RECLAMATION

*Managing Water in the West*

# River Maintenance Program -- San Marcial Delta Water Conveyance Channel Maintenance Project Biological Assessment


**U.S. Department of the Interior**
**Bureau of Reclamation**
**Albuquerque Area Office**

**July 2013**

# MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Front Cover Photo Caption – Photo showing San Marcial Delta Water Conveyance Channel, looking downstream (south) from about River Mile 39 (J. Bachus photo, C. Donnelly caption, 2013).

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## 1.0 Background Information on the Existing San Marcial Delta Water Conveyance Channel

The Bureau of Reclamation (Reclamation) has authorization for river channel maintenance of the Rio Grande from Velarde, New Mexico, south to the headwaters of Caballo Reservoir, as specified by the Flood Control Acts of 1948 and 1950. Under this authority, Reclamation monitors priority sites along the river, which are locations where channel conditions could damage infrastructure, or impair or interrupt water delivery.

One such priority site is the existing San Marcial Delta Water Conveyance Channel (Delta Channel, formerly known as the Temporary Channel), located within the boundaries of the Elephant Butte Reservoir between about 2002 River Mile (RM) 57.8 and the current reservoir pool. River Mile locations in this document refer to the 2002 RM delineation to maintain consistency with the previous consultation (January 25, 2008, Cons. #22420-2008-F-0017). 2012 RM locations have recently been established based on the channel centerline in 2012. River Mile locations are approximate and are not an exact measurement of channel distance.) Reclamation, in cooperation with the New Mexico Interstate Stream Commission (ISC), currently maintains the existing channel to facilitate delivery of water and sediment. This biological assessment (BA) analyzes the effects of proposed maintenance of the Delta Channel on listed species in the action area: the Rio Grande silvery minnow (*Hybognathus amarus*; minnow) and the Southwestern willow flycatcher (*Empidonax traillii extimus*; flycatcher). Reclamation expects the proposed action and the analysis of its effects will remain the same for an indefinite period of time.

Disconnection between the Rio Grande and the active reservoir pool has been a persistent problem since the early 1950's that leads to high water loss and impacts New Mexico's Rio Grande Compact (Compact) deliveries. With channelization work during the 1950's and 1960's and subsequent maintenance in the 1970's and 1980s, followed by a period of increasing reservoir pool elevation, the river was able to maintain a connection. However, dry years in 1989 and 1990 required construction of a pilot channel in the early 1990's to maintain a connection between the river and the reservoir pool. The term "temporary channel" was used, as the pilot channels are not permanent features and serve a purpose only until the reservoir level rises. In 1998, the river once again became disconnected from the reservoir pool and design/work began on a project for a new water conveyance channel, known as the 2000 Temporary Channel. Conditions in 1998 are shown in Figure 1.

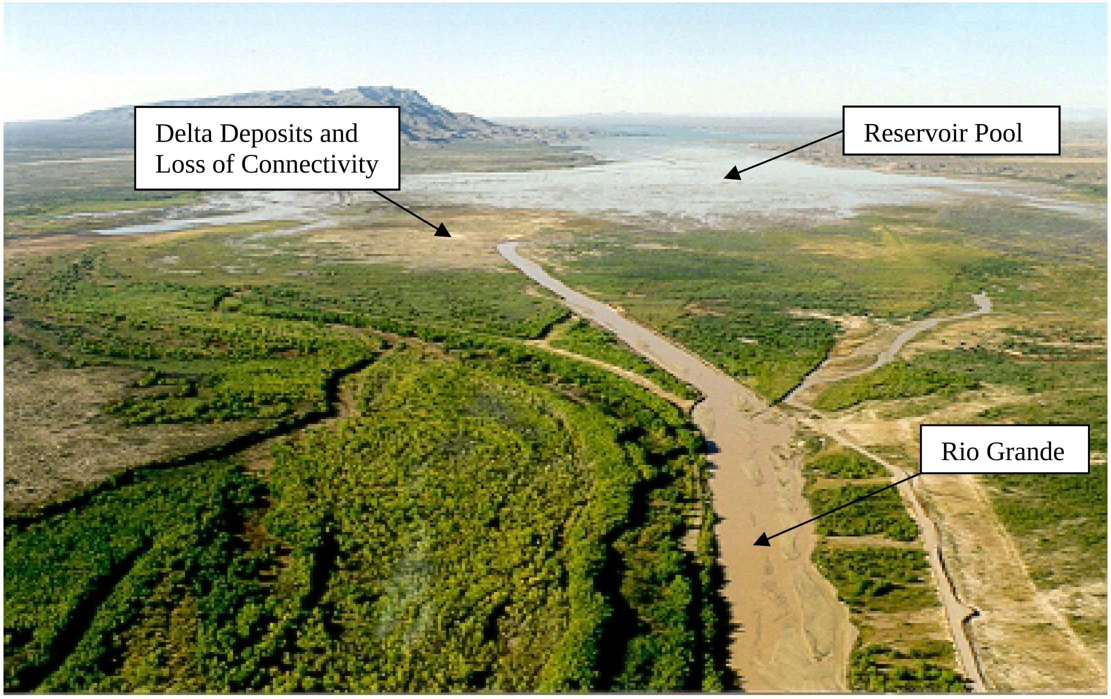


Figure 1. Photograph showing the Rio Grande's inability to maintain a channel through the sediment delta (1998)

As the reservoir has continued to recede, construction of additional Delta Channel reaches became necessary to maintain a connection between the river and reservoir pool. Table 1 defines the reaches of the Delta Channel and summarizes the original channel construction. The action area includes these reaches and extends to the active reservoir pool. The existing access road between the Delta Channel and RM 62 is also included in the action area, for maintenance purposes (as are other access roads, discussed in Section 2.1, Site Access and Staging Areas). The lateral extent of the action area is the width of the active floodplain, as bounded by levees or natural geologic formations and the access roads. While the Delta Channel starts at RM 57.8, the action area extends to RM 62 to include the maintenance of an access road in that area. The length shown for each reach is the constructed channel length, which differs slightly from the river mile (RM) lengths. River miles shown were developed in 2002. Figure 2 provides a graphical depiction of the reaches.

Table 1. Summary of Delta Channel Reaches

| Project Reach | Construction | Length | Start | End |
|---|---|---|---|---|
| Upper | 2000 to 2004 | 7.0 miles | RM 57.8 | RM 51.2<br>Nogal Canyon |
| Middle | 2003 to 2004 | 11.1 Miles | RM 51.2<br>Nogal Canyon | RM 40.7<br>d/s of Narrows |
| Lower | Started 2005 | 2.7 miles to date | RM 40.7<br>d/s of Narrows | Reservoir pool |

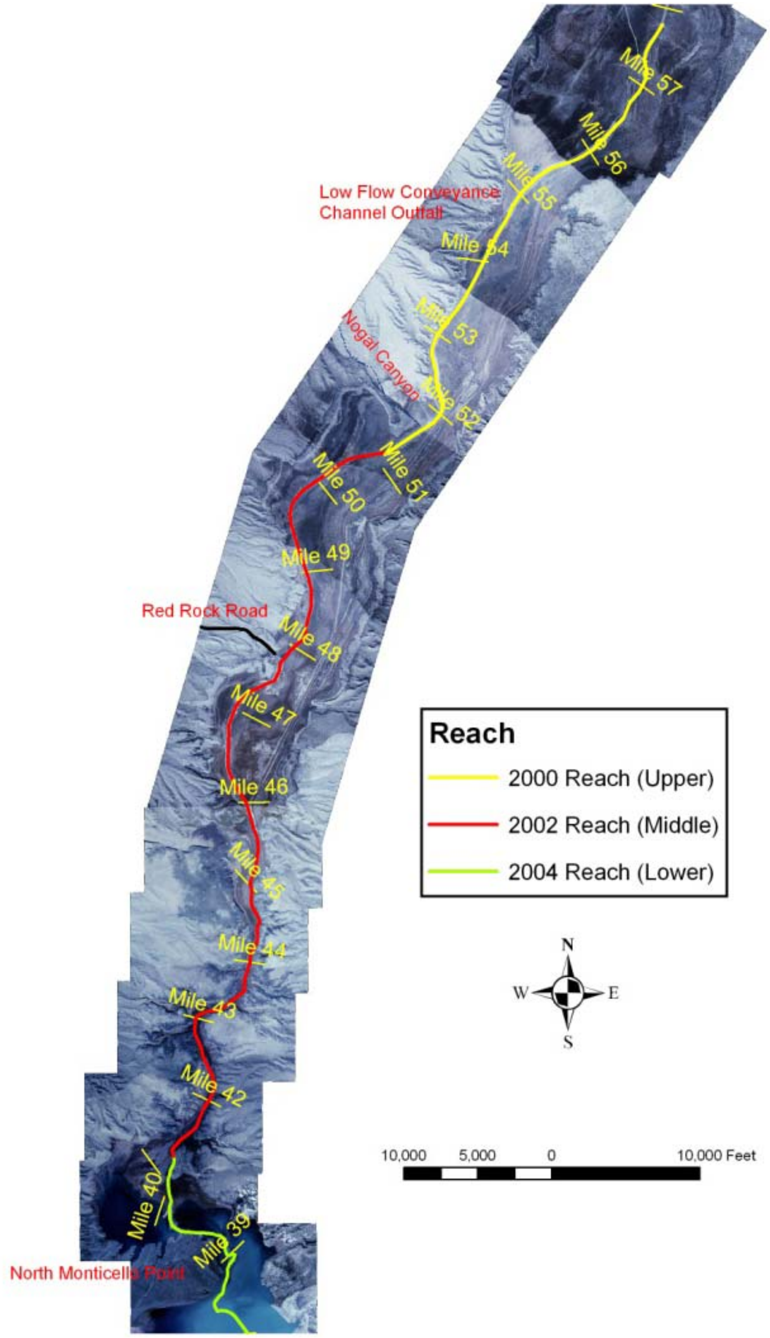


Figure 2. Delta Channel Reaches

The efforts to maintain the Delta Channel through the headwaters of the reservoir have provided significant water delivery benefits. Dry conditions since 1996, especially during 2002, 2003, 2011, 2012, and 2013 led to annual flow volumes that were significantly less than the long-term average. During periods of 2012, river flows recorded at the San Marcial USGS gage were at or below 10 cfs. Even during these low flow periods (2011-2013), water was being delivered to Elephant Butte Reservoir due to the Delta Channel. It is highly unlikely that these flows would have made it to the active reservoir pool without the continued maintenance of the Delta Channel.

## 1.1 Upper Reach (River Mile 57.8 to 51.2)

Since the construction of the Upper Reach, the Delta Channel has changed over time. Figure 3 and Figure 4 show two existing cross-sections surveyed in 2010 within the Upper Reach that are good representations of the existing conditions within the reach. Additional cross-sections showing variability over time can be seen in Appendix B, Geomorphic Assessment of the Rio Grande Upstream of Elephant Butte Reservoir (Figures 23, 24, and 25).

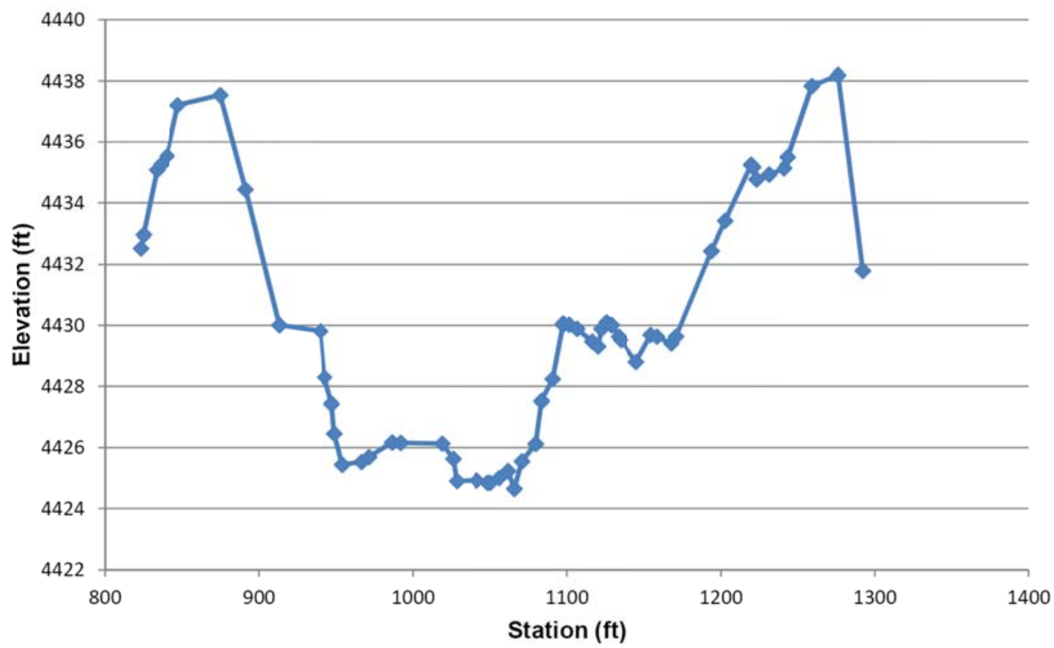


Figure 3. EB 30.6 (approx. RM 56) Cross Section (2010)

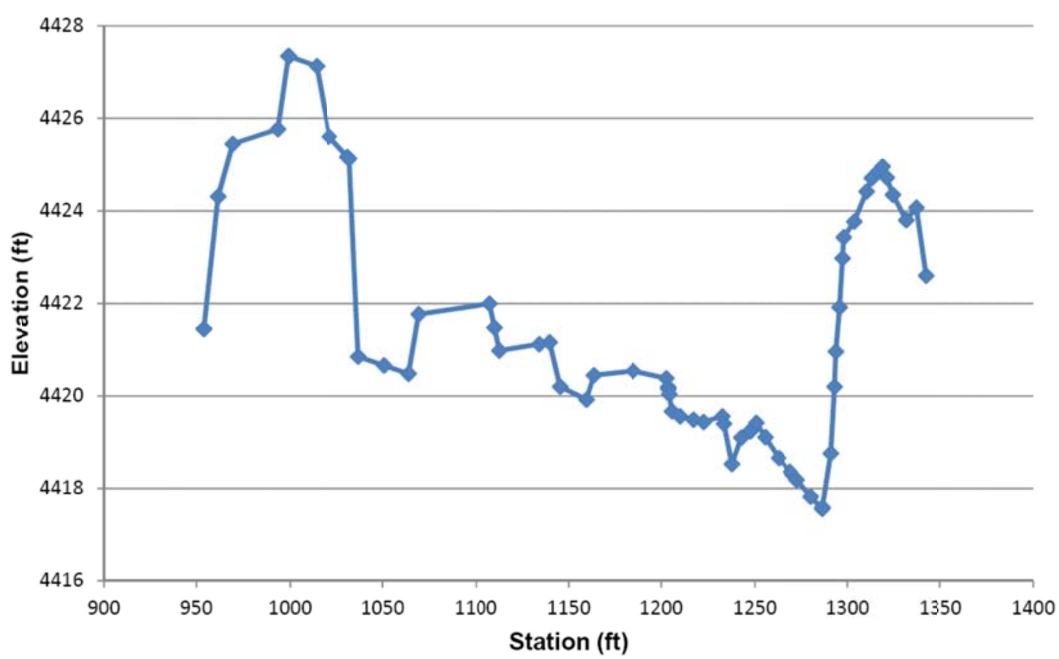


Figure 4. EB 34.8 (approx. RM 53.5) Cross Section (2010)

The cross-sections show the variability of the channel section through the Upper Reach. The existing maximum construction footprint (measured from outside toes of the berm slopes) within the Upper Reach is 590 feet and the existing minimum is 210 feet, both measured from the outside toes of the berm slopes. The channel bed through the Upper Reach has developed from a uniform section to a more natural channel bed. The development of a natural channel bed allows hydraulic properties such as width, depth, and velocity to vary throughout the reach at different flow regimes. Sinuosity of the existing Delta Channel in this reach was 1.07 in 2006; channel maintenance has intentionally sustained that sinuosity (1.08 in 2011, computed in the conventional manner of channel length divided by valley length using 2011 NAIP New Mexico aerial photography).

Hydraulic modeling of the Upper Reach was done using GPS cross section data collected during 2010. Cross sections were analyzed to determine the hydraulic capacity of each cross section. Results from the hydraulic model revealed that some cross sections within the Upper Reach had a hydraulic capacity greater than 5,000 cfs; however, given the geotechnical soil stability of the material present, it is highly unlikely that channel berms would withstand flows in excess of 5,000 cfs. Table 2 shows capacity analysis results for the existing Delta Channel within the Upper Reach.

Table 2. Existing Upper Reach Channel Capacity (2010)

| Minimum | Maximum | Reach Weighted Average |
|---|---|---|
| 3,300 cfs | 5,000 cfs | 4,502 cfs |

### 1.2 Middle Reach (RM 51.2 to 40.7)

The overall footprint within the Middle Reach remains relatively the same; however, the channel bed has changed over time from a constructed uniform section to a varying geometry (low flow sinuous inner channel with alternate bars). Figure 5 and Figure 6 show two existing cross-sections surveyed in 2010 within the Middle Reach that are good representations of the existing channel conditions within the reach. Additional cross-sections showing variability over time can be seen in Appendix B (Figures 23, 24, and 25). In the Narrows between RM 46 to RM 42, the river has eroded much of the berm material away and substantially widened the originally constructed Delta Channel. In this reach the berm has not been reconstructed, as discharge is confined by the natural narrow valley and the berm is not needed to provide the desired conveyance capacity.

The existing maximum construction footprint within the Middle Reach is 407 feet, while the minimum construction footprint is 232 feet. The channel bed through the Middle Reach has developed from a uniform section to a more natural channel bed. The development of a natural channel bed allows hydraulic properties such was width, depth, and velocity to vary throughout the reach at different flow regimes. Sinuosity of the constructed Delta Channel in this reach is 1.08, computed in the conventional manner of channel length divided by valley length using 2011 NAIP New Mexico aerial photography. However, valley conditions in this reach are somewhat unique, and for comparison, the sinuosity was also computed based on channel length divided by the straight line distance from start to end of the reach. That sinuosity is 1.17.

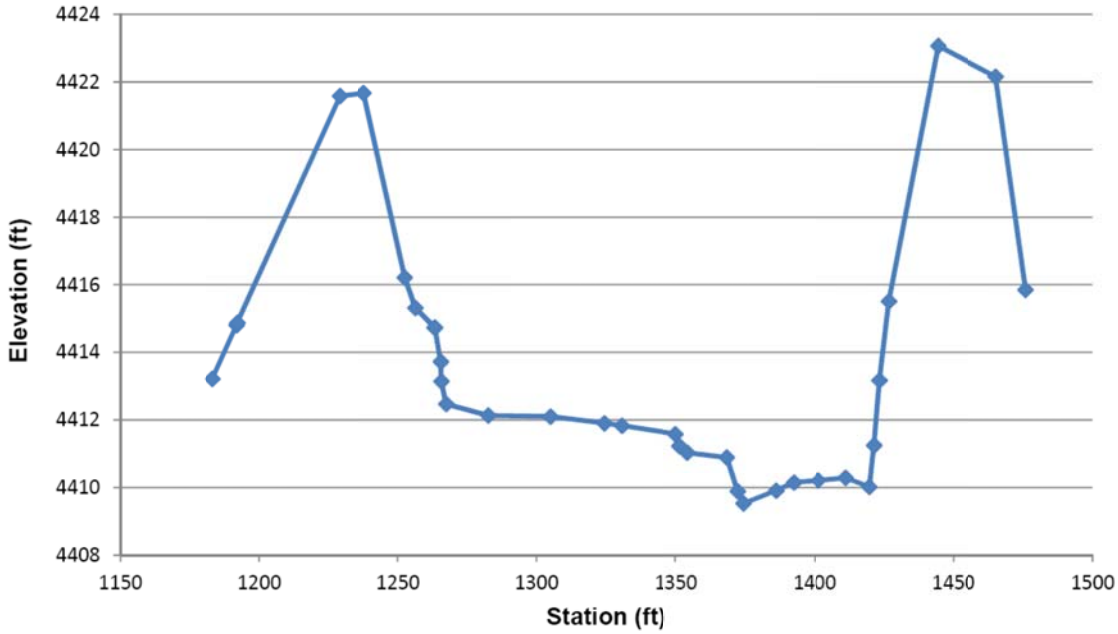


Figure 5. EB 39.3 (approx. RM 50) Cross Section (2010)

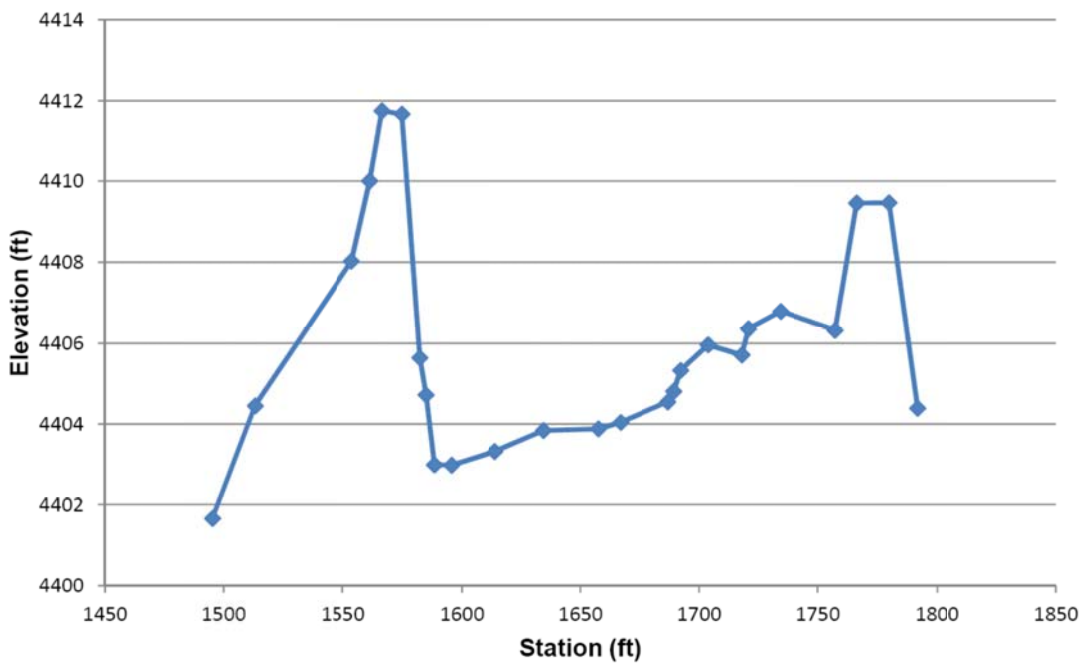


Figure 6. EB 44 (approx. RM 48) Cross Section (2010)

Hydraulic modeling of the Middle Reach was done using GPS cross section data collected during 2010. Cross sections were analyzed to determine the hydraulic capacity of each cross section. Results from the hydraulic model revealed that some cross sections within the Middle Reach had a hydraulic capacity greater than 4,000 cfs; however, given the geotechnical soil stability of the material present, it is highly unlikely that channel berms would withstand flows in excess 4,000 cfs. Therefore, 4,000 cfs has been set as the maximum. Portions of the Middle Reach from EB-43 to EB-46 have been observed to breach at flows less than 1,000 cfs; therefore, the cross section channel capacities within this range were set to 1,000 cfs. Naturally occurring breaches often remain open for a period of several months, providing overbanking flow to the adjacent floodplain. Such breaches are typically not viewed as emergencies and usually not repaired immediately for a variety of reasons, such as flows may be too high to safely work in the river, spawning is occurring, and to avoid disturbance to nesting migratory birds. The flows from the breaches return to the Delta Channel at a downstream location. Table 3 shows capacity analysis results for the existing Delta Channel within the Middle Reach.

Table 3. Existing Middle Reach Channel Capacity

| Minimum | Maximum | Reach Weighted Average |
|---|---|---|
| 1,000 cfs | 4,000 cfs | 3,371 cfs |

### 1.3 Lower Reach (RM 40.7 to active reservoir pool)

The length of the Delta Channel within this reach varies from year to year, according to reservoir levels. As reservoir levels rise, some or all of this reach will become inundated and portions of the constructed channel may be obliterated, resulting in a need for reconstruction after the reservoir recedes again. This reach was constructed with an excavated channel width averaging 50 to 75 feet, plus embankment berms on each side providing a maximum total channel width of approximately 150 feet, and a construction footprint of approximately 250 feet. Figure 7 shows the design cross section for this reach of the Delta Channel. Cross sections have not been collected within the Lower Reach because it has usually been inundated by the reservoir pool; therefore, the design cross section is shown here instead of an actual cross-section.

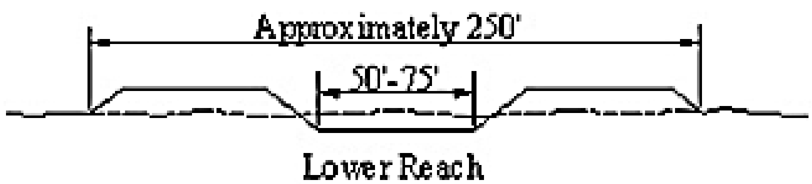


Figure 7. Lower Reach Cross Section Design

## 2.0 Proposed Action

### 2.1. Site Access and Staging Areas

Access for maintenance of the three reaches of the existing Delta Channel will be on existing roads. These are public roads, or roads within the reservoir boundary, constructed or improved during original construction of the Delta Channel. While the Delta Channel begins at RM 57.8, the proposed action includes maintenance of the portion of the access road between RM 58 and RM 62. As long as the Delta Channel exists, annual maintenance will be performed on the roads, which will consist of: 1) smoothing of the road surface with a road grader and potential addition of gravel surfacing; 2) repair of washout areas, when needed; and 3) routine mowing of vegetation only along the road shoulders for safety, to a maximum distance of 10 feet from each road shoulder. Road maintenance such as grading and washout repair may be performed throughout the year, but mowing is not planned to occur between April 15 and August 15. If mowing should be needed between April 15 and August 15, migratory bird surveys will be conducted prior to mowing and no mowing will occur within a 0.25 mile buffer of any nests found. No new access roads are planned at this time; if they should become needed, Reclamation will coordinate with the Service prior to any road construction activity.

Eleven existing staging areas, constructed during original Delta Channel construction, will also be used for future maintenance operations. Staging areas are leveled areas where equipment, materials, and temporary fuel tanks are stored. Spill prevention measures are provided for the fuel tanks. Staging areas are located near launching areas, where amphibious excavators or airboats can be launched into the Delta Channel. Figure 8 shows all access roads and staging areas.

### 2.2 Maintaining Existing Delta Channel (approximately 20.8 miles)

2.2.1. Upper Reach (River Mile 57.8 to 51.2): Maintenance of the Delta Channel in this section will focus on maintaining existing berms, management of sediment accumulation, and the management of vegetation growth within the channel cross section to maintain a target conveyance capacity equal to 5,000 cfs. The existing low flow thalweg in this reach will remain, allowing low flows to meander within the boundaries of the channel. Disturbance during maintenance activities will be confined within the existing construction footprint.

Naturally occurring breaches may remain open for a period of several months, providing overbanking flow to the adjacent floodplain. Such breaches are typically not viewed as emergencies and will usually not be repaired immediately for a variety of reasons, such as flows may be too high to safely work in the river, spawning is occurring, and to avoid disturbance to nesting migratory birds. The flows from the breaches return to the Delta Channel at a downstream location.

The existing channel berm was constructed with a break at RM 54.7, west side, at the current Low Flow Conveyance Channel (LFCC) outfall. The constructed LFCC ends between RM 60 and 61, and its discharge then follows a low point in the valley to the west of the river, returning to the Delta Channel at the RM 54.7 outfall. Future Delta Channel maintenance will include removal of sediment from the outfall area, to allow LFCC discharge to enter the Delta Channel. Approximately 850 feet downstream of the LFCC outfall is a constructed feature referred to as the wing wall, which is essentially a small secondary channel that collects excess LFCC discharge. The wing wall extends from the Delta Channel to the west, a length of approximately 1,300 feet. In the past, maintenance of the wing wall included periodic removal of sediment; however, maintenance is no longer planned for this feature in order to preserve the flycatcher habitat that has developed at this location.

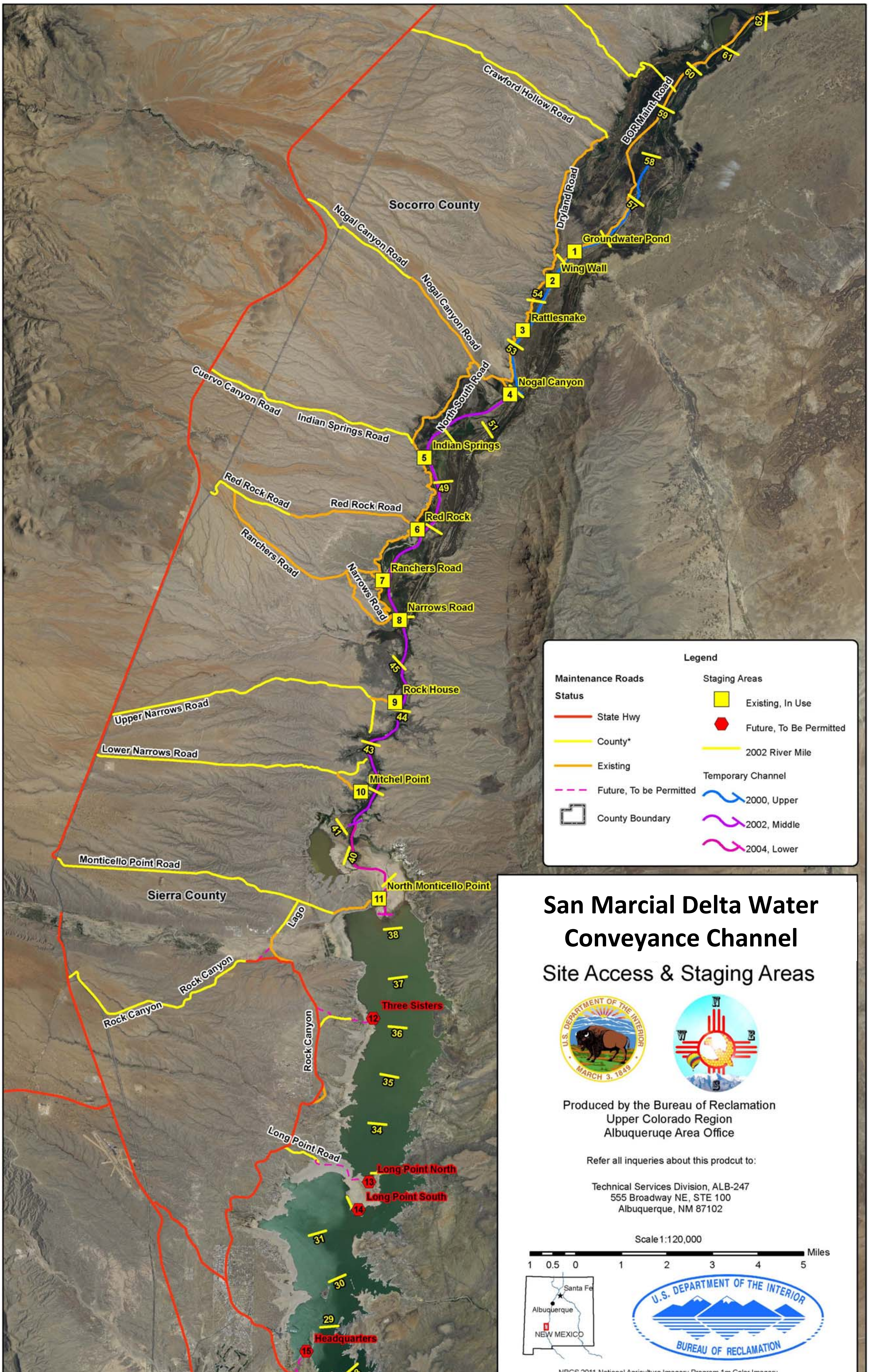


Figure 8. Site Access and Staging Areas

With the exception of the wing wall, secondary channels protruding from the main Delta Channel will not be excavated for the purpose of draining water from adjacent areas. Breaks in the berms may be constructed or naturally occurring inflow breaches allowed to remain for the purpose of allowing natural drainage into the Delta Channel and to prevent water from accumulating behind the berms, thus compromising their stability. Additionally, these openings allow water from the river to inundate areas behind the levee during the snowmelt runoff, providing a measure of ecosystem function to those areas. These openings will be maintained as necessary within the limits of the existing Delta Channel footprint. The determination to create breaks will be evaluated through an annual adaptive maintenance approach based on the river and reservoir conditions and influenced by habitat for endangered species.

Each of the four staging areas in this reach are located near existing equipment launching areas, and will be maintained to the general dimensions originally constructed. These launching areas consist of a ramp into a very short secondary channel where equipment can be put in and taken out of the channel. Airboats are also typically docked in these areas when Delta Channel work is in progress. Maintenance of the launching areas will involve periodic removal of accumulated sediment.

<u>2.2.2. Middle Reach (RM 51.2 to 40.7):</u> Maintenance of the Delta Channel in this section will also focus on maintaining existing berms, management of sediment accumulation, and the management of vegetation growth within the channel cross section to maintain a target conveyance capacity equal to 4,000 cfs. The existing low flow thalweg in this reach will remain, allowing low flows to meander within the boundaries of the channel. Disturbance during maintenance activities will be confined within the existing berm to berm foot print of the channel.

Naturally occurring breaches and secondary channels in this reach will be managed in the same manner as the Upper Reach, as described above in section 2.2.1 Upper Reach.

Five of the seven staging areas located within this reach have existing equipment launching areas, which will be maintained to the original constructed dimensions, as described for the Upper Reach.

<u>2.2.3. Lower Reach (RM 40.7 to Active Reservoir Pool):</u> The Delta Channel width varies from 50 to 75 feet, and the general maintenance strategy will be the same as the Upper and Middle Reaches. The portion of this reach that has been constructed to date ends at RM 38. In some years, this reach may require extensive maintenance if the reservoir inundates the area for periods of time, which typically causes significant damage to the Delta Channel and berms. Following a period of inundation, reconstruction of the channel may be required, in which case reconstruction will be in accordance with the typical section for the lower reach shown in Figure 7. General practice will be to reconstruct the channel in the same location, but conditions may necessitate construction of a new channel utilizing a different alignment.

Below RM 38, field observations during 2012 and 2013 show that a natural dominant channel has formed as the reservoir level dropped below RM 38, due to the naturally steeper reservoir slope downstream of The Narrows. Field observations in 2012 documented this natural channel was beginning to form distributary flowpaths. "A channel with defined banks became naturally established for a distance of more than one mile during April –September 2012 as the reservoir receded below RM 37" (Holste 2013). Reclamation will maintain the alignment of the natural channel below RM 38 until such time that the area is inundated by the rising pool elevation and destroyed. Reclamation will repeat this process below RM 38 as needed. Maintenance of the naturally formed channel will be in wet conditions, with amphibious excavators, in the same general manner as described for maintaining the existing Delta Channel. Accumulated sediment will be excavated to maintain the natural dominant flowpath and used to form berms along the side.

Reservoir recession may expose cottonwood and salt cedar snags that will be removed during maintenance of the naturally formed channel. Prior to removal of such snags, a biological evaluation will be conducted to determine their significance for raptor use.

Maintenance of this reach may also include excavation of secondary channels extending a short distance from the main Delta Channel, in order to provide an outlet to the main Delta Channel for isolated side pools or side channels in the delta area. These are low areas in the delta area (where there is limited vegetation) that continue to hold water after the reservoir pool recedes; connecting them to the main Delta Channel will reduce evaporation losses and increase deliveries to the reservoir for Compact deliveries. Construction of these channels will not be conducted in a manner that would completely drain the large isolated pool on the west side of the Delta Channel, between RM 40 and RM 41. However, if extremely dry conditions persist and the reservoir recedes, it is uncertain if groundwater flows will continue to keep the isolated pool wet.

<u>2.2.4. Equipment Operations and Channel Disturbance:</u> Delta Channel maintenance work on all reaches generally consists of removal of sediment deposits within the channel and repair of damage to berms. Berm damage may occur in several ways, including: 1) erosion of berm slopes or overtopping of berms due to high flows within the channel; 2) saturation of berm material or overtopping of berms due to arroyo flows. Typical channel maintenance procedures involve removal of sediment from within the channel and placement of the material on the berms.

In-water maintenance work is performed by amphibious excavators, and dozers often work on the berms, pushing material deposited by excavators into place for berm repairs. Dozers may also work on the elevated floodplain bench surface within the existing channel of the Upper Reach. Maintenance work will include removal of vegetation from berm slopes and point bars within all reaches. Vegetation removal may be accomplished by excavators or dozers.

Amphibious excavators are conventional tracked excavators mounted on pontoons to allow operation on very soft ground. Excavators generally work in the channel, often in water, and also move between work sites within the channel. At a work site they are typically set up in a stable position for performing work within a radius of approximately 40 feet. When work within that radius is complete, the excavator moves and begins excavation from the new setup location. When work in the general area is complete the excavator moves to the next work site.

Typical excavator operation involves removal of accumulated sediment from the channel and placement of the material on berms. In some cases, the berms have been eroded and have vertical banks on the Delta Channel side, and the berms are reconstructed using material from the channel. The excavators move material from the channel to the berm in three ways: 1) working from the channel, the excavator scoops up a bucket of channel material, often mixed with water, and then dumps the bucket on the berm; 2) working from the channel, the excavator pushes material from the channel up the slope of the berm with the back of the bucket; 3) working from the berm, the excavator pulls material up the slope of the berm with the bucket. Excavator operators are given instructions to structure their excavation operations to avoid the creation of isolated pools that could trap fish. Although it is possible that fish could be caught in the excavator bucket and placed on the berms, operators and inspectors report that they have not observed this happening during the last 12 years.

Delta Channel maintenance activities for all reaches will be confined to the area within the existing construction footprint and will not occur between April 15 and August 15. The regular maintenance period is September 1 to April 1 every year, although the work typically does not last through that entire period. An exception to the regular maintenance period would be in the case of emergency channel and berm repairs during spring runoff, and we expect that this event would happen once in a five year period for a period of two weeks near the end of runoff. Reclamation will coordinate with the Service if emergency work is needed, prior to any activity. If it is determined in the future that Delta Channel maintenance between April 15 and August 15 needs to become a routine annual activity, Reclamation will coordinate with the Service prior to implementing that decision, and migratory bird surveys would be conducted prior to any activity that has the potential to disturb migratory bird breeding behavior and no such activity would occur within a 0.25 mile buffer of any nests found. Road maintenance, with the exception of mowing, may be performed throughout the year.

An estimation of the portion of the Delta Channel impacted by maintenance work each year is as follows. Computation details are provided in Appendix A.

- 75 to 100% of the channel length is traveled by amphibious excavators and fuel transporters, moving back and forth between equipment launching areas and work sites. This computes to an estimated 944 acres of channel disturbance in most years. If workload requires a third crew, there would possibly be an additional 629 acres of channel disturbance, for a total possible 1,573 acres in those years with three crews.

- Active work sites, where excavation is performed within the channel, are estimated to cover approximately 25% of the entire channel area each year for most years. For most years where two crews are needed, this computes to an estimated 113 acres per year that will have an excavator working within the existing channel area. If workload requires a third crew, there would possibly be an additional 82 acres per year that would have an excavator working within the existing channel area. Thus, the total possible area of active work sites would be 195 acres in those years with three crews.

## 2.3 Delta Channel Maintenance Support Operations

2.3.1. Airboat Transport: Equipment operators and fuel for the equipment are often transported from equipment launching areas to work areas via airboats while maintenance work is in progress. Additionally, airboats cover the entire length of the Delta Channel an average of eight times per year (four round trips) for channel inspections. Channel inspections are typically conducted with two airboats traveling together due to safety concerns.

2.3.2. Refueling: Amphibious excavators are often fueled while in the water, and fuel is transported to them either by airboat or by an amphibious fuel transporter, which is also on tracked pontoons. Excavators are equipped with spill kits, which include booms designed to contain spilled fuel and absorbent pads. Operators are trained and knowledgeable on how to deal with spills should they occur.

2.3.3. Pumping Water from River: Water will be pumped from the river at times for wetting of road surfaces to facilitate grading of roads, and for dust abatement during high traffic periods to insure safe conditions and reduce environmental impacts. Pumping sites will be at or near existing equipment launching areas, requiring no new ground disturbance. Pump intake pipes will be placed directly in the channel and will utilize a 0.25 inch (0.64 cm) mesh screen at the opening to the intake hose to minimize entrainment of aquatic organisms. Pumping rates will vary between 1.8 and 2.2 cfs, requiring four to eight minutes to fill a water truck. This would be a minimal impact to river flows, equating to a decrease in flows of approximately 0.7% for river flows of 300 cfs and approximately 0.2% for river flows of 800 cfs for four to eight minutes. A typical project may use four to six truckloads per day and, at a maximum, 18 truckloads per day. This Project is expected to use the typical amount or less.

# 3.0 Species Habitat and Life History

## 3.1 Rio Grande Silvery Minnow

Information pertaining to life history and habitat needs of the minnow is incorporated by reference from the following documents. The proposed Delta Channel maintenance area is located downstream of the power lines (approx. RM 62), outside designated minnow critical habitat, entirely within the reservoir pool, ending at where the active reservoir pool begins.

U.S. Fish and Wildlife Service. 1994. Endangered and threatened wildlife and plants; final rule to list the Rio Grande silvery minnow as an endangered species. Federal Register 59: 36988-36995.

Dudley, R.K. and S.P. Platania. 1997. Habitat use of the Rio Grande silvery minnow. Report to the U.S. Bureau of Reclamation, Albuquerque, NM. 88 pp.

U.S. Fish and Wildlife Service. 2003. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Rio Grande Silvery Minnow; Final Rule. Federal Register 68: 8087-8135.

Massong, T.M. 2004. Rio Grande river maintenance priority sites on the Pueblo of Cochiti: U.S. Department of the Interior, Bureau of Reclamation, Albuquerque Area Office, 10 p.

U.S. Fish and Wildlife Service. 2010. Rio Grande Silvery Minnow (*Hybognathus amarus*) Recovery Plan, First Revision. Albuquerque, NM. viii + 210 pp.

Dudley, R. K., and S. P. Platania. 2011a. Summary of the Rio Grande silvery minnow population monitoring program results from December 2010. American Southwest Ichthyological Researchers, L.L.C, Albuquerque, New Mexico. Available online at http://www.asirllc.com/rgsm/rgsm2010/pdf/RGSM_December2010.pdf.

Dudley, R.K. and S.P. Platania. 2011b. Draft Rio Grande silvery minnow population monitoring Program Results From September 2009 to October 2010. A Middle Rio Grande Endangered Species Act Collaborative Program Funded Research Project. American Southwest Ichthyological Researchers, L.L.C., Albuquerque, New Mexico. 187 pp.

Dudley, R. K., and S. P. Platania. 2011c. Summary of the Rio Grande silvery minnow population monitoring program results from October 2011. American Southwest Ichthyological Researchers, LLC, Albuquerque, New Mexico. Available online at http://www.asirllc.com/rgsm/rgsm2011/pdf/RGSM_October2011.pdf.

### 3.2 Southwestern Willow Flycatcher

Information pertaining to the habitat needs and life history of southwestern willow flycatchers (flycatchers) is incorporated by reference from the following documents which provide extensive details on these subjects. The proposed Delta Channel maintenance area is located within the revised designated flycatcher critical habitat which extends through the Elephant Butte Reservoir area to RM 54 (Service 2013).

U.S. Fish and Wildlife Service. 2002. Final Southwestern Willow Flycatcher Recovery Plan. U.S. Fish and Wildlife Service, Albuquerque, N. M. 210 pp. + appendices (15).

U.S. Fish and Wildlife Service. 2005. Designation of Critical Habitat for the Southwestern Willow Flycatcher (*Empidonax traillii extimus*), Federal Register 70:60886-61009.

Ahlers, D., V. Johanson, S. Ryan, R. Siegle. 2010. Southwestern Willow Flycatcher Habitat Suitability, 2008. Highway 60 Downstream to Elephant Butte Reservoir, NM. U.S. Department of the Interior - Bureau of Reclamation, Denver, Colorado, and Albuquerque Area Office, New Mexico, 271 pp.

Moore, D. and D. Ahlers. 2012. 2012 Southwestern Willow Flycatcher study results: selected sites along the Rio Grande from Bandelier National Monument to Elephant Butte Reservoir, New Mexico. U.S. Bureau of Reclamation, Denver, CO. 111 pp.

U.S. Fish and Wildlife Service. 2013. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Southwestern Willow Flycatcher, Final Rule. Federal Register 78:343-534.

## 4.0 Environmental Baseline

Regulations implementing the ESA define the environmental baseline as the past and present impacts of all Federal, State, or private actions and other human activities in the action area; the anticipated impacts of all proposed Federal actions in the action area that have undergone formal or early Section 7 consultation; and the impacts of State and private actions that are contemporaneous with the consultation in progress. The environmental baseline defines the current status of the species and its habitat in the action area to provide a platform to assess the effects of the action.

The Service has produced biological opinions for recent Reclamation activities and other agencies' activities in the Middle Rio Grande (MRG) that describe the environmental baseline with regard to factors affecting the species' environment. The pertinent information regarding environmental baseline relevant to the minnow and flycatcher is incorporated by reference from the following documents:

U.S. Fish and Wildlife Service. 2003. Biological and Conference Opinions of the Effects of Actions Associated with the Programmatic Biological Assessment of Bureau of Reclamation's Water and River Maintenance Operations, Army Corps of Engineers' Flood Control Operation, and Related Non-Federal Actions on the Middle Rio Grande, New Mexico.

Reclamation. 2012. Southwestern Willow Flycatcher Management Plan for the Rio Grande Project. Bureau of Reclamation, Albuquerque Area Office, Albuquerque, New Mexico.

### 4.1 Current Status of Minnow in Action Area

Construction and maintenance of the Delta Channel is maintaining a riverine habitat suitable for minnows, including slackwater, backwaters, shoals, and pools, in an area that previously lacked any habitat. Minnows are known to be present within the action area. Surveys for minnows in the Delta Channel, conducted by Reclamation at 4 sites in September 2010 and 5 sites in September 2011, found a mean density of 24 minnows per 100 $m^2$ in 2010 and 3 minnows per 100 $m^2$ in 2011. Reclamation also conducted surveys at 4 sites in October 2012, but no minnows were captured at any of the sites. The decrease in density between 2010 and 2012 follows a similar pattern for the minnow throughout the MRG due to drought and decreased spring runoff. In 2010 and 2011 surveys, minnows were found in suitable habitat (shorelines, backwaters, pools). Though there was not a statistically significant difference between the densities of minnow at individual sites, the upper two sites had higher mean density than the downstream sites. Minnows are not expected to be found past the inflow to the active reservoir pool.

### 4.2 Current Status of Southwestern Willow Flycatcher in Action Area

#### 4.2.1 Presence

Patches of vegetation at the northern-most extent within the historic reservoir (considered south of RM 62) began to reach suitability for flycatchers in the mid-1990's. While only 16 territories existed in the San Marcial survey reach in 1996, Table 4 shows the increase in number of flycatcher territories from 2000 to 2013 (preliminary data) in the reach, which extends from the San Marcial railroad trestle (RM 68.6) downstream to the reservoir pool. Of the total territories in the riparian areas adjacent to the Delta Channel in 2011 (152) and 2012 (103), 85 and 47 (sites DL 6-10), respectively, were 0.25 miles or further from the Delta Channel, with several territories along the unmaintained portion of the LFCC. The remaining territories are within 0.25 miles of the Delta Channel, and mostly south of RM 55. Appendix C shows general locations of territories; for more specific locations of recent territories in the action area, see Moore and Ahlers (2012).

Table 4. Flycatcher territories in San Marcial Reach (Moore and Ahlers 2012, Ryan pers. comm)

| **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 25 | 63 | 86 | 113 | 107 | 142 | 197 | 235 | 319 | 298 | 318 | 252 | 265 |

The length of the San Marcial survey reach has tripled since 1995 as flycatcher habitat developed in new areas made available as the reservoir level dropped. It continues to be the most productive survey reach of the river, with some of the best native habitat within the subspecies range (Moore and Ahlers 2012). The majority of the territories are within the reservoir pool area, with only 4 and 7 territories between the railroad bridge (RM 68.6) and the power lines (approx. RM 62) in 2011 and 2012, respectively. Most recently, flycatchers have extended their occupied habitat further south of the Narrows as new habitat has developed (Ryan pers. comm.).

