considered when delineating the erosion hazard zones. Additional considerations of channel movement in the placement of the EHZ were:

- The mechanisms of channel movement during the 2005 flood, and the potential for a repeat of the mechanisms during future floods
- Topographically low areas in the overbanks and floodplains
- Maximum distances of channel change from the 2005 flood

When considering the historical record, it is important to place the 2005 event in its proper context. The estimated peak of the 2005 flood on the Santa Clara River was equivalent to about a 25-year flood. The current estimate of the 100-year peak is about twice the magnitude of the 2005 flood. It is likely that more severe flooding will occur in the future. We also note that the December 1966 flood was similar to the January 2005 flood in magnitude and volume, but resulted in almost no significant erosion damage. Possible causes of the different responses to the 1966 and 2005 flood include cessation of river maintenance activities by local landowners due to restrictions imposed by environmental permitting agencies, increased residential development in areas close to the main channel, and increased vegetative growth (debris sources) along the main channel.

3.1.5. Geology/Soils Mapping

The mapping published by the SCS and UTGS was used primarily to differentiate geologically young and old surfaces. Young surfaces are generally composed of unconsolidated, highly erosive sediments that are easily transported during floods. Identification of these surfaces aids in bracketing the zone of potential lateral migration. Older surfaces may have greater resistance to lateral erosion due to accumulations of carbonate and clay that increase cohesion. Older surfaces also provide a historical record of areas that have not, for whatever reason, been eroded for a very long time. While the presence of geologically old surfaces does not preclude future erosion, it does indicate that the river has preferred to erode other areas for a very long time. Lacking any other information, geomorphically young surfaces (e.g., the active floodplain) were considered to be in the erosion hazard zone unless there was a compelling reason to remove them, such as presence of structural erosion control measures. Geologically old surfaces were considered to be out of the erosion hazard zone except along their margins where they abut the active channel. Geologic mapping of bedrock provided a definitive limit on future lateral erosion if the rock units were composed resistant material, such as basalt.

3.1.6. Quantitative Analyses and Expected Future Channel Behavior

The results of the quantitative analyses from both the 1997 study and this study provided insightful information on the stability and equilibrium state of both the Santa Clara and Virgin Rivers. The results of these analyses combined with expected future channel behavior in, light of the NRCS structures, were considered in the delineation of the erosion hazard zones.

3.2. Definition of the Erosion Hazard Zone

The erosion hazard zone is defined as a land area adjoining a body of water or adjacent to or located partially or wholly within a delineated floodplain which due to the soil instability, is likely to suffer flood-related erosion damage. The erosion hazard zones consist of the channel margin area likely to be eroded by a “typical” series of floods over a sixty year period, plus the erosion that would be caused by a 100-year flood. It also includes the natural channel movement due to geomorphic processes such as meander migration or channel avulsion.

The erosion hazard zones are a distinct management tool for protecting the health, safety and welfare of landowners and users of the river corridors in the study area. Although they are based on the same hydraulic data, the erosion hazard zones are independent of the FEMA 100-year floodplain and floodway limits. The FEMA floodplain boundaries are primarily intended to prevent damage from flood inundation. The erosion hazard zones are intended to prevent damage from erosion during flooding, whether or not the property is located within the 100-year floodplain.

It is important to recognize that the erosion hazard zone is not a "no-build" zone. The erosion hazard zone depicts areas that deserved special design consideration to account for some risk of being affected by lateral erosion during the design life of any structure or the tenure of land ownership. The erosion hazard zones also serve as notice to landowners that development of the property carries inherent risk that should be adequately addressed through engineering design, insurance, appropriate land uses, or avoidance. As delineated, the erosion hazard zones depict the long-term potential for river movement should no river management plan be adopted and enforced, and the river is allowed to migrate naturally within the river valley.

The use of erosion hazard zones rather than erosion hazard lines reflects the inherent uncertainty in predicting future channel changes such as lateral migration. Stream morphology and behavior are governed by a large number of variables, few of which can be predicted with certainty. Therefore, prediction of future channel change and future lateral movement is subject to similar uncertainty. The uncertainty and/or measurement error associated with each of the specific methodologies used to assess channel stability was described in the previous chapters of this report. Even if the uncertainties associated with the methodologies used and the variables that impact lateral erosion were eliminated, the sequence, timing, and magnitude of future floods cannot be predicted. Therefore, future erosion cannot be known with a high degree of certainty.

3.3. EHZ Boundary Location Scenarios

Four basic river management scenarios were considered in determining the location of the EHZ for the Santa Clara River.