### 4.2.2 Geomorphology

In one specific area, sites DL-03 and DL-04 (just north of RM 58), vegetative decline followed an apparent drop in alluvial groundwater levels and subsequent water stress on the willows. At these sites, prior to and during 2005, groundwater levels were near the surface, oftentimes with moist soils present. Under such conditions, trees likely had a very shallow root system. Between 2000 and 2005, the number of territories at these sites increased and in 2005, these two sites had 22 total nests found (with fates known) and 55% nest success. Bed degradation in this area began during the 2005 spring runoff (discussed in further depth below and in Appendix B) and the bed had degraded almost 12 feet by 2007 in comparison to 2002 (Holste 2013). Beginning in 2006, observations during annual flycatcher surveys reported soils were no longer moist at these sites (Ryan pers. comm.). Although monitoring wells did not exist in this area at that time, it is likely there was a rapid drop in groundwater below the root zone of the trees, resulting from the combined effects of bed degradation and recurring dry conditions. Drought conditions in New Mexico ranged from abnormally dry to extreme drought from 2006 to 2008, contributing to the effects of previously dry conditions since 2000 (U.S. Drought Monitor 2013). Also, no springs or other groundwater controls exist nearby that might have prevented or minimized the drop in groundwater. A decline in vegetative health was observed to begin in 2006 and by 2008, only 3 nests were found at these sites. One nest was predated and the other two nest fates were unknown. The remaining vegetation in this area is now mainly salt cedar instead of Goodding's willow, as previously existed. Nesting has not occurred at these sites since 2008.

In other areas, the reasons for declines in groundwater level are not clear-cut because groundwater levels are complex and can be highly variable across time and space. Near the river, groundwater levels show an influence from water surface elevations (Tetra Tech 2010), but data at different locations suggest a complicated interaction. Appendix B includes an analysis of groundwater wells, bed degradation, and river discharge near the BDANWR south boundary, near San Marcial, and RM 63 (south of Fort Craig). The analysis shows a groundwater level that is a gradient between the river water surface and the LFCC water surface. Also, thalweg elevation appears to have less effect on groundwater levels than river discharge. Groundwater peaks occur during spring runoff or other high flow events, while low groundwater elevation corresponds to periods of low river discharge. Figure 9 shows river thalweg elevation, groundwater elevation, and river discharge near RM 63 and Appendix B contains similar figures for other wells near San Marcial and the BDANWR south boundary. Analyzing these figures, it appears that groundwater levels are "primarily a function of river discharge (or river water surface elevation) and nearby groundwater controls (i.e., LFCC and ponded areas). River thalweg elevation trends over time and space can influence, but may not directly correspond to, trends in groundwater elevation" (Holste 2013). While the vegetation in areas such as DL-03, DL-04 and other sites has clearly shown decreased health and mortality probably due to lowered water tables, it is difficult to separate the impacts of extended drought (reduced discharge) and channel degradation on groundwater levels.

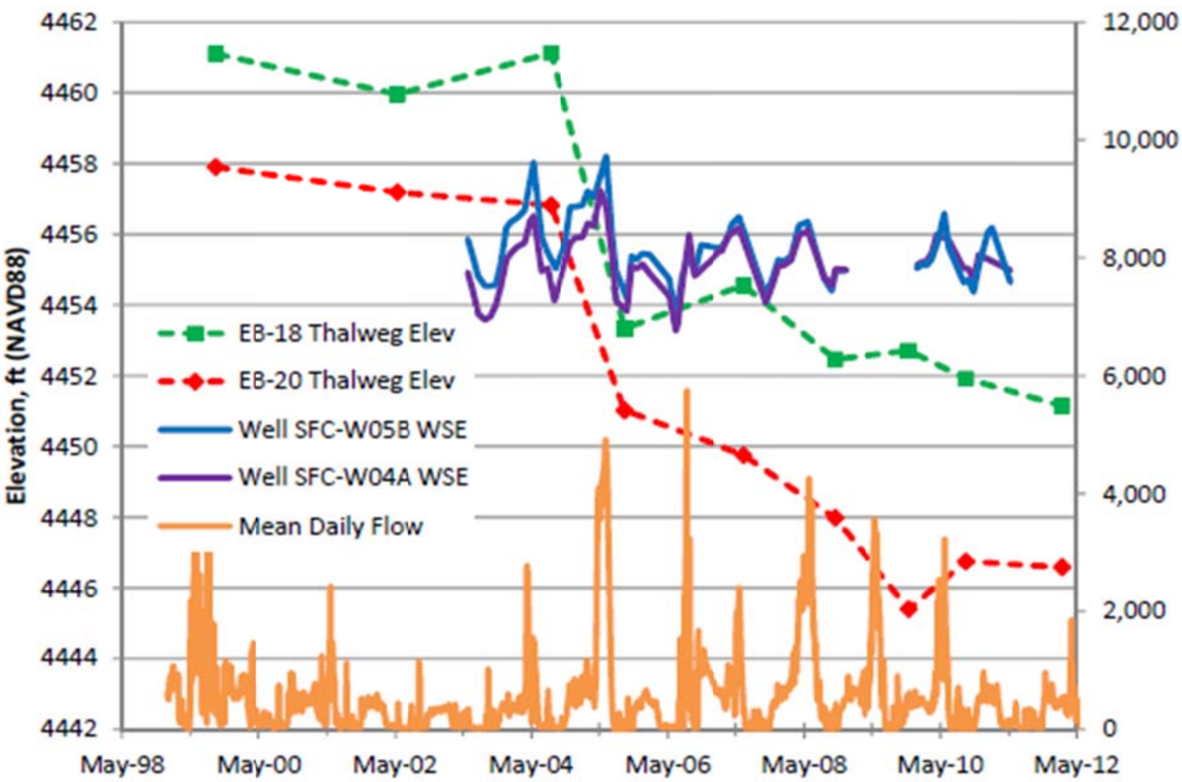


Figure 9. River thalweg elevation, groundwater elevation, and river discharge over time near RM 63

Similar to groundwater levels, the causes of channel degradation are complicated. Based on information in Reclamation's October 2007 BA, the Service's 2008 Biological Opinion (BO) on the effects of the Temporary Channel Maintenance Project stated the degradation was initiated by a headcut that formed in 2003. The 2007 BA and 2008 BO recognized the primary driver for the headcut was lowering of the reservoir due to drought, but also indicated an expectation that Delta Channel maintenance and excavation work was expected to create additional riverbed degradation. Today's best available data and a more thorough analysis of that data provide a clearer understanding of how and when the headcut formed and whether degradation was caused by the Delta Channel. Reclamation has conducted a thorough assessment of channel conditions and dynamics in the reach from the Highway 380 Bridge to Elephant Butte Dam (60 miles) to examine potential effects from initial Delta Channel construction and recurring maintenance. This assessment, provided as Appendix B, considers the past and present impacts of Delta Channel construction and maintenance within a geomorphic framework that considers the primary physical processes that govern alluvial river morphology. Furthermore, while initial Delta Channel construction effects were combined with recurring Delta Channel maintenance effects in previous assessments, Appendix B makes it clear that both the action and the subsequent effects are distinctly different for initial construction and recurring maintenance activities. The following discussion is a summary of the assessment, which describes the relative impacts of natural events and past Delta Channel construction and maintenance actions.

The morphology (planform, cross-sectional shape, slope, bed elevation, and other characteristics) of the MRG, like other alluvial rivers, is continuously changing in response to changes in water discharge, sediment load, base level, and anthropogenic actions. In geomorphic terms, the river is responding to upstream drivers and downstream controls. The primary drivers in alluvial channel morphology are the flow regime and sediment load (Schumm 1977, Watson et al. 2007) and the controls are the base level of the stream system and channel and floodplain characteristics. Controls either constrain or amplify the effect that the drivers have on channel adjustment (Makar and AuBuchon, 2012).

*Geomorphic Drivers*

On the Rio Grande upstream of Elephant Butte, the geomorphic drivers of water discharge and sediment load, coupled with the primary control of downstream base level (reservoir pool) elevation, have varied significantly from the early 1900's to the present. During dry periods from 1943 – 1978 and 1996 – present, most of the recorded peak flows were substantially less than 5,000 cfs, and the annual flow volume has been typically less than one million acre-feet. Wet periods from 1903 – 1942 and 1979 – 1995 saw streamflow peaks significantly greater than 5,000 cfs and annual flow volumes greater than one million acre-feet.

Flow duration is also important because peak discharges may occur during prolonged snowmelt runoff events or short-lived monsoon events. "Historically, most significant channel adjustments on the Middle Rio Grande have occurred during high magnitude, long duration runoff events. The river also adjusts to periods of low flows, but at a more gradual rate" (Holste 2013).

High variability in the balance between sediment load and sediment transport capacity on the Rio Grande drives continuous channel adjustments as the channel changes to balance the capacity to do work (related to sediment transport) with the work that must be done (related to sediment supply). Typically, sediment supply exceeds the transport capacity on the Rio Grande upstream of Elephant Butte because of the high sediment loads and the relatively flat slope upstream of the reservoir pool, inducing deposition and causing aggradation of the channel. For more discussion of sediment balance, see Appendix B.

*Geomorphic controls*
An important geomorphic control for upstream reaches of a river is the base level. The base level is the downstream limit of the river system and the origin of the thalweg profile; on the Rio Grande (between San Acacia Diversion Dam and Elephant Butte Dam), the base level is the level of Elephant Butte Reservoir pool and it is a dominant geomorphic control.

The Rio Grande base level has fluctuated greatly since 1915 (Figure 10). After dam construction in 1915 and the initial filling of the reservoir, the water surface "has fluctuated over a vertical range of 150 feet (a shift in the horizontal water surface of around 32 river miles) corresponding to climatic wet and dry periods" (Holste 2013). In recent history, the average annual pool elevation increased 101 feet between 1978 and 1986, with the reservoir essentially full between 1985 and 1995. After declining slightly between 1995 and 1998, the average pool elevation dropped 90 feet between 1998 and 2004. An increase of 35-40 feet in elevation between 2004 and 2009 was followed by a similar decrease of 30-40 feet through 2012. The minimum 2012 elevation was only 3.2 feet higher than the minimum 2004 elevation (both in September) (Holste 2013). The riverbed responds to these fluctuations in base level, with downstream reaches (closest to the reservoir) responding quickly while upstream reaches respond later.

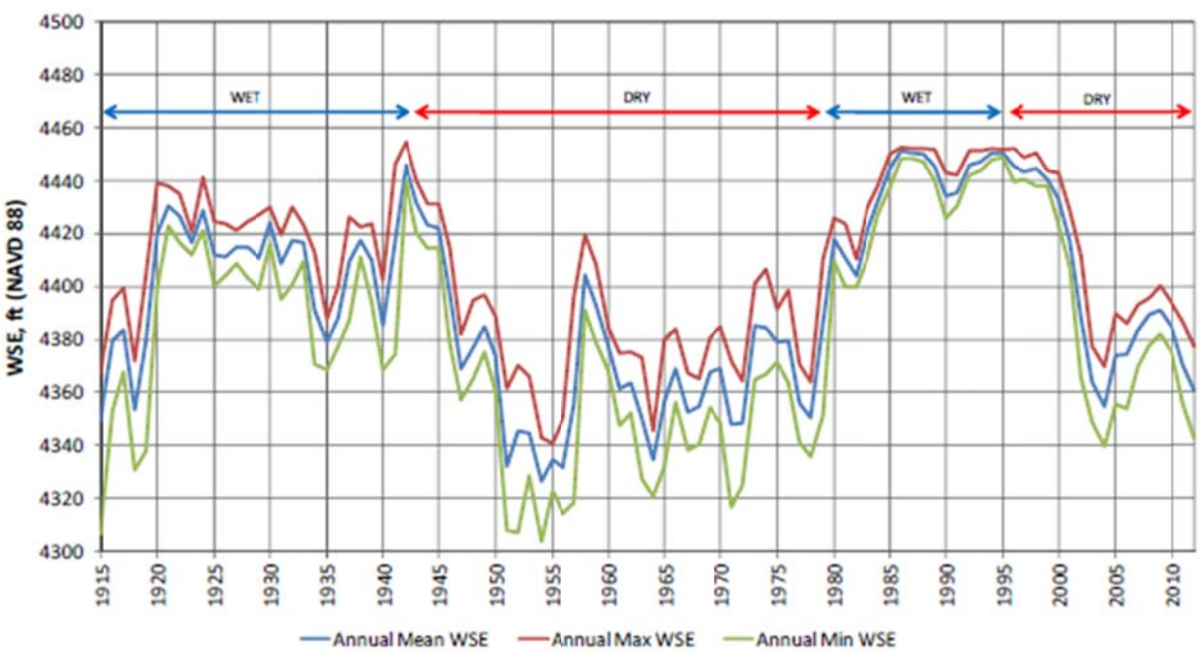


Figure 10. Elephant Butte Reservoir pool elevation time series (1915 – 2012) (modified from Owen 2012)

A rise in base level, such as the rise that began at the reservoir in 1978 and held through 1995, reduces local transport capacity, as discussed previously, with resulting aggradation of the streambed. In fact, "aggradation is the most dominant characteristic of this reach over time. The riverbed elevation at San Marcial has increased by a cumulative total of about 18 feet since 1915, while areas further downstream near the historic average pool location (the Narrows) have aggraded 40-50 feet" (Holste 2013). The aggradational effect tends to travel less far upstream than the headcut migration induced by lowering of the reservoir (Knighton 1998, Leopold et al. 1964).

When the base level drops, it exposes the steep slope that exists downstream of the transition between the aggraded streambed and the former level of the reservoir pool, as shown in Figure 11. Strand and Pemberton (1982) describe the development of the upstream riverbed elevation (topset slope) relative to a reservoir pool, with the oversteep slope (foreset slope) beginning at the transition between the stream and the initial base level. On average, the topset slope is half of the original channel slope and the foreset slope is 6.5 times steeper than the topset slope.

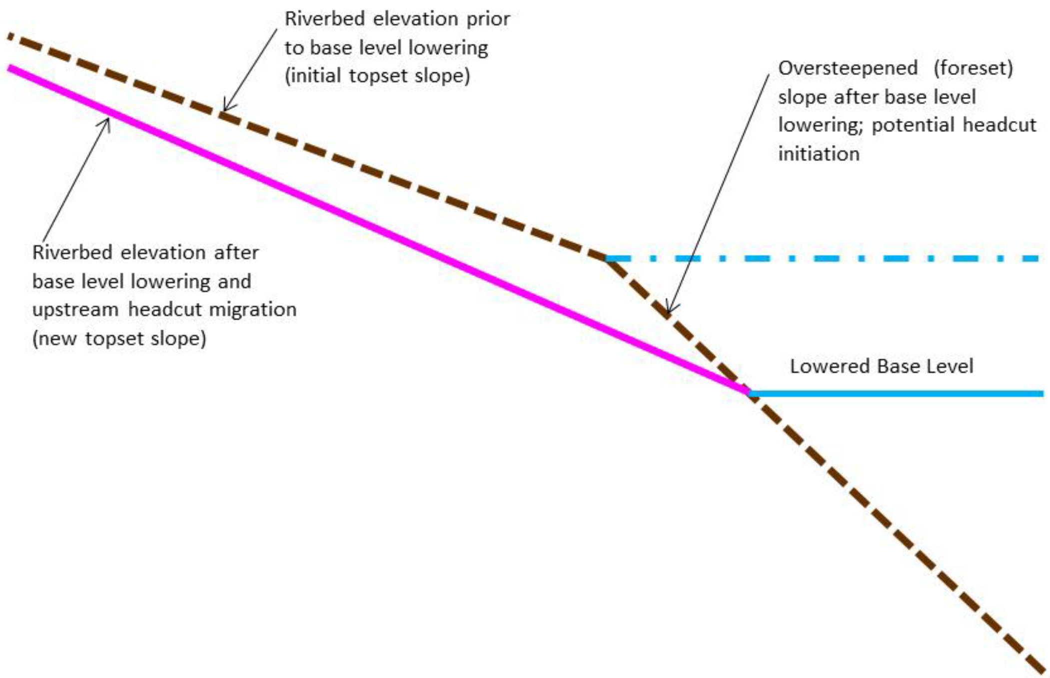


Figure 11. Conceptual diagram of upstream headcutting caused by base level lowering

When the reservoir pool elevation drops, it exposes the steeper (foreset) slope. This increases the sediment transport capacity beyond the sediment supply, causing this abrupt break in slope (headcut or knickpoint) to migrate upstream as the stream adjusts. The streambed degradation typically moves upstream fairly quickly, then slows over time and declines with distance from the reservoir (Knighton 1998).

*Aggradation and degradation on the Rio Grande*

These cycles of aggradation and degradation have occurred before on the Rio Grande over the history of the reservoir. Figure 12 compares the water surface elevation of the reservoir to the average bed elevation at San Marcial gage, which is about 42 miles upstream of Elephant Butte Dam, 31 miles upstream of the average 2012 pool elevation, and about 5 miles upstream of the full reservoir pool. Periods of increasing or full reservoir pool correspond to the largest rates of aggradation, from 1920 to 1948 and from 1978 to 1995. Periods of low or declining reservoir elevation correspond to periods of historical degradation, 1949 – 1972 and 2005–2011. Both 1949 and 2005 had large spring runoff events, both about seven to ten years after the reservoir pool began to lower. The degradation rate between 1949 and 1972 was about one half to one third of the rate between 2005 and 2011, mostly due to the substantially higher sediment load that existed on the MRG between 1949 and 1972. Figure 12 also shows significant short-term degradation events that occurred during 1937 (Happ 1948), 1991, and 1995, caused by avulsions or sediment plugs that reduced upstream sediment supply (Holste 2013).

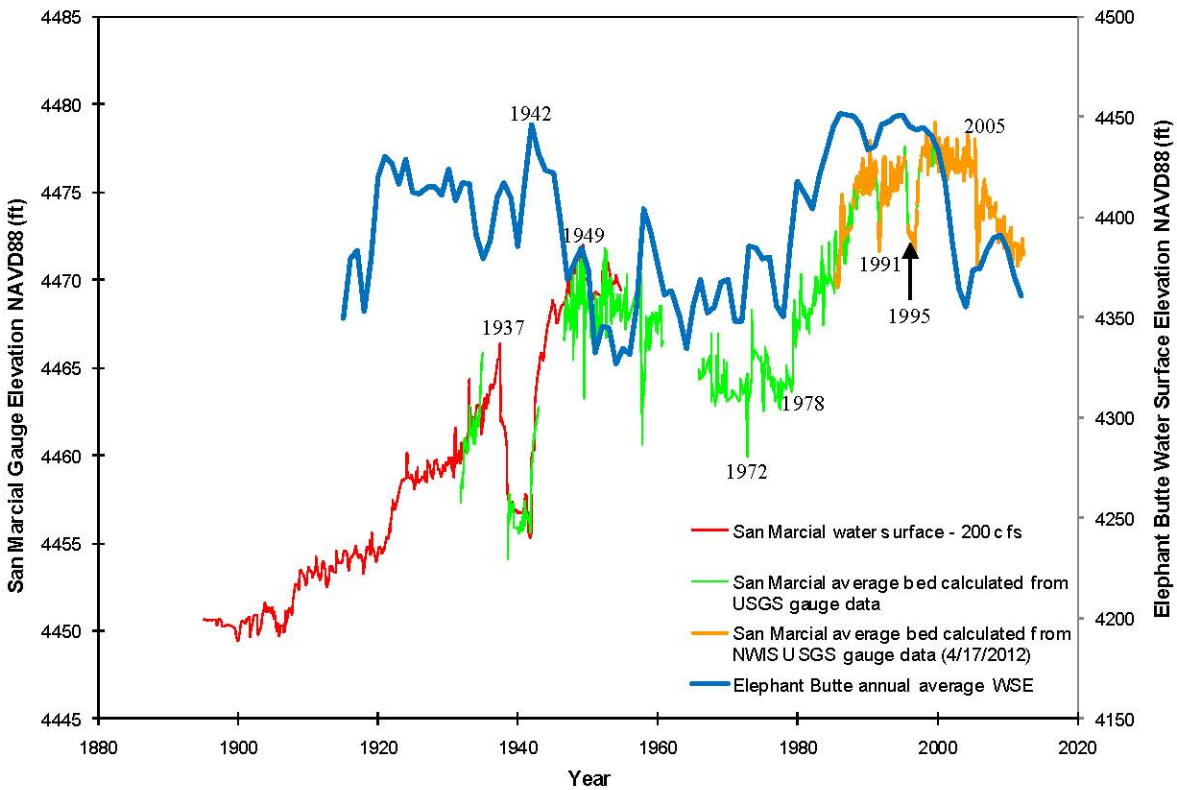


Figure 12. Elevation changes of the USGS San Marcial gauge and Elephant Butte Reservoir pool over time (modified from Makar 2013, pers. comm.)

As discussed, degradation and aggradation can be induced by either upstream drivers (water discharge, sediment load) or downstream controls (base level). Table 5 identifies the different primary causes for downstream and upstream progression of bed elevation changes. Also, controls and drivers interact, such that the effects from the reservoir level lowering downstream on a river can be amplified or dampened by upstream water discharge and sediment load. Thus, in a river like the Rio Grande, where water discharge and sediment inputs are highly variable and the base level is changing, the geomorphological response to events is highly complex and reaching dynamic equilibrium is nearly impossible.

Table 5. Main Causes of Streambed Elevation Change (adapted from Knighton 1998)

| Type of Bed Elevation Change | Upstream Driver – Cause of Downstream Progression | Downstream Control – Cause of Upstream Progression |
|---|---|---|
| *Degradation* | water discharge increase; sediment supply decrease | base-level fall |
| *Aggradation* | water discharge decrease; sediment supply increase | base-level rise |

This complexity and dynamic nature of the MRG and Elephant Butte Reservoir can clearly be seen in Figure 13, which overlays six different pool elevations on longitudinal reservoir profiles from 1915, 1988, 1999, and 2007. Figure 13 is also presented in an expanded view. The grade breaks or knickpoints discussed previously can be seen in historic reservoir longitudinal profiles, corresponding to specific pool water surface locations. A knickpoint can be seen at the Narrows in the more recent profiles, where the greatest historical aggradation (40-50 feet) has occurred. This is not surprising because that is also the elevation of the historical average reservoir pool.

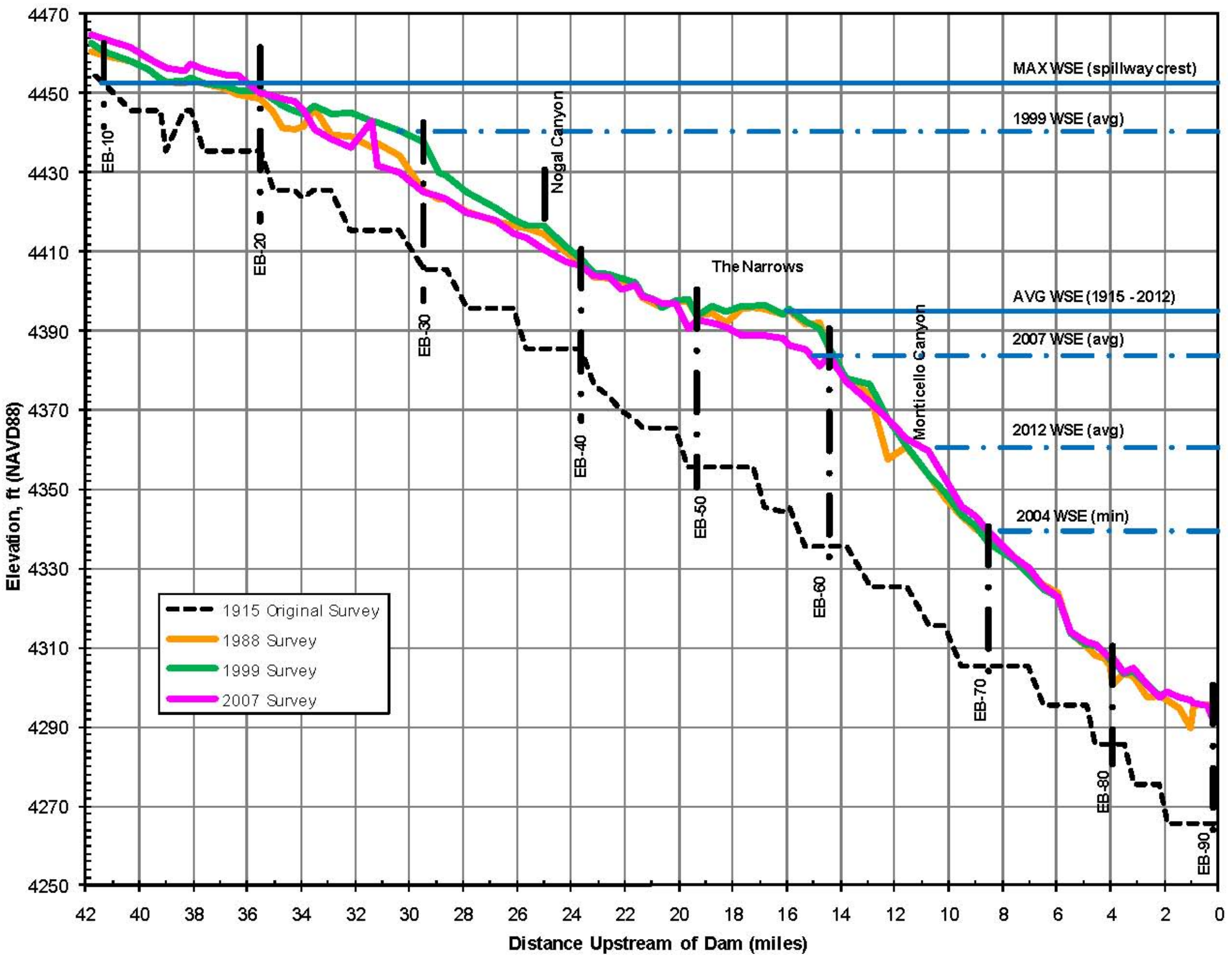


Figure 13. Elephant Butte Reservoir longitudinal profiles and pool elevations (modified from Ferrari 2008) (presented next page in an expanded view)

The 1999 longitudinal profile reveals a second pivot point at EB-30 (RM 56), just downstream of the 1999 pool location. "The reservoir pool had been mostly full and operating at an elevation between 4450 feet and 4440 feet from 1985 to 1999 so the development of a pivot point at an elevation of approximately 4438 feet is not surprising. The 1999 topset slope above EB-30 is about 70% of the 1915 bed slope, and the 1999 foreset slope is about 3 times steeper than the topset slope. As the reservoir pool continued to drop between 1999 and 2004, the previously submerged foreset slope was exposed and became the new river thalweg. This resulted in an oversteepened local slope between EB-30 and EB-33 and a relatively steep slope between EB-30 and EB-47 upstream of the Narrows" (Holste 2013).

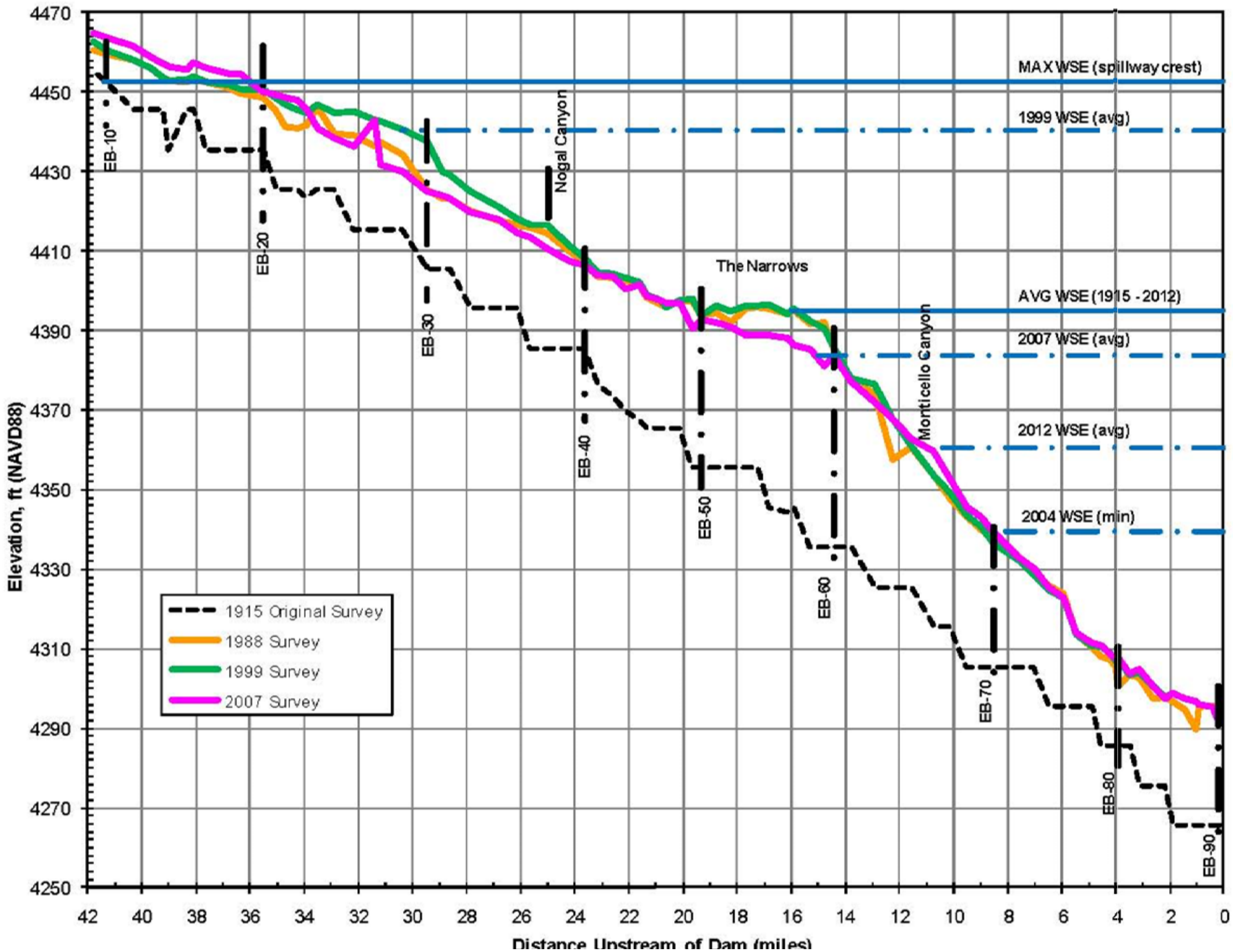


Figure 13. Elephant Butte Reservoir longitudinal profiles and pool elevations (modified from Ferrari 2008) (expanded)

*Slope adjustments*
Initial construction on the Delta Channel began in 2000 to restore the river's connection to the receding reservoir pool. A flowpath about 3 feet deep was excavated through the delta, whereas there was 90 feet of drop in the reservoir pool between 1998 and 2004. Comparing the 3 foot drop to the 90 foot drop makes it clear that the 3 foot excavation was not a significant base level change (as contrasted to the 90 foot drop). A sinuous design was used, such that the channel length remained within 1% of the 1972 length and the slope within the area of excavation was not overly steepened. A close examination of the 1999, 2002, and 2004 thalweg profiles reveals that it is probable that initial excavation was responsible for a local slope increase of only about 8-12% within the upper reservoir delta (from about RM 58 to RM 46). The slope was steepened somewhat (8-12%), but not overly steepened (given that the foreset slope is naturally 6.5 times steeper than the topset slope on average) (Holste 2013). Also, this slope change must be viewed in concert with slope changes caused by changes to the reservoir pool.

Figure 14 shows a clear relationship between changes in channel slope and reservoir pool elevation during the period of Delta Channel initial construction and maintenance for the two subreaches upstream of the reservoir pool: an upper subreach of 8.9 miles, measured along the thalweg, from near RM 68 to near RM 60 (EB-10 to EB-24A) and a lower subreach of 8.9 thalweg miles from near RM 60 to near RM 52 (EB-24A to EB-38). The lines connecting the discrete slope values in the figure do not represent the channel slope itself but instead are meant to show the direction of slope change. The actual values of the channel slope are labeled on the left y-axis and reversed (steeper slope values are at the bottom of the graph).

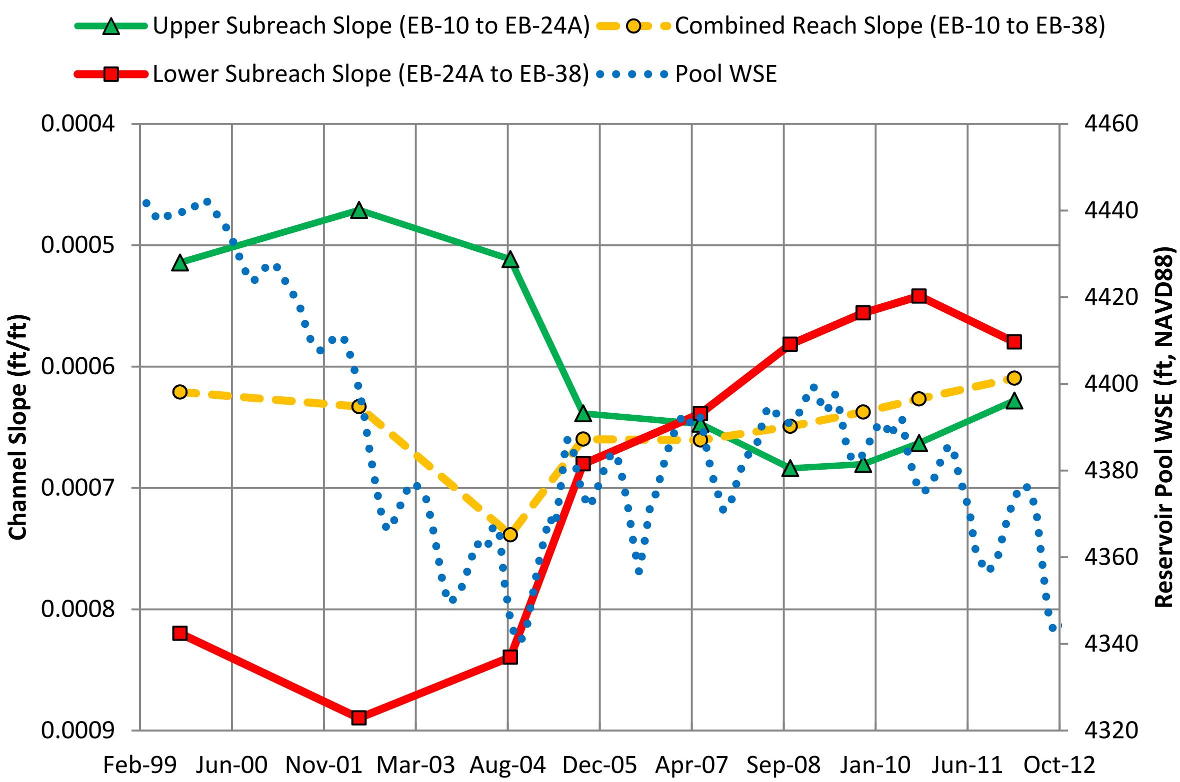


Figure 14. Changes to Rio Grande channel slope over time (1999–2012)

In 1999, the lower subreach was partially inundated by the reservoir pool and includes the transition into the upper Delta Channel work area that began in 2000. This lower subreach also contains the 1999 pivot point at EB-30. The channel slope trend of the lower subreach closely follows the pool elevation while the change in slope of the upper subreach is out of phase with changes to the pool elevation. This indicates the delayed response discussed previously for reaches further from the base level (reservoir pool). The changes in the upper subreach are naturally later in time because it is responding to changes in the lower subreach that were earlier induced by the change in reservoir pool elevation.

*2005 spring runoff*

The degradation that was already occurring as a result of the drop in the reservoir level was greatly accelerated in 2005 due to a confluence of several events that resulted in magnified feedback for geomorphic effects. Between 1998 and 2004, the average pool elevation dropped 90 feet. A sediment plug formed during the 2005 spring runoff slightly upstream of San Marcial that blocked most of the upstream sediment supply (in contrast to the high sediment load during degradation occurring between 1949 and 1972). Also, a high magnitude, long duration (above normal) spring runoff occurred that year. Thus, all three of the primary degradation causes (Table 5) were present in 2005: water supply increase, sediment supply decrease, and a lowered base level.

Figure 15 is a time-series plot of rangeline thalweg elevations between Highway 380 and the reservoir along with reservoir pool elevation. The figure illustrates the migration of the headcut, with degradation occurring first closer to the reservoir and a dampened effect as the changes propagate upstream. The 2005 sediment plug can be clearly seen at SO-1665. Holste (2013) discusses Figure 15: "After river connectivity was restored, sediment was eroded from the plug and deposited downstream as represented by the 2005-2007 aggradation at SO-1701.3. Attenuation of the upstream migrating headcut is depicted by degradation at SO-1665 from 2005 to 2007, and a minor or negligible amount of degradation at SO-1626 and SO-1585 from 2007 to 2008. The area between RM 78 and RM 74, represented by SO-1585 and SO-1626, has been the most stable section between Highway 380 and the reservoir pool." Also, Table 3 in Appendix B provides a detailed explanation of MRG slope changes and bed degradation, including the 2005 time period.

*Geomorphic changes and Delta Channel construction and maintenance*

Reclamation's assessment of geomorphic effects on the Rio Grande in Appendix B provides a clearer understanding than was available at the time of the 2008 Section 7 consultation for the Delta Channel. To summarize, channel degradation occurred when the average pool elevation dropped about 90 feet between 1998 and 2004, whereas the Delta Channel excavation was about 3 feet in that same time period. While the initial Delta Channel construction is estimated to be responsible for steepening the local slope (~RM 58 to RM 46) about 8 – 12%, slope changes are also clearly related to the reservoir pool levels. Finally, the headcut formed in 1999 (prior to the original Delta Channel construction in 2000), not in 2003, and migrated upstream about 3 miles between 1999 and 2004. In contrast, during the 2005 spring runoff, the headcut migrated about 10 miles upstream due to the confluence of events previously discussed. The slope change from the Delta Channel construction may have temporarily increased the rate of channel lowering after 2000, but the lower reservoir pool and

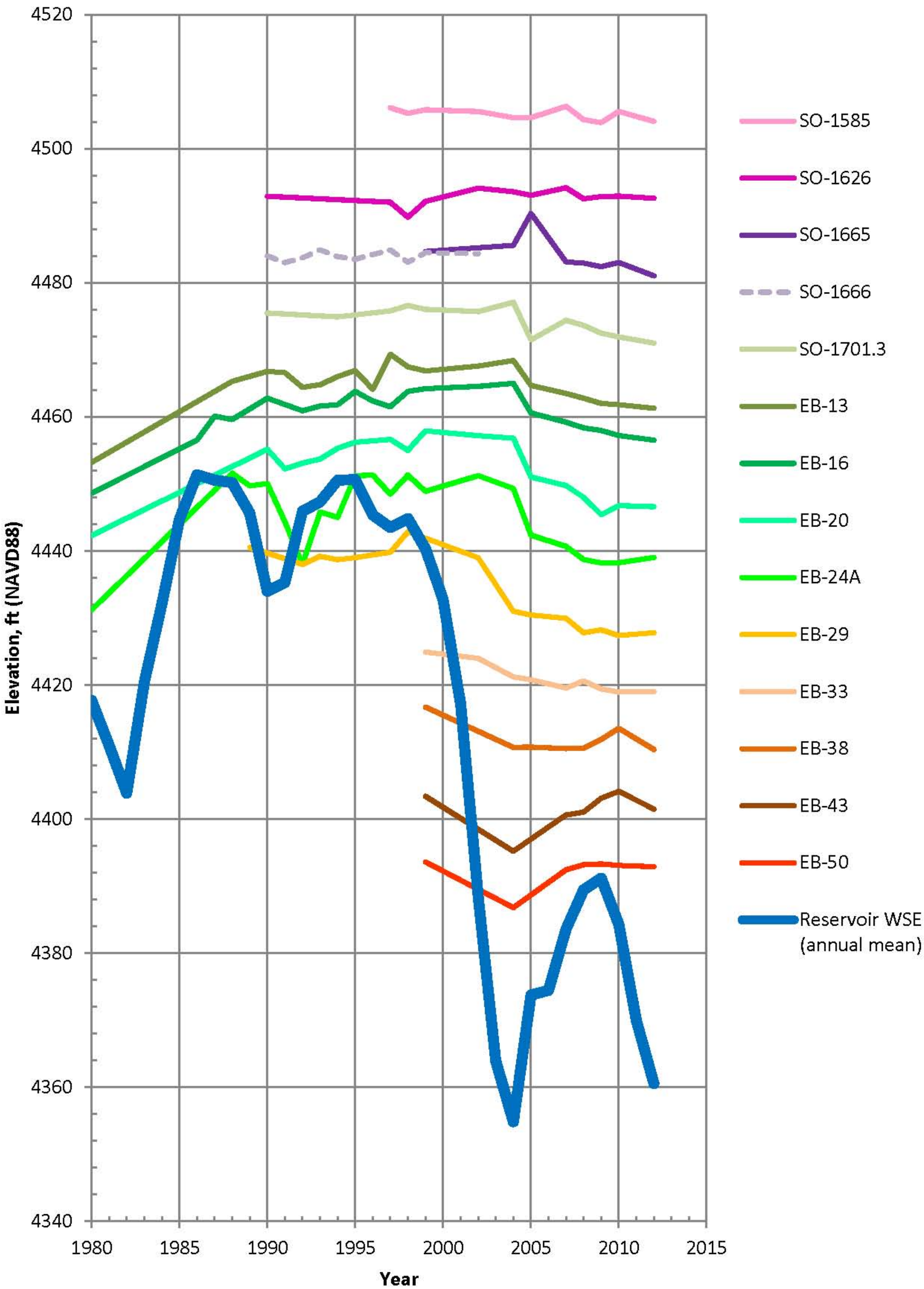


Figure 15. Change in thalweg and reservoir pool elevation over time (after Owen 2012)

2005 events would have eventually created the elevation changes seen in the reaches upstream of the Delta Channel. Moreover, the Delta Channel aggraded by a cumulative average of almost 3 feet from 2004 to 2010, with maintenance occurring every year (Holste 2013). Figure 16 shows a distance-weighted, reach-average thalweg elevation for the Delta Channel between 2004 and 2012, illustrating the aggradation that occurred even though sediment was frequently removed to maintain channel capacity. Also, this figure clearly highlights the similar trends in average thalweg elevation and reservoir water surface elevation.

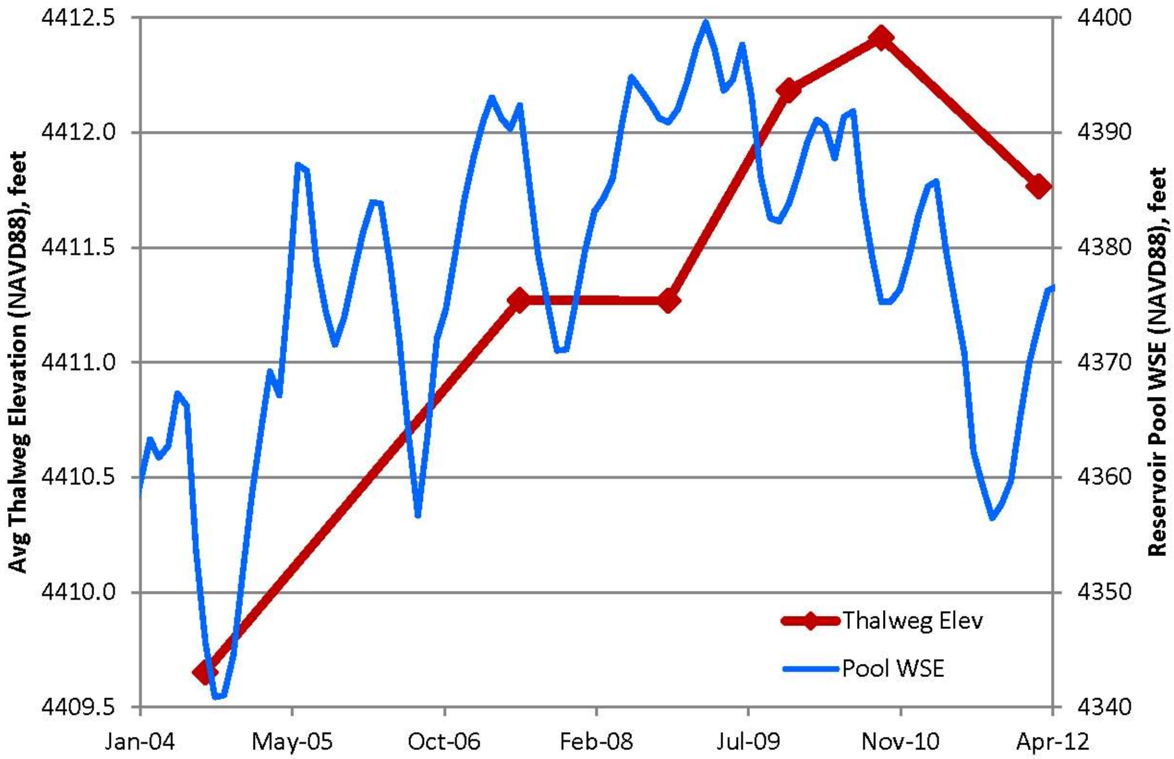


Figure 16. Distance-weighted average thalweg elevation over time for the Delta Channel between EB-28 and EB-50 during recurring channel maintenance (Holste 2013)

Furthermore, nesting in the San Marcial reach outside the reservoir pool and in Tiffany reach has consistently been low for several years, but the number of territories have greatly expanded both upstream (in the Bosque del Apache reach) and downstream in the reservoir pool. The 2012 data shows a drop in territories in the reservoir pool, but that is clearly due to the drought and resulting reduced overbank flows in this area. Flycatcher habitat is naturally a dynamic system, with suitable habitat developing and then declining in relatively short periods of time. The recent decrease in nest success in the Tiffany reach is an example of this, as flycatchers disperse to more favorable sites.

### 4.2.3 Reclamation's efforts to minimize effects to flycatchers

Terms and conditions in the 2008 BO for the Delta Channel included the planning and implementation of a restoration project to establish flycatcher habitat on the Rio Grande, outside of the San Marcial Reach. Reclamation worked with ISC, the State Parks Division of the New Mexico Energy, Minerals and Natural Resources Department and local stakeholders on a flycatcher habitat restoration project on the Broad Canyon property along the Rio Grande approximately 15 miles north of Las Cruces. The project was completed in February 2013, with employees from ISC and Reclamation and volunteers from Audubon New Mexico planting 4.5 acres with 4,650 coyote willow poles and 600 Goodding's willows. Planting parameters were in accordance with the Flycatcher Recovery Plan (Service 2002) for patch size (4.5 acres) and minimum width (33 feet), as well as the density (2800 whips or poles per hectare) from the flycatcher habitat quantification report completed for the San Marcial area (Moore 2007). Monitoring of the project, including vegetation and groundwater monitoring will continue for 5 years. Once the vegetation becomes suitable, flycatcher monitoring will also take place. Additionally, in compliance with the terms and conditions of the 2008 BO, Reclamation continues to monitor the river bed elevations over time and ISC has monitored groundwater levels in the area. The bed elevation and groundwater data was used in Reclamation's geomorphic assessment in Appendix B.

### 4.2.4 Salt cedar leaf beetle

The salt cedar leaf beetle (*Diorhabda* spp.) (beetle) was released in field cages in six States (California, Nevada, Utah, Texas, Colorado, and Wyoming) in 1999 and field released in 2001 (DeLoach et al. 2003). The beetles defoliate salt cedar during the growing season, which corresponds to the flycatcher breeding season, and take multiple years of continuous defoliation to eventually kill salt cedar (Paxton et al. 2011). The abundance of beetles may provide a temporary food source for flycatchers, however, once defoliation takes place it is likely that other foliage feeding insects would disperse (Paxton et al. 2011). With reduced canopy cover as well as food source, flycatchers occupying habitat composed of mainly salt cedar would be at a disadvantage.

At this time, the beetle has been observed as close as Highway 313 just north of Albuquerque. Also, the subtropical beetle has been observed at Indian Hot Springs, Esperanza, and Ft Quitman (Tracy pers. comm. and Verdecchia pers. comm.). Within the MRG, flycatchers use salt cedar as a nesting substrate at a disproportionate rate, which is a concern due to the inevitable expansion of the beetle. However, the vast majority of flycatcher territories are in native dominated stands, and the defoliation or mortality of a few salt cedar trees within those stands likely will not reduce overall habitat quality (Moore and Ahlers 2012).

## 5.0 Effects of the Action

Effects of the proposed action are summarized in Table 6 below.

The designated critical habitat for the minnow extends to the power lines (approx. RM 62); therefore, there is no minnow critical habitat within the Delta Channel maintenance project area, which is below the power lines (approx. RM 62) and within the reservoir pool. Revised designated critical habitat for the flycatcher includes the Elephant Butte Reservoir area to RM 54.

Table 6. Summary of direct and indirect effects of proposed action on endangered species in the reservoir pool

| | ***Effects on minnow*** | ***Effects on flycatcher*** |
|---|---|---|
| ***Maintenance of existing Delta Channel*** | Direct – movement of excavators, airboats, and fuel transporter in the channel and excavation of sediment from the channel may disturb or injure minnows | Direct – no effect because maintenance activities will not occur between April 15 and August 15 |
| | Indirect – channel degradation caused by the proposed action is not expected to occur; thus, it will not affect upstream minnow habitat, and maintenance of point bars and sinuosity maintains minnow habitat within the Delta Channel | Indirect – channel degradation caused by the proposed action is not expected to occur; thus, it will not affect adjacent or upstream flycatcher habitat |
| ***Maintaining naturally formed channel below RM 38*** | Direct – movement of excavators, airboats, and fuel transporter in the channel and excavation of sediment from the channel may disturb or injure minnows | Direct – no effect as channel maintenance would occur in areas where no flycatcher habitat exists and maintenance activities will not occur between April 15 and August 15 |
| | Indirect – riverbed degradation caused by the proposed action is not expected to occur; thus, it will not affect upstream minnow habitat | Indirect – riverbed degradation caused by the proposed action is not expected to occur; thus, it will not affect adjacent or upstream flycatcher habitat. Also, channel maintenance would occur in areas where no flycatcher habitat exists |
| ***Connecting isolated pools and channels in lower reach*** | Direct – movement of excavators, airboats, and fuel transporter in the channel and excavation of sediment may disturb or injure minnows | Direct – no effect as channel excavation would occur in areas where no flycatcher habitat exists |
| | Indirect – no effect to minnows | Indirect – no effect as channel excavation would occur in areas where no flycatcher habitat exists |
| ***Site access and staging areas*** | Direct – existing staging areas will be utilized thus no effect | Direct – existing staging areas will be utilized thus no effect |
| | Indirect – no effect due to use of existing roads and staging areas | Indirect – no effect due to use of existing roads and staging areas |
| ***Re-fueling Equipment*** | Direct – no effect | Direct – no effect |
| | Indirect – fuel spill in the water may affect temporarily minnow food base and habitat | Indirect – no effect |
| ***Pumping water from river for dust abatement*** | Direct – no effect to minnows due to small amount of water, utilize screened intake for pumps, and at existing staging areas | Direct – no effect to flycatchers or habitat |
| | Indirect – no effect to minnows and utilize exclusion period | Indirect – no effect to flycatchers or habitat |

## 5.1 Rio Grande Silvery Minnow

5.1.1. Direct Effects: Potential effects to minnows are summarized in Table 6 above.

*Site Access and staging areas*: All necessary project related roads and staging areas have been built and maintained to date. There is access from the uplands to the Delta Channel along existing access points.  Thus, there are no direct effects on minnows or their habitat from access to the project area.  The excavators and airboats are launched from launching areas near the staging areas utilizing an existing ramp and side channel into the Delta Channel.

*Delta Channel Maintenance*:  Channel maintenance, including maintenance of the naturally formed channel (as needed), will be done every year as long as the Delta Channel is in existence, with the excavators moving in the channel to work sites, then working at the work site, and returning to a staging area.  Maintenance activities will include maintaining existing berms and removing vegetation within the channel, as well as removing a portion of accumulated sediment to maintain the channel capacity (some aggradation will likely remain depending on reservoir pool elevation).  These maintenance activities will not occur between April 15 and August 15. An exception to this would be in the case of emergency channel and berm repairs during runoff, and we expect that this event would happen once in a five year period for a period of two weeks near the end of runoff.  If emergency channel and/or berm repairs are needed, Reclamation will coordinate the activity with the Service.

The amphibious excavators move slowly at an average speed of two mph and the fuel transporter about ten mph along the channel.  The swath of disturbance can be considered to be 24 ft for the excavator with a three ft avoidance area on either side for a total of 30 ft.  This slow movement should allow for fish to be able to move away from the excavator.  An estimation of the portion of the impacted area by the Delta Channel maintenance work each year is as follows (computation details are provided in Appendix A.):

- 75 to 100% of the total channel length is traveled by an amphibious excavator and fuel transporter.  The excavator and transporter generally travel from the equipment staging areas to the work sites and back.  This computes to an estimated 944 acres of channel disturbance in most years.  If workload requires a third crew, there would possibly be an additional 629 acres of channel disturbance, for a total possible 1573 acres in those years with three crews

- Active work sites, where excavation is performed within the channel, are estimated to cover approximately 25% of the entire channel area each year for most years.  For most years where two crews are needed, this computes to an estimated 113 acres per year that will have an excavator working within the existing channel area.  If workload requires a third crew, there would possibly be an additional 82 acres per year that would have an excavator working within the existing channel area.  Thus, the total possible area of active work sites would be 195 acres in those years with three crews.

Reclamation assumes that minnows are present in the Delta Channel when the excavators are moving in the channel to the work sites and at the work sites.  As the excavators move along the channel they displace water which cause the fish to flee the area, but this is short in duration.  As shown above and in more detail in the Appendix, Reclamation is estimating the area maintained per year as an attempt to establish an area of impact, but there is no way to know up front the exact level of work for each year because the sediment load and flows are dependent on spring runoff, the summer monsoons, and localized rain storms.  Channel excavation may also cause localized increases in turbidity and suspended sediments, but minnows are expected to have fled the area as the excavators move into place and/or begin activity.

*Connecting isolated pools and channels in the lower reach*: Maintenance of the lower reach may also include excavation of secondary channels that would extend a short distance from the main Delta Channel to connect water-holding low areas that occur as the reservoir fluctuates. Minnows are not expected to be found within the reservoir, and these low areas with water should not have minnows present prior to being connected to the main Delta Channel. Short-term adverse effects on minnows could occur during excavation at the confluence of the secondary channels and the Delta Channel, but minnows are expected to exhibit an avoidance response to the excavator activity. These secondary channels will extend a distance of no more than ½ mile from the main Delta Channel.

*Airboat Transport*: Daily transport of personnel and fuel to the equipment via airboats has limited disturbance but does not expose fish to propeller blades. Normal avoidance behavior would protect all fish species from injury by airboats in the river, and airboats move mainly along the thalweg of the channel.

*Refueling*: Even though refueling over water has been done with the excavators for many years without any major spills and each excavator has a fuel spill kit, there is a potential for a fuel spill. The fuel spill would be limited to the area of the spill and downstream. The buoyancy of diesel fuel would keep it on the water surface until it evaporates and have no adverse effect on fish.

*Pumping Water from the River*: To provide dust abatement related to access and road maintenance, water will be pumped from the river at the secondary channels that act as access points. The pump setup will utilize a 0.25 inch (0.64 cm) mesh screen at the opening to the intake hose to minimize entrainment of aquatic organisms and no impacts to fish are expected. The pump intakes will not be placed directly in the active channel, but will be placed in an excavated sump adjacent to the channel. Water will likely be pumped at a rate between 1.8 and 2.2 cfs for four to eight minutes to fill a water truck. This would be a minimal impact to river flows, equating to a decrease in flows of approximately 0.7% for river flows of 300 cfs and approximately 0.2% for river flows of 1000 cfs for four to eight minutes. A typical project may use four to six truckloads per day and, at a maximum, 18 truckloads per day. This Project is expected to use the typical amount or less. The pumping of this amount of water will have no effect on minnows.

<u>5.1.2. Indirect Effects:</u> The Delta Channel continues to provide additional habitat for the minnow that didn’t exist previously (prior to the existence of the Delta Channel). Furthermore, the Delta Channel has remained wet under the recent severe drought conditions and provided habitat for minnows. The habitat for the minnow is good within the Delta Channel because the original construction provided sinuosity (meandering). Sinuosity is beneficial to the minnow as it provides variable depth and flow velocity, helping to create the type of preferred habitat conditions for juvenile and adult minnows. The thalweg is allowed to meander in both upper and middle reaches which allows for the formation of point bars and small backwater areas. Point bars are always being created by the channel flow and are only removed as required to maintain the design conveyance capacity of the 250 foot wide channel, and to maintain the low flow channel with effective sediment transport capacity, which has a width that varies from 50 to 100

feet. The maintenance program allows for these features to remain temporarily, providing quality habitat for minnows. The removal of excess sediment does not change the composition of the substrate, and the channel bed is kept at a shallow, stable level. The increase in turbidity and suspended sediments caused by excavation may create indirect effects, with decreases in primary production and negative impacts to aquatic invertebrates. However, any excavation related increase in turbidity would be minor compared to the high sediment concentration already present. Also, conservation measures (water quality monitoring, compliance with CWA permitting processes) will help minimize the risk due to dispersal of suspended sediments. Therefore, no significant indirect effects are expected to occur due to suspended sediments.

The proposed action does not occur within minnow critical habitat. Maintenance of the existing Delta Channel will not cause bed degradation within or upstream of the Delta Channel (see section 5.2.2 or for a detailed discussion, Appendix B). However, channel bed lowering is expected as long as the reservoir pool continues to lower, but that would occur due to natural geomorphic processes, whether maintenance activities occurred or not. In fact, a natural channel with defined banks has already formed for a distance of one mile where the reservoir receded below RM 37. Therefore, the proposed action will have no effect on upstream designated critical habitat.

## 5.2. Southwestern Willow Flycatcher

5.2.1 Direct Effects: Potential effects to flycatchers are summarized in Table 6 above.

*Site Access and staging areas*: All necessary project related roads and staging areas have been built and maintained to date. There is access from the uplands to the Delta Channel along existing access points. No new access roads are planned at this time; if they should become needed, Reclamation will coordinate with the Service prior to any road construction activity. Annual maintenance will be performed on the existing roads, which will consist of: 1) smoothing of the road surface with a road grader and potential addition of gravel surfacing; 2) repair of washout areas, when needed; and 3) routine mowing of vegetation along the road shoulders for safety, to a maximum distance of 10 feet from each road shoulder.

Road maintenance such as grading and washout repair may be performed throughout the year. The majority of roads are in upland areas, while some roads are in flycatcher habitat, including critical habitat. Grading and washout repair have occurred routinely for several years between April 15 and August 15 with no negative impacts to flycatchers, which have continued to nest successfully near the roads. Mowing will not occur between April 15 and August 15, and the area mowed consists of mostly salt cedar, is not suitable habitat, and is small relative to the overall critical habitat. If mowing should be needed between April 15 and August 15, migratory bird surveys will be conducted prior to mowing and no mowing will occur within a 0.25 mile buffer of any nests found. Therefore, road maintenance will have no effect on flycatchers or critical habitat.

*Delta Channel Maintenance*: Channel maintenance, including maintenance of the naturally formed channel below RM 38 (as needed), will be done every year as long as the Delta Channel is in existence, with the excavators moving in the channel to work sites, then working at the work site, and returning to a staging area. Channel maintenance activities will not occur between

April 15 and August 15. An exception to this would be in the case of emergency channel and berm repairs during runoff, and we expect that this event would happen once in a five year period for a period of two weeks near the end of runoff. If emergency channel and/or berm repairs are needed, Reclamation will coordinate the activity with the Service.

Maintenance activities will include maintaining existing berms and removing vegetation within the Delta Channel, as well as removing a portion of accumulated sediment to maintain channel capacity (some aggradation will likely remain depending on reservoir pool elevation). The vegetation to be removed is located in small areas on sandbars within the channel, and is not suitable habitat for flycatchers, both in patch size and vegetation maturity. Vegetation on the sides and tops of berms contributes to the desired stability of the berms and will not be removed, except for some rare cases where the vegetation lower on the inside of a berm interferes with the required channel capacity. Excavators and the maintenance activity for all reaches will be confined to the area within the existing construction footprint (berms and channel) and would not affect vegetation in adjacent areas. Therefore, the proposed work of maintaining the existing Delta Channel would have no impacts to flycatchers. There is no effect to critical habitat because the effect of removing small areas of non-suitable habitat within the channel is insignificant and will not diminish the capability of existing critical habitat to satisfy the essential requirements for the flycatcher.

*Connecting isolated pools and channels in the lower reach*: Maintenance of the lower reach may also include excavation of secondary channels that would extend a short distance (no more than ½ mile) from the main Delta Channel to connect water-holding low areas that occur as the reservoir recedes. The areas of excavation, in the Reservoir's delta area, are unvegetated and outside of critical habitat; therefore, this action will have no effect on the flycatcher or critical habitat.

*Airboat Transport*: Brief periods of noise disturbance from airboats may interrupt flycatcher behavior (feeding, sheltering, and breeding), but in the past flycatchers have been observed to nest successfully near the San Marcial railroad trestle which carries daily train traffic that produces significant noise (Ryan, pers. comm.). Also, while airboats are expected to have no effect on flycatchers, airboat transport is not expected to be needed between April 15 and August 15. If airboat transport is needed between April 15 and August 15, Reclamation will coordinate with the Service prior to the activity.

*Refueling*: Fueling of equipment will primarily take place over water or on berms adjacent to the Delta Channel. This activity would have no effect on flycatchers or critical habitat.

*Pumping Water from the River*: Water will be pumped from the river at times for wetting of road surfaces to facilitate grading of roads, and for dust abatement during high traffic periods to insure safe conditions and reduce environmental impacts. Pumping sites will be at or near existing equipment launching areas, requiring no new ground disturbance. The amount of water used in pumping for dust abatement is insignificant (less than 1% of river flow). Also, given the observed lack of response of flycatchers to train noise, the pump noise would have no effect on flycatchers. Thus, there is no effect to flycatchers or critical habitat from pumping from the river.

### 5.2.2. Indirect Effects:

The proposed action consists of maintaining Delta Channel capacity, repairing berms, and other associated activities to sustain the current Delta Channel condition indefinitely. No new Delta Channel construction is planned, and maintenance action will be to remove a portion of accumulated sediment to maintain channel capacity (some aggradation will likely remain depending on reservoir pool elevation). Specific maintenance activities for each year would be dependent on the channel adjustment that occurred during the previous six months between mid-April and mid-October.

The geomorphic effects of this proposed action must be evaluated in the context of the geomorphic drivers and controls, as described in Section 4.2, Current Status of Southwestern Willow Flycatcher in Action Area. Future riverbed elevation within the Delta Channel will be primarily controlled by the rate, magnitude, and duration of reservoir pool elevation fluctuations. Riverbed elevation further upstream will be controlled by the response of the naturally formed channel (below RM 38), and then the response of the Delta Channel to reservoir pool levels, as well as upstream water and sediment discharges. The following discussion analyzes net geomorphic effects of the proposed actions in the light of reservoir pool levels and Table 7 summarizes these potential future scenarios.

*Rising reservoir pool*

A rising reservoir pool would be the result of high water discharge years. Assuming water and sediment discharge are similar to 2005–2010 or increased, such years would likely require the greatest amount of maintenance. With the increase in pool elevation, a decrease in bed slope would occur. Also, sediment deposition would occur throughout the Delta Channel, spoil berms would possibly be breached, overbanking would increase, and sediment plugs and avulsions would be more likely. Delta Channel maintenance would remove accumulated sediment and repair spoil berms to maintain the target capacity specified in Section 2.0 (Proposed Action) for each reach. Overbanking flow would likely occur at Delta Channel breaches during high flow events (i.e., spring runoff and late summer monsoons) and repair of these breaches during the following fall/winter maintenance season would minimize continued overbanking. Sediment plugs block sediment supply, consequently causing or increasing local degradation downstream of the plug, and interfere with water delivery; therefore, sediment plugs would be removed. The probability of breaches or avulsions would be decreased by Delta Channel maintenance, but not eliminated. If a high flow event created a channel avulsion, Reclamation would assess the location of the avulsion and its impact to water delivery and habitat when deciding whether to reconstruct the original alignment. If the pool elevation remains high for an extended period of time (more than one year), net aggradation throughout the Delta Channel would be the likely result with the greatest amount of aggradation closest to the active reservoir pool.

*Stable reservoir pool*

If the reservoir level stabilized for multiple years, the prevailing aggradational trend would continue at a lesser rate. The proposed action is the same recurring maintenance that has been occurring since 2005, during which aggradation has been the prevailing trend within the Delta Channel. "Sediment was frequently removed in order to maintain channel capacity, yet the riverbed aggraded by a cumulative average of almost 3 feet from 2004 to 2010 before degrading about 0.5 feet from 2010 to 2012" (Holste 2013). Aggradation is expected to continue under the proposed action as long as the reservoir pool is relatively stable and conditions are similar to the recent past (2007–2012).

In this scenario, fewer substantial maintenance activities would be required. The maintenance would cause some reduction in the aggradation rate and it may be possible for Delta Channel maintenance to facilitate a balance between sediment supply and sediment transport capacity. If so, there is potential to achieve some level of short-term channel stability in terms of dynamic equilibrium. Overbanking at breach points, sediment plugs and avulsions would be less likely to occur and would be treated as described under the *Rising reservoir pool* scenario.

*Lowering reservoir pool*
The analysis of geomorphic effects caused by the proposed action also needs to consider the scenario of additional reservoir pool lowering. The historic minimum pool elevation (August 1954) is only about 40 feet lower than the 2012 minimum, and a further decline in pool elevation will likely occur if the current dry hydrology continues. Longitudinal reservoir profiles (Figure 12) show that the slope is naturally steeper below the Narrows than above the Narrows (foreset and topset slopes, Fig 10). This difference in slope should allow the river to form a competent channel downstream of about RM 38 if the pool elevation decreases. Figure 17 illustrates that this is already beginning to occur, as observed in the field during August 2012 near RM 37 and from the air in April 2013 (see Appendix B for additional photos (Figure 26) and discussion). Therefore, construction of additional channel will not be needed and Reclamation will maintain the naturally formed channel.

Figure 17. Naturally formed reservoir Delta Channel (looking southeast) near RM 37 (August, 2012)

However, as long as the reservoir pool continues to lower, bed elevation lowering could occur in the Delta Channel and then progress upstream. This process, described in detail in Appendix B and summarized in section 4.2, Current Status of Southwestern Willow Flycatcher in Action Area, is not a result of Delta Channel maintenance activities. Instead, it is caused by the drop in reservoir pool elevation, which induces a degradation wave that forms a natural channel for the water (as currently observed near RM 37). The degradation wave may move further upstream, depending on the rate, magnitude, and duration of the reservoir recession as well as the discharge and sediment supply conditions. It is not possible to accurately predict the magnitude or extent of the degradation as those factors are highly variable and have a complex interaction. However, a future degradation wave is likely to be less severe than the degradation caused by the 1998–2004 lowering, because the reservoir cannot physically lower that far (an additional drop of 60 feet from the 2012 average would completely empty the reservoir compared to the 90 feet drop in 1998–2004). In such a scenario, minimal channel maintenance would be needed, including removal of in-channel immature vegetation to prevent channel narrowing and possible localized removal of sediment accumulation and berm repair. These activities would be insignificant compared to the base level (pool elevation) control, as discussed previously, and would not decrease Delta Channel overall bed elevation any further than what is caused by the reservoir lowering and would therefore have an insignificant geomorphic effect.

Table 7. Potential future scenarios and effects upstream of Elephant Butte Reservoir

| Water and Sediment Discharge | Reservoir Pool | Expected Maintenance and Maint. Effects | Net Geomorphic Effects |
|---|---|---|---|
| Similar to recent past (2007–2012) | Relatively stable: between about RM 37 (~4355 ft) and RM 42 (~4385 ft) | Standard maintenance actions causing some reduction in aggradation rate | Current channel conditions are maintained; some areas aggrade and some areas are stable |
| Similar to 2005–2010, or increased peak flows, annual flow volumes, and sediment load | Rising above RM 46 (~4395 ft); continues to rise or stabilizes above RM 46 | Increased maintenance actions causing some reduction in aggradation rate and possibly reducing likelihood of channel avulsion | Slope decrease, significant aggradation, increased overbanking, increased likelihood of sediment plugs and avulsions |
| Similar to 1998–2004, 2010–2012, or high flow event after period of reservoir lowering | Receding below about RM 36 (~4345) for multiple years | Minimal maintenance (removal of in-channel vegetation to prevent channel narrowing; possible localized removal of sediment and berm repair) causing negligible effects | Slope increase, possible initiation of new degradation wave depending on rate/magnitude/duration of reservoir recession |

*Indirect effects on vegetation and flycatcher habitat*

Beneficial effects to the flycatcher would occur, as a result of how Delta Channel maintenance activities are implemented. Naturally occurring breaches are often allowed to remain open for a period of several months during the spring and summer, providing overbanking flow to the adjacent floodplain. Such breaches are typically not viewed as emergencies and usually not repaired immediately for a variety of reasons, such as flows may be too high to safely work in the river, spawning is occurring, and to avoid disturbance to nesting migratory birds. The flows from the breaches return to the main Delta Channel at a downstream location. Also, breaks in the berms may be constructed or naturally occurring inflow breaches allowed to remain for the purpose of allowing natural drainage into the Delta Channel and to prevent water from accumulating behind the berms, thus compromising their stability. Additionally, these openings allow water from the river to inundate areas behind the levee during the snowmelt runoff. These openings will be maintained as necessary within the limits of the existing channel footprint. Overbanking at both constructed and natural breaches would likely increase the development of flycatcher habitat as well as improve vegetative health and territory establishment. Furthermore, in the past, maintenance of the wing wall included periodic removal of sediment; however, maintenance is no longer planned for this feature in order to preserve the flycatcher habitat that has developed in this location.

Sediment plugs can have both positive and negative effects and would be removed to improve water delivery and prevent local degradation that would negatively affect downstream vegetation. However, prior to removal, the sediment plugs increase overbank flows in the local area, benefitting the vegetation. Maintenance actions for avulsions will consider habitat impact as well as water delivery and are not expected to have an adverse effect to critical habitat or occupied critical habitat. If maintenance action for an avulsion should require an impact to either critical habitat or occupied suitable habitat, Reclamation will coordinate with the Service to minimize the effect prior to the maintenance action.

Under the rising pool and stable pool scenarios discussed previously, the proposed maintenance actions in the channel will result in a relatively stable or somewhat aggrading bed elevation, as has mostly occurred since 2005 (Figure 16) during recurring maintenance, which is the same as the currently proposed actions. If water discharge increases, the combination could have a positive effect on groundwater levels and a beneficial effect to flycatcher habitat, including critical habitat. Thus, there will be no negative impact to vegetation in the Delta Channel or in upstream reaches and no adverse effect to flycatcher habitat, including critical habitat. If drought continues, vegetation could suffer, but that will not be an effect of channel maintenance activities.

Under the lowering reservoir pool scenario, bed degradation could occur in the Delta Channel due to the change in base level and then progress upstream. No new anthropogenic channel construction would occur and the minimal maintenance required in this scenario would maintain the naturally occurring bed elevation, consistent with the adjustments in response to the reservoir pool lowering. Any slope changes and bed degradation would be a result of the drop in the reservoir pool (rate, magnitude, and duration), either amplified by water discharge and sediment supply as seen in the large spring runoff events of 1949 and 2005, or reduced by those factors as seen in the comparison of the degradation of the 1949–1972 period to the 2005–2011 period. Thus, although the degradation would likely have an adverse effect to groundwater levels and flycatcher habitat, that effect is not due to the proposed action. To restate, using data from previous years, no correlation can be made between recurring maintenance actions and geomorphic effects and consequent effects to flycatcher habitat; whereas, there are clearly significant geomorphic effects that are caused by upstream water discharge, sediment load, and downstream reservoir pool elevation.

As in past years, Reclamation will continue to monitor the channel morphology in the Delta Channel and upstream of the power lines (approx. RM 62) to improve understanding of the river and develop appropriate management alternatives. Reclamation will also monitor flycatcher populations in this area.

Based on the preceding discussion, Reclamation has determined the proposed action is not likely to have adverse effects to designated critical habitat for the flycatcher and will not alter the function and intended conservation role of flycatcher critical habitat.

## 6.0 Cumulative Effects

Cumulative effects include the effects of future state, tribal, local or private actions that are reasonably certain to occur in the action area.

The Delta Channel is located in its entirety within the reservoir pool. The operating reservoir pool is non-discretionary and at the mercy of the drought conditions, the use of water by continued human population growth and water based industry along the Rio Grande, deliveries of irrigation water to the south, and compact deliveries and restrictions. The land use surrounding the area of the Delta Channel is also under the management of the Bureau of Land Management under their grazing allotment program. Recreational activities occur on reservoir land and water. North of the power lines (approx. RM 62), all the way to Cochiti reservoir there are many local, state, and private entities and landowners, and Pueblos that are participating with the federal agencies in the Middle Rio Grande Endangered Species Collaborative Program (Collaborative Program). As the Collaborative Program transitions to the Recovery Implementation Program (RIP), it will likely continue to fund habitat restoration projects and conduct research that will benefit minnows and flycatchers. Outside of the Collaborative Program and RIP, there are state, city, other groups, and Pueblos that are improving riparian and riverine conditions along the MRG.

Activities that affect water quality along the MRG consist of municipal wastewater discharges, urban runoff, agricultural runoff, riparian clearing, chemical use for vegetation control and crops, recreation along and in the riparian zone, which can be compounded by urban growth, stocking of exotic and predators fish, industrial growth along the river, riparian clearing without a revegetation plan, that could affect both minnows and flycatchers and their habitat.

## 7.0 Determination of Effects of the Proposed Action

### 7.1 Rio Grande Silvery Minnow

This effects determination considers population status of the minnow, the occurrence of minnows below the power lines (approx. RM 62) in the reservoir reach, and the possibility of minnows occurring in the vicinity of the excavators, airboat, and fuel transporters. The likelihood of minnows being present at project areas has increased due to the incidental point bars in the upper channel. The maintenance techniques in the proposed action are designed to minimize contact with any fish and minimize potential for harm or harassment. After twelve years of channel work, normal operation of the equipment minimizes impacts to fish. Minnows present near the work area would be able to freely move to avoid contact with the equipment and are expected to do so similar to natural predator avoidance from birds, for example. Use of airboats and heavy equipment may disturb minnows in the immediate area of operation. These effects are spatially localized but not discountable. A diesel fuel spill would not have measurable effects on minnows, but should be avoided and contained for water quality issues.

The effects determination encompasses the presence of minnows in the vicinity of excavation equipment. Harm to minnows may be unavoidable during Delta Channel maintenance, and Reclamation requests Incidental Take for the proposed action. Because of minnows in the existing Delta Channel, and the proposed maintenance activity occurring within the Delta Channel, this proposed action may affect, and is likely to adversely affect the minnow. The Delta Channel maintenance activities would occur in an area that has no designated critical habitat and channel maintenance will not cause bed degradation that affects critical habitat; therefore, Reclamation has determined that the proposed action will have no effect on minnow critical habitat.

### 7.2 Southwestern Willow Flycatcher

This effects determination takes into account the current flycatcher population within the reservoir pool and their suitable (occupied or unoccupied) habitat. The existing flycatchers at the reservoir will not be affected by the proposed action because vegetation adjacent to the Delta Channel will not be affected. Delta Channel maintenance will not occur between April 15 and August15, except for emergencies that will be coordinated with the Service prior to any activity occurring. Also, the water that flows to the west side suitable/occupied habitat in the Upper Reach comes from the LFCC.

Degradation occurring in the Delta Channel or in upstream reaches as a result of the proposed Delta Channel maintenance is not expected because the proposed action is maintenance of the existing Delta Channel only. If the reservoir level drops and remains low, that may institute another round of degradation. However, that degradation will be a direct result of the reservoir pool elevation change (rate, magnitude, and duration) whereas the proposed action, in this scenario, will be minimal maintenance that will not further lower the bed elevation below the elevation that develops as a response to the reservoir level

The possibility does exist that some minimal disturbance from noise may occur during the flycatcher breeding season from road maintenance activities that will occur year round, including during the flycatcher breeding season. This possible disturbance is not anticipated to be severe enough nor of lengthy duration to where territory establishment and/or reproductive success would be negatively affected, as demonstrated by flycatchers nesting adjacent to roads in the past. Therefore, noise would have an insignificant effect. Also, airboat transport is not expected to occur between April 15 and August 15. If airboat transport is needed between April 15 and August 15, Reclamation will coordinate with the Service prior to the activity.

Beneficial effects to the flycatcher would occur, as a result of how Delta Channel maintenance activities are implemented. Overbanking at both constructed and natural breaches would likely increase the development of flycatcher habitat as well as improve vegetative health and territory establishment. Maintenance of the wing wall will no longer occur in order to preserve the flycatcher habitat that has developed in this location. Sediment plugs within the Delta Channel need to be removed to improve water delivery; however, prior to removal, sediment plugs increase overbank flows in the local area, benefitting the vegetation.

Therefore, in considering the above effects, our determination is that the proposed action may affect, but is not likely to adversely affect the flycatcher, and will have no effect on designated critical habitat for the flycatcher.

## 8.0 Conservation Measures

Reclamation proposes the following conservation measures to minimize or avoid adverse effects of implementing Delta Channel Maintenance.

- Reclamation will obtain all applicable permits prior to implementation of the project, to include Clean Water Act Section 404 and 401 permits as needed. Reclamation will comply with conditions of these permits.

- Reclamation will seek to avoid impacts to birds protected by the Migratory Bird Treaty Act (16 U.S.C. 703) by conducting Delta Channel maintenance activities outside of the normal breeding and nesting season (April 15 to Aug 15). Road maintenance such as grading and washout repair may be performed throughout the year, but mowing will not occur between April 15 and August 15. If emergency channel maintenance is needed between April 15 and August 15, Reclamation will coordinate with the Service prior to making repairs.

- Minimize impact of hydrocarbons: To minimize potential for spills into or contamination of aquatic habitat:
  - Hydraulic lines will be checked each morning for leaks and periodically throughout each work day.
  - All equipment will undergo high-pressure spray cleaning and inspection prior to initial operation in the project area.
  - Equipment will be parked on pre-determined locations on high ground away from the river overnight, on weekends, and holidays.
  - Spill protection kits will be onsite, and operators will be trained in the correct deployment of the kits.
  - Fuel, oil, hydraulic fluid, lubricants, and other petrochemicals will be stored outside the 100-year floodplain.

- Spill Protection BMPs. The excavators and fuel transporters have fuel spill kits, which include booms designed to contain spilled fuel and absorbent pads. Operators are trained and knowledgeable on how to deal with spills should they occur. Regular update sessions on use of the kit and on prevention measures will take place with the equipment operators.

- Steel-mesh guards will cover all external hydraulic lines.

- Reclamation will visually monitor for water quality at the areas below areas of river work before and during the work day.

- Whenever possible, airboats will be operated through the center of the channel to minimize disturbance to minnows.

- To allow fish time to leave the area before maintenance activities begin, the first piece of equipment (excavator) should initially enter the water slowly at the start of each work sequence in the river. If the excavator is already in place at the start of each work day, then the bucket of the excavator should be lowered slowly into the water at the start of each work day.

- Reclamation will excavate an area as few times as possible in the annual maintenance effort to minimize disturbance of sediments. When excavating within the wetted channel, the following practices will be used to minimize disturbance of sediments: minimize movement of excavator tracks and minimize excavator bucket contact with riverbed when not excavating.

- If work is necessary between April 15 and August 15, avoidance of suitable/occupied flycatcher habitat will occur during the maintenance activities as much as possible, utilizing the annual survey results in conjunction with habitat suitability. Reclamation will use current flycatcher monitoring data to avoid work within 0.25 miles of an active nest as much as possible. Coordination and consultation with the Service will occur prior to such work activities.

- Reservoir recession may expose cottonwood and salt cedar snags that will be removed during maintenance of the naturally formed channel below RM 38 or excavation of secondary channels to connect isolated pools to the Delta Channel. Prior to removal of such snags, an evaluation will be conducted by a biologist to determine their significance for raptor use. The channel alignment will be adjusted to avoid removal of significant snags when possible.

- If water is needed for dust abatement or to facilitate grading of roads, water will be pumped from the river. Pump intake pipes will use a 0.25 in (0.64 cm) mesh screen at the opening to the intake hose to minimize entrainment of aquatic organisms. From May 1 through July 1, Reclamation will avoid pumping directly from the channel to minimize the number of eggs and larvae that may be entrained. Sumps adjacent to the channel will be used whenever feasible.

- Reclamation will maintain a floodplain and low flow channel (thalweg) in the upper seven miles of the Delta Channel. To the extent feasible, maintenance actions will allow for the naturally created point bars and small embayments within the low flow channel to remain in place.

- Reclamation will continue to closely monitor channel bed elevation in the Delta Channel and upstream reaches (to RM 69), with data collection performed at least annually.

- Reclamation will continue to conduct annual flycatcher surveys following established protocol and will conduct fish community surveys annually.

- Reclamation will report annually to the Service the results of species surveys and work accomplished on the Delta Channel maintenance project.

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## Appendix A: Additional Information on the Area of Disturbance

| Table A.1: Estimated In-Water Area of Disturbance per Year<br>Maintenance of Existing Channel (20.8 miles) | | | | |
|---|---|---|---|---|
| | Amphibious Tracked Machines | | Airboats | |
| | Maintenance Work | Movement in Channel | Maintenance Support | Inspection Trips |
| | (acres) | (acres) | (miles) | (miles) |
| **Crew #1** | | | | |
| (a) In-channel maintenance work: 25% of channel area in northern 9 miles of channel | 63 | | | |
| (b) Movement of excavators (30’ width): 2 excavators @ 2.5 x 9 miles; 1 excavator @ 2.5 x 2 miles | | 182 | | |
| (c) Personnel Transport & Fueling | | | 648 | 144 |
| | | | | |
| | | | | |
| **Crew #2** | | | | |
| (a) In-channel maintenance work: 25% of channel area in southern 12.4 miles of channel | 50 | | | |
| (b) Movement of excavators (30’ wide path): 2 excavators @ 2.5 x 11.8 miles; 1 excavator @ 2.5 x 2 miles | | 233 | | |
| (c) Fueling: Amphibious Transporter (22’ wide path): 198 miles per year | | 529 | | |
| (d) Personnel Transport | | | 595 | 198 |
| | | | | |
| **Totals (average per year)** | **113 acres** | **944 acres** | **1,243 miles** | **342 miles** |
| | | | | |

| **Table A.2: Estimated In-Water Area of Disturbance per Year<br>Extra Crew as Needed (9 miles)** | | | | |
|---|---|---|---|---|
| | Amphibious Tracked Machines | | Airboats | |
| | Maintenance Work | Movement in Channel | Maintenance Support | Inspection Trips |
| | (acres) | (acres) | (miles) | (miles) |
| | | | | |
| **Crew #3** | | | | |
| (a) In-channel maintenance work: 100% of channel area | 82 | | | |
| (b) Movement of excavators (30' wide path): 3 excavators @ 2.5 x 9 miles | | 245 | | |
| (c) Fueling, Amphibious Transporter (22' wide path): 144 miles per year | | 384 | | |
| (d) Personnel Transport | | | 432 | 144 |
| | | | | |
| **Totals** | **82 acres** | **629 acres** | **432 miles** | **144 miles** |
| | (0.33 $km^2$) | (2.55 $km^2$) | | |

**Area Computation Details:**

<u>Crew #1 (Reclamation):</u> This crew will cover the northern 9 miles of channel. It was assumed that two excavators will work 4 months per year and a third excavator will work 1 month per year. The first two excavators will cover the entire 9 miles and the third excavator will be brought in only where extensive work is needed, for an assumed length of 2 miles. It was assumed that two different launching areas will be used, to reduce distance from equipment work areas. This pertains to movement of equipment to work areas, transport of operators to excavators each day, and fueling of excavators.

The largest excavator has pontoons that are each 6 feet in width, with a distance from outside to outside of pontoons of 23.5 feet. Areas in table are computed based on a disturbance width of 30 feet for each excavator. For disturbance area due to excavators moving from work sites, it was assumed excavators will cover 2.5 times the distance of channel being maintained. This accounts for moving excavators to each worksite from the launching area, as well as other incidental movement required.

Fueling of excavators and transport of operators, from launching areas to equipment, will typically be performed by airboat. It was assumed that fueling will be performed every other day and transport of operators every day.

Crew #2 (Contractor): This crew will cover the southern 11.8 miles of channel. It was assumed that two excavators will work 4 months per year and a third excavator will work 1 month per year. The first two excavators will cover the entire 11.8 miles and the third excavator will be brought in only where extensive work was needed, for an assumed length of 2 miles. It was assumed that two different launching areas will be used, to reduce distance from equipment work areas. This pertains to movement of equipment to work areas, transport of operators to excavators each day, and fueling of excavators.

The largest excavator has pontoons that are each 6 feet in width, with a distance from outside to outside of pontoons of 23.5 feet. Areas in table are computed based on a disturbance width of 30 feet for each excavator. For disturbance area due to excavators moving from work sites, it was assumed excavators will cover 2.5 times the distance of channel being maintained. This accounts for moving excavators to each worksite from the launching area, as well as other incidental movement required.

Fueling of excavators will typically be performed by a tracked amphibious transporter, with pontoon widths of 4 feet and a total width, from outside of pontoons, of 16 feet. Areas in table are computed based on a disturbance width of 22 feet for the fuel transporter. It was assumed that the transporter will fuel excavators every 3 working days.

Transport of excavator operators, from launching areas to equipment work areas, will occur every work day, by airboat.

Crew #3 (Contractor): It was assumed that 3 excavators will work 4 months per year. It was assumed that two different launching areas will be used, to reduce distance from equipment work areas. This pertains to movement of equipment to work areas, transport of operators to excavators each day, and fueling of excavators.

The largest excavator has pontoons that are each 6 feet in width, with a distance from outside to outside of pontoons of 23.5 feet. Areas in table are computed based on a disturbance width of 30 feet for each excavator. For disturbance area due to excavators moving from work sites, it was assumed excavators will cover 2.5 times the distance of channel being constructed. This accounts for moving excavators to each worksite from the launching area, as well as other incidental movement required.

Fueling of excavators will typically be performed by a tracked amphibious transporter, with pontoon widths of 4 feet and a total width, from outside of pontoons, of 16 feet. Areas in table are computed based on a disturbance width of 22 feet for the fuel transporter. It was assumed that the transporter will fuel excavators every 3 working days.

Transport of excavator operators, from launching areas to equipment work areas, will occur every work day, by airboat.

Appendix B

Geomorphic Assessment of the Rio Grande Upstream of Elephant Butte Reservoir

RECLAMATION
*Managing Water in the West*

# Geomorphic Assessment of the Rio Grande Upstream of Elephant Butte Reservoir

U.S. Department of the Interior
Bureau of Reclamation
Albuquerque Area Office
Albuquerque, New Mexico

April 2013

## Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Geomorphic Assessment of the Rio Grande Upstream of Elephant Butte Reservoir

*prepared by*

**Technical Services Division**
**River Analysis Group**

**Nathan Holste, M.S., P.E.**
**Hydraulic Engineer**

Cover Photograph: Elephant Butte Reservoir Delta, looking downstream from near RM 39
(photo taken April 23, 2013)

**U.S. Department of the Interior**
**Bureau of Reclamation**
**Albuquerque Area Office**
**Albuquerque, New Mexico**

**April 2013**

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# Executive Summary

The Rio Grande has episodically become disconnected from the Elephant Butte Reservoir pool after periods of drastic reservoir recession, most recently from 1998 to 2004. Relatively high sediment loads coupled with low water discharge and a flat valley slope caused the river channel to lose form within the reservoir delta. Water and sediment could not be effectively delivered to the reservoir pool due to the lack of an established channel, which led to high evapotranspiration water loss within the delta area. Therefore, a channel was constructed between 2000 and 2004 to maintain a connection from the river to the reservoir pool. Maintenance of this channel has been required every year since initial construction because of the prevailing aggradational trend that results in loss of channel capacity and breaches of the spoil berms. A thorough assessment was performed to examine potential effects from initial channel construction and recurring maintenance activities. Channel conditions and dynamics were assessed within a geomorphic framework that considers the primary physical processes that govern alluvial river morphology. A reach length of 60 miles was evaluated from Elephant Butte Dam to the Highway 380 Bridge, with emphasis on the subreaches closest to the reservoir pool.

This reach of the Rio Grande, upstream of Elephant Butte Reservoir, is highly dynamic and behaves with a great deal of complexity. The geomorphic drivers of water discharge and sediment load, coupled with the primary control of downstream base level (reservoir pool) elevation, have varied significantly from the early 1900's to the present. After a period of initial reservoir filling that followed dam construction in 1915, the reservoir water surface has fluctuated over a vertical range of 150 feet (a shift in the horizontal water surface of around 32 river miles) corresponding to climatic wet and dry periods. Given that the Rio Grande's water and sediment inputs are varying while the downstream control is changing, it is clear that a complex series of responses should be expected. The river's planform, cross-sectional shape, slope, bed elevation, and other morphological characteristics are continuously changing in response to alterations in water discharge, sediment load, base level, and anthropogenic actions.

The relationship between upstream geomorphic drivers and the downstream control often results in a sediment imbalance upstream of the reservoir pool. An imbalance between sediment supply and sediment transport capacity is the prevailing condition within this reach of the Rio Grande, which causes frequent channel adjustments over space and time. Analysis demonstrates that the slope and bed elevation of the Rio Grande through this reach respond to a rising or falling reservoir pool. For example, a 100 foot decrease in reservoir pool elevation between November 1998 and September 2004 resulted in a wave of up to 12 feet of degradation (riverbed lowering) that migrated several miles upstream. Additionally, a 60 foot increase in pool elevation from September 2004 to February 2009 induced a wave of up to 10 feet of aggradation (riverbed rise) that also migrated upstream. Locations near the reservoir pool tend to adjust quickly, while channel response further upstream occurs later in time and at a lesser rate. Upstream water and sediment discharge may amplify or dampen effects from the downstream reservoir. Time-series bed elevation data at the San Marcial gauge about 5 miles upstream of the full reservoir pool show two periods of historical degradation, both following a similar decline in reservoir elevation: 1949–1972 and 2005–2011. The 1949–1972 degradation rate was only about one half to one third that of the recent rate, mostly due to the substantially higher sediment load during 1949–1972.

Although periods of degradation have been initiated when a high flow event occurs while the reservoir pool is low, aggradation is the most dominant characteristic of this reach over time. The riverbed elevation at San Marcial has increased by a cumulative total of about 18 feet since 1915, while areas further downstream near the historic average pool location (the Narrows) have aggraded 40–50 feet. In addition to the aggradational trend, historic reservoir longitudinal profiles show the development of grade breaks (knickpoints) corresponding to specific pool water surface locations. These knickpoints affect channel response when areas formerly inundated by the reservoir pool become the river thalweg as the reservoir recedes. A knickpoint is evident in the 1999 thalweg profile near River Mile (RM) 56, which was just downstream of the pool location during the previous 15 years. When the reservoir pool dropped below this knickpoint, the local slope became three times steeper than the river slope upstream of RM 56.

The previous discussion of geomorphic concepts that determine the Rio Grande's morphology upstream of Elephant Butte Reservoir provides necessary context for river maintenance actions within this reach. Adaptive management is likely the most appropriate strategy, given that the design life of any maintenance approach will be greatly reduced because of fluctuations in the upstream drivers (water and sediment discharge) and downstream control (reservoir pool elevation) (Reclamation, 2012). The Temporary Channel has been adaptively maintained in response to river channel adjustments to the drivers and control. Anthropogenic Temporary Channel actions and effects can be divided into two distinct periods: initial channel construction (2000–2004) and recurring channel maintenance (2005–2012).

Initial channel construction restored the Rio Grande's connection to the receding reservoir pool by excavating a flowpath about 3 feet deep through the delta. Sinuosity was incorporated into the design so that the channel length was within 1% of the 1972 length. A close examination of the 1999, 2002, and 2004 thalweg profiles reveals that it is probable that initial excavation was responsible for a slope increase of about 8–12% within the upper reservoir delta (from about RM 58 to RM 46). The riverbed elevation upstream of the Temporary Channel was very stable during initial construction (2000–2004), although the preexisting knickpoint near RM 56 moved about three miles upstream between 1999 and 2004. Significant degradation took place during the 2005 spring runoff for several miles upstream of the Temporary Channel as the headcut migration was accelerated. This degradation occurred during a high magnitude, long duration spring runoff event combined with a sediment plug that blocked sediment supply upstream of San Marcial, which was subsequent to a rapidly and substantially lowered reservoir pool. Historical data and an understanding of fundamental geomorphic concepts show the relative effect of the Temporary Channel, compared to other reach processes, on upstream riverbed elevation. Levish (2012) concludes that Temporary Channel construction may have initiated and temporarily increased the rate of channel lowering, but this elevation change would have eventually occurred in response to the lower reservoir pool elevation.

Riverbed adjustment, such as the 2005 degradation, is an important environmental concern because of the potential to affect aquatic and riparian habitat and species. One specific consideration is the impact on vegetation and the relationship between groundwater elevation and riverbed elevation. Groundwater elevation is complex, highly variable, and appears to be primarily a function of river discharge (or river water surface elevation) and nearby groundwater controls (i.e., LFCC and ponded areas). River thalweg elevation trends over time and space can influence, but may not directly correspond to, trends in groundwater elevation.

Recurring channel maintenance differs from initial construction because there was an existing river channel being adaptively maintained rather than a new channel that was excavated. The goal of recurring maintenance actions (2005–2012) was to maintain sufficient channel conveyance by removing accumulated sediment deposits and repairing spoil berms. During recurring maintenance, the average Temporary Channel thalweg elevation responded directly to the reservoir pool: aggradation occurred between 2004 and 2010 as the pool elevation increased and degradation occurred between 2010 and 2012 while the pool receded. The Temporary Channel planform did not change during recurring maintenance and cross section plots illustrate the variable depth and morphology that is typical of alluvial rivers. In a dynamic and complex system, geomorphic effects that may have been caused by maintenance actions are not discernable compared to the significant effects from the geomorphic drivers and the primary control of base level elevation.

# Geomorphology and Channel Adjustment Concepts and Analyses

Geomorphology is the study of landforms and the processes which control them, while fluvial geomorphology is specific to landforms that are shaped by the action of flowing water. The fluvial system is formed by the interrelationship between several factors: climate and geology, independent basin controls (basin physiography, vegetation, soils, land use), independent channel controls (valley slope, stream discharge, sediment load input, bank material composition), and dependent channel and flow geometry parameters (channel slope, width, depth, roughness) (Knighton, 1998). Anthropogenic influences and controls are also extremely important and must be considered. The interaction between river channel boundaries and the flow of water and sediment essentially determines the channel morphology (Schumm, 1977; Leopold et al., 1964). Ultimately, channel form is not the product of a single formative discharge, but of a range of discharges and of the temporal sequence of flows (Wohl, 2007; Knighton, 1998).

*Temporal and spatial scale*

Knighton's (1998) discussion of geomorphic variables implies a consideration of multiple temporal and spatial scales. The complexity and dynamic nature of the river system make it important to define an appropriate timescale prior to beginning a geomorphic analysis. The timescale of interest changes the relationships between independent and dependent variables (cause and effect). Schumm (1977), Knighton (1998), and Watson et al. (2007) discuss several different timescale definitions and the implications when analyzing fluvial systems. Geologic time is typically measured in thousands or millions of years, while engineers usually consider a time scale between 10 and 100 years. For example, valley dimensions within geologic time are a function of paleoclimate and tectonic activity, yet an engineer may assume that valley characteristics are an independent constant that influences river behavior. Biologists are often concerned with a shorter time scale depending on the species of interest. Some species may be sensitive to fluctuations (anthropogenic or natural) on the order of one to three years or less, which may otherwise be insignificant within the context of a long-term trend. Data exists for many river system parameters on the Middle Rio Grande over the last 100 years, while some qualitative accounts date back 500 years. This historical information provides insight regarding the natural tendencies of the river and the system's response to changes in conditions over space and time.

Spatial scale should also be considered when conducting a geomorphic analysis. Channel adjustment at specific locations may or may not be indicative of a reach-wide trend. It is important and often difficult to distinguish local instability from system instability. A dynamically stable system will still exhibit local adjustments such as channel lengthening through bank erosion in growing meander bends that is offset by cutoffs at other bends. Local instability exists where there are adjustments at individual locations, while reach-averaged parameters such as hydraulic geometry and slope remain steady. Conversely, system instability propagates throughout a stream network as a result of water and sediment discontinuity, changes to downstream base level, and land use changes. System instability is visible through reach-wide aggradation, degradation, or planform metamorphosis. Most importantly in a dynamically changing system, short-term or local changes are not necessarily indicative of long-term or system-wide behavior (Watson et al., 2007).