1. NRCS dikes on both channel banks
2. NRCS dikes on one channel bank
3. No bank protection but implementation of the Master Plan recommendations
4. No bank protection and no implementation of the Master Plan recommendations

3.3.1. Scenario 1 – NRCS dikes on Both Channel Banks

The NRCS dikes were constructed along both banks of the Santa Clara River for a 1.5-mile section beginning just upstream of the Mathis Bridge and extending about half-way through the Riverwood subdivision (Figure 25). This reach contains the most densely developed areas directly adjacent to the river corridor, and subsequently resulted in the most concentrated number of damaged and destroyed structures. The presence of the NRCS dikes greatly reduces the risk of lateral erosion from high frequency floods (e.g. 20-year and less). However lower frequency, higher magnitude floods (e.g. 50-year and greater) will overtop the dikes resulting in potential overbank flooding and erosion hazards. The following factors were evaluated in determining the location of the EHZ in the reach with NRCS dikes on both banks:

- Channel pattern – straight channel vs. channel bends. Higher energy conditions occur on the outside of channel bends resulting in a higher scour potential than would occur in straight reaches. Where sufficient data were available, general, bend and long-term scour estimates were made within the scenario 1 reach. Bends with higher scour could result in potential partial failure of the NRCS dikes. The location of the EHZ was adjusted to account for bend scour components.
- Overtopping of the dikes – where sufficient data were available, hydraulic models were prepared to estimate the overbank depths and velocities when flows overtopped the dikes. Where overbank velocities were high (erosive), the EHZ location was adjusted to account for potential erosion of the bank slope above the dikes.
- Increased lateral erosion at the downstream end of the protected reach due to potential sediment deficits.
- Meander migration impacting the entry section of the protected reach.

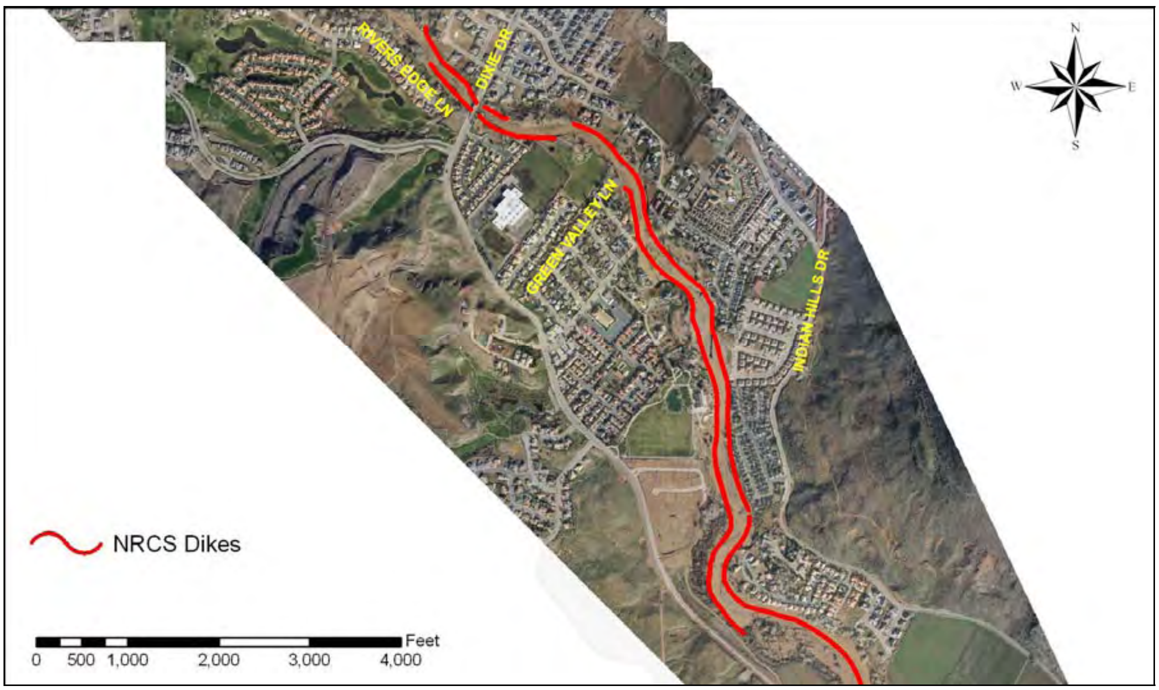


Figure 25. Scenario 1 - NRCS dikes on both banks

3.3.2. Scenario 2 – NRCS Dikes on One Channel Bank

Single-bank dikes were constructed in multiple locations along both the left or right bank of the Santa Clara River. The single-bank dikes were built to the same specification as those in Scenario 1, thus the scour and overtopping considerations described above are also applicable. Figure 26 shows some of the locations of the single-bank dikes within the study area. An additional segment of single-bank dike was constructed downstream of the Scenario 1 area and is shown in Figure 25.