*Dynamic equilibrium and stability*

A stable alluvial channel means that the cross-sectional form and longitudinal slope of a stream have adjusted to convey the available water and sediment discharges with no net change to hydraulic geometry or planform. Stability requires a consideration of time scale because temporary morphological adjustments to extreme events can still occur in a stable (graded) stream (Watson et al., 2007). A short-term adjustment will return to the average condition over time in a stable system. Conversely, a river that appears stable in the short term may actually be unstable and moving toward a new condition over the long term. Dynamic equilibrium is often a more appropriate descriptor than stable, because it accounts for the naturally frequent short-term changes within a river system. Schumm (1977) clarifies that a river in dynamic equilibrium is not static or fixed, but oscillates around an average condition. Dynamic equilibrium also requires a general balance between sediment transport capacity and supply. Sediment balance will be discussed in more detail later, and is necessary for dynamic equilibrium so that sediment transported into a reach is also transported out, without net aggradation or degradation (Watson et al., 2007).

A stable system contains negative feedback mechanisms that dampen external factors and allow moderate events to restore the graded condition (recovery time). An example of negative feedback is a well-connected floodplain that dissipates increasing energy during large overbanking flows. For an unstable system, positive feedback amplifies any displacement in the same direction, thereby resulting in a new position (Knighton, 1998). A channel avulsion that results in a new long-term river location is indicative of an unstable system.

Dynamic equilibrium implies that the recovery time is shorter than the return period for the extreme event (recurrence interval). Formative flows in a dynamically stable stream work to restore morphology to the graded condition after disturbance, rather than perpetuating the changes of the extreme event. Sufficient time and space are also required for the stream to make necessary adjustments. It should be noted that few natural rivers are truly stable due to changes in water discharge and sediment load, but the concept indicates stream evolution trends and how the river will adjust to intervention. Rivers in disequilibrium tend to be close to a geomorphic threshold in which the system is sensitive to destabilization and a minor change may result in a dramatic response (Watson et al., 2007). For example, a small amount of degradation in an incised channel may cause the riverbed to lower below the vegetative root mass, thereby crossing a geomorphic threshold and causing widespread bank collapse.

*The system is dynamic*

The Rio Grande, like all alluvial rivers, is dynamic and continuously changes planform, cross-sectional shape, slope, and other morphological characteristics in response to alterations in water discharge, sediment load, and boundary conditions (Watson et al., 2007). The fine sand bed material present in the Rio Grande upstream of Elephant Butte Reservoir makes the channel quite susceptible to change from perturbations (e.g., flow events, reservoir levels, anthropogenic actions). This concept is helpful to consider when analyzing bathymetric, topographic, and sediment data collected from the river. Data collection efforts are snapshots in time that represent river conditions at a specific moment. Data is often interpreted to represent periods of a year or longer, but the dataset may only be truly accurate for the day it was collected, depending on antecedent or subsequent flow events. Conclusions regarding riverine processes and trends should be made cautiously, and only after consideration of numerous datasets.

Figure 1 and Figure 2 show two cross sections that were each surveyed five months apart (July and December, 2009) with no spring runoff events between the survey dates. The cross sections are located within Bosque del Apache National Wildlife Refuge (BDANWR) about 36 miles downstream of the San Acacia Gauge and 12 miles upstream of the San Marcial Gauge. SO-1566 is about 1.7 river miles downstream of SO-1550. The maximum mean daily flow that occurred between the two surveys was approximately 900 cfs (894 cfs at San Acacia and 912 cfs at San Marcial). The corresponding maximum instantaneous flow was 2,280 cfs as measured at the San Marcial Floodway Gauge (#08358400). At SO-1550, the thalweg elevation increased by 1.9 feet between July and December. At SO-1566, the thalweg elevation decreased by 1.8 feet between July and December. The modeled 500 cfs water surface elevation and the calculated mean bed elevation were within 0.2 feet for the two survey dates at both cross sections. The cross section plots illustrate the dynamic nature of the Rio Grande and that the mean bed elevation often controls the water surface and channel capacity more than the thalweg elevation. Thalweg elevation changes of less than 2–3 feet should be examined within the context of mean bed elevation, nearby cross section data, and reach longitudinal profiles to determine if a true shift in bed elevation has occurred.

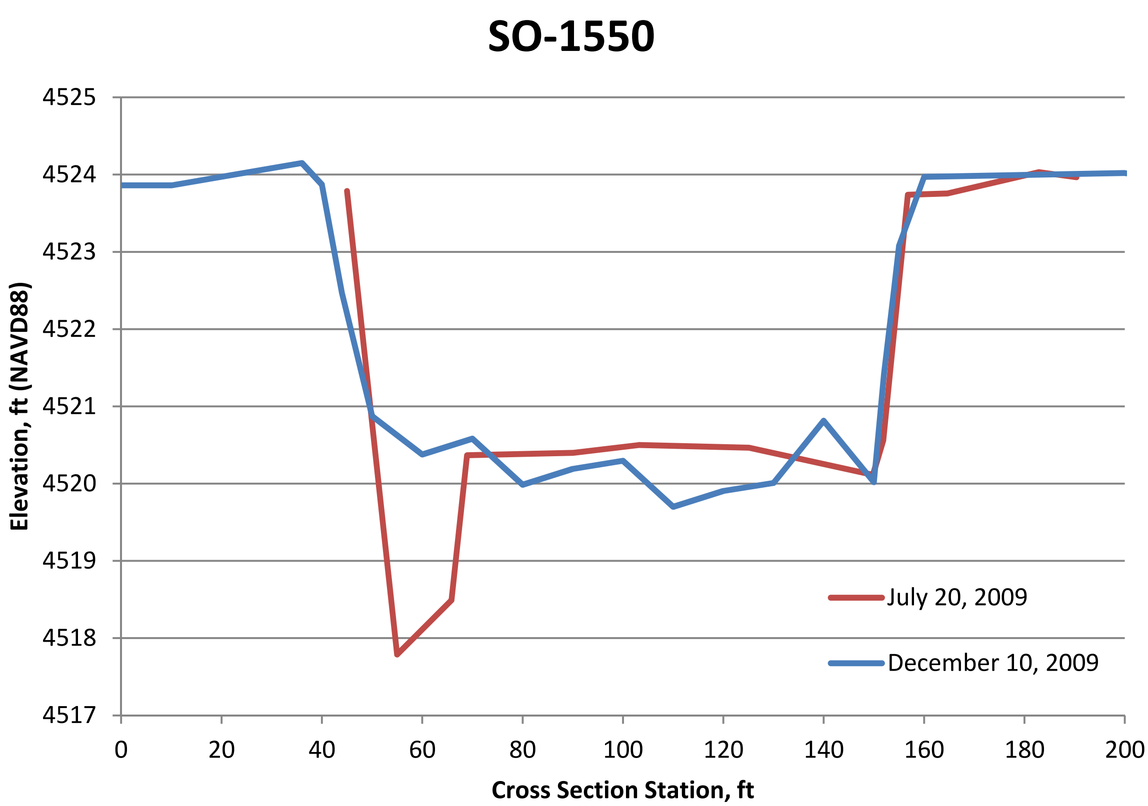


**Figure 1. Short-term cross-sectional changes at SO-1550.**

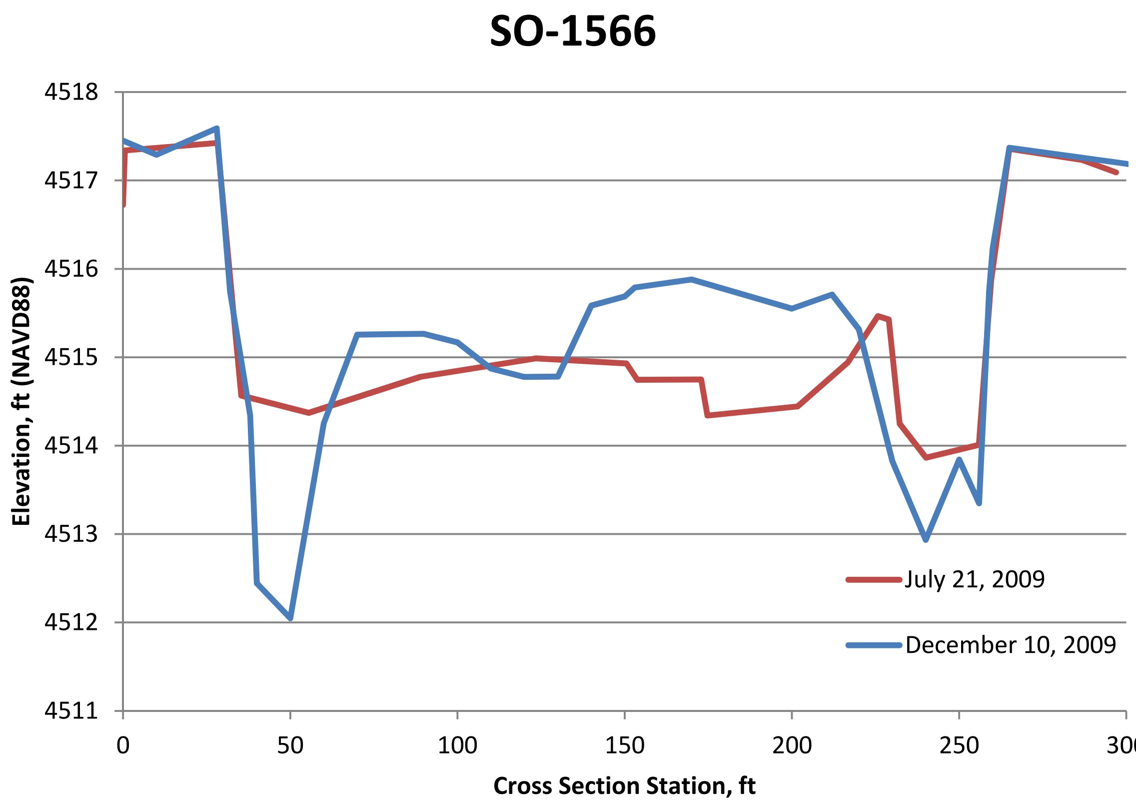


**Figure 2. Short-term cross-sectional changes at SO-1566.**

*The system behaves with complexity*

Schumm (1977) introduced the idea of complex geomorphic response, which is further discussed by Watson et al. (2007). The fluvial system responds through different processes at different locations and times to changes in hydrology, sediment, base level, or anthropogenic intervention. For example, base level lowering in a drainage basin can cause erosion and adjustment in the main channel near the mouth of the basin. The steepened slope may increase the sediment transport capacity beyond what is supplied from upstream, thereby resulting in headcutting that migrates upstream as the stream adjusts through degradation. Figure 3 illustrates this process of a lowered base level (reservoir level) resulting in a steeper slope and causing upstream riverbed degradation. A lowered main channel bed elevation is also a lowered base level for any tributaries, and a similar process is likely to occur throughout the upper reaches of the basin. As erosion progresses upstream, an increased sediment supply will be provided to the downstream main channel that has already adjusted to the lowered base level. However, the downstream reach is not yet adjusted to the increased sediment supply and a new phase of responses will begin. Aggradation may result from the reduced slope and increased sediment supply with multiple cycles of degradation/aggradation occurring over a period of time. The example shows a likely series of complex responses to a single perturbation (base level lowering) and also demonstrates the importance of temporal and spatial scale. Downstream reaches are closest to the reservoir and respond quickly to base level changes but more slowly to changes in upstream sediment supply. Upstream reaches are farthest from the reservoir and respond to base level changes at a later time. Given the complex responses to a single perturbation, it is evident that dynamic equilibrium is nearly impossible in a system with frequent variations to upstream and downstream conditions.

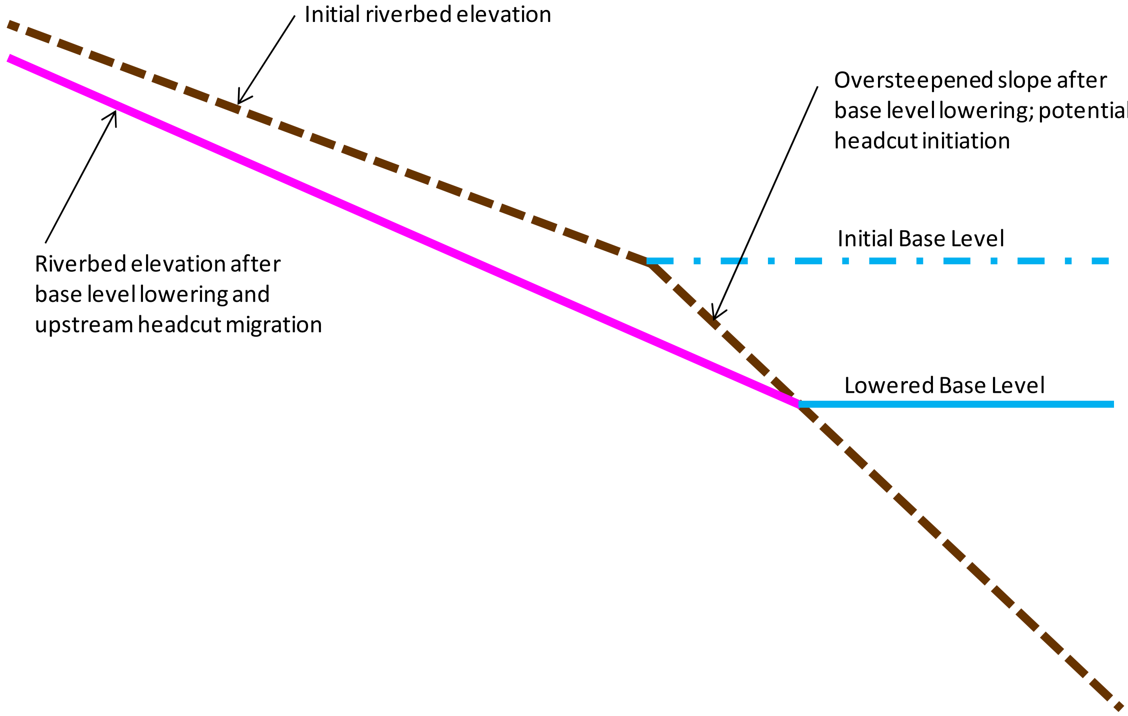


**Figure 3. Conceptual diagram of upstream headcutting caused by base level lowering**

Davis (1895) explains how the gradient of a stream is adjusted so that the capacity to do work (related to sediment transport capacity) is equal to the work that must be done (related to sediment supply). Both sediment transport capacity and supply will be discussed in the Sediment Balance section below. Davis's description of work is essentially the river's ability to effectively transport the available water and sediment. Water and sediment inputs fluctuate constantly, which drive frequent adjustments to the river's slope and cross-sectional form. The river morphology adjusts in an attempt to maintain dynamic equilibrium while balancing the capacity to do work with the work that must be done. Considering that the Rio Grande's water and sediment inputs are varying while other factors such as reservoir level are also changing, it is clear that a series of complex responses should be expected.

## Sediment Balance

Sediment balance implies a relative equality between the material made available to a stream from a watershed (sediment supply) and the capacity of a stream to convey the available material (sediment transport capacity). Sediment supply to a river is primarily a function of water discharge and the quantity and characteristics of available sediment. Sediment transport capacity is determined by the channel morphology and its interaction with flowing water. A thorough understanding of the relationship between sediment supply and transport capacity is essential so that the causes of channel instability may be treated rather than the symptoms (Schumm et al., 1984). The fundamental cause of most channel and floodplain adjustments is an imbalance between sediment supply and transport capacity (Lane, 1955; Schumm, 1977; Biedenharn et al., 2008).

Figure 4 shows that the rate of sediment transport in a river, or section of river, is governed by a limited sediment supply (supply limited) or a limited transport capacity (capacity limited) (Julien, 1998). The relative magnitude of these two variables determines the response of the river. Where a river system has excess transport capacity, typical adjustments include channel incision, bank erosion, and potential planform change from a braided sand bed channel to a single thread, mildly sinuous channel with a coarser bed. Additionally, a reduction in sediment supply generally results in a narrower, deeper channel with a flatter local slope and increased sinuosity. Where a river has excess sediment supply and limited transport capacity, channel aggradation will occur. Aggradation usually causes a wider, shallower channel with a steeper slope, decreased sinuosity, and reduced flow capacity (Reclamation, 2012). Reduced flow capacity under aggrading conditions assumes that there is a net loss in cross-sectional area as riverbed rise exceeds channel widening, which is typically the case on the Rio Grande. A greater amount of channel adjustment is expected for a severe imbalance between sediment supply and transport capacity, while a balance between these two conditions indicates that a river is near dynamic equilibrium.

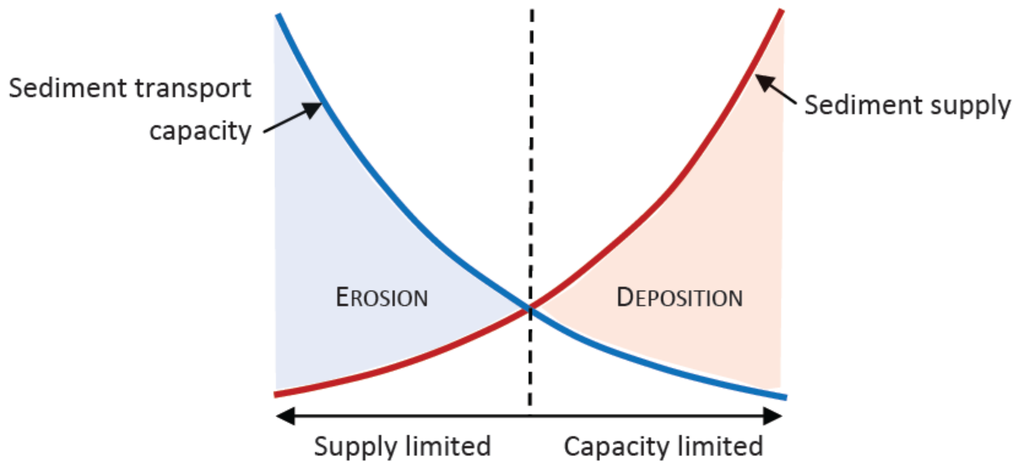


**Figure 4. Sediment transport capacity and supply curves (after Julien, 1998).**

Lane (1955) proposed a qualitative relationship for adjustment in alluvial streams as a function of sediment supply and transport capacity. This relationship, known as Lane's balance ($Q_s d_{50} \sim QS$), states that the river's sediment load ($Q_s$) and median sediment size ($d_{50}$) are proportional to the river's water discharge (Q) and slope (S). Figure 5 illustrates Lane's balance and how changes to any of the four driving parameters will tend to affect the others so that a balance is achieved. Assuming that each variable is dependent, the expected responses are also described below, where a plus (+) indicates an increase and a minus (–) indicates a decrease. Water discharge is actually independent of the other three variables and sediment load may or may not be independent depending on the temporal and spatial scale. Regardless of a variable's independence or dependence, the plus or minus sign shows the direction of change that would restore balance to the system.

Increased water discharge: $Q^{+} \sim Q_s^{+} d_{50}^{+} S^{-}$

Decreased water discharge: $Q^{-} \sim Q_s^{-} d_{50}^{-} S^{+}$

Increased sediment load: $Q_s^{+} \sim Q^{+} S^{+} d_{50}^{-}$

Decreased sediment load: $Q_s^{-} \sim Q^{-} S^{-} d_{50}^{+}$

Increased slope: $S^{+} \sim Q_s^{+} d_{50}^{+} Q^{-}$

Decreased slope: $S^{-} \sim Q_s^{-} d_{50}^{-} Q^{+}$

Increased sediment size: $d_{50}^{+} \sim Q^{+} S^{+} Q_s^{-}$

Decreased sediment size: $d_{50}^{-} \sim Q^{-} S^{-} Q_s^{+}$

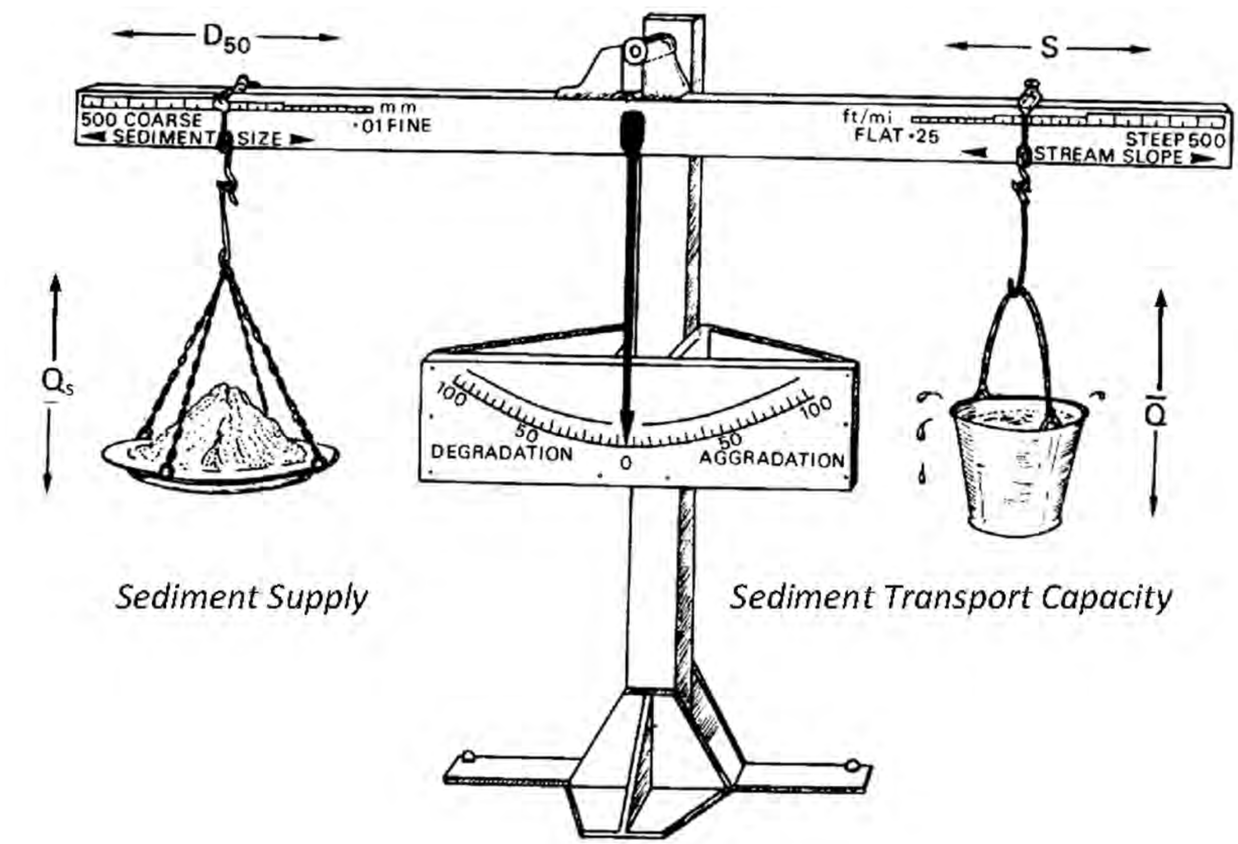


**Figure 5. Lane's Balance (after E.W. Lane, from W. Borland) from *Demonstration Erosion Control Design Manual* (Watson et al., 1999) with adaptations.**

## Drivers

Sediment balance, or imbalance, is affected by two types of factors: drivers of channel adjustment and controls on channel adjustment (Makar and AuBuchon, 2012). During a period of years, decades, or centuries, the primary drivers that determine alluvial channel morphology are the flow regime and sediment load (Schumm, 1977; Watson et al., 2007).

## Flow Magnitude, Frequency, and Duration

Water discharge determines the energy provided to the fluvial system over space and time. Flow magnitude and frequency are a measure of the size of specific flow events and how often a given flow event occurs. Duration is important because peak discharges may occur during prolonged snowmelt runoff events or short-lived monsoon events. Monsoon events supply a tremendous amount of sediment to the river system during arroyo flows, which can influence the channel morphology through the input of both cohesive and coarse material. The extended duration of spring runoff events allows for the downstream transport of a larger total volume of sediment and provides a greater opportunity for the flow to modify channel form. This sequencing, or relationship, between monsoon and spring runoff events contributes to the sediment balance complexity because much of the sediment is supplied to the river during monsoons and transported during spring runoff flows.

On the Middle Rio Grande, flood and sediment control dams have altered the recent hydrologic regime by reducing flood peaks. Natural climate cycles have also affected peak streamflow. During dry periods from 1943–1978 and 1996–present (data includes 2012, although current dry period may continue indefinitely) most of the recorded peak flows are substantially less than 5,000 cfs, and the annual flow volume is typically less than one million acre-feet. Wetter cycles from 1903–1942 and 1979–1995 resulted in peaks significantly greater than 5,000 cfs and annual flow volumes greater than one million acre-feet. The variable and irregular wet and dry periods are typical of southwestern rivers and continue to this day on the Middle Rio Grande.

Figure 6 illustrates the total annual valley flow volume, as calculated by combining values from the Rio Grande Floodway at San Marcial (USGS Gauge 08358500 and 08358400) and the Rio Grande Conveyance Channel at San Marcial (USGS Gauge 08358300). The two gauge locations are combined in order to maintain consistency across the period of record while accounting for operation of the Low Flow Conveyance Channel (LFCC) from 1952 to 1975 and 1983 to 1985. A graph of the annual peak flows would show similar trends, although the wet and dry periods are not as distinct. The annual flow volume incorporates both the magnitude and duration of flow events so it is a good indication of the energy provided to the river. Historically, most significant channel adjustments on the Middle Rio Grande have occurred during high magnitude, long duration runoff events. The river also adjusts to periods of low flows, but at a more gradual rate. The channel planform has narrowed and become more uniform as decreased peak flows result in the channel not being reworked to the degree it was historically. Increased duration of low flows from anthropogenic regulation can also aid encroachment of vegetation into the active channel, which narrows it and increases the geotechnical strength of channel banks (Makar and AuBuchon, 2012). It is evident that flows upstream of Elephant Butte are quite dynamic; the variability exists within wet/dry cycles and across the entire period of record.

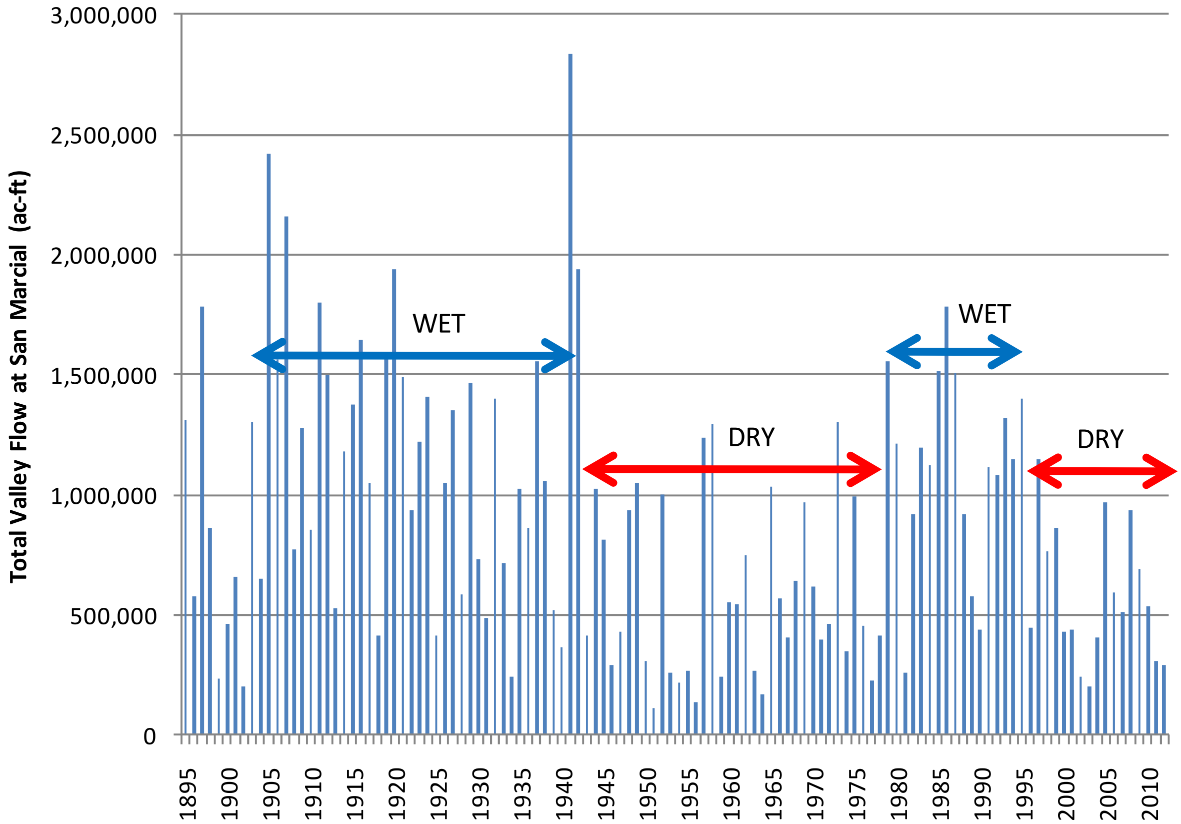


**Figure 6. Annual valley flow volume at San Marcial (1895–2012)**

## Sediment Supply

Sediment supply is coupled with water discharge as the primary driver of channel morphology and is also half of the sediment balance equation. Sediment particles at a given stream cross section must have been eroded from within the watershed above the cross section and also transported by flow from the place of erosion to the cross section (Julien, 1998). The Rio Grande is a sediment-laden river with many sources contributing to the total load including upland erosion (overland flow), tributaries (arroyo flow), and bed/bank erosion (main channel flow). Sediment supply is difficult to quantify due to the highly spatially and temporally variable physical processes that are not easily measured. Julien (1998) has identified several variables that contribute to the character and quantity of sediment supply such as watershed topography, geology, the magnitude, intensity, and duration of rainfall and snowmelt, vegetation, grazing and land use, soil type, cohesion, surface erosion, bank cutting, and sediment supply from tributaries. Bed material from upstream river sections is also an important component of sediment supply and is related to several of the factors mentioned by Julien.

Land use practices and changes to upland vegetation have had a significant impact on sediment load. Vogt (2003) describes the most recent period of arroyo formation (1865–1915) in the southwest and the causative factors of climate, land use, and internal adjustments. Unusually large floods in the late 1800's were likely the primary driver, followed by livestock overgrazing and tributary incision. The Rio Puerco alone added nearly 400,000 acre-feet of sediment to the Rio Grande between 1885 and 1929 (Leopold et al., 1964). Sediment loads of the Middle Rio Grande may have been unusually high during the late 1800's through mid 1900's due to the wet climate, arroyo formation, and land use.

Sediment loads have been reduced on the Middle Rio Grande due to reduction of peak flows, deposition in reservoirs, and other sediment control measures (Makar and AuBuchon, 2012). Figure 7 is a double mass curve of cumulative suspended sediment load versus water discharge at San Marcial. It should be noted that suspended load is only a portion of the total load and does not include coarser particles that are transported near the bed. A steeper slope on the graph indicates that a greater volume of sediment is being carried for an equal discharge, as compared to a flatter slope that represents a smaller volume of suspended sediment for the same discharge. The figure shows a high concentration of sediment from 1955 to 1977, a slightly lower concentration from 1978 to 1982, and an even lower concentration from 1983 to 1992. Beginning in 1993, it appears that the concentration increased for a period through 2006, after which it decreased again between 2007 and 2011. Table 1 presents average suspended sediment concentration values for the discussed time periods.

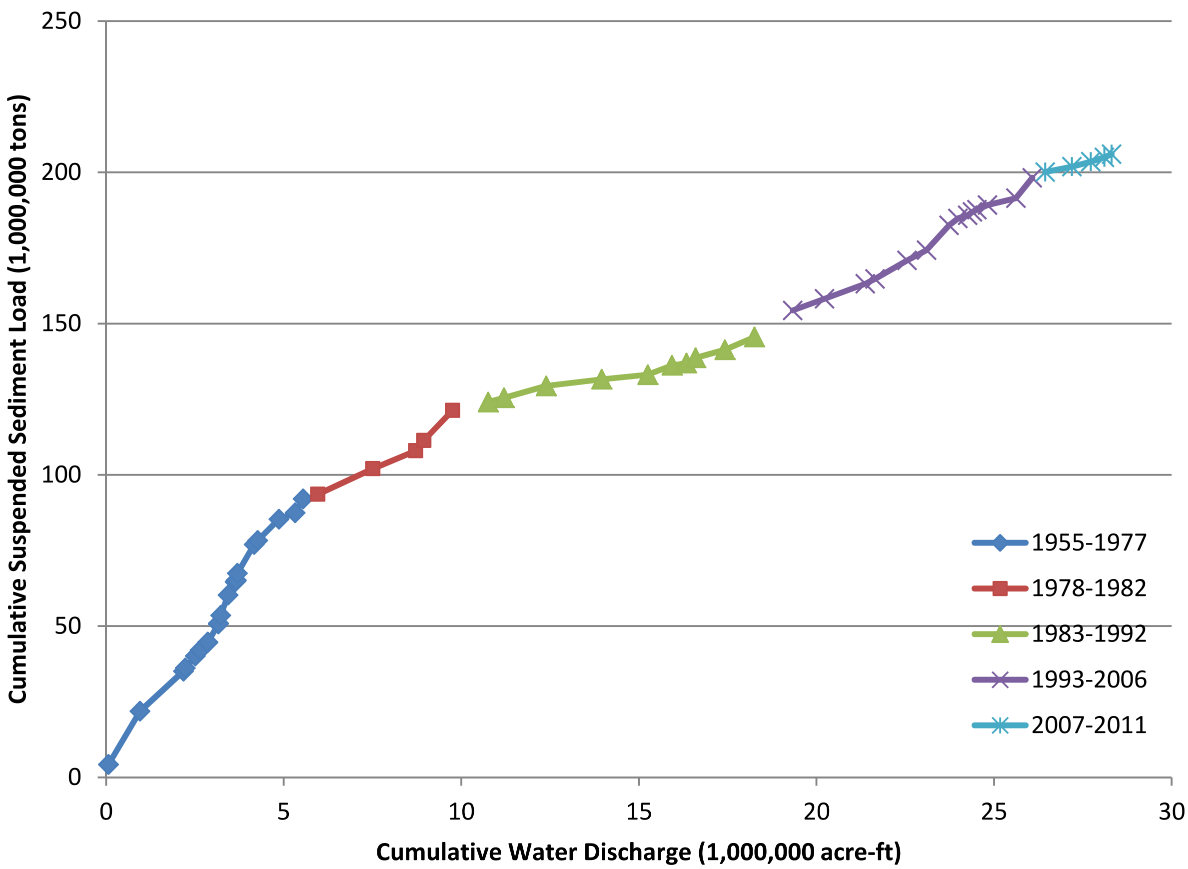


**Figure 7. Cumulative suspended sediment versus discharge of the Rio Grande Floodway at San Marcial**

**Table 1. Average daily suspended sediment concentration of the Rio Grande Floodway at San Marcial**

| | |
|---|---|
| 1957–1977 | 9,882 mg/L |
| 1978–1982 | 6,989 mg/L |
| 1983–1992 | 2,573 mg/L |
| 1993–2006 | 3,989 mg/L |
| 2007–2011 | 3,291 mg/L |

# Controls

Controls can be defined as factors that limit or influence the effect that drivers have on channel adjustment (Makar and AuBuchon, 2012). These factors are further characterized as channel and floodplain controls or base level control.

## Channel and Floodplain

The channel boundary consists of the stream bed and stream banks; the material composition of these features significantly affects channel planform and cross-sectional geometry. Bed and banks that are erodible allow the river to freely shift position or pattern. The relative stability and roughness of the bed and banks often determines whether the channel will adjust laterally or vertically. When sediment transport capacity exceeds supply, a channel with an erodible bed and resistant banks will tend to incise. Over time, the bed material may coarsen and the incision may continue below the vegetative root mass, thus stabilizing the bed and destabilizing the banks. At this time, lateral erosion of the banks will occur as described in the Channel Evolution Model (Schumm et al, 1984; Watson et al., 2007). Coarser bed and bank material typically provide enhanced stability, but fine-grained cohesive sediments may also be relatively erosion resistant. The presence of clay layers has been well documented within the study area (Hilldale, 2001 and 2003; Bauer, 2004 and 2007). Cohesive silt and clay are usually most prominent on bars and floodplain surfaces, although there have been observations of clay spanning the entire riverbed. Existing clay layers may have been deposited long ago in former overbank or reservoir pool areas, but there is also a significant amount of cohesive material deposited annually by arroyo flows. Analysis has shown that the Rio Puerco and Rio Salado contribute the majority of tributary sediments supplied to the river downstream of Albuquerque. Most of this input load from the arroyos is cohesive, but there is some sand and gravel as well (Reclamation, 2012). The stability added to channel boundaries by cohesive sediment varies by location and depends on the thickness and if the deposits are intermittent or continuous.

Figure 8 shows the median bed material size over time at a number of locations upstream of the reservoir pool. It is clear that coarsening has occurred during the previous 40 years, a trend that is consistent with other reaches throughout the Middle Rio Grande (Makar and AuBuchon, 2012; Bauer, 2009). Grain size within this reach is classified as fine sand (0.125–0.25 mm) but may shift to medium sand (0.25–0.5 mm) if coarsening continues over the next several years. The increase in bed material size could have significant implications to sediment transport and the overall sediment load (Makar and AuBuchon, 2012). Lane’s balance indicates that a larger bed material size could lead to a reduction in sediment load because it would be more difficult to mobilize the coarser particles. Also, a slope increase would be required to transport the same amount of bed material with the same water discharge.

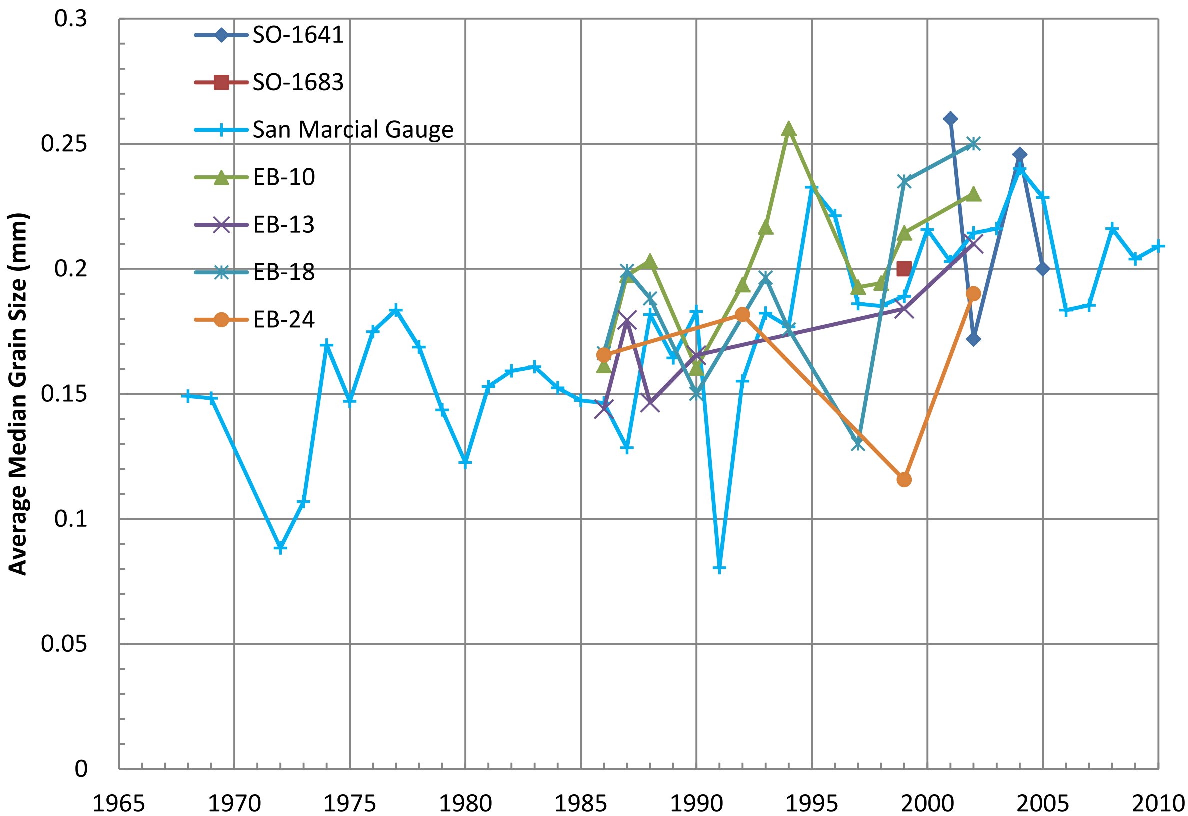


**Figure 8. Bed material size over time at different locations upstream of Elephant Butte Reservoir pool (modified from Owen, 2012)**

Floodplain characteristics also act as a control on channel adjustment. A well connected floodplain in which flows frequently go overbank provides a negative feedback mechanism that dissipates energy during large floods. A positive feedback loop occurs in channels with a disconnected floodplain as the energy is confined to the channel and increasing velocity and shear stress are amplified. Floodplain confinement is a control that limits the width of overbanking flow due to natural geologic outcrops or artificial levees. Lateral constraints confine sediment-carrying flood waters and may increase the depth of deposition because the available area is reduced. However, floodplain sediment deposition depends on a variety of factors such as the frequency, magnitude, and duration of overbanking events during a time period. Deposition across a river and floodplain cross section is not uniform, owing to the non-uniform vertical sediment concentration profile and local site conditions. Many cross sections within BDANWR or near San Marcial show a channel perched above the floodplain, and a floodplain perched above the valley. Overbanking flows within these areas are often separated from main channel flows, thereby reducing channel sediment transport capacity and contributing to sediment imbalance. A perched system is indicative of disequilibrium and increases the probability of channel avulsions or levee breaches. Lateral constraints may also limit the lateral migration or meandering of the river channel.

## Base Level

Base level, the downstream limit of the stream network and origin of the thalweg profile, can greatly affect the stability of a fluvial system. The elevation of this downstream limit controls the longitudinal water surface profile for typical alluvial rivers. Changes in base level have the potential to initiate instability within the river system (Watson et al., 2007). Table 2 distinguishes the primary causes of downstream progressing bed elevation change (water and sediment discharge) from that of an upstream progression (base level). The channel response to base level lowering, such as a drop in reservoir pool elevation, is often upstream-progressing degradation. Slope at the channel outlet (e.g., reservoir delta) is locally steepened thus increasing sediment transport capacity. If the increased capacity exceeds sediment supply, the abrupt break of slope (headcut or knickpoint) migrates upstream through the system. The peak rate of degradation usually occurs fairly quickly and then slows over time, while also declining at further distances upstream. Incision may trigger bank instability that generates lateral erosion and channel widening. Bank erosion provides additional sediment input to the stream and the system oscillates through a series of adjustments to the new base level until stability is restored. (Stability may never be restored if the base level continues to fluctuate and there is not a balance between sediment supply and transport capacity.) In the absence of a geologic control, the final gradient resembles the same form as the original slope, but at a lower bed elevation throughout the affected reach (Knighton, 1998; Watson et al., 2007).

**Table 2. Main Causes of Streambed Elevation Change (adapted from Knighton, 1998)**

| **Type of Bed Elevation Change** | **Upstream Driver: Cause of Downstream Progression** | **Downstream Control: Cause of Upstream Progression** |
|---|---|---|
| *Degradation* | water discharge increase; sediment supply decrease | base-level fall |
| *Aggradation* | water discharge decrease; sediment supply increase | base-level rise |

Conversely, a rise in base level reduces local transport capacity at the river/pool interface and initiates or increases deposition. Aggradational effects due to a rising base level do not have a tendency to continue as far upstream as headcut migration caused by reservoir lowering (Knighton, 1998; Leopold et al., 1964). This is likely the result of the concave shape of the longitudinal profile and the transition curve between the sloping river and flat reservoir pool. Lai and Capart (2008) conducted physical and numerical modeling to examine longitudinal delta profile evolutions over time for a constant base level and a steadily rising base level. For both cases, the greatest amount of aggradation occurred at the intersection of the pool water surface and the riverbed, while the rate of aggradation decreased further upstream. The rising base level models showed that the zone of greatest aggradation moved upstream in response to the advancing reservoir pool shoreline. At a constant location significantly upstream of the reservoir pool, there was more aggradation during the rising base level experiment than the steady base level experiment.

### *Reservoir Analysis*

Construction of Elephant Butte Dam began in 1908 and was completed in 1916, with water storage operations beginning in 1915. The dam's spillway is an uncontrolled ogee crest weir structure and has a crest elevation of 4407 feet in the original project datum, which is 4452.5 feet in the NAVD88 datum (Ferrari, 2008). Figure 9 shows a time series plot of the annual minimum, average, and maximum pool water surface elevation. The water surface elevation of Elephant Butte Reservoir is related to the climatic wet and dry periods presented earlier in Figure 6. Operation of the LFCC also provided water salvage and increased delivery to the reservoir from about 1959 to 1975 (Reclamation, 1981). The reservoir filled fairly rapidly between 1915 and 1920, then declined slightly until large floods in 1941 and 1942 completely filled the reservoir. The average annual pool elevation dropped 114 feet between 1942 and 1951, while the minimum pool elevation dropped 132 feet. The reservoir pool stayed fairly low through the end of the dry period in 1978 and then increased to full pool elevation in 1986 due to large flows in the early 1980's. The average annual pool elevation increased 101 feet between 1978 and 1986, while the minimum pool elevation increased by 113 feet. The reservoir was essentially full between 1985 and 1995, before declining slightly through 1998. Between 1998 and 2004, the average pool elevation dropped 90 feet and the minimum elevation declined by 98 feet. A moderate increase of 35–40 feet occurred between 2004 and 2009 prior to a similar decrease of 30–40 feet through 2012. The minimum 2012 elevation was only 3.2 feet higher than the minimum 2004 elevation (both in September).

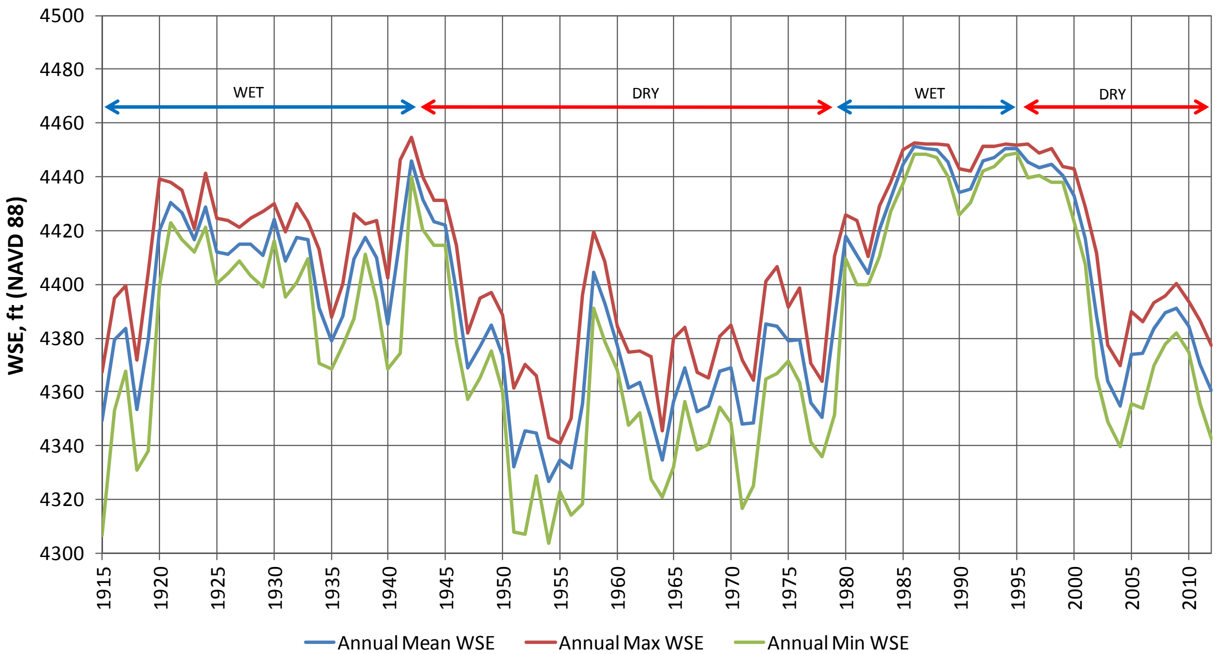


**Figure 9. Elephant Butte Reservoir pool elevation time series (1915–2012) (modified from Owen, 2012)**

It is instructive to consider the geographic locations of the reservoir pool shoreline that correspond to the varying elevations presented in the above figure. Figure 10 overlays six different pool elevations on longitudinal reservoir profiles from 1915, 1988, 1999, and 2007. Sonic depth sounding equipment was used to conduct the underwater portion of the surveys, which was combined with topographic data upstream of the reservoir pool. Upstream of about EB-23, the channel is perched in some areas, so the main channel thalweg may be higher than the reservoir profile that is shown in the figure. When the reservoir was full during the 1988 survey, the pool intersected the Rio Grande thalweg about 34 miles upstream of the dam (~RM 61) and the valley thalweg about 37 miles upstream of the dam. The average 1999 pool elevation reached about 30 miles upstream of the dam (~RM 57) and the average 2007 pool elevation was about 15 miles upstream of the dam (~RM 42). The reservoir was nearly full in February 1998 at a pool elevation of 4450 feet that matched the Rio Grande thalweg elevation at RM 59.4. Less than seven years later in September 2004, the reservoir had receded 24 miles to an elevation of 4340 feet at RM 35.3. (River Mile locations referenced in this report use the 2002 designations based on the channel centerline in 2002. River Mile delineations are not an exact measurement of channel distance and are adjusted approximately every ten years. RM 0.0 begins at Caballo Dam, with mile numbers increasing while moving upstream. 2012 RM locations are now available, and both 2002 and 2012 RM designations are presented along with Rangeline locations in Appendix B. Rangeline locations are fixed and carry the prefix SO- for Socorro and EB- for Elephant Butte. Also, Rangeline numbers increase while moving downstream.)

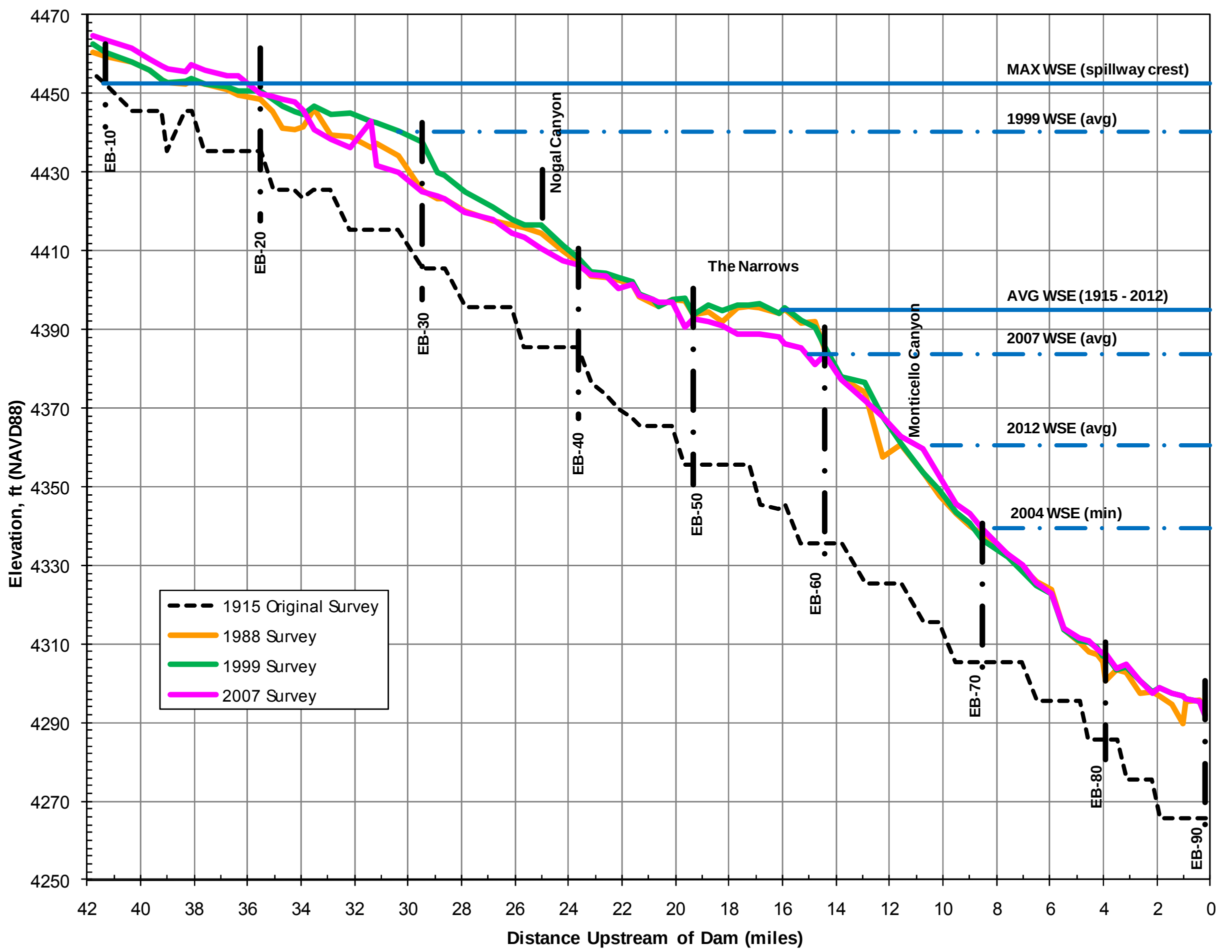


**Figure 10. Elephant Butte Reservoir longitudinal profiles and pool elevations (modified from Ferrari, 2008)**

The slope of the reservoir longitudinal profiles can also be analyzed within the context of the pool water surface elevations. It is evident that the original 1915 slope was fairly uniform from the dam upstream to EB-10. The more recent profiles show a break in slope (pivot point or knickpoint) at the Narrows where the greatest amount of historical aggradation has occurred. This is also the historical average pool elevation, corroborating the model results of Lai and Capart (2008). (Degradation at the Narrows and locations further upstream can be observed in the profiles between 1999 and 2007, corresponding to a decline in reservoir pool elevation.) Strand and Pemberton (1982) describe the development of a topset slope and foreset slope during the delta formation process as shown below in Figure 11. They found that, on average, the topset slope is half of the original channel slope and the foreset slope is 6.5 times steeper than the topset slope. The grade break between the two slopes is known as the pivot point, which becomes a knickpoint or headcut within the river channel after the pool water surface lowers. Strand and Pemberton suggest that if the reservoir water surface fluctuates often, the pivot point will be established at the mean operating level. Otherwise, the pivot point elevation will be at the top of the conservation pool if the reservoir is usually full. A pivot point does not develop when a reservoir is emptied every year.

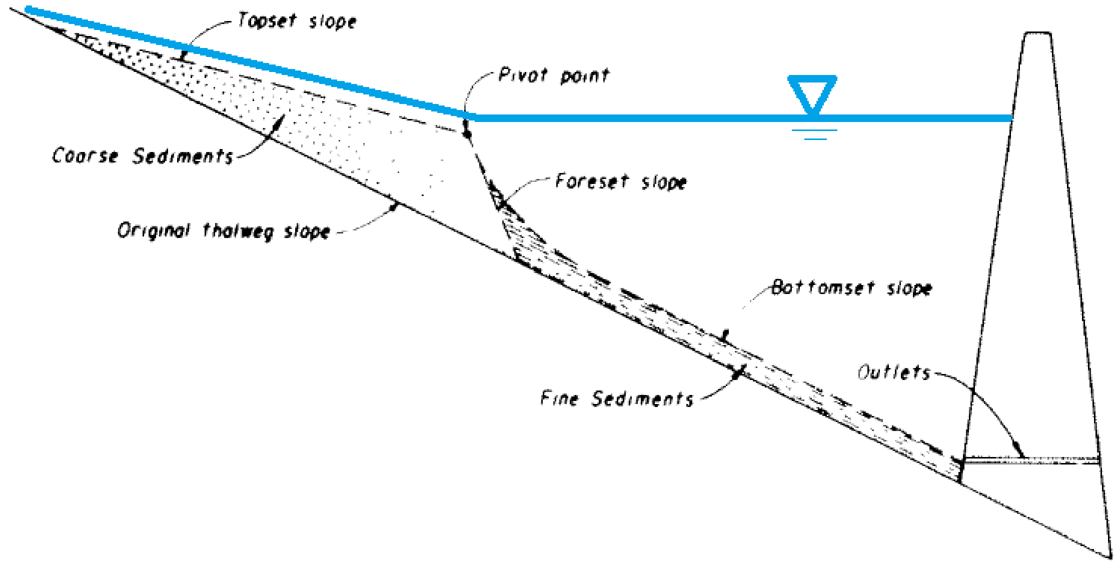


**Figure 11. Typical reservoir delta sediment deposition profile (modified from Strand and Pemberton, 1982)**

A closer examination of the 1999 longitudinal profile reveals a second pivot point at EB-30. The reservoir pool had been mostly full and operating at an elevation between 4450 feet and 4440 feet from 1985 to 1999 so the development of a pivot point (knickpoint) at an elevation of approximately 4438 feet is not surprising. The 1999 topset slope above EB-30 is about 70% of the 1915 bed slope, and the 1999 foreset slope is about 3 times steeper than the topset slope. As the reservoir pool continued to drop between 1999 and 2004, the previously submerged foreset slope was exposed and became the new river thalweg. This resulted in an oversteepened local slope between EB-30 and EB-33 and a relatively steep slope between EB-30 and EB-47 upstream of the Narrows.

***Slope Analysis***

River slope is one of the best indicators of the river's ability to do morphological work (Watson et al., 2007) and, as discussed earlier, slope directly affects the transport capacity and sediment balance of a river system. Fundamentally, sediment transport capacity is a function of the shape of the river cross section and the hydraulic properties of the flow (Julien, 1998). There are a multitude of transport capacity formulas in the literature, and they are primarily empirical. A vast majority of the formulas are strongly dependent on, and directly proportional to, hydraulic radius and slope. An increase or decrease in the river slope over time provides insight regarding the river's response to changes in upstream drivers (water and sediment discharge) and downstream control (base level). It should be noted that the thalweg, water surface, and energy slopes are not necessarily equal, but the thalweg slope provides a reasonable basis for calculating stream power (Watson et al., 2007). Figure 12 presents thalweg profiles of the Rio Grande from the Highway 380 Bridge to the Narrows between 1999 and 2012. (Larger profiles on 11x17 plots are provided in Appendix A, and bed elevation adjustments will be discussed further in the next section.) Changes in slope are a measure of the relative bed adjustment between the upper and lower sections of a reach; if all cross sections aggraded or degraded equally the slope would not change. A steeper slope that provides increased transport capacity would result from aggradation at the upper portion of a reach and/or degradation at the lower end. A flatter slope that provides reduced transport capacity could by created by degradation at the upstream section of a reach and/or aggradation downstream.

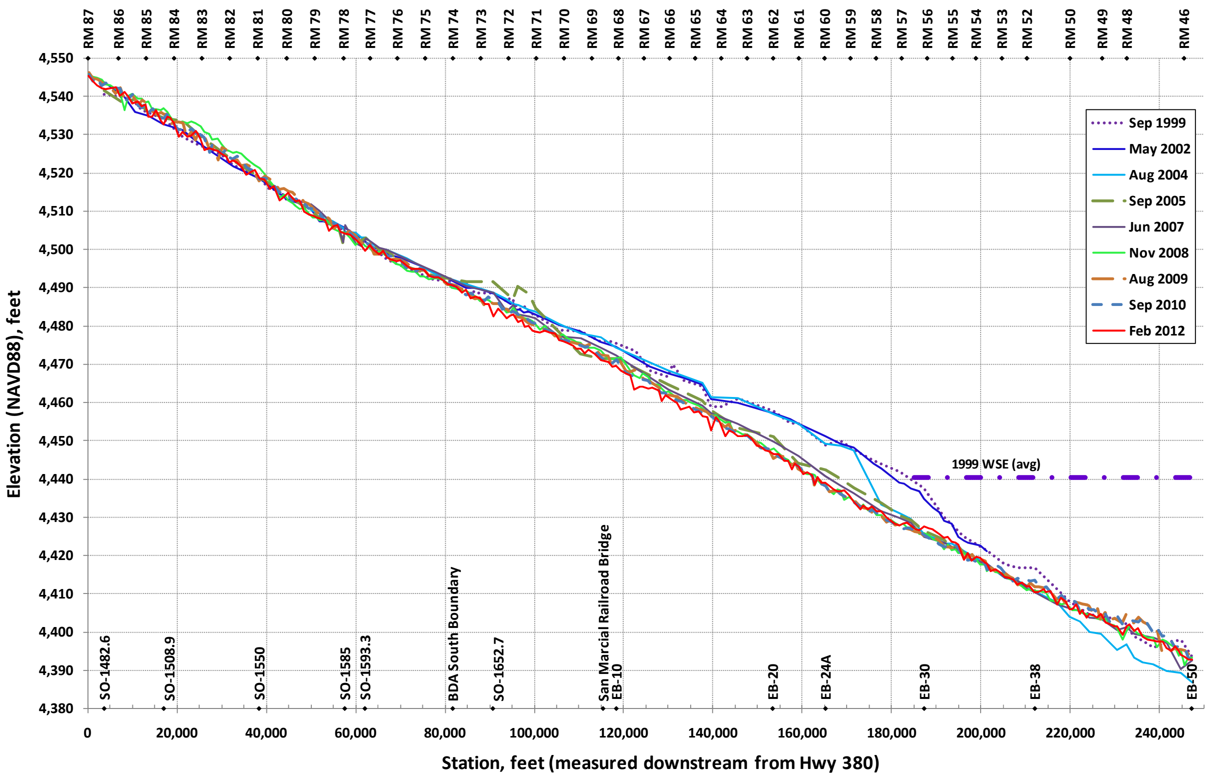


**Figure 12. Thalweg profile from Highway 380 Bridge to the Narrows**

Figure 13 and Figure 14 show the relationship between channel slope and reservoir pool elevation, and channel slope over time for different Rio Grande subreaches upstream of the reservoir pool, respectively. The upper subreach contains 8.87 miles, measured along the thalweg, from near RM 68 to near RM 60 (EB-10 to EB-24A) and the lower subreach contains 8.87 thalweg miles, from near RM 60 to near RM 52 (EB-24A to EB-38). Results for the entire 17.74-mile reach are also shown for comparison. Subreach and reach lengths, in addition to longitudinal profile stationing, were measured along the 2010 thalweg. The lower subreach was partially inundated by the reservoir pool in 1999 and includes the transition into the upper Temporary Channel work area that began in 2000. The lower subreach also includes the 1999 pivot point at EB-30 and is assumed to be the critical sediment transport capacity subreach in which capacity must exceed supply for a headcut to migrate upstream of RM 60. Downstream of the lower subreach, the section between EB-38 and EB-50 was not included because data was not always available, and it should also be noted that this area is flatter as the Rio Grande enters the Narrows. The graphics illustrate the highly variable slope over time as the river attempts to adjust to changes in downstream base level or upstream drivers. The lower subreach is particularly sensitive to the reservoir pool and the river slope trend closely follows the pool elevation. Although the response is not as dramatic, the overall reach slope adjustment is also in sequence with the reservoir pool elevation, steepening when the pool elevation drops and flattening when the pool elevation rises. For the upper subreach, the change in slope is out of phase with changes to the pool elevation. This indicates a delayed response in which the upper subreach adjusts to changes in the lower subreach. Table 3 provides a more detailed explanation of the specific slope changes for each period of time. Note that lines connecting discrete slope values in the graphics illustrate trends over time (direction of slope change), and actual channel slope values are labeled on the reversed y-axes (steeper slopes are near bottom of graphs).

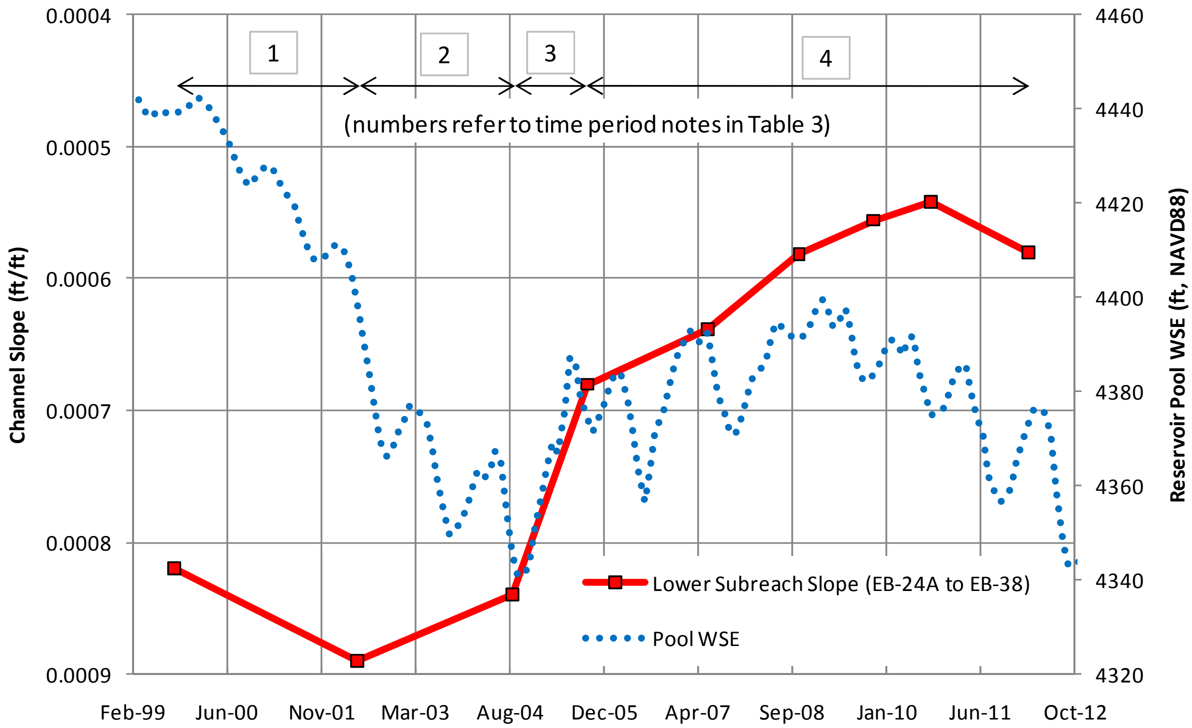


**Figure 13. Changes to Rio Grande lower subreach channel slope and Elephant Butte reservoir pool elevation over time (1999–2012)**

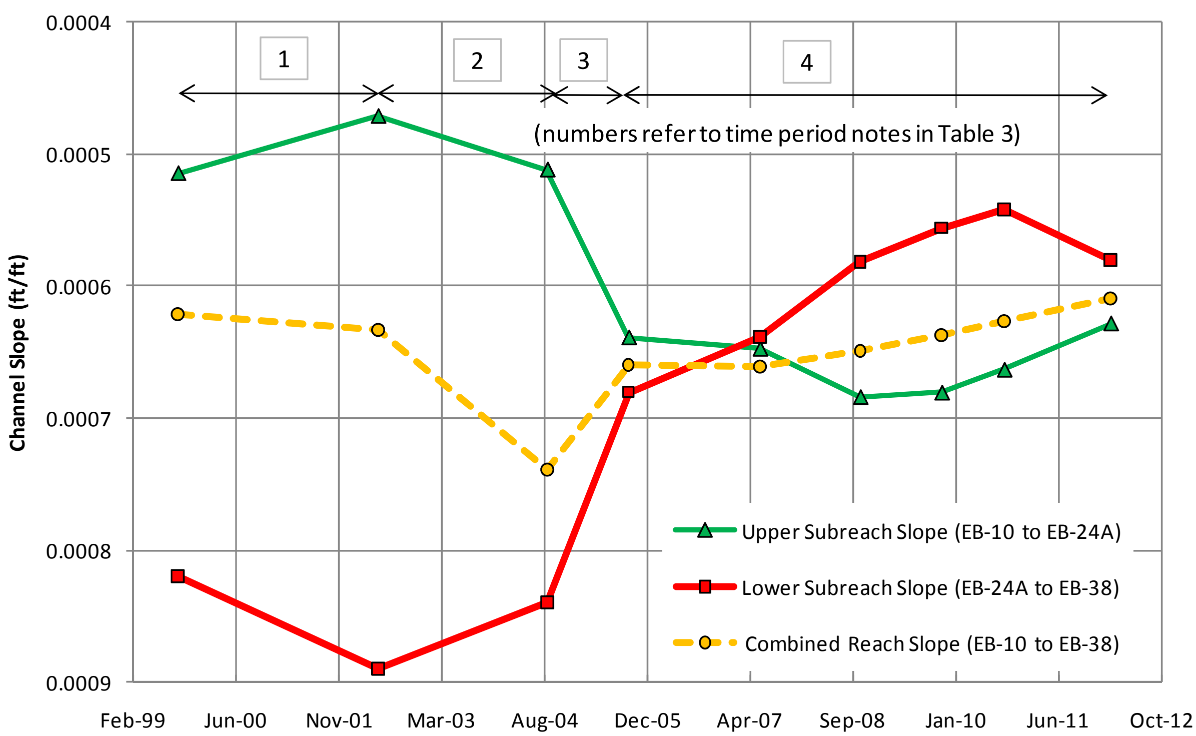


**Figure 14. Changes to Rio Grande channel slope over time (1999–2012)**

**Table 3. Detailed explanation of Rio Grande slope changes (see Figure 13 and Figure 14)**

| Note | Time Period | Lower Subreach (8.9 mi) (EB-24A to EB-38) | Upper Subreach (8.9 mi) (EB-10 to EB-24A) | Combined Reach (17.7 mi) (EB-10 to EB-38) |
|---|---|---|---|---|
| 1 | Sep 1999 to May 2002 | -Initially steep slope (S=0.00082) due to transition from topset to foreset (pivot point or knickpoint at EB-30).<br>-Slope steepens (to S=0.00089) as pool elevation drops (slight aggradation upstream at RM 60, slight degradation downstream RM 54–58). | -Initially flat slope (S=0.00051) due to deposition upstream of full reservoir pool.<br>-Slope flattens (to S=0.00047) due to slight aggradation downstream at RM 60 and slight degradation upstream at RM 68. | -Initially flat slope (S=0.00062) due to 2/3 of reach being just above reservoir pool (1/3 underwater)<br>-Slope change almost negligible (slightly steeper to S=0.00063). Overall more areas of aggradation upstream and degradation downstream in response to falling reservoir pool. |
| 2 | May 2002 to Aug 2004 | -Slope flattens as knickpoint moves about 2.8 miles upstream.<br>-Severe degradation near upstream end of subreach, moderate degradation within downstream section of subreach. | -Slope steepens. Some areas of slight aggradation upstream (RM 65–67) with some degradation downstream near RM 60. | -Significant slope increase due to degradation and headcutting within lower section as reservoir continued to drop. |
| 3 | Aug 2004 to Sep 2005 | -Slope flattens drastically as headcut moves upstream of this subreach.<br>-Downstream portion of subreach stabilizes as reservoir begins to rise, severe degradation upstream. | -Slope steepens severely as headcut moves through this subreach.<br>-Degradation throughout subreach, but disproportionate amount within lower area of subreach. | -Slope flattens as downstream section of reach is stable and large degradation occurs upstream. |
| 4 | Sep 2005 to Feb 2012 | -Slope continuously flattens 2005–2010, then steepens 2010–2012.<br>-Flatter slope from 2005–2008 primarily due to some degradation within upper half of subreach.<br>-Flatter slope from 2008–2010 primarily due to some aggradation within lower half of subreach.<br>-Steeper slope from 2010–2012 due to some aggradation within upper half of subreach and some degradation within lower half of subreach. | -Slope steepens slightly 2005–2008, then flattens 2008–2012.<br>-Steeper slope 2005–2007 due to aggradation within upper half of subreach.<br>Steeper slope 2007–2008 due to degradation within lower half of subreach.<br>-Flatter slope from 2008–2012 generally due to some degradation within upper half of subreach and a stable lower half of subreach. | -Slope flattens continuously, generally due to some degradation within upper half of reach and some aggradation within lower areas of reach. |

Using a constant reservoir water surface elevation at the average 2008 level, mobile bed modeling results predict that the stable slope between RM 78 and RM 46 is flatter than the existing slope. This means that a combination of aggradation in the lower portion of the modeled reach (~RM 62–46) and degradation in the upper portion of the modeled reach (~RM 62–78) is expected (Reclamation, 2012). Of course, these results are only appropriate for the representative hydrology, sediment, and base level conditions used in the modeling effort. As part of a sensitivity analysis, Reclamation (2012) also found that for some discharge scenarios this reach did not achieve equilibrium even after 120 years of simulation. The model results show that the Rio Grande upstream of Elephant Butte Reservoir is inherently unstable and terms such as equilibrium or stable slope do not apply for timescales less than about 100 years.

#### *Bed Elevation Analysis*

Aggradation or degradation within the river channel can change the flow capacity, floodplain connectivity, and potentially the groundwater elevation. If the channel banks aggrade or degrade by the same height as the riverbed, then the main channel flow capacity and floodplain connectivity will remain relatively unchanged. Figure 15 shows the average bed elevation at San Marcial compared to the water surface elevation of Elephant Butte Reservoir from 1895 to 2012. San Marcial is about 42 miles upstream of Elephant Butte Dam (see Figure 10), 31 miles upstream of the average 2012 pool elevation, and 5 miles upstream of the full pool elevation. The largest rates of aggradation (1920–1948 and 1978–1995) have occurred during periods of increasing or full reservoir pool elevations. Periods of riverbed degradation (1949–1972 and 2005–2011) correspond to low or decreasing reservoir pool elevations. The periods of degradation began during large spring runoff events of 1949 and 2005, both about 7–10 years after the reservoir pool started to lower. Bed elevation stabilized briefly from 1950 to 1956, before large flows in 1957 and 1958 initiated a more constant degradational trend through about 1972. A sediment plug formed during the 2005 spring runoff slightly upstream of San Marcial that blocked most of the upstream sediment supply. All three of the primary degradation causes (Table 2) were present during the 2005 spring runoff: water supply increase, sediment supply decrease, and a lowered base level. The 1949–1972 degradation rate was only about one half to one third that of the recent rate, most likely due to the substantially higher sediment load (Figure 7 and Table 1). Temporary degradation during 1937 (Happ, 1948), 1991, and 1995 was caused by avulsions or sediment plugs that reduced upstream sediment supply. Although degradation has occurred during the identified periods, the overall dominant historic trend is aggradational. The average riverbed elevation at San Marcial has increased by about 21 feet since 1895 and by about 18 feet since Elephant Butte water storage began in 1915.

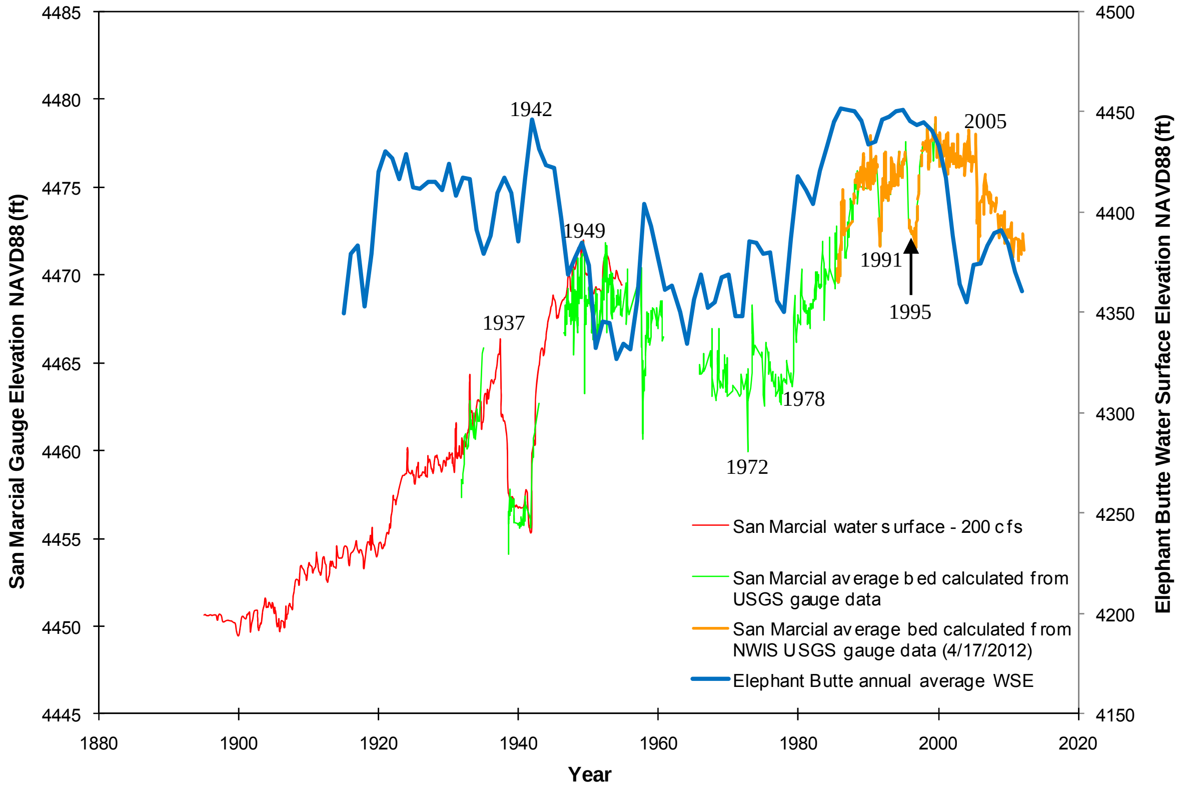


**Figure 15. Elevation changes of the USGS San Marcial gauge and Elephant Butte Reservoir pool over time (modified from Makar 2013, pers. comm.)**

The San Marcial bed elevation historical analysis can be expanded to include multiple locations between RM 78 (SO-1585) and RM 46 (EB-50). Figure 16 presents a time-series plot of selected rangeline thalweg elevations and shows the relationship to the reservoir pool. The orange lines (EB-29 to EB-50) are within the Temporary Channel, the green lines (SO-1701.3 to EB-24A) are just upstream of the full reservoir pool, and the purple lines (SO-1585 to SO-1652.7) are near the southern portion of BDANWR. It is clear that rangelines closer to the reservoir become increasingly sensitive to fluctuations in pool elevation and the effect is damped as the changes propogate upstream. The orange rangeline thalweg elevations degraded between 1999 and 2004 as the reservoir pool dropped, and aggraded or stabilized between 2004 and 2010 as the pool elevation increased. Elevations of the green rangelines were stable or slightly aggrading between 1999 and 2004 before degrading rapidly between 2004 and 2005 as the headcut moved upstream. Some degradation at these locations has continued from 2005 to 2012 as the river continues to adjust to the lowered reservoir pool. The purple lines have been relatively stable since 1990, and the 2005 sediment plug can be seen at SO-1665. After river connectivity was restored, sediment was eroded from the plug and deposited downstream as represented by the 2005–2007 aggradation at SO-1701.3. Attenuation of the upstream migrating headcut is depicted by degradation at SO-1665 from 2005 to 2007, and a minor or negligible amount of degradation at SO-1626 and SO-1585 from 2007 to 2008. The area between RM 78 and RM 74, represented by SO-1585 and SO-1626, has been the most stable section between Highway 380 and the reservoir pool.

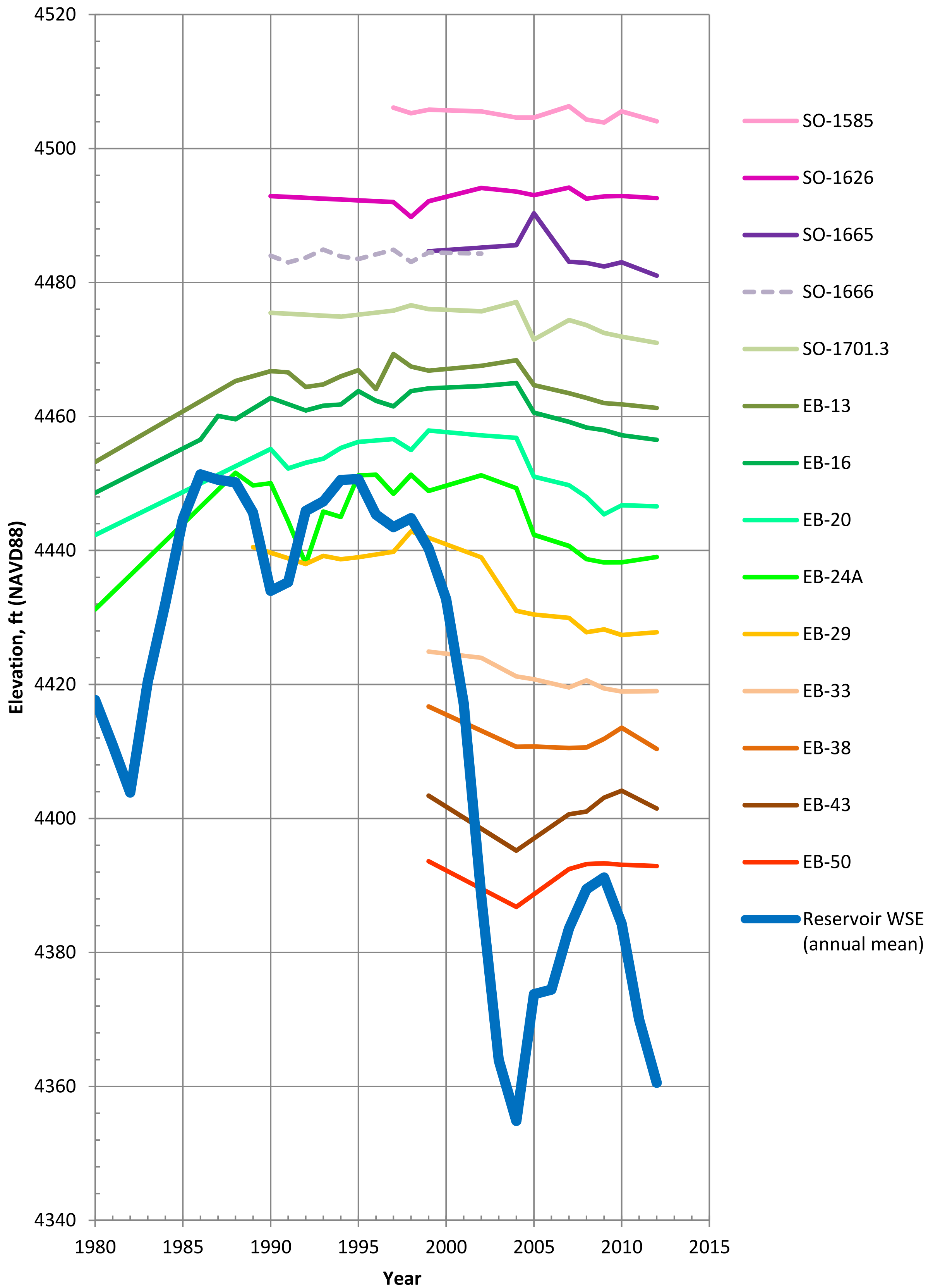


**Figure 16. Change in thalweg and reservoir pool elevation over time (after Owen, 2012)**

The response of riverbed elevation to reservoir pool elevation is best illustrated by rangeline EB-24A near RM 60. Thalweg elevation increased by 20 feet between 1980 and 1988 as the pool elevation increased by 32 feet during the same time period. Next, thalweg elevation decreased 12 feet between 1990 and 1992 before increasing 13 feet between 1992 and 1995. The reservoir pool elevation decreased 16 feet between 1988 and 1990 before increasing 17 feet between 1990 and 1994. The shape of changes to thalweg elevation mirrors the shape of changes to pool elevation with a lag time of about 1–2 years. After 1999, when the pool elevation is substantially downstream of EB-24A, an attenuated relationship exists with increased lag time and a damped response. Between 2002 and 2008, the thalweg elevation at EB-24A lowered by approximately the same amount as between 1990 and 1992 (~12 feet). However, the reservoir pool had lowered by about 90 feet between 1998 and 2004, compared to only 16 feet from 1988 to 1990.

Owen (2012) identified "waves" of degradation and aggradation that resulted from changes to reservoir level as seen in Figure 17. A degradation wave began at EB-30 (~RM 56) in 1999, and the headcut was most noticeable at EB-26 (~RM 59) in 2004. The rate of upstream headcut migration accelerated during the 2005 spring runoff while moving to near SO-1692 (~RM 69.4) by September 2005. Finally, the degradation wave propagated upstream to near the BDANWR south boundary (~SO-1641, ~RM 74) by 2008, where it tapered out in 2009. This degradation was in response to a pool elevation decrease of about 14 feet/year and a recession of about 3 miles/year from 1997 to 2004. A wave of aggradation resulted from an increase in base level (pool water surface) elevation of about 7 feet/year and a progression of 1.4 miles/year from 2004 to 2009. The induced aggradational wave began at the reservoir pool in 2004 (~EB-66, ~RM 37) and moved upstream to near EB-37.5 (~RM 52) by 2010. The graphic illustrates two separate degradation/aggradation waves during the same time period because the upstream portion of the degradation wave was a delayed response to the previously lowered reservoir level.

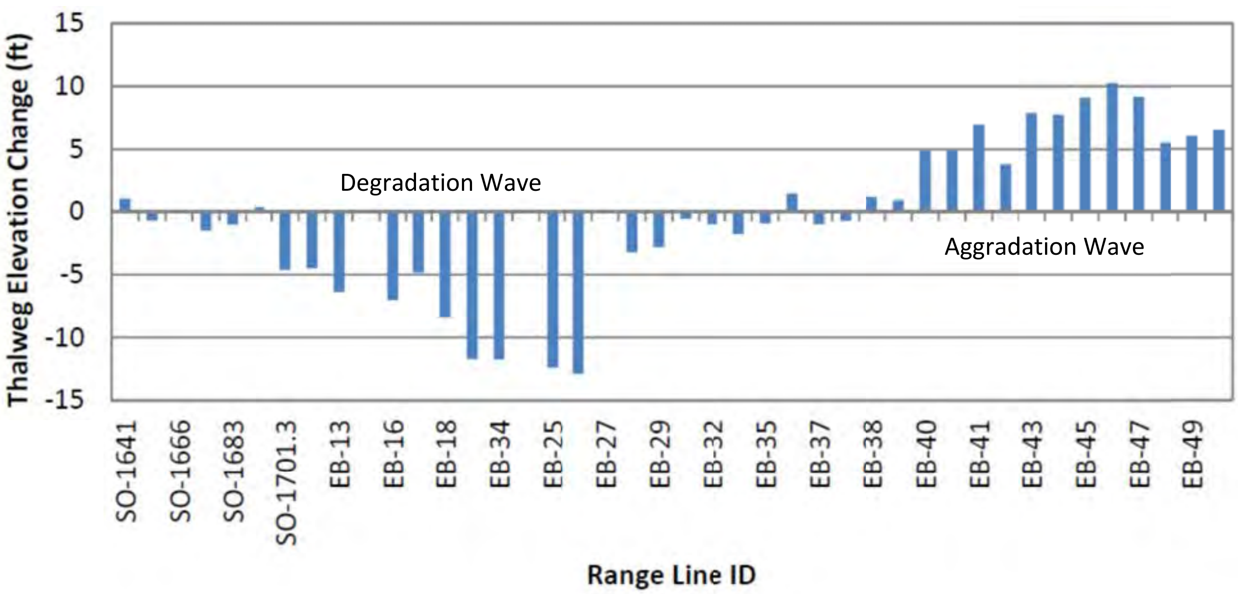


**Figure 17. Change in thalweg elevation from 2004 to 2009 (from Owen, 2012)**

## Summary of Channel Conditions and Dynamics

The Rio Grande fluvial system upstream of Elephant Butte Reservoir is highly dynamic and behaves with a great deal of complexity. The primary drivers of water discharge (Figure 6) and sediment load (Figure 7), coupled with the primary control of base level elevation (Figure 9 and Figure 10), exhibit a large degree of variability. An imbalance between sediment supply and sediment transport capacity is the prevailing condition that necessitates continuous channel adjustments over space and time (Figure 4 and Figure 5). Typically, sediment supply exceeds sediment transport capacity due to high sediment loads and a relatively flat river slope upstream of the reservoir pool. This type of sediment imbalance causes deposition within the river channel. Occasionally, sediment transport capacity exceeds sediment supply due to a steeper slope from a lowered reservoir pool, a reduction in sediment load, or both. This form of sediment imbalance causes erosion of the river channel bed and banks. Sediment imbalance has occurred during periods with a relatively stable reservoir pool (i.e., 1905–1915, 1920–1932, 1985–1998), but is often exacerbated by frequent changes to water discharge, sediment load, and base level elevation.

Equilibrium or stability over a period of several years is not a reasonable outcome for this reach, owing to the variable nature of the drivers and controls. As the pool elevation of Elephant Butte Reservoir rises or falls, the slope of the Rio Grande is forced to respond (Figure 13). The river's response to fluctuations in base level and delta formation has controlled the channel elevation upstream of the reservoir (Figure 15 and Figure 16). The rate and magnitude of bed elevation changes is highly dependent on proximity to the reservoir pool and upstream water and sediment discharge (Levish, 2012). Channel bed adjustment is a function of sediment imbalance, which generally depends on the relative magnitude of upstream sediment supply and effects from the downstream reservoir (Park et al., 2012).

Significant aggradation is the most defining historical characteristic of the Rio Grande upstream of Elephant Butte Reservoir (Makar and AuBuchon, 2012). This aggradation is primarily caused by low valley and channel slopes combined with a relatively high sediment load (Levish, 2012). During wet periods with a full reservoir, the reach experiences high levels of aggradation. Aggradation appears to slow in upstream reaches as the reservoir pool elevation drops, and degradation is initiated when a high flow event occurs when the reservoir is low. Degradation is likely to continue for a period of time as the river adjusts to the initial reservoir recession, and the bed may eventually stabilize if the reservoir pool remains at a constant low elevation for several years. The dominant aggradational trend will resume when the reservoir begins to rise. Adaptive management is likely the most appropriate strategy for this reach, given that the design life of any maintenance approach will be greatly reduced due to fluctuations in the upstream water discharge and sediment load and the downstream base level control (reservoir pool elevation) (Reclamation, 2012).

# Geomorphic Effects of Channel Maintenance

In 1998, the Rio Grande became disconnected from the reservoir pool as the water surface drastically receded. High evapotranspiration water loss within the delta negatively impacted New Mexico's Rio Grande Compact deliveries. A channel, termed the Temporary Channel as it will be inundated by future increases in reservoir level, was constructed to maintain the connection from the river to the reservoir pool by providing effective transport of water and sediment. Construction began on the upper Temporary Channel reach (RM 57.8 to RM 51.2) in 2000 and continued through 2004. The middle reach (RM 51.2 to RM 40.7) was built between 2003 and 2004, while construction was initiated for the lower reach (RM 40.7 to the reservoir pool) in 2005. The channel was initially excavated at a depth of about 3 feet to follow the declining reservoir pool and subsequent adaptive maintenance activities have occurred every year to maintain the general form and function of the existing channel.

Effects of channel maintenance are best analyzed within a geomorphic framework that considers impacts from maintenance actions relative to the principles of sediment balance, upstream drivers, and downstream controls. Channel adjustment and geomorphic effects can be discussed in two phases: initial construction (2000–2004) and recurring maintenance (2005–2012).

## Initial Channel Construction

It is difficult to separate the effects of initial channel construction from the rapid base level lowering since they occurred contemporaneously. The preceding discussion of fundamental geomorphic concepts, including historical and recent Middle Rio Grande data analysis, demonstrates the range of effects that result from changes to the drivers (water and sediment discharge) and controls (primarily reservoir pool elevation). Within the Temporary Channel area, the effect from construction activities was essentially the creation of a river channel through the reservoir delta. Prior to channel construction, water within the delta area was consumed by evapotranspiration, or flowed as shallow overland flow. After construction, the river channel conveyed the majority of water and sediment directly to the reservoir pool. The water table adjacent to the Temporary Channel may have been lowered by 1–3 feet during initial construction, although overbanking still occurred and other sources (such as springs and a naturally high water table) provided water to the riparian delta. For river sections upstream of the Temporary Channel, initial construction can be considered as a type of downstream boundary condition effect. Therefore, a comparison between the relative magnitude of channel excavation and reservoir pool lowering provides insight regarding the individual effects.

An important concern for the period of initial construction and base level lowering is the wave of degradation that propagated upstream. As discussed, there was a knickpoint (pivot point) in the channel thalweg profile present in 1999 near RM 56 before any channel excavation began. This headcut moved about 3 miles upstream between 1999 and 2004 and about 10 miles upstream during the 2005 snowmelt runoff. The average annual pool elevation lowered about 85 feet between 1999 and 2004, and this strong control on upstream channel elevation was described in the Base Level section. Temporary Channel excavation of about 3 feet, compared to the 85 feet of reservoir lowering, would have a negligible effect on the downstream base level elevation. Any degradation potentially caused by the Temporary Channel would more likely be the result of a locally increased slope that increased the sediment transport capacity, thus allowing a headcut to migrate upstream.

For a reach of the same length and slope as the lower subreach (EB-24A to EB-38) in 1999, mathematically lowering the downstream half of the subreach by 3 feet would increase the slope by 10%. This is in agreement with the actual change between 1999 and 2002 of an 8% increase. Between 2002 and 2004, the slope flattened by 6% for an overall increase of 2% from 1999 to

2004. It is reasonable to assume that the thalweg profile changes from RM 58 to RM 54 between 1999 and 2002 show the effect from the initial channel excavation. The 1999 and 2002 profiles converge at RM 54 and data is not available downstream of RM 54 for 2002. A comparison between 1999 and 2004 from RM 54 to RM 46 shows a slope increase of about 15%. It is reasonable to assume that some, but not all, of this 15% slope increase is the result of Temporary Channel construction. Therefore, it is probable that initial Temporary Channel construction was responsible for steepening the local slope (~RM 58 to RM 46) by about 8–12%.

Another possible effect of the Temporary Channel on slope is if the constructed channel alignment significantly shortened the channel length. Table 4 shows that all river adjustments (not just Temporary Channel construction) between 1972 and 2006 resulted in a channel shortening of about 550 feet, which would only steepen the slope by about 1%. This is relatively minor compared to the approximately 13,000 feet that the channel has shortened since 1918 due to a variety of factors (Levish, 2012). The cause of channel shortening between 1918 and 1935 is unknown; Reclamation's river maintenance activities did not start until the early 1950's. The 1918 channel centerline meanders across the entire valley between the mesas, while the 1935 alignment is fairly straight against the west mesa (RM 58 to RM 52) or east mesa (RM 50 to RM 47). One possible cause for this channel straightening is the large floods that occurred in the 1920's, such as the 47,000 cfs peak flow in 1929. Levish (2012) concludes that excavation of the Temporary Channel may have initiated and temporarily increased the rate of channel lowering, but ***this elevation change would have eventually occurred in response to the lower reservoir pool elevation***.

**Table 4. Total channel length for the Rio Grande between RM 58 and RM 47 (2002 River Miles)**

| Year | Channel Length (ft) | Channel Length (mi) | Difference in Channel Length Compared to 2010 (ft) |
|---|---|---|---|
| 1918 | 75,613 | 14.32 | +13,400 |
| 1935 | 61,530 | 11.65 | –683 |
| 1949 | 65,167 | 12.34 | +2,955 |
| 1962 | 66,076 | 12.51 | +3,863 |
| 1972 | 62,778 | 11.89 | +565 |
| 2006 | 62,225 | 11.78 | +12 |
| 2010 | 62,213 | 11.78 | 0 |

### *Groundwater Analysis*

The effect of riverbed elevation adjustments on groundwater elevation is an important environmental concern along the Middle Rio Grande. Floodplain vegetation is dependent on the water table for a large portion of its water supply. An increase in groundwater elevation may saturate the soil root zone, while a decrease in groundwater elevation could result in drying of the soil root zone. Saturation or drying of the roots would significantly impact vegetation health throughout the floodplain, which would then impact any species relying on the vegetation for habitat. Interactions between the river and groundwater can be analyzed to infer how changes to the channel bed would affect riparian vegetation and species.

Tetra Tech (2010) assessed the relationship between groundwater, surface water, and wetlands between RM 79 and RM 85 on the east side of the Rio Grande. Their discussion relies heavily on observation well data near Highway 380 coupled with river discharge hydrographs during the 2009 spring runoff. Groundwater modeling was also conducted for several inundation scenarios corresponding to varied river conditions and flow rates. Tetra Tech observed that groundwater levels respond directly to river stage elevation, which responds to riverbed elevation. Therefore, Tetra Tech concluded that changes in river morphology that cause changes in river stage lead to corresponding changes in groundwater elevation.