The following factors were evaluated in determining the location of the EHZ in the reaches with single-bank NRCS dikes:

- The same factors as Scenario 1 were applied to the banks with single dikes
- The presence of any geologic control or erosion-resistant sediments along the unprotected bank
- The potential for future debris dam blockage
- The potential for channel avulsions and/or vegetation flanking
- The potential for preferential erosion of the non-protected bank
- The potential for reflective scour downstream of a protected bank

Figure 26. Scenario 2 - single-bank NRCS dikes

3.3.3. Scenario 3 – No Bank Protection With Master Plan Recommendations

A significant portion of the Santa Clara River study area does not contain NRCS dikes or other engineered bank protection. Without future management of the river corridor in these areas, flood damage experienced during the 2005 flood will likely be repeated several times over the design life of any permanent structure. The Master Plan prepared by Natural Channel Design, Inc. (NCD) discusses specific recommendations pertaining to restoration and management of the active channel corridor and floodplain of the Santa Clara River. These recommendations are for the purpose of reducing the potential for lateral erosion of the river in addition to restoring its riparian functions. The Master Plan specifically address the mechanisms of channel change that occurred during the 2005 flood (described in this report in Section 2.4.2) and provides recommendations for channel designs that potentially reduce the chance the mechanisms will be repeated in the future. For Scenario 3, it is assumed that implementation of the Master Plan will occur and the recommendations of channel, overbank, and floodplain designs be implemented. Adoption and implementation of the Master Plan recommendation in area without bank protection will result in a narrower EHZ. The Master Plan recommends a minimum upper-terrace width of 360 feet. The geomorphic assessment of channel width change in the River Stability Study portion of the Mater Plan indicated a mean change within the Santa Clara River study area of 147 feet. To determine the EHZ, assuming scenario 3, a factor of safety of 1.3 was applied to the 147 foot value, resulting in a buffer of 200 feet. The 200 foot buffer was then applied to the 360 foot upper-terrace width. This approach was applied in all locations without NRCS dike protection. Additional physical factors were considered, and if applicable, overwrote the 360 foot + 200 foot rule. The additional factors included:

- Presence of geologic control or erosion-resistant soils
- Physical structures that prevent or inhibit lateral channel migration
- Potential future debris blockage
- Potential channel avulsions and/or vegetation flanking
- Potential for channel widening

3.3.4. Scenario 4 – No Bank Protection and No Master Plan Recommendations

Although cooperation from both county and city municipalities on implementation of the Master Plan recommendations is expected, the potential exists that individual landowners may chose not to comply with the recommended river management plan. If the Master Plan recommendations are not implemented, such as vegetation management, terracing, and channel width, the channel change mechanisms discussed in Section 2.4.2 would have a high probability of reoccurring, and the destructive, unpredictable behavior that was observed during the 2005 flood would likely be repeated. Therefore, the EHZ would be wider to encompass the poorly managed river. This wider EHZ would be in effect if the Master Plan recommendations were not met, and/or up to the time when the implementation of the recommendations were completed.

3.4. Summary

Map sheets included in Appendix A (separate volume) show the EHZ delineations for the Santa Clara and Virgin Rivers within the study area, based on the criteria listed in Section 3.

4. CONCLUSIONS

Washington County, Utah in conjunction with the Cities of St. George and Santa Clara initiated a River Master Plan study in response to flooding damage on the Santa Clara and Virgin Rivers in January 2005. JE Fuller/Hydrology & Geomorphology, Inc. performed a river stability study by analyzing the geomorphic impacts of the 2005 flood, identified principal causal mechanisms responsible channel changes, and delineated an erosion hazard zone. JEF has prepared this river stability study as a component to the Master Plan to aid in future management and regulation of the river corridors.

Erosion hazard zones for both the Santa Clara and Virgin Rivers were delineated based on the results of the geomorphic, historical, quantitative, and engineered structures analyses. The erosion hazard zones are intended for use in floodplain and river management and should be used in conjunction with the Master Plan recommendations.

5. RECOMMENDATIONS

The following recommendations are presented for the Santa Clara and Virgin Rivers with the study area. All the general recommendations from the 1997 study remain applicable to the present study.