Data from other observation wells at different locations near the Rio Grande also demonstrate a relationship between river water surface elevation and groundwater level, but suggest that the interaction is more complex than suggested by Tetra Tech (2010). Figure 18, Figure 19, and Figure 20 show the river thalweg elevation compared to nearby groundwater elevation at locations near the BDANWR south boundary, near San Marcial, and south of Fort Craig, respectively. River discharge is also shown on the secondary axes for reference. Figure 18 includes a well about 30 feet east of the river (SBB-E01B) and a well about 250 feet east of the river (SBB-E02B); both wells are approximately 1,200 feet upstream of SO-1641. The river has been slightly degradational since 1999 and the thalweg has lowered about one foot since water table monitoring began in 2003. The groundwater elevation shows either no trend, or a slightly increasing elevation trend. Figure 19 includes a well about 200 feet west of the river (SMC-W08EX) and a well about 1200 feet west of the river (SMC-W04B); both wells are between SO-1701.3 and EB-10. SMC-W04B is also about 40 feet east of the LFCC. The river thalweg lowered about 5 feet between 2003 and 2011, while the water table lowered 0–1 feet during the same period. There is not much of a trend in the water table elevation compared to the trend in thalweg elevation. Figure 20 includes a well about 300 feet west of the river (SFC-W05B) and a well about 450 feet west of the river (SFC-W04A); both wells are between EB-18 and EB-20 and within 50 feet the LFCC. (SFC-W05B is to the east of the LFCC and SFC-W04A is to the west of the LFCC.) The river thalweg lowered about 9–10 feet between 2003 and 2011, while the water table trend remained constant. The groundwater elevation was about 3–4 feet below the river thalweg in 2003 and 5–6 feet above the river thalweg in 2011 as the riverbed was no longer perched above the LFCC. Also, there are other ponded areas of water to the west of the river and LFCC between RM 60 and RM 64 that indicate a very high water table in this area. Groundwater elevation for the west floodplain is essentially a gradient between the river water surface and the LFCC water surface. All three figures show a higher groundwater table near the river, particularly at San Marcial where the river is perched above the west floodplain and the LFCC. Groundwater data is limited or not available for locations near the river and south of San Marcial, where most of the degradation occurred during the monitoring period.

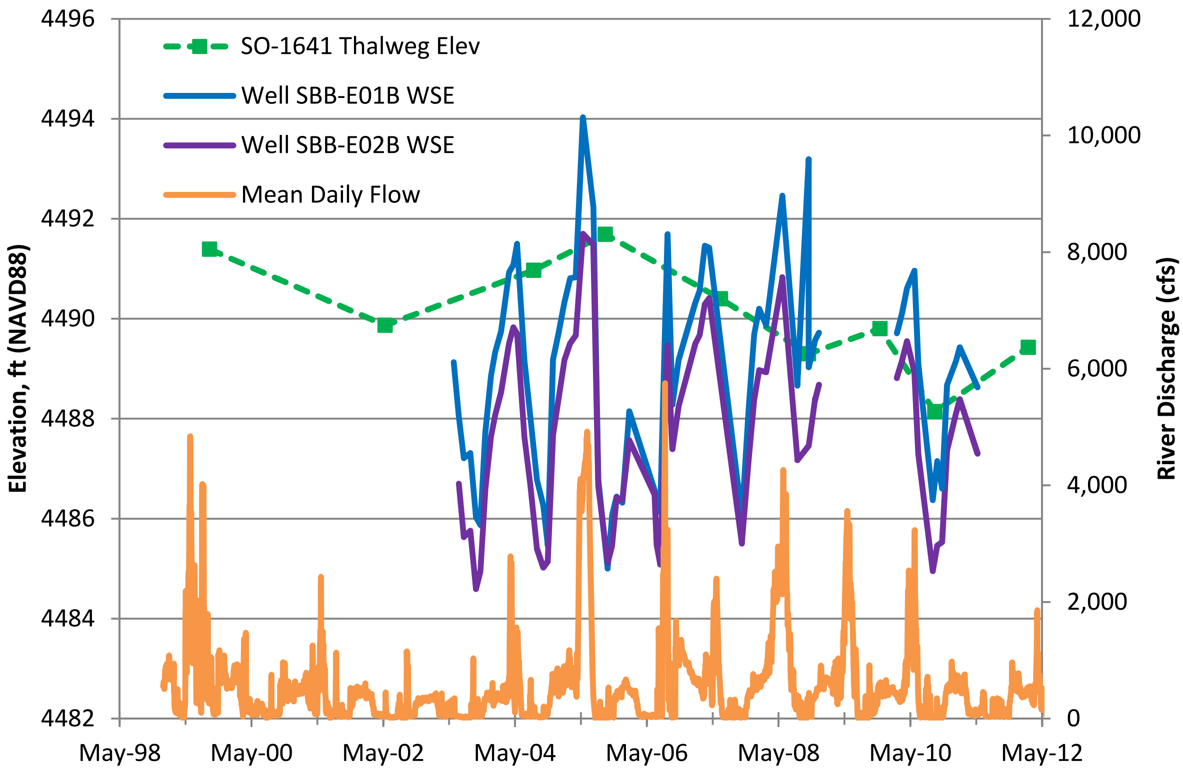


**Figure 18. River thalweg elevation, groundwater elevation, and river discharge over time near BDANWR south boundary**

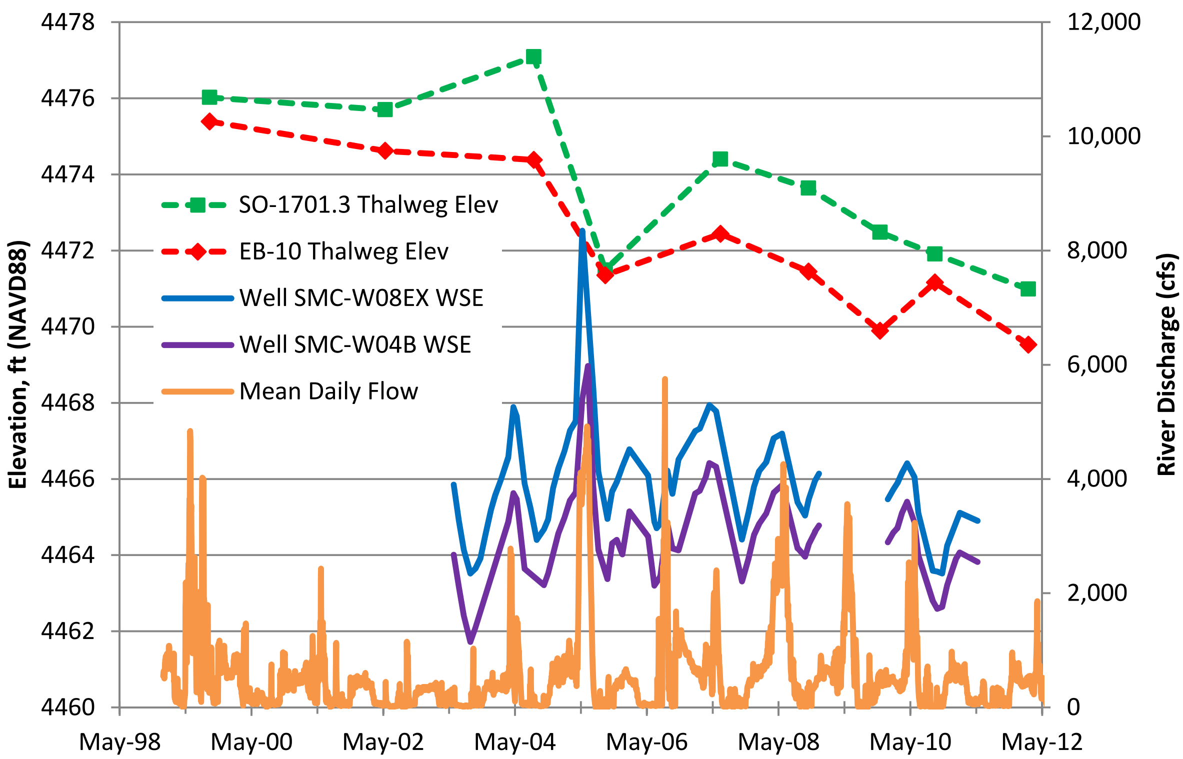


**Figure 19. River thalweg elevation, groundwater elevation, and river discharge over time near San Marcial**

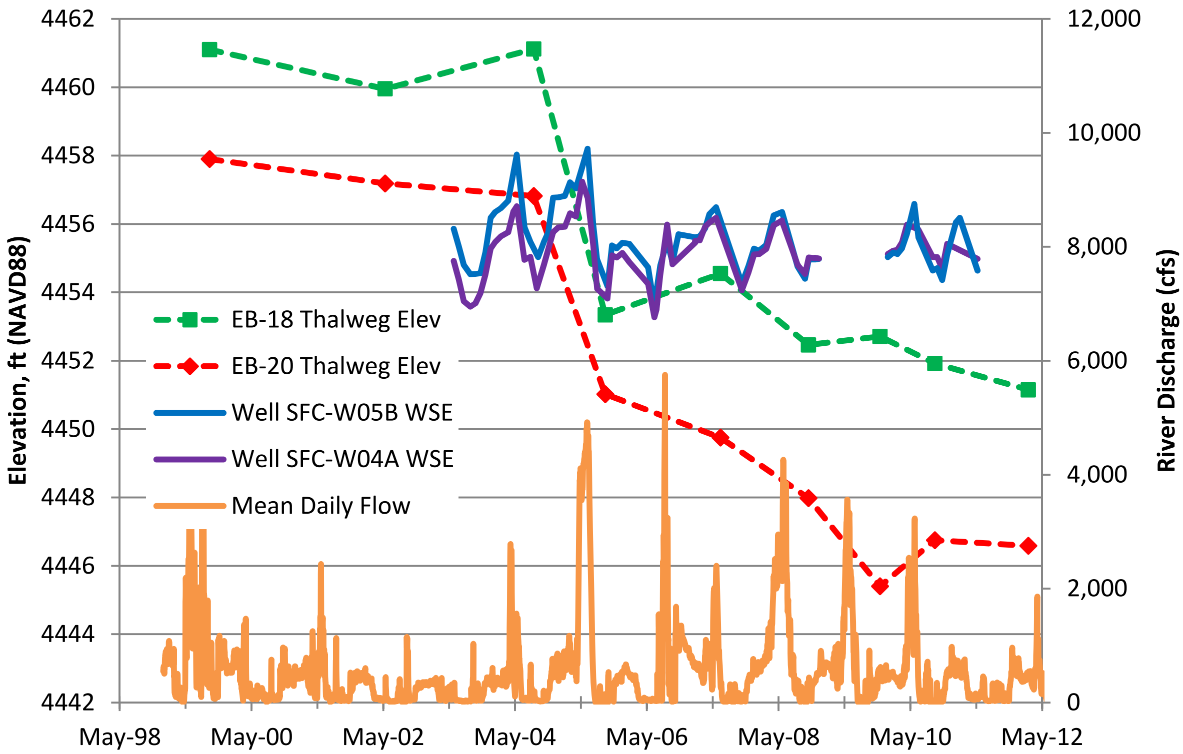


**Figure 20. River thalweg elevation, groundwater elevation, and river discharge over time near RM 63**

All three graphics show that the strongest correlation is between groundwater elevation and river discharge, not thalweg elevation. Peaks in groundwater elevation occur during spring runoff or other high flow events, and the highest groundwater peak in all three graphs is during the 2005 spring runoff, which was the largest flow event during the monitoring period. (The August 2006 monsoon had a higher peak flow, but a shorter duration, thus the smaller effect on groundwater.) Low groundwater elevations occur during periods of low river flow rates. Additional river water surface elevation, thalweg elevation, and mean bed elevation data would be needed to expand this analysis and draw more definitive conclusions. Specifically, river geometry and water surface data would need to be collected concurrently with groundwater data multiple times per year, especially during high flow events, to thoroughly examine the relationship. Collection of this amount of data is probably cost-prohibitive, but the currently available data demonstrates average trends and correlations over a period of several years. Groundwater elevation is complex, highly variable, and appears to be ***primarily a function of river discharge (or river water surface elevation) and nearby groundwater controls*** (i.e., LFCC and ponded areas). River thalweg elevation trends over time and space can influence, but may not directly correspond to, trends in groundwater elevation.

## Recurring Channel Maintenance

Initial Temporary Channel construction was substantially finished by the end of 2004, so activities completed between 2005 and 2012 can be described as recurring channel maintenance. Recurring maintenance actions were primarily the removal of accumulated sediment to maintain channel capacity (bar lowering, pilot channel excavation through sediment plugs, etc.) and repair of spoil berms near the constructed channel banks. Specific maintenance activities varied slightly every year depending on channel conditions, but all maintenance essentially had those two functions. Data collected from 2005 to 2012 illustrate the geomorphic effects of recurring channel maintenance during a period with the given changes to drivers and controls. Within the Temporary Channel project area, 2005 data is not available below Nogal Canyon (near EB-38) so cross section data from August/September 2004 was used to represent the “as-built” conditions after initial construction and prior to recurring maintenance.

Figure 21 shows thalweg profile snapshots in time during the period of recurring channel maintenance. The profiles begin at the upper end of the work area (EB-28) and continue to the start of the Narrows (EB-50); this includes the Upper Reach and half of the Middle Reach. Data was often not collected below EB-50 due to inundation from the reservoir pool. Aggradation has been the prevailing trend within the Temporary Channel during recurring channel maintenance, especially downstream of EB-38. The profiles also illustrate a significant degree of variability, even though it is likely that continuing maintenance minimized the amount of aggradation that would have occurred in some years. Figure 22 uses the same data from Figure 21 and calculates a distance-weighted, reach-averaged thalweg elevation for each year. This procedure reduces the multiple data points collected over approximately 12 river miles to a single representative thalweg elevation. Although spatial variability is no longer evident in the graphic, the dominant temporal trend of aggradation is more easily seen. The average thalweg elevation adjustment presented in Figure 22 strongly resembles the trend in reservoir pool elevation over the same time period (shown on secondary axis and previously discussed in Base Level section). Sediment was frequently removed in order to maintain channel capacity, yet the riverbed aggraded by a cumulative average of almost 3 feet from 2004 to 2010 before degrading about 0.5 feet from 2010 to 2012. Geomorphic effects from recurring channel maintenance are dominated by effects from the primary drivers (water and sediment discharge) and control (base level).

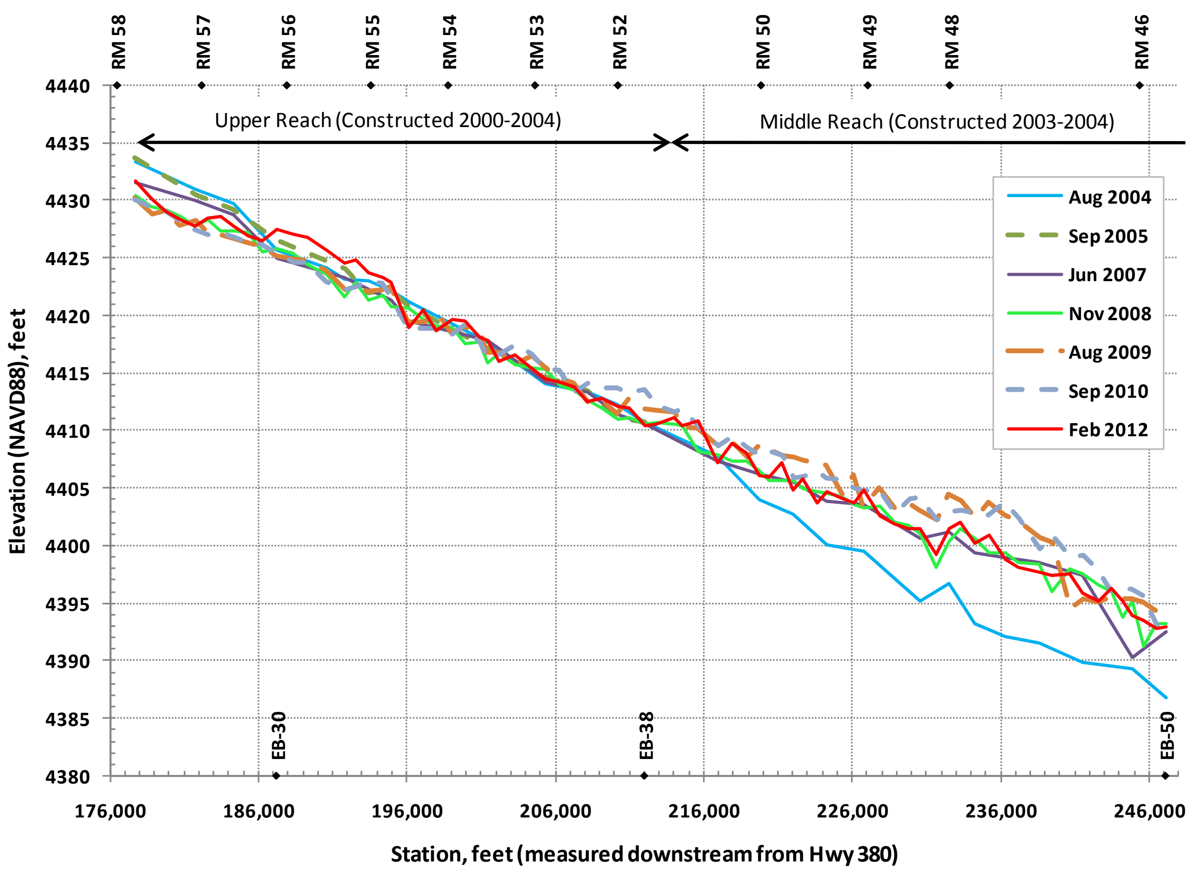


**Figure 21. Partial Temporary Channel thalweg profiles over time during recurring channel maintenance**

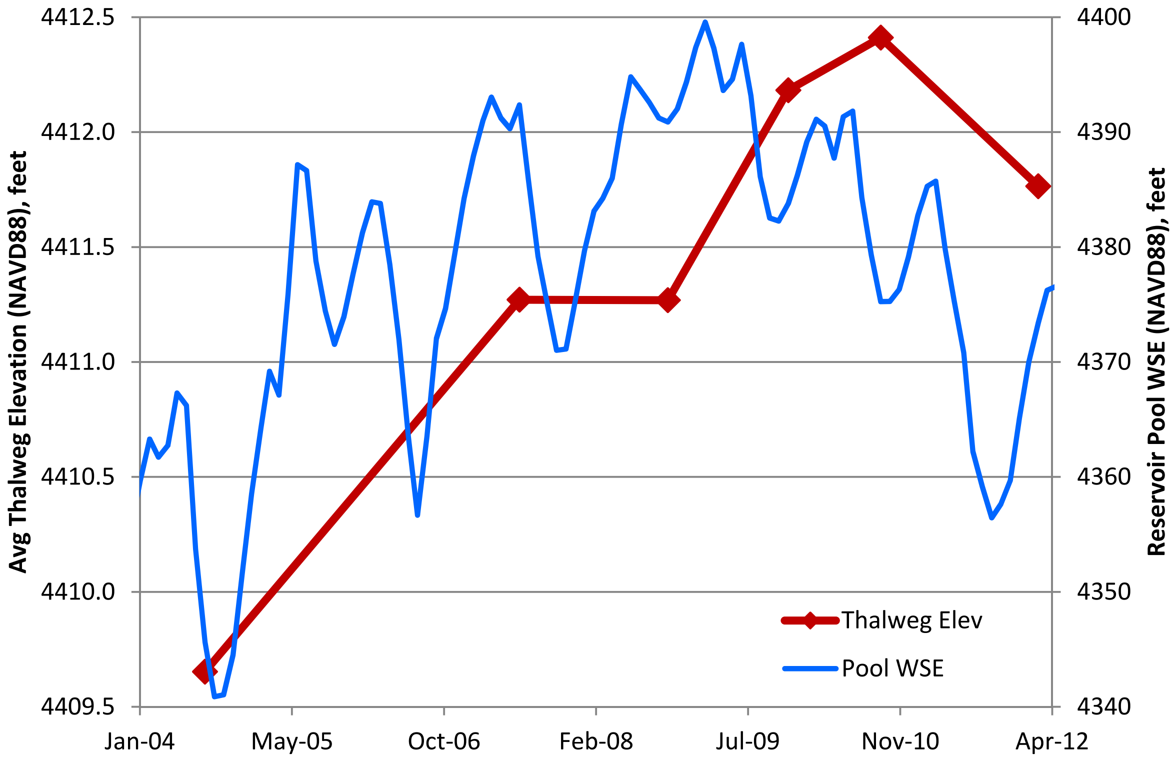


**Figure 22. Distance-weighted average thalweg elevation over time for the Temporary Channel between EB-28 and EB-50 during recurring channel maintenance**

Changes to channel planform and cross-sectional shape are also an important consideration when analyzing the geomorphic effects of recurring channel maintenance. Recurring maintenance actions either reconstruct or maintain the original channel, so there would not be any expected changes to channel planform. Table 4 and a review of aerial imagery confirm that there were not any significant alterations to channel planform or sinuosity between 2004 and 2012. Cross section plots complement thalweg profile analyses to present a more complete picture of the flow depth and velocity variability across the entire channel. Figure 23, Figure 24, and Figure 25 show three example cross sections within the Temporary Channel (EB-32.7, EB-37.5, and EB-43, respectively). The cross sections were selected at approximately 25%, 50%, and 75% of the total channel distance from EB-28 to EB-50. At EB-32.7 the lowest recorded thalweg elevation was 4420.74 feet in 2008 and the highest recorded thalweg elevation was 4422.93 feet in 2012 for a measured range of about 2.2 feet. During 2004 and 2005, the primary flow path was along the toe of the right (west) bank before an additional flow path developed near the channel center as seen in the 2007 cross section. Formation of a mid-channel bar from 2007 to 2012 caused aggradation near the channel center as dual flow paths developed along the toe of the left (east) and right banks. Other notable changes include the apparent lowering of the left berm crest by about 3 feet between 2009 and 2010 and the lowering of the right berm crest by about 4 feet between 2005 and 2007. These specific channel adjustments are limited to EB-32.7, but the trends of a relatively stable riverbed with yearly (or more frequent) variations in morphology would apply to other nearby locations.

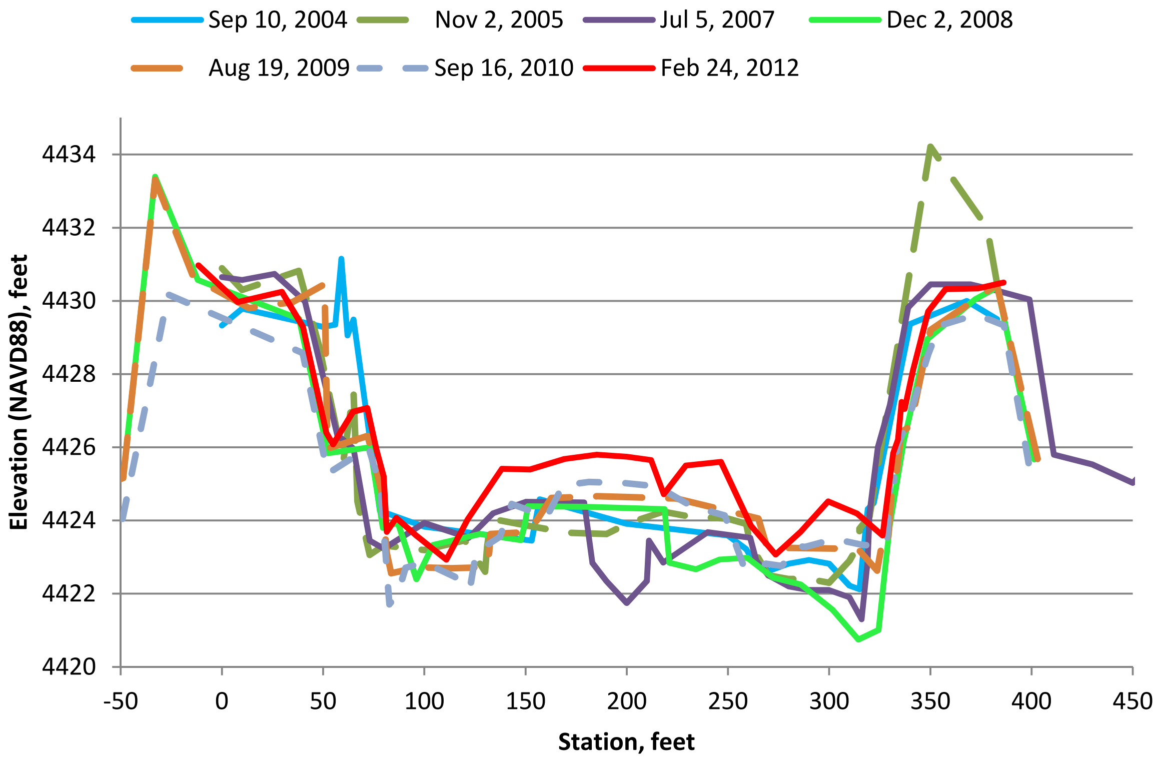


**Figure 23. EB-32.7 cross section plots (looking downstream) during recurring channel maintenance (near thalweg profile station 194,900)**

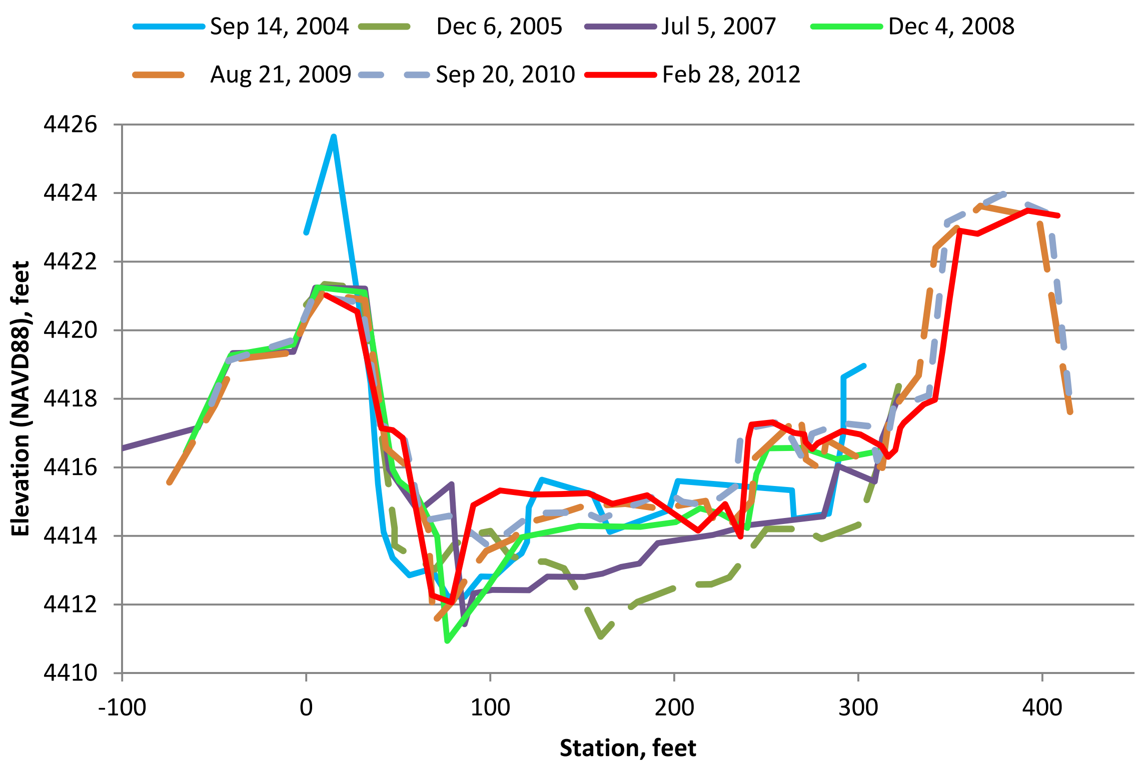


**Figure 24. EB-37.5 cross section plots (looking downstream) during recurring channel maintenance (near thalweg profile station 210,200)**

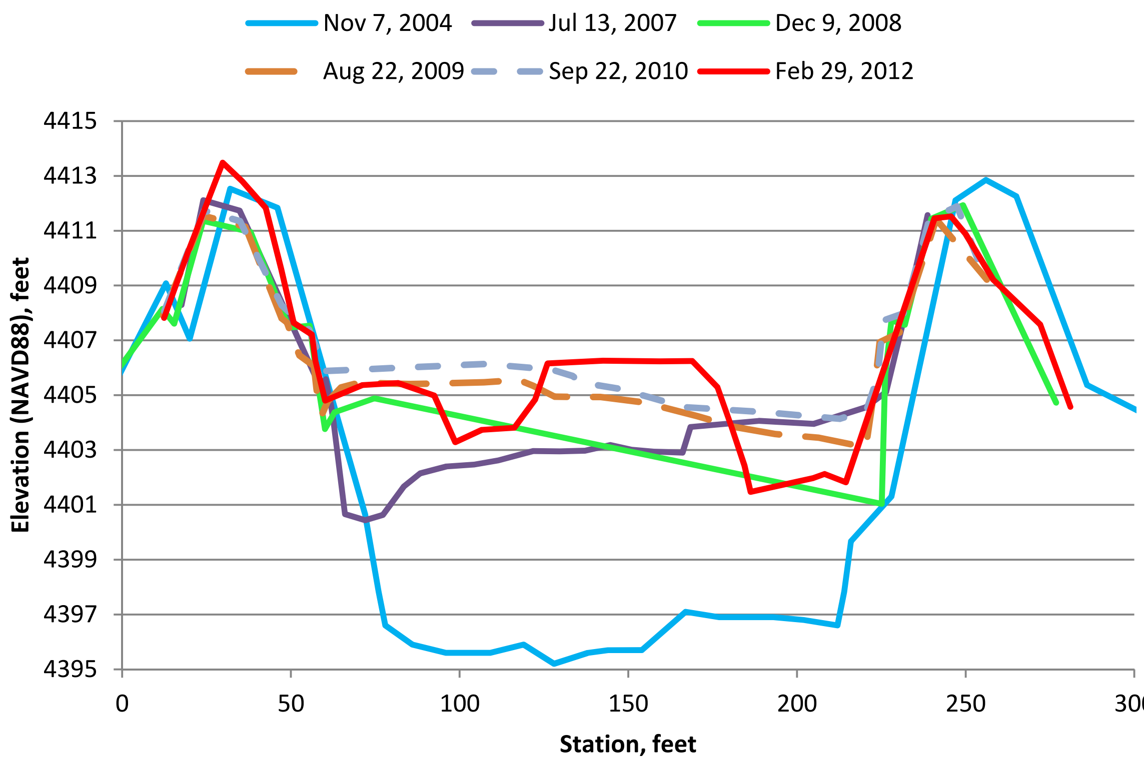


**Figure 25. EB-43 cross section plots (looking downstream) during recurring channel maintenance (near thalweg profile station 230,600)**

At EB-37.5 the lowest recorded thalweg elevation was 4410.94 feet in 2008 and the highest recorded thalweg elevation was 4413.69 feet in 2010 for a measured range of about 2.8 feet. EB-37.5 is near the apex of a bend, with the outside of the bend along the left bank (looking downstream). Therefore, the cross section plots show the expected shape of the deepest channel section near the toe of the outside bank. 2005 is the only year in which the thalweg is near the channel center rather than along the left bank. Most of the cross section adjustments occurred during the 2004–2007 time period, and the channel shape is relatively unchanged between 2007 and 2012. The specific channel adjustments are limited to EB-37.5 as discussed, but thalweg profiles and other cross section plots suggest that the channel morphology has been relatively stable at nearby locations.

At EB-43 the lowest recorded thalweg elevation was 4395.20 feet in 2004 and the highest recorded thalweg elevation was 4404.14 feet in 2010 for a measured range of about 8.9 feet. EB-43 is in the middle of a relatively straight channel section about 0.5 miles upstream of the Red Rock Staging Area. Significant aggradation occurred across the entire channel between 2004 and 2007, followed by a shift in thalweg location from near the left bank to near the right bank between 2007 and 2008. Both the thalweg and mean bed elevation continued to increase from 2007 to 2010 before decreasing between 2010 and 2012. 2012 is the first year in which two low flow paths exist due to the presence of a mid-channel bar. The aggradation seen at EB-43 and in the thalweg profiles between RM 46 and RM 50 (Figure 21) correspond to field observations of sediment plugs and multiple channel breaches within this area, which are indicative of a general loss of channel capacity despite the recurring maintenance activities.

Although data is limited below EB-50, field observations can be used to assess the general effects of channel maintenance. Within the Narrows (~EB-50 to EB-60; ~RM 46 to RM 41), flow is geologically confined by mesas on each side and maintenance needs have been minimal, such as removal of in-channel vegetation. A sediment plug formed just downstream of the Narrows near RM 41 in 2005 and was later removed. The valley width expands and meanders abruptly to the east between about RM 41 and RM 38, and some recurring work has been required in this area to maintain an effective connection with the reservoir pool. As the reservoir pool receded below RM 38, the effect of the longitudinal reservoir profile (Figure 10) could be examined. The slope is naturally steeper below the Narrows than above the Narrows (foreset and topset slopes, Figure 11), and this difference in slope should allow the river to form a competent channel downstream of about RM 38. Figure 26 illustrates that this concept was observed in the field during August 2012 near RM 37 and from the air in April 2013. The reservoir inundated the Narrows in 2009, and maintenance has never been performed downstream of about RM 38 or RM 39. A channel with defined banks became naturally established for a distance of more than one mile during April–September 2012 as the reservoir receded below RM 37. Additional distributary flowpaths have also formed through the reservoir delta. It is likely that sediment will deposit in the existing flowpaths once the reservoir stops receding, thus flattening the slope upstream of the reservoir pool and requiring maintenance.

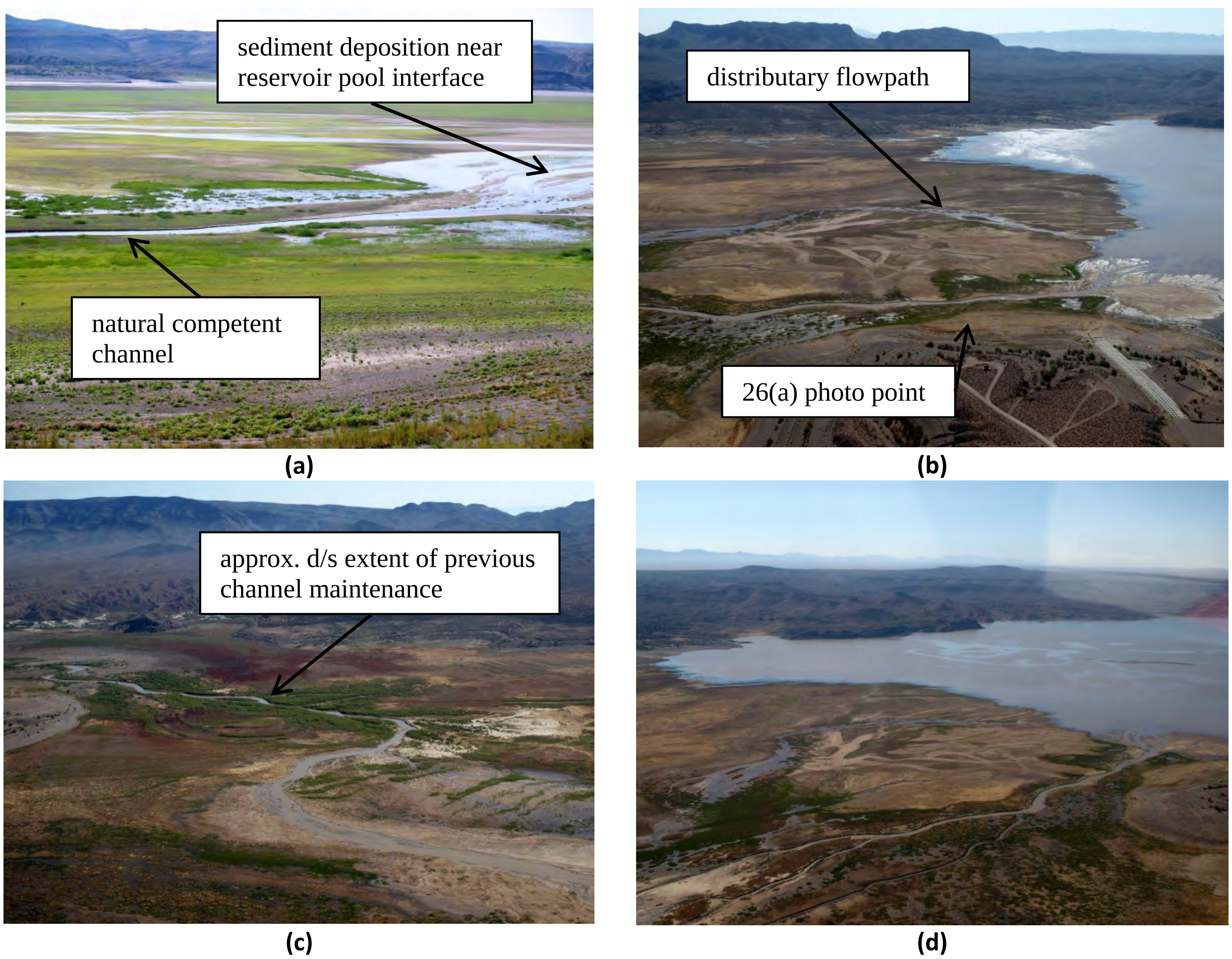


**Figure 26. Naturally formed reservoir delta channel and flowpaths downstream of the Narrows: (a) on ground looking southeast near RM 37, August 2012 (b) oblique aerial looking southeast near RM 37.5, April 2013 (c) oblique aerial looking northeast near RM 37.5, April 2013 (d) oblique aerial looking southeast near RM 38, April 2013**

In summary, analysis of data within the defined Temporary Channel work area verifies that the primary drivers (water and sediment discharge) and control (base level) dominate any effects from recurring channel maintenance. Also, potential effects from channel maintenance would be evident within the Temporary Channel prior to being observed in upstream reaches. The average thalweg elevation between EB-28 and EB-50 mirrors the temporal reservoir pool elevation trends (Figure 22). Aggradation occurred as the reservoir pool rose, even as recurring channel maintenance was performed. Degradation occurred between 2010 and 2012 as the reservoir pool declined. Less sediment removal and berm repair was required during 2011–2012 compared to 2005–2010 because of differences in the reservoir pool elevation and hydrology. The Temporary Channel planform has not changed during recurring maintenance and the cross section plots illustrate the variable depth and morphology that is typical of alluvial rivers.

# Conclusions

The Rio Grande fluvial system upstream of Elephant Butte Reservoir is highly dynamic and behaves with a great deal of complexity. The primary drivers of water discharge (Figure 6) and sediment load (Figure 7), coupled with the primary control of base level elevation (Figure 9 and Figure 10), exhibit a large degree of variability. Channel bed adjustment is a function of sediment imbalance, which generally depends on the relative magnitude of upstream sediment supply and effects from the downstream reservoir (Park et al., 2012). An imbalance between sediment supply and sediment transport capacity is the prevailing condition that necessitates continuous channel adjustments over space and time (Figure 4 and Figure 5). Equilibrium or stability over a period of several years is not a reasonable outcome for this reach, owing to the variable nature of the drivers and controls. As the pool elevation of Elephant Butte Reservoir rises or falls, the slope of the Rio Grande is forced to respond (Figure 13). The river's response to fluctuations in base level and delta formation has controlled the channel elevation upstream of the reservoir (Figure 15 and Figure 16). The rate and magnitude of bed elevation changes is highly dependent on proximity to the reservoir pool and upstream water and sediment discharge (Levish, 2012).

Significant aggradation is the most defining historical characteristic of the Rio Grande upstream of Elephant Butte Reservoir (Makar and AuBuchon, 2012). This aggradation is primarily caused by low valley and channel slopes combined with a relatively high sediment load (Levish, 2012). During wet periods with a full reservoir, the reach experiences high levels of aggradation. Aggradation appears to slow in upstream reaches as the reservoir pool elevation drops, and degradation is initiated when a high flow event occurs when the reservoir is low. Degradation is likely to continue for a period of time as the river adjusts to the initial reservoir recession, and the bed may eventually stabilize if the reservoir pool remains at a constant low elevation for several years. The dominant aggradational trend will resume when the reservoir begins to rise. Adaptive management is likely the most appropriate strategy for this reach, given that the design life of any maintenance approach will be greatly reduced due to fluctuations in the upstream water discharge and sediment load and the downstream base level control (reservoir pool elevation) (Reclamation, 2012).

The Temporary Channel has been adaptively maintained every year since initial construction in response to channel adjustments that were caused by changes to the primary geomorphic drivers and control. Initial excavation was likely responsible for increasing the local slope within the upper reservoir delta by about 8–12%, but some sinuosity was incorporated into the design so that the constructed channel length was within 1% of the 1972 channel length. A common assumption has been that Temporary Channel construction caused a headcut and ensuing upstream migration of a degradation wave from 2005 to 2008. However, a knickpoint existed in 1999 prior to construction and moved about three miles upstream by 2004 in response to the falling reservoir pool. Geomorphic concepts and analyses show that all three of the primary causes of channel degradation existed naturally in 2005: (1) a recently and rapidly lowered base level (reservoir pool) elevation, (2) a high magnitude, long duration flow event, and (3) a reduction in upstream sediment supply due to the Tiffany sediment plug. Levish (2012) concludes that Temporary Channel construction may have initiated and temporarily increased the rate of channel lowering, but this elevation change would have eventually occurred in response to the lower reservoir pool elevation. Riverbed degradation is a concern because of the potential relationship between thalweg elevation and groundwater elevation, which could impact riparian vegetation. Groundwater elevation is complex, highly variable, and appears to be primarily a function of river discharge (or river water surface elevation) and nearby groundwater controls (i.e., LFCC and ponded areas). River thalweg elevation trends over time and space can influence, but may not directly correspond to, trends in groundwater elevation.

As riverbed degradation upstream of the Temporary Channel began in 2005, bed elevation within the lower and middle portions of the Temporary Channel increased in response to a rising reservoir pool. Temporary Channel aggradation continued through 2010 with the river adjusting to an increased pool elevation. Recurring channel maintenance was performed every year during this time period, yet the average thalweg elevation increased 3 feet between 2004 and 2010. Then, about 0.5 feet of average degradation occurred from 2010 to 2012 in response to lowering of the reservoir pool. The thalweg elevation immediately upstream of the reservoir pool mirrors temporal reservoir pool elevation trends, while the riverbed further upstream responds later in time at an attenuated rate. Recurring maintenance actions attempt to maintain channel capacity, so the likely effect is a partial reduction in aggradation rate during some years. However, in a dynamic and complex system, data analysis verifies that the primary drivers (water and sediment discharge) and control (base level) dominate any effects from recurring channel maintenance. The riverbed elevation within the Temporary Channel (and nearby upstream reaches) is primarily controlled by the rate, magnitude, and duration of reservoir pool elevation fluctuations, in addition to the primary drivers. The scale of Temporary Channel maintenance actions is quite small compared to fluctuations in the other geomorphic drivers and controls. Using data from previous years, no correlation can be made between adaptive maintenance actions and geomorphic effects; whereas, there are clearly significant geomorphic effects that are caused by upstream water discharge, sediment load, and downstream reservoir pool elevation.

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# Appendix A: Thalweg Profiles

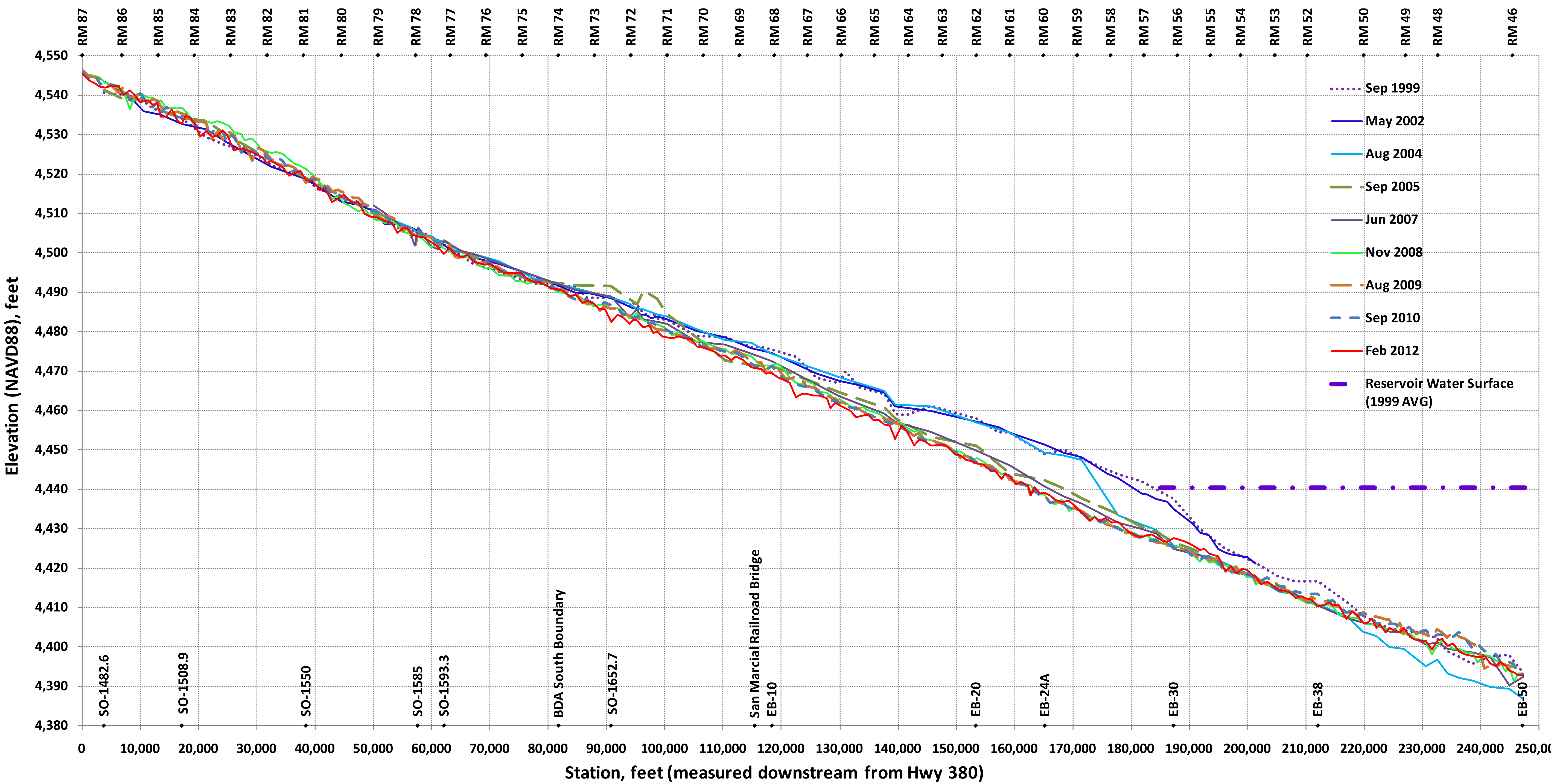



**Figure A - 1. Thalweg Profile from Highway 380 Bridge to the Narrows (river miles on secondary x-axis use 2002 delineation)**

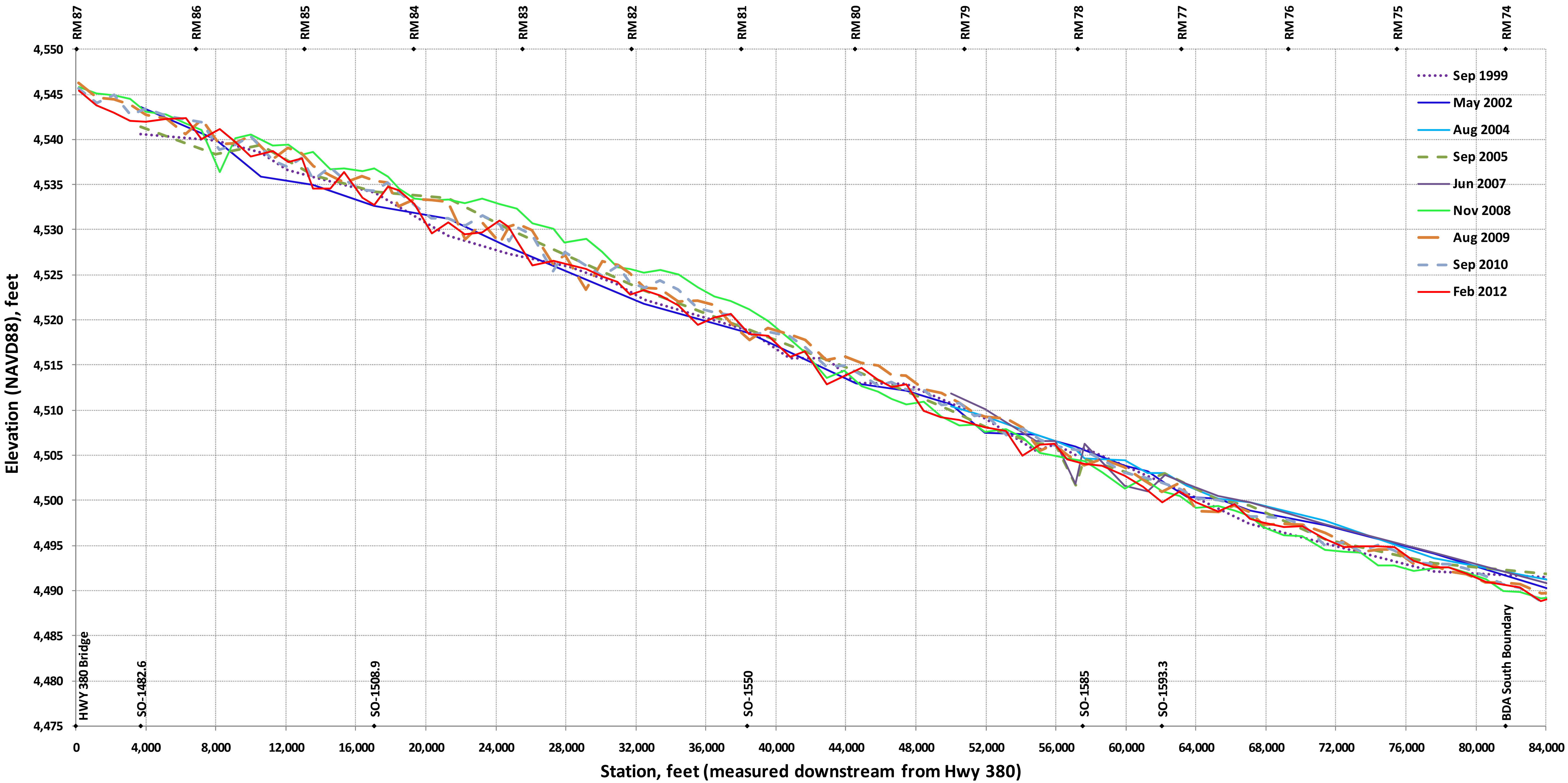



**Figure A - 2. Thalweg Profile from Highway 380 Bridge to BDANWR South Boundary (river miles on secondary x-axis use 2002 delineation)**

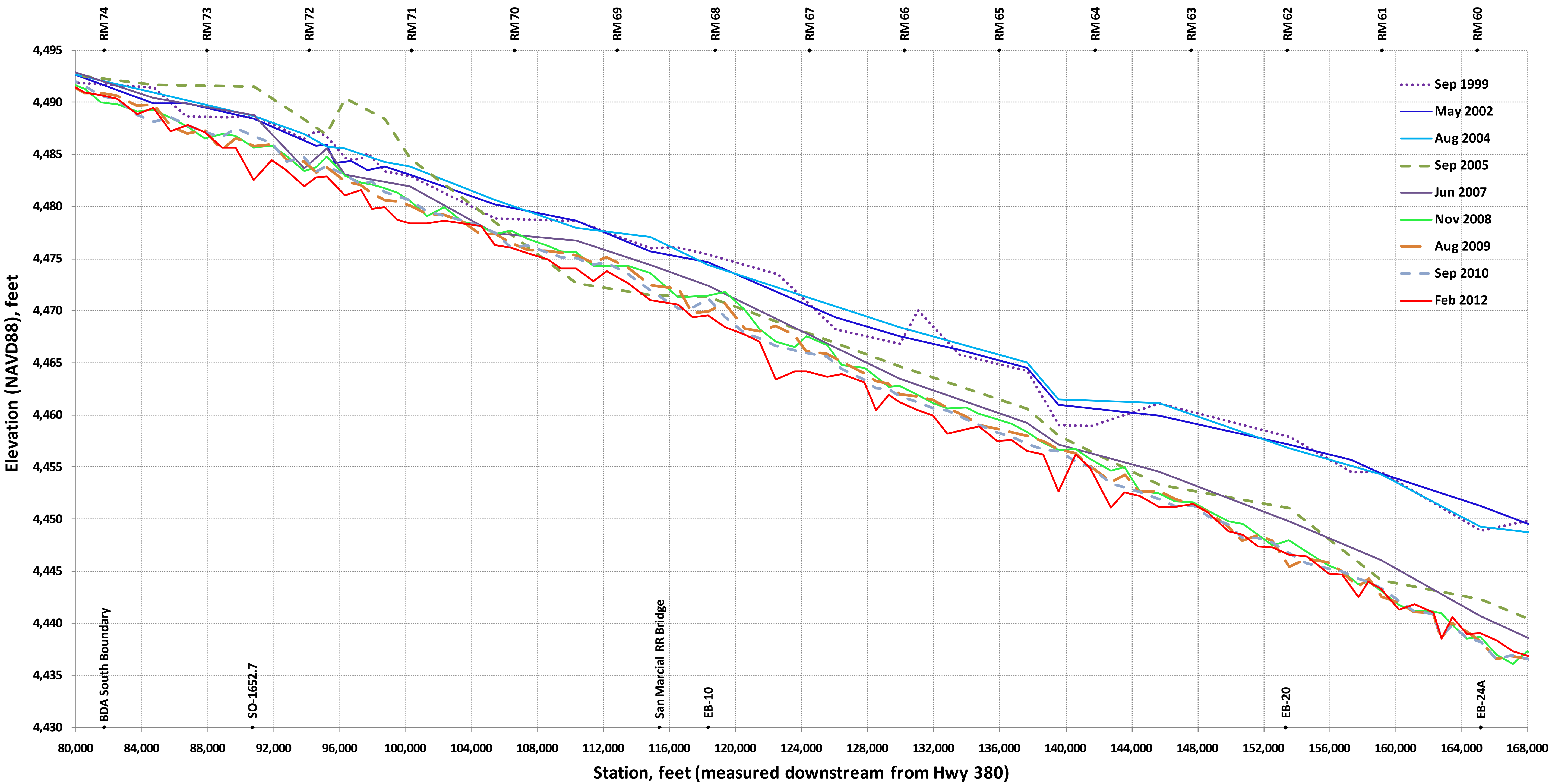



**Figure A - 3. Thalweg Profile from BDANWR South Boundary to RM 60 (river miles on secondary x-axis use 2002 delineation)**

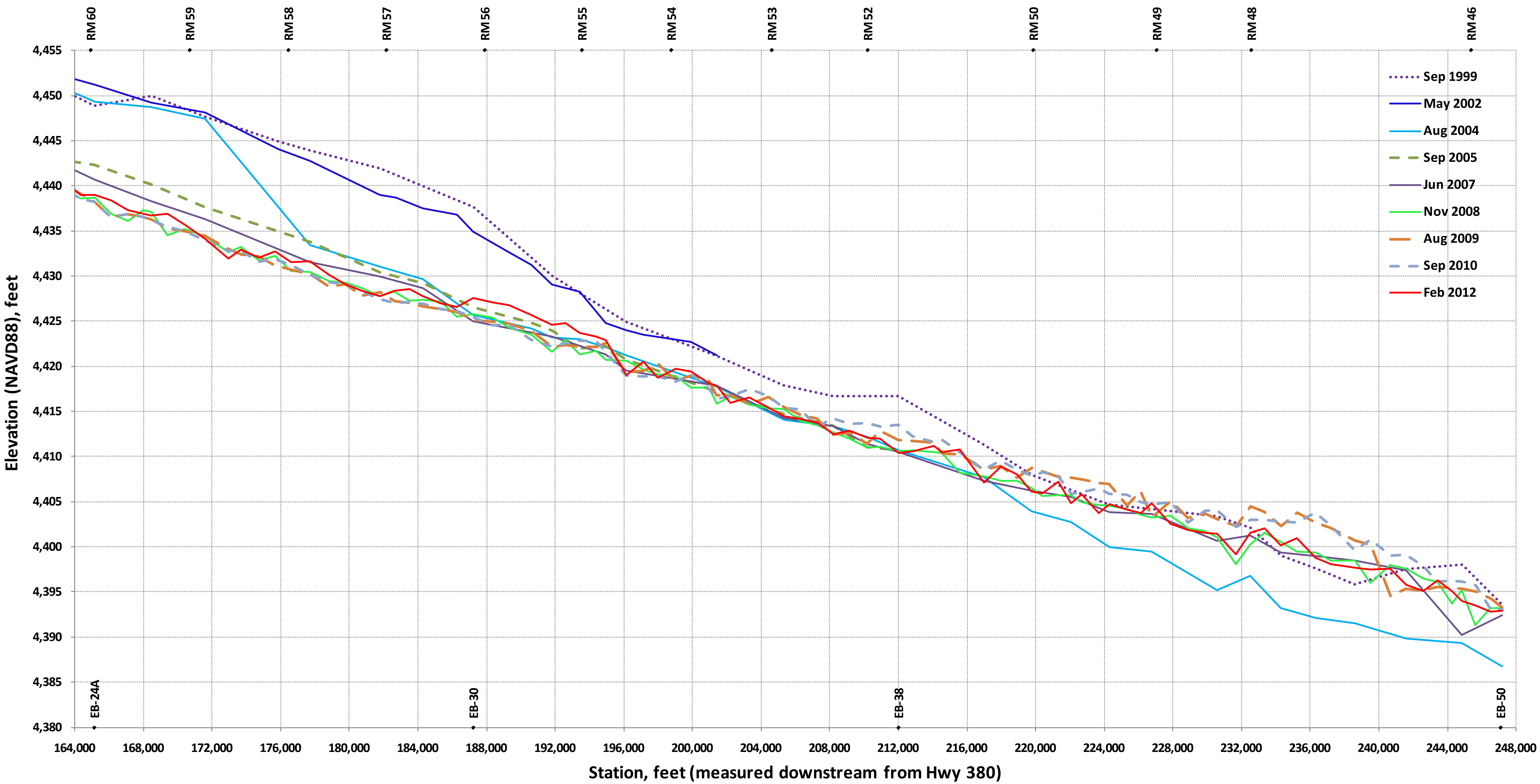
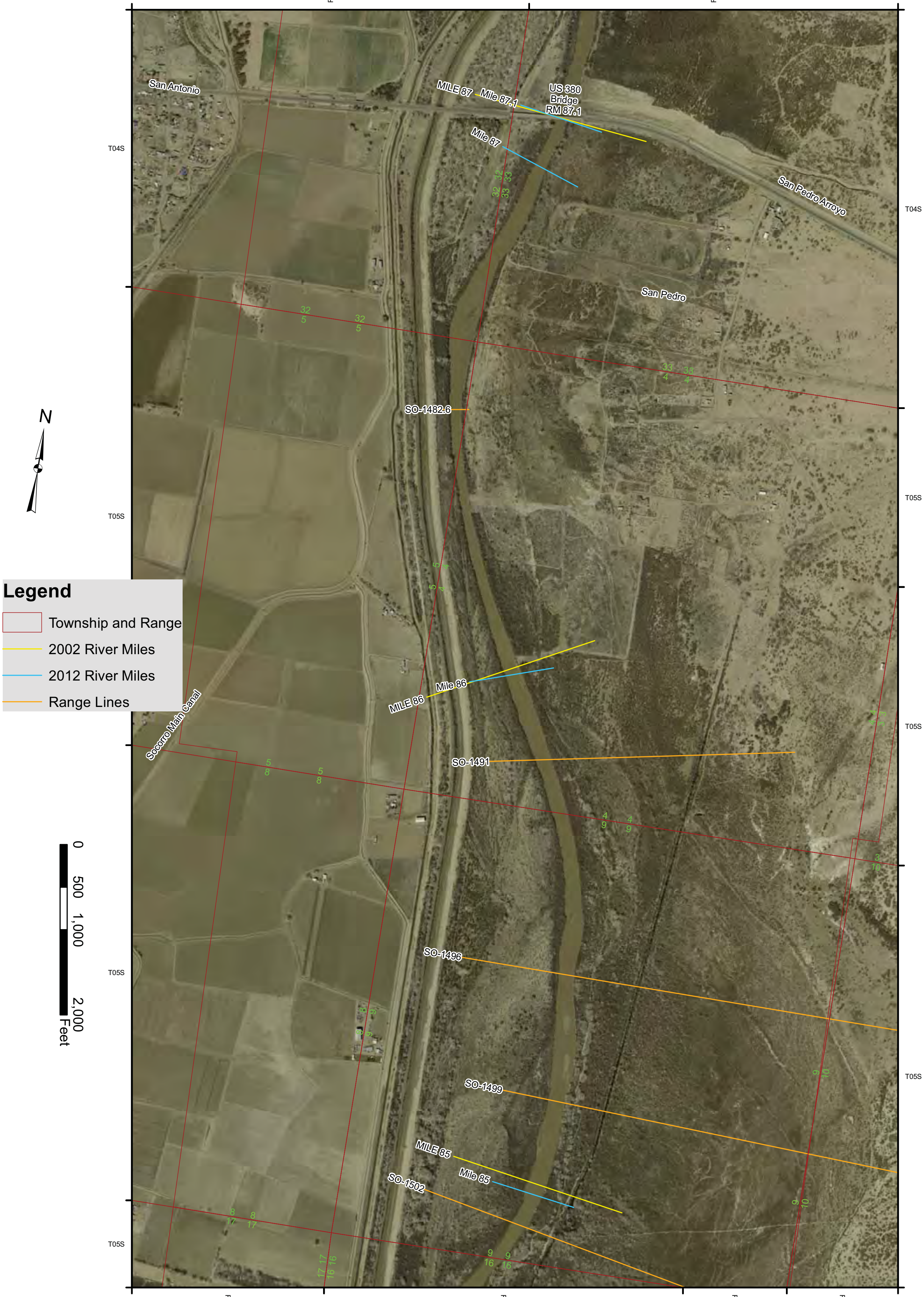



**Figure A - 4. Thalweg Profile from RM 60 to the Narrows (river miles on secondary x-axis use 2002 delineation)**

# Appendix B: River Miles and Rangelines Location Map

# Middle Rio Grande, New Mexico: River Miles and Rangelines

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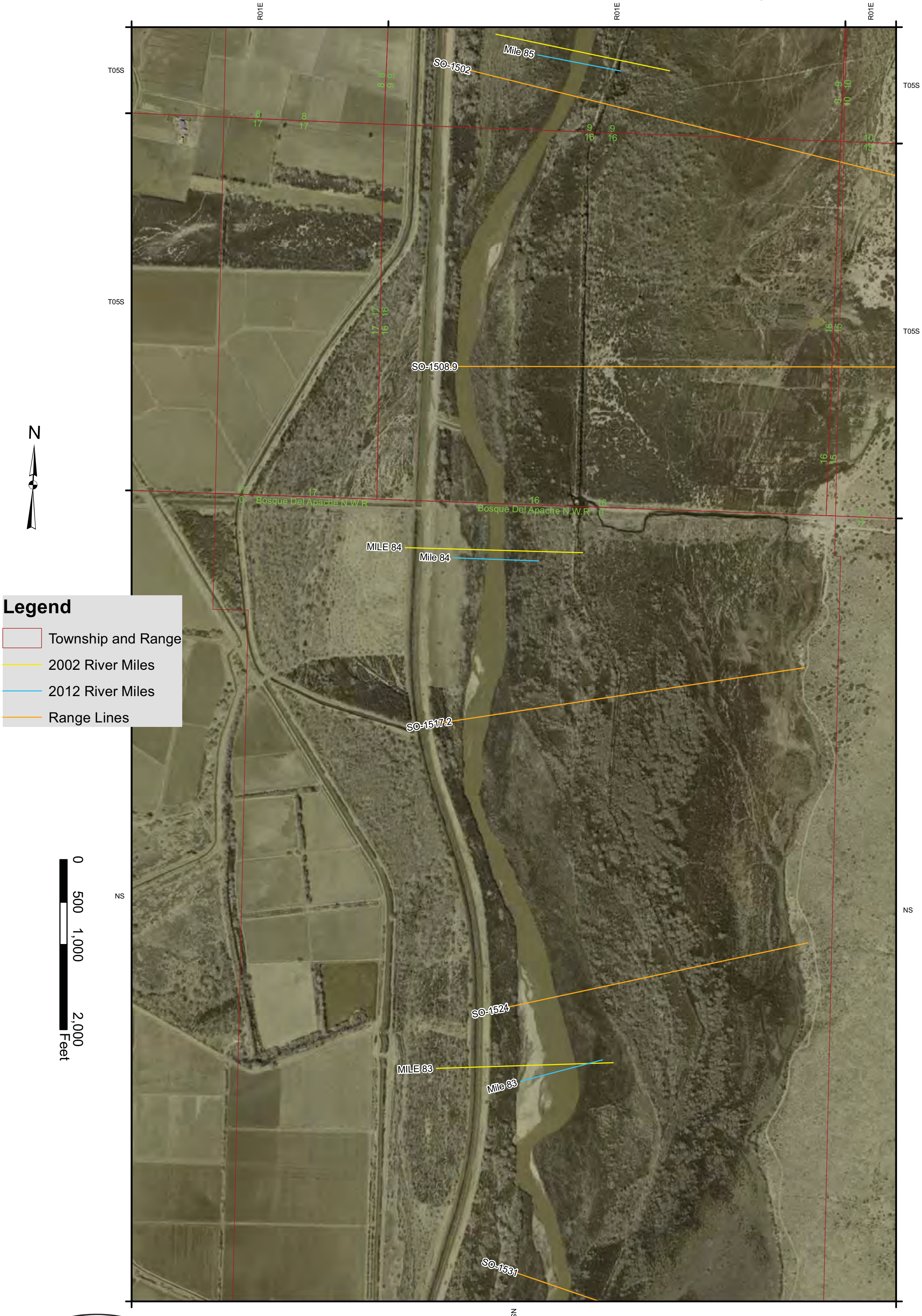
Flown by and produced (1:24000) by Woolpert NAD83-HARN New Mexico Central Zone.
All line locations are from end point coordinates provided by Surveying Services, Inc.
PLSS information obtained from RGIS website, represents data collected by the BLM.
Produced by the Bureau of Reclamation.

# Middle Rio Grande, New Mexico: River Miles and Rangelines

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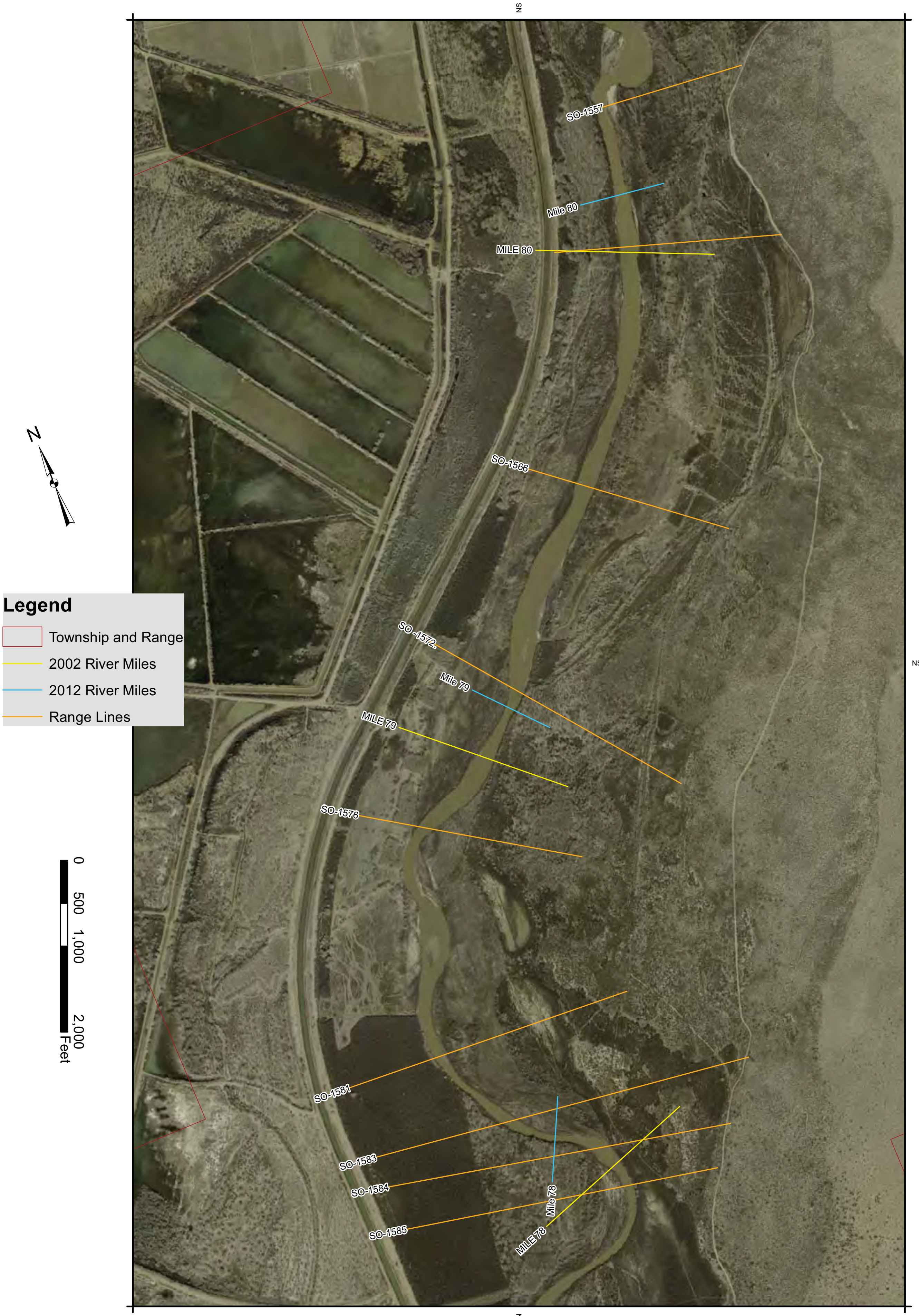


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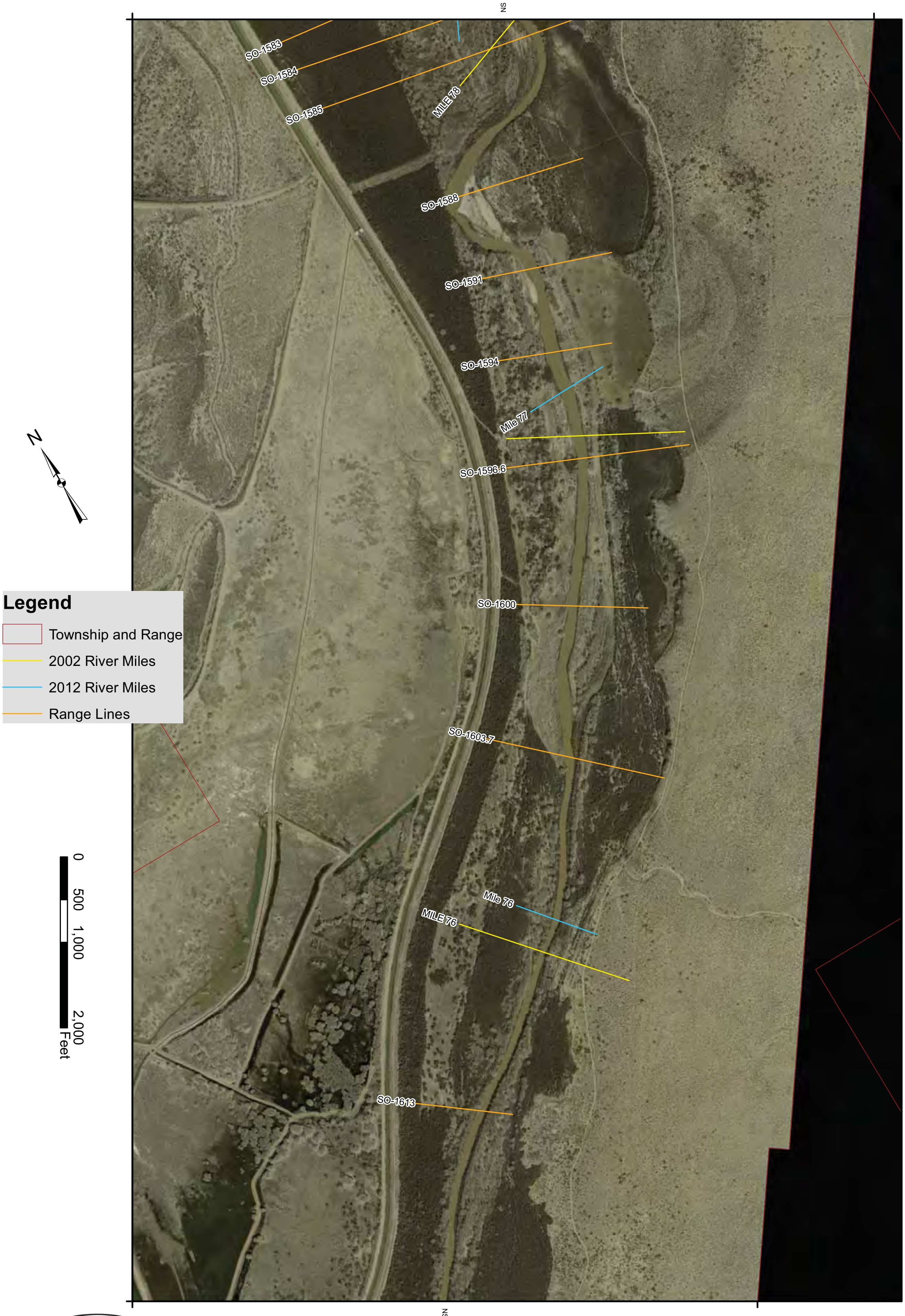


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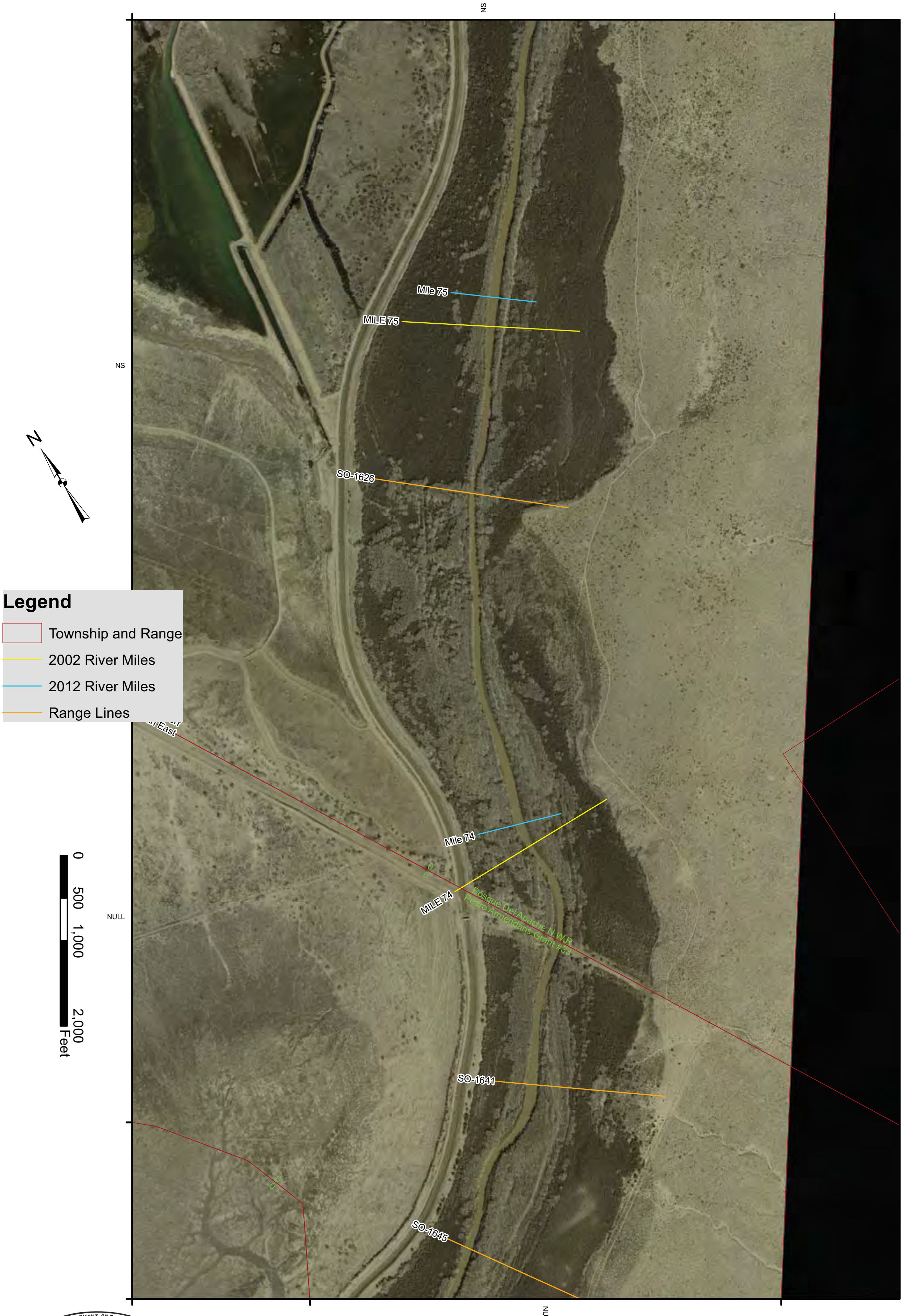


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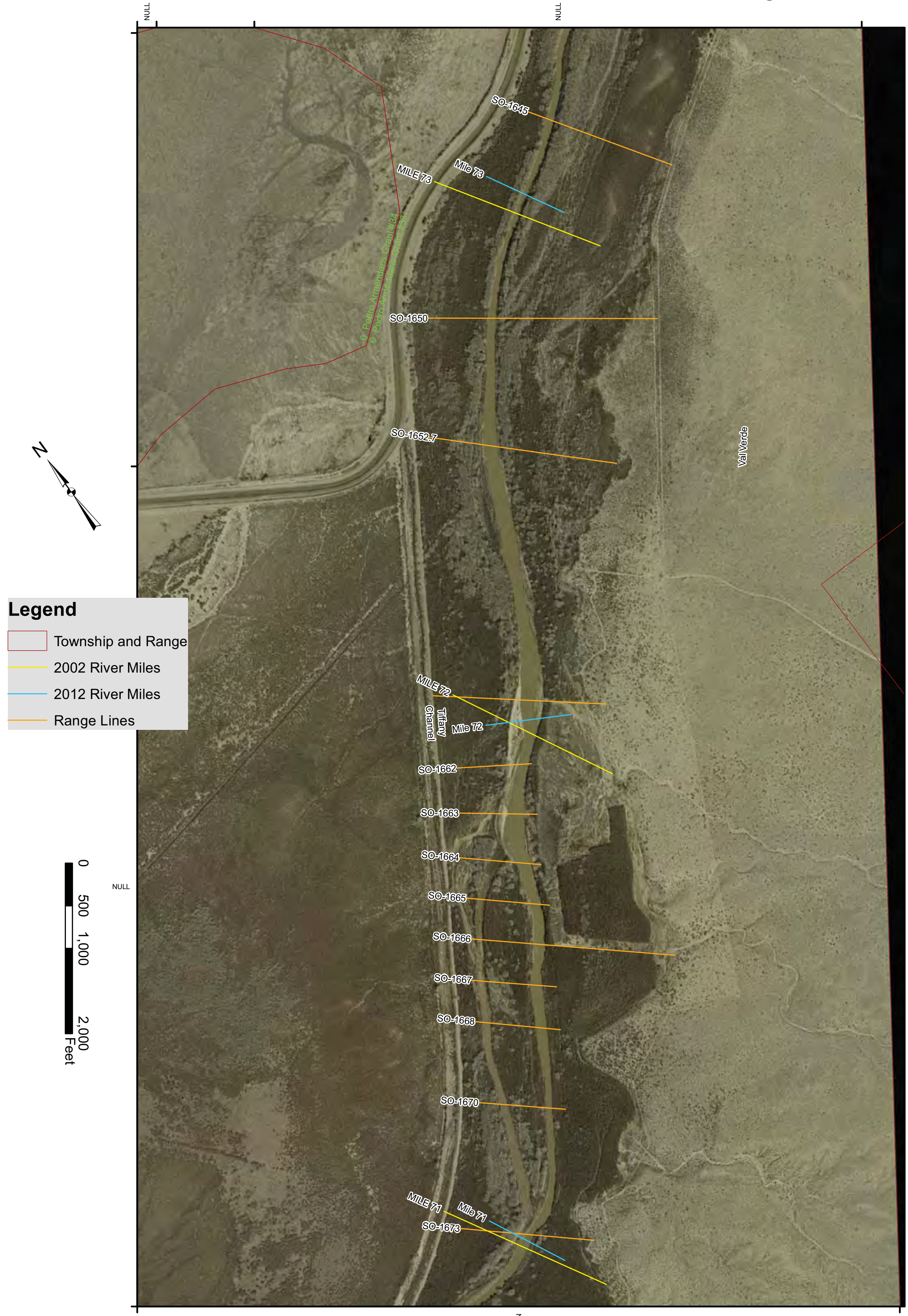


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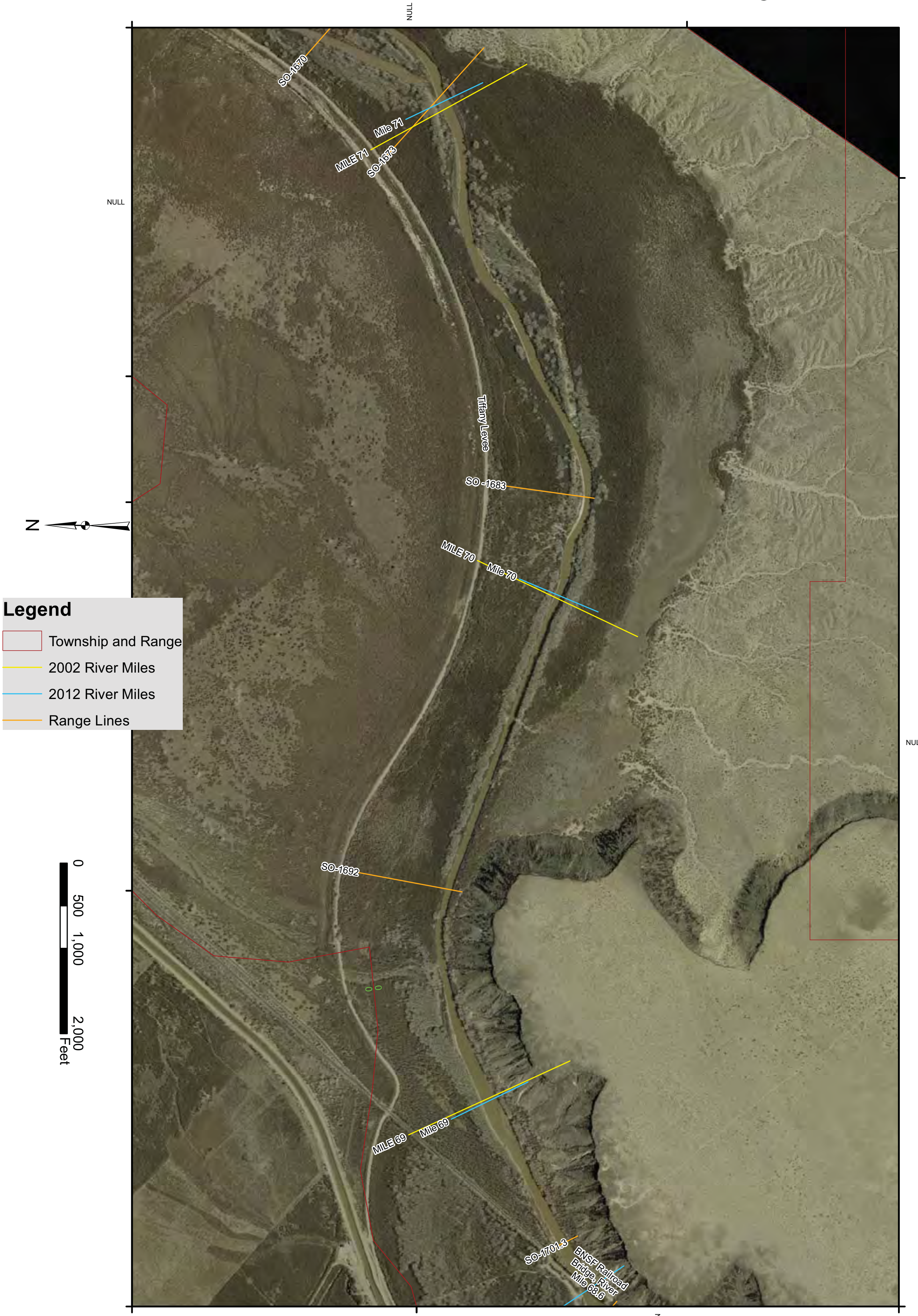


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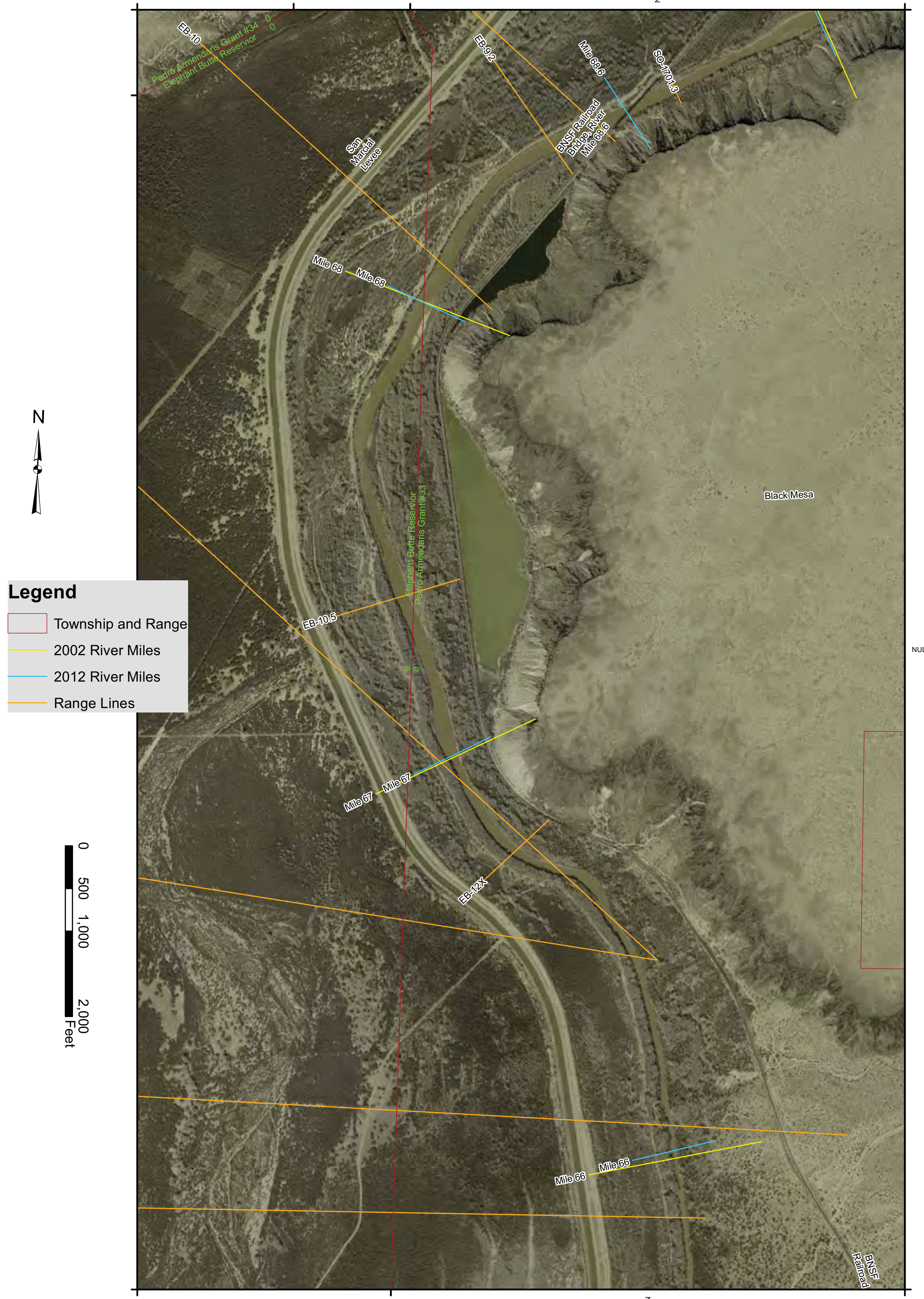


**Legend**

- Township and Range
- 2002 River Miles
- 2012 River Miles
- Range Lines

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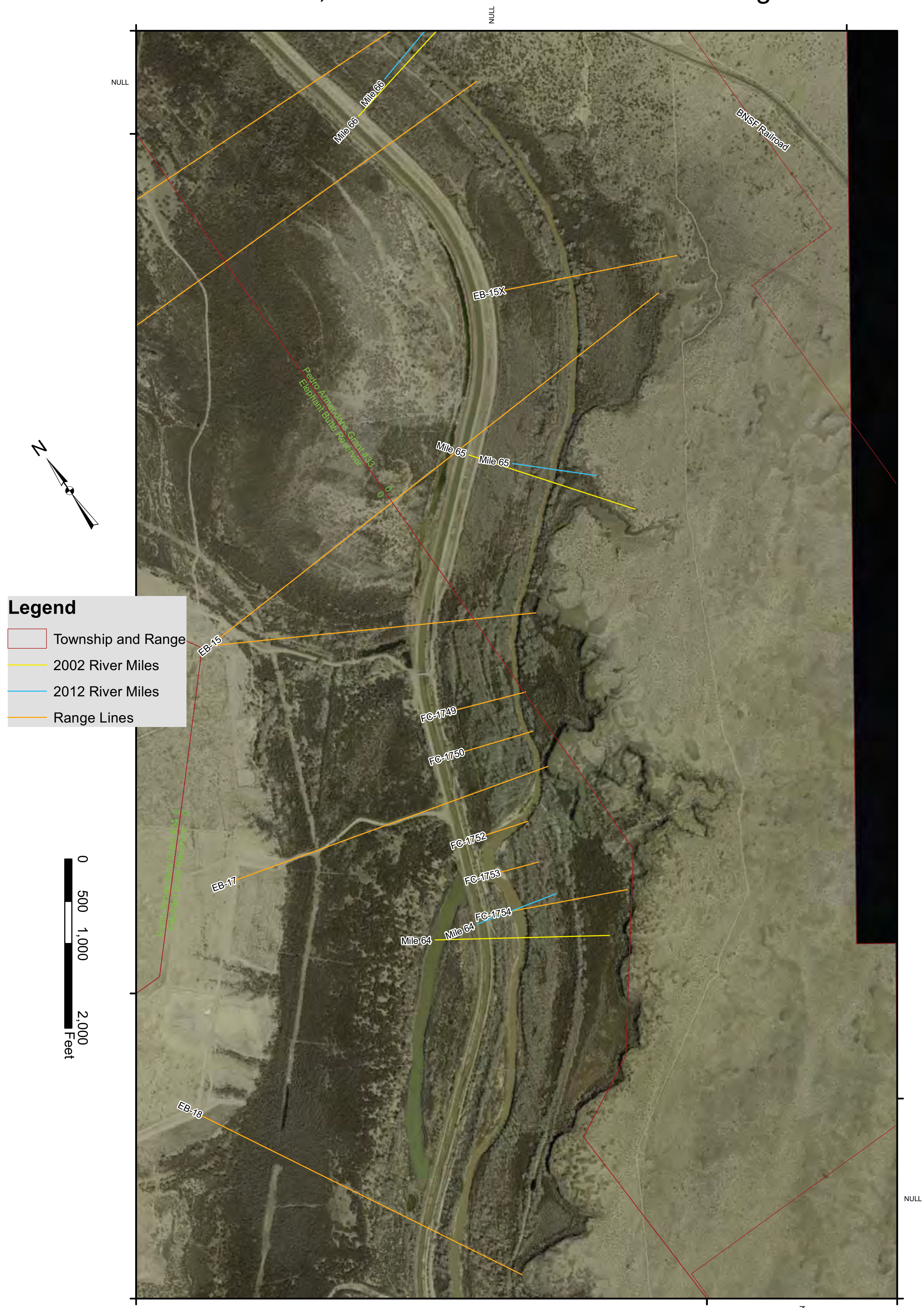


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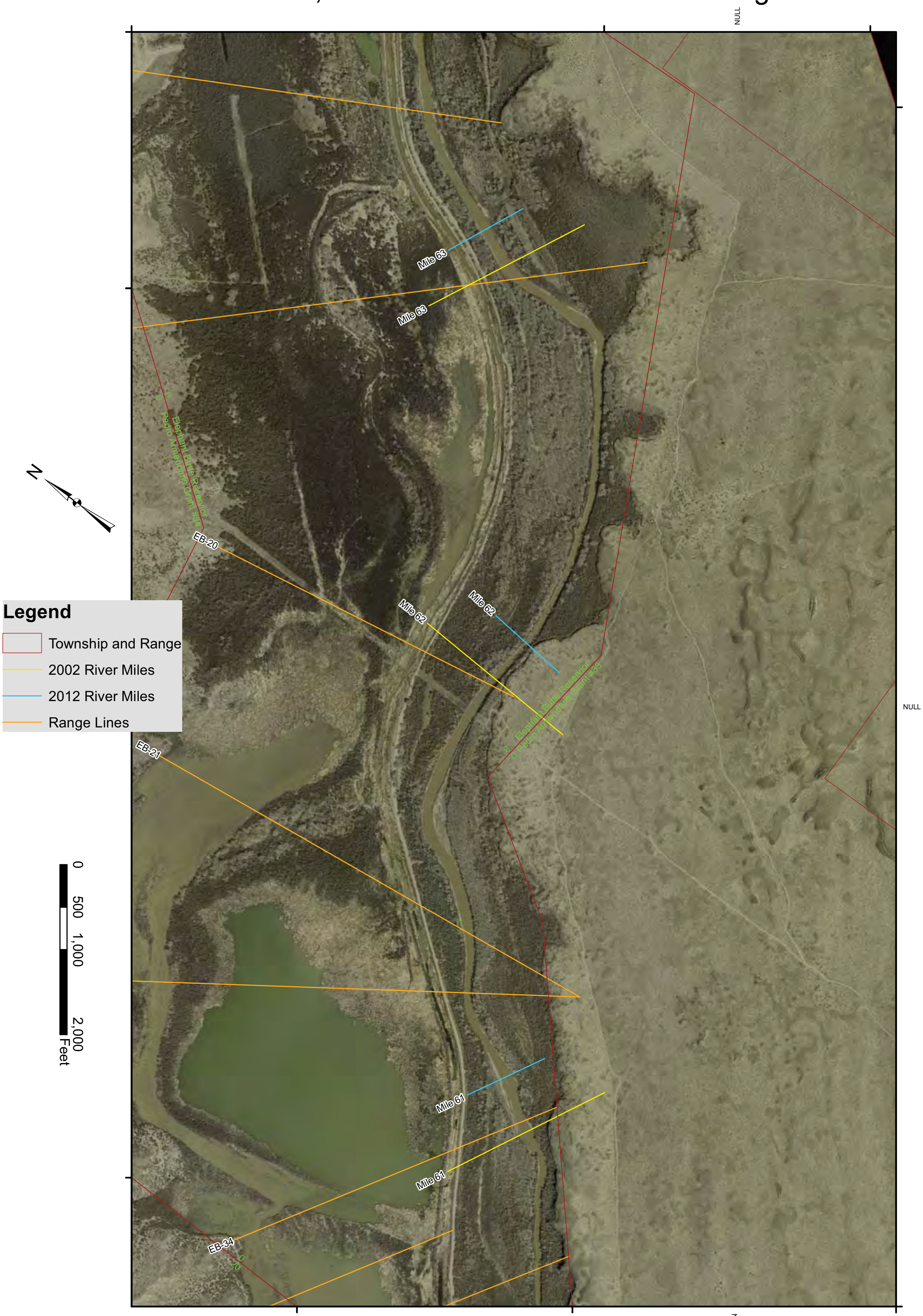