- *Adopt the recommended erosion hazard zone delineations for floodplain management and regulation purposes. Proposed development within the erosion hazard zone should be allowed only if it is protected from erosion by structural measures and can be shown to have no adverse impact on adjacent properties.*

- *Amend existing flood control ordinances and policies to include river management policies that support preservation of the natural river systems, promote land uses that are compatible with a natural river system, and limit construction of structural improvements inside the erosion hazard zone, except to protect existing structures needed of public safety such a s bridges and existing buildings, or where the channel threatens to move outside of the established erosion hazard corridor.*

- *Regulate all development within the erosion hazard zones by requiring a special use permit that meets the following:*
    - *Meet NFIP requirements for development within a floodway or floodplain.*
    - *Provide and engineering and geomorphic study prepared by a professional engineer licensed to practice in the State of Utah certifying that the proposed development will not be affected by erosion over a 100-year planning period.*
    - *Demonstrate that proposed bank stabilization, if any, will not adversely impact adjacent property.*
    - *Demonstrate the stability of proposed bank stabilization. Local scour, long-term degradation, channel movement, and bank erosion shall be explicitly addressed in the proposed bank protection design.*
    - *Hold the City harmless from any and all claims resulting from erosion or any other flood related damage to development within the erosion hazard corridor.*
    - *Provide for perpetual maintenance of the bank stabilization that protects private property at no cost to the City or any other public agency.*
    - *Obtain necessary floodplain, wetlands (404), water quality (401), and stream alteration permits or approvals for any construction activities at no cost to the City.*

- Add additional bank protection structures in areas of discontinuous NRCS dikes. Areas located within the breaks in the current NRCS dikes are potentially subject to a greater erosion hazard. Figure 27 illustrates examples of such locations.

Figure 27. Examples of gaps in NRCS dikes

- Development of a river management plan for the low-flow channel corridor from the Hilton Drive Bridge downstream to the I-15 Bridge. The plan should include vegetation management within the low-flow channel corridor to allow sufficient flood conveyance. The plan should also include monitoring of lateral erosion of the channel banks and intervention measures if such erosion occurs.

Require that any development adjacent to the NRCS structures be required to adhere to specific guidelines in analysis and design to comply with the Master Plan. A sample scope of services that outlines these guidelines is attached to this report in Appendix C.

6. REFERENCES

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APPENDIX A
Erosion Hazard Zone Map Sheets

(Separate Volume)

APPENDIX B
Historical Aerial Photo Comparison Sheets

(Separate Volume)

APPENDIXC

Development Scope of Service Examples

and

Erosion Hazard Identification Guidelines

Example Scope of Services
Scour Protection Analysis
Reach Type: NRCS Levee Areas
Santa Clara River, St. George, Utah

Overview: This scope of services is intended to guide land owners, their engineers, and community officials assess development potential in stream reaches adjacent to NRCS stabilization measures. NRCS channel stabilization measures were not designed specifically for the 100-year flood, but may in fact provide sufficient protection for some types of development. The additional analyses described below will help assess whether additional flood and erosion protection is needed, and provide data for design of such protection.

Data Needs: The following data are required to complete the recommended analyses:

- Design discharge – typically the 100-year peak is used. FEMA is currently re-evaluating the 100-year discharge for the Santa Clara River. Peak discharge information can be obtained from the City of St. George.
- Channel cross section(s) – surveyed cross sections showing the final constructed channel cross section (with levees) or other grading, cross sections showing any proposed modifications (fill, vegetation, additional flood or erosion control measures, etc.). Multiple cross sections are recommended where channel geometry changes within the reach adjacent to the subject property.
- Hydraulic coefficients – Manning's n values (existing & future condition), channel slope and any other data required for performing a hydraulic rating.
- Site plan – show location of proposed buildings or other constructed facilities.

Technical Analyses: The following types of engineering analyses should be completed to support the evaluation:

- Scour – a scour analysis is recommended to assess the adequacy of the NRCS design. The scour analysis should include bend, general, thalweg, anti-dune, and long-term scour elements. The computed scour depth should be compared to the toe-down of the NRCS levee to assess the potential for undermining of the levee.
- Levee rock volume - If the NRCS levee will be undermined by scour, then the potential for a portion of the levee to function as a "launching pad" and still provide adequate lateral erosion protection should be assessed.
- High flow scour – flow velocities in the portion of the floodplain outside of and above the height of the NRCS levee should be evaluated using a Manning's rating or HEC-RAS model relative to erosive thresholds. The Manning's rating or HEC-RAS model should consider channel pattern affects (e.g., bends), floodplain vegetation, and future and existing land cover when estimating velocities. It may also be important to consider maximum, rather than average flow velocities within the channel, as is typically report in HEC-RAS or Manning's program output.

- Scour mitigation – if erosive velocities will occur, adequate erosion protection should be provided at all points and elevations up to the 100-year level between the river and any habitable structure.

Design Guidelines: Design guidelines for erosion mitigation measures will be provided in the Master Plan Report. Design guidelines may include recommendations for maximum side slope, fill compaction standards, revegetation plans, open space and access needs, or other factors.

Community Input: Design of structures or placement of fill in areas near the river corridor and NRCS levees should be coordinated with appropriate community regulatory staff.

Typical Scope of Services for Erosion Hazard Assessment

The following scope of services shall be applied if the adopted erosion hazard is proposed to be amended by a private landowner. The analysis described below should be completed by a registered professional engineer with expertise in river mechanics, hydraulics, hydrology, sediment transport, and geomorphology. A detailed erosion hazard analysis should consist of the following elements:

1. Historical Analyses
    a. Historical analysis of horizontal channel change
        i. Quantify maximum long-term channel movement by comparing channel position on rectified historical (oldest available) and modern (most recent) aerial photographs and/or historical survey data.
        ii. Quantify maximum single event channel movement by comparing channel position on a sequence of rectified historical and modern aerial photographs and/or historical survey data.
        iii. Identify trends of channel movement (direction, scale, and type) related to the current or historical channel pattern that may affect future channel movement.
        iv. Identify changes in channel pattern during the period of historical record. Determine whether channel pattern changes are cyclical or evolutionary, and relate pattern changes to the potential future channel movement.
        v. For streams with limited historical data, expand the study reach to adjacent stream reaches or adjacent watercourses (spatial data substitutes for temporal data) to identify regional rates of historical channel movement. Where regional rates of channel movement are significantly different from historical channel movement in the project reach, the regional rates should be used to estimate future erosion potential, or a physical reason for the differences is required.
        vi. Identify land use changes and human impacts to watercourse, as well as the historical channel response to those changes. Relate the potential for future land use changes and human impacts to future channel changes.
        vii. Catalogue the record of past floods by magnitude and relate the observed historical channel changes to the flood series. Where no flood records exist, examine rainfall records or flood series from adjacent watercourses to identify periods of likely flooding or drought.
        viii. Relate the observed historical scale of channel change to the magnitude and frequency of historical floods, as well as to a potential future flood series that might occur during the design life of the proposed development.
    b. Historical analysis of vertical channel change
        i. Quantify past bed elevation changes by comparing historical and modern topographic mapping, field observations, and channel elevations shown on structure as-built plans.

ii. Identify long-term degradation or aggradation trends in the project reach indicated by the historical record.
iii. Relate observed changes in elevation to historical watershed changes, natural riverine processes, and manmade changes to the river system.
iv. Predict future channel elevation changes and the anticipated channel response given past trends and likely future watercourse and watershed changes.

2. Geomorphic and Geologic Mapping & Analyses
   a. Delineate Holocene and Pleistocene surfaces and landforms. Surficial geologic mapping for many parts of Utah is available from the Utah Geological Survey (http://geology.utah.gov/). Detailed soils mapping may be available in published soil surveys by the Soil Conservation Service or U.S. Forest Service. References to publications describing procedures for mapping geomorphic surfaces are provided elsewhere.
   b. Subdivide Holocene surfaces by age, topography, and surficial characteristics to constrain long-term rate of lateral movement in modern geologic time. Map the extent and describe the physical characteristics of each Holocene surface.
   c. Conduct subsurface investigations using test pits or borings to quantify physical differences between Holocene surfaces such as resistance to erosion, clay content, degree of carbonate cementation, induration, sediment size, bedding, degree of soil development, color, provenance, or other characteristics.
   d. Use geomorphic mapping to calibrate the mimimum long-term rate of lateral movement within the stream corridor, and maximum magnitude of channel movement within different time periods represented by the Holocene surfaces.
   e. Identify and map the extent and lithology of bedrock outcrops. Identify physical barriers to lateral channel movement.
   f. Describe modern geomorphic setting relative to local historical geology and channel evolution to determine trends of expected future channel change.
   g. Examine a longitudinal profile of the stream to identify knickpoints, convexities, or other slope irregularities relative to the position of the proposed development. Predict changes in channel profile and discuss the implications of profile changes on potential lateral and vertical erosion.

3. Field Investigation
   a. Describe and document channel and bank conditions in reach, at minimum using appropriate field data collection methodologies.
   b. Identify and document stream characteristics indicative of active or recent lateral erosion. Provide photographs of diagnostic features.
   c. Identify and document stream characteristics indicative of resistance to lateral erosion. Provide photographs of diagnostic features.
   d. Identify and document stream and floodplain characteristics indicative of potential, historical, or active channel avulsions. Provide photographs of diagnostic features.

e. Conduct stream classification analysis to identify the scale of erosion potential by analogy to similar stream types.
f. Apply bank stability indexes based on field parameters. A variety of bank stability indexes have been published.
g. Identify local bank failure mechanisms. Relate observed bank failure mechanisms to flow hydraulics & sediment transport analysis results.
h. Identify evidence of long-term degradation or aggradation near the proposed development site or in adjacent stream reaches.
i. Identify evidence of bed sediment movement, armoring, imbrication, and scour for use in verifying the results of sediment transport and scour analyses.
j. Identify archaeological evidence to help identify the age of geomorphic surfaces.