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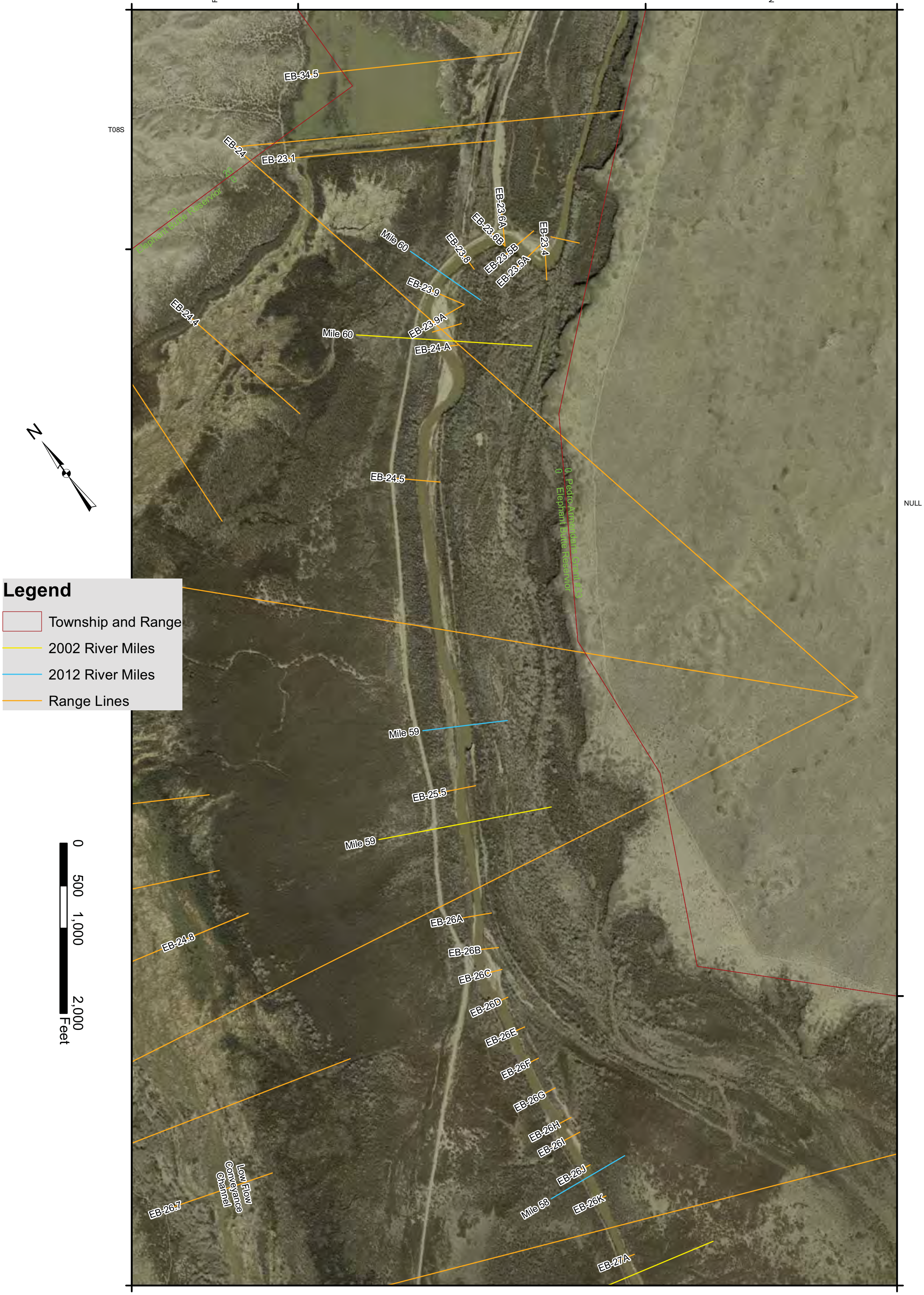


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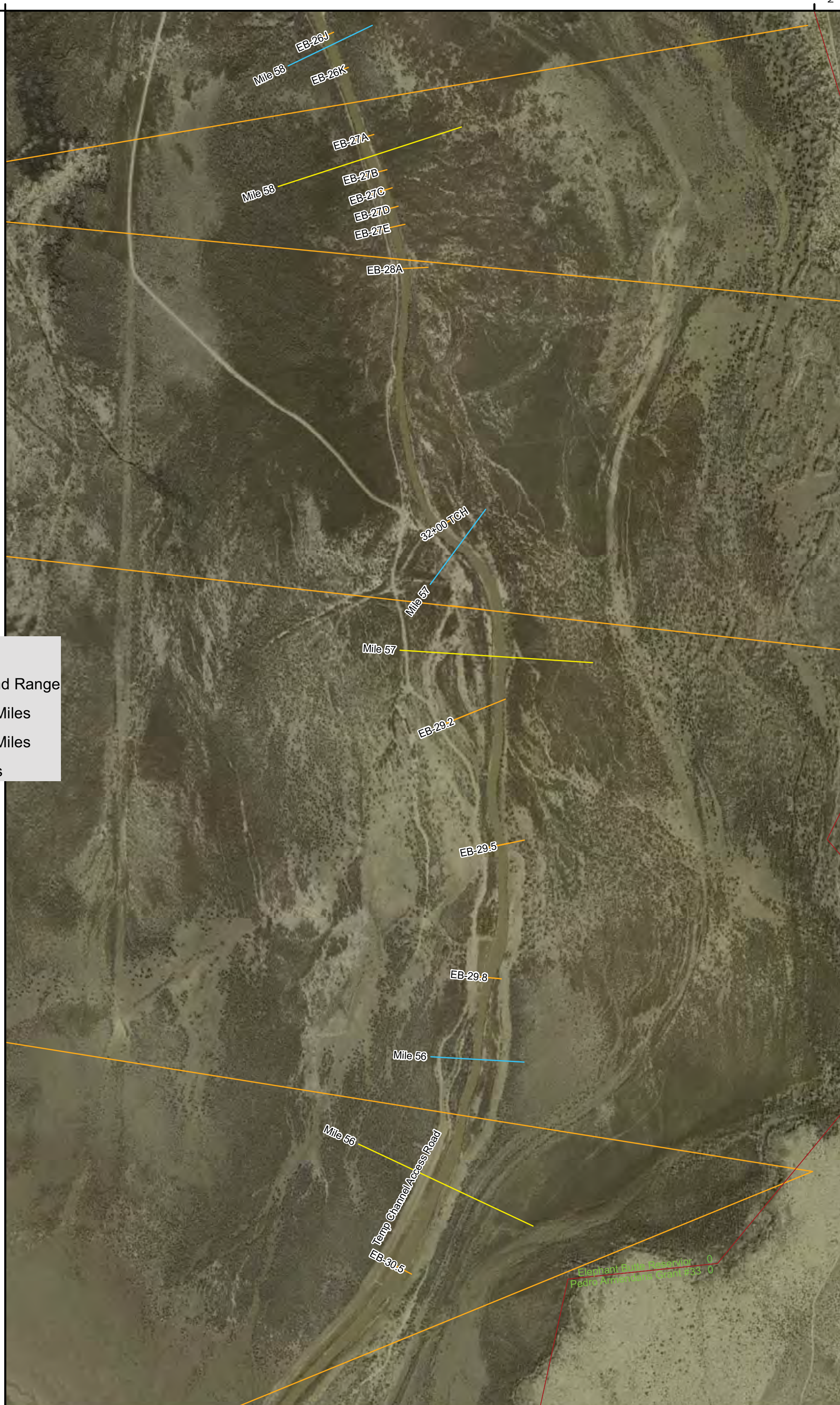


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**Legend**

- Township and Range
- 2002 River Miles
- 2012 River Miles
- Range Lines

0 500 1,000 2,000 Feet

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PLSS information obtained from RGIS website, represents data collected by the BLM.
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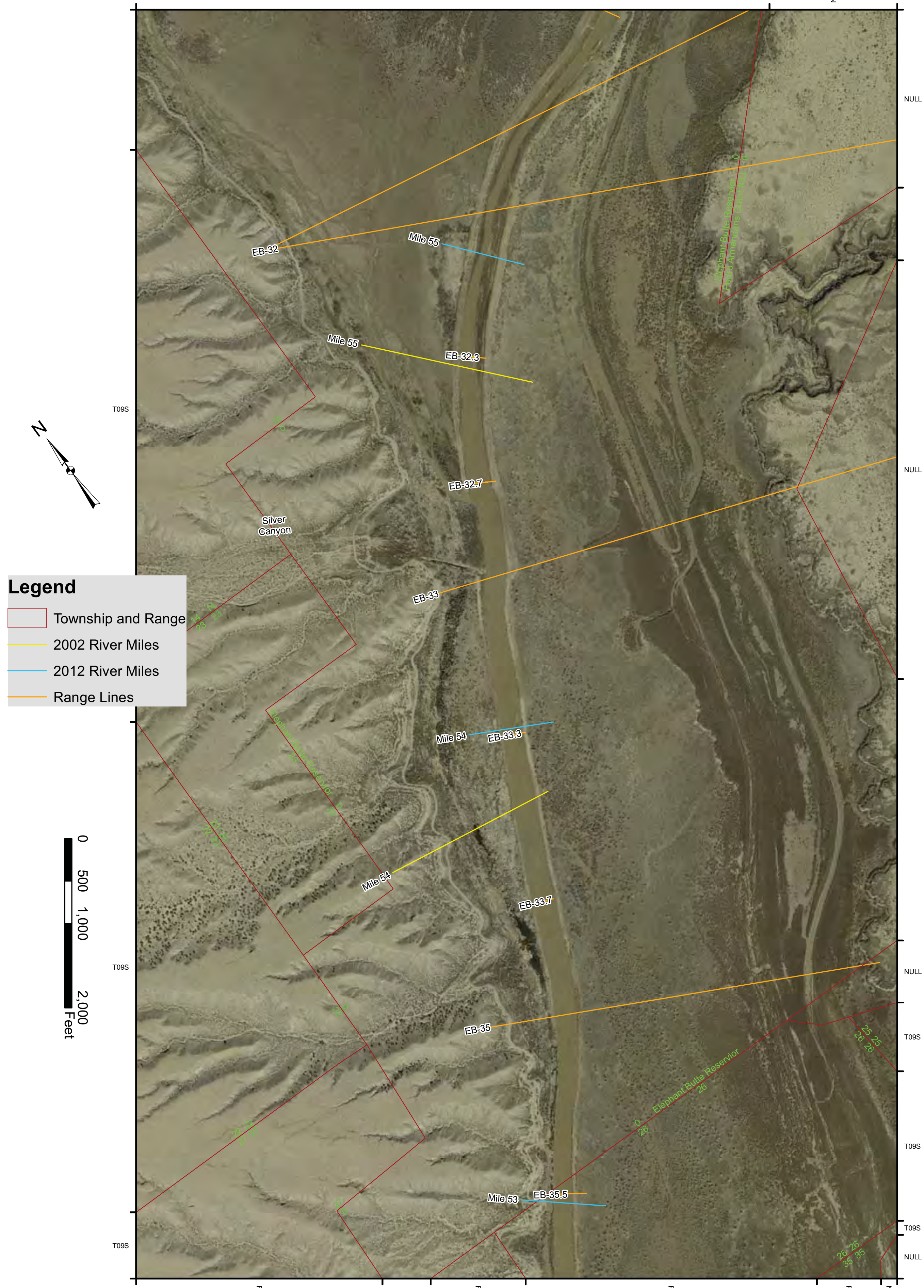
# Middle Rio Grande, New Mexico: River Miles and Rangelines

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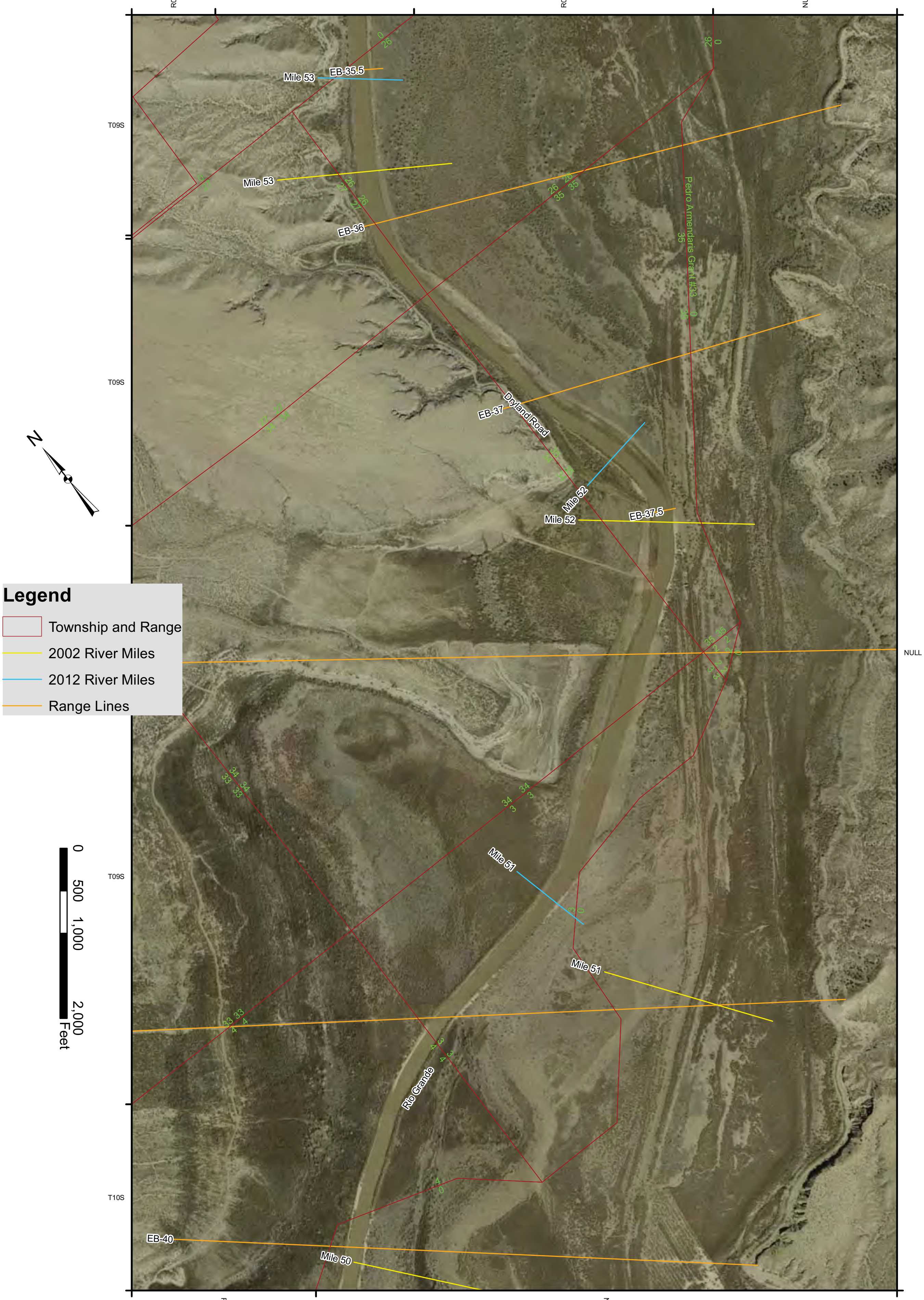


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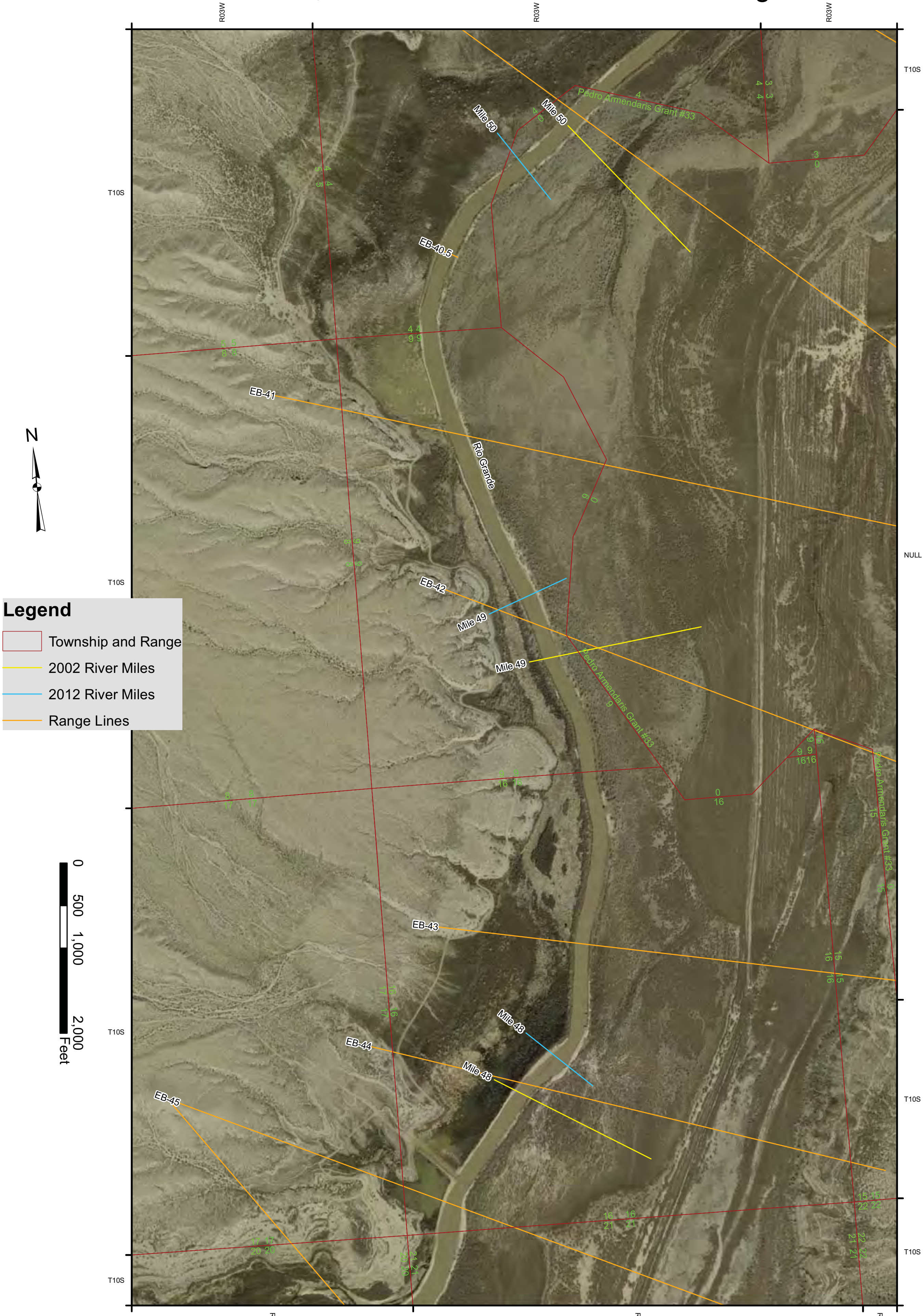


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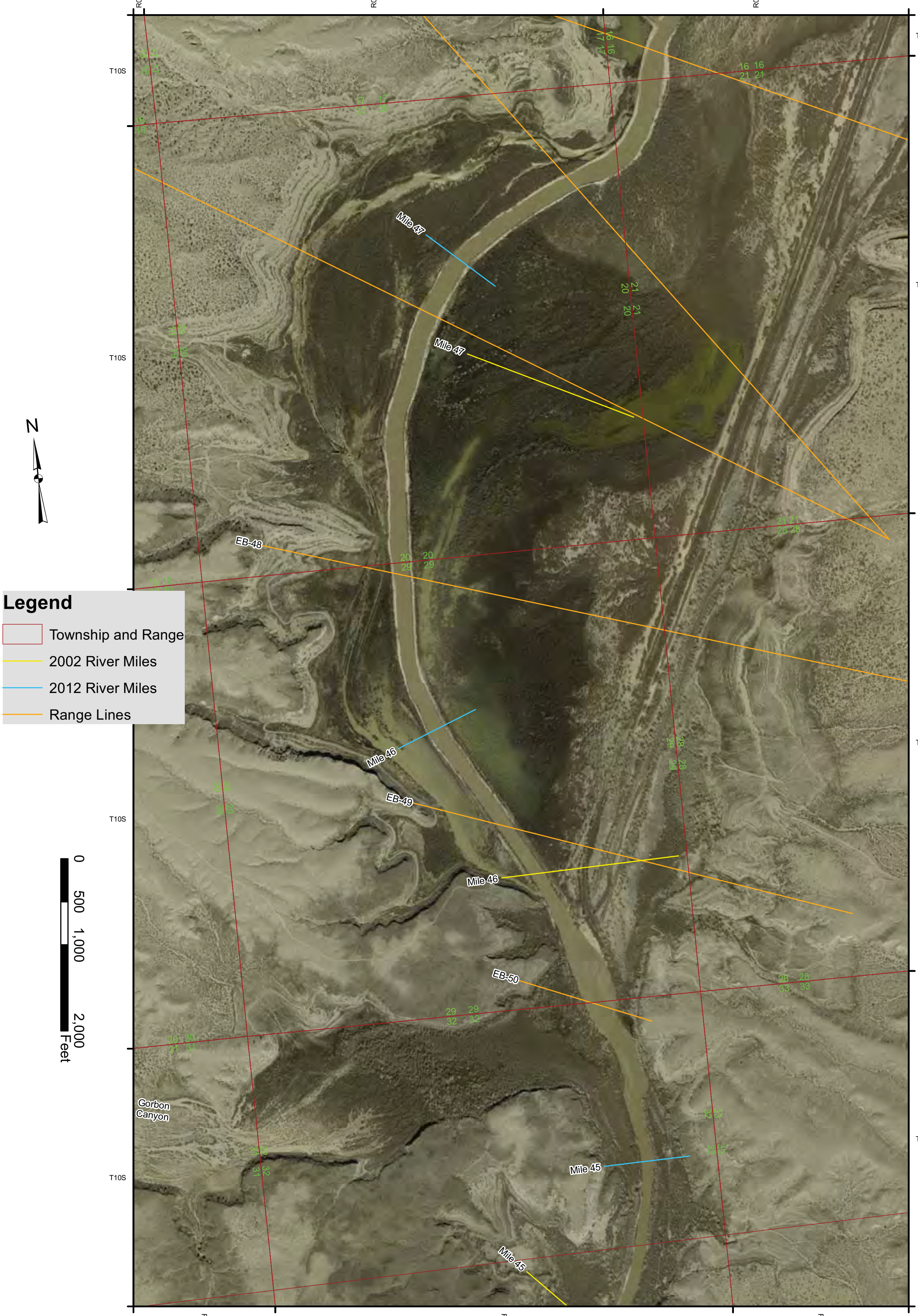


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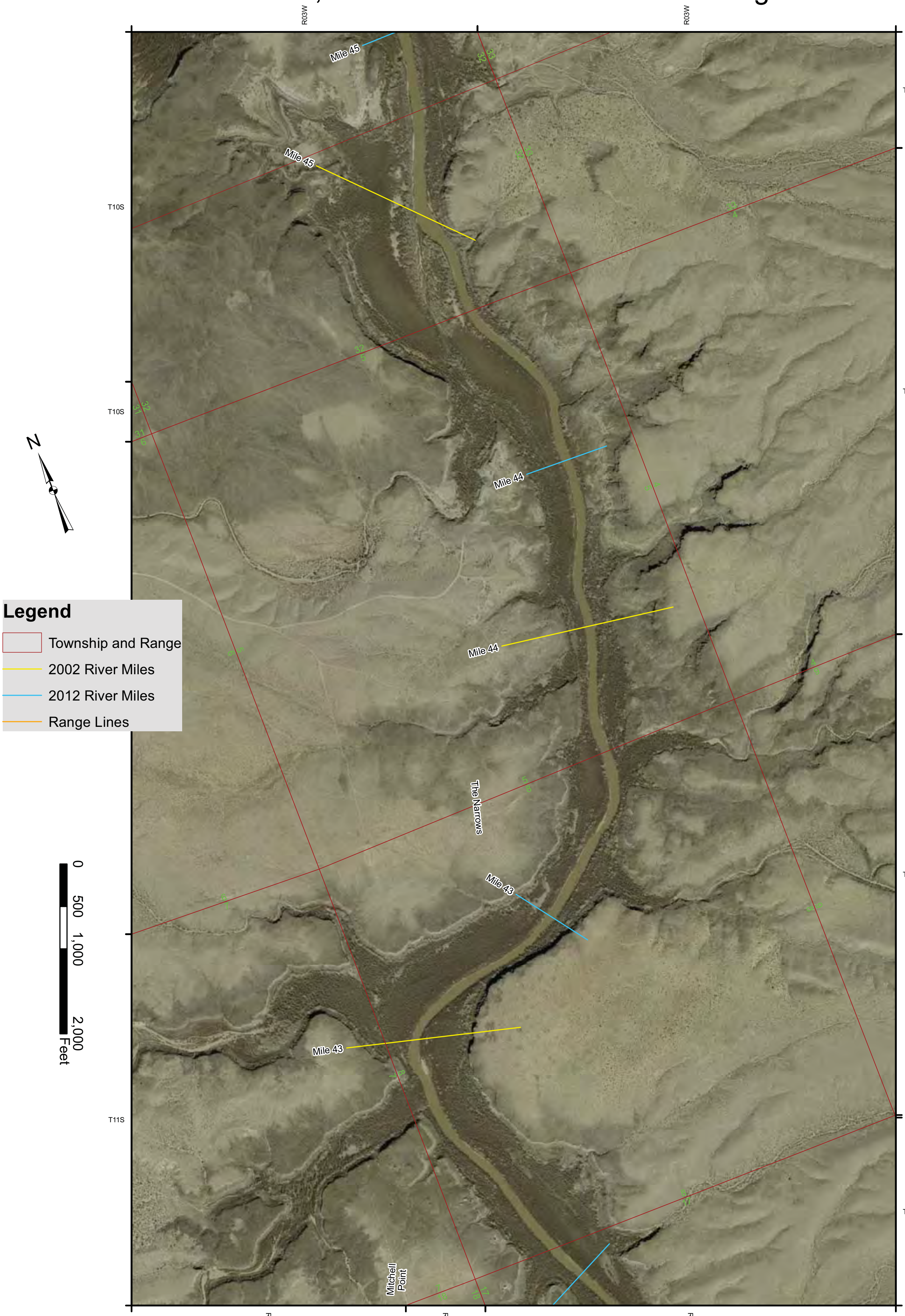


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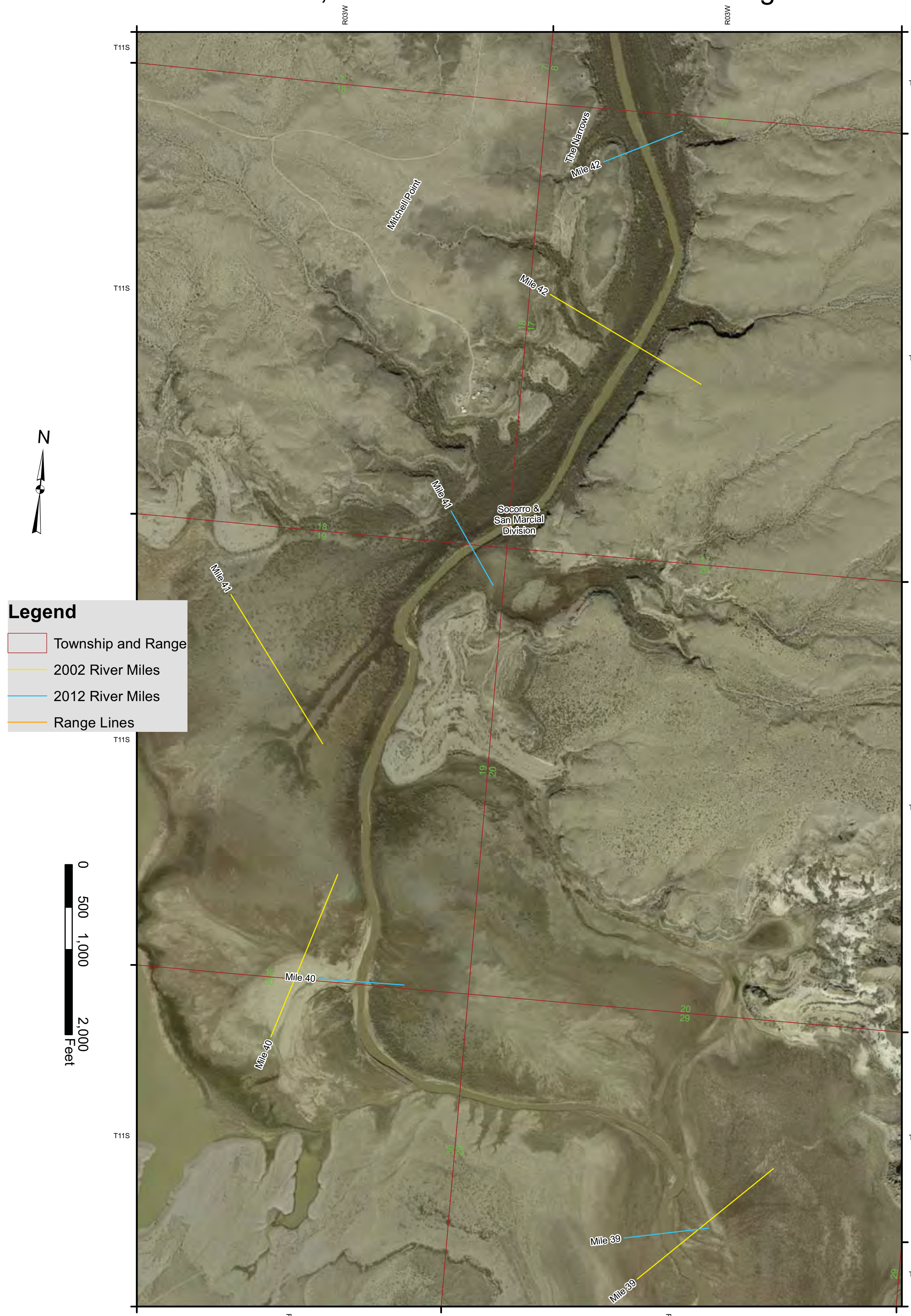


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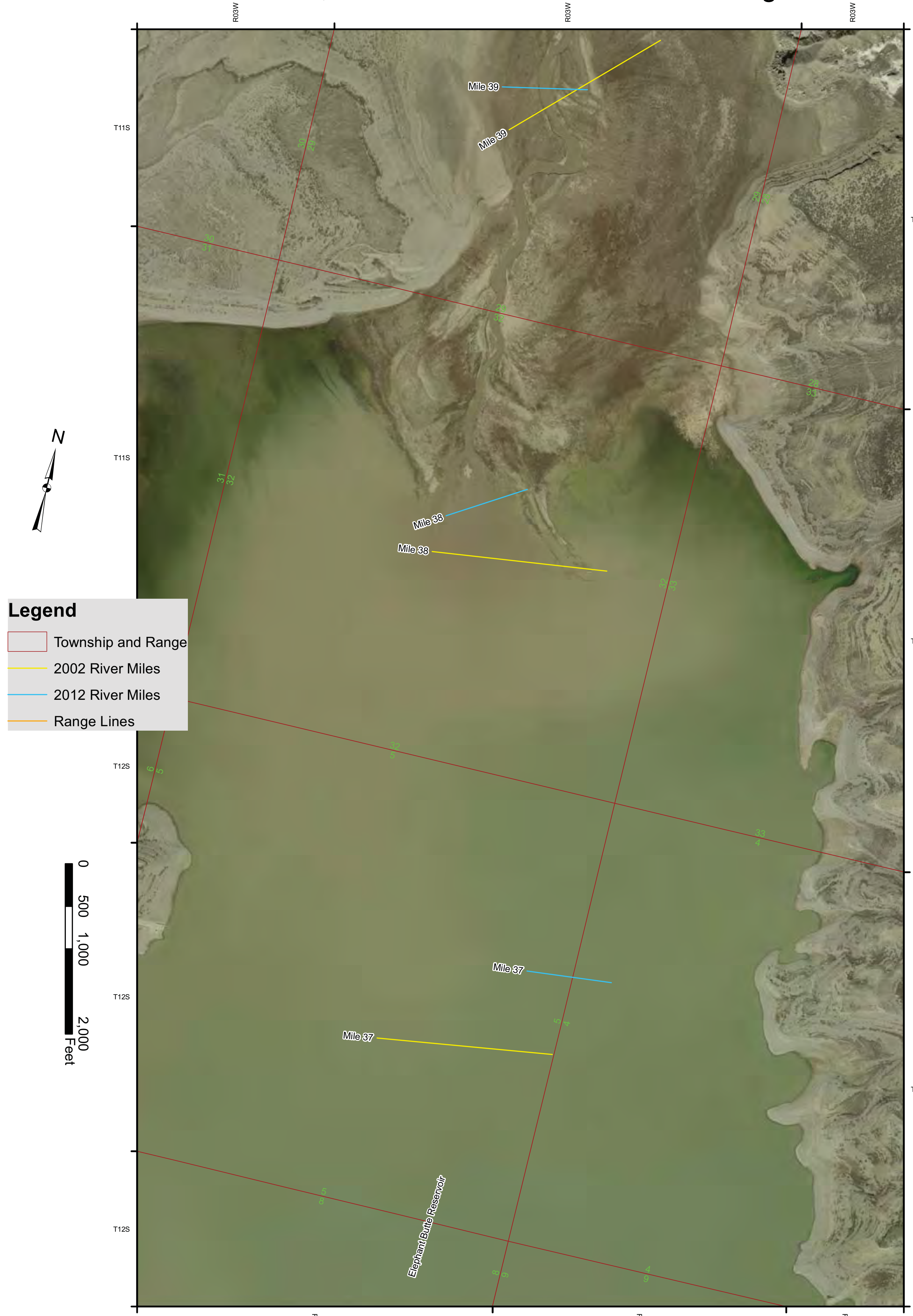


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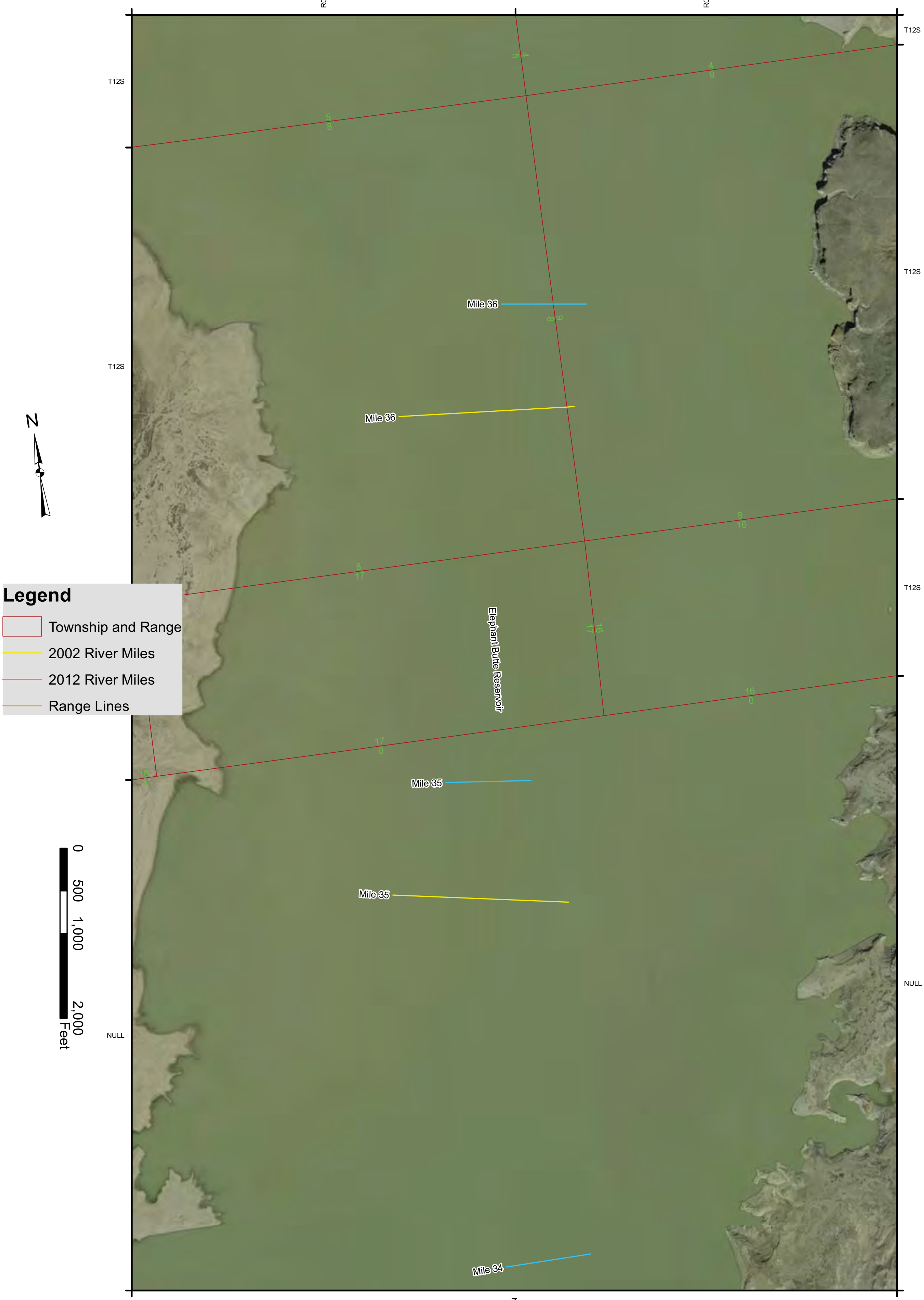


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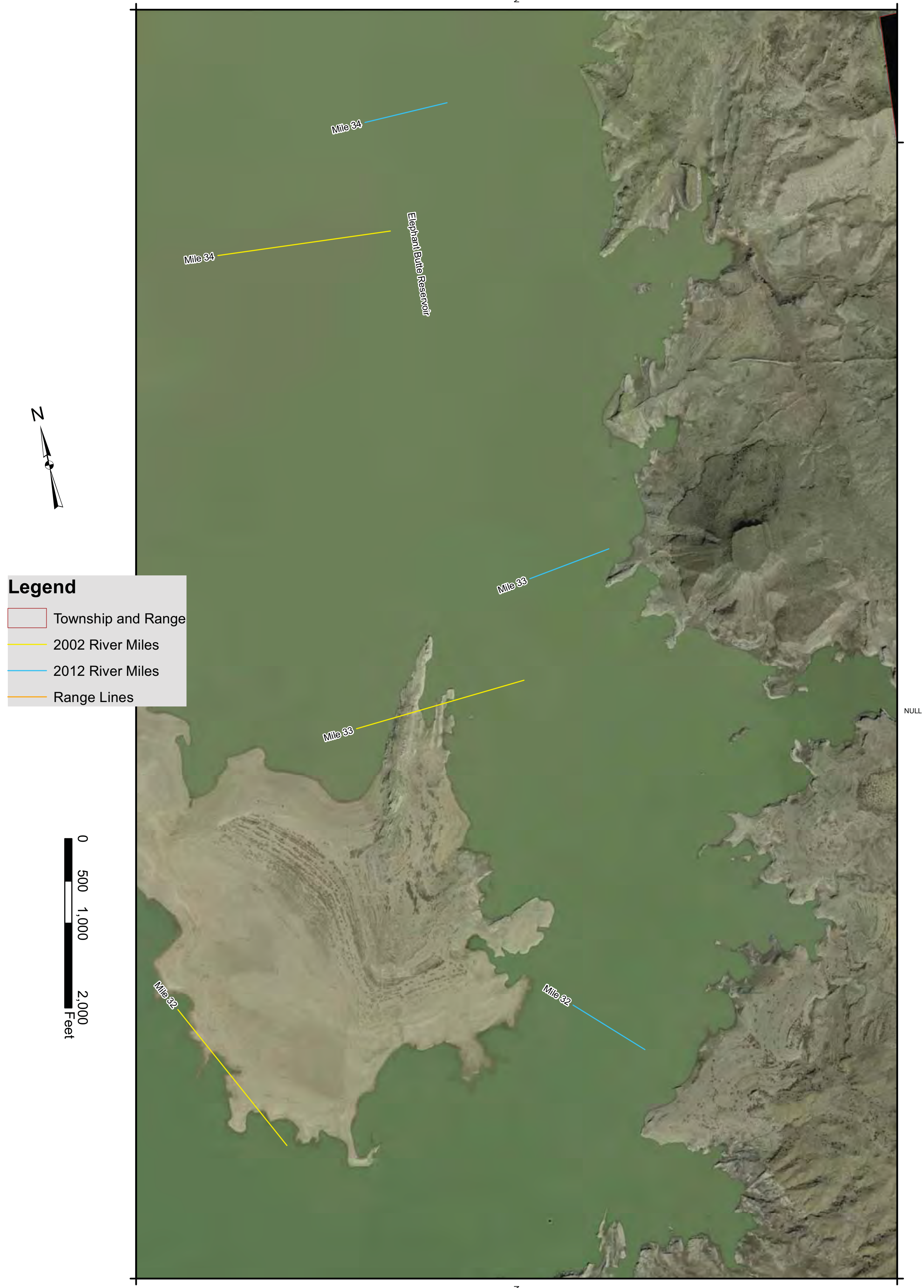


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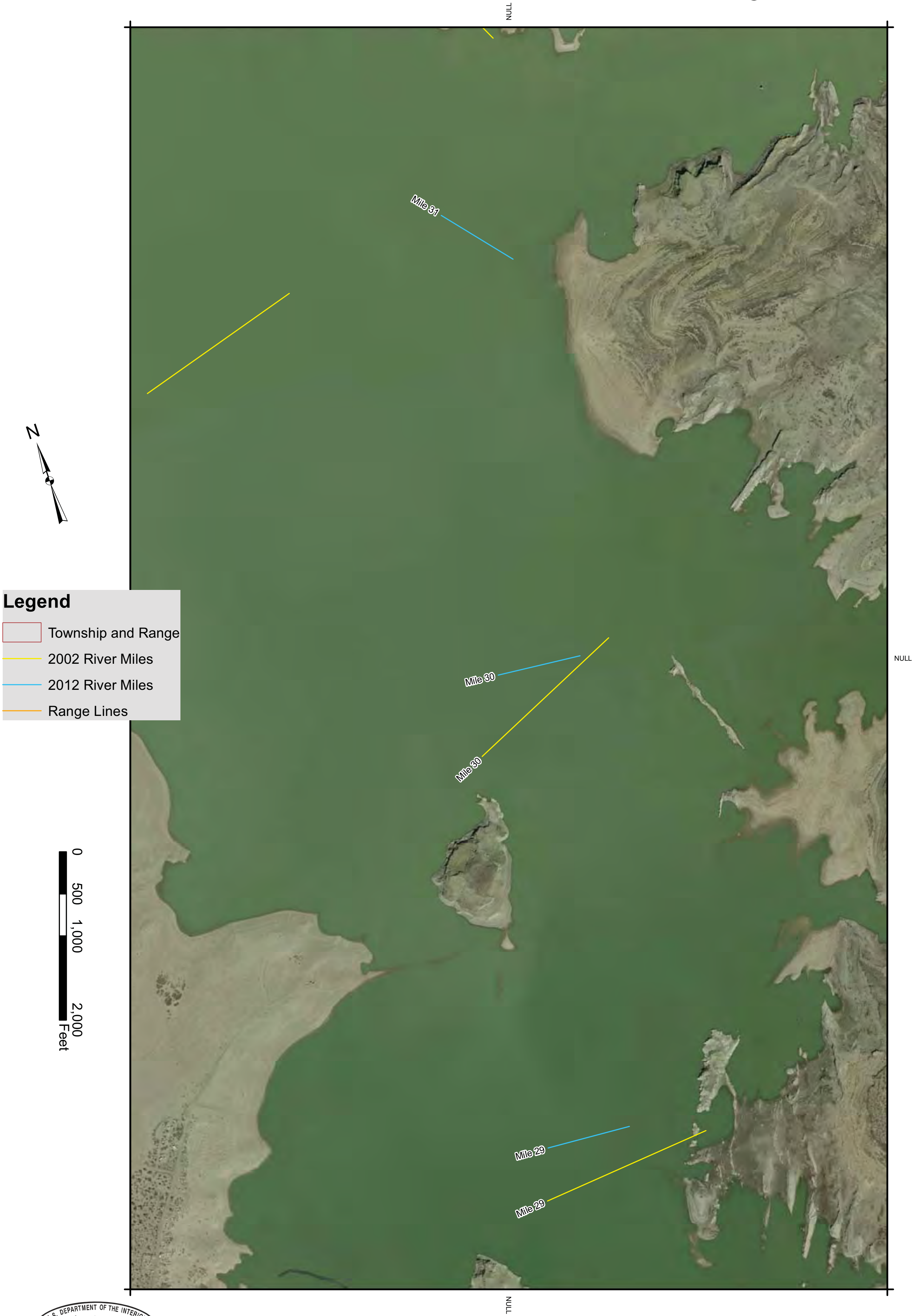


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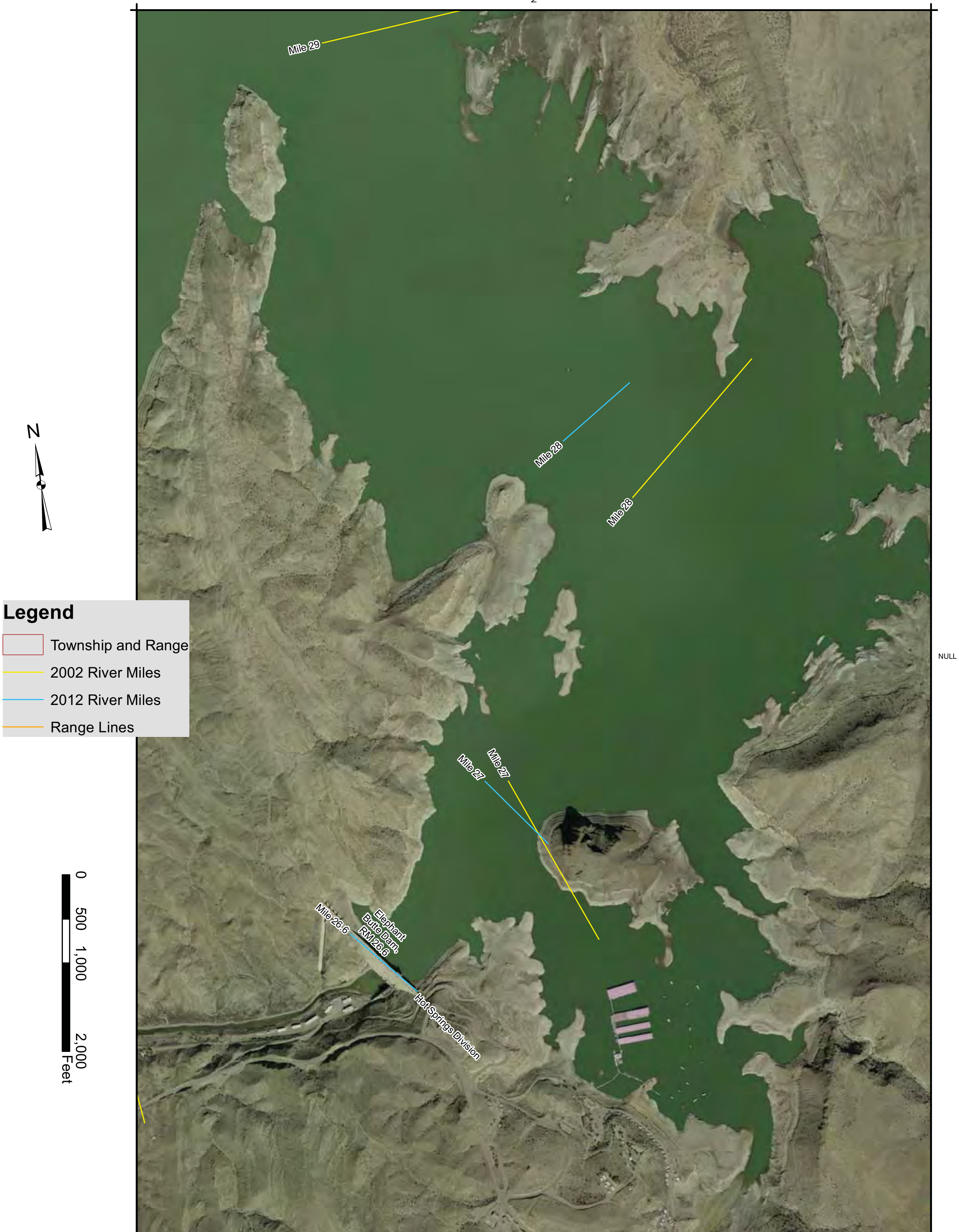


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Appendix C

Map of Flycatcher Detections


Figure C-1. Map of 2012 and 2013 Flycatcher Detections, Delta Channel