4. Hydraulic Modeling
   a. Perform inundation mapping using HEC-RAS or other hydraulic models to determine the relative magnitude and frequency (recurrence interval) of floodplain inundation and inundation of Holocene geomorphic surfaces. Relate the inundation frequency to avulsion potential and definition of channel bank stations.
   b. Determine channel and floodplain hydraulic data, such as velocity, depth, and stream power, for a range of flood frequencies to determine thresholds of channel and floodplain erosion, and for use in sediment transport analyses. Plot changes in channel velocity and other hydraulic variables versus stream distance to identify trends and discontinuities, and to identify channel choke points and flow expansion areas that may impact the lateral erosion potential.
   c. Map overbank flow patterns at various flow frequencies, and identify overbank flow concentration areas to identify possible avulsive flow paths.
   d. Determine bankfull discharge for use in applying regime and hydraulic geometry equations.

5. Sediment Transport & Engineering Analysis
   a. Estimate sediment transport competence and size range of transported material at various flow frequencies. Relate transport competence to bed material gradations observed in the streambed and banks.
   b. Estimate local scour at a range of flow frequencies and rates and predict the impact of such scour on bank stability and lateral erosion.
   c. Estimate armoring potential to whether vertical scour limit exists in channel at a range of flow frequencies. If armoring is likely, revise scour estimates accordingly and estimate the potential impacts of armoring on the potential for lateral erosion.
   d. Apply equilibrium and stable slope equations to estimate long-term degradation or aggradation potential. Relate equilibrium slope predictions to the observed longitudinal profile and potential armoring. Predict long-term scour by comparing the estimated equilibrium slope and the existing channel slope, considering natural or man-made grade control features that may serve as hinge points for channel slope adjustments.

e. Apply bank resistance methodologies such as allowable velocity, tractive force, and tractive shear to determine susceptibility of banks and surfaces to lateral erosion or avulsion.
f. Apply regime and hydraulic geometry equations to determine direction or potential for future channel adjustments in the main channel width and depth.
g. Perform sediment continuity analysis to identify localize sediment deficits or surplus and relate to areas of expected erosion and deposition. Consider potential changes in predicted sediment deficit and surplus due to channel pattern migration and lateral erosion.
h. Consolidate results of engineering and sediment transport analyses to identify stable and unstable stream reaches and the expected direction and magnitude of future channel changes.

6. Computer Modeling of Lateral Erosion
   a. Computer models have not advanced to the point of being able to accurately predict single event or long-term lateral channel movement. Therefore, computer modeling shall not be included in the scope of analysis for a detailed erosion hazard analysis without prior approval by the local floodplain manager. Sediment transport computer models have some utility for identifying reaches of sediment deficit or sediment surplus, comparing relative differences between management alternatives, or predicting the expected direction of vertical channel changes.

7. Delineate Erosion Hazard Zone
   a. An erosion hazard zone shall be delineated that is based on the results of the methodologies and analyses outlined above.

8. Report
   a. An engineering report shall be prepared summarizing the methodologies used to support the erosion hazard delineation, the assumptions and limitations of those methodologies, the results of the analysis, and the applicable time frame for the erosion hazard zone delineation. The report shall include photographic and other documentation supporting the analyses and conclusions. An engineer's certification shall be provided with the erosion hazard analysis report.

Scope of Services to Determine if Adverse Impacts to Adjacent Properties Occur

Sound floodplain management requires that structural erosion control measures not negatively impact flood and erosion hazards on adjacent properties and stream reaches. Therefore, it is required that an engineering assessment of erosion control structures impacts be reviewed and approved prior to development. To facilitate review of proposed structural measures, it is recommended that the following criteria be adopted that, if met, it may be assumed that minimal impacts will occur.

Low impact structural measures should be implemented wherever possible. The best way to minimize impacts on stream corridors is to maintain the form and function of the natural stream system to the greatest degree possible. The following definition of low impact criteria is intended to achieve the goals of minimum disturbance of the natural system:

- Minimal velocity increase.
    - The average 10-year velocity in the channel or overbank should not change (± 0.0 fps).
    - The average 100-year velocity in the channel or overbank should not change (increase or decrease) by more than 10 percent or 1 foot per second (fps), whichever is less.
- Minimal water surface elevation increase.
    - The 10-year water surface elevation or energy grade line should not change (± 0.0 ft.).
    - The 100-year water surface elevation or energy grade line should not increase or decrease by more than 0.1 foot.
- Minimal change in floodplain width
    - The 10-year floodplain width should not change (± 0.0 ft.).
- Minimal disturbance of the main channel.
    - The natural bankfull width of the main channel should not decrease.
    - The streambed in the main channel should not be excavated or deepened.
    - Bank vegetation should not be removed. Where bank vegetation is temporarily disturbed by construction, it should be replaced, monitored for health, and irrigated if required to assure its survival.
    - The low-flow channel should not be relocated within the floodplain.
- Minimal disturbance of the 10-year floodplain
    - Alteration of the natural vegetation and ground elevations within the 10-year floodplain should be minimized, except for purposes of restoration of disturbed areas to natural conditions.
- No offsite impacts.
    - No erosion, sedimentation, or flood impacts to adjacent properties shall occur without the written permission of all affected property owners.
- Preservation of natural landscape character and habitat within the floodplain.

In general, the less the natural channels and floodplains are disturbed, the less sedimentation, erosion and flood problems will occur.

Impact Analysis

If a proposed development in an erosion hazard zone does not meet the Low Impact Criteria defined above, an analysis of the potential impacts of the development on adjacent properties and the watercourse system sediment balance is required. Note that, in general, it is assumed that any channelization or other forms of structural erosion control will impact adjacent parcels and will have negative cumulative impacts on the watercourse that will require mitigation. It is the developer's responsibility to demonstrate that any such impacts are minimal, justified, and consistent with the local jurisdiction's regulatory objectives. An engineering analysis of stream impacts typically consists of the following elements:

1. <u>Regulatory Floodplain/Floodway Impacts</u>. Hydraulic modeling of the pre- and post-project channel and floodplain conditions must be submitted and approved by the local floodplain manager to document the following:
    a. Floodplain.
        i. Changes in the 100-year water surface elevation must be less than one foot within the property limits.
        ii. No changes in the 100-year water surface elevation may occur on adjacent properties.
    b. Floodway.
        i. No changes in the regulatory floodway elevation are permitted, either within or adjacent to the proposed project limits.
2. <u>Stream Stability and Sedimentation Impacts</u>. Engineering analyses must be submitted to document that no adverse impacts occur on adjacent properties due to the proposed structural measures. It is recommended that the applicant's engineer meet with local floodplain management staff prior beginning any analyses to discuss and review the engineering methodologies to be used to evaluate sedimentation impacts.
    a. Sedimentation impacts from floodplain encroachment or channelization. The engineering analysis must address each of the following types of sedimentation impacts:
        i. Deflection scour. Deflection scour occurs on a stream bank when the channel or floodplain alignment is modified causing changes in flow direction, or where only one bank is protected, thus limiting the available sources of sediment in the reach. The following conditions can lead to reflective scour:
            1. Change in the main channel alignment
            2. Change in the overbank flow path alignment
            3. Concentration of overbank flow
            4. Increase in percentage of flow carried in the main channel due to overbank encroachment or deflection
            5. Protection of only one channel bank
            6. Severe contraction of the channel or floodplain

            The evaluation of potential deflection scour should account for development of adverse channel alignment caused by exposure of proposed flood control structures following long-term channel movement. Channelization or structural measures located within the EHZ should be designed with smooth transitions.

ii. Contraction scour. Floodplain encroachment increases flow velocity and depth, which results in increased channel bed erosion and sediment transport capacity. Hydraulic data from the pre- and post-project hydraulic models should be used in conjunction with an approved sediment transport function to demonstrate that the proposed mining plan does not increase scour, erosion, or deposition on any adjacent property.

iii. Upstream scour and degradation. Upstream scour occurs when floodwater enters an excavated channel reach that is below the grade of the surrounding floodplain or channel. Upstream scour consists of two primary elements: (1) a headcut that migrates upstream as floodwater falls over a steep face into the excavation, and (2) long-term degradation as the watercourse adjusts to a new base level provided by the bottom of the excavation. Long-term and single headcut migration should be limited to the property owned by the applicant. Long-term degradation should also be assessed.

iv. Downstream degradation. Downstream degradation is caused when sediment is trapped or depleted in a reach, and sediment-deprived water flows downstream. Downstream degradation potential should be estimated.

b. Cumulative impacts analyses. Effect on the river system, adjacent properties, and public infrastructure will be considered as if all landowners along the watercourse were allowed the same degree of impact on the river system as the permit applicant. On streams lacking a watercourse master plan, local floodplain administrators may require a cumulative impacts analysis as part of the floodplain use permit application engineering report.

c. Guidelines for Use of Computer Sediment Transport Modeling. Guidelines for use of computer sediment transport models are provided elsewhere. To facilitate the permitting process and to prevent any wasted effort and funds by permit applicants, engineers are strongly advised to coordinate any computer modeling efforts with local floodplain managers prior to undertaking the modeling effort and prior to submittal of results.

3. Statement of Findings.

a. An engineering report shall be prepared summarizing the methodologies used to support the impact analysis, the assumptions and limitations of those methodologies, and the results of the analysis. The report shall include all computations and other documentation supporting the analyses and conclusions. An engineer's certification shall be provided with the impact analysis report.

Identifying Lateral Erosion Hazards

The following guidelines to help identify erosion hazards along streams and watercourses in southern Utah. Stream channel erosion can increase local flood hazards by causing bank failures or undermining structures. Channel erosion can occur on all stream types, including perennial streams, ephemeral washes, man-made channels, or in areas of sheet flow. The following guidelines are intended to help identify watercourses that could be subject to erosion.

Identifying Characteristics for Stream Channel Erosion

Streams that have experienced erosion exhibit certain characteristics that can be readily identified in the field. The lists of characteristics shown below are divided into those that can be observed along natural reaches (no structures present), and those that can be observed where structures have been built in the channel. In addition, the following general rules apply to streams in southern Utah:

- Streams that have experienced erosion problems in the past will experience erosion problems in the future.
- Undisturbed natural streams are less likely to experience erosion than streams that have been altered or that flow through urban areas.
- As a stream and its watershed become more disturbed, the stream is more likely to experience channel erosion.
- The most effective way to avoid erosion damages is to avoid construction or other development activities in the floodplain.
- Bank erosion occurs more rapidly on the outside of bends (meanders) than on the inside of bends.
- Vertical bank slopes are the most readily identified sign of high potential for channel erosion

Natural Features. The following list of natural channel features are evidence that stream erosion has occurred in the recent past, or is likely to occur in the future. However, erosion can occur on any streams, regardless of its current appearance.

- **Cut or undercut stream banks**. Cut banks occur where erosion has left stream banks steeper than the natural angle of repose of the soil material. Signs of cut banks include lack of bank vegetation, loose soil material (slides when touched), tension cracks in the soils adjacent to the banks, piles of soil at the base of the bank slope, and bank vegetation leaning into the stream corridor.

- **Vertical banks**. Vertical banks are the most easily identified evidence of bank erosion. Except where the vertical banks are composed of solid bedrock, vertical banks are never stable, and indicate recent channel erosion.

- **Bank vegetation leaning into channel**. Trees and other bank vegetation will fall into the channel as the soil around the roots is removed by erosion. Once the bank vegetation fails, bank erosion occurs more rapidly.

- **Roots of bank vegetation exposed**. Exposed roots of bank vegetation indicate that soil material has been removed from the banks and that erosion is beginning to occur.

- **Lack of bank vegetation**. Where no vegetation is present along the banks, especially on perennial or intermittent streams, it has either been artificially removed or eroded away by the stream. Where a stream's bank vegetation is discontinuous compared to upstream and downstream reaches, the stream is more likely to erode its banks.

- **Mid-channel bars higher than floodplain elevation**. Where the elevation of the top of the mid-channel bars is close to or higher than the floodplain elevation, rapid bank erosion and channel avulsions are more likely.

- **Gully formation in the watershed**. Gully formation in a watershed indicates excess runoff and a sediment deficit, which may cause bank erosion on main stem streams.

- **Irregular channel geometry**. Natural channels generally have gradual changes in the channel width and depth over short reaches. Where channel width and depth change rapidly without a recognizable pattern, it is likely that the channel is unstable and subject to erosion.

- **Piping of bank soils**. Piping, or formation of zones of high hydraulic conductivity in a stream bank, can destabilize the banks and lead to more rapid erosion.

- **Perched tributaries**. Tributaries normally join the main stream at an elevation equal to the bed elevation of the main channel. Where the elevation of the tributary mouth is significantly higher than the main stem, it is likely that accelerated bank erosion of the main stem will occur.

Man-Made Features Man-made structures, since they are generally not designed to move, offer a reference point from which to assess the magnitude of channel change since their construction date. Some types of structures that can be used to identify erosion include the following:

- **Failed bank protection**. Failures of bank protection, such as slumped riprap or cracked concrete, may indicate long term degradation of the channel or channel movement.

- **Footings of structures.** Footings are typically designed below the elevation of the stream bed. If exposed or undercut, it can be assumed that the stream channel has degraded or moved.

Activities That Can Increase the Potential for Stream Erosion:

The following human activities can increase the potential for river erosion:

- Removing vegetation from channel banks or the channel bed.
- Excavating sand and gravel material from the channel bed.
- Lining only one bank with permanent bank protection such as riprap.
- Changing the natural channel geometry by channelization or grading.
- Straightening a naturally sinuous channel.
- Increasing the frequency of runoff by discharging urban runoff into a stream.
- Developing within the floodplain.
- Constructing an on-line detention basin or dam upstream.
- Removing a large number of trees from a forested watershed.
- Removing of watershed vegetation by overgrazing.

Erosion hazards should be considered in the design of structures along any watercourse that exhibits any of the features described above